DPS 50 Abstract Book

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Monday, October 22, 2018
08:30 AM-10:00 AM
Ballroom A (Knoxville Convention Center)

100 Meteoroids, Meteors, Meteorites, Dust and Solar Wind
Chair(s): Peter Brown, Quanzhi Ye

08:30 AM-08:40 AM
100.01 High-precision Measurements of Meteoroid Compressive Strengths Derived from Direct Observations of Fragmentation
Denis Vida, Peter Brown, Margaret Campbell-Brown
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Abstract
The Canadian Automated Meteor Observatory (CAMO) is an electro-optical system which uses an 80 mm f/11 telescope and a set of palm-sized mirrors driven by galvanometers to track meteors in real-time. The system achieves a spatial resolution of 1 m at 100 km using a camera operated at 100 frames per second. CAMO consists of 2 identical setups separated by 45 km that observe the same volume of the sky, enabling the computation of very precise meteor trajectories, as well as studies of meteoroid structure and fragmentation.
In July, 2017, CAMO observed a 4-second-long meteor moving at only 16.5 km/s. The event was interesting as it had a very low entry angle of only 8° and fragmented into 12 distinct fragments in 5 separate fragmentation episodes. The dynamics of each fragment was precisely measured and thus the dynamic pressure ($P = v^2\rho_{atm}$) exerted by the atmosphere at each fragmentation is measurable. Thus we are able to use the dynamic pressure at the fragmentation point as a proxy for the compressive strength of this mm-sized meteoroid.
The bulk meteoroid fragmented at pressures of 2 – 2.15 kPa while the resulting fragments started disintegrating at dynamic pressures of 3.25 – 3.5 kPa. Prior to fragmentation, a long wake consisting of many small grains was observed persisting for 1 s, leaving the fragments exposed. We estimate the compressive strength of the matrix that caused the continuous fragmentation to be < 1 kPa.
The orbit of the meteoroid was computed (a = 3.3 AU, q = 0.95 AU, e = 0.71, Q = 5.6 AU, T_J = 2.7) indicating that it crossed Jupiter's orbit, implying a short dynamical lifetime. The Rosetta mission visited 67P/Churyumov-Gerasimenko, a JFC comet on a similar type of orbit. Due to the unsuccessful landing of the Philae lander it was possible to measure the compressive strength of the top 10 cm of the comet surface – the strength was estimated to be from 2 to 3 kPa, which is in excellent accordance with our independent result.
In addition to this event, CAMO has recorded fragmenting meteoroids for several meteor showers with known parent bodies. We apply our method to other high-precision ground-based measurements from CAMO to estimate of the compressive strength of a suite of additional meteoroids.

08:40 AM-08:50 AM
100.02 Asteroid ocean impact tsunami: Transient crater scaling laws
Darrel Robertson[1], Paul Register[1], Clemens Rumpf[1], Ashley Coates[1], Bond Nguyen[1], Lorien Wheeler[1], Jacqueline Macheskey[1], Ted Manning[1], Amy Gresser[1], Ginevra Robertson[2], Viktorija Rumpf[4], Jacob Crabill[3]

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Abstract
Tsunamis caused by asteroid impacts into oceans have been an area of disagreement in the planetary defense community regarding how dangerous they are. Part of this comes from estimates of the size of transient crater produced by an asteroid impact in the ocean. Previous estimates from the semi-empirical law of Holsapple 1993 predict larger craters than hydrocode simulations suggest for asteroids between 100m and 1km diameter. Asteroids of this size are large enough to create potentially dangerous tsunami but smaller than of concern for global climatic effects. The transient craters produced are significant fractions of the ocean depth which result in a smaller crater than predicted by Holsapple's law. The law comes from a power fit to two laboratory experiments: Hypervelocity impacts of centimeter size projectiles and slow speed impacts of sub-millimeter size droplets. Scaling laws allow these laboratory experiments to be scaled up to kilometer scale asteroids hitting the ocean. Experiments and hydrocode simulations of various laboratory and asteroid impacts into shallow water and with different background air pressure allow Holsapple's power law to be extended to account for these affects.

08:50 AM-09:00 AM
100.03 The Draconid meteoroid stream 2018: prospects and observations

Auriane Egal[1, 2], Paul Wiegert[1], Peter Brown[1], Danielle Moser[3], Althea Moorhead[4], William Cooke[4]
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Abstract
The October Draconids is an established meteor shower that occurs annually around the 9th of October, caused by meteoroids ejected from the JFC 21P/Giacobini-Zinner. The annual activity of the shower is usually quite low (a few meteors per hour), but it occasionally produces spectacular displays such as the visual and radar meteor storms of 1933, 1946 and 2012. The irregularity of the shower displays makes the Draconids a difficult shower to predict. Due to the low velocity of the meteoroid stream, the Draconids have a particularly high spatial density and may present an impact threat to spacecraft.
For the 8-9 of October 2018 shower return, the geometrical configuration between the Earth and the comet is suggestive of potentially intense activity. However, previous Earth passages through the stream decrease the intensity that can be expected for 2018. In this work, we use a model calibrated to the timing and intensity of previous Draconid storms and outbursts to produce a prediction for the 2018 Draconids. The flux estimates were performed using numerical simulations of meteoroid stream ejection and evolution from 21P following the methodology of Vaubaillon 2005.
The simulations suggest comparatively low Draconid activity will be seen near 0 UT Oct 9, 2018 on Earth, consistent with other model predictions (e.g. Maslov 2011, NASA/MEO). However, activity will be much higher at the L2 point and surroundings of GAIA. The satellite might detect a significant increase in meteoroid flux on Oct 8, 2018, reaching the level of a storm for a few minutes. From our modelled flux calibration, the probability of impact by Draconid meteoroids of mass > 10 mg during this brief storm at GAIA should not exceed about 0.01%. Because of ejection parameters uncertainties, a stronger activity than predicted cannot be excluded. The sensitivity of GAIA to Draconid meteoroids might allow performing an unprecedented direct *in situ* measurement of a meteoroid stream by a spacecraft.
In this work, modelled timing and flux profiles were determined for the 2018 Draconids on Earth and near

the L1 and L2 points. Predictions of the 2018 Draconids activity on Earth will be compared to observations made by radar and video on the night of Oct 8, 2018.

09:00 AM-09:10 AM

100.04 Source regions for meteorite falls

Mikael Granvik[1, 2], Peter Brown[3]

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Abstract

Over the past decade there has been a large increase in the number of automated camera networks that monitor the sky for fireballs. One of the goals of these networks is to provide the necessary information for linking meteorites to their pre-impact, heliocentric orbits and ultimately to their source regions in the solar system. We re-computed heliocentric orbits for the 25 meteorite falls published to date from original data sources (Granvik and Brown 2018). Using these orbits, we constrained their most likely escape routes from the main asteroid belt and the cometary region by utilizing a state-of-the-art orbit model of the near-Earth-object population (Granvik et al. 2016), which includes a size-dependence in delivery efficiency. While we find that the general results for escape routes are comparable to previous work, the role of trajectory measurement uncertainty in escape-route identification is explored for the first time. Moreover, the improved size-dependent delivery model sub-stantially changes likely escape routes for several meteorite falls, most notably Tagish Lake which seems unlikely to have originated in the outer main belt as previously suggested. In addition, we find that reducing the uncertainty of fireball velocity measurements below about 0.1 km/s does not lead to reduced uncertainties in the identification of their escape routes from the asteroid belt and, further, their ultimate source regions. The analysis suggests that camera networks should be optimized for the largest possible number of meteorite recoveries with measured speed precisions of order 0.1 km/s. We will present these results combined with 2-3 more recent events that are about to be published.

References:

Granvik, M. and Brown, P. (2018). "Identification of meteorite source regions in the Solar System", Icarus 311, 271-287.

Granvik, M., Morbidelli, A., Jedicke, R., Bolin, B., Bottke, W. F., Beshore, E., Vokrouhlicky, D., Delbo, M., Michel, P. (2016). "Super-catastrophic disruption of asteroids at small perihelion distances", Nature 530, 303-306.

09:10 AM-09:20 AM

100.05 The Detection of Earth Impactors

David Clark, Paul Wiegert

Earth Sciences, University of Western Ontario, London, Ontario, Canada

Abstract

Begun in 2010, the Fireball Retrieval on Survey Telescopic Images (FROSTI) project (Clark, 2010) seeks to locate larger meteoroids that were serendipitously observed on archived sky survey images. Only three meteoroids are known to have been observed in space, 2008 TC3, 2014 AA, and 2018 LA, all discovered by the Catalina Sky Survey immediately prior to Earth impact. Western University and NASA Meteor Environment Office ASGARD Networks, the European Network, and other meteor observation systems are used to obtain fireball atmospheric contact state vectors. A RADAU-based (Everhart, 1985)

gravitational integrator produces precise pre-impact trajectories which are used to search a database of sky survey image descriptions. Both Earth and space-based images are represented as spatial volumes in a survey-independent fashion allowing for efficient recognition of object-image intersections. I present results on the search fireball-producing meteoroids against approximately 10,000,000 images and discuss these results in the context of the effectiveness of current sky surveys to detect larger impacting bodies as modelled using an impactor population derived from the Granvik et al. (2018) Near Earth Object population.

09:20 AM-09:30 AM

100.06 Diamonds in ureilites: A tale of three planets, none of them lost

Steven Desch, Joseph O'Rourke, Laura Schaefer, Devin Schrader, Thomas Sharp
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Abstract

Ureilites are enigmatic meteorites. Although very C-rich achondrites, they formed in the inner solar system [1] when an asteroid in the midst of differentiating was catastrophically disrupted [2]. In graphite-rich regions in the Almahata Sitta ureilite are large (~100 μm) diamonds that formed at pressures $P > 2$ GPa [3]. Recently, [4] identified $(Fe_{0.932},Ni_{0.068})_3(S_{0.88},P_{0.12})$ inclusions in these diamonds, implying formation in a metallic melt of specific composition, at $P > 21$ GPa. They suggested the ureilite parent body (UPB) was a planet-sized body, now lost.

We present an alternative hypothesis. Diamonds formed at Mars's core-mantle boundary when late-forming C-rich metallic melt met the S-rich liquid iron core, precipitating diamond, as seen in experiments [5]. Diamonds moved up through the magma ocean, partially graphitizing, leading to a diamond-bearing graphite layer in Mars's upper mantle. The Borealis basin impact ejected mantle fragments into the asteroid belt. One struck and catastrophically disrupted the UPB. Ureilite daughter bodies (UDBs) formed from mixtures of the martian impactor and the UPB. Ferroan olivines and diamond-bearing graphite in ureilites are exogenous to the UPB.

Our model explains the existence and size of diamonds and the Fe/(Fe+Ni) and P/(S+P) ratios of the inclusions. We use olivine Mg#, FeO/MnO, plus O and C isotopes, to show ureilite olivine data is consistent with a UPB that underwent partial smelting, plus contributions from the uppermost crystallized martian magma ocean. Based on these insights, we identify a specific large S-type asteroid as the largest UDB and a small F-type asteroid as the parent of 2008TC3 / Almahata Sitta. We note other high-pressure components with similar origins in other meteorites. Our model allows for a 600-km Fe7C3 inner core of Mars, of relevance to the InSight mission.

The ureilite diamonds started inside Mars, resided on the UPB, and are now on Earth. They tell a tale of three planets, none lost, one perhaps recently found.

[1] Warren, P (2011) *GCA* 75, 6912. [2] Goodrich et al. (2015) *MAPS* 50, 782. [3] Miyahara, M et al. (2015) *GCA* 163,14. [4] Nabiei, F et al. (2018). *Nat. Comm.* 9, 1327. [5] Palyanov, Y et al. (2006) *EPSL* 250, 269.

09:30 AM-09:40 AM

100.07 Dynamical model for the origin of the circumsolar dust ring near the orbit of Venus

Petr Pokorny[1, 2], Marc J. Kuchner[2]

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Abstract
Four spacecrafts HELIOS A/B and STEREO A/B found evidence for an increase in zodiacal light brightness near the orbit of Venus. Photometry from HELIOS A/B and imaging from orbits close to 1 au by STEREO A/B imply a narrow (0.08 au) circumsolar ring-like structure positioned at or slightly outside of the orbit of Venus. The height of this circumsolar ring was estimated to be twice that of its width (0.16 au), where the zodiacal light brightness enhancement introduced by the circumsolar ring might be to up to 10% of the total zodiacal light brightness at heliocentric distances around 0.732 au. Attempts to model this ring by other authors have failed because of the low trapping probabilities into Venus's outer mean motion resonances.
We present a dynamical model for the distribution of the dust and meteoroids in the innermost parts of the solar system, including the vicinity of this circumsolar ring. Using large numbers of particles and results from recent calibrated dynamical models of main-belt and cometary meteoroids, our model reproduces the overall zodiacal dust cloud radial scaling and both the thickness and height of Venus's circumsolar ring derived from HELIOS and STEREO observation.

09:40 AM-09:50 AM
100.08 Compositional and Spectral Properties of Ureilitic Regolith from Samples of Almahata Sitta
Cyrena A. Goodrich[1], Anna Fioretti[10], Michael Zolensky[3], Muawia Shaddad[4], Takahiro Hiroi[5], Issaku Kohl[6], Edward Young[6], Noriko Kita[2], Matthew Sanborn[7], Qing-Zhu Yin[7], Hilary Downes[11], Daniel Ross[8], Petrus Jenniskens[9]
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Abstract
The Almahata Sitta (AhS) polymict ureilite was recovered as >700 stones from the impact of asteroid 2008 TC_3 in Sudan in October 2008. The asteroid had been tracked and studied for ~19 hours before the impact, making it the first NEO to be detected before it hit the Earth, and making AhS the first meteorite derived from a spectrally classified asteroid. Of ~180 studied stones, ~80% are ureilites (carbon-rich ultramafic achondrites) and ~20% are various types of chondrites. It has been inferred that 2008 TC_3 was loosely aggregated and porous, so that it disintegrated in the atmosphere with most of its mass being lost as dust and only its most coherent clasts falling as individual stones. Understanding the structure and composition of this asteroidal breccia has been limited because none of the studied stones showed contacts between ureilitic and chondritic lithologies. We describe the first AhS stones that do.
AhS 91/91A (paired) and AhS 671 are friable breccias. They consist of a hydrous carbonaceous chondrite (C1) lithology (phyllosilicates, carbonates, magnetite) enclosing ~10 μm to 3 mm-sized clasts of ureilitic olivine, pyroxenes, plagioclase and graphite, as well as chondrules from OC and type-3 CC, and metal from OC and EH. This type of breccia is new among known meteorites. Oxygen and Cr isotopes show that the C1 lithology is a previously unknown type and provide direct evidence for mixing of inner (ureilitic) and outer (CC-like) solar system materials. AhS 91/91A and 671 are fine-scale breccias of a diverse array of solar system materials, which suggests that they are derived from well-mixed regolith. Their extreme friability suggests that they could represent the type of material that was lost from 2008

TC_3. If so, regolith on ureilitic asteroids could contain a significant component of dark, CC-like material, similar to Vesta and Psyche. Reflectance spectra of 91/91A and 671 are dark (albedo = 0.03-0.05) and nearly featureless in VNIR, with a ~2.7-3 µm band indicative of OH^- in phyllosilicates, similar to some CM and ungrouped C2. The presence of 2.7-3 µm band is usually considered diagnostic of a CC-like asteroid. The discovery of AhS 91/91A and 671 shows that this criterion may not be robust.

09:50 AM-10:00 AM

100.09 Exogeneous delivery of water to Mercury

Michael Mueller[1, 2], Kateryna Frantseva[2, 1], David Nesvorny[3], Inge Loes ten Kate[4], Floris van der Tak[2, 1]
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Abstract

Radar and in-situ observations of the bright and dark polar deposits in permanently shadowed north-polar regions of Mercury indicate that these regions contain water ice despite the planet's proximity to the Sun. Previous studies have shown that interplanetary dust particles (IDPs), asteroids and comets are possible sources of water on Mercury. Here we study how much water and organics certain asteroids (C-type), comets and IDPs can deliver to Mercury using the most recent minor bodies catalogs.

We have performed numerical gravity simulations of asteroid and comet impact rates on Mercury within the past few Myr. We use the N-body integrator RMVS/Swifter to propagate the Sun and the eight planets from their current positions. Separately, we add comets and asteroids to the simulations as massless test particles, based on their current orbital distributions. Asteroid impactors are assigned a probability of being water-rich (C-class) based on the measured distribution of taxonomic types across the Main Asteroid Belt. For comets, we assume a constant water fraction. For IDPs, we use a dynamical model to compute the dust flux on Mercury. Immediate post-impact ejection into outer space is taken into account as is water diffusion across the surface into the polar cold traps.

We find that exogeneous water sources can easily deliver the amount of water required by the available radar and MESSENGER data; taken together, they require 250--670 Myr to deliver the lower limit on available water. Over the $\sim$ 3.5 Gyr since the end of the Late Heavy Bombardment, exogenous sources delivered a maximum of 1.7--7.4 m of water ice to the polar regions of Mercury.

Among exogeneous water sources, we find IDPs to dominate over asteroids and comets.

Implications for the upcoming Bepi-Colombo observations are discussed.

Monday, October 22, 2018
08:30 AM-10:00 AM
Ballroom B (Knoxville Convention Center)

101 Formation of Planets and Satellites
Chair(s): Julie Brisset, Billy Quarles

08:30 AM-08:40 AM
101.01 Feasibility of in-situ water production during fast-accreting super-earth formation
Benjamin Cassese, David J. Stevenson
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Abstract
In recent years, the Kepler mission and subsequent follow up studies have revealed numerous super-earth terrestrial exoplanets. Although these make tempting targets for habitability assessment, it is possible that these worlds form dry in regions too close to their host stars for water to condense in the adjacent nebula. Indeed, Earth's water was likely delivered from elsewhere, a process that may not be universal. We propose a mechanism distinct from our solar system's own icy body bombardment that could lead to the accumulation of substantial quantity of water on these worlds. Central to this mechanism is the presence of a primordial gaseous nebula of mostly hydrogen during this fast formation. As rocky precursor material encounters this atmosphere, it can break up into liquid droplets, whereupon silica can react with molecular hydrogen to produce silane gas and water vapor. A fraction of this vapor could partition into the liquid melt, where it would be trapped and protected from the XUV which will eventually dislodge their gaseous counterpart volatiles. Upon cooling, the planet would be left with a substantial mass of water trapped in the now solid rocky bulk which may even be outgassed via volcanic processes to form a surface ocean. We present an initial review of the parameter space that would enable this process to take place, as well as basic calculations of the state of the atmosphere of an actively accreting planet. We find that under the expected conditions of 3-10 earth mass planets forming within a 200-1000K nebula in < 3Ma that the mass equivalent of a tens of km ocean of water could be produced and stored via this mechanism. This finding illustrates the need for acknowledging non-traditional modes of water accumulation on terrestrial planets when estimating their total water budget, and potentially increases the population of feasibly watery, or even habitable, worlds.

08:40 AM-08:50 AM
101.02 Streaming Instability in Turbulent Protoplanetary Disks: Expanded Theoretical Predictions
Orkan Umurhan[1, 2], Paul R. Estrada[1, 2], Jeff Cuzzi[2], Thomas Hartlep[1, 2]
[1]SETI Institute, Mountain View, California, United States, [2]NASA Ames Research Center, Moffett Field, California, United States

Abstract
Recent meteorite data, e.g. NWA5717, increasingly supports the picture of the first planetesimals forming in under 0.5-2.1 Ma after the incorporation of Calcium Aluminum Inclusions. Analysis of the extant few pristine chondrites show that chemically and lithologically distinct grain populations are incorporated into the same parent bodies suggesting that a substantial amount of transport also occurred during the accretion of the first planetesimals. However, the formation of structures past the cm-m size encounters several barriers to growth. A complete theory of how these first planetesimals formed given these facts

about the early solar-system remains elusive — however — two processes, namely, the streaming instability (SI) and turbulent concentration have been suggested as ways of overcoming these aforementioned growth barriers. In a parallel vein, recent theoretical studies have indicated that the planetesimal forming regions of the solar nebula are likely dynamically active owing to several identified turbulence generating linear instabilities. How this turbulence effects the ability of the SI to help concentrate particles remains to be seen.

In this study we re-analyze the SI in an alpha-disk model setting and assess its ability to concentrate particles within a variety of constraints placed by physics and observations. We find that for predicted values of disk turbulent intensity based on the recently identified linear instability mechanisms ($10^{-5} < \alpha < 10^{-3}$) the SI continues to operate — but at a muted level — wherein the growth timescales of the SI are on the order of several hundred to a thousand local disk orbit times corresponding to particle density enhancements being most pronounced on radial scales approximately equal to the local disk scale height. Furthermore, we find that the mechanism is viable in a protoplanetary disk for grains whose sizes are just under cm sizes (i.e., for particle Stokes number < 0.01). Given these trends, the role that the turbulent SI plays in the formation of the first planetesimals must be re-evaluated and we offer some suggestions at the time of the talk.

08:50 AM-09:00 AM
101.03 Collisional evolution of small particles within mean motion resonances
Rogerio Deienno, Kevin Walsh, Harold F. Levison, Katherine Kretke
Department of Space Studies, Southwest Research Institute, Boulder, Colorado, United States

Abstract
Early in Solar System history small particles (meter-sized) can drift inwards through the terrestrial planet region due to their interaction with a gaseous protoplanetary disk. It has been proposed that these particles could eventually get caught in mean motion resonance (MMR) with protoplanets and push the planet into the Sun. This mechanism had been used to explain the lack of super-Earths interior to the orbit of Mercury in our Solar System. Although appealing, it remains to be demonstrated whether such a mechanism would work when collisions are considered. Therefore, we studied the collisional evolution of a swarm of particles in MMRs with planets of different masses. We first investigated the size dependence of particles that can be captured in different MMRs for a given planetary mass and distance from the Sun. Secondly, we addressed the collisional evolution of such particles in two different ways, one considering a large amount of mass in particles of a given size already in the resonance, and another with a large swarm of drifting particles that are continually being captured by planet's MMRs. In both situations, we find that captured particles rapidly collisionally evolve. Thus, depending on the assumed collisional scaling law coefficients, the swarm of particles either decrease in size, leaving the MMR, or grow, slowing down or even stopping their inward drift. Therefore, in no case that we studied did the drifting particles significantly change the orbit of the planet.

09:00 AM-09:10 AM
101.04 The Nature of Mean Motion Resonant Chains Arising From In Situ Planet Formation
Sarah Morrison, Rebekah Dawson, Mariah MacDonald
Pennsylvania State University, University Park, Pennsylvania, United States

Abstract
Exoplanet systems with multiple planets in mean motion resonances have often been hailed as a signpost

of disk driven migration. Here we investigate whether planets can be established in resonant chains without migration, and assess the influence of additional planets and the system's dissipative history in establishing resonant chains. We simulate the giant impact phase of planet formation including eccentricity damping from a gaseous disk followed by subsequent evolution over tens of millions of years. We find a handful of example systems with established resonant chains in which the three planet resonance angle is librating, along with systems with successive pairs with librating, two planet first order resonance angles. A subset of systems arising from the giant impact phase contain several successive pairs of planets at period ratios close to integer ratios, suggestive of a resonance chain. However, a lower fraction of these systems are actually in resonance with librating resonance angles. We also investigate whether the gravitational influence of additional planets in the system and eccentricity damping from a remnant disk affects the establishment and characteristics of resonance chains. We examine the properties of the near-resonant and resonant systems from our simulations to compare to the sample of observed multi-planet systems and in an effort to identify distinguishing characteristics of resonant chains arising from planet migration vs. in situ planet formation.

09:10 AM-09:20 AM

101.05 Formation of planetary systems from pebble accretion and migration I: the growth dichotomy between close-in rocky super-Earth systems and terrestrial planets

Seth A. Jacobson[1], Michiel Lambrechts[2], Alessandro Morbidelli[3], Anders Johansen[2], Bertram Bitsch[4], André Izidoro[5], Sean N. Raymond[6]

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Abstract

Exoplanet surveys have discovered that a large fraction of planetary systems (perhaps, a third around Sun-like stars) possess super-Earth planets on orbits tighter than Earth's. These super-Earths with masses between that of Earth and Neptune are not found in the Solar System, however it has been proposed that they formed in a similar way to our terrestrial planets. Instead, we find that these two inner planetary system architectures correspond to two clearly defined planet formation pathways regulated by the pebble mass-flux.

Radio observations of protoplanetary disks reveal large reservoirs of "pebbles" (approximately cm-sized objects), which spiral inwards towards the central star through the disk due to drag with the nebular gas. Protoplanets embedded in the disk accrete a portion of these pebbles as they drift by. Pebble accretion can be the most efficient growth process of solid material. We modeled the growth of a system of rocky protoplanets embedded in disks of varying pebble mass-fluxes, and we find that a change of less than a factor of two in the pebble mass-flux significantly alters the architecture of the final planetary system.

When the pebble mass-flux is low, protoplanets grow slowly and remain small. Their low-mass strongly limits their migration and so they are located near where they originally grew in the disk. When the gas disappears, they naturally become dynamically unstable, collide with one another, and a smaller number of larger planets remain, i.e. the terrestrial planet formation process. We find the largest final planets are at most a few Earth masses, which grow from embryos that are at most a third of an Earth mass when the gas disappears and pebble accretion ceases.

If the pebble mass-flux is higher, protoplanets grow faster and become more massive while the protoplanetary disk still possesses nebular gas. These massive protoplanets interact with the gas disk and

migrate inward leading to stronger planet-planet interactions, mutual merging, and even faster growth. As the nebular gas dissipates, it leaves behind a system of close-in super-Earths, which eventually undergo dynamical instabilities responsible for further growth and the removal of orbital resonances.

09:20 AM-09:30 AM

101.06 Formation of planetary systems from pebble accretion and migration II: Hot super-Earth systems from breaking compact resonant chains

André Izidoro[1], Bertram Bitsch[3], Sean N. Raymond[2], Anders Johansen[4], Alessandro Morbidelli[5], Michiel Lambrechts[4], Seth A. Jacobson[6]

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Abstract

At least 30% of the FGK-type stars host "hot Super-Earths" with sizes between 1 and 4 Earth radii and orbital periods of less than 100 days. Here we use N-body simulations that simultaneously model gas-assisted pebble accretion and disk-planet tidal interaction to study the formation of hot super-Earths systems. Our results show that the integrated pebble mass reservoir primarily controls the system fate. A simple factor of ∼2 difference in the pebble flux bifurcates the final outcome of our simulations between systems of hot super-Earths or hot-Neptunes ($\leq$20 M_{Earth}) and systems containing multiple massive cores able to become gas giants ($\geq$20 M_{Earth}). Simulations with low to moderate pebble fluxes grow multiple super-Earths that migrate inward and pile up at the disk's inner edge in long resonant chains. We follow the long-term dynamical evolution of these systems and use the period ratio distribution of observed planet-pairs to constrain our model. We find that up to ∼95% of the resonant chains become dynamically unstable after the gas disk dispersal. Supporting previous studies, our simulations match observations if we combine a fraction of unstable and stable systems (e.g. 95% unstable plus 5% stable). Our results also reinforce the claim that the Kepler dichotomy is an observational artifact. Finally, our results predict that in every hot super-Earth system at least some hot super-Earths should be ice-rich, if not most of them. If observations instead find a lack of ice-rich super-Earths it may suggest that planetesimal formation is far more efficient than expected well inside the snowline, or perhaps that pebbles in the inner refractory disk are as large as in the outer icy disk. Indeed, this would favor rapid growth in the inner disk, although it is at odds with the inferred conditions in the early solar system.

This talk comes as the 2nd part of a series of papers, where the 1st talk will be presented by Dr. S. Jacobson about the formation of terrestrial planets and rocky super-Earths. The 3rd talk will be presented by Dr. B. Bitsch about the formation of gas giant planets.

09:30 AM-09:40 AM

101.07 Formation of Planetary Systems from Pebble Accretion and Migration III: The Formation of Gas Giants

Bertram Bitsch[1], André Izidoro[2], Sean N. Raymond[3], Anders Johansen[4], Alessandro Morbidelli[5], Michiel Lambrechts[4], Seth A. Jacobson[6]

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Abstract
Previous simulations of planet formation utilizing single bodies including pebble accretion and planet migration imply that giant planets found in orbits exterior to 1 AU originate from the outer regions of protoplanetary discs (30-40 AU). Here we generalize such models to include the mutual gravity between a high number of growing planetary bodies. We investigate how the formation of planetary systems depends on the radial flux of pebbles through the protoplanetary disc and on the planet migration rate. Our N-body simulations confirm previous findings that giant planets originate from 30-40 AU when using nominal type-I and type-II migration rates and a pebble flux of approximately 100-200 Earth masses per Myr, enough to grow Jupiter within the lifetime of the solar nebula. However, planetary embryos growing interior to 30-40 AU also grow and migrate inwards to the inner system (r<1 AU) to form super Earths or gas giants, inconsistent with the configuration of the solar system, but consistent with many exoplanetary systems. Slower planetary migration rates, however, allow the formation of gas giants from embryos forming in the 5-10 AU region, which are stranded exterior of 1 AU at the end of the gas-disc phase. We identify a pebble flux threshold below which migration dominates and moves the planetary core to the inner disk, where the pebble isolation mass is too low for the planet to accrete gas efficiently. At the same time our simulations show that planetary embryos forming interior to 5 AU do not grow to gas giants, even if the migration rates are low and the pebble flux is large. The formed planets instead grow to just the mass regime of super-Earths. This stunted growth is caused by the low pebble isolation mass in the inner disc aided by the reduced pebble flux due to exterior growing planets and is thus mostly independent of the pebble flux. Additionally we show that the long term evolution of our formed planetary systems can naturally produce systems with inner super Earths and outer gas giants as well as systems of giant planets on very eccentric orbits.

This talk comes as the 2nd part of a series of talks, where the 1st talk will be presented by Dr.A.Izidoro about the formation of super-Earth systems.

09:40 AM-09:50 AM
101.08 Formation of close-in super-Earths under suppressed type I migration
Masahiro Ogihara[1], Eiichiro Kokubo[1], Takeru Suzuki[2], Alessandro Morbidelli[3]
[1]Division of Theoretical Astronomy, National Astronomical Observatory of Japan, Tokyo, Japan, [2]University of Tokyo, Tokyo, Japan, [3]Observatoire de la Cote d'Azur, Nice, France

Abstract
Planets with masses larger than Mars mass undergo rapid inward migration (type I migration) in a standard protoplanetary disk with a power-law density profile. Recent magnetohydrodynamical simulations revealed the presence of magnetically driven disk winds, which would alter the disk profile and the type I migration in the close-in region. We investigate orbital evolution of planetary embryos in a disk that viscously evolves under the effects of disk winds. We also aim to examine whether observed distributions of close-in super-Earths can be reproduced by our N-body simulations. As a result, we find that the type I migration is significantly suppressed in many cases, because the gas surface density is decreased and has a flatter profile in the close-in region due to disk winds. After planetary embryos undergo slow inward migration, they are captured in a chain of resonant planets outside the disk inner edge. The resonant chain undergoes late orbital instability during the gas depletion, leading to a non-resonant configuration. We also find that observed distributions of close-in super-Earths (e.g., period ratio) can be reproduced by results of our simulations.

09:50 AM-10:05 AM

101.09D Global Dust Modeling in a Planet Forming Disk: Implications for Opacity, Thermal Profile, and Gravitational Instability.

Debanjan Sengupta[1, 2], Neal J. Turner[2], James MacDonald[1]
[1]Physics and stronomy, University of Delaware, Newark, Delaware, United States, [2]Jet Propulsion Lab, Pasadena, California, United States

Abstract

In spite of making a small contribution to total protoplanetary disk mass, dust affects the disk temperature by controlling absorption of starlight. As grains grow from their initial ISM-like size distribution, settling depletes the disk's upper layers of dust and decreases the optical depth, cooling the interior. In this talk, we will discuss the effect of collisional growth of dust grain and their dynamics on the thermal and optical profile of the disk, the vertical structure of dust grains, and will discuss the possibility that cooling induced by grain growth and settling could lead to gravitational instability.

First, we present a new fast and numerically inexpensive Monte Carlo model with a weighting technique, which models collisional growth of dust, along with vertical settling, turbulent diffusion and radial drift. We explore three disk models, and perform simulations for both constant and variable turbulence profile, α. The variable α profile is computed from the ionization fraction, calculated from an ionization-recombination chemical network. We then calculate wavelength-dependent opacities for the evolving disks and perform radiative transfer to calculate the temperature profile. We find that the growth of large particles in the mid-plane can make a massive disk optically thick at millimeter wavelengths, making it difficult to calculate the surface density of dust available for planet formation in the inner disk.
Finally, we calculate the ToomreQ parameter, a measure of the disk's stability to axisymmetric perturbations, for each disk model after it reaches a steady state dust-size distribution, and show that for an initially massive disk, grain growth and settling can produce a drop in the ToomreQ parameter, driving the disk to $Q < 1.4$ and possibly triggering spiral instabilities.

In the second part, we apply our dust model to calculate the new hydrostatic equilibrium for vertical gas column and show that the local gas scale heights become significantly less compared to the canonical value of $h/R \sim 0.05$ for isothermal MMSN disk models. We discuss this result in the context of the minimum mass for a planet to open a gap in a settled disk, and its possible implications for planet migration.

Monday, October 22, 2018
08:30 AM-09:20 AM
Ballroom C (Knoxville Convention Center)

102 Venus
Chair(s): Eliot F. Young, Xi Zhang

08:30 AM-08:40 AM

102.01 Environmental Factors Affecting Chemistry and Viscosity in Venus Cloud Droplets
M. L. Delitsky[1], K. H. Baines[2]
[1]California Specialty Engineering, Flintridge, California, United States, [2]University of Wisconsin, Madison, Wisconsin, United States

Abstract
The clouds of Venus consist of liquid droplets of concentrated aqueous sulfuric acid ranging in concentration from 75-99 wt% (Krasnopolsky 2015). The clouds are at altitudes ~ 40-70 km above the surface. Atmospheric gases can diffuse into these droplets and change the chemical composition at different altitudes. Droplets are more dilute as altitude increases (i.e. they contain more water) and uptake of gases will increase leading to more chemical reactions. As temperatures decrease at higher altitudes, uptake of gases and viscosity of the droplets changes. The ratio of dissolved gases in the liquid phase to that in the gas-phase is given by the Henry's Law constant, H*. Atmospheric HCl and HF will diffuse into the droplets, react with sulfuric acid and form sulfonic acids (Robinson et al 1998). The chloro- and fluorosulfonic acids are called "superacids" which will have large solubilities in the droplet solutions and can be 1000x more acidic than sulfuric acid. The reaction is $HCl + H_2SO_4 \rightarrow ClSO_3H + H_2O$. The presence of $ClSO_3H$ in solution improves the uptake, or γ, of HCl into H_2SO_4. Utilizing uptake data from Williams et al (1994), we derive an equation for the Henry's Law constant for uptake of HCl into aqueous H_2SO_4 as a function of temperature and weight percent of H_2SO_4. H* increases with altitude. $ClSO_3H$ and its decomposition products, sulfuryl- and thionyl- chlorides (SO_2Cl_2 and $SOCl_2$) have UV absorbances and may contribute to the unknown Venus UV-active material in the atmosphere that absorbs between 0.5-0.2 µm. In the droplets, sulfuric acid can add water via hydrogen-bonding to form sulfuric acid hydrates, $H_2SO_4.nH_2O$, where n = 1-8 (Carslaw et al, 1997). The viscosity (or "runniness") of aqueous H_2SO_4 changes dramatically as temperature decreases. Therefore, the flow characteristics will vary with altitude. The viscosity of the droplets will change from the consistency of motor oil at 50 km to that of honey at 70 km. Any cloud materials plating out on the wings or instruments of long-duration Venus atmospheric spacecraft could cause damage or corrosion. Chemical and viscosity effects in the clouds should be taken into account on any future Venus atmospheric probe missions.

08:40 AM-08:50 AM
102.02 Laboratory investigations of Venus aerosol analogs
Michael J. Radke, Sarah M. Horst, Chao He, Marcella Yant
Earth and Planetary Sciences, Johns Hopkins University, Baltimore, Maryland, United States

Abstract
The Venusian cloud deck is a ~20-km-thick layer of sulfuric acid and other trace species that is maintained by a complex sulfur cycle. Despite 50 years of spacecraft observation, several major questions persist about the Venusian cloud deck: what is the nature of ultraviolet-absorptive species at the cloud

tops? Do large particles exist in the clouds? What is the composition of the non-sulfuric-acid component of the clouds? What are the properties of the (non-cloud) haze layers and how do they form?
We designed a series of gas irradiation experiments to attempt to answer these outstanding questions. Our novel experiments are based on a large body of work regarding the production of organic aerosol in the atmosphere of Titan. Laboratory experiments of sulfate aerosol formation have been performed with Earth-like atmospheres (e.g., DeWitt et al. 2010; Friend et al., 1973; Masterson et al., 2011), but similar investigations have not yet been performed for strongly oxidized Venus-like atmospheres. In our experiments, we exposed simulated Venusian atmospheres composed of CO_2 and SO_2 (with SO_2 mixing ratios ranging from parts-per-million to several percent) to an energy source to initiate photochemical reactions, thus creating Venus analog aerosol in the lab. Aerosol analogs were analyzed with FTIR and UV-Vis spectroscopy (0.2 – 40 μm), mass spectrometry, and atomic force microscopy to determine their optical, chemical, and material properties, respectively.
The results of these investigations allow us to compare the properties of our Venus analog aerosol to the properties of the real Venusian clouds and haze as well as proposed unknown absorber candidates. Recent spacecraft observations have provided new constraints on the optical properties of the unknown ultraviolet absorber (Pérez-Hoyos et al. 2018; Lee et al. 2017; Petrova et al., 2015) that can be compared with this new laboratory data and data from future missions.

08:50 AM-09:00 AM
102.03 A Fully Coupled Photochemical-Cloud Model of the Venus Atmosphere From Ground To 110 km
Xi Zhang[1], Carver Bierson[1], Peter Gao[2]
[1]Earth and Planetary Sciences, University of California Santa Cruz, Santa Cruz, California, United States, [2]University of California Berkeley, Berkeley, California, United States

Abstract
Ground-based and Venus Express observations have provided a wealth of information on the vertical and temporal distribution of many chemical species in the Venusian atmosphere [Marcq et al., Space Science Reviews 2018]. To date, the following important observations still lack a satisfactory explanation: (a) near constant water vapor mixing ratio in the middle atmosphere [Bertaux et al., Nature 2007], (b) SO_2 vertical profile including inversion at high altitudes (>70 km) [Zhang et al., Nature geoscience 2010; Belyaev et al., Icarus 2012], and (c) H_2SO_4 gas mixing ratio and cloud acidity measurements [Arney et al., JGR 2014; Cottini et al., Icarus 2012; Oschlisniok et al., Icarus 2012].

Unlike previous modeling efforts that focused on either gas chemistry [Zhang et al., Nature geoscience 2010; Zhang et al., Icarus 2012; Krasnopolsky, Icarus 2012] or sulfuric acid haze and cloud formation [Gao et al., Icarus 2014; Krasnopolsky, Icarus 2015] and separately modeled either the lower (0-50 km) or the middle (40-100 km) atmosphere, here we introduce a new photochemical-condensation framework to understand the interaction among gas, haze, and cloud in Venus' atmosphere. First, our new 1D Venus photochemistry model encompasses the region from the ground to 110 km with a sulfuric acid cloud condensation scheme that includes gravitational settling, allowing us to self-consistently solve for the chemistry and cloud formation. Second, we further investigate the interaction between the vapor and particles using the microphysical model CARMA [Gao et al., Icarus 2014]. We couple a simple H_2O-H_2SO_4chemical scheme based on our photochemical model with CARMA to create the first self-consistent H_2O-H_2SO_4 gas-cloud microphysics model of Venus. We find that condensation-chemistry interactions could stabilize the H_2O-H_2SO_4 system, a new mechanism that has not been discussed before. Our model can also reproduce the observed H_2SO_4 vapor mixing ratio. This new Venus photochemical-condensation framework provides significant implications for the sulfur mass budget and dynamics of the Venus atmosphere.

09:00 AM-09:10 AM

102.04 The Total Possible Biomass of Venus' Clouds

Mark Bullock

Science & Technology Corp., Boulder, Colorado, United States

Abstract

The hypothesis that Venus' clouds harbor life is not ruled out by the currently available remote sensing and in situ data. Several authors have suggested that unidentified UV and blue absorbers in the Venus clouds may due to microbes that metabolize sulfur or iron compounds[1,2]. Aside from *p*H, the physical condition in Venus' lower clouds are Earth-like. Microbes in terrestrial water cloud aerosols have been shown to complete entire lifecycles within the aerosols. If thermo-acidophilic organisms live within the Venus clouds, what is their potential biomass?

The number of microbes in each lower cloud aerosol, n_B, can be calculated by solving a rate equation with growth and loss terms. Microbes grow at an exponential rate characterized by the generational life time, t_B, and are lost by the evaporation of cloud aerosols at the bottom of the cloud, characterized by the aerosol residence time, t_S. Microbial growth is limited by the available nutrients in the cloud aerosol, and total biomass M_B is assumed to not exceed a fraction f of the aerosol mass M_P. The maximum number of microbes in an aerosol is $n_B{*} = f(M_P/M_B)$. The rate equation is:

The steady state solution is:

The residence time of mode 3 (r=3.6 μm) aerosols in Venus' lower cloud is about 2 days3 The rate equation shows that if the microbial lifetime is shorter than this, a steady state population can exist within the aerosols.

The column mass of mode 3 particles is 7.85 x 10^{-3} g/cm^2 (Esposito et al., 1983). The global surface area of the clouds is approximately 4.6 x 10^{18} cm^2. If microbes grow to represent one tenth of the aerosol mass, the total biomass in Venus' clouds would be 3.6 billion tonnes, or about the biomass of the Earth's oceans.

[1]Schulze-Makuch, et al., Astrobiology 4**,** 11-18.

[2]Limaye, S. S., et al, 2018. Astrobiology, 18.

[3]James, E. P., et al, 1997. Icarus. 129**,** 147-171.

[4]Esposito, L. W., et al, Venus D. M. Hunten et al, eds,University of Arizona Press, Tucson, 1983, pp. 484-564.

09:10 AM-09:20 AM

102.05 Observational Analysis of Venusian Atmospheric Equatorial Waves and Superrotation

Ryan M. McCabe[1], Kunio M. Sayanagi[1], John J. Blalock[1], Jacob L. Gunnarson[1], Javier Peralta[2], Candace Gray[3], Kevin McGouldrick[4], Takeshi Imamura[2], Shigeto Watanabe[5]

[1]Atmospheric and Planetary Sciences, Hampton University, Hanover, Pennsylvania, United States, [2]Institute of Space and Astronautical Sciences - Japan Aerospace Exploration Agency (JAXA), Sagamihara, Japan, [3]Apache Point Observatory, Sunspot, New Mexico, United States, [4]LASP, University of Colorado, Boulder, Colorado, United States, [5]Hokkaido University, Sapporo, Japan

Abstract
We investigate the dynamics of Venus's atmosphere in an attempt to link variability of atmospheric superrotation to the existence and occurrences of the Y-feature seen at ~365 nm, representing an altitude of ~65 km. The atmospheric superrotation, in which the equatorial atmosphere rotates with a period of approximately 4-5 days (~60 times faster than the solid planet), has forcing and maintenance mechanisms that remain to be explained. Temporal evolution of the zonal wind could reveal energy and momentum transport in or out of the equatorial region and shed light on mechanisms that maintain the superrotation. We postulate that the Y-feature is a manifestation of equatorial waves (Kelvin, Rossby, or a combination of the two) that may play a role in such energy transport that could affect superrotation. To understand the connection between the Y-feature and the superrotation, we must determine the frequency of Y-feature existence, the variability of the atmospheric wind field, and analyze the connection between the two to determine to what extent the Y-feature plays a role in Venus's superrotation.

We characterize the total and annual zonal mean wind fields of Venus between 2006 and 2013 in ultraviolet images captured by the Venus Monitoring Camera on board the ESA Venus Express (VEX) spacecraft which observed Venus's southern hemisphere. Our measurements show that, between 2006 and 2013, the westward wind speed at mid- to equatorial latitudes exhibit an increase of ~20 m/s. We additionally review longitude and local time dependencies. We also conduct ground-based observations, concurrent to observations by the Japanese spacecraft Akatsuki, with the 3.5 m ARC telescope at the Apache Point Observatory (APO) in Sunspot, NM to extend our temporal coverage to present. Images captured at APO to date demonstrate that it is possible to see large features that could be used to confirm the Y-feature existence to later be compared to future wind analyses of Akatsuki images. The viability of tracking the existence of the Y-feature during VEX and Akatsuki is discussed and the analysis of such occurrences and wind field variability is ongoing.

Our work has been supported by NASA MUREP NNX15AQ03A and NASA PATM NNX14AK07G.

09:20 AM-10:00 AM
Ballroom C (Knoxville Convention Center)

103 Moon: Surface and Atmosphere
Chair(s): Paul Hayne, Amanda Hendrix

09:20 AM-09:30 AM
103.01 The Migration of Impact-Delivered Water to the Cold Traps of Airless Bodies
Jordan K. Steckloff[1, 2], David Goldstein[1], Parvathy Prem[3], Philip Varghese[1], Laurence Trafton[1]
[1]Aerospace Engineering and Engineering Mechanics, University of Texas at Austin, Whitmore Lake, Michigan, United States, [2]Planetary Science Institute, Tucson, Arizona, United States, [3]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, United States

Abstract
Water-rich impactors deliver water to the cold traps of large, airless bodies in the inner Solar System (Mercury, the Moon, Ceres, and Vesta). Indeed, Earth-based radar and the *MESSENGER*, *LRO*, and *Dawn* spacecraft have returned striking data constraining the location, distribution, and abundance of water in these cold traps. The formation of these deposits, and why concentrations vary between bodies, is important in understanding the evolution and habitability of their host bodies. In spite of this, the processes involved are complex, limiting our understanding of how water migrates from impact site to cold trap. Most of the cold-trapped water first lands elsewhere on the surface, before migrating to the cold traps over many rotational cycles, during which numerous competing processes affect the quantity and distribution of water ice. For example, the larger of these airless bodies have higher escape velocities and thus retain more impact vapor, but are closer to the Sun, where more intense insolation increases thermal escape and photodissociation rates. In addition, self-shielding, surface roughness, spin rate and axis orientation affect the migrating water.

Furthermore, these vapor plumes are too rarefied to study with continuum fluid dynamics, yet too collisional to approximate as free molecular flow. Thus, collisional molecular numerical methods such as the Direct Simulation Monte Carlo (DSMC) approach are required to accurately model the behavior of impact-delivered water on these large, airless, inner Solar System bodies. In this presentation, we use our PLANET DSMC code to compare how competing processes affect the distribution of cold-trapped water on these bodies from an identical impact event. PLANET is built to numerically model the evolution of such rarefied gas flows, accounting for photodissociation and self-shielding, vapor adsorption/desorption at a rough surface, spin rate and axis orientation, and the location of cold traps. We simulate an identical 2 km diameter comet impacting these objects' north poles at 30 km/s at a 60° angle, and show how differences in these bodies' orbital locations and physical properties affect the retention, photodissociation, and delivery of water to the cold traps.

09:30 AM-09:40 AM
103.02 Formation and Liberation of Lunar Water by Dual Solar Wind Irradiation and Micrometeorite Impact
Cheng Zhu, Jeffrey J. Gillis-Davis, Parker B. Crandall, Hope A. Ishii, John P. Bradley, Laura M. Corley, Ralf I. Kaiser
University of Hawaii at Manoa, Honolulu, Hawaii, United States

Abstract
Recent remote infrared spectroscopic evidence of water (H_2O) and hydroxyl radicals (OH) on the lunar surface has challenged the presumption that the Moon is anhydrous. The sources and chemical processes responsible for the production of this surface water are still uncertain. The interaction of solar wind protons (H^+) with silicates and oxides is suggested as one possible mechanism However, several laboratory simulations exploiting keV proton bombardment of minerals typical in lunar regolith and even one experiment with actual lunar regolith yielded conflicting results with only one study claiming the detection of water. Here we establish that proton implantation alone is insufficient to generate and liberate detectable surface water. As an alternative, our study reveals that water is released by micrometeorite impact and resultant thermal/shock pulses into materials doped with solar wind hydrogen. We support this conclusion with the first definitive chemical and electron microscopy analyses of water expulsion from anhydrous San Carlos olivine samples that were first exposed to deuterium ions and subsequently laser irradiated. Laser irradiation, which simulates micrometeorite impact exposure, generated water at mineral temperatures from 10 K to 300 K. Hence, we propose that micrometeorite impact of regolith materials saturated with hydrogen atoms may also contribute to the surface H_2O/OH as detected on airless bodies such as Mercury, S-type asteroids 433 Eros and 1036 Ganymed, and possibly C-type asteroids 1 Ceres and 24 Themis.

09:40 AM-09:50 AM
103.03 Evidence for glass-rich surfaces on lunar impact melt deposits
Catherine Neish[1], Kevin Cannon[2], Livio Tornabene[1], Michael Zanetti[1], Eric Pilles[1]
[1]The University of Western Ontario, London, Ontario, Canada, [2]The University of Central Florida, Orlando, Florida, United States

Abstract
Deposits of smooth, low albedo material are observed around many fresh impact craters on the Moon. These deposits are interpreted to be solidified silicate melts produced from the impact event, and emplaced during the late stages of impact crater formation. Despite their resemblance to lava flows in optical images, lunar impact melt deposits have a surface texture unlike any measured terrestrial lava flow. They are incredibly rough at decimeter scales, with radar returns at S-Band (12.6 cm) similar to blocky lava flows on Earth. However, in high-resolution, submeter scale optical images, they appear quite smooth, more similar to pahoehoe flows than blocky flows. The cause of this unusual surface texture is unknown, but may relate to the unique cooling conditions experienced by lunar impact melts. Lunar impact melt deposits cool under vacuum with initial temperatures far in excess of their liquidus, while terrestrial lava flows cool under a convective atmosphere with initial temperatures close to their liquidus. In this work, we propose that the unique cooling conditions experienced by lunar impact melt deposits cause them to form with a glassy surficial layer. This layer is then disrupted after formation to produce decimeter sized blocks covering an otherwise ‘smooth’ flow. To test this hypothesis, we use data from the Lunar Reconnaissance Orbiter’s (LRO) Mini-RF instrument to characterize the small-scale texture of the deposits, and data from Chandrayaan-1’s Moon Mineralogy Mapper (M^3) to characterize their composition. We look for evidence in the M^3 data for a glass-rich composition using laboratory spectra acquired of a range of glass-bearing materials as inputs for a spectral unmixing model described in *Cannon et al*. [2017]. We find that glass-bearing materials with microcrystalline inclusions of pyroxene are consistent with observations by both Mini-RF and M^3 of impact melt deposits on the Moon. This suggests that their rapid cooling history can explain the discrepancy between the optical and radar observations of impact melts on the Moon.

09:50 AM-10:00 AM

103.04 On the Angular Width of the Opposition Effect of Planetary Regoliths
Bruce W. Hapke
Geology and Environmental Science, University of Pittsburgh, Gibsonia, Pennsylvania, United States

Abstract
Coherent backscatter is thought to be a major contributor to the opposition effect (OE – the surge observed in the reflectance of particulate media around zero phase angle). In this phenomenon waves traveling in opposite directions along chains of independent scatterers interfere constructively [1]. The angular width is predicted theoretically to depend on the wavelength divided by the transport mean free path (TMFP) which, in turn, depends on the particle size and media porosity. Thus, it was hoped that observations of the OE would give information on these quantities in planetary regoliths. However, planetary observations and laboratory studies finds lack of dependence on all these quantities. Instead, the TMFP inferred from the OE in media of large particles in contact with one another is found to be of the order of the wavelength. Because short chains are much more numerous than long ones, and the wavelength is the shortest separation distance for which scatterers may be considered independent, binary scattering chains of this length apparently make the major contribution to the OE and determine its width.
References: 1. B. Hapke, *Theory of Reflectance and Emittance Spectrosscopy,* 2nd edition, Cambridge University Press, Cambridge, UK.
Acknowledgement: This research is supported by the Lunar Reconnaissance Orbiter mission of the National Aeronautics and Space Administration.

Monday, October 22, 2018
10:30 AM-12:00 PM
Ballroom A (Knoxville Convention Center)

104 Planetary Rings
Chair(s): Estela Fernández-Valenzuela, Shawn M. Brooks

10:30 AM-10:40 AM
104.01 What has been happening to Saturn's innermost ringlet?
Matthew Hedman
Physics, University of Idaho, Moscow, Idaho, United States

Abstract
The innermost narrow ringlet in Saturn's ring system is located around 67,630 km from Saturn's center and is designated D68. Observations of this ringlet early in the Cassini mission showed that it was composed primarily of small particles and was roughly the same brightness all the way around the planet. However, images of this ring taken after 2015 revealed a series of clumps in this ringlet that were up to four times brighter than the background ring. Over the course of the 18 months that they could be observed, these localized enhancements of material drifted and spread very slowly, indicating that all the visible material consisted of particles spanning a sub-kilometer range of semi-major axes. This material was probably released from the surfaces of multiple source bodies at least several meters wide orbiting within or close to this ringlet. These clumps may therefore provide new insights into how this narrow dusty ringlet is maintained, and might also be a source of the material seen by the in-situ instruments during Cassini's grand finale.

10:40 AM-10:50 AM
104.02 Radial stratification of propeller size distributions in Saturn's main rings
Matthew Tiscareno[1], Jesse Modesto[2, 1]
[1]SETI Institute, Mountain View, California, United States, [2]California State Polytechnic University, Pomona, Pomona, California, United States

Abstract
"Propellers" are eponymously-shaped disturbances in Saturn's rings centered on embedded moons (see [1] and references therein).

During its Ring Grazing Orbits (RGO) and Grand Finale (GF), the Cassini spacecraft passed very close to the outer and inner edges (respectively) of Saturn's main rings. During these maneuvers, the Cassini ISS camera executed a series of very high-resolution images of the main rings [2]. Among other priority science targets, the Propeller Belts of the mid-A ring were imaged at resolutions better than 0.4 km/pixel and high S/N. These images (see sample at https://photojournal.jpl.nasa.gov/catalog/PIA21448) show large numbers of swarming propellers even in a single image.

The swarming propellers in the Propeller Belts of the mid-A ring are distinct from the "giant propellers" that orbit beyond the Keeler gap [3]. It is the latter whose individual orbits have been tracked for over 10yr (see [1] and references therein).

The ratio between the largest and smallest propellers seen in a typical RGO image is a factor of 4x or 5x.

For the first time, the class of tiny propellers first discovered during Cassini's arrival at Saturn [4] are seen again and can be understood in context of the slightly larger propellers that we have observed during the main part of the mission [5,6].

The Propeller Belts are known to have a threefold structure, divided by the "halos" of strong density waves [6]. Although the RGO images sample only a small radial portion of these belts, the large sample of detected propellers allows us to show that the Propeller Belts exhibit strong radial variations in size distribution on much finer scales than previously realized. This implies that some combination of the parent bodies, subsequent evolution, and/or visibility of propellers is highly radially stratified.

We will present details and will discuss the implications.

References: [1] Spahn *et al.* 2018, in Tiscareno and Murray, eds., *Planetary Ring Systems* (Cambridge Univ. Press), 157. [2] Tiscareno *et al.* 2018, Science, submitted. [3] Tiscareno *et al.* 2010, ApJL **718**, L92. [4] Tiscareno *et al.* 2006, Nature **440**, 648. [5] Sremcevic *et al.* 2007, Nature **449**, 1019. [6] Tiscareno *et al.* 2008, AJ **135**, 1.

10:50 AM-11:00 AM

104.03 Processing and Calibration of the Cassini RADAR Ring Observations

Richard West[1], Michael Janssen[1], Zhimeng Zhang[1], Jeff Cuzzi[2], Yanhua Anderson[1], Gary Hamilton[1], Charles Elachi[1]

[1]Jet Propulsion Laboratory, Pasadena, California, United States, [2]NASA Ames, Moffet Field, California, United States

Abstract

In its last year of operation, the Cassini spacecraft executed a series of short highly inclined orbits that brought it close to Saturn's rings. First, a series of F-ring orbits crossed the ring plane just outside of the F-ring, and then a series of Proximal orbits crossed the ring plane inside of the D-ring just above the cloud tops. The Cassini RADAR instrument collected active and passive data of the rings in five separate observations. These observations provided a unique opportunity to obtain backscatter measurements and relatively high-resolution brightness temperature measurements from the rings. Preliminary examination of the active data showed major ring structural features such as the Cassini Division, the Encke Gap, and the Keeler Gap. This presentation will show both real aperture and higher resolution range compressed processing results from the radar rings scans and discuss the calibration and processing issues. These ring scan measurements provide a 1-D profile of backscatter obtained at 2.2 cm wavelength that complements similar passive profiles obtained at optical, infrared, and microwave wavelengths. Such measurements can further constrain and inform models of the ring particle composition and structure, and the local vertical structure of the rings. This work is supported by the NASA Cassini Program at JPL - CalTech.

11:00 AM-11:10 AM

104.04 Constraints on Saturn D Ring Composition from Cassini Ion Neutral Mass Spectrometer

Kelly E. Miller[1], J. H. Waite[1], Rebecca Perryman[1], Mark Perry[2], Alexis Bouquet[1], Brian Magee[3], Bryce Bolton[4], Chris Glein[1]

[1]Southwest Research Institute, San Antonio, Texas, United States, [2]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, United States, [3]Southwest Research Institute, Boulder, Colorado, United States, [4]Artistic Sciences Inc., San Antonio, Texas, United States

Abstract
During Cassini's Grand Finale, the Ion Neutral Mass Spectrometer (INMS) acquired some of the first in situ data from particles flowing from the D ring into Saturn's upper atmosphere. Volatiles derived from the particles include water, ammonia, carbon monoxide and/or nitrogen, carbon dioxide, and organics. INMS data are dominated by organics (~50% by mass), and signal was detected across the full mass range from 1 to 99 u.

Using a combination of ionization fragmentation patterns from the INMS engineering unit and the NIST catalog, we performed model fits to integrated spectra with average altitudes between 1900 and 1950 km to constrain the elemental H/C, O/C, N/C, and S/C ratios. Our results suggest C abundances that are enhanced relative to solar values, and an H/C ratio for non-methane organics >2, consistent with a primarily aliphatic composition. Model fits for the upper mass range suggest the presence of organics heavier than 99 u, which break up to produce the observed mass peaks.

The final five complete orbits of Cassini passed from north to south between Saturn and its rings. They crossed the equatorial ring plane, and closest approach was approximately 6 S latitude. In contrast, Cassini's final plunge (Prox293) did not cross the equator, and terminated at 11 N latitude. Preliminary comparisons of Prox293 indicate that influxing material may be depleted in compounds with vapor pressures less than or equal to that of CO_2. If so, this suggests latitudinal fractionation of the influxing composition is a function of volatility.

However, it is possible these differences are caused by instrumental effects. To test for instrumental effects we used the Simulator for Chemical Reactions in the Antechamber of a Mass spectrometer (SCRAM), which models the evolution of the population within the INMS antechamber, including effects from adsorption and desorption. From the time-dependent density and mixing ratios, SCRAM outputs the model counts for the compound of interest. The results improve understanding of the overall composition of influxing ring material and test for possible latitudinal dependence of the ring rain composition.

11:10 AM-11:20 AM
104.05 Wakes Versus Wakes: Trends in Ring Particle Size Distributions After Satellite Passage.
Rebecca Harbison
Physics & Astronomy, University of Nebraska - Lincoln, Lincoln, Nebraska, United States

Abstract
The behavior of ring material near the satellite-bearing gaps in the A Ring is shaped by several gravitational processes. Like the rest of the A Ring, self-gravity pulls material together into larger, temporary aggregates called 'self-gravity wakes'. However, regular passage of Pan and Daphnis in their respective gaps stirs up adjacent material in the ring into 'satellite wakes'. Numerical simulations by Lewis and Stweart (2005) show that 'satellite wakes' can disrupt 'self-gravity wakes' and the region a few tens of kilometers from the gap edge changes in time after a satellite passage.

During stellar occultations of Saturn's rings observed by Cassini, we have observed 'gap overshoots' or 'horns': places near a sharp edge of the rings, such as the gaps of A Ring, where the transmission of starlight appears to exceed unity. This excess light is due to starlight forward-scattered from the nearby ring into the detector and is dependent on the particle size distribution. Work by Becker et al. (2016) with UVIS occultations detected a possible change in the observed particle-size distribution in data taken shortly after a Pan encounter but limited to a few data points. We will present particle size distribution

models from dozens of VIMS occultations, showing any trends at the Encke Gap edges with Pan longitude, and examine the Keeler Gap.

11:20 AM-11:30 AM

104.06 Kronoseismology IV: More planet-driven waves in Saturn's C ring

Philip D. Nicholson[1], Richard G. French[2], Matthew Hedman[3]

[1]Astronomy, Cornell University, Ithaca, New York, United States, [2]Wellesley College, Wellesley, Massachusetts, United States, [3]University of Idaho, Moscow, Idaho, United States

Abstract

In previous work (Hedman & Nicholson 2013, 2014, French et al. 2016) we identified nine inward-propagating density waves in Saturn's middle C ring with resonances generated by internal *f*-mode oscillations in Saturn. The oscillations involved were all sectoral modes (ie., modes with $l = m$) with $m =$ 1, 2, 3, 4 and 10, as originally predicted by Marley & Porco (1993). Development of an improved radius scale for Cassini occultations, accurate to ~150m, led to the identification of an additional seven Saturn-driven waves in the inner C ring with $m = 2$, 4, 7, 8 and 9, four of which turned out to be bending waves rather than density waves (French et al. 2018), as well as six more Saturn-driven density waves in the middle C ring (Hedman et al. 2018) with $m = 5$, 6, 7, 8, 9 and 11. These advances provide a more complete picture of the spectrum of planetary normal modes and thereby place strong constraints on Saturn's internal structure and rotation rate (Fuller et al. 2014, Mankovich et al. 2017, 2018).

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11:30 AM-11:40 AM

104.07 Uranian Atmosphere and Rings Probed with ALMA Observations

Edward Molter[1], Imke de Pater[1], Statia Luszcz-Cook[2, 3], Joshua Tollefson[1], Arielle Moullet[4], David deBoer[1]

[1]UC Berkeley, Berkeley, California, United States, [2]Columbia University, New York, New York, United States, [3]American Museum of Natural History, New York, New York, United States, [4]National Radio Astronomy Observatory, Charlottesville, Virginia, United States

Abstract

We present new 2- and 3-mm wavelength ALMA maps of Uranus. The Uranian rings are detected at radio wavelengths for the first time, and azimuthal variations in their brightness are mapped. Basic radiative transfer calculations through toy models of the ε (main) ring are presented; these predict that the mm-wavelength brightness is dominated by thermal emission, contributing ~350 times as much flux as scattered light from Uranus. We compare these models to the observations to constrain the millimeter-wavelength opacity and/or albedo of the ε ring. The ALMA maps also probe brightness temperature

variations in the Uranian atmosphere at pressures from 0.5-5 bar with high (~0.3") spatial resolution. The north pole of Uranus is ~25 K brighter than the equator, confirming a strong depletion of hydrogen sulfide (H_2S) and perhaps other absorbers in that region. At the midlatitudes and near the equator, alternating dark and bright bands suggest regions of humid (H_2S rich) upwelling and dry subsidence, respectively. We discuss the implications of these observations for circulation models of the Uranian atmosphere.

11:40 AM-11:50 AM

104.08 Numerical Simulations of Ring-Moon Interactions at Uranus

Douglas P. Hamilton[1], Thomas Rimlinger[1], Lucy Lu[1], Joseph M. Hahn[2]
[1]Astronomy, University of Maryland, College Park, Maryland, United States, [2]Space Sciences Institute, Cedar Park, Texas, United States

Abstract
One of the enduring mysteries of the uranian system is the longevity of its 10 narrow rings. While the Epsilon ring is bracketed by a pair of shepherd satellites, all of the others appear to be isolated. We have previously shown that eccentric and inclined rings can self-confine radially for ~10^5 times longer than the spreading timescale of circular rings (Hamilton et. al. 2016, Rimlinger et. al. 2016) but, even so, sources of eccentricity and inclination excitation are needed at various times during the history of the Solar System. We suggest past resonant passages as a promising source of this excitation. Tidal evolution of the main uranian satellites ensures that the physical locations of resonances have continuously shifted in time. Moreover, considering the vast number of two- and three-body resonances generated by Uranus' 18 regular satellites, all of the narrow rings have experienced at least some such interactions in the relatively recent past.

The uranian rings are observed to have shapes that can be described as specific combinations of radial and vertical normal modes. We are currently modeling the response of these rings to various resonant interactions. We employ several complementary methods of numerically modeling a narrow ring, the simplest of which is simply a single chain of N interacting masses. We consider resonances both weak and strong and investigate the patterns that they imprint in the rings. Some resonances can capture rings and move them radially, while others impart sharp kicks to inclinations and eccentricities. Finally, we have undertaken a detailed search for past and present resonances in the uranian system and will report on our modeling of the most promising recent interactions.

11:50 AM-12:00 PM

104.09 New Horizons Imaging of Jupiter's Main Ring

Henry Throop[1], Mark R. Showalter[2], Henry C. Dones[3], Harold Weaver[4], Andrew Cheng[4], S. Alan Stern[3], Leslie A. Young[3], Catherine B. Olkin[3]
[1]PSI, Mumbai, India, [2]SETI, Mountain View, California, United States, [3]SwRI, Boulder, Colorado, United States, [4]JHU-APL, Laurel, Maryland, United States

Abstract
We have performed an analysis of over 500 images returned by New Horizons' LORRI visible-light camera during the 2007 flyby of Jupiter. We find that:

- Radial profiles from New Horizons give unprecedented insight into the ring's structure. The main ring is clearly subdivided into three distinct and complete rings. These rings -- between 128,000 km and 129,000 km -- have been seen in several earlier individual images from Galileo (Burns et al 2004) but not

previously mapped completely. The New Horizons imaging shows them to be continuous and uniform. They are composed predominantly of large grains, and are probably the source of dust in the ring. Inward of 128,000 km, the main ring is predominantly made of small dust grains.

- The main ring is less dusty than it used to be. The phase curve indicates that the quantity of large bodies remains similar to that observed by Cassini in 2000 (Throop et al 2004), but the quantity of dust has decreased by a factor of 2-4.

- The main ring is azimuthally uniform, with none of the large-scale asymmetry seen in Galileo and earlier observations. We do not identify any clumps beyond than those seen by Showalter et al 2007.

- New Horizons clearly detected Jupiter's Amalthea gossamer ring out to roughly 185,000 km. We have not found the fainter Thebe gossamer ring and are unlikely to do so, due to contamination from stray light.

This work was supported by NASA's Outer Planets Research program.

Monday, October 22, 2018
10:30 AM-12:00 PM
Ballroom B (Knoxville Convention Center)

105 Asteroid Dynamics and Theory
Chair(s): Shantanu Naidu, Leos Pohl

10:30 AM-10:40 AM
105.01 Combining Gaia DR2 and ground-based astrometry in asteroid mass estimation
Lauri Siltala[1, 2], Mikael Granvik[2, 3]
[1]Nordic Optical Telescope, Santa Cruz de La Palma, Santa Cruz de Tenerife, Spain, [2]University of Helsinki, Helsinki, Finland, [3]Luleå University of Technology, Kiruna, Sweden

Abstract
The recently published Gaia Data Release 2 contains asteroid astrometry of unprecedented accuracy on the milliarcsecond level. Such an accuracy promises reduced uncertainties for estimates of asteroid orbits and masses.

We have recently implemented support for combining Gaia DR2 astrometry with ground-based astrometry in our novel Markov-chain Monte Carlo algorithm for asteroid mass estimation based on asteroid-asteroid
perturbations. We have previously shown that our algorithm provides results that largely agree with previous values while having larger uncertainties than most least-squares estimates. In this case this can be seen as a positive result as asteroid mass estimates are generally believed to be unrealistically low. Here we will briefly describe the latest version of our algorithm and showcase some of our initial results with combined Gaia DR2 and ground-based astrometry. We compare these results to mass estimation runs with solely ground-based astrometry to showcase the difference DR2 can make in asteroid mass and orbit computation.

We also briefly discuss other recent improvements to our algorithm, such as the recently implemented option to include gravitational perturbations by asteroids not directly considered in our model via the BC430 ephemeris, which may also lead to significant improvements particularly in cases where our asteroids have other unidentified close encounters with some of the BC430 asteroids.

Finally, we discuss future improvements and plans for our mass estimation algorithm.

10:40 AM-10:50 AM
105.02 The structure of the Kirkwood gaps and their implication for the Yarkovsky Effect
Oleksiy Golubov[1, 2], Ihor Kyrylenko[2], Daniel J. Scheeres[1]
[1]Aerospace Engineering, University of Colorado Boulder, Kharkiv, Ukraine, [2]V. N. Karazin Kharkiv National University, Kharkiv, Ukraine

Abstract
The distribution of asteroids over their orbital semi-major axes demonstrate prominent depressions at orbital periods commensurable with Jupiter, called the Kirkwood gaps. These gaps are emptied by secular

gravitational resonances with Jupiter at all sizes. However, at smaller sizes they are repopulated by orbital drift processes, which include Yarkovsky drift and collisions, and at all sizes by planetary gravitational perturbations. The interplay between the orbital drift towards the resonance and the emptying of the resonance by strong gravitational perturbations can be approximated by a diffusion equation with a sink term, and the analytic solution of this equation can be found. This allows the Kirkwood gaps to be used to constrain the action of non-gravitational effects on small asteroids. Their finite lifetime in the gap region, and the processes that transport them there, can be analyzed to gain significant insight into the interplay of these phenomena.

We analyze the observational data for the known orbits of asteroids, obtain shapes of the Kirkwood gaps at different resonances and for different asteroid sizes, and fit the analytic solution of the diffusion equation to the data. This allows us to find the diffusion coefficient and the sink term, which can be compared to the predicted physical effects. We find that for the smallest asteroids the Kirkwood gaps turn into the "Kirkwood peaks" in terms of observed asteroids, due to a strong observational bias towards asteroids on more eccentric orbits.

The obtained size dependence of the Yarkovsky coefficient poorly agrees with the Yarkovsky drift limited by the YORP cycles, as predicted in previous work (e.g., Bottke et al., 2015, Icarus, 247, 191). This discrepancy could be explained if the asteroids spend the major part of their lives in YORP equilibria (see Golubov & Krugly, 2012, ApJL, 752, 11; Golubov & Scheeres, 2016, ApJL, 833, 23; Golubov, Unukovytch, & Scheeres 2018, ApJL, 857, L5), while being occasionally kicked out of them by collisions. We will present the theory, observations and our interpretations relating to this.

10:50 AM-11:00 AM

105.03 Near-Earth Asteroid and Meteorite Source Regions: The Big Picture

Richard P. Binzel[1, 2], Francesca DeMeo[1], Alessandro Morbidelli[3], Benoit Carry[3], Mikael Granvik[4, 5], Thomas Burbine[6], Pierre Vernazza[7], Mirel Birlan[2]
[1]Earth, Atmospheric, Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States, [2]Observatoire de Paris, Paris, France, [3]Observatoire de la Côte d’Azur, Nice, France, [4]Univ. Helsinki, Helsinki, Finland, [5]Lulea University of Technology, Lulea, Sweden, [6]Mount Holyoke College, South Hadley, Massachusetts, United States, [7]Laboratoire d'Astrophysique de Marseille, Marseille, France

Abstract
"Where do meteorites come from?" has been an enduring question in planetary science, placing "traceability" (e.g. sample return) at the forefront of current exploration. Towards this goal, orbits for ~2 dozen recovered meteorite falls have been determined by dedicated teams over many decades. Herewith we now add the orbits for more than 1000 near-Earth asteroids (NEAs) for which we have telescopic spectral measurements [1] sufficient to make meteorite analog assessments. For hundreds of these NEAs, their meteorite analogs have a high degree of confidence to specific classes (e.g. H, L, LL chondrites) based on detailed mineralogical modeling [2] tested against the ground truth from the Hayabusa mission [3]. As independent variables, we correlate each NEA’s meteorite analog with its dynamical source region derived from the models by Granvik et al. [4,5] accounting for Yarkovsky drift and resonance delivery efficiencies. When ratioed to the overall flux rate for the diffusion of main-belt asteroids into the inner solar system, distinct source region signatures emerge for all major meteorite classes. Most interestingly, a high degree of correlation is found with respect to the compositional gradient in the asteroid belt [6,7], with the most primitive classes preferring an outer belt or Jupiter Family Comet origin. We integrate all of these results together into a new "Big Picture" view of where the major classes of meteorites come from. *Observational data used in this research were obtained using the NASA Infrared Telescope*

Facility, which is operated by the University of Hawaii under contract NNH14CK55B with the National Aeronautics and Space Administration. This work supported by the National Science Foundation Grant 0907766 and NASA Grant NNX10AG27G.

References:
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11:00 AM-11:10 AM
105.04 A main-belt source for retrograde jovian co-orbital asteroids
Sarah Greenstreet[4, 1], Henry Ngo[3], Brett Gladman[2]
[1]University of Washington, Seattle, Washington, United States, [2]University of British Columbia, Vancouver, British Columbia, Canada, [3]National Research Council of Canada, Victoria, British Columbia, Canada, [4]B612 Asteroid Institute, Mill Valley, California, United States

Abstract
Weigert et al. (2017) announced the discovery of a jovian co-orbital asteroid (2015 BZ509) on a retrograde orbit and demonstrated orbital stability for at least a million years. Namouni & Morais (2018) calculate that 1 in 300,000 clones near the nominal orbit remain co-orbital over the age of the Solar System; they propose the object was thus captured from the interstellar medium during the Solar System's formation. However, it is also possible that temporarily stable jovian co-orbitals are continuously resupplied from a solar system source. In 2012, we (Greenstreet et al. (2012a,b)) published an updated NEO orbital distribution model in which we discovered a mechanism that delivered main-belt asteroids to retrograde orbits. Motivated by the jovian retrograde co-orbital discovery, we re-examined the particle histories for temporary jovian co-orbital captures and immediately found examples of asteroids originating in the main belt becoming temporary jovian co-orbitals with orbital elements similar to that of 2015 BZ509 shown in Weigert et al. (2017) and its clones shown in Namouni & Morais (2018). We illustrate orbital evolutions leaving the main asteroid belt and arriving in the co-orbital state. We therefore believe this object is most likely not a long-term stable captured interstellar asteroid, but rather a temporarily captured escaped main-belt asteroid in retrograde co-orbital motion with Jupiter, thus rendering natural its non-cometary appearance.

11:10 AM-11:20 AM
105.05 Forming the Flora Family: Implications for the Near-Earth Asteroid Population and Large Terrestrial Planet Impactors
William F. Bottke[1], David Vokrouhlicky[2], David Nesvorny[1]
[1]Southwest Research Institute, Boulder, Colorado, United States, [2]Charles University, Prague, Czechia

Abstract
The Flora family dominates the innermost region of the main asteroid belt. It was formed from the catastrophic disruption of an S-type parent body larger than 150 km in diameter in a region adjacent to the nu6 secular resonance. Family members, when pushed onto planet-crossing orbits, tend to have relatively

high probabilities of striking the Earth. These factors suggest that the Flora family may be a primary source of present-day LL chondrite-like NEOs as well as Earth/Moon impactors. To investigate this possibility, we used collisional and dynamical models to track the evolution of Flora family members immediate after the family-forming event. We created an initial Flora family and followed test asteroids 1 and 3 km in diameter using a numerical code that accounted for both planetary perturbations and non-gravitational effects (e.g., Yarkovsky and YORP thermal forces). We find that our test Flora family members can reproduce the observed semimajor axis, eccentricity, and inclination distributions of the real family after 1 to 1.5 Gyr of evolution. We favor the latter age, since it allow us to reproduce the surface age inferred from crater spatial densities found on Flora-family member (951) Gaspra. To get this age, most family members had to have bulk densities near 2.7 g cm^{-3}. Our combined collisional and dynamical runs indicate that the family has lost nearly 90% of its initial kilometer-sized members. At its peak, approximately 100-300 Myr after the family-forming event, Flora family members filled NEO space with nearly 1000 D > 1 km diameter bodies before fading to its present contribution of 35–50 such NEOs. Accordingly, it is not currently a major source of large NEOs or impactors. Overall, 700–950 and 35–47 kilometer-sized asteroids struck the Earth and Moon from the Flora family, respectively, most within the first 300 Myr after family formation. Accordingly, the Flora family was a major source of terrestrial planet impactors to both the mid-Proterozoic Earth and Amazonian-era Mars, with potentially interesting implications for each world in terms of the evolution of their biospheres.

11:20 AM-11:30 AM

105.06 A visible and near-IR spectral search for NEOs originating from the Euphrosyne Main-belt asteroid family.

Heather Kaluna[1], Maria Daniella Douglas[2], Joseph Masiero[3], Vishnu Reddy[4], Patrice Smith[1], James Bauer[5], Driss Takir[6]

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Abstract

Members of asteroid families are given a velocity kick following the partial or catastrophic disruption of a parent body that causes them to spread out in orbital-element-space. Subsequent gravitational perturbations and non-gravitational forces such as the Yarkovsky effect can result in family members entering a mean-motion or secular resonance, and being transported into the NEO population (defined as objects with perihelia q< 1:3 AU, see Bottke et al. 2002). The ~800 Myr old Euphrosyne family is the only known asteroid family bisected by the v6 secular resonance. Recent work by Masiero et al. (2015) traces the dynamical evolution of Euphrosyne family members over the family's lifetime, showing that members near the v6 secular resonance will evolve to populate a specific sub-region of NEO orbital element space.

In this work, we will present observations of both main belt members and near-Earth candidates made using visible and near-IR spectrometers on the Palomar 5-m and NASA IRTF 3-m telescopes, respectively. While the majority of the NEO candidates appear consistent with other spectral types, we have at least one NEO candidate that appears to originate from the carbonaceous-type Euphrosyne family. Relative to the main-belt family spectra, this NEO does not show any evidence of spectral variations between the near-Earth and main-belt populations.

Near-Earth objects should experience increased solar heating and ion bombardment relative to objects in the main-belt, however processes resulting from close planetary encounters can also refresh the regolith of NEOs (Binzel et al. 2010). Either process would result in a highly mature regolith or fresh surfaces for Euphrosyne-type NEOs. Assuming the Euphrosyne-type NEO does indeed originate from the Euphrosyne

family, the lack of spectral variation indicates several possibilities. One is that this NEO was recently injected into its current orbit, and thus should have similar features as its main-belt family. Another possibility is that if this NEO was not recently injected, the lack of spectral variations may indicate that space weathering processes do not manifest in the spectra of these carbonaceous main-belt and near-Earth objects.

11:30 AM-11:40 AM

105.07D Ages of Asteroid Pairs and Clusters

Petr Fatka[1, 2], Petr Pravec[1], David Vokrouhlicky[2]

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Abstract

We will present the results of our backward orbital integrations for a sample of 93 asteroid pairs and 16 asteroid clusters. In our simulations, each asteroid was represented by 1 000 geometric clones with various strength of the Yarkovsky effect. To detect close and slow encounters between the clones for a given asteroid pair, we chose a relative distance limit of several Hill radii of the primary asteroid and with the assumption of a gentle break up event (e.g., by rotational fission), we limited the maximum relative velocity between the clones to a few times escape velocity of the primary asteroid. We estimated the separation time (T_{sep}) for a given asteroid pair as the median of detected encounters between its clones and we chose the lower and the upper uncertainty limits for the T_{sep} estimate as the 5th and the 95th percentile of obtained encounters, respectively. Most of the studied pairs show T_{sep}< 1 Myr. The oldest asteroid pair in our sample is 13284–154828 with T_{sep} ~ 2.3 Myr and the youngest pairs are 87887–415992 with T_{sep} ~ 7.3 kyr and 53576-421781 with T_{sep} ~ 8 kyr. The ages of the studied asteroid clusters range from ~100 kyr up to 3.5 Myr. The clusters consist of between 3 and 19 known members and in most cases we obtained overlapping histograms of the times of close and slow encounters between clones of the cluster secondaries with the primary, suggesting a single separation time for all the secondaries of a given cluster. In the case of the cluster of Emilkowalski, 2 of its 7 secondaries converged at ~ 320 kyr in the past, but the other 5 secondaries of this cluster show a convergence about 1 Myr earlier. It suggests that the cluster of Emilkowalski was formed by multiple breakups.

11:40 AM-11:50 AM

105.08 Ejecta Clouds with a Chance of Binary Asteroids: Application of an Ejecta Dynamics Package to the DART Mission Target

Jennifer Larson[1], Gal Sarid[2]

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Abstract

The Double Asteroid Redirection Test (DART) mission is aimed at demonstrating an approach to solving the challenge of an asteroid on a collision path with Earth. This “kinetic impact” approach, applied to the Didymos binary component, crucially depends on the momentum transfer during the collision event and complimentary ejecta dynamics. The N-body modeling results presented here will have a major contribution to the operation planning, as well as provide a range of expected behaviors based on impact parameters for long, medium and short timescales in and around the binary asteroid system.

We introduce a working version of the *Rebound* impact ejecta dynamics Python package we developed and present relevant results for the DART mission. Our implementation can simulate systems with wide

ranges of particle sizes, solar radiation effects, particle-particle interactions and non-spherical target and perturbing bodies. Each simulation can track ejecta particles from a small near-surface region just after the initial impact outflow out to beyond the boundary of the binary system. Particle-particle collisions are included early in the ejecta cloud evolution, where the collision cross-section is greatest, with accretion, disruption and bouncing outcomes used to update the mass and 3D velocity and spatial components. For the binary Didymos system, we provide maps of final particle positions on both binary components. Ejecta initial conditions are derived from a combination of impact simulations, scaling relations and experiments. Our simulations include 10^3-10^7 particles, launched from up to 1 meter above the surface (Didymoon, the system secondary component), close to the escape velocity. At 1 meter and 0.8 the escape velocity, we find that about half of the particles fall back and distribute on the target's surface, while the rest remain in orbit around the system.

11:50 AM-12:00 PM

105.09 Discovery of asteroids captured temporarily by the Earth with LSST

Grigori Fedorets[1], Mikael Granvik[1, 2], Lynne Jones[3], Mario Juric[3]
[1]University of Helsinki, Helsingin yliopisto, Finland, [2]Luleå University of Technology, Kiruna, Sweden, [3]University of Washington, Seattle, Washington, United States

Abstract

Introduction: It has been predicted that there is a population of small asteroids orbiting the Earth at any given time [1]. They have been temporarily captured by the Earth from the population of near-Earth asteroids (NEAs). Temporarily-captured orbiters (TCOs) have elliptic geocentric orbits and come within 0.03 au from the Earth, making at least one revolution around the Earth. Recent results suggest that at any given time there is one 70 cm-diameter asteroid captured on a geocentric orbit within 0.03 au from the Earth [2].

Discovery of captured asteroids: The major bottleneck in studying of TCOs is the difficulty of observing them. So far, only one TCO, 2006 RH120, has been discovered [3]. The Large Synoptic Survey Telescope (LSST) will have the highest likelihood of obtaining regular detections of TCOs. LSST is expected to cover the available sky every 4 nights for the duration of 10 years. The cadence, combined with the expected limited magnitude, r=24.5, suggest that LSST will reliably detect a TCO once every two months [4]. The size-frequency distribution (SFD) of NEAs down to a diameter of 1 m is based on bolide data [5]. Regular discovery of TCOs would extend the SFD to diameters below 1 m, providing a continuous flow of small targets for follow-up observations and space missions.

Simulations: We use synthetic TCO populations with a realistic magnitude distribution, that is based on a NEO model [6], to

test the limits of the current LSST prototype and data processing pipeline. TCOs serve as suitable and challenging targets for testing the LSST system. Observational statistics from simulated data serves as the first step for constructing an observationally-constrained model of TCOs. We extend the previous study [4] to include the linking of TCO detections, aiming at extracting TCO trajectories and orbits fromm LSST data.

References: [1] Granvik M. et al. (2012) Icarus, 218, 262. [2] Fedorets G. et al. (2017) Icarus 258, 83.. [3] Kwiatkowski T. et al. (2009) A&A 495, 967. [4] Bolin B. et al. (2014) Icarus 241, 280. [5] Brown P. et al. (2013) Nature, 503, 238. [6] Granvik M. et al. (2016) Nature, 530, 303.

Monday, October 22, 2018
10:30 AM-11:30 AM
Ballroom C (Knoxville Convention Center)

106 Comet Physical Characteristics: Nuclei and Surfaces
Chair(s): Adeline Gicquel, Susan M. Lederer

10:30 AM-10:40 AM
106.01 Argon adsorption in amorphous water ice and release in response to heating
Reika C. Yokochi
Geophysical Sciences, The University of Chicago, Chicago, Illinois, United States

Abstract
Previous experimental studies re- ported that amorphous water can efficiently encapsu- lates ambient gases during its condensation at low temperature and high deposition rates [1,2], reflecting the physical and chemical conditions of the surrounding environment. It was suggested that the gas trapping may be understood as two stage process; gas adsorption onto ice surface and subsequent burial by added layer of ice, based on the pressure-dependent nature of the gas trapping at 77K [3]. Here I report the adsorption and trapping of Ar in amorphous ice under close system setting for temperatures between 50 and 80K. The experimental system consists of a cryogenic chamber, water vapor reservoir, a gas reservoir, and pumps, following the basic design of the setup presented in Yokochi et al. [3]. The temperature inside the glass tube was evaluated based on the vapor pressure of Ar [4]. The deviation of the internal temperature from the sensor reading was between 1.5-1.9 K for a temperature range between 35.1 and 64.3K. Water vapor was introduced via the leak valve to form amorphous water ice in the presence of Ar gas for determining the efficiency of Ar trapping. The quantity of deposited water ice was deduced from the pressure before and after the deposition. The Ar pressure change in the gas phase was measured by a quadrupole mass spectrometer after appropriate dilution. Adsorption experiments was performed by depositing amorphous water ice in the absence of gas, and subsequently exposing a known quantity of Ar to it. The trapping efficiency of Ar scales well with the adsorption, and the pressure dependence of Ar trapping efficiency was confirmed for the entire temperature range of the experiments. As expected, the adsorption of Ar is highly temperature dependent, and different ice deposition temperatures result in different number of adsorption sites. From the model pressure and temperature conditions of the early solar nebula, trapped Ar concentration in amorphous water ice formed in the Kuiper belt and inward is expected to be <10 ppb level. A large fraction of trapped Ar is released in response to heating prior to 100K.

10:40 AM-10:50 AM
106.02 Fragmenting Comet 73P/Schwassmann-Wachmann 3
Ariel Graykowski[1], David Jewitt[1], Harold A. Weaver[2], Jing Li[1], Jessica Agarwal[3], Max Mutchler[4]
[1]Earth, Planetary, and Space Sciences, UCLA, Dublin, California, United States, [2]Johns Hopkins University, Baltimore, Maryland, United States, [3]Max Planck Institute for Solar System Research, Katlenburg-Lindau, Lower Saxony, Germany, [4]Space Telescope Science Institute, Baltimore, Maryland, United States

Abstract
73P/Schwassmann-Wachmann 3 is a Jupiter-family comet that has been observed to fragment on several

occasions since 2005. Fragment C (73P-C) is believed to be the primary component of the nucleus. Knowing the nucleus rotation period is important because it can provide invaluable clues about the mechanism responsible for the breakup of this comet. Unfortunately, studies of 73P-C using a variety of techniques have reported rotational periods that range over an order of magnitude, from about 2.8 to 27.2 hours. The lower end of the reported range is compatible with rotational breakup of a low strength nucleus whereas the higher end would rule that possibility out completely. We have undertaken a systematic analysis of unpublished archival Hubble Space Telescope data from 2006 April in order to determine the rotation period and to assess other aspects of 73P-C. We find strong, cyclic photometric variations of about 0.4 magnitudes in the central light from this object. Similar variations with a smaller range are apparent in the surrounding dust coma, compatible with rotational modulation of the mass loss rate. We will present our measurements and inferences.

10:50 AM-11:00 AM

106.03 The Formation of Bilobate Comet Shapes through Sublimative Torques

Taylor Safrit[2], Jordan K. Steckloff[1, 2], Amanda S. Bosh[2], David Nesvorny[3], Ramon Brasser[4], David A. Minton[5]
[1]University of Texas at Austin, Austin, Texas, United States, [2]Massachusetts Institute of Technology, Providence, Rhode Island, United States, [3]Southwest Research Institute, Boulder, Colorado, United States, [4]Earth Life Science Institute, Tokyo Institute of Technology, Tokyo, Japan, [5]Purdue University, West Lafayette, Indiana, United States

Abstract

Approximately 70 percent of observed cometary nuclei are bilobate (made of two primary masses connected by a narrow neck) (Hirabayashi et al. 2016). Subcatastrophic collisions between cometary bodies can result in these shapes, but require impact speeds an order of magnitude smaller than typical impact velocities in the scattered disk (Gomes et al. 2008), the reservoir from which most Jupiter-family comets (JFCs) originate. Additionally, only 10–20 percent of similarly-sized asteroids are bilobate (Benner et al. 2015), suggesting that the mechanism producing bilobate shapes must be unique to comets.

We investigate a novel mechanism for bilobate comet nucleus formation in JFCs, in which sublimative torques acting on comet nuclei during their dynamical migration through the Centaur region spin them up to disruption. Simulations of rotationally disrupted, comet-like rubble-piles (with strengths of ~1–10 Pa and internal friction angles of ~35°) (Steckloff and Samarasinha 2018) find that rotationally disrupted nuclei reform as bilobate objects (Sánchez and Scheeres 2016; Sánchez and Scheeres 2018). Although centaurs are too distant for H_2O ice to sublimate vigorously, they are near enough to the Sun for CO_2 and CO ices to do so. We therefore focus on whether CO_2- and CO-driven sublimative torques are sufficient to rotationally disrupt centaurs.

We combine simulations of the dynamical evolution of centaurs with our SYORP sublimative torque model to compute the torques created by the sublimation of CO_2 and CO ices. We find that JFCs smaller than ~100 kilometers in radius typically experience sufficient sublimative torques during their migration through the Centaur region to be restructured into bilobate shapes. This suggests that the observed bilobate distribution of comet shapes is likely the result of cometary sublimative evolution, rather than a primordial property of objects in cometary reservoirs. Thus, we expect to observe more bilobate shapes as comets migrate inward. This population-scale shape evolution could be detected with occultation studies.

11:00 AM-11:10 AM

106.04 Changes in Cometary Rotation: Predictions, Correlations, and Trends

Beatrice E. Mueller, Nalin Samarasinha
Planetary Science Institute, Tucson, Arizona, United States

Abstract
Previously Samarasinha & Mueller (2013) related changes of cometary rotation to other physical parameters for four Jupiter family comets, and two additional comets were added in a subsequent paper (Mueller & Samarasinha 2018) confirming the stated relationship, albeit with increased scatter. Predicted changes in the rotation periods for a sample of 24 periodic comets were derived. We identify comets from this sample that are most likely to show observationally detectable changes in their rotation periods. We also found a correlation between the total water production per unit surface area per orbit approximated by that inside of 4 au and the perihelion distance. This relationship enables ready comparisons of activity due to insolation between comets. Additionally, a trend between the nuclear radius and the rotation period was found. Specifically, we found that on average smaller nuclei have smaller rotation periods compared to the rotation periods of larger nuclei. This result provides strong observational evidence for sublimation-driven changes in cometary rotation.
The research we will present is based on our accepted paper to the Astronomical Journal (Mueller & Samarasinha 2018).

We gratefully acknowledge support from the NASA Planetary Astronomy Program.

References:

Samarasinha, N.H., & Mueller, B.E.A. 2013.
Relating changes in cometary rotation to activity: Current status and applications to Comet C/2012 S1 (ISON).
Astrophys. J. Letters 775, article id. L10, 6pp.

Mueller, B.E.A., & Samarasinha, N.H. 2018.
Further investigation of changes in cometary rotation.
Astronomical Journal, in press.
http://arxiv.org/abs/1806.11158

11:10 AM-11:20 AM
106.05 HST Observations of the Nucleus of Comet 41P/Tuttle-Giacobini-Kresak
Tony Farnham[1], Matthew M. Knight[1], Dennis Bodewits[2], David G. Schleicher[3], James Bauer[1], Nora L. Eisner[4]
[1]University of Maryland, College Park, Maryland, United States, [2]Auburn University, Auburn, Alabama, United States, [3]Lowell Observatory, Flagstaff, Arizona, United States, [4]University of Sheffield, Sheffield, United Kingdom

Abstract
In early 2017, we discovered that comet 41P/Tuttle-Giacobini-Kresák (TGK), was spinning down at an incredibly rapid rate, with a rotation period that changed from 20 hours in early March (Farnham et al. CBET 4375, 2017) to 27 hours in late March (Knight et al. CBET 4377 2017) and >42 hours in early May (Bodewits et al. Nature 553, 186, 2017). These results indicate that the comet's rotation period decreased by ~0.5 hr/day during this time period—the fastest changes ever observed in any comet. Thus, TGK is ideal for testing models of cometary dynamics, allowing us to investigate how the torques respond to

changing production rates and illumination conditions. Furthermore, if the spin-down of TGK continues at this pace over the next apparition or two, it may be possible to document a comet's behavior as it transitions through a slow-rotation end state (e.g., will it enter a stage of complex rotation? Spin up in the opposite direction? Or will it exhibit some other response?).
To follow up on this work, we were awarded 10 orbits of HST WFC3/UVIS time in December 2017 to observe the lightcurve of TGK. Our goal is to characterize the rotation state of the nucleus after its activity had subsided. Results from this work will not only provide a measurement of the "final" spin state achieved during the 2017 apparition, but will also define the initial state for future monitoring of any continuing changes over the next apparition. We can also take advantage of the high resolution of the HST images to separate the nucleus signal from that of any coma that is present. This allows us to constrain properties of the nucleus, including its general size and shape, that will be used in models of the comet's dynamical evolution. Although we requested our 10 orbits to be spaced over a 7-day baseline to cover any expected rotation period, scheduling constraints forced us to restrict our observational window to 3.5 days. This affects our ability to fully define the lightcurve, but otherwise our analyses will continue as planned.
We will present results from this work, and will discuss how they might relate to the rapid evolution of the comet's dynamics.

11:20 AM-11:30 AM

106.06 Arguments for NPA rotation of comet 41P/Tuttle-Giacobini-Kresák

Ellen Howell[1], Michael J. Belton[2], Nalin H. Samarasinha[3], Beatrice E. Mueller[3], Walter Harris[1], Michael Nolan[1], Patrick A. Taylor[4], Edgard G. Rivera-Valentin[4], Luisa Zambrano-Marin[5]
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Abstract
Bodewits et al. (2018) stated that the spin period of comet 41P/Tuttle-Giacobini-Kresák (41P/TGK), assumed to be in a state of simple rotation, increased by over a factor of two (130 – 201% increase;a decrease in angular momentum of 56 to 67%) during an interval of roughly 62 days from 7 March, 2017, to 10 May, 2017. This result, if true, is well out of the range of change in rotation observed in other active Jupiter Family comets, e.g., 10% in comet 103P/Hartley 2 in 61 days, and 0.6% in 9P/Tempel 1 over 50 days. Also, the above conclusion on the spin evolution for 41P/TGK is in conflict with radar observations in that that they yield an unreasonably low value (0.01) for the radar albedo. We show that, if the comet spins in an excited state, i.e., non-principal axis (NPA) rotation, the conflict between the radar and published observations can be effectively removed and the change in angular momentum reduced. We demonstrate how the data can be interpreted as resulting from different rotation components in a self-consistent way. Our model, while an advance on the simple rotator model, has its own deficiencies and is certainly not unique. An NPA model involving *all* the available data, and which explores asymmetric rotators, is clearly needed.

Monday, October 22, 2018
11:30 AM-12:00 PM
Ballroom C (Knoxville Convention Center)

107 67P/Churyumov-Gerasimenko
Chair(s): Jordan K. Steckloff, Gal Sarid

11:30 AM-11:40 AM
107.01 Spatial Distribution of Atomic Emission During Cometary Activity from 67P/Churyumov-Gerasimenko as Observed by the Rosetta Alice Ultraviolet Spectrograph

John Noonan[1], Joel Parker[2], Brian A. Keeney[2], Alan Stern[2], Mark Hofstadter[3], Seungwon Lee[3], Dominique Bockelée-morvan[8], Paul Feldman[4], Ron J. Vervack[5], Harold Weaver[5], Matthew M. Knight[6], Lori Feaga[6], Jean-Loup Berteaux[7]
[1]Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona, United States, [2]Southwest Research Institute, Boulder, Colorado, United States, [3]Jet Propulsion Laboratory, Pasadena, California, United States, [4]The Johns Hopkins University, Baltimore, Maryland, United States, [5]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, United States, [6]University of Maryland, College Park, Maryland, United States, [7]CNRS, LATMOS, Guyancourt, France, [8]LESIA, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universites, UPMC Univ. Paris 06, Univ. Paris-Diderot, Sorbonne Paris Cite, Meudon, France

Abstract
The *Rosetta* Alice ultraviolet spectrograph observed atomic and molecular emission from the comet 67P/Churyumov-Gerasimenko at a range of activity levels and distances, providing critical information on the near-nucleus coma environment. This work will discuss observations from the 7th and 8th of November 2015, from both Alice and the MIRO instrument. Due to a fortuitous alignment of the observing plan the near-nucleus coma environment was captured both with stable "stare"-type exposures and a raster scan, allowing a characterization of the coma's components and implementation of a new image generation technique to map the atomic emissions from the near-nucleus coma. In addition to analysis of the coma's spectral signature we will present two-dimensional spatial distributions of H, C, and O emissions derived from Alice exposures. The atomic emission distributions will then be compared to the spatial distributions of H_2O emissions observed from MIRO and VIRTIS-H to place the UV observations in context and better understand the special distributions of molecular and atomic emissions.

11:40 AM-11:50 AM
107.02 Implications of Philae magnetometry measurements at comet 67P/Churyumov-Gerasimenko for the outer solar system nebular field

John B. Biersteker[1], Benjamin P. Weiss[1], Philip Heinisch[2], David Hercik[2], Karl-Heinz Glassmeier[2], Ulrich Auster[2]
[1]Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States, [2]Technische Universität Braunschweig, Braunschweig, Germany

Abstract
Magnetic fields are thought to play a central role in determining the evolution and structure of protoplanetary disks by transporting angular momentum and driving stellar accretion. They also directly influence disk dynamics through the generation of turbulence and disk winds. These processes have

important implications for the formation of the first solids and the accretion of planetesimals. Recent paleomagnetic measurements of chondrules from the Semarkona meteorite have found that the midplane solar nebula magnetic field was 50 μT (0.5 G) in the terrestrial planet region sometime between ~1-3 million years after solar system formation. However, there have been no constraints on the nebular field in the giant planet and Kuiper belt region, and no intensity measurements at all beyond 3 AU. Here we show how magnetic field measurements taken by the Rosetta Magnetometer and Plasma Monitor (ROMAP) of comet 67P/Churyumov-Gerasimenko (67P) can constrain the intensity of the nebular paleomagnetic field in the outer solar system. In particular, ROMAP found no detectable (<2 nT or 0.02 mG) remanent magnetic field at the surface of 67P, which places stringent constraints on its magnetization. We modeled the comet's magnetic field assuming various characteristic spatial scales of uniform magnetization, finding that for ≥10 cm radius regions of coherent magnetization, the specific magnetic moment is $<1 \times 10^{-5}$ A m^2 kg^{-1}. This value is lower than essentially all known meteoritic materials. Assuming 67P has not experienced collisional or aqueous alteration capable of erasing a primordial magnetic signature, this upper limit is consistent with its formation from the gentle gravitational collapse of a cloud of ~1 mm pebbles in a background magnetic field with an intensity ≤1 μT (0.01 G). This provides the first observational constraint on the nebular magnetic field intensity in the outer solar system.

11:50 AM-12:00 PM

107.03 Did the building blocks for Titan form in the same region of the Protosolar Nebula as 67P?

Kathleen Mandt[1], Olivier Mousis[2], Hugo Audiffren[2], Stephanie Treat[1], Adrienn Luspay-Kuti[1]
[1]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, United States, [2]Laboratoire Astrophysics Marseille, Marseille, France

Abstract

In our previous studies of the evolution of Titan's atmosphere, we found that the nitrogen isotope ratio could not have evolved significantly over the history of the solar system and that the primordial ratio must have been similar to the value measured in ammonia in comets (Mandt et al. 2014, ApJ, 778, L24; Mandt et al., 2015, Icarus, 254, 259-261). This means that Titan's building blocks may have formed in conditions similar to comets, allowing them to obtain nitrogen with an isotope ratio that is strongly enriched in the heavy isotope. The noble gases ^{22}Ne and ^{36}Ar were also measured in Titan's atmosphere while upper limits were provided for Kr and Xe. The ROSINA instrument on the Rosetta spacecraft measured the Ar, Kr and Xe abundances in comet 67P/Churyumov-Gerasimenko (67P) and the bulk abundance of several constituents was measured by both ROSINA and VIRTIS. These observations allow us to compare the potential Titan building block composition with scenarios for the evolution of Titan's interior and atmosphere to evaluate whether Titan's building blocks formed in similar conditions to the formation conditions of 67P.

This work was supported by the Rosetta project through JPL subcontract 1585002. Additional comparisons with Pluto composition supported by the NASA NFDAP program through grant number 80NSSC18K1233.

Monday, October 22, 2018
01:30 PM-02:35 PM
Ballroom F-G (Knoxville Convention Center)

108 Plenary: Historical
Chair(s): Dale Cruikshank
01:35 PM-01:50 PM

108.01 The First Fifteen Years of the Division for Planetary Sciences
Clark R. Chapman
Southwest Research Institute, Boulder, Colorado, United States

Abstract
The DPS was founded in 1968, an eventful year indeed. I am the only person who has attended every DPS meeting, including the Inaugural Meeting on 10 December 1968 in Austin. Thirty-five presentations, including a panel (with Masursky, Cameron, and Urey), began at 9 a.m. and ended at 10:30 p.m. on that one day. I talked about my Master's Thesis on Jupiter's atmospheric circulation; good luck with never being sick enabled me to attend every meeting since. My first organizational involvement with the DPS was chairing a Publications Subcommittee, which negotiated with Academic Press and Carl Sagan to endorse the journal Icarus. Later the DPS selected a replacement editor (Joe Burns), when Carl's commitments, e.g. to "Cosmos", overwhelmed the time he could devote to Icarus.

A major motivation for creating the DPS, during the field's first decade of rapid growth, was to avoid the multiple sessions of AAS meetings. As planetary science grew further, the continuing debates on meeting format began (how many days, length of talks, ratio of oral talks to posters, etc.). The problem was memorably manifested at the 1979 St. Louis meeting when speakers were lined up at the side of the stage to minimize turn-over time between the short (3.5-minute!) oral talks.

Other early DPS issues concerned obtaining Congressional approval for JOP (Galileo) and LST (HST). Regarding the latter, there was much controversy over George Field's address about Space Telescope (ST) to the 1977 Honolulu DPS meeting. Field thought that it was only realistic that planetary astronomy have lower priority on ST than astrophysics. Later, in the early 1980s, the DPS played a major role in reversing OMB Director Stockman's plan to zero-out NASA's planetary program over a three-year period.

Despite a history of prominent women in astronomy, women played a minimal role in the DPS organization until fortunate changes in the 1980s. The 11 organizers of the DPS were all men, the speakers/panelists/chairs at the Inaugual Meeting apparently did not include women, and the first woman to serve as a DPS officer was Laurel Wilkening in 1979.

01:50 PM-02:05 PM
108.02
Meandering Around with the Division for Planetary Sciences of the American Astronomical Society: The Middle-Aged years
Anita Cochran
McDonald Observatory, The University of Texas at Austin, Austin, Texas, United States

Abstract
The Division for Planetary Sciences (DPS) of the American Astronomical Society has turned 50 years old with its meeting in Knoxville, TN. Those 50 years have seen much change. My first meeting was the 11th meeting in 1979 in St. Louis and I have attended every meeting since. I went on to chair the LOC at a meeting in 1988, joined the committee and chaired the society in the subsequent years. In this talk, I will discuss how the management of the meeting has changed as our membership has grown. I will also discuss how the meeting has wandered around the US and Europe and how our gender-awareness has changed with time. As the Division has aged, its members have aged in reverse – we now are populated by a terrific number of young scientists. We have broadened our subject matter to include planetary systems around other stars.

A major role of the DPS is to run our annual meeting. However, the DPS also has the role to advocate for its members. The Division has added (a very active) Federal Relations Subcommittee, and has attempted to foster a sense of openness and inclusiveness in its activities. We welcomed our European colleagues when no society existed in Europe. Today, the European Planetary Science Congress has taken on some of the roles of the DPS within the European planetary science community, including running meetings (often jointly with DPS). DPS has also played a major role in the publication of scientific articles, with the journal Icarus.

02:05 PM-02:35 PM
108.03 PCCS Talk: Diversity, Equity, and Inclusion in Action: Lessons from NCAR/UCAR
Carolyn Brinkworth
Office of Diversity & Inclusion, University Corporation for Atmospheric Research, Boulder, Colorado, United States

Abstract
A significant body of research has found that groups with a diversity of identities and experiences make better decisions, are more innovative and creative, and produce more highly cited papers in higher impact journals than groups that are homogenous. Diversity, when combined with equity and inclusion, is both the right thing to do, and also benefits our field and our institutions. The National Center for Atmospheric Research (NCAR) and its managing organization, the University Corporation for Atmospheric Research (UCAR) have recently established an Office for Diversity and Inclusion and have implemented significant changes to ensure more equitable and inclusive policies and practices that support a diverse workforce. Dr. Carolyn Brinkworth is the UCAR Chief Diversity, Equity, and Inclusion Officer and will address the research that points to the power of diversity, along with actionable steps that NCAR/UCAR has taken to develop and implement a DE&I program with significant buy-in and support from staff members across the 1400-employee organization. Dr. Brinkworth has a PhD in Astrophysics from the University of Southampton and a MA in Education from Claremont Graduate University.

Monday, October 22, 2018
02:35 PM-03:35 PM
Ballroom F-G (Knoxville Convention Center)

109 Plenary: Historical Panel
Chair(s): Dale Cruikshank

109.01 My >50 years exploring the Solar System

Thomas McCordl
The Bear Fight Institute, Winthrop, WA, USA

Abstract
Fifty-year celebrations are occurring regularly these days. This is because the “modern” era of planetary science and exploration began in the 1960s. I and a few of my early colleagues are what remains of the direct memory of those early years. Some of us are the first generation that purposely set out to be planetary scientists. My 50-yr celebrations included the formation of the planetary science graduate program at Caltech, the formation of the UH Institute for Astronomy, and the formation of my MIT-PAL program. Here we celebrate the 50th DPS meeting, a society that I have chaired and contributed to in its formative years. A few others here will have similar stories. We were young, full of energy, and maybe a bit abrasive. We didn’t know we were making history, nor could we. It wasn’t very complicated; we just did our thing, and the funding and environment mostly enabled us. The Apollo Program was just beginning, the technology boom, started in WWII, was moving into the civilian world (solid state detectors, computers, big telescopes, spacecraft), and NASA and NSF were flush with money and programs. Yes, it was about science and knowledge and technology and exploration, but it was also about people. Discoveries are superseded, knowledge marches on, but people are much more lasting and have a greater impact on our civilization. My wife and I consider our graduates and their graduates as our extended family. We have great-great-grand “students!” We began using telescopes, with “real” astronomers complaining, developing the basic knowledge of solar system objects, many appearing as point sources. In my case, black-box IR solid-state detectors from the military enabled IR spectroscopy and started the development of our knowledge of surface compositions and hints of object evolutions. Spacecraft began flying by some of the major objects in the late 1960s and early 1970, producing mostly images but beginning the approaches that dominate our field today. Today, I hope we remember that the early telescope findings formed the knowledge and technique bases for today’s science and the people developed in these early activities are the parents of our vastly increased society.

Monday, October 22, 2018
03:35 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

110 67P/Churyumov-Gerasimenko Posters

110.01 The Role of Electron Irradiation in the Sputtering of H_2O-dominated Planetary Ices
Robyn Meier, Mark J. Loeffler
Physics and Astronomy, Northern Arizona University, Flagstaff, Virginia, United States

Abstract
Here we present results for sputtering of H_2O-ice induced by electron irradiation at low temperatures performed using our new ultra-high vacuum system at Northern Arizona University. In this study, we measured the Sputtering Yield (*Y*) as a function of energy for 0.5 keV – 10 keV electrons on thin amorphous ice films using microbalance gravimetry and mass spectroscopy, finding that *Y* increases with stopping power. Additionally, we will also present our results on experiments considering potential dependences of *Y* on the incident electron flux, ice thickness and irradiation history of the film. Finally, we compare our new results with previous ones and discuss the relative importance of keV electrons' role in the sputtering of icy planetary surfaces.

110.02 New Progress on CH_3OH and NH_3 Spectroscopy in the Far-infrared Region
Keeyoon Sung[1], John C. Pearson[1], Shanshan Yu[1], Brian J. Drouin[1], Jeniveve J. Pearson[1], V. M. Devi[2], D. C. Benner[2]
[1]Science Division, Jet Propulsion Laboratory, Pasadena, California, United States, [2]The College of William and Mary, Williamsburg, Virginia, United States

Abstract
High resolution spectroscopy of the interstellar medium provides a mechanism to identify the local physical, chemical and dynamical conditions. Methanol (CH_3OH) and ammonia (NH_3) are among the most important molecules ubiquitously observed in the molecular clouds, star-forming regions, and planetary atmospheres. We present recent progress on the high-resolution measurements and Hamiltonian modeling of their spectroscopic line parameters in the far-infrared region.
[1] We have measured the line intensities of CH_3OH in the 100 – 200 cm^{-1} region, covering strong transitions ($S > \sim 1\times10^{-21}$ $cm^{-1}/(molecule.cm^{-2})$) in seven torsional bands from $v_t = 0, 1, 2$ and $\Delta v_t = 0, \pm1$. For this, six spectra of pure CH_3OH sample were obtained at room temperature using a high-resolution Fourier transform spectrometer, Bruker 125HR, at the Jet Propulsion Laboratory. All the six spectra were fitted simultaneously using a multi-spectrum curve-fitting technique to determine their line positions and strengths. The results will be presented and discussed in comparison with the theoretical model calculations from early literatures.
[2] Sung et al. (2016) reported an experimental linelist of NH_3 in 50-660 cm^{-1}, from which the retrieved line positions and intensities were used as standards to validate HITRAN 2012 database and our empirical Hamiltonian models (Yu et al. 2010; Pearson et al. 2016). We have found that, while the line position comparisons with HITRAN and our Hamiltonian models were excellent, the intensity comparisons were less satisfactory, in particular, for the $\Delta K = 3$ forbidden transitions of the ground state rotational inversion. In this presentation, we report a newly updated Hamiltonian model, in which the intensity predictions have greatly improved for the gs (a-s, $\Delta K=3$). We also report the new model predictions updated with

dipole moments adopted from recent ab initio calculations for other rotation-inversion and difference bands, involving ν_2, $2\nu_2$, $3\nu_2$, and ν_4 in comparison with the Sung et al.'s measurements and HITRAN 2016.

110.03 Types of Outbursts From 67P/Churyumov-Gerasimenko, as Seen by Alice: Gas, Dust, Ice, and Hybrid

Andrew J. Steffl[1], Michael F. A'Hearn[2], Jean-Loup Bertaux[3], Lori Feaga[2], Paul Feldman[4], Brian A. Keeney[1], John Noonan[5], Joel Parker[3], Alan Stern[1], Harold Weaver[6]
[1]Space Studies, Southwest Research Institute, Boulder, Colorado, United States, [2]University of Maryland, College Park, Maryland, United States, [3]LATMOS, CNRS/UVSQ/IPSL, Guyancourt, France, [4]Johns Hopkins University, Baltimore, Maryland, United States, [5]University of Arizona, Tucson, Arizona, United States, [6]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, United States

Abstract
During ESA's *Rosetta* mission, the Alice far-ultraviolet spectrograph (700-2050Å) monitored gas and dust emissions from the comet 67P/Churyumov-Gerasimenko. Several large outbursts of gas and dust were observed. We classify these outbursts into four types: gas, dust, ice, and hybrid. During a gas outburst, the brightness of coma emission lines can increase by factors of a few on short time scales. In the case of dust outbursts, the brightness of sunlight reflected from dust can increase by almost two orders of magnitude on timescales of a few tens of minutes. Typically, the reflectance spectrum of dust is very similar to that of the pre-perihelion nucleus: dark and relatively featureless with a blue spectral slope. However, a subset of the sedust outbursts show a markedly different character, with dust that is bright--in some cases brighter than the sunlit nucleus itself-- and displaying a strong absorption feature around 1700Å, characteristic of water ice. In such outbursts, the "dust" is likely to consist primarily of icy grains. There are also a class of hybrid outbursts that show enhancements of gas, dust, and/or water ice. We present examples of each of these types and discuss possible creation mechanisms.

110.04 Modelling of the activity (gas and dust) of comet 67P/Churyumov-Gerasimenko during the summer of 2015 with Rosetta

Adeline Gicquel, Paul von Allmen, Mark Hofstadter, Anthony Lethuillier-Letoquin
JPL/Caltech, Pasadena, California, United States

Abstract
The ESA Rosetta spacecraft reached comet 67P/Churyumov-Gerasimenko (67P) in August 2014, and over the course of the 2.5 year mission, many outbursts were seen. Close to perihelion in August 2015, a display of 34 outbursts on 67P (Vincent et al. 2016) were observed with the Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS) and the Navigation Camera (NAVCAM). Many of these were also detected by the Microwave Instrument for the Rosetta Orbiter (MIRO). We hope to better understand the physics creating outbursts on the surface of comets and derive the dust/gas ratio by using the OSIRIS/NAVCAM images (more sensitive to the dust) and MIRO spectra (more sensitive to the gas). We use a Collisionless Gas Simulation to model the gas flow from the nucleus and in the coma, and are improving our fully-collisional DSMC model to calculate the excitation state of gases in the coma. The resulting gas models will then be used in a radiative transfer calculation to accurately simulate MIRO spectra. We have added dust-grains to our collisionless gas model, with dust trajectories controlled by gas drag, gravity and radiative pressure. We assume that the dust particles start with zero velocity at the nucleus surface, and are initially accelerated by gas flow perpendicular to the surface. A distribution of dust sizes is included in the model. Mie theory is used to calculate the optical properties of the dust, and

we are in the process of simulating sunlight scattered by the dust particles. At the time of the meeting, we will present the physics of the models being used and hope to be able to compare simulated visible-wavelength images with OSIRIS and NAVCAM data.

110.05 CrawlNAC—Image Searching Tool for Rosetta OSIRIS NAC data of 67P/Churyumov-Gerasimenko

Yuhan Yang[1], Archie Gao[2], Yiren Wang[1], Xiaoduan Zou[3], Boyang Liu[4, 5]
[1]Taizhou High School Affiliated to Beijing Normal University, Taizhou, Zhejiang, China, [2]Abington Friends School, Jenkintown, Pennsylvania, United States, [3]Planetary Science Institute, Tucson, Arizona, United States, [4]National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China, [5] International Center for Radio Astronomy Research / The University of Western Australia, Perth, Western Australia, Australia

Abstract
ESA's Rosetta spacecraft closely observed one comet during a large portion of its orbit around the Sun. The OSIRIS Narrow-Angle Camera (NAC) on-board has obtained numerous high-resolution images of the nucleus of 67P/Churyumov-Gerasimenko. These images have brought unprecedented resolution and precision for comet research, providing an opportunity for detailed analysis of comets. The analyses of certain areas of the nucleus often require image searching based on spatial coverage. Currently, none of the publicly available tools serves this purpose. If we manually sort the huge amount images of NAC by regions, it'll waste a lot of time and the results could be still unreliable. And the work could be tedious and redundant. Here we provide CrawlNAC, an image searching tool for NAC images, which enables efficient searching of images that cover specific regions from the dataset. Our team designed a python program of image recognition based on Dr. Jean-Baptiste Vincent's software shapeViewer (www.comet-toolbox.com) to categorize the data by the comet's twenty-six geological regions. With this CrawlNAC, anyone could retrieve image data of certain region or regions from the dataset named MTP001 to MTP025 (relating prelanding and escort phase) on NASA PDS Small Bodies Node (https://pdssbn.astro.umd.edu/data_sb/missions/rosetta/index.shtml). Simply input the name of a region, the tool would provide an image list with automatic download option. The tool would be available publicly via https://github.com/Project-HighSchool.

110.06 The global compositional change in the lower atmosphere of comet 67P from Rosetta VIRTIS-H observations

Yu-Chi Cheng, Dominique Bockelée-morvan, Cedric Leyrat, Stephane Erard
Observatoire de Paris, Meudon, France

Abstract
We analyzed the Rosetta VIRTIS-H data to measure the intensity of H_2O (2.60~2.73 μm) and CO_2 (4.20~4.31 μm) bands in the lower atmosphere (< 10km) of comet 67P at different heliocentric distances (from 2 AU pre-perihelion to 3 AU post-perihelion). Combining with the geometry and spacecraft trajectory information, we reconstruct the H_2O and CO_2 distributions around the nucleus. We will report preliminary results on the spatial distribution and temporal variations of H_2O and CO_2 emissions observed by VIRTIS-H during the Rosetta space mission.

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111 Asteroid Dynamics and Theory Posters
Chair(s): Shantanu Naidu, Leos Pohl

111.01 Development of a Realistic Set of Synthetic Earth Impactor Orbits
Steven Chesley[1], Siegfried Eggl[1], Giovanni B. Valsecchi[2]
[1]JPL/Caltech, Pasadena, California, United States, [2]IAPS-INAF, Rome, Italy

Abstract
We present a refined method for creating orbits of fictitious Earth impactors that are representative of the actual impactor population. Such orbits are crucial inputs to a variety of investigations, such as those that seek to discern how well and how early a particular asteroid survey can detect impactors, or to understand the progression of impact probability as an object is tracked after discovery. We will describe our method, which relies on Opik's b-plane formalism, and place it in context with previous approaches. While the Opik framework assumes the restricted three body problem with a circular Earth orbit, our final synthetic impactors are differentially corrected to ensure an impact in the N-body problem of the solar system. We also test the validity of the approach through brute force numerical tests, demonstrating that the properties of our synthetic impactor population are consistent with the underlying Near-Earth Object (NEO) population from which it is derived. The impactor population is, however, distinct from the NEO population, not only by virtue of the proximity of the asteroid orbit to that of the Earth, but also because low encounter velocities are strongly favored. Thus the impacting population has an increased prominence of low inclination and low eccentricity orbits, and Earth-like orbits in particular, as compared to the NEO population as a whole.

111.02 The impact of small near-Earth asteroid 2018 LA
Davide Farnocchia[1], Eric Christensen[2], Alex Gibbs[2], Richard Kowalski[2], Larry Denneau[3], Aren Heinze[3], Peter Brown[4], Marco Micheli[5], Paul Chodas[1]
[1]Jet Propulsion Laboratory, Pasadena, California, United States, [2]University of Arizona, Tucson, Arizona, United States, [3]University of Hawaii, Honolulu, Hawaii, United States, [4]University of Western Ontario, London, Ontario, Canada, [5]ESA-SSA NEO Coordination Centre, Frascati, Italy

Abstract
2018 LA was an asteroid of few meters in size discovered by the Catalina Sky Survey on 2018 June 2 at 08:15 UT near the opposition at one lunar distance from the Earth. Before the object set below the horizon, the Catalina Sky Survey obtained eleven astrometric observations over one hour and a half that were promptly reported to the Minor Planet Center. Once the astrometry became publicly available, JPL's Scout system identified a 5% probability that 2018 LA could reach the Earth within hours of discovery, from 13:30 UT to 17:15 UT. The impact corridor extended from the Pacific Ocean east of Papua New Guinea to the Atlantic Ocean west of Namibia. The remeasurement of the initial astrometry and the report of a twelfth detection by the Catalina Sky Survey increased the impact probability to 30%. Because of the short observation arc and the proximity of 2018 LA to the Earth, the plane-of-sky uncertainties were large and so no targeted additional observations were made before 2018 LA actually reached the Earth around 16:45 UT. Within a few hours of the impact, the event was confirmed by independent sources. First,

eyewitnesses reported a fireball sighting to the American Meteoritic Society. Moreover, before knowing that the impact had taken place, we searched the images of the ATLAS survey and found two astrometric detections obtained at about 12 UT. Because clouds prevented ATLAS from obtaining its usual four images (and automatically flagging 2018 LA as a candidate NEO), these two detections had to be manually extracted based on the asteroid's expected plane-of-sky location. The ATLAS astrometry confirmed that the impact must have taken place between 16:30 UT and 17:00 UT, with an impact footprint extending from Mozambique to the Atlantic Ocean off the western coast of Namibia. Finally, the Comprehensive Nuclear-Test-Ban Treaty Organization's I47 station in South Africa detected a strong infrasound signal of a bolide over Botswana. On June 5, a release of data provided by US Government sensors reported a fireball event with an impact energy of 0.98 kt corresponding to the impact of 2018 LA. The peak brightness was at 16:44:12 UT at an altitude of 28.7 km, a longitude of 23.3 deg E, and a latitude of 21.2 deg S.

111.03 Twenty Years of Tracking Near-Earth Objects: The Role of JPL's Center for NEO Studies (CNEOS)

Paul Chodas
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Abstract
Now entering its third decade, NASA's Near-Earth Object (NEO) Program has been a highly successful effort, leading not only to a dramatic increase in the size of the NEO catalog, but also increased public awareness of the importance of monitoring objects that could potentially collide with the Earth. This poster provides a brief history and overview of the important role JPL has played in these developments, starting with the establishment of the NEO Program Office at JPL twenty years ago, and evolving into the Center for NEO Studies (CNEOS) operating today. Over the whole period, this JPL group has focused on the calculation of high precision orbits for NEOs and the robust assessment of their chances of impacting our planet. Although in the beginning the group performed only manual monitoring of a handful of the Potentially Hazardous Asteroids (PHAs), it quickly developed fully automated processes to monitor all known NEOs (now numbering about 19000). CNEOS is embedded in the JPL Solar System Dynamics Group (SSD) which uses the same processes to automatically determine precise orbits for all asteroids and comets in the solar system (now numbering nearly 780,000). CNEOS orbit calculations are based on the latest astrometric data from the Minor Planet Center, including radar data, and use sophisticated numerical methods and accurate models. Special attention is paid to the accurate assessment of orbital uncertainties, primarily a function of measurement uncertainties. These are key ingredients for close approach predictions and a robust assessment of impact probabilities from the CNEOS Sentry and Scout systems. CNEOS data products are stored in the JPL small-body database (SBDB), upon which the extensive, customizable and searchable CNEOS and SSD websites are based. An especially important service that CNEOS/SSD provides for the observing community and other outside users is the online Horizons ephemeris generation system.

111.04 Yarkovsky Acceleration of (99942) Apophis

David J. Tholen[1], Davide Farnocchia[2]
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Abstract
A reliable detection of Yarkovsky acceleration requires that the data be free of significant systematic errors that might mimic a signal that in reality is not there. Until recently, reference star catalogs have suffered from significant biases and/or absence of proper motion information that precluded a trustworthy astrometric analysis of the Yarkovsky acceleration of (99942) Apophis, which remains an impact hazard for the Earth, with impact solutions as soon as 2068 April 12. With the release of Gaia DR2, we now have an astrometric reference catalog that enables positional measurements not limited by the catalog itself. We have begun to reprocess nearly a thousand observations of Apophis spanning 14 years, most with astrometric uncertainties of less than 0.1 arcsec, with the goal of placing limits on the amount of Yarkovsky acceleration this asteroid is experiencing, and refining impact predictions for the next century. Preliminary analysis using roughly half of the reprocessed data paints a puzzling picture that we hope will become clearer as more of the reprocessed older data are incorporated into the solution. Apophis becomes observable again in early 2019, with another radar opportunity during a close approach in March 2021. This next apparition will be crucial for firmly establishing the impact threat represented by this near-Earth asteroid.

111.05 Performance analysis of short-arc orbit determination and hazard assessment systems
Otto Solin[1], Mikael Granvik[1, 2], Davide Farnocchia[3], Federica Spoto[4, 5]
[1]University of Helsinki, Helsinki, Finland, [2]Luleå University of Technology, Luleå, Sweden, [3]Jet Propulsion Laboratory, Pasadena, California, United States, [4]Université Côte d'Azur, Nice, France, [5]IMCCE, Observatoire de Paris, Paris, France

Abstract
Three different automatic systems (Scout, Farnocchia et al. 2015, Icarus 258, 18-27; NEOScan, Spoto et al. 2018, A&A 614, A24; NEORanger, Solin and Granvik, 2018, A&A, accepted) routinely monitor Minor Planet Center's Near-Earth-Object Confirmation Page (NEOCP) to identify imminent impactors. We assess the ability of each system to predict correct orbital classifications and identify impactors based on scarce synthetic astrometry sets obtained on one or two nights, that is, each data set spans either about 1 hour or about 25 hours. The central goal of the study is to identify the strengths and weaknesses of the three systems and to improve each system based on our findings. To this end, we process the same synthetic astrometry with the three systems and compare the results. The synthetic astrometry is based on synthetic populations of Earth impactors (Vereš et al. 2009, Icarus 203, 472-485), near-Earth objects (Granvik et al. 2016, Nature 530, 303-306), and main-belt objects (Grav et al. 2011, PASP 123, 423-447). The synthetic astrometry is similar in cadence and average noise characteristics to Pan-STARRS PS1. For impactors the astrometry of the first tracklet is generated between two weeks and 26 hours prior to impact. Our preliminary findings suggest, for example, that it is typically challenging to tell apart impactors from generic near-Earth objects and main-belt objects based on the first tracklet alone. Adding the second night improves the results dramatically and allows the correct identification of most impactors.

111.06 Impact simulations with rotating targets - draining vs. embedding of the angular momentum
Pavel Sevecek, Miroslav Broz
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Abstract
About 10 percent of the observed asteroids have rotational period lower than P = 3 h, i.e. close to the break-up limit, but rotation has been previously neglected in simulations of asteroid collisions. To determine the role of rotation, we computed 475 SPH/N-body impact simulations, using a new code, which includes self gravity already in the fragmentation phase, rotational stress, together with material strength and Grady-Kipp model. The code has been validated against SPH5 (Benz and Asphaug, 1994). We ran simulations with D_pb = 10 km monolithic targets and compared synthetic fragment distributions for rotating and non-rotating targets. It turned out rotation affects mostly cratering impacts at oblique impact angles. The total mass ejected by the collision can be up to 5 times larger for the critically rotating target.

We further compared the transfer of the angular momentum and determined conditions under which the impact accelerates or decelerates the target or the largest remnant. It depends on the impact angle, the angular momentum of the impactor
and the ejection of prograde and retrograde material. If we averaged the result over impact angles, the angular momentum is drained in most cases; it is only embedded if the target was previously almost stationary. Finally, we computed an efficiency of the transfer of the angular momentum and found an approximate efficiency function of the impact parameters, which can be subsequently used in collisional models of the Main belt population that also track rotation of asteroids.

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112 Comet Physical Characteristics: Nuclei and Surfaces Posters

112.01 A Stereophotoclinometry Model of Comet Tempel 1

Carolyn M. Ernst[1], Robert Gaskell[2], Ronald T. Daly[1], Olivier S. Barnouin[1]
[1]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, United States, [2]Planetary Science Institute, Tucson, Arizona, United States

Abstract
In 2005, the Deep Impact (DI) spacecraft performed an active experiment by impacting comet 9P/Tempel 1, and carried with it three visible imagers: the High-Resolution Instrument (HRI), the Medium-Resolution Instrument (MRI), and the Impactor Targeting Sensor (ITS). The nucleus was shown to have smooth areas, pits, knobs, and even possible impact craters. In 2011, the repurposed Stardust-NExT (SD-N) spacecraft also flew by Tempel 1. Images from the NavCam provided a unique second view of a comet nucleus, including areas not seen by DI. Layering, smooth areas, and pits were re-imaged, and changes were detected along the margins of smooth flows.
Co-registration and comparison of datasets obtained by multiple instruments and spacecraft are difficult, due to complexities of coordinating spacecraft positioning, instrument pointing, data calibration, and data archives. Yet this synthesis is critical for proper interpretation of the datasets. The irregular shape of Tempel 1 also poses considerable obstacles. Visualizing and mapping features on such bodies becomes a difficult task, two-dimensional map projections lead to severe distortions of spatial relationships and size, and rapidly changing photometric angles make spectral analyses impossible without accurate photometric corrections.
We have performed quality assessments of all images of Tempel 1 from DI (318 HRI images, 379 MRI images, and 83 ITS images) and SD-N (72 NavCam images) for which there are at least 10 pixels across the nucleus. Of these images, approximately 90% are of sufficient quality (e.g., not saturated, no major artifacts) to be of use for analysis. We have constructed a global shape model of Tempel 1 using the stereophotoclinometry method. The combination of DI and SD-N images cover ~70% of the surface. These images have been co-registered and incorporated into a high-resolution shape model (~15 m globally, where data exist, with some areas as high as 5 m). This model is significantly higher in resolution than the previous best shape model globally (a 2 degree, or ~157 m, shape model made by Peter Thomas and available in the Planetary Data System). Inclusion of limb imaging allows for additional shape constraints.

112.02 Investigating the ongoing fragmentation of comet 96P/Machholz 1

Matthew M. Knight[1], Nora L. Eisner[1, 2], Colin Snodgrass[3, 4], Rosita Kokotanekova[3, 5], Michael S. Kelley[1], Karl Battams[6], Alan Fitzsimmons[7]
[1]University of Maryland, College Park, Maryland, United States, [2]University of Oxford, Oxford, United Kingdom, [3]The Open University, Milton Keynes, United Kingdom, [4]University of Edinburgh, Edinburgh, United Kingdom, [5]Max Planck Institute for Solar System Research , Gottingen, Germany, [6]Naval Research Laboratory, Washington, District of Columbia, United States, [7]Queen's University Belfast, Belfast, United Kingdom

Abstract
Comet 96P/Machholz 1 is an enigmatic object on a highly inclined (58.5 deg), 5.3 yr period orbit. It has an extremely small perihelion distance of 0.12 AU that makes it unobservable by most Earth-based telescopes around perihelion. 96P has transited the SOHO fields of view during all five of its perihelion passages since 1996, and several faint fragments were observed accompanying it during its 2012 and 2017 apparitions. Furthermore, two groups of near-Sun comets seen only by SOHO have been dynamically linked to 96P (Ohtsuka et al. 2003, Sekanina & Chodas 2005), suggesting that 96P has been shedding small fragments for centuries.

We imaged 96P with the 4.1-m SOAR telescope in July 2017, prior to its most recent perihelion passage in October 2017. The comet showed limited signs of activity and exhibited a double-peaked lightcurve implying a rotation period of approximately 4.1 hr. Combined with a peak-to-trough amplitude of roughly 0.5 mag, this suggests that 96P was spinning near its rotational breakup limit for an assumed strengthless body with cometary density. We obtained additional, post-perihelion observations with SOAR and the 3.58-m NTT telescope in July 2018 to investigate if the rotation period has changed. We will present results of our ongoing analyses of the lightcurve and consider these findings in the context of the SOHO data.

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113 Formation of Planetary Systems Posters
Chair(s): Billy Quarles, Julie Brisset

113.01 A Laboratory Study of $^{12}CO/^{13}CO$ Ice-Gas Fractionation in Interstellar Ice Analogues
Lucas Smith[1], Robert D. Lewis[1], Elisabeth M. Panto[1], Murthy S. Gudipati[2], Rachel L. Smith[1, 3]
[1]Appalachian State University, Boone, North Carolina, United States, [2]Jet Propulsion Laboratory, Pasadena, California, United States, [3]North Carolina Museum of Natural Sciences, Raleigh, North Carolina, United States

Abstract
Understanding carbon chemistry in forming planetary systems is a critical step toward establishing detailed formation pathways for solar system planets, exoplanets and their atmospheres, and prebiotic molecules. Carbon monoxide (CO) is a key tracer of this evolution, as it is a large reservoir of nebular carbon, and can be observed astronomically. High-resolution observations of CO isotopologues toward a range of young stellar objects (YSOs) have revealed heterogeneity in gas-phase $[^{12}C^{16}O/^{13}C^{16}O]$ (heretofore $^{12}CO/^{13}CO$), with values ranging from ~ 85 to 165. Comparison of the CO ice fraction $([^{12}CO]_{Ice}/[^{12}CO]_{Ice} + [^{12}CO]_{Gas})$ with gas-phase $[^{12}CO]/[^{13}CO]$ suggests that CO ice may influence gas-phase reservoirs in the YSOs. Toward exploring potential preferential fractionation of ^{12}CO versus ^{13}CO, we conducted thermal desorption and photodesorption experiments in the Ice Spectroscopy Lab at JPL, using astrophysical temperatures (~ 10 to 35 K) and pressures (~ 10^{-9} mbar). Infrared spectroscopy was used to examine ice composition and abundance, and mass spectrometry monitored desorbed CO and residual gas in the vacuum chamber. CO ice was prepared (thicknesses ~ 0.2 to 200 μm) through gas-phase deposition of ^{12}CO and ^{13}CO at 20 K. CO ice was slowly warmed up to different set temperatures and spectra were taken at each interval to measure changes in the CO ice. Our latest results show that ^{12}CO vs. ^{13}CO sublimation is identical except for a 0.1 K delay in the ^{13}CO sublimation curve: ^{12}CO (^{13}CO) complete sublimation at 28.9 (29.0) K and 50% depletion at 28.6 (28.7) K. Our sublimation curves for ^{12}CO and ^{13}CO are used as benchmarks for the ongoing photodesorption and photodissociation experiments of pure CO ice, as well as CO trapped CO_2 and H_2O ice mixtures to study isotopic fractionation by Ly-α radiation (121.6 nm), a major component of the background radiation in protoplanetary environments.

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA). Funds were provided through NASA Emerging Worlds Program.

113.02D Atomic-scale simulation of chemistry and plastic deformation in dust grain aggregation
William C. Tucker, Baochi D. Doan, Abrar H. Quadery, Adrienne R. Dove, Patrick K. Schelling
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Abstract
Dust grain aggregation as an initial stage of planet formation is often modeled with continuum theories, which depend on relatively few materials parameters, to describe grain-grain interactions. Much work has

been done to theoretically describe various dissipation mechanisms required to ensure aggregation. Atomic-scale simulation, in which all atomic degrees of freedom are explicitly described, offers a way to elucidate specific mechanisms of dissipation. Of the relatively few atomic-scale simulations of dust grain aggregation previously published, most either utilize simple pair potentials or model small numbers of atoms. By including many-body atomic interactions in molecular dynamics simulations of nanoparticle (NP) collisions, we explore dissipation in Fe NPs ($npFe^0$) and the effect of hydroxylation on amorphous silica (a-SiO_2) NPs. Our simulations span a length scale of NP radii of 1-11 nm and a velocity range of 10-3000 m s^{-1}. $npFe^0$ simulations utilized an EAM potential, appropriate for metals with surfaces and defects, while hydroxylated a-SiO_2 NPs were simulated using the ReaxFF potential which is capable of modeling chemical processes. The probability and strength of adhesion was analyzed for both materials systems. In $npFe^0$ collisions, strong disagreement exists between our results and the Johnson-Kendall-Roberts (JKR) model of contact mechanics that is often used to describe collisions in planetary formation models. Sticking was observed at all simulated velocities for $npFe^0$ collisions. Intersurface interactions during initial approach increase velocities such that plastic deformation is inevitable at the nanoscale; similarly, collision timescales do not allow elastic response of atoms at the interface as in the JKR paradigm. Our a-SiO_2 simulations demonstrate that surface hydroxylation, an effect often present in laboratory settings during experiments, significantly reduces adhesive properties and contributes to the observation of bouncing at higher velocities for a-SiO_2 NPs. Unpassivated surface states present in the space environment may broaden the velocity range at which dust grains adhere. In these ways, our simulations reveal that JKR does not adequately describe dissipation at the nanoscale.

113.03 Gravitational settling of condensate grains in protosolar gas rings of non-uniform specific angular momentum

Andrew J. Prentice[1, 2]
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Abstract
The Modern Laplacian Theory [MLT] of Solar System origin proposes that the planets condensed from a concentric family of orbiting gas rings (Prentice 1978, *Moon Planets* 19, 341; 2015, *LPSC* 46 2664.pdf). These rings are shed by the protosolar cloud [PSC] as a means for ridding excess spin angular momentum during gravitational contraction. The rings, of mean orbital radius R_n $\{n = 0,1,2,3\ldots\}$, have uniform specific angular momentum $h(s, z)$ = constant. The gas angular velocity $\omega(s, z)$ varies as $\omega \propto s^{-2}$. Here (s, z) denote cylindrical polar coordinates referred to the PSC spin axis. The mass density $\rho(s, z)$ declines with meridional distance ξ from the central Keplerian orbit $\{s = R_n, z = 0\}$ as $\rho \propto \exp(-\tfrac{1}{2}A_n[\xi/R_n]^2)$, where $A_n \sim 400$ are constants. The gas rings are thus narrow isolated tori. The contours of constant density in the meridional planes are nearly circular. All condensing grains migrate spoke-wise onto the central orbit of each ring to form a concentrated stream of solids. This focussing property of the gas rings greatly assists the subsequent self-gravitational accretion of smaller condensate masses into larger ones, so hastening the process of forming a single solid core (Hourigan 1977, *Proc. Astron. Soc. Aust.* 3 169).

A major difficulty with the MLT is that gas rings of uniform specific angular momentum are dynamically unstable and fragment (Zurek & Benz 1986, *ApJ* 308, 123; Monaghan 1995, *Earth Moon & Planets* 71, 73). They evolve to a new specific angular momentum distribution having $h \propto s^{0.25}$ and $\omega \propto s^{-1.75}$. Fortunately the density distribution in each new ring retains its Gaussian-like structure. The meridional contours change from circles to ellipses with axis ratio $a{:}b = \sqrt{2}{:}1$. The grains settle gravitationally onto the central Keplerian orbit of the gas ring to form a concentrated stream, just as before, but they now pursue parabolic rather than straight-line paths. The evolved gas rings thus retain their orbital focussing property, so enhancing planetary core formation.

I submit that the MLT may admit timely *in situ* formation of Uranus and Neptune (cf. Thommes et al 2003, *Icarus* 161 431) and of the giant planets of HR 8799 (Marois *et al* 2010, *Nature* 468 1080) and PDS 70 (Keppler *et al* 2018, in press).

113.04 Long-lasting Vortices as Nurseries for Planetesimal Formation in Protoplanetary Disks

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Abstract
The formation of planetesimals has been long-studied yet is still an ongoing problem in modern Astrophysics. It is believed that the coagulation of micron-sized dust particles in protoplanetary disks serves as a possible mechanism for which larger planetesimals to grow, but this coagulation has yet to be modelled in full detail. Furthermore, with the age of high-resolution observatories like the Atacama Large Millimeter Array (ALMA) providing a plentiful bounty of observations, there has been increased interest in resolving the discrepancy between models and observations. Using LA-COMPASS and the supercomputing resources at Los Alamos National Laboratory, we performed large-scale, hydrodynamic simulations. Being high-resolution and two-dimensional, these simulations aim to investigate the role long-lasting vortices, formed at the edge of dead-zones in protoplanetary disks, play in the coagulation and trapping of dust particles. Furthermore, we investigate the effects of dust coagulation and whether dust will affect the gas distribution.

113.05 Experimental and Numerical Studies of Planetsimal Formation via Collisional Accretion

Stephanie Jarmak, Joshua Colwell, Julie Brisset, Adrienne R. Dove, Addison Brown
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Abstract
Small particles (μm to cm-size) in planetary ring systems and protoplanetary disks collide at low velocities (less than 1 m/s) and tend to aggregate through non-gravitational interactions. Additionally, exploration and sample return missions to asteroids and other small, airless bodies involve low energy interactions with weakly-bound regolith particles. Therefore, to characterize the processes that lead to planetesimal formation and planetary ring collisional evolution, and to develop appropriate procedures for asteroid sample return missions, it is necessary to understand how regolith responds to low-energy collisions in a microgravity environment. The COLLIDE (Collisions Into Dust Experiment) and PRIME (Physics of Regolith Impacts in Microgravity Experiment) programs produced observations of mass transfer of regolith onto cm-scale projectiles at impact velocities < 40 cm/s in microgravity conditions. These experiments were carried out on orbit (COLLIDE, COLLIDE-2), in suborbital space (COLLIDE-3), and on parabolic airplane flights (PRIME) under vacuum. To study this phenomenon with significantly reduced cost and time constraints we have developed an experimental apparatus that makes use of a laboratory drop tower (free-fall time ~0.75 s). The experiment consists of a tube pumped to vacuum conditions containing a cm-diameter marble suspended from a spring in contact with a bed of regolith. The spring contracts during free-fall allowing us to simulate the rebound portion of a low-velocity collision in a laboratory microgravity environment. We are also carrying out concurrent numerical simulations with the use of a discrete element method particle simulation program, LIGGGHTS (Kloss et al. 2012, Prog. Comp. Fluid Dyn., 12, 140), to replicate these environmental

conditions and study the role of cohesion in mass transfer events. We will present the results of our laboratory and numerical studies where we vary rebound velocity, target material type and grain size distribution, projectile size and material, and regolith packing density designed to bolster our understanding of collisional evolution in the protoplanetary disk and planetary rings.

113.06 Linking the Moon-forming impact to Earth's circular orbit with impact ejecta

Nathan Hung, Seth A. Jacobson
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Abstract
A major goal of planetary science is to create a planet formation model that simultaneously reproduces all the observed characteristics of the terrestrial planets, such as their orbits, masses, and compositions. In particular, a number of trade-offs have been discovered between different sets of characteristics. For instance, we demonstrate that due to dynamical friction, quickly growing Earth-like planets – those with early (Moon-forming) last giant impacts – form dynamically colder disks with lower final eccentricities and inclinations. Alternatively, we find that terrestrial systems created during the Grand Tack are too dynamically hot, if the corresponding last giant impact on the Earth-like planet is late enough to be consistent with estimated ages of the formation of the Moon.

Typically, past simulations have treated all collisions as being mergers, which is computationally cheaper but less realistic. Numerical simulations conducted in recent years have provided a formulation for describing the dynamical outcome of planetary collisions (Leinhardt and Stewart 2011), allowing for sounder physics of subsequent formation simulations. Here, we examine whether implementing impact debris generates more dynamical friction, leading to dynamically colder systems. We present results of many Grand Tack simulations that account for collisional debris creation. Typically, there are 10 collisions that create a significant amount of debris. We also tested the effects of an extended gas phase that contributes to drag and tidal damping in the system. All of these models are compared to perfect accretion simulations whose collisions only form mergers. We find that although the presence of debris generation increases dynamical friction and creates less dynamically excited systems, it does not help the models meet other constraints such as the time of last giant impact, which is still earlier than expected among dynamically colder simulations. Finally, we discuss what other metrics should be studied in more detail or reevaluated, such as the possibility of a younger Moon formation age.

113.07 Numerical Evidence for Terrestrial Planet Debris in the Asteroid Belt

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Abstract
The history of terrestrial planet formation in the Solar System is dominated by the collisions between large planetary embryos. These collisions are responsible for planetary growth, but this process also ejects debris into heliocentric orbit. However, planet formation has historically been studied assuming that all collisions are perfectly accretionary. Here, we break that assumption to understand the role of debris created during planetary accretion. We implemented a full collision model (Leinhardt & Stewart 2011) inside an N-body algorithm, which we used to simulate the formation of the terrestrial planets. Using this model, we show that ejected planetary debris can end up on stable orbits scattered throughout the Main Belt. We have determined the transport history of these asteroids as they traveled from the planet-crossing

region into the asteroid belt, and that there is significant cross-pollination of material between the forming planets. By examining the giant impacts that generated the debris, we also report the distribution of potential compositions and origin bodies found amongst the debris in the asteroid belt. Prior to considering the ejected debris from giant impacts, the asteroid belt was presumed to consist of leftover planetesimals and their fragments, but now we conclude that amongst differentiated asteroids and achondritic meteorites that the forming planets could be a significant source.

113.08 Collisional erosion during accretion and Earth's non-chondritic Sm/Nd ratio

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Abstract
Superchondritic Sm/Nd (Samarium/Neodymium) ratio has been evidenced in Earth's mantle rocks [1]. This observation is at odds with the canonical view of planetary accretion from chondritic building blocks, leading to chondritic ratios of lithophile (i.e. rock loving elements) and refractory elements in the silicate Earth. Here we evaluate the influence of collisional erosion during accretion on the budget of lithophile and refractory elements such as Sm and Nd. During the late stages of planetary accretion, planets grow by colliding with other embryos and a remnant planetesimals population. It has been suggested that the superchondritic Sm/Nd could have been produced by collisional striping of the Earth's early crust during its accretion. We quantitatively constrain the amount of eroded mass during the late-stage growth of Earth analogs using a combination of analytical modeling [2] and N-body numerical simulations [3]. Our model takes into account the distribution of impactors and their evolving compositions during accretion. The effect of changing accretion scenarios is also studied (e.g. with or without a Grand-Tack). The final Sm/Nd ratio of the bulk silicate Earth is determined under 3 sets of assumptions: (1) The mantle and crust fully reequilibrate after each impact; (2) The accreted material merges with the crust only and the mantle does not reequilibrate with the crust (3) an intermediate case that depends on the size of the impactors. We show that planetesimal impacts play a dominant role in determining Earth's Sm/Nd ratio due to the efficiency of crustal erosion. This work has implications for understanding Earth's accretion history.

[1] Boyet and Carlson, 2005. Science 309, 576-581
[2] Svetsov, 2011. Icarus 214, 316-326
[3] Raymond, O'Brien, Morbidelli, Kaib, 2009. Icarus 203, 644-662

113.10 The hot Jupiter period-mass distribution as a signature of in-situ formation

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Abstract
More than two decades after the widespread detection of Jovian-class planets on short-period orbits around other stars, their dynamical origins remain imperfectly understood. In the traditional narrative, these highly irradiated giant planets, like Jupiter and Saturn, are envisioned to have formed at large stello-centric distances and to have subsequently undergone large-scale orbital decay. Conversely, more recent models propose that a large fraction of hot Jupiters could have formed via rapid gas accretion in their current orbital neighborhood. In this study, we examine the period-mass distribution of close-in giant planets, and demonstrate that the inner boundary of this population conforms to the expectations of the in-

situ formation scenario. Specifically, we show that if conglomeration unfolds close to the disk's inner edge, the semi-major axis-mass relation of the emergent planets should follow a power law $a \propto M^{-2/7}$ — a trend clearly reflected in the data. We further discuss corrections to this relationship due to tidal decay of planetary orbits. Although our findings do not discount orbital migration as an active physical process, they suggest that the characteristic range of orbital migration experienced by giant planets is limited.

113.11 Formation of the Planetary Candidates Observed by Kepler Mission

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Abstract

To date, there are more than 4400 planetary candidates have been released, and plenty of planet pairs are trapped near the first order mean motion resonance. We propose a formation scenario for the planetary configurations near 3:2 and 2:1 MMRs. Firstly, the low-mass planets form in a distant region rather than at their present locations; then they will undergo type I migration until they reach the inner region of the gaseous disk and stop migrating. Subsequently, tidal interactions between the planets and the central star will circularize their resultant orbits. This formation scenario will provide a likely explanation for the configuration of Kepler candidates which are very close to the central star and are involved in 2:1 and 3:2 MMRs. During this formation process, the mass accretion of planets is a key factor which will affect the final configuration of systems, more planet pairs can be trapped into 3:2 MMR. For the systems with the innermost planets far away from the central star, the configuration of near MMRs may be induced by the depletion of gas disk. The studies will be helpful to broaden the comprehension on the formation of the solar system and extrasolar planetary systems and provide theoretical explanation and guidance for observing of extrasolar planets.

113.12 Light scattering of irregularly shaped dust grains applied to debris disks

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Abstract

Several hundred nearby main sequence stars host debris disks, a type of circumstellar disk that contains µm- to mm-sized dust [1,2] generated by collisions and disruptions of protoplanets and/or planetesimals. We seek to determine the composition of the material within these extrasolar systems in order to better understand the planet formation process. As debris disks are typically too cold to produce key identifying silicate spectral features near 10 µm in TIR emission, understanding scattering properties in the VNIR is important for making compositional determinations.
Many previous works have relied on Mie theory to calculate the scattering properties of particulates in a variety of astrophysical and planetary settings, including circumstellar disks [e.g. 3,4]. However, not all dust shapes are well-approximated by a sphere. Circumstellar dust grains are expected to take on complex, porous structures similar to dust from a wide variety of sources within our own solar system. For example, IDPs have a wide variety of shapes [5] and comet grains were shown by the Stardust mission to have diverse shapes and densities [6]. Irregularly-shaped particles produce a better match to the interstellar silicate extinction spectrum [7] and can be used to model photo-polarimetric data of comets [8,9].
We use the Zubko et al. implementation of the DDA method [10] to calculate the light-scattering

properties of irregularly shaped agglomerated dust grains. In the DDA code, targets are generated by placing electric dipoles within a 3D lattice of points. Each dipole has a specified index of refraction *m*. The number of and spacing between the dipoles are constrained by the condition $|m|kd < 1.0$ [9,11], where *d* is the lattice spacing and *k* is the wavenumber. We compare modeled disk spectra of AU Mic using spherical grains with those modeled using agglomerated dust grains as well as with telescopic data.
[1]Wyatt 2008 [2]Hughes, Duchene & Matthews 2018 [3]Kruegel and Siebenmorgen 1994 [4]Wolf and Voshchinnikov 2004 [5]Brownlee 1985 [6]Hörz et al. 2006 [7]Min et al. 2006 [8]Mukai & Mukai 1990 [9]Zubko et al. 2015 [10]Zubko et al. 2010 [11]Draine & Flatau 1994

113.13 On The Origin of Free Floating Planets: Planet Ejection During Terrestrial Planet Formation

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Abstract
During the formation of terrestrial planets, many planetesimals and planetary embryos may be ejected from the formation region. As the dynamics of these objects are affected by the perturbation of giant planets, questions have been raised as to whether any of these bodies reach interstellar space where they can become free-floating planets. We present results of 7000 integrations of objects scattered out of the formation region during the simulations of the formation of terrestrial planets in our solar system. We show that many of these bodies may potentially leave the solar system and form a population of free-floating planets. Our integrations show that the average mass of these bodies is 0.4 Mars-masses implying that small free-floating planets may be common.

Monday, October 22, 2018
03:35 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

114 Future Missions, Instruments, and Facilities Posters
Chair(s): Devon Burr

114.01 Planetary Entry Probe Explorations of an Ice Giant
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Abstract
The largely unexplored ice giants Uranus and Neptune fill the gap in size between the terrestrial and gas giant planets. To date, our knowledge of ice giant composition and atmospheric processes is limited to space-based or Earth-based observations. Remote sensing is not capable of providing the essential measurements of noble gas and key isotope abundances, however. Only *in situ* exploration by an entry probe can reveal the well-mixed atmosphere beneath the cloud tops wherein resides pristine materials from the location and epoch of ice giant planet formation. Reflecting the processes of ice giant origin, formation, and evolution, possibly including evidence of giant planet migration, chemically inert noble gases are of particularly high importance. With no detectable radio signature, the essential measurement of noble gas abundances requires an in situ probe.

An atmospheric entry probe would sample well into the cloud-forming regions of the troposphere far below regions directly accessible to cloud top remote sensing. A concept for an ice giant entry probe mission includes a spacecraft to carry and deliver the probe to the ice giant atmospheric entry interface point and subsequently act as a receiving station for the probe science telemetry. The primary goal of an ice giant atmospheric probe would be to measure the well-mixed abundances of the noble gases He, Ne, Ar, Kr, Xe and their isotopes, as well as the altitude profile of heavier elements C, N, S, and P, key isotope ratios $^{15}N/^{14}N$, $^{13}C/^{12}C$, $^{17}O/^{16}O$ and $^{18}O/^{16}O$, and D/H, and disequilibrium species CO and PH_3.

The ice giants represent the last unexplored class of planets in the solar system and the most frequently observed type of exoplanets. Extended studies of one or both ice giants, including *in situ*with an entry probe, are necessary to further constrain models of solar system formation and chemical, thermal, and dynamical evolution, the formation and evolution of atmospheres, atmospheric processes, and to provide additional ground-truth for improved understanding of exoplanetary systems.

114.02 Solar System Observations with the Habitable Exoplanet Observatory
John T. Clarke[1], scott gaudi[2], Alina Kiessling[3], Bertrand Mennesson[3], Paul Scowen[4], Sara Seager[5], Rachel Somerville[6], Daniel Stern[3], Keith Warfield[3]
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Arizona, United States, [5]MIT, Cambridge, Massachusetts, United States, [6]Rutgers, New Brunswick, New Jersey, United States

Abstract
The Astrophysics Division at NASA has commissioned four large mission concept studies in preparation for the upcoming decadal survey. One of these mission concepts is the Habitable Exoplanet Observatory (HabEx), which will nominally be a 4 meter UV/vis/IR telescope in space and is expected to include a coronagraph and/or starshade to assist in exoplanet detection and characterization. While HabEx will concentrate on exoplanet studies, there will be powerful capabilities for the study of solar system objects well beyond the present capability of HST, and these observations are included as considerations in the design study. This paper will present the status of the trade study and summarize the expected capabilities of HabEx for solar system observations. It is our hope that DPS members will consider the capabilities of HabEx for their own research and provide input about the most important parameters for future solar system science.

114.03 Planetary and Exoplanetary Science with the Twinkle Space Mission
Billy Edwards[1], Giovanna Tinetti[1], Marcell Tessenyi[1, 2]
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Abstract
Twinkle is a 45cm space telescope conceived to characterise extrasolar planets and Solar System objects over a broad wavelength range (0.4 – 4.5mm) and I will present the work being done to model the performance of Twinkle's spectrometers.
Exoplanets will be observed through transit and eclipse photometry and spectroscopy, as well as phase curves, eclipse mapping and multiple narrow-band time-series. The ability of Twinkle's infrared spectrometer to characterise the currently known exoplanets has been assessed by calculating the spectral resolution achievable by combining multiple observations. Spectral retrievals have also been simulated for some well-known planets.
It has been found that Twinkle could probe a large number of known planets at low spectral resolution, useful to refine planetary, stellar and orbital parameters, search for TTV and monitor stellar activity through time. For planets orbiting bright stars, Twinkle observations at higher spectral resolution will enable to probe atmospheric chemical and thermal properties, with the potential to revisit them many times to detect variations such as non-uniform cloud cover.
Further surveys will reveal thousands of new exoplanets, of which many will be located within Twinkle's field of regard. TESS in particular is predicted to discover many targets around bright stars which will increase the number of exoplanets Twinkle could observe and simulated TESS detections have been analysed to confirm this.
Twinkle's ability to study Solar System objects has been explored by determining when objects are observable as well as the data quality and resolution obtainable. It was found that many celestial bodies would have long periods during which they could be observed with observation windows occurring on a periodic basis. Having determined that a target was observable, the SNR for photometric and spectroscopic data was calculated for a given exposure time. For a number of targets, including the outer planets, their large moons and bright asteroids, the model created predicts short exposure times will achieve high quality, high resolution spectroscopic data.
Hence, Twinkle is found to have great potential for contributing to both these fields.

114.04 CAESAR Sample Preservation and Analysis

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Abstract

The primary goal of the Comet Astrobiology Exploration SAmple Return (CAESAR) mission (Squyres et al. 2018) proposed for NASA's New Frontiers 4 program is to bring the first sample (dust, organics, and ices) collected at the surface of a comet nucleus back to Earth for study, specifically from comet 67P/Churyumov-Gerasimenko (67P). This requires storage of the collected solids at temperatures above that of the comet itself during the return voyage back to Earth and capturing sublimating gases in a separate, cooled container. To prevent alteration that would affect interpretations of sample analyses upon retrieval after delivery back to Earth, a thorough understanding of the effects on the sample caused by sublimation and exposure to evolved gases is necessary. We will present a detailed description of the CAESAR sample preservation strategy, including the results of breadboard and brassboard testing with analog cometary materials.

Detailed investigations of CAESAR returned samples will resolve major questions about the origin and evolution of comets and cometary materials and the potential role of comets in delivering water and organics to the early Earth necessary for the origin of life. Hypotheses about the origin and evolution of 67P will be tested through a large variety of available laboratory analytical techniques. The CAESAR science traceability path from these hypotheses to objectives to measurements will be presented.

References:

Squyres S. W. et al. (2018) LPSC 49, 1332.

114.05 The Europa Lander Mission Concept

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Abstract

Europa is a prime target in our exploration of potentially habitable worlds beyond Earth. The combination of an ocean in contact with a rocky seafloor may yield an ocean rich in the elements and energy needed for the emergence of life, and for potentially sustaining life through time. Europa may hold the clues to one of NASA's long-standing quests – to determine whether or not we are alone in the universe.
The *Europa Lander Study 2016 Report* provided recommendations for the science requirements and model payload consistent with the goals of searching for biosignatures, assessing Europa's habitability, and understanding the chemical, geologic, and geophysical context of Europa's ice shell, and its relationship to the putative ocean below. Following the work of the Science Definition Team (SDT), and after valuable feedback from both the science community, the Europa Lander project presented a technically viable concept at the Mission Concept Review (MCR) in June of 2017.
Subsequent to the MCR, direction was given to undertake additional architectural trades that could reduce cost and complexity while optimizing science return. The charter was to "design-to-cost," with "science vs. cost trades expected." Multiple variations were considered from the MCR baseline, with the most significant gain achieved by adopting a Direct to Earth (DTE, i.e., eliminating the communications relay) architecture. DTE significantly reduced cost, and cost risk, while still providing high science return.

During the post-MCR effort, the science goals as per the SDT report were preserved, with the exception that the operational capability to achieve 'life detection' was relaxed to that of searching for biosignatures. Searching for biosignatures – which the SDT report defined as 'a feature or measurement interpreted as evidence of life' - has the benefit of maintaining the capability for life detection, while removing much of the operational burden. This change also served to protect Goals 2 and 3, which ensures that even in the absence of any biosignatures, the mission would still return detailed in situ science capable of revolutionizing our understanding of ocean worlds, and the surfaces of ice-covered bodies in our solar system.

114.06 Twinkle – a low-Earth orbit visible and infrared exoplanet spectroscopy observatory

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Abstract
Twinkle is a small, dedicated satellite that has been conceived to measure the atmospheric composition of exoplanets. This cost-effective spacecraft is being constructed on a short timescale in the UK and is planned for launch in early 2022. The satellite uses a high-heritage satellite platform and instrumentation built by a consortium of UK institutes. Twinkle will carry a 45cm telescope with two instruments (visible and near-IR spectrographs providing simultaneous wavelength coverage from 0.4 to 4.5μm with resolving power up to R~250) and will follow a Sun-synchronous low-Earth polar orbit. With the model taken to develop the Twinkle satellite, scientists worldwide will be able to directly use Twinkle to carry out their research.

Twinkle is being built to carry out cutting-edge science: Twinkle will use visible and infrared spectroscopy to analyse the chemical composition and weather of exoplanets in the Milky Way, including super-Earths (rocky planets 1-10 times the mass of Earth), Neptunes, sub-Neptunes and gas giants like Jupiter. It will also be capable of follow-up photometric observations of 1000+ exoplanets. Photometric measurements, taken simultaneously in the visible and the infrared bands, will allow orbital parameters of systems to be well-constrained and will enable precise measurements of transit timing variations, present in multi-planetary systems. The exoplanet targets observed by Twinkle will be composed of known exoplanets discovered by existing and upcoming ground- and space-based surveys (e.g. K2, GAIA, Cheops, TESS). Solar system objects ideally suited for spectroscopic and photometric observations with Twinkle include asteroids and comet comae, for which the broad wavelength range allows the observation of key hydration, organic and volatile features in their spectrum.

This presentation will provide a summary of the mission and the approach taken. For more information, visit www.twinkle-spacemission.co.uk.

114.07 The Dragonfly Titan Lander: Phase A Payload Developments

Ralph Lorenz
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Abstract
The Dragonfly mission concept, one of two undergoing Phase A study for possible flight in NASA's New Frontiers program, is a rotorcraft lander to explore Titan's rich prebiotic organic chemistry and habitability. Dragonfly offers the revolutionary ability to visit multiple sites on Titan's diverse surface,

tens to hundreds of kilometers apart. At any of these sites, Dragonfly's innovative instrument payload can answer key scientific questions in a range of disciplines including astrobiology, planetary evolution, geomorphology, meteorology, and geophysics. During the Phase A study, many aspects of the instrumentation have been advanced and demonstrated.
A rotary-percussive drill has been demonstrated to generate fine cuttings in a range of cryogenic ices and organic material. A pneumatic transfer system conveys these cuttings from redundant drills (one on each landing skid) to a mass spectrometer with laser-desorption and gas-chromatography capability. The pneumatic transfer ensures samples are maintained at near-ambient temperatures, with particular attention to avoiding cross-talk between samples.
Meteorological and geophysical instrumentation identified in previous Titan Flagship mission studies, is being qualified for Titan conditions. A new component is a solid-state hydrogen abundance sensor, to measure spatial and temporal variations of that gas as a possible tracer of geological or biological exchange with the surface.
Another novel element of the Dragonfly payload is a neutron-activated Gamma-Ray Spectrometer to quickly identify bulk elemental composition at landing sites. This investigation uses a High-Purity Germanium (HPGe) detector for superior spectral resolution. Previous mission applications have required active cryocoolers, but for Dragonfly the dense, cold Titan atmosphere can be used to passively hold the detector at temperature.
The Huygens probe demonstrated the potential for aerial and landed imaging of Titan using the ambient reddish lighting. Dragonfly will use LED arrays to provide both visible/near-IR color imaging of Titan materials, and ultraviolet illumination to characterize Titan organic sediments and hydrolysis products by fluorescence.

114.08 Overview of the Comet Astrobiology Exploration Sample Return (CAESAR) Mission
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Abstract
The Comet Astrobiology Exploration Sample Return (CAESAR) mission was recently selected by the NASA New Frontiers Program for Phase A study. If selected for flight, CAESAR will acquire and return to Earth surface material, including ice, dust, and organics, from the nucleus of comet 67P/Churyumov-Gerasimenko (67P). The CAESAR spacecraft will characterize the surface region sampled, preserve the collected sample in a pristine state, return evolved volatiles by capturing them in a separate gas reservoir. Once returned to Earth, the CAESAR team will conduct coordinated sample analyses that will link macroscopic properties of the comet with microscale mineralogy, chemistry, and isotopic studies of volatiles and solids. Most of the sample (≥75%) will be set aside for analysis by generations of scientists using continually advancing tools and methods, yielding an enduring scientific treasure that only sample return can provide.

Detailed laboratory analyses of the sample from 67P will trace the history of volatile reservoirs, delineate the chemical pathways that led from simple interstellar species to complex molecules, constrain the evolution of the comet, and evaluate the role of comets in delivering water and prebiotic organics to the early Earth. This presentation will provide an overview of the CAESAR mission goals, strategy, and design.

114.09 SNAP: Small Next-generation Atmospheric Probe Concept

Kunio M. Sayanagi[1], Robert A. Dillman[2], David Atkinson[3], Jing Li[4], Sarag Saikia[5], Amy Simon[6], Thomas Spilker[7], Michael Wong[8], Drew Hope[2], Archit Arora[5], Stephen C. Bowen[2], Stephen J. Horan[2], David G. Goggin[2], Samantha I. Infeld[2], John P. Leckey[2], Timothy E. Marvel[2], Ryan M. McCabe[1], Anish M. Parikh[2], David J. Peterson[2], Stephanie J. Primeaux[2], Alexander D. Scammell[2], Kevin M. Somervill[2], Lawrence W. Taylor[2], Chris Thames[2], Hernani P. Tosoc[2], Loc D. Tran[2]
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Abstract
We present a concept for a small, atmospheric probe that could be flexibly added to future missions to a giant planet as a secondary payload, which we call the Small Next-generation Atmospheric Probe (SNAP). SNAP's main scientific objectives are to determine the vertical distribution of clouds and cloud-forming chemical species, thermal stratification, and wind speed as a function of depth. As a case study, we present the advantages, cost and risk of adding SNAP to the future Uranus Orbiter and Probe flagship mission; in combination with the mission's main probe, SNAP would perform atmospheric in-situ measurements at a second location, and thus enable and enhance the scientific objectives recommended by the 2013 Planetary Science Decadal Survey and the 2014 NASA Science Plan to determine atmospheric spatial variabilities.

Out study demonstrates that the science objectives can be achieved with a 30-kg entry probe, 0.5m in diameter (less than half the size of the Galileo probe) that reaches 5-bar pressure-altitude and returns data to Earth via the carrier spacecraft. As the baseline instruments, the probe will carry an Atmospheric Structure Instrument (ASI) that measures the temperature, pressure and acceleration, a carbon nanotube-based NanoChem atmospheric composition sensor, and an Ultra-Stable Oscillator (USO) to conduct a Doppler Wind Experiment (DWE). We also catalog promising technologies currently under development that will strengthen small atmospheric entry probe missions in the future. The cost estimate for such a mission is about $80 Million (in FY18 dollars), including 30 percent reserve. The current estimate for the total atmospheric entry mass is 20.5 kg. The total mass including a 30 percent mass-growth allowance is 26.6 kg, which leaves 13 percent margin in our 30 kg target design. With the 30 kg design target (accounting for the 30 percent mass-growth allowance and 13 percent mass margin), the TPS mass fraction is 21 percent, and the instrument mass fraction is 19 percent.

114.10 Science with EnVision: understanding why our most Earth-like neighbor is so different

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Abstract
Why our most Earth-like neighbor is so different ? Venus should be the most Earth-like of our planetary neighbors: its size, bulk composition and distance from the Sun are similar to those of Earth. Surprisingly

little is known about its past and current state, not even the basic sequence and timing of events that formed its dominant surface features. NASA's 1989–1994 Magellan mission provided a global image of the surface at 100 − 200 m resolution, comparable in coverage and resolution to that of Mars after the Viking missions in the 1970s. Magellan revealed an enigma: a relatively young surface, rich in apparent geological activity, but with a crater distribution indistinguishable from random.

Venus' primary outgassed atmosphere was probably similar to that of early Earth, with abundant water that would have been liquid under the fainter young Sun conditions. Did global composition, internal structure, and long term geodynamical evolution play an important part in their different evolutionary path, or were today's differences driven solely by the Earth's and Venus' distance from the Sun ? What lessons can be learned about the life story of terrestrial planets in general, in this era of discovery of Earth-mass exoplanets?

Following the primarily atmospheric focus of Venus Express, we proposed a new Venus orbiter mission named EnVision, selected for phase-A study in response to ESA's M5 call for Medium-size missions for its Science Program. EnVision will take a comprehensive look at our nearest planetary neighbor in unprecedented detail. The payload comprises a state-of-the-art S-band inSAR radar which will be able to return imagery at spatial resolutions of 1 - 30 m, and capable of measuring cm-scale deformation; this is complemented by subsurface radar, IR and UV spectrometers to map volcanic gases, and by geodetic investigations.

114.11 OLAF: Reducing the Barriers to PDS Archiving

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Abstract
For years, the Planetary Data System (PDS) has focused its archiving efforts on archiving mission data. A few years ago, Congress directed NASA to ensure the all publicly funded data, including that from individually funded projects, is made publicly available through PDS or another permanent archive.

To aid in this task, the Small Bodies Node (SBN) has put significant effort into reducing the barriers that exist to archiving, especially for individual researchers who have a single and focused research project (ie. non-mission data).

The PDS uses an archiving standard (PDS4) that greatly improves the long-term stability of a data set, allowing metadata to be searched and machine-parsed to aid future researchers to access the data. While the labels for PDS4 are machine-friendly, they are complex with extensive interconnections with PDS4 metadata, making them non-trivial to generate by hand, particularly for small projects which have a limited budget for archiving.

The Asteroid and Dust Subnode of the Small Bodies Node has developed a suite of tools to easily and efficiently archive data that comply with NASA's requirements. We have made major upgrades to the On-Line Archiving Facility (OLAF) to improve the user interface, making it a clear, focused and easy to use tool. This new system provides support for CSV and fixed-width tables, simple FITS images, documents, and very soon, generic 2D binary arrays (general images). With OLAF, a researcher can create a PDS4 archive package that is ready for submission, often in only a few days or even an afternoon.

https://olaf.psi.edu

114.12 PDS4 Dictionaries as Quality Assurance Tools

Anne Raugh[1], John S. Hughes[2]
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Abstract

PDS4 "dictionaries" are, in fact, definitions of namespaces within the PDS4 Information Model (IM). The division of the IM into namespaces facilitates independent development of metadata models for specific disciplines. So, for example, the "core" namespace defines the metadata common across the entire archive, including data structures, identification, provenance, and so on. The "geometry" namespace defines metadata related to observational geometry. The "spectral" namespace defines metadata for spectroscopic observational parameters, and so on.

These namespaces, expressed as XML schemas, include not only English definitions of metadata terms, but organizational structures and validation constraints for values appearing in labels based on those dictionary schemas. The validation constraints enforced vary from the simple "Must be present"-type constraint, up through fairly sophisticated constraints that ensure consistency in cross-referencing and metadata selection ("If this datum has this value, then that datum must have that unit of measure," for example).

PDS uses these dictionary schemas to achive several quality assurance goals. First, the structures defined in the discipline dictionaries provide templates to guide non-specialist users in providing complete metadata for the discipline. Second, the structural validation constraints ensure that details like units of measure or epoch of coordinate are not inadvertently omitted. And finally, higher-level validation constraints are coded to ensure that, for example, units of measure are used consistently (i.e., spectroscopic units do not change unexpectedly from wavelength to frequency).

Further, as the same PDS4 dictionaries are used by all data providers with relevant metadata to document, the schematic enforcement helps to ensure both completeness and a reasonable degree of consistency in metadata across disparate sources.

Taken together, the PDS4 discipline dictionaries and their use in development and, in particular, validation of candidate archive data sets provide a high degree of quality assurance both for the content of a particular submission, and for consistency in description across the archive.

114.13 The Keck Observatory Twilight Observing Program

Carlos Alvarez[1], Edward Molter[2], Shui Kwok[1], Katherine de Kleer[3], Randall Campbell[1], Imke de Pater[2]
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Abstract

The W.M. Keck Observatory has implemented a cadence observing program for observations conducted during twilight - periods that are not otherwise utilized by the classically-scheduled observers due to limitations on the sky brightness. We initiated observations with NIRC2 NGS-AO during semester 18A

as a pilot program to monitor spatially resolved, temporal phenomena on Solar System objects. The observations are performed when the classically-scheduled observers on Keck II using optical spectrometers DEIMOS or KCWI surrender the twilight time, because the sky is too bright to obtain any useful data at visible wavelengths. The observations can be executed by the Keck Observing Assistants (OAs). To facilitate the work of the OAs, web-based planning tools, observation scripts, and instructions (https://www2.keck.hawaii.edu/inst/tda/TwilightZone.html) were developed by N. Molter, with contributions from K. de Kleer, in the framework of the Keck Visiting Scholars program. The twilight observing program has already proven very successful, with observations carried out on 26 different nights within the last year, leading to a science publication (Molter et al. 2018, submitted) and to a considerable gain on telescope time utilization.

Due to the success of the pilot twilight observing program, cadence twilight observing is included in our call for proposals starting in semester 18B. The twilight observing program is open to the four major W. M. Keck Observatory constituents; UC, CIT, NASA and UH. Each institution is limited to one program, where programs designed for a duration of 1 to 2 years have priority. The main guiding principles of this program are (1) voluntary participation by classically-scheduled PI and OA, and (2) execution of observations completely at the discretion of the classically-scheduled PI and OA.

Any PI proposing a cadence twilight observing program is required to develop the appropriate tools for the OAs to conduct the observations autonomously. Specifically, PIs are required to (1) develop target and observation managers, (2) develop, test and debug observation scripts, (3) employ simple instrument configurations, and (4) dissect the observations in short individual integrations (<5min).

114.14 Planetary Science at IRSA

Luisa Rebull, Vandana Desai, Steve Groom, Harry Teplitz
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Abstract

The NASA/IPAC Infrared Science Archive (IRSA) curates and maintains data from NASA's long wavelength missions. There is over a petabyte of data, including almost a trillion astronomical measurements at IRSA. This includes missions that targeted Solar System Objects (SSOs; e.g., Spitzer, Herschel, IRTF) as well as missions that serendipitously observed SSOs while conducting all-sky surveys (e.g., WISE and Planck). The newest SSO-rich data sets at IRSA come from the IRTF: SpeX data from 2016B and iSHELL data from 2017A are now publicly available, with more coming soon. SOFIA data will be included at IRSA starting in 2019. This poster outlines some of the tools that IRSA provides to make it easy to find SSO observations at IRSA. Additional demos can be found at the IPAC booth at the DPS, or on the IRSA YouTube feed.

114.15 Trident: Mission to a Candidate Ocean World

Louise Prockter[1], Karl L. Mitchell[2], David A. Bearden[2], William D. Smythe[2], William E. Frazier[2], Carly Howett[3]
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Abstract
Neptune's large moon Triton is one of a rare class of solar system bodies with a substantial atmosphere and active geology. Primarily composed of N_2, H_2O, CO_2, CH_4, and CO, Triton is subject to the tidal, radiolytic, and collisional environment of an icy satellite, however, its starting point and initial composition is that of a KBO Dwarf Planet. Capture into Neptunian orbit would have resulted in substantial heating early in Triton's history. Triton's high inclination results in significant obliquity, possibly sufficient to maintain an internal ocean. Confirmation of the presence of an ocean would establish Triton as an exotic and probably the most distant ocean world in the solar system, potentially expanding the habitable zone to 30 AU. Triton's typical surface age from cratering is probably <10 Ma, with an upper limit of <50 Ma, probably the youngest surface age of any planetary body in the solar system except Io. Candidate endogenic features include tectonic structures, cryovolcanic landforms, "cantaloupe terrain", and several particulate plumes and associated deposits. Post-Voyager, the preferred mechanism for Triton's plumes was an exogenic solar-driven solid-state greenhouse effect. However, this paradigm is being questioned in the context of plume observations on much smaller Enceladus and possibly Europa. Triton's atmosphere is thin (~1 Pa), but sufficiently substantial to be a major sink for volatiles, and sufficiently dynamic to play a role in movement of surface materials.
We have identified an optimized solution for a New Horizons-like flyby of Triton in 2038 which appears compatible with the Discovery 2019 opportunity. The science goals are: (1) Determine if Triton has a subsurface ocean or had one in recent history; (2) Understand the mechanisms by which Triton is resurfaced and what energy sources and sinks are involved; and (3) Investigate the diversity, production, and distribution of organic constituents on Triton's surface. The concept uses high heritage components and builds on the New Horizons concept of operation.
This research was carried out at Caltech-JPL under a contract from NASA. Predecisional, for planning and discussion only.

114.16 A compact, low-power planetary imager for radiometric LWIR and remote thermal imaging
Rebecca Schindhelm, David Osterman, Reuben Rohrschneider, Alfonso Amparan, Sandra Collins, Alia Ghandour, Patrick Kerrigan, Kevin McQuirk, Joe Necas, David Piqueira, Gretchen Reavis, Michael Veto, Robert Warden
Ball Aerospace, Boulder, Colorado, United States

Abstract
Ball Aerospace has developed a low size, weight and power instrument for radiometrically calibrated imaging in multiple Long Wave Infrared (LWIR) bands. Among the potential planetary applications of CIRiS are minerology, surface thermal mapping, heat flux measurement, detection of trace gases and particulates, and other atmospheric phenomena. The instrument, CIRiS (Compact Infrared Radiometer in Space) includes a versatile on-board calibration system that supports a range of modes optimized for different conditions, e.g., thermal mapping of terrain that is hot, cryogenic, or a combination of the two. CIRiS fits within a 20 cm x 20 cm x 10 cm volume and achieves high radiometric stability through multiple controlled thermal zones and other features. Power consumption with heaters off is < 8 Watts. Image format is 640 x 480, with capability to acquire frames at a rate up to 60 fps.

A multi-element filter over the FPA enables multi-spectral operation, including pushbroom scanning of the instrument field of view (FOV) in the different bands over the same planetary surface area. The present CIRiS implementation has three discrete bands in the range from 7.5 um to 13.75 um and an F/1.8 transmissive optical system with 9 deg x 12 deg FOV. A modular architecture facilitates changes to the filter and optical parameters.

The instrument utilizes a fold mirror to rotate the field of view, without varying reflection angles, between the science scene and one of three calibration scenes. The latter comprises views to two on-board blackbody sources and deep space. The capability to view deep space on command provides a useful temperature reference for cryogenic planetary surfaces. In -space selection of one of the on-board blackbody source temperatures is an additional optimization element, contributing to high radiometric absolute and relative accuracy and dynamic range.

CIRiS has been integrated to a 6U CubeSat spacecraft for LEO and is currently undergoing calibration and thermal testing in a thermalvac chamber. Demonstration is planned for 2019 in low earth orbit.

Monday, October 22, 2018
03:35 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

115 Meteoroids, Meteors, Meteorites, Dust and Solar Wind Posters
Chair(s): Peter Brown

115.01 The ability of NASA's Meteoroid Engineering Model to replicate *in situ* impact data
Althea Moorhead
NASA Marshall Space Flight Center, Huntsville, Alabama, United States

Abstract
Meteoroid environment models must describe the mass, directionality, velocity, and density distributions of meteoroids in order to correctly predict the rate at which meteoroids impact spacecraft. We present an updated version of NASA's Meteoroid Engineering Model (MEM) that better captures the correlation between directionality and velocity and incorporates a bulk density distribution. We compare the resulting model with the rate of large particle impacts seen on the Long Duration Exposure Facility (LDEF) and the Pegasus I and II satellites. The updated model shows closer agreement with these *in situ* data than previous versions of MEM.

115.02 Automation of Meteor Modeling Using a Genetic Algorithm
Ana M. Tarano[1, 2], Lorien Wheeler[4], Sigrid Close[1], Donovan Mathias[3]
[1]Aeronautics/Astronautics, Stanford University, San Francisco, California, United States, [2]Science and Technology Corp., Moffett Field, California, United States, [3]NASA Ames Research Center, Moffett Field, California, United States, [4]CSRA, Moffett Field, California, United States

Abstract
As a body enters the atmosphere, its mechanical energy transforms into heat, light, and ionization. However, these energy signatures do not provide direct measurements of the meteoroid's properties, which are critical to establish reliable asteroid impact risk assessments. Modelers thus attempt to reproduce observed events using theoretical, semi-analytic, or numerical models to enable inference of initial meteor characteristics, such as mass, diameter, bulk density, and breakup strength. Producing the best matches can be laborious because solutions are not typically unique and most models require trajectory information to constrain possible values. Therefore, we developed a genetic algorithm (GA) routine to automate the search of the best fitting curves and their corresponding modeling parameters to facilitate inference. We employ the GA in conjunction with a simplified version of the fragment-cloud model from Wheeler et al. (2017) to model the energy deposited by the entering body. Our objectives are to develop a robust approach that automates the matching of modeled curves to the observed ones, to thoroughly explore potential initial meteoroid properties, and systematically evaluate fit of a match.

We present an overview of the improved GA hyperparameters and examples of meteor properties inference from three case studies—Lost City, Benesov, and Chelyabinsk—to demonstrate its capabilities. For these three tests cases, the GA design consistently finds diameters and masses within 25% of other published values. Bulk density is not as readily constrained due to mass trade-offs but the best solutions are within 10% of previously used values, with the exception of Lost City. Estimates of the initial breakup

strength correspond to previously reported strength values leading to fragmentation events of the major flares. These results imply that the current methodology can enable meteoroid inference by providing quick meteor modeling capabilities for events with known entry angle and velocity.

115.03 Exploring the Chemical Diversity of Comets, Asteroids, and Interstellar Dust at 1 AU.

Mihaly Horanyi[1], Eberhard Gruen[1], Antal Juhasz[1], Sascha Kempf[1], Petr Pokorny[2, 3], Andrew Poppe[4], Neal J. Turner[5], Ralf Srama[6], Zoltan Sternovsky[1], Jamey Szalay[7], Diane H. Wooden[8], Tibor Balint[5]
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Abstract
Interplanetary and interstellar dust particles (IDP and ISD) continually bombard the Earth. They ablate in the atmosphere, and their trajectories change due to drag forces by the time ground based optical and/or radar observations characterize them. These particles carry valuable information about their parent bodies that can now be fully harvested by measurement in space using newly-developed in-situ instrumentation. Placing dust instruments onboard a near-Earth spacecraft can revolutionize our understanding of the composition of IDP, at 1 AU dominated by Jupiter Family Comet particles, and ISD. Deciphering the composition of interstellar, cometary, and asteroidal dust - successive generations of the planets' building blocks - offers an unparalleled opportunity to explore the origin and evolution of our Solar System. In addition to testing ideas about planet formation, these observations will enable: a) probing the large-scale structure of the heliosphere's magnetic fields through monitoring changes in the ISD flux over space and time; b) comparing our dust disk of IDPs to Zodiacal dust disks around other stars, to assess the distribution of comets and asteroids in other planetary systems; and c) identifying the composition cosmic matter ablating in our atmosphere each day.

Monday, October 22, 2018
03:35 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

116 Moon: Interior, Surface and Atmosphere Posters
Chair(s): David T. Blewett, David A. Minton

116.01 Ejecta Plume Detectability in the NMSU-NASA Marshall Space Flight Center LCROSS Observational Campaign using PCA Filtering
Payton L. Mueller[1], Emily L. Karls[1], Paul D. Strycker[1], Nancy J. Chanover[2]
[1]Concordia University Wisconsin, Mequon, Wisconsin, United States, [2]New Mexico State University, Las Cruces, New Mexico, United States

Abstract
On 9 October 2009, NASA's Lunar Crater Observation and Sensing Satellite (LCROSS) mission produced the collision of a kinetic impactor with the permanently shadowed Cabeus crater [1, 2]. Following impact, a spatially resolved plume was not detected from multiple Earth-based imaging cameras [3]. After image filtering utilizing Principal Component Analysis (PCA), the data from four Earth-based cameras revealed three plume detections and one non-detection [4-6]. The purpose of this extension of the LCROSS analysis is to inspect R-band video from the New Mexico State University (NMSU) 1.0 meter telescope and near-IR video from the Tortugas Mountain Observatory (TMO) 0.6 meter telescope for the presence of a plume. We utilized the same data reduction methodology as the four prior cameras [5, 6]. PCA breaks the videos into statistically independent contributions, termed principal components (PCs), which reveals the different sources of the temporal changes to the scene. Filtering out select PCs from the videos allows us to remove atmospheric seeing effects to search for plume signal within Cabeus crater. Preliminary analysis of the NMSU and TMO videos revealed non-detections. Factors leading to plume non-detectability could include ambient light scattering [7], the large lunar landscape field of view, or the analog to digital conversion (ADC) of the data with the use of 8-bit resolution. We explore the effects of ADC with and without gamma correction as a possible cause of the NMSU and TMO non-detections. We also investigate the effect of field of view on our PCA filtering technique. This work was supported by grant number NNX15AP92G. [1] Colaprete, A. *et al*. (2010) Science, 330, 463-468. [2] Schultz, P. H. *et al*. (2010) Science, 330, 468-472. [3] Heldmann, J. L. *et al*. (2012) SSRv, 167, 93-140. [4] Strycker, P. D. *et al*. (2013) Nat. Commun., 4:2620, doi:10.1038/ncomms3620. [5] Temme, R. L. *et al.*(2016) LPS XLVII, Abstract #1166. [6] Schotte, J. M.*et al*. (2017) LPS XLVIII, Abstract #1503. [7] Strycker, P. D. *et al*. (2017) AAS DPS #49, 417.14.

116.02 Investigating stratification of lunar regolith through modeling of the ground based detection of the LCROSS debris plume light curve
Kristen Luchsinger[1], Nancy J. Chanover[1], Paul D. Strycker[2], Charles Miller[1]
[1]Astronomy, New Mexico State University, Las Cruces, New Mexico, United States, [2]Concordia University Washington, Mequon, Wisconsin, United States

Abstract
The Lunar CRater Observation and Sensing Satellite (LCROSS) mission impacted a Centaur second stage rocket into Cabeus crater, a permanently shadowed crater near the southern pole of the Moon. This impact

produced a debris plume in which a shepherding spacecraft detected spectroscopic signs of water ice (Colaprete et al. 2010). Ground-based observations were also acquired in an international campaign to collect complementary data in support of the mission (Heldmann el al. 2012). A signal was detected in the V-band images from the Astrophysical Research Consortium 3.5 m telescope at Apache Point Observatory (APO) using a principal component analysis (Strycker et al. 2013).

In order to match the observed plume light curve, Strycker et al. (2013) generated a series of ballistic plume models with a range of initial conditions with which they were able to identify constraints on the shape and mass of the plume. We present here a new analysis of the ground-based observations wherein we fit the modeled light curves to multiple datasets simultaneously. We have two new detections of the LCROSS plume taken with two cameras at the Magdalena Ridge Observatory (MRO) (Strycker et al. 2017). Both of the light curves were extracted using an improved principal component analysis that allows for higher signal to noise at finer spatial resolution.

The original Strycker et al. (2013) models imposed strict constraints on the initial velocities of plume particles in order to match observations. Newer results (Lucey et al. 2014) instead support an albedo variation of the lunar regolith particles with depth, suggestive of a stratified ice content in permanently shadowed regions. We will fit our model to the data using this stratified lunar sediment. This model will therefore provide information about the distribution of water ice in permanently shadowed regions on the Moon.

This work was supported by the Lunar Data Analysis Program through grant number NNX15AP92G.

References:
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Heldmann, J. L. et al. (2012) SSRv, 167, 93-140.
Lucey, P. G. et al. (2014) J. Geophys. Res. Planets, 119, 1665–1679.
Strycker, P. D. et al. (2013) Nat. Commun., 4:2620.
Strycker, P. D. et al. (2017) AAS DPS #49, 417.14.

116.03 Deriving Lifetimes of Lunar Ejecta Constituents Using Remote Sensing Data: A Model for Lunar Erosion and Regolith Overturn.

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Abstract

Impact craters on the lunar surface exhibit wide variations in morphology, roughness, and optical maturity. In radar and thermal infrared (TIR) images, some lunar impact craters appear bright, indicating significant roughness in the surface and near-surface layers of the lunar regolith. Although prior work has shown that these elevated data signatures fade with time, the exact rates at which the geologic constituents represented in each data set change with time remain ill-constrained. In this study, we seek to quantify the rates at which the various constituents of ejecta blankets erode with time. We accomplish this goal by characterizing the ejecta of 162 small impact craters (~1.5 to 5.0 km in diameter) on the lunar maria using thermal infrared and S-band (12.6 cm) radar data from the Lunar Reconnaissance Orbiter (LRO) Diviner Radiometer instrument and Miniature Radar Frequency (Mini-RF) instrument, and associating these two data sets with inferred age dates modelled from topography by Fassett and Thomson (2014) for all craters in our study. The radar product used to assess the near-surface roughness of crater ejecta in this study is Mini-RF circular polarization ratio data (CPR). CPR is defined as the ratio of backscatter power reflected in the same sense of circular (SC) polarization as that transmitted over the echo in the opposite sense of circular (OC) polarization. CPR is useful in the analysis of lunar regolith as it is sensitive to rocks in the lunar near-surface and surface regolith. Surface rock abundance (RA) values were derived from Diviner data by Bandfield et al. (2011) and are a measure of the fraction of rocks exposed at the lunar surface. We find that RA and CPR values associated with craters in our study remain elevated above background values for the lifetime of the lunar maria in some cases. Our results indicate that rates of regolith overturn on the Moon may be slower than rates of surface rock degradation, and meter-sized rocks on the lunar maria may remain present at the lunar surface for timescales on the order of 10^8-10^9 years.

116.04 Comparison of FeO and TiO_2 abundance with 6-meter wavelength radar mapping of the Moon

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Abstract

Low-frequency radio waves can penetrate the lunar surface and provide novel insights to subsurface structures invisible at high-frequency radar and optical wavelengths. Observing beneath the lunar regolith provides a means to view the history of lunar geologic stratigraphy, transition zones and buried features. Recent range-Doppler images of the Moon made with the Jicamarca Radio Observatory 49.92 MHz radar are used to map radar backscatter of the lunar nearside up to a subsurface depth of approximately 1 km. The images have approximately 10 km resolution in range and 20 km resolution in Doppler, allowing many large scale features, including maria, terrae, and impact craters to be identified. Radar mapping is done with polarizations opposite to and matched to the expected specular return from the surface. Strong return is observed from relatively new impact craters with large breccia and shallow regolith. Terrae regions with less lossy surface material also appear brighter. We present a comparison of these 6-meter radar images with lunar maps of FeO abundance from Clementine UltraViolet/Visible (UVVIS) data and TiO_2 abundance from LROC WAC. By comparing lossy regions from maps of low-frequency radar with maps of surface FeO and TiO_2composition, we can pinpoint areas of cryptomare, or mare material obscured from visible lunar observation. These areas of low radar backscatter return correspond to basaltic mare material buried beneath a layer of non-feldspathic surface material, and can be evaluated as deposits of older volcanic material resurfaced by subsequent impacts, newer volcanic flows, or both. Two regions of particular interest are the Mare Frigoris region in the northern hemisphere and the site of an old impact in the Schiller-Zucchius basin. Both of these regions have an optical appearance of Terrae composition, with high FeO abundance and relatively low TiO_2 abundance, suggesting a composition of mixed Terrae and basalt from lava flows distinct from the TiO_2-rich basalts forming the surrounding mare. The low 6-meter radar return in these regions confirms the presence of buried cryptomare, which we propose is remnant from very old lunar volcanic activity.

116.05 Cometary Volatiles in Micro Cold Traps on the Moon

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Abstract

Volatiles are key tracers of interior outgassing and exogenic delivery of materials to airless bodies. On the Moon, vast regions of perennial shadow at the poles are known to be efficient cold traps for water molecules. At temperatures < 110 K, the sublimation timescale for water ice is ~1 Gyr. Previous work has

shown that a significant fraction of volatile materials delivered to the Moon by comets may be ballistically transported to the polar regions. However, it has remained unclear how much of the lunar surface area is sufficiently cold to trap highly volatile compounds such as CO_2, CH_4, CO, and NH_3, whose sublimation temperatures are much lower than that of water.

Here, we investigate whether singly and multiply shadowed surfaces on small scales create "micro cold traps" capable of sequestering an array of cometary volatiles on the Moon. To evaluate this hypothesis, we used data from the Lunar Reconnaissance Orbiter (LRO), the Lunar Crater Observation and Sensing Satellite (LCROSS), and thermal models. LRO's Diviner instrument determines temperatures down to < 30 K at a range of spatial scales by measuring thermal emission in 7 infrared spectral bands from ~8 to 400 μm. Although Diviner's typical detector footprint is ~250 m, we extract sub-pixel temperature distributions by fitting brightness temperatures in multiple spectral bands.

Our results indicate that a significant fraction of surface and subsurface area in the Moon's polar regions remains cold enough to trap cometary volatiles with sublimation temperatures < 100 K. These findings are consistent with the detection of several common cometary species in the LCROSS ejecta plume, and the possible detection of condensed CO_2 by LRO's Lyman-alpha Mapping Project. We find that the most common length scale by number for cold traps on the Moon is ~1 - 10 cm. Ice-filled micro cold traps may be subsequently buried by other nearby impacts. We therefore suggest that the lunar surface and subsurface at high latitudes is peppered with cm-scale reservoirs, each holding a unique record of cometary influx to the Earth-Moon system.

116.06 Early Dynamics of the Moon's Core

Matija Cuk[1], Douglas Hamilton[2], Sarah Stewart[3]
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Abstract
The Moon has a small molten iron core (Williams et al. 2006). Remanent magnetization in lunar rocks likely derives from a past lunar dynamo (Wieczorek 2018 and references therein), which may have been powered by differential precession between the mantle and the core. The rotations of the lunar mantle and core were largely decoupled for much of lunar history, with a large mutual offset during the Cassini State Transition (Meyer and Wisdom, 2011). It is likely that the past work underestimated lunar obliquities, and therefore core offsets, during early lunar history (Cuk et al. 2016). Here we investigate the dynamics of the lunar core and mantle using a Lie-Poisson numerical integrator (Touma and Wisdom 2001) which includes interactions between triaxial core and mantle, as well as all gravitational and tidal effects included in the model of Cuk et al. (2016). Since we assume a rigid triaxial mantle, this model is applicable to the Moon only once it has acquired its current shape, which probably happened before the Moon reached 25 Earth radii. While some details of the core dynamics depend on our assumptions about the shape of the lunar core-mantle boundary, we can report some robust preliminary findings. The presence of the core does not change significantly the evolutionary scenario of Cuk et al. (2016). The core and mantle are indeed decoupled, with the core having a much smaller obliquity to the ecliptic than the mantle for almost all of the lunar history. The core was largely in an equivalent of Cassini State 2, with the vernal equinoxes (wrt the ecliptic) of the core and the mantle being anti-aligned. The core-mantle spin axis offset has been very large during the Moon's first billion years (this is true both in canonical and high-inclination tidal evolution), causing the lunar core to be sub-synchronous. If the ancient lunar magnetic dipole was rotating around the core axis that was inclined to the Moon's spin axis, then the magnetic poles would move across the lunar surface as the mantle rotates independently. This relative

motion would dilute the average dipole field over much of the lunar surface, and would would restrict meaningful average fields to low lunar latitudes.

116.07 Optical analog studies to improve understanding of radar measurements of icy regoliths

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Abstract
Icy surfaces (e.g., Mars polar caps, icy satellites) exhibit high radar backscatter and high circular polarization ratios (CPR). CPR refers to the power received in the same sense of circular polarization (SC) that was transmitted divided by the power received in the opposite sense (OC), CPR = SC/OC. The generally accepted explanation for these unusual radar properties is volume scattering within a weakly absorbing medium in which scatterers with sizes near that of the wavelength of the radar are embedded. Ice does not strongly absorb at radar wavelengths, and voids, cracks, density variations, or rocks could serve as scatterers. A wavefront impinging upon such a medium undergoes multiple scattering, and rays traversing opposite paths will combine coherently upon reemerging from the surface. This scattering mechanism preferentially returns the incident polarization state, producing an enhancement in CPR. The coherent effect is found within a narrow peak centered on the direct backscatter direction (zero phase angle), and is referred to as CBOE (coherent backscatter opposition effect).

Hapke and Blewett (1991, *Nature*) reported measurements of CPR vs. phase angle for an aqueous suspension of microbeads illuminated by 633-nm laser light. The size of the suspended beads was similar to the laser wavelength; hence the experiment constituted an optical-wavelength analog to radar sensing of an icy regolith. They found an increase in CPR with decreasing phase angle, indicating that CBOE was taking place, and supporting the CBOE explanation for the radar properties of icy surfaces. However, many questions regarding the ice deposits remain, particularly potential deposits in the polar regions of the Moon and Mercury: little is known about the thickness of the ice, or the abundance and size of the embedded scatterers. We have undertaken a project that will expand upon the parameter space of the original 1991 study. In this presentation we will describe our goniometer apparatus at York University used for making small-phase-angle measurements of CPR, and report on initial results for dry aluminum oxide powders that have been use as standards for previous phase and polarimetric studies (e.g., Nelson et al., 2002, 2018).

116.08 Simulation Studies of Lunar Sodium Tail and The *Lunar Ring* Phenomenon

Dong Wook Lee, Sang J. Kim
School of Space Research, Kyung-Hee university, Yongin, Gyeonggi-do, Korea (the Republic of)

Abstract
Physical properties of the lunar sodium tail are investigated by using Monte-Carlo simulations. The lunar sodium tail and its bright spot are formed at the anti-lunar point around new moon phase by escaping sodium from the lunar exosphere and subsequent gravitational focusing effect by the Earth. Using several major lunar sodium sources including solar wind sputtering, photon stimulated desorption, and micrometeoroid impact, we have tried to reproduce the velocity distributions of the lunar sodium tail and the bright spots observed by Mierkiewicz et al. (2006).
The Monte-Carlo simulations include the gravitational effects of the Moon, Earth, and the Sun, variable solar radiation pressure, variable g-factor, variable ionization lifetime of sodium depending on solar

activities, and the Earth's umbra and pen-umbra effects.
We predict an interesting phenomenon, the 'Lunar Ring' of the lunar sodium tail, which can form only when the total solar eclipse occurs. We will present preliminary results.

116.09 LEMS: Lunar Environment Monitoring Station

Mehdi Benna[1, 2], Charles Malespin[1], Eric Raaen[1], Menelaos Sarantos[1], Nicholas Schmerr[3], Lenore Dai[4], Zuofeng Zhao[4]
[1]NASA Goddard Space Flight Center, Greenbelt, Maryland, United States, [2]University of Maryland Baltimore County, Baltimore, Maryland, United States, [3]University of Maryland College Park, College Park, Maryland, United States, [4]Arizona State University, Tempe, Arizona, United States

Abstract
The planetary community has recognized that solar system exploration must fill gaps in our knowledge concerning surface boundary exospheres, the most commonly found type of atmosphere in the solar system (surrounding e.g., asteroids, Mercury, and numerous moons). Likewise, planetary interiors remain largely unexplored, and seismology from Apollo gave us our first glimpse of the inner workings of the Moon. At the Moon, these tasks are of higher priority in light of the imminent restart of manned and unmanned lunar exploration for both scientific and commercial purposes. A strategy of long-term in-situ monitoring of the lunar exosphere is important for our understanding of the dynamics of surface boundary exospheres in general, and for determining the response of the lunar environment at various time scales to injections of exotic materials from natural or manmade events. This in-situ, long-term approach readily lends itself to concurrently monitoring the seismicity of the Moon as well.

Here we present the concept of a compact, autonomous, and self-sustaining mass spectrometer that will enable the long-term, in-situ, monitoring of the lunar exosphere. The Lunar Environment Monitoring Station (LEMS) will be capable of collecting daily in-situ measurements of exospheric composition for a nominal duration of 2 years from its deployment on the surface of the Moon. Additionally, the instrument package will accommodate a miniature seismometer that will be capable of continuously monitoring the Moon's seismic activities in order to constrain the structure of the lunar interior. LEMS is an opportunistic investigation that can be deployed as a secondary payload from manned or robotic, commercial or scientific missions. Once delivered and deployed on the lunar surface, it will require no additional support from the primary mission.

116.10
High-Spectral Resolution Observations of the Lunar Potassium Atmosphere

Sara Rosborough[1, 2], Ronald J. Oliversen[2], Sarena D. Robertson[4, 5], Nicholas J. Derr[3, 6], Dona C. Kuruppuaratchi[5], Edwin J. Mierkiewicz[5], Menelaos Sarantos[2], Margaret A. Gallant[5]
[1]University of Maryland, College Park, Maryland, United States, [2]NASA GSFC, Greenbelt, Maryland, United States, [3]Harvard University, Cambridge, Massachusetts, United States, [4]United States Navy, Charleston, South Carolina, United States, [5]Embry-Riddle Aeronautical University, Daytona Beach, Florida, United States, [6]University of Wisconsin, Madison, Wisconsin, United States

Abstract
We observed potassium D1 (7698.9646 Å) emissions off the sunlit limb of the moon, providing the first potassium line profile measurements of the lunar exosphere. These synoptic, high-spectral resolution (R = 180,000 or 1.7 km/s) observations were obtained using a dual etalon Fabry-Perot spectrometer with a 180" field of view, in order to constrain atmospheric source and sink processes and their variations with

lunar phase and seasonal cycle. Data were collected at select locations off the sunlit limb of the moon from January 2014 through December 2014 from the National Solar Observatory (NSO) McMath-Pierce Solar Telescope (MMP) at Kitt Peak, Arizona and were reduced with automated processes using Python, MATLAB, and VoigtFit. Data from January to April 2014 coincide with the science phase of the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission. We present and compare these results to ground-based sodium observations by Kuruppuaratchi et al. 2018. The potassium emission intensity decreases by a factor of ~3 during the waxing lunar phase (83° to 19°). The emission increases by a similar amount during the waning phase (22° to 88°) but is more variable. The intensity has an asymmetrical distribution around the moon with the brightest emission at the limb near Aristarchus. Emission in the polar regions was fainter near the southern limb, close to Tycho, compared to the northern limb, near Plato. Aristarchus and Plato are in or near the KREEP (Potassium, Rare-Earth Element, and Phosphorous) region where potassium is more abundant on the surface. The intensity at phase angles less than 20° (i.e., full moon) are lost in the increasing continuum of scattered moonlight. The line width reflects the potassium velocity distribution and, therefore, the effective temperature. The temperature during the waxing phase is about 2700 K with an increasing trend approaching full moon while the waning phase is lower at about 1700 K. However, the range of inferred temperatures is greater during the waxing phase compared to the waning phase.

Monday, October 22, 2018
03:35 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

117 Planetary Rings Posters
Chair(s): Rebecca Harbison

117.01 An Evolving Dusty RInglet in Saturn's Rings
Bill Bridges
Physics, University of Idaho, Moscow, Idaho, United States

Abstract
The ringlet designated as R/2006 S3, also known as the "Charming Ringlet", is located within the Laplace Gap of the Cassini Division. It is a dusty, low-optical-depth ringlet that sits at around 119,940 km from the center of Saturn. Prior to April of 2013, the ringlet had a simple shape that can be fit with a simple Lorentzian peak with an optical peak of 10^{-3}. Observations after this point reveal that the overall shape of the ringlet changed such that a shelf appeared on the inner edge of the ringlet. The shelf has a typical optical depth of 10^{-4} and is more easily visible when the phase angle is above 100°, consistent with it being dust-rich like the main ringlet. Further investigation into this changing feature could provide some new understanding of how material in this dusty ringlet is confined and maintained.

117.02 The Structure of Saturn's B Ring from CIRS High-Resolution Thermal Scans
Shawn M. Brooks[1], Linda J. Spilker[1], Mark R. Showalter[2], Stuart H. Pilorz[2], Scott G. Edgington[1]
[1]JPL/Caltech, Pasadena, California, United States, [2]SETI Institute, Mountain View, California, United States

Abstract
Cassini's 126th flyby of Titan on 29 November 2016, sent the spacecraft on a trajectory carrying it within 10,000 kilometers of Saturn's F ring before the encounter on 22 April 2017 dropped the spacecraft's periapse location between Saturn's cloud tops and the planet's D ring. This geometry has proven beneficial for high-resolution rings studies because of Cassini's proximity to the rings and the spacecraft's high elevation angle above the rings, which reduces the foreshortening that tends to degrade resolution in the ring plane.

We will report on high spatial resolution observations made by Cassini's Composite Infrared Spectrometer of Saturn's main rings, particularly the B ring, during the F-ring and proximal orbits. CIRS' three infrared detectors cover a combined spectral range of 10 to 1400 cm^{-1} (1 mm down to 7 μm). We use data from Focal Plane 1, which covers the 10 to 600 cm^{-1} range (1 mm to 16 μm) (Flasar *et al.* 2004). FP1's wavelength range makes it well-suited to sensing thermal emission from objects at temperatures typical of Saturn's rings.

Correlating temperatures retrieved from scans of the lit and unlit rings with ring optical depth suggests differences in ring structure or particle transport between the lit and unlit rings in different regions of the B ring. The lit/unlit side temperature differential varies from 2-3 K in the most optically thin sections of the B ring's B1 region up to 20 K in the optically thick portions of the B2 region of the B ring. Moreover, temperatures on the unlit side of the B ring's B3 region vary by 5-6 K and are correlated with slight

optical depth variations. No such correlated temperature variations are observed on the lit side of the B3 region. Hedman *et al.* (2013) report unusual photometric properties in this region of the B ring. Ferrari *et al.* (2013) and Pilorz *et al.*(2015) published thorough analyses of the thermal throughput across this optically thick ring. We will discuss these CIRS observations and their implications in the context of such work.

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA.

117.03 Post-Cassini update on the D ring's resonant structures
Robert Chancia, Matthew Hedman
Physics, University of Idaho, Moscow, Idaho, United States

Abstract
Observations from early in the Cassini mission, revealed that Saturn's faint D ring contains several azimuthal brightness variations that can be explained by resonances with forcing frequencies near the planet's rotation rate. An assortment of structures with azimuthal wavenumber m=2 span the region between 70,000 and 73,000 km. No strong satellite resonances fall in this region, but the amplitude and motions of the fractional brightness variations across some of these structures indicate that they are being strongly perturbed by something moving at roughly the same rate as Saturn's winds. As the mission progressed we realized that the radial position of some of these structures can vary between observations only a few years apart. We've found compelling evidence that some of the more dynamic structures can be associated with the varying rotational modulation of Saturn's Kilometric Radiation and other periodic magnetospheric phenomena. The few structures that remain nearly constant over the course of the mission may be attributed to resonances with mass anomalies rotating in the range of Saturn's wind speeds.

117.04 Sizes of Particles, Clumps, and Holes in Saturn's Rings from Cassini UVIS Stellar Occultation Statistics
Stephanie Eckert[1], Joshua Colwell[1], Raechel Green[1], Jaida Payne-Avary[1], Larry Esposito[2]
[1]Physics - Planetary Sciences Track, University of Central Florida, Winter Park, Florida, United States, [2]University of Colorado Boulder, Boulder, Colorado, United States

Abstract
The high speed photometer (HSP) aboard Cassini's Ultraviolet Imaging Spectrograph (UVIS) observed more than 170 ring stellar occultations between 2004 and 2017. Because photon counts are described by Poisson statistics, we expect our data to exhibit a variance equal to the mean when there is no ring material obstructing the view of the instrument. Large ring particles obstruct the field of view in an irregular manner, causing an excess variance related to the size of the largest particles or clumps in the rings. Showalter and Nicholson (1990, Icarus, 87, 285) analyzed the Voyager 2 stellar occultation of dScorpii to obtain an effective particle size across the rings except for the densest regions of the B ring. Colwell et al. (2018, Icarus, 300, 150) analyzed the excess variance across the rings in two UVIS occultations. Here we remove secular trends in the data to allow for a determination of the excess variance due to finite particle or clump sizes within regions where there is structure in the rings, such as within density waves and at the edges of ringlets and plateaus. We determine a best fit by testing varying degrees of polynomial fits to the data. After removing the trend due to underlying ring structure we will explore variations in particle or clump size across small spatial scales that were not included in Colwell et

al. (2018). In particular, this trend removal allows for examination of the particle properties within density wave troughs, within the Mimas 5:3 bending wave, and across the relatively broad edges of C ring plateaus where Colwell et al. (2018) found transitions in particle sizes. Examination of the next higher moment of the data, the skewness, provides information on the distribution of localized holes, nicknamed “ghosts” (Baillie et al. 2012, Astron. J., 145, 171), in the rings which are necessary to explain the skewness observed in the C ring. We will present results from the Cassini data with comparisons to Monte Carlo simulations of the distribution of ring particle sizes and holes in the rings.

117.05 The Dynamics of the Small Satellites and the Ring System of Neptune
Silvia M. Giuliatti-Winter, Daniel Gaslac, Gustavo Madeira, Rafael Sfair
Mathematics, UNESP, Guaratinguetá, São Paulo, Brazil

Abstract
The Neptune system has small satellites located nearby its ring system. By using frequency analysis, we determined the stability of the small satellites and characterize, through diffusion maps, the dynamical behaviour of a wide region of geometric phase space surrounding these satellites and the rings. Our preliminary results showed that the Le Verrier and Lassel rings are close to a chaotic region due to the satellite Despina. The Adams ring, the external ring close to the satellite Galatea, has several arcs which need a confinement mechanism to contain their destruction against dissipative forces and collisions. We also present the results of a set of numerical simulations of the system formed by Neptune, the satellite Galatea, dust ring particles and hypothetical coorbital satellites. We find that the arcs Couragé and Liberté have a very short lifetime, about 30 years, while the arcs Fraternité and Egalité live longer, ~ 50 years. These results corroborated the recent data obtained by the telescopes, which show that the arcs Couragé and Liberté are disappearing. An analysis of the dust production due to collisions between interplanetary debris on the surface of the coorbital satellites ruled out the hypothesis that small satellites located close to or in an arc structure could be its source.

117.06
Radial Distribution of Textures in Saturn’s Main Rings
Jesse Modesto[1, 2], Matthew Tiscareno[2]
[1]Department of Physics and Astrononmy, California State Polytechnic University, Pomona, Artesia, California, United States, [2]SETI Institute, Mountain View, California, United States

Abstract
During its Ring Grazing Orbits (RGO) and Grand Finale (GF), the Cassini spacecraft passed very close to the outer and inner edges (respectively) of Saturn’s main rings. During these maneuvers, the Cassini ISS camera executed a series of very high-resolution images of the main rings [1]. While hints of ring textures (clumpy, feathery, streaky, etc.) had been previously seen in some anomalously high-resolution images (e.g., [2]), the RGO/GF images constitute a complete radial survey for these structures, revealing that in many locations they occur in sharply defined radial bands that are not obviously correlated with other ring features.

There is growing evidence that some of the more eye-catching sharply-bounded features in the main rings, such as the A ring inner edge and the C ring plateaux, are not due to changes in surface mass density (e.g., [3,4]) and thus must be due to variations in particle properties of some kind. Composition, particle size, and regolith character are candidates for various observed effects, though it is not yet clear why ring particles should be strongly sorted according to these properties. The strongly banded ring

textures described here provide another window onto this process. We speculate that they may be due to different ways in which ring particles bounce off each other when they collide, and thus might be correlated to regolith character. Be that as it may, further research is greatly needed.

We will present a "geological map" of the main rings, in terms of the textures observed in the RGO/GF images, and we will discuss the implications for ring particle character and interactions.

References: [1] Tiscareno *et al.* 2018, Science, submitted. [2] Porco *et al.* 2005, Science 307, 1226. [3] Tiscareno *et al.* 2013, Icarus 224, 201. [4] Hedman and Nicholson 2013, Astron. J. 146, 12.

117.07 Photometry of Giant Propellers in Saturn's Rings from Close-range Cassini Images

Jakayla Robinson[1], Matthew Tiscareno[2]
[1]University of Alabama at Birmingham, Birmingham, Alabama, United States, [2]Carl Sagan Center for the Study of Life in the Universe, SETI Institute, Mountain View, California, United States

Abstract
"Propellers" are eponymously-shaped disturbances in Saturn's rings centered on embedded moons (see [1] and references therein). In particular, a handful of "giant propellers," created by km-size embedded moons [2], have predominantly keplerian orbits that have been shown to contain clear but enigmatic patterns of change as they have been tracked for over 10 years by frequent Cassini images [1].

During its Ring Grazing Orbits (RGO) and Grand Finale (GF), the Cassini spacecraft passed very close to the outer and inner edges (respectively) of Saturn's main rings. During these maneuvers, the Cassini ISS camera executed a series of very high-resolution images of the main rings [3]. Among other priority science targets, several giant propellers were imaged at resolutions better than 0.4 km/pixel and high S/N. The propeller "Santos-Dumont" was imaged in this way during a single Cassini pass on both the lit and unlit sides of the rings (see images at https://photojournal.jpl.nasa.gov/catalog/PIA21433), revealing detailed structure of the propeller-disturbance in two very different photometric regimes [3].

The photometry of propellers has previously been found difficult to interpret [4,5]. We use the lit/unlit pair of Santos-Dumont images as a "Rosetta Stone" to determine how the propeller's photometry follows or deviates from classic Chandrasekhar theory.

We will present details and will discuss the implications.

References: [1] Spahn *et al.* 2018, in Tiscareno and Murray, eds., *Planetary Ring Systems* (Cambridge Univ. Press), 157. [2] Tiscareno *et al.* 2010, ApJL **718**, L92. [3] Tiscareno *et al.* 2018, Science, submitted. [4] Tiscareno *et al.* 2008, AJ **135**, 1. [5] Tiscareno *et al.* 2010. AJ **139,** 492.

Monday, October 22, 2018
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Cumberland Concourse and Ballroom E (Knoxville Convention Center)

118 Venus Posters
Chair(s): Chris Parkinson, Mark Bullock

118.01 Reconciling Models for the Centimeter-Wavelength and Millimeter-Wavelength Sulfuric Acid Vapor Absorption for Future Radio Sounding at Venus
Alexander Akins, Paul Steffes
Georgia Institute of Technology, Atlanta, Georgia, United States

Abstract
Retrievals of temperature and neutral constituent abundance profiles from passive microwave radiometry and radio occultation measurements of planetary atmospheres require accurate models of microwave absorption for the relevant constituents. At Venus, these constituents include carbon dioxide, nitrogen, sulfur dioxide, and sulfuric acid vapor. Accurate models of microwave absorption for carbon dioxide and nitrogen have been developed with specific application to Venus (Ho, Kaufman, and Thaddeus *JGR* 71, 1966), and recent measurements of sulfur dioxide absorption at millimeter wavelengths (Bellotti and Steffes, *Icarus* 254, 2015) and under extreme conditions relevant to Venus (Steffes, et al., *Icarus* 245, 2015) have confirmed the validity of a lineshape model (Fahd and Steffes, *Icarus* 97, 1992). We present the results of recent measurements of sulfuric acid vapor absorption at millimeter wavelengths, extending upon work done at centimeter wavelengths (Kolodner and Steffes, *Icarus* 132, 1998). Measurements at millimeter wavelengths support the use of a lineshape model, in stark contrast to the results at centimeter wavelengths. We explore different mechanisms that can be introduced to develop a unified model of sulfuric acid vapor absorption. Laboratory measurements of absorption at Ka band are underway to characterize the transition region between centimeter and millimeter wavelengths. These measurements have direct application to future radio occultation measurements at Venus by ESA's *EnVision* or microwave radiometry by Roscosmos' *Venera D*. This work is supported by the NASA Solar System Workings Program under grant NNX17AB19G.

118.02 Variation of short-lived species in the upper atmosphere of Venus
Mao-Chang Liang[1], Karen Willacy[2], Frank Mills[3], Run-Lie Shia[4], Yuk Yung[4]
[1]Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, [2]Jet Propulsion Laboratory, Pasadena, California, United States, [3]Australian National University, Acton, Australian Capital Territory, Australia, [4]California Institute of Technology, Pasadena, California, United States

Abstract
Most simulations of chemical species in the mesosphere of Venus have used one-dimensional numerical models that represent global-average or diurnal-average conditions. However, we expect significant variations over a diurnal cycle. Here, in order to provide a quantitative assessment on the observed species subject to diurnal variations for an assumed zonal transport rate, we applied a recently developed one-dimensional chemical transport model that simulates the production of the chemical compounds of interest at a diurnal time scale, with prescribed vertical atmospheric transport. Diurnal variations are primarily driven by diurnal solar forcing and transport that includes both eddy mixing and advection.

Comparison with observations (e.g., HCl and ClO measured by Sandor and Clancy 2012 and 2018, respectively) provide constraints on chemical processes and dynamics in the upper atmosphere of Venus.

118.03 Scaling of Dielectric Breakdown Thresholds on Earth, Mars, and Venus: Impact for Predictions of Extraterrestrial TLEs and Lightning Discharges
Jeremy A. Riousset, Amitabh Nag, Csaba Palotai
APSS, Florida Institute of Technology, Melbourne, Florida, United States

Abstract
Voyager 1 observations of Jupiter confirmed the existence of extraterrestrial lightning but its presence on our closest neighbors, Mars and Venus remains controversial. In particular, the current detection effort rests on the physics of terrestrial lightning, which may be very different in other planetary atmospheres. The meteorological processes able to trigger lightning discharges in extraterrestrial atmospheres remain ill-defined, as do the expected characteristics of such discharges. In this work, we use the conventional breakdown threshold field, E_k, as a reference value for the initiation of atmospheric discharges. Its exact value depends on atmospheric composition, charge density, pressure, and temperature, but approximate altitude profiles can be obtained by means of scaling laws. We develop E_k profiles from ground to the ionosphere for Earth, Venus, and Mars to include the possibility of upper atmospheric discharges and TLEs. We establish that classic approximations, which use atmospheric scale heights and neutral gas density respectively become inaccurate above the tropopause and mesopause of all three planets. We also compare the results with reported or hypothesized electrical activity in the peer-reviewed literature and investigate the role of atomic oxygen in the drop of the electric field threshold. We conclude that hypothesized Martian discharges would be favored by the planet's low atmospheric pressure while electrical discharges in the Venusian cloud deck would require similar charging than in Earth's thunderstorms and that Venusian volcano lightning is less likely due to significantly more stringent initiation conditions.

118.04 Variability of the Venusian and Martian nightside ionosphere after solar storms and evidence of proton aurora
Candace Gray[1], Tom Nordheim[2], Jamie Jasinski[2], Zachary Girazian[5], Bernd Hausler[3], Kerstin Peter[4], Martin Paetzold[4], Silvia Tellmann[4]
[1]Apache Point Observatory, Las Cruces, New Mexico, United States, [2]Jet Propulsion Laboratory, Pasedena, California, United States, [3]Institut für Raumfahrttechnik und Weltraumnutzung, Neubiberg, Germany, [4] Rheinisches Institut für Umweltforschung, Cologne, Germany, [5]University of Iowa, Iowa City, Iowa, United States

Abstract
Interactions between planetary atmospheres and the solar wind can be observed via atmospheric emission and ion/electron density profiles. The interaction of the solar wind with Venus and Mars is unique given that both planets lack an intrinsic magnetic field (or, in the case of Mars, only possesses a weak crustal field) and have similar atmospheric composition (95% CO_2).
The Venusian and Martian nightside ionospheres have two distinct electron density peaks: the V1 and V2 peak for Venus (located near 125 and 150 km) and the M1 and M2 peak for Mars (located near 100 and 150 km). These peaks are known to be be highly variable for both planets but the chemical pathways and processes, particularly for the V1 and M1 layers, are not well understood.
Both the V1 and M1 layers exhibit increases in density after intense solar storms, such as coronal mass ejections (CMEs) and solar flares [1, 2]. These increases in density are observed almost immediately and

are present on the deep nightside. Similarly, both planets exhibit auroral emission which are most intense after solar storms [5, 6]. For Venus, (1S-1D) OI 557.7nm auroral emission is present immediately after solar storms and are concurrent with V1 electron density increases [7]. Here, we propose solar wind protons, gyrating with a radius similar to that of Venus' (~6,000 km) and Mars' (~2,100 km), are capable of impinging directly in the nightside atmosphere, driving auroral emission and electron density increases in the V1 and M1 layers.

References

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Monday, October 22, 2018
03:35 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

119 Monday Afternoon Break with iPoster and Poster Viewing

119.02 Signatures of the Impact Histories of Comets and Asteroids within Shocked Phyllosilicates, Enstatite, and Forsterite Minerals

Susan M. Lederer[1], Zoe A. Landsman[2], Akbar Whizin[3], Douglas C. Smith[4], Taj Rai[4], Mark Cintala[1], Deborah Domingue[5], Elizabeth Jensen[5], Neil Pearson[5], Melinda Dyar[5], Melissa D. Lane[6], Diane Wooden[7], Sean Lindsay[8], Lindsay Keller[1], Michael Zolensky[1]
[1]NASA Johnson Space Center, Houston, Texas, United States, [2]Univ Central FL, Orlando, Florida, United States, [3]Southwest Research Institute, San Antonio, Texas, United States, [4]Cal State Univ SB, San Bernardino, California, United States, [5]PSI, Tucson, Arizona, United States, [6]Fibernetics, Lancaster, Pennsylvania, United States, [7]NASA Ames Research Center, Moffet Field, California, United States, [8]Univ Tenn, Knoxville, Tennessee, United States

Abstract
Throughout the lifetime of the solar system, collisions between small bodies and impacts on the surfaces of small bodies in the Kuiper Belt have occured at speeds of 1.5 - 3 km s^{-1} (*Stern, Astron J 124, 2002*), typically at 1-10 km s^{-1} between Trojan asteroids (*Marzari et al. Icarus 119, 1996*), and at ~4-8 km s^{-1} in the asteroid belt (*Farinella and Davis, Icarus 97, 1992)*. Shock effects recorded by minerals composing these bodies are one observable legacy of this evolutionary process, whether they were generated through large collisions, micrometeoroid impacts, or processing during the formation of the solar system. Shock metamorphism has been observed in cometary samples such as those from Comet Wild 2 (*Keller et al. Geochim. Cosmochim. Acta 72, 2008; Tomeoka et al. MAPS 43, 2008; Jacobs et al. MAPS 44, 2009)* as well as in forsterites and enstatites found in meteorites (*McCausland et al. AGU, 2010*).

To investigate the observable signatures of these processes, we have conducted a suite of impact experiments at NASA Johnson Space Center's Experimental Impact Laboratory (EIL). Target materials included Mg-rich forsterite (olivine), Mg-rich enstatite (orthopyroxene), and antigorite and lizardite (both in the serpentine group of phyllosilicates).

Alumina-ceramic spheres were launched at speeds ranging from ~2.0 – 2.6 km s^{-1} into targets at temperatures from 25°C to -100°C. Recent advancements have been made in cooling targets in the EIL's vertical gun. Liquid nitrogen (LN_2) is fed through a unique jacket surrounding the metallic sample container to chill the samples. Real-time values from temperature sensors attached to the sample holder are converted to target temperature through predetermined regression relationships, providing the target temperature at the time of impact with sub-degree accuracy. Fourier Transform Infrared Spectrometer (FTIR) data in the near to mid-IR will be presented, along with trends relating temperature and velocity with impact speeds, and thereby peak shock stresses experienced by the impacted minerals.

Funding provided by the NASA PG&G grant 09-PGG09-0115, NSF grant AST-1010012, and SSERVI16 for TREX NNH16ZDA001N. Special thanks to NASA EIL staff, F. Cardenas and R. Montes.

119.03 The Sustainable Development of Space: on the possibility of debris stream formation during asteroid mining operations

Aaron Boley, Logan Fladeland
Physics and Astronomy, The University of British Columbia, Vancouver, British Columbia, Canada

Abstract
The sustainable development of space is a challenge that is continuously growing in complexity, with the need to balance common heritage, economic opportunity, international relations, and scientific and technical advancement. The 1967 Outer Space Treaty established that celestial bodies may not be appropriated, but does not directly address space resource use. Building on interpretations of international law, in 2015 the United States enacted domestic legislation according its citizens the right to possess and sell space resources. Luxembourg established its own legal framework in 2017, with other nations expected to follow suit. There is a need for new international policies that address the expanding demands of space use, particularly with the possibility of asteroid mining. With this in mind, we explore potential targets for future mining operations, in part to highlight possible overlapping interests among state and non-state actors. Using several of those potential targets, we then calculate the formation of debris streams due to the envisaged generation of mining dust and waste, highlighting astro-environmental considerations for policy advocacy.

119.04 The Small Body Mapping Tool (SBMT) for Accessing, Visualizing, and Analyzing Spacecraft Data in Three Dimensions

Ronald T. Daly, Carolyn M. Ernst, Olivier S. Barnouin, James H. Roberts, Josh R. Steele, James M. Peachey, Michael I. Zimmerman
Space Exploration Sector, Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, United States

Abstract
Spacecraft missions return massive amounts of valuable data, but those data can be hard to access, visualize, and analyze. Most asteroids, comets, Kuiper belt objects, and small moons present additional challenges because two-dimensional map projections severely distort features on irregularly shaped bodies. The Small Body Mapping Tool (SBMT) developed at the Johns Hopkins University Applied Physics Laboratory addresses these challenges.

The SBMT lets users search for analysis-ready spacecraft data and project it onto shape models of small bodies. As a result, users can quickly find the data they need, look at the data in context, and do their science in three dimensions, without worrying about map projection issues or wading through Planetary Data System (PDS) archives. The Tool includes a diverse suite of bodies and data types (images, spectra, altimetry data), supports co-registration of these data products, and has built-in data analysis tools.

For each object in the Tool, the SBMT includes a 3D shape model and available spacecraft datasets. As of summer 2018, the public version of the SBMT includes spacecraft data for several asteroids (Ceres, Vesta, Eros, Itokawa) and moons (Phobos, Dione, Mimas, Phoebe, Tethys). More bodies will soon be available, including an improved Phobos model, Deimos, 9P/Tempel 1, 67P/Churyumov-Gerasimenko, 81P/Wild 2, 103P/Hartley 2, and the saturnian moons Atlas, Calypso, Epimetheus, Helene, Hyperion, Janus, Pan, Pandora, Prometheus, Rhea and Telesto. Some datasets, such as those for active missions, have restricted access; however, they will become publically available in the SBMT once the data have been archived with the PDS.

The Small Body Mapping Tool is publically available as a free download at sbmt.jhuapl.edu. It works on Mac, Linux, and Windows operating systems and has an easy-to-use graphical user interface. The SBMT

is written in Java and uses the Visualization Toolkit (VTK), an open-source, freely available software system for 3D computer graphics, rendering, and visualization. The SBMT is actively being developed, and we will continue to release new datasets and functionality. We invite everyone in the community to use the SBMT or reach out and discuss collaborations.

119.05 Gemini Operations for Non-sidereal Target Science

Bryan Miller, Andy Adamson, Andrew Stephens, Arturo Nunez
Gemini Observatory, La Serena, Coquimbo, Chile

Abstract

Gemini Observatory will continue be an important facility for following up time domain discoveries in the coming decade. We will summarize the Gemini operations model and instrumentation suite and describe how this will complement the current and future surveys, especially LSST. Currently observations are carried out in queue (service), classical (visitor), and priority visitor (visitors execute the queue) modes. Time is allocated by regular partner TACS, a common large program TAC, and by peer review for "fast-turnaround" proposals. Queue observing allows Gemini to easily and frequently execute target-of-opportunity (TOO) observations and this capability will be very important for transient and solar-system science. An example is Gemini's role in the observations of 'Oumuamua in 2017. Gemini's optical and near-IR instrumentation covers a wide range of spatial and spectral resolutions. The next Gemini instrument, SCORPIO, is being designed with LSST follow-up in mind and the current status will be reviewed. Non-sidereal target positions are calculated using ephemerides that are either uploaded by the user or automatically updated daily from JPL's Horizons service. Changes being planned to the operations software to handle the increased volume of TOO triggers and to improve overall efficiency and ease of use will also be presented.

119.06 Local Gravitational Instabilities inside Density Waves in Saturn’s Rings

Glen Stewart
LASP, University of Colorado, Boulder, Colorado, United States

Abstract

In unperturbed regions of Saturn’s A ring, local gravitational instabilities result in transient clumps of ring particles, called “self-gravity wakes.” These wakes have scales of less than 100 meters, as determined by the Toomre wavelength for axisymmetric gravitational instabilities in disks. Although Cassini imaging does not resolve these structures, their presence is believed to be responsible for the global azimuthal brightness asymmetry of the rings as viewed from Earth and by the Cassini spacecraft.

Within the troughs of strong spiral density waves, however, Cassini images often show kilometer-scale structures that are sometimes described as straw-like textures. These structures are likely super-sized self-gravity wakes and have the potential to enhance the local viscous angular momentum transport and thereby limit the maximum amplitude of the density wave. Since the straw-like structures vary in scale and pitch-angle as a function of location in Saturn’s rings, they have the potential to constrain the properties of ring particles and their collisional dynamics. In order to explore this possibility, a theory has been developed that can describe the rate of local gravitational instabilities inside density waves. The Hamiltonian for single particle motion in the vicinity of an inner Lindblad resonance with a Saturnian satellite can be formulated such that the angle variable conjugate to the radial action is the resonant argument for the resonance. Hamiltonian perturbation methods are used to remove the satellite

perturbation such that the transformed radial action and conjugate angles include the usual solution for self-gravitating density waves. Local gravitational instabilities in the density wave can now be formulated using a linearized collisionless Boltzmann equation that is expressed in terms of the transformed action-angle variables that contain the density wave solution. The gravitational potential of the linearized perturbation is enhanced by a factor of ten or more in strong density waves, which likely explains the observation of kilometer-scale structures in these waves.

119.07 Modeling the Meteoritic Bombardment of Saturn's Rings to Estimate Their Age

Joshua P. Elliott[1, 2], Larry Esposito[1, 2], Eric T. Bradley[3], Greg Holsclaw[1, 2]
[1]LASP, University of Colorado, Boulder, Colorado, United States, [2]Laboratory for Atmospheric and Space Physics, Boulder, Colorado, United States, [3]University of Central Florida, Orlando, Florida, United States

Abstract
The rings of Saturn vary radially in brightness due to a variety of factors such the optical depth of the rings and the ratio of endogenous water ice to non-icy exogenous material, as well as the morphology of the ring particles. The radial optical depth profile, as measured by UVIS stellar occultations (Colwell et al. 2009), provides the filling factor of each of the major regions of the rings. Taking this into account, we perform a meteoritic bombardment simulation, using a Markov Chain based simulation (Elliott and Esposito 2011), which calculates the evolution of the fractional pollution over long time scales. This gives us a fractional pollution time series which we can then compare to the fractional pollution observed by UVIS. In order to calculate the current fractional pollution of the ring system, taking the filling factor into account, we model the UVIS spectra for the A, B and C rings using Hapke's 2012 model for bidirectional reflectance of a surface composed of an intimate mixture of regolith grains. We then perform a non-linear least-squares fit to these spectra with two free parameters, the fractional pollution of the rings and the surface roughness of the particle. UVIS observations at different phase angles are used to constrain the surface roughness. We perform this fit for several different pollutants, and a statistical goodness-of test is performed to assess the quality of each fit. We then compare the Markov-chain model result to the UVIS fit spectrum, which gives us an estimate for the age of the rings.

119.08 Automated Pipeline for Venusian Cloud Tracking

Nicholas Ardavin[1], Kenyon Prater[1], Eliot F. Young[2], Mark Bullock[3], Siddharth Krishnamoorthy[1], Attila Komjathy[1], James Cutts[1]
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Abstract
At 2.3 microns, a gap in the absorption spectrum of Venus' CO_2-atmosphere allows observations of the nightside, where the lower clouds show up as silhouettes, backlit by thermal emission from below. Observations in this region are of particular interest for determining wind velocities via cloud tracking. Wind velocity measurements allow us to compare observed winds with those predicted by Global Circulation Models (GCMs). Of particular interest are latitudinal wind-velocity profiles, time-varying cycles in the Venusian atmosphere, and correlation of wind speeds with surface features. We are currently investigating all of the above.

We present an automated pipeline for data reduction, from raw images of Venus' nightside to useful wind velocity maps using cloud-tracking methods. By stacking subsets of the sharpest Venus images, we are able to achieve angular resolutions of 0.5" or better, corresponding to an approximately 150 km resolution near the center of Venus' disk. From these image stacks we are able to extract wind velocity fields over the night side with at least 20 latitudinal divisions, RMS errors of approximately 5 m/s, and temporal changes in wind speeds at the 10% level or less. We use this pipeline to reduce data from the IRTF's SpeX instrument, spanning over 15 years of observation. In particular, we compare methodology and results between two image sets: an IRTF campaign from April-May 2017 and Akatsuki IR2 images taken in 2016.

119.09 Response of Venus's Topside Ionosphere to Changes in Solar Activity
Kerry Hensley[1], Paul Withers[1, 2], Zachary Girazian[4], Martin Patzold[3], Silvia Tellmann[3], Bernd Hausler[5]
[1]Boston University, Boston, Massachusetts, United States, [2]Center for Space Physics, Boston University, Boston, Massachusetts, United States, [3]University of Cologne, Cologne, Germany, [4]University of Iowa, Iowa City, Iowa, United States, [5]Bundeswehr University Munich, Munich, Germany

Abstract

The ionosphere of Venus is a weakly ionized plasma layer embedded in the planet's upper atmosphere. Planetary ionospheres provide an excellent opportunity to study how our variable Sun affects the planets in our solar system. Because ionospheres are reservoirs from which atmospheric species can be lost to space, studying ionospheric variability can help us understand how planetary atmospheres have evolved since their formation. While variations of the main and lower ionospheric peaks of Venus have been well-studied, the behavior of the topside ionosphere — above the altitude of the highest electron density — has not been fully constrained. To investigate the behavior of the topside Venus ionosphere, we use electron density profiles obtained by the Venus Radio Science experiment aboard Venus Express. An increase in the variability of the ionospheric electron density with increasing altitude above the peak is readily apparent in these data. By using a one-dimensional photochemical model to investigate the factors that drive the variations of the topside ionosphere of Venus, we find that changes in the composition of the underlying neutral atmosphere are responsible for the observed increase in ionospheric variability with altitude.

119.10 A Ringside View of the Io Plasma Torus: Perijove Observations by Juno-UVS
Joshua Kammer[1], G. R. Gladstone[1], Thomas Greathouse[1], Vincent Hue[1], Maarten H. Versteeg[1], Scott J. Bolton[1], John E. Connerney[2, 3], Steven M. Levin[4]
[1]Southwest Research Institute, San Antonio, Texas, United States, [2]Space Research Corporation, Annapolis, Maryland, United States, [3]NASA Goddard Space Flight Center, Greenbelt, Maryland, United States, [4]Jet Propulsion Laboratory, Pasadena, California, United States

Abstract

Juno-UVS is an ultraviolet imaging spectrograph onboard the Juno spacecraft currently in orbit around Jupiter. The instrument has a bandpass of 70 - 205 nm, and is primarily used to observe UV emission from the Jovian aurorae during each close pass to the north and south polar regions of the planet, but the instrument also observes a variety of other bright sources in the UV, including reflected sunlight from Jupiter itself, as well as light from a variety of UV-bright stars. In addition, Juno-UVS has detected relatively fainter and more diffuse UV emission primarily due to sulfur ions in the Io plasma torus. The emission from the torus has been seen during every perijove pass at multiple viewing angles from about five hours before to five hours after closest approach. We present initial analysis of these integrated emission features and their longitude-dependent morphology as seen by Juno-UVS during each of the 14 perijove passes so far.

119.11 Simulating Drifting Features in the Atmospheres of the Ice Giants

Raymond P. Le Beau[1], Kevin Farmer[1], Csaba Palotai[2], Nathan Hadland[2], Ramanakumar Sankar[2], Noah Nodolski[2]
[1]Aerospace and Mechanical Engineering, Saint Louis University, Saint Louis, Missouri, United States, [2]Florida Institute of Technology, Melbourne, Florida, United States

Abstract

The Dark Spots of the Ice Giants have exhibited a variety of behaviors and characteristics, ranging in size, latitude, shape, and accompanying cloud structure. Two these features, the original Great Dark Spot (GDS-89) and the most recently observed SDS-2015, appear to have shifted in latitude over extended periods—GDS-89 by about 10 degrees equatorward over 8 months (Sromovsky et al., 1993), and SDS-2015 a few degrees poleward in two years (Wong et al., 2018). A potentially third significant drifter is the "Berg" cloud feature on Uranus, which appears to have drifted more than 20 degrees equatorward over 4 years (de Pater et al., 2011). This motion may reflect clouds being generated by a long-lived companion vortex that was too deep in the atmosphere or failed to develop sufficient contrast to be observed.

A mechanism that can cause similar meridional drift in large geophysical vortices on Earth is the "beta gyre" concept (Fiorino and Elsberry, 1989) in which the advection of environmental potential vorticity by and about the vortex generates a residual vortex dipole, effectively propelling the original vortex away from or towards the equator. This mechanism relies on the natural gradient in the Coriolis effect with latitude created by the rotating planet. However, on Uranus and Neptune this background gradient is further dependent on the gradient in zonal wind vorticity, making the drift rate sensitive to the zonal wind structure as well (LeBeau and Dowling, 1998; Hammel et al., 2009).

To better understand these drift dynamics, a parametric approach using the EPIC General Circulation Model (Dowling et al., 2006) is applied in which vortex characteristics such as size and wind strength as well as environmental conditions are varied through a range of values consistent with observationally defined zonal wind profiles. While these simulations are not designed to capture a particular Dark Spot, these simulations aim to determine conditions that might lead to the observed drift motions.

119.12 Detection of a Warm Thermal Anomaly in Jupiter's Stratosphere

Thomas Greathouse[1], Richard Cosentino[2], Glenn Orton[3], Raúl Morales-JuberÍas[4], Rohini Giles[3], Leigh Fletcher[5], Therese Encrenaz[6], Thierry Fouchet[6]
[1]Space Science Division, Southwest Research Institute, San Antonio, Texas, United States, [2]NASA Goddard Spaceflight Center, Greenbelt, Maryland, United States, [3]The Jet Propulsion Laboratory, Pasadena, California, United States, [4]New Mexico Tech, Socorro, New Mexico, United States, [5]University of Leicester, Leicester, United Kingdom, [6]Observatoire de Paris, Meudon, France

Abstract

We present 3-dimensional thermal mapping results of Jupiter's stratosphere between atmospheric pressures of 30 and 0.01 mbar. By scan-mapping Jupiter with TEXES (the Texas Echelon cross-dispersed Echelle Spectrograph) mounted on the 3-m NASA Infrared Telescope Facility atop Maunakea, we measure methane (CH_4) emission features across Jupiter with complete zonal coverage and meridional

coverage between 40° South and 40° North planetocentric latitude. Since methane is well mixed in Jupiter's stratosphere, variations of the methane emission in the CH_4 ν_4 vibrational band at 8 μm are caused by variations in the atmospheric temperature. Line-by-line radiative transfer modeling of these thermal emission maps reveal a large scale (~15° in latitude and ~30° in longitude) thermal anomaly reaching 15 K above ambient centered at 28°N latitude and 176° W longitude (System III) at a pressure of 1.2 mbar. A map retrieved a week later shows how this anomaly moved and evolved. We will present the observations, radiative-transfer modeling results, and analysis of the thermal anomaly and its evolution.

119.13 Using HST bandpass filter images from the OPAL program to test the ability of candidate chromophores to model spatial and temporal variations on Jupiter

Patrick M. Fry, Lawrence Sromovsky
Space Science & Engineering Center, University of Wisconsin - Madison, Madison, Wisconsin, United States

Abstract
The colorless main components of Jupiter's upper cloud layers require one or more chromophores to create the color variations it displays in bands, zones, and discrete features. Sromovsky et al. (2017, Icarus 291, 232-) were able, using a single chromophore, to obtain good fits to several regions/features: the North Equatorial Belt (NEB), Equatorial Zone (EZ), South Equatorial Belt(SEB), and Great Red Spot (GRS). This chromophore, produced and measured by Carlson et al. (2016, Icarus 274, 106-), is created when NH_3reacts with acetylene (C_2H_2). Another possible chromophore is yellow phosphorus (P_4), a product of photolyzed NH_3 (Noy et al. 1981, J Geophys Res 86, 11985-), that has spectral properties similar to the Carlson et al. chromophore. Another possible chromophore is a tholin (Khare et al. 1993, Icarus 103, 290-). Real and imaginary refractive indices have been determined for all three, allowing their evaluation with accurate radiative transfer modeling. The HST imaging record of Jupiter runs from 1994 to the present and provides consistent spatial resolution and absolute calibration. Our initial modeling efforts have concentrated on Outer Planet Atmosphere Legacy (OPAL) observations (2015-present, Amy Simon, PI), since they have a broad wavelength range, multiple views of the same region in close time proximity with different view angles, and will continue into the near future. Our system for fitting bandpass filter observations of targets at multiple view angles is now operational and we are currently determining vertical structure parameter constrainability. Initial modeling of 2018-04-17 observations of the GRS (observer cosine range 0.43-0.94) show similar fit qualities for P_4 and Carlson et al. chromophores. We will present modeling results for the 2014-2018 OPAL dataset for the GRS, NEB, EZ, and SEB, indicating the preferred chromophore identity, and highlighting the possible causes for recent coloration changes in those regions.

This work is supported by the NASA Solar System Workings program. Thanks to Mike Wong for the WFC3 FQ889N fringe flats.

Tuesday, October 23, 2018
08:30 AM-09:30 AM
Ballroom A (Knoxville Convention Center)

200 Trojan Asteroids
Chair(s): Sarah Sonnett, Bin Yang

08:30 AM-08:40 AM
200.01D The consequences of planetary migration on minor bodies in the solar system.
Simona Pirani[1], Anders Johansen[1], Bertram Bitsch[2], Alexander J. Mustill[1], Diego Turrini[3]
[1]Dept. of Astronomy and Theoretical Physics, Lund Observatory, Lund, Sweden, [2]Max-Planck-Institut für Astronomie, Heidelberg, Germany, [3]Institute for Space Astrophysics and Planetology INAF-IAPS, Rome, Italy

Abstract
Pebble accretion is an efficient mechanism able to build up the core of the giant planets within the lifetime of the protoplanetary disc gas-phase. The core grows via this process until the protoplanet reaches its pebble isolation mass and starts to accrete gas. During the growth, the protoplanet undergoes a rapid, large-scale, inward migration due to the interactions with the gaseous protoplanetary disc. In our work, we investigate how this early migration would have affected the minor body populations in our solar system. In particular, we focus on the Jupiter Trojan asteroids (bodies in the coorbital resonance 1:1 with Jupiter, librating around the L4 and L5 Lagrangian points called, respectively, the leading and the trailing swarm). We characterize their orbital parameter distributions after the disc dispersal and their formation location and compare them to the same populations produced in a classical in situ growth model. Our simulations show that inward migration of the giant planets always produces a Jupiter Trojans' leading swarm more populated than the trailing one, with a ratio comparable to the current observed Trojan asymmetry ratio. The in situ formation of Jupiter, on the other hand, produces symmetric leading/trailing swarms. The reason for the asymmetry is the relative drift between the migrating planet and the particles in the coorbital resonance. The capture happens during the growth of Jupiter's core and Trojan asteroids are afterwards carried along during the giant planet's migration to their final orbits. Our results thus overall imply (a) that the Trojan asymmetry originated from the large-scale migration of proto-Jupiter and (b) that the building material of Jupiter's core is preserved in the Trojan population and (c) that the photometric colors of the Neptune and Jupiter Trojans should be similar because both planets formed close to each other at significant distances from the Sun, likely beyond 15-20 au.

08:40 AM-08:50 AM
200.02 The hypnotic dance of Patroclus and Menoetius: Ground-based observations of their 2017-2018 mutual event season.
Noemí Pinilla-Alonso[1, 2], Marcel Popescu[3, 7], Estela Fernández-Valenzuela[1], Javier Licandro[3], René Duffard[4], Joel Castro[5], Raúl M. Murillo[5], William Grundy[6], Mauricio Reyes-Ruiz[5], José Silva[5]
[1]Florida Space Institute, FSI/UCF, Orlando, Florida, United States, [2]Arecibo Observatory, Arecibo, Puerto Rico, [3]Instituto de Astrofísica de Canarias, IAC, La Laguna, Spain, [4]Instituto de Astrofísica de Andalucía, IAA-CSIC, Granada, Spain, [5]Instituto de Astronomía, UNAM, Ensenada, Mexico, [6]Lowell Observatory, Flagstaff, Arizona, United States, [7]Astronomical Institute of the Romanian Academy, Bucharest, Romania

Abstract
Trojans are a significant portion of the small bodies population located within two clouds in the L4 and L5 Lagrangian points of Jupiter's orbit. The study of primitive small bodies is relevant to the origin and nature of volatile and organic material in the early Solar System. Dedicated studies of the nature of these bodies can significantly improve our understanding of their nature, origin and evolutionary mechanisms. Lucy, a mission of the NASA's Discovery Program, is planned to launch in October 2021 for a 12-year journey. Lucy will explore seven different primitive small bodies, six of which will be Trojans. The mission will use a suite of remote sensing instruments to map the geology, surface color, composition, thermal and other physical properties of the targets at close range.
Our international team performed observations during 2017 and 2018 to record the light-curve of the mutual events of the binary system formed by Patroclus and Menoetius, providing a unique opportunity to refine their orbit characteristics as well as other properties of the system (sizes, shape, and mass of both objects).
Patroclus is the first binary trojan to be discovered. Previous studies by Marchis, *et al.* (2016, Nature, 439) determined the mutual orbit of the system to have a period of 4.283 ± 0.004 days and a semimajor axis of 680 ± 20 km, leading to a system mass of (1.36 ± 0.11) x 10^{18}kg and an average bulk density of 0.8 ± 0.2 g cm^{-3}. When the plane of their mutual orbit is aligned with the direction to the Sun or to an observer, Patroclus and Menoetius take turns eclipsing or occulting one another. Such an alignment occurs during mutual event seasons, twice during the ~12 year orbit around the Sun. We show, for the first time, a collection of light-curves that are the result of about 20 detections. Our analysis puts a special focus on the differences between the observations and the models of the orbit (Grundy et al. 2018, Icarus 305) providing unique and crucial information that includes the possible topographic variation on Menoetius' south pole, a refinement to the orbit model, and improved predictions for shadowing and occultation events.

08:50 AM-09:00 AM
200.03 Near-Infrared Spectroscopy of *Lucy* Mission Targets
Benjamin Sharkey[1], Vishnu Reddy[1], Juan Sanchez[2]
[1]LPL, University of Arizona, Tucson, Arizona, United States, [2]Planetary Science Institute, Tucson, Arizona, United States

Abstract
NASA Lucy mission will flyby five Jupiter Trojan asteroids and a main belt asteroid starting in 2027. We observed all six targets using the SpeX instrument (0.7-2.5 microns) on the NASA IRTF in an effort to spectroscopically characterize their surface. These include main belt asteroid (52246) Donaldjohanson and L4 Jupiter Trojan asteroids (3548) Eurybates, (11351) Leucus, (15094) Polymele, and (21900) Orus. We place our results in the context of previous observations of small (D<75 km) Trojan asteroids, including Patroclus and Eurybates, and discuss predictions made by current hypotheses of their surface compositions and potential for low-level surface activity. Our observations of these enigmatic bodies will help in planning for the encounter and comparison with spacecraft flyby observations. This work is supported by NASA Earth and Space Science Fellowship grant (PLANET18F-0104).

09:00 AM-09:10 AM
200.04 Evidence for Two Components in the Stable Neptunian Trojan Population
Hsing-Wen Lin[1], David Gerdes[1], Stephanie Hamilton[1], Fred Adams[1], Ying-Tung Chen[2], Kathryn Volk[3], Brett Gladman[4], Ruth Murray-Clay[5]
[1]Department of Physics, University of Michigan, Ann Arbor, Michigan, United States, [2]Academia Sinica, Taipei, Taiwan, [3]University of Arizona, Tucson, Arizona, United States, [4]University of British Columbia,

Vancouver, British Columbia, Canada, [5]University of California Santa Barbara, Santa Barbara, California, United States

Abstract
Three recent large-scale sky surveys -- the DES, OSSOS and PS1-- have discovered/rediscovered a total of 14 stable Neptunian Trojans and have increased the known members of this population by a factor of two. The three surveys have their own characteristics: the DES provides color information and has wide coverage in ecliptic latitude, the OSSOS is very well-characterized, and the PS1 has the largest ecliptic plane coverage.
In this report, we summarize the main results of Neptunian Trojan studies from the three surveys: 1. The DES found the first-ever ultra-red stable Trojan, with an orbital inclination larger than 30 degrees. 2. OSSOS found that the small Trojans (H < 8) have a very hot inclination distribution (inclination width ~ 26 degrees). Additionally, it seems that few Trojans have H between 8.2 and 8.8. 3. The PS1 found that the large Trojans (H > 8) have a colder inclination distribution (inclination width ~ 6 degrees). These three results hint that, like the classical Kuiper Belt, the Neptunian Trojan population seems to consist of two components that have different inclination distributions and possibly different color distributions. We will discuss an exploration of the idea that Trojan-Plutino collisions may change the color and size distributions of low-inclination Trojans to form the two components and produce the observational results. However, more Trojan colors and Trojan discoveries are needed to fully understand the color and orbital distributions of Neptunian Trojans.

09:10 AM-09:20 AM
200.05 Refining the composition of Jupiter Trojans with UV spectroscopy
Ian Wong[1], Michael E. Brown[2], Jordana Blacksberg[3], Bethany Ehlmann[2], Ahmed Mahjoub[3]
[1]EAPS, MIT, Boston, Massachusetts, United States, [2]Caltech, Pasadena, California, United States, [3]JPL, Pasadena, California, United States

Abstract
Recent developments in theories of solar system formation and evolution have pushed Jupiter Trojans into the spotlight. Current models describe a scenario in which a major episode of dynamical instability after the end of planet formation led to significant restructuring of the orbital architecture throughout the middle and outer Solar System. The major implication of these models is that the present-day Trojans did not form in situ, but rather were scattered and subsequently captured into resonance from the outer Solar System. Obtaining a better understanding of the surface properties of Trojans will help us constrain their composition and formation, and more fundamentally, provide a crucial litmus test for current dynamical instability models of solar system evolution.

Despite a decades-long concerted effort, spectroscopy of Trojans has hitherto uncovered only a few spectral features throughout the optical, near-infrared, and thermal infrared that can be used to build a compositional outline for these objects. In this talk, we present new results from a recent Hubble program utilizing the STIS instrument to observe six Trojans in the ultraviolet (200-550 nm). These spectra provide a unique window into a poorly-understood and rarely-analyzed part of the electromagnetic spectrum in the context of small solar system bodies and are the first such UV spectra of Trojans. The six targets are evenly distributed among the two attested sub-populations in the Trojans. We discuss these observations using compositional modeling and consider the results alongside previously-obtained laboratory spectra of analog volatile ice mixtures that simulate the surface properties of Trojans within the framework of current dynamical instability models. In addition, we compare the spectra of less-red and

red Trojans and explore the implications for our understanding of the physical and chemical processes responsible for the color bimodalities in all middle and outer solar system minor body populations.

09:20 AM-09:30 AM
200.06 The Trojan Color Conundrum
David Jewitt
Earth, Planets & Space, UCLA, Los Angeles, CA, California, United States

Abstract
The giant planet Trojans are widely supposed to be captured counterparts of the hot population of the Kuiper belt. If true, the color distribution of the Trojans should be the same as that of the hot population. It has been known for decades that this is *not* true of the Jupiter Trojans, which lack the distinctive ultrared material (color index B-R > 1.6) found in the Kuiper belt. We have conjectured that the lack of ultrared material on the Jupiter Trojans is a reflection of surface modification caused by their higher temperatures (125K) relative to Kuiper belt objects (40K). However, we now possess the colors of 16 Neptune Trojans (13 compiled by Jewitt 2018, 3 others by Lin et al. 2018) showing that they, too, are depleted in ultrared matter, with a B-R distribution like that of the Jupiter Trojans but unlike that of the hot population. Whereas 1/3 of the hot population objects are ultrared, this fraction in the Neptune Trojans is only 1/16. A K-S test comparing the Neptune Trojans and hot classicals, for example, gives the probability of them being drawn from a common parent population as only 0.007. This is interesting, because the Neptune Trojans are too cold for thermal modification by processes like those conjectured to occur at Jupiter.

The Trojan Color Conundrum is that the Trojans of both planets have color distributions consistent with each other but incompatible with the hot population from which they are supposed to be derived. No known thermal modification process can operate at both planets. Collisions between Neptune Trojans and Plutinos (noted by Almeida et al 2009) occur at a rate that appears too small and independent observational evidence for collisional resurfacing is lacking.

We will discuss the Color Conundrum and its possible resolutions.

Jewitt, D. (2018). Trojan Color Conundrum. The Astronomical Journal, 155:56
Lin, H. et al. (2018). Preprint

Tuesday, October 23, 2018
08:30 AM-09:30 AM
Ballroom B (Knoxville Convention Center)

201 Comets: Dynamics, Origins, and Theory
Chair(s): Henry Hsieh, Stubbe Hviid

08:30 AM-08:40 AM
201.01 Exploring the Secular Evolution of the Solar System and Debris Disk in the Birth Cluster
Diptajyoti Mukherjee[1, 2], Santiago Torres[2], Maxwell Cai[2], Simon Portegies Zwart[2]
[1]Physics, Allegheny College, Meadville, Pennsylvania, United States, [2]Leiden University, Leiden, Netherlands

Abstract
The present day solar system contains different populations of planetesimals that exist beyond the orbit of Neptune like the Kuiper Belt, Scattered Disk and the Oort Cloud. Most widely accepted models argue that these populations are a result of the dynamical chaos that occured in the primordial solar system. The Nice Model, for example, argues that the Oort Cloud was formed as a result of dynamical instability between the giant planets which resulted in the scattering of planetesimals.
The dynamics of the primordial solar system, nevertheless, remain an enigma. Current theories of the dynamical evolution of the solar system during and after the formation of the planets assume that the Sun was born in isolation and the effects of nearby stars was minimal. However, modern theories of the formation of the Sun contend that the sun did not form in isolation, but in a cluster of about 2000 stars. The probability that the primordial solar system faced multiple close encounters in a star cluster is significant and cannot be ignored. In particular, multiple encounters would have imparted energy to the giant planets and the debris disk affecting the dynamical evolution of the planetary system.
In our work, we explore to what extent the encounters would perturb the system and how that would affect the ejection of planetesimals to larger distances. We also investigate the secular evolution of the planetesimals systematically, including their early history in the cluster and subsequent evolution in an isolated environment. Through N Body simulations, we observe that multiple encounters with stars in a star cluster along with planetary migration are a robust mechanism of particle excitation and ejection.

08:40 AM-08:50 AM
201.02 Interstellar interlopers in the outer Solar System.
Edward Ashton[1], Brett Gladman[1], J. Kavelaars[2], Gareth Williams[3]
[1]University of British Columbia, Vancouver, British Columbia, Canada, [2]NRC Canada, Victoria, British Columbia, Canada, [3]Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, United States

Abstract
The first Interstellar Object (ISO) discovered, 'Oumuamua, was found in close proximity to the Earth, travelling at on-sky speeds similar to that of typical Near-Earth Asteroids. Is it possible that (larger) ISOs passing through the outer Solar System have escaped detection? An interstellar interloper passing through the 5-100 au region of the Solar System would have a slower on-sky rate but could be moving in any

direction. Bound distant Solar System objects (like trans-neptunain objects, TNOs) are restricted to a small range of on-sky retrograde directions when imaged at opposition. Thus most opposition TNO surveys have a small search cone around the precise retrograde direction, severely reducing the detectability of ISOs in the outer Solar System. We increase the opening angle in the TNO search of the Outer Solar System Origins Survey (OSSOS) to include all angles. Since we used different flux cuts, we rediscovered most, but not all, of the OSSOS objects along with a few new TNOs. Currently, at ~90% completion, no ISOs have been discovered. However, we have found bound objects travelling at motions (when observed only over short arcs) that an ISO in the outer Solar System could have, and we show how previous moving-object surveys may have detected ISOs but incorrectly assigned them to bound orbits.

08:50 AM-09:00 AM

201.03 The Contribution of Dwarf Planets to the Origin of Low Inclination Comets by the Replenishment of Mean Motion Resonances in Debris Disks

Marco A. Muñoz Gutiérrez[1], Antonio Peimbert[2], Barbara Pichardo[2]

[1]Academia Sinica Institute of Astronomy and Astrophysics, Taipei, Taipei, Taiwan, [2]Instituto de Astronomía, UNAM, Ciudad de México, Ciudad de México, Mexico

Abstract

In this work we explore a new dynamical path for the delivery of low-inclination comets. In a conguration formed by an interior giant planet and an exterior massive debris disk, where the mass is accounted for by the 50 largest objects in the disk, the strongest mean motion resonances of the giant, located along the belt, are replenished with new material (test particles) due to the influence of the 50 massive objects. Once in resonance, slow chaotic diffusion stirs the orbital elements of the cometary nuclei enough to encounter the giant and to be scattered by it. When the disk is massive enough, both resonant and non-resonant particles are stirred quickly to encounter the giant and form an scattered disk component, greatly increasing the rate for the delivery of cometary material to the inner part of the system. This mechanism is applicable both to the solar system and extrasolar systems in general. Preliminary results, using a disk as massive as the classical Kuiper belt, indicate that the mechanism here proposed can account for about a tenth of the injection rate required to maintain the population of ecliptic comets in steady state. In a more massive belt of 0.25 Earth masses, an estimated rate of around 0.6 new comets per year is found. Such a high rate would pose a serious risk for the habitability of rocky interior planets, yet would resemble events such as the late heavy bombardment that was present in the early solar system.

09:00 AM-09:10 AM

201.04D Orbital Alignment of Main-belt Comets

Yoonyoung Kim[1, 2], Youngmin JeongAhn[3], Henry Hsieh[4]

[1]Max Planck Institute for Solar System Research, Göttingen, Germany, [2]Seoul National University, Seoul, Korea (the Republic of), [3]Korea Astronomy & Space Science Institute, Daejeon, Korea (the Republic of), [4]Planetary Science Institute, Tucson, Arizona, United States

Abstract

We present an empirical analysis of the current osculating elements of main-belt comets (MBCs), which are objects that exhibit cometary activity yet orbit in the main asteroid belt and may be potentially useful as tracers of ice in the inner solar system. We report two key findings: (1) the currently known MBCs have remarkably similar longitudes of perihelion, which are also aligned with that of Jupiter, and (2) the clustered objects have significantly higher current osculating eccentricities relative to their proper eccentricities. These findings can be explained by the secular theory that Jupiter's gravitational

perturbation periodically excites eccentricities of main-belt objects and that secularly excited objects tend to have current osculating angular elements which are aligned due to Jupiter's influence. Currently, though only temporarily, most MBCs seem to have current osculating elements that may be particularly favorable for icy objects becoming active (e.g., maybe because of higher perihelion temperatures or higher impact velocities causing an effective increase in the size of the potential triggering impactor population). At other times, other icy asteroids will have those favorable conditions and might become MBCs at those times as well. Reference: Kim, Y., et al. 2018, AJ, 155, 142.

09:10 AM-09:20 AM
201.05
Pebble scale heterogeneity on comet 67P
Stubbe Hviid
DLR Institute for Planetary Reserch, Berlin, Germany

Abstract
One of the primary goals of the Rosetta mission was to constrain the origin and evolutionary history of 67P. Rosetta and the OSIRIS instrument have provided several hints constraining the origin of 67P. This talk will discuss the bright spots observed on the surface in the Imhotep region by the OSIRIS camera system and the bright surface observer on a freshly exhumed surface on the Aswan cliff in the Seth region. These bright spots are most likely water ice based on OSIRIS and Virtis spectra. The ice in the spots survived for an extended time period (> 6 months) indicating a significant size of the particles (centimeter to decimeter size). Lab and modeling work shows that the ice particles must have high purity with a dust to ice ratio much lower than the cometary mean. The ice particles in Imhotep are located in the debris talus from a cliff collapse indicating that the particle originates from deeper down in the comet (meters). It can be argued that we observed fresh exhumation of such particles in the large Aswan cliff collapse that occurred during the northern winter. The origin of these ice particles is not certain but most likely the particles are primordial because of the depth from which they were exhumed (much higher than the orbital thermal skin depth of the comet). The pebbles are in a size range compatible with current pebble accretion models. This hints at heterogeneities in the protoplanetary disk from which 67P formed.

09:20 AM-09:30 AM
201.06 Large scale planetesimal formation and water transport in evolving protoplanetary disks with a dead-zone
Sebastien Charnoz[1], Francesco Pignatale[1], Ryuki Hyodo[2], Brandon Mahan[1], Julien Siebert[1], marc chaussidon[1], Moynier Frédéric[1]
[1]Universite Paris Diderot, Insitut de Physique du Globe, Paris, France, [2]ELSI, Tokyo, Japan

Abstract
When, where planetesimals form in a protoplanetary disk are highly debated questions. While streaming instability is considered as the most promising mechanism for forming planetesimals, the conditions for its onset are very stringent. The planet forming region is possibly not turbulent because of the lack of ionization forming dead-zones (DZ). \textit{Aim:} We investigate planetesimal formation in an evolving disk over millions of years, including DZ starting from a power-law disk. \textit{Method:}We use a 1D time-evolving stratified disk model with composite grains dust transport (Si, Fe, refractory material, H2O, CO) and dust growth and fragmentation \textit{ Results:} Accretion of planetesimals develops from the water snow-line, up to the dead-zone outer edge (about 20 au), with a strong enhancement close to the

snow-line. The ratio of pebbles/planetesimals surface density is always < 1, up to 20 au. In about 1 Myr, the snow-line moves outward because of mass-loading of the dead-zone, leaving water rich planetesimals inward the snow-line in addition to water poor ones. Water vapor abundance increases by a factor 10-100 inward the snow-line in about 1 Myr (due to the drift of icy pebbles) and drops after a few Myr.
Conclusion: A dead-zone allows the formation of planetesimals over wide regions, but the regions close to the snow-line, or the inner edge of the dead-zone, are favored. All planetesimals are constituted of pebbles coming from much larger distances, consistent with laboratory data on chondrites. The time evolution of water vapor is also consistent with recent chemical data on dated chondrules showing an increase of oxygen fugacity in the inner solar system after 1 Myr followed by a decrease after 2-3 Myr. Giant planets could form at about 20 au, where pebbles are the most abundant.

Tuesday, October 23, 2018
08:30 AM-09:30 AM
Ballroom C (Knoxville Convention Center)

202 Education and Outreach
Chair(s): Joel Green, Robert Novak

08:30 AM-08:40 AM
202.01 Weaving a Webb story: Communicating Science for JWST
Alexandra Lockwood, Bonnie Meinke, Denise Smith, Christine Pulliam, Joel Green
Space Telescope Science Institute, Baltimore, Maryland, United States

Abstract
Humanity's next flagship-class space observatory is a complex mission with many tales to tell. JWST (or Webb for public audiences) will be a centerpiece of 21st century science communications, with discoveries ranging from our solar system to the first galaxies. How are we preparing to share the scientific news to come from this telescope? From news releases to multimedia content to a vast online presence, the discoveries of the James Webb Space Telescope will appear in multiple places with a broad reach across multiple audiences. At the same time, Webb's infrared observations present new challenges to inspiring the public and sharing the science. For example, Webb's science results are likely to be dominated by many different, and complex, data types (e.g. IFUs, coronagraphy), including some that have never before been deployed in space (e.g. multi-object spectroscopy and aperture masking interferometry). It will be more difficult to capture the public eye with these than it has been with the beautiful visible images of Hubble, but preparing resources in advance is helping science communication professionals worldwide anticipate these challenges. Each science story will need to be carefully crafted in multiple formats to reach the widest audience possible while also providing sufficient detail to further public understanding. We discuss strategies for developing stories based on messaging, goals, mediums, and audience, and how you can apply the same principles to communicating your own research.

08:40 AM-08:50 AM
202.02 NASA's Universe of Learning: Enabling Learners to Explore Exoplanets
Emma Marcucci[1], Thalia Rivera[2], Denise Smith[1], Anya Biferno[2], Gordon Squires[3], Kathleen Lestition[4], Lynn Cominsky[5]
[1]Space Telescope Science Institute, Baltimore, Maryland, United States, [2]NASA's Jet Propulsion Laboratory, Pasadena, California, United States, [3]Caltech/IPAC, Pasadena, California, United States, [4]Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, United States, [5]Sonoma State University, Rohnert Park, California, United States

Abstract
NASA's Universe of Learning (UoL) is an integrated astrophysics-focused program designed to enable learners of all ages to explore fundamental questions in science, experiment with how science is done, and discover what the universe holds, for themselves. Through a diverse portfolio of products, UoL provides a direct connection to the science and the experts of missions and programs that encompass NASA Astrophysics. At the intersection of astrophysics and planetary science, UoL provides resources to support learning in the area of exoplanet research and exploration. These products include resources that engage the learner in a pathway to *explore* and understand the complexities and uniqueness of exoplanet

surfaces, *interact* with and visualize a 3D rendered universe, and *participate* in the search for distant worlds. These resources provide the public with an understanding of one of NASA's big questions (How does the universe work? How did we get here? *Are we alone?*) UoL provides digital and print resources for a range of audiences in the form of immersive experiences, multimedia, engaging posters and informative exoplanet exhibits. This presentation will include an overview of resources that are available to the public and to science community members looking to engage the public. Scientists can get involved with UoL by signing up to provide their expertise in science content review, participate in events, and/or assist in the development of products.

08:50 AM-09:00 AM

202.03 Girl Scout Badges: Engaging Girls in Planetary Science

Pamela K. Harman[1], Wendy Chin[2], Cole Grissom[2], Wendy Friedman[4], Don McCarthy[3], Larry Lebofsky[3], Louis Mayo[5], Jean Fahy[6], Elspeth Kersh[6], Jessica Henricks[6], Vivian White[7], Theresa Summer[7]
[1]Center for Education, SET Institute, Mountain View, California, United States, [2]Girl Scouts USA, New York, New York, United States, [3]University of Arizona, Tucson, Arizona, United States, [4]Girl Scouts Research Institute, New York, New York, United States, [5]ARIES Scientific, Silver Spring, Maryland, United States, [6]Girl Scouts of Northern California, Alameda, California, United States, [7]Astronomical Society of the Pacifica, San Francisco, California, United States

Abstract

Reaching for the Stars: NASA Science for Girl Scouts (Girl Scout Stars) engages Girl Scouts in NASA planetary and astrophysics science and programs through badges and summer camps, disseminates STEM education-related resources, and fosters interaction between Girl Scouts and Subject Matter Experts (SMEs). Space science badges have been released for three levels of Girl Scouts: Daisies, Grades K-1; Brownies, Grades 2-3; and Juniors, Grades 4-5. Space science badges for Cadettes, Grades 6-8; Seniors, Grades 9-10; and Ambassadors, Grades 11-12 are scheduled for release next year. The badges consist of science activities, finding role models (SMEs), and opportunities for girls to share their findings and excitement with others. Girl Scout Stars also offers three unique training and camp experiences that support the facilitation of space science exploration at the council and troop levels: The University of Arizona holds Girl Scout volunteer and staff astronomy training; Astronomy Adventure Destination Camp, for individual girls ages 13 and older, is held at Pine Mountain Observatory, OR; and the Girl Scout Astronomy Club training at NASA Goddard where Girl Scout councils send two girls, a council volunteer, and an amateur astronomer—the girls will lead the clubs, aided by the council and amateur astronomer. This session will highlight the evaluation data, badge activities, and how SMEs can connect with their local Girl Scout council.
In Girl Scouting, girls discover their skills, talents and what they care about; connect with others in their community; and take action to change the world. This is called the Girl Scout Leadership Experience (GSLE). With girl-led, hands on activities where girls can team up and work together—they successfully achieve the five leadership outcomes: strong sense of self, positive values, challenge seeking, healthy relationships, and community problem solving. When girls exhibit these attitudes and skills, they become responsible, productive, caring, and engaged citizens. The badges' activities are aligned with these principles.

Funded by NASA:NNX16AB90A.

09:00 AM-09:10 AM

202.04 Unistellar EVscopes: Smart, Portable And Easy-To-Use Telescopes For Exploration, Interactive Learning, And Citizen Astronomy

Franck Marchis[1, 2], Emmanuel Arbouch[2], Martin Costa[1], Arnaud Malvache[2], Antonin Borot[2], Laurent Marfisi[2]
[1]SETI Institute, Mountain View, California, United States, [2]Unistellar, Marseille, France

Abstract
Unistellar is reinventing popular astronomy with the Enhanced Vision Telescope: a combination of optics, electronics, and proprietary image-processing technology to make astronomy easy, fun and interactive. In partnership with the SETI Institute, the company will build the largest network of telescopes capable of observing the sky 24/7 from everywhere on this planet.

Unistellar's Enhanced Vision Telescope is the first telescope that accumulates light so the user can finally see hundreds of faint astronomical objects in all their shapes and colors live through its lens. Because classical high end telescopes only allow the user to see the four main planets, this technology will radically transform amateur astronomy. Relying on its on-board computer, the telescope also recognizes the observed area and can guide and inform the user in real time.

Thanks to its sensitivity, the eVscope is a powerful tool capable of generating data that can be used by scientists to search for transient events like supernovae, near-earth asteroids, and comets. Because of the larger field of regard provided by a constellation of small, smart telescopes, our network could provide additional data to the few existing large telescopes. Unistellar initiated a partnership with the SETI Institute to identify and develop scientific applications for our network of telescopes.

We will summarize the technology behind the telescope and its real-time data processing, then show several recent observations, including asteroid occultations, lightcurves and astrometry of asteroids accessible to the users. Finally, we will discuss Unistellar network's potential to make citizen astronomy a reality by offering all users (newbie or experienced) a tool to explore the night sky with a powerful and reliable instrument while they contribute to scientific investigations.

09:10 AM-09:20 AM
202.05 Update on an Analog Rover Exploration Mission for Education and Outreach
Charissa Campbell[1], Christina L. Smith[1], Brittney Cooper[1], John E. Moores[1], Rachel Ward-Maxwell[2]
[1]York University , Toronto, Ontario, Canada, [2]Ontario Science Centre, Toronto, Ontario, Canada

Abstract
The analog rover exploration mission is designed as an outreach program to educate high school and undergraduate students on basic mission control operations. By simulating a rover on another planet, participants must complete science goals through remote management over the course of several sessions. As of June 2018, three iterations of this program have been completed. In our fourth trial for the Ontario Science Centre, we've made significant edits to allow flexible attendance between sessions. If successful, this program will be adaptable to different outreach scenarios.

In the previous three runs, participants were given different mission operation roles with specific responsibilities and meetings to attend. Roles included Science Planners (planning observations and drives), Rover Engineers (maintenance of instrument health) and Mission Lead (oversees entire mission). Introducing varying roles was thought to bring more discussion into the program, however, this was not the case. In every run, participants assumed more than one role to skip discussion between others. To address this, participants will be given the same role (Science Planners) while volunteers will be leadership roles. Another change in our program includes limiting the rover's traverse path. Originally,

participants would choose where to drive indicating distance and azimuthal angle. Instead, we created our own traverse path with set stop locations where participants will make the decision whether or not to include a drive.

An update will be provided after our fourth run to include any discussion and present lessons learned from this new style. By running this event at the Ontario Science Centre, we hope to gain knowledge on how to adapt this program for different scenarios and demographics.

09:20 AM-09:30 AM
202.06 Global Pro-Am Networks for Science Research and Citizen Science
Padma Yanamandra-Fisher
Research, Space Science Institute, Rancho Cucamonga, California, United States

Abstract
I present the current scenario of conflation of scientific research with amatuer astronomy and the pervasive social media; and contrast it with traditional fields of outreach. With the inclusion of amateur astronomers, educators, students, outreach coordinators and astronomy journalists; adaptation of various social media platforms and components of emerging field of citizen science, four phases for a successful pro-am collaboration were identified: (1) identification of a scientific knowledge gap; (2) integration of the pro-am communities; (3) adopt emerging technology and (4) stay in the limelight with results of the campaign. Several important results that emerged from the successful campaigns are: (i) establishment of a global network of astronomers that can be galvanized into action on short notice; (ii) provide an alert-sounding mechanism to all observers; (iii) immediate outreach and dissemination of results via our media/blogger members; (iv) provide a forum for discussions between the communities to help strategize the observing campaign for maximum benefit and (v) identify potential challenges on the data archival and its crowdsourcing. Examples of the synergy of pro-am observer communities will be showcased with The PACA Project observing campaings, from the Sun to outer planets, comets and also various observing modes and analysis techniques.

Tuesday, October 23, 2018
10:00 AM-12:05 PM
Ballroom A (Knoxville Convention Center)

203 Titan: Atmosphere, Surface and Interior
Chair(s): Catherine Neish, Emilie Royer

10:00 AM-10:10 AM
203.01 Calculation of high-level *ab initio* rate constants for key neutral–neutral reactions in low-temperature Titan conditions
Shiblee R. Barua[1, 2], Paul N. Romani[1]
[1]Planetary Sciences (Code: 693), NASA Goddard Space Flight Center, College Park, Maryland, United States, [2]Universities Space Research Association, Columbia, Maryland, United States

Abstract
The ultimate source of the complex photochemistry in Titan's upper atmosphere (70–187K) is its background neutral environment which is composed primarily of N_2 and CH_4. Previous photochemical models show that such complex chemistry is strongly influenced by neutral–neutral reactions. Global sensitivity analyses confirm that the large errors associated with the mole fractions of various compounds in the upper atmosphere of Titan originate mainly from the uncertainties in low-temperature rate constants of "key" neutral–neutral reactions. Unfortunately, accurate experimental rate constants for such low-*T* reactions are difficult, if not impossible, to measure, and the lab data are affected by uncertainties in determining the absolute concentrations of radical species. Currently, the most common theoretical approach involves uncertainty extrapolation technique in which uncertainties in room-temperature rate constants are extrapolated to low-temperature conditions, resulting in large errors in the theoretical low-*T* rate constant data. To solve this existing problem, we are employing the two-transition-state (2TS) model developed by Klippenstein and coworkers to calculate high-level *ab initio* rate-constants for key low-*T* reactions in Titan, and subsequently evaluating the mole fractions using our existing one-dimensional (1D) photochemical model. In particular, we are investigating key reactions that have not yet been studied in the lab, and for which accurate rate coefficients are still unknown. Our highly accurate theoretical rate constants will be made available to the astrochemistry community at large, and our calculated mole fractions will be used to analyze the Composite Infrared Spectrometer (CIRS) observational data which will vastly improve our current knowledge of the atmosphere of Titan.

10:10 AM-10:20 AM
203.02 Photodesorption and Photochemistry of Ices in Titan Lower Atmosphere
Benjamin Fleury[1], Murthy S. Gudipati[1], Isabelle Couturier-Tamburelli[2], Nathalie Carrasco[3]
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States, [2]Aix-Marseille University, Marseille, France, [3]LATMOS, University of Versailles Saint-Quentin, Guyancourt, France

Abstract
Complex photochemical processes are initiated in the thermosphere of Titan at about 1000 km by the dissociation and the ionization of N_2 and $CH_4$by the VUV solar photons. This leads to the formation of a number of hydrocarbons and nitrile species, which might condense in the troposphere and the lower stratosphere of Titan (<150 km) [1]. The most energetic solar photons are absorbed at higher altitude but

longer wavelength photons ($\lambda > 300$ nm) can reach these lower atmospheric layers [2]. These photons are not energetic enough to cause photochemical transformations of molecules in the gas-phase. However, molecules in the solid-phase could undergo photochemical transformation. Additionally, aerosols with longer wavelength absorption could transfer that energy to other molecules resulting in indirect photo-induced transformations as demonstrated experimentally by our recent works [3, 4, 5]. We will present here an experimental study simulating the reactivity of ices in the atmosphere of Titan and will discuss the photoreactivity occurring in the lower atmospheric layers of Titan despite the absorption of the most energetic photons.

Acknowledgments
This work is supported by NASA Solar System Workings grant " Photochemistry in Titan's Lower Atmosphere". The research work has been carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration. NC acknowledges the European Research Council for their financial support (ERC Starting Grant PRIMCHEM, grant agreement n°636829).

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[2] Tomasko, M. G., et al., *Rain, winds and haze during the Huygens probe's descent to Titan's surface*, (2005), Nature 438, 765-778.
[3] Gudipati, M. S., et al., *Photochemical activity of Titan's low-altitude condensed haze*, (2013), Nature Communications, 4: p1648.
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[5] Fleury B., et al., *Photoreactivity of condensed acetylene on Titan aerosols analogues*, (2018), under review.

10:20 AM-10:30 AM

203.03 Seasonal evolution of temperatures in Titan's lower stratosphere

Melody Sylvestre[1], Nicholas A. Teanby[1], Jan Vatant d'Ollone[3], Sandrine Vinatier[2], Bruno Bézard[2], Sébastien Lebonnois[3]
[1]School of Earth Sciences, University of Bristol, Bristol, United Kingdom, [2]LESIA - Observatoire de Paris, Meudon, France, [3]Laboratoire de Météorologie Dynamique, Paris, France

Abstract

Titan's atmosphere undergoes significant variations of insolation, due to its obliquity (26.7°) and Saturn's eccentricity (0.0565). The Cassini mission offered us the opportunity to monitor its temporal evolution from 2004 to 2017, i.e. half a Titan year, and unveiled seasonal changes of temperature and composition in the stratosphere ([1], [2], [3]). The lower part of the stratosphere (pressures greater than 10 mbar) is a region of particular interest, as there are few available temperature measurements, and its thermal response to seasonal and meridional insolation variations remains poorly known.

In this study, we measure temperatures in Titan's lower stratosphere between 6 mbar and 25 mbar using Cassini/CIRS (Composite InfraRed Spectrometer) nadir high resolution (0.5 cm-1) far-IR spectra (70-400 cm-1). These data span the whole latitude range and duration of the mission (from 2004 to 2017), thus providing an overview of the thermal structure of Titan's lower stratosphere and its evolution from northern winter to summer solstice. Our observations show that significant seasonal temperature changes occurred in Titan's lower stratosphere, especially at high latitudes. For instance, we measure a strong cooling at 70°S (-19 K at 15 mbar) from summer (2007) to late autumn (2016), similar to previous CIRS measurements between 10 mbar and 0.3 mbar ([2], [3]), and caused by enhancement of radiative coolers

of photochemical origin, due to the onset of a subsidence above the South Pole after the autumn equinox. Hence, our results show that the seasonal evolution of the atmospheric circulation also affects the lower stratosphere down to 25 mbar, via a complex interplay between dynamical, radiative, photochemical, and possibly condensation processes. Our results also show good agreement with recent GCM simulations ([4], [5]), which provide further constraints on the processes at play in the evolution of Titan's lower stratosphere.

References: [1]Vinatier et al., 2015, Icarus, 250, 95-115; [2]Coustenis et al., 2016, Icarus 270, 409; [3]Teanby et al., 2017, Icarus 202, 620-631; [4]Lebonnois et al., 2012, Icarus 218, 707-722; [5]Vatant d'Ollone et al., 2017, EGU

10:30 AM-10:40 AM

203.04 Using Far-Infrared Observations to Probe Ethane Abundance in Titan's Lower Stratosphere

Nicholas Lombardo[1, 2], Conor Nixon[1], Melody Sylvestre[3], Nicholas A. Teanby[3], Don Jennings[1], Patrick Irwin[4], Michael Flasar[1]

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Abstract

Ethane, C2H6, is an abundant constituent in Titan's atmosphere, with production pathways initiated by the photolytic destruction of methane high in the atmosphere. With a stratospheric volume mixing ratio near 10 ppmv, ethane has been a critical component in photochemical models of Titan's atmosphere. The molecule exhibits several bright mid-infrared transitions, including the v9 band from 820 to 880 cm-1, v6 and v8 bands from 1350 to 1550 cm-1, and the v1, v7 and v10 bands from 2850 to 3050 cm-1. In the far-infrared, ethane has its v4 torsional band centered at 289 cm-1. The Composite Infrared Spectrometer (CIRS) instrument on the Cassini spacecraft was sensitive to the wavenumber region between 10 and 1500 cm-1, including the v4, v6, v8, and v9 bands of ethane. In the past, CIRS data has been used to model the v6, v8, and v9 bands to determine seasonal and spatial variations in stratospheric ethane; though the opacity of these lines have hindered the ability to probe altitudes below ~100km.

With the recent release of line parameters for the weak (and relatively transparent) v4 torsional band of ethane in the Hitran database, we are able to peer deeper into Titan's stratosphere than before, extending our current knowledge of the vertical variations in the abundance of the gas. The ethane v4 band is relatively weak compared to transitions from other molecules in its spectral neighborhood. In order to be able to properly model this gas, we must increase the signal-to-noise of the v4 band sufficiently by making use of several thousand CIRS spectra. We do this by defining regions of latitude on Titan where the stratosphere can be considered relatively constant over a season, i.e. molecular abundances and temperature do not change significantly. We then reduce all CIRS spectra of certain observing geometries together for each season to a single spectrum, which we then model with the NEMESIS radiative transfer retrieval algorithm. We also model the v6 and v8 bands for the same time-latitude bins and combine the retrieved abundances to produce a profile of ethane that extends well below and above the limits constrained by modeling an individual band.

10:40 AM-10:55 AM

203.06D Titan's Atmospheric Dynamics Revealed Through Temperature and Chemical Abundance Measurements from 2012–2015 ALMA Observations

Alexander Thelen[1, 2], Conor Nixon[2], Nancy J. Chanover[1], Martin Cordiner[2, 3], Edward Molter[4], Nicholas A. Teanby[5], Patrick Irwin[6], Joseph Serigano[7], Steven Charnley[2]
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Abstract
The Atacama Large Millimeter/submillimeter Array (ALMA) has proven to be a highly capable asset to study the vast inventory of chemical species produced in Titan's N_2/CH_4 dominated atmosphere. The spatial distribution of organic trace constituents, and their variation through time, exhibits the influence of seasonal changes on Titan's atmospheric dynamics and photochemistry. Here we present the analysis of 13 short integration (~3 minute) observations of Titan used by ALMA for flux calibration from 2012 to 2015. We retrieved vertical profiles of temperature and abundance in Titan's lower stratosphere through mesosphere for three spatially independent regions by using datasets with beam sizes < 1″. We modeled CO emission lines to obtain temperature profiles between ~50–550 km, and retrieved vertical abundance profiles at similar altitudes for HCN, HC_3N, and C_3H_4; we also present abundance measurements for CH_3CN, which eluded previous observations in the IR by the Cassini orbiter. The combination of integrated flux maps of HC_3N and CH_3CN, stratospheric temperature profiles, and chemical abundances from spatially resolved observations enables us to study the circulation of Titan's middle atmosphere during northern spring. We observed increased temperatures in Titan's stratopause at high northern latitudes and a persistent northern enhancement of HCN, C_3H_4, and CH_3CN during this epoch; however, increased abundances of all molecules in the southern mesosphere, particularly HCN, and image maps of HC_3N also show evidence for enriched air circulating to the south pole. We validated these results through direct comparisons with contemporaneous Cassini observations. As the Cassini mission came to an end near Titan's summer solstice in 2017, ALMA will be a valuable resource for the continued study of Titan's atmospheric dynamics, composition, and chemistry into the future.

This research was funded by the NASA AS&ASTAR-JGFP Grant #NNX15AU59H.

10:55 AM-11:10 AM
203.07D Interpreting Sand Formation on Titan: Insight from Interparticle Forces and Mechanical Properties of Titan Organic Analogs
Xinting Yu[1], Sarah M. Horst[1], Chao He[1], Patricia McGuiggan[1], Bryan Crawford[2]
[1]Johns Hopkins University, Baltimore, Maryland, United States, [2]Nanomechanics Inc., Oak Ridge, Tennessee, United States

Abstract
Dunes on Titan have been observed by Cassini and are inferred to be made of mainly organics. However, it has been a mystery how the small photochemical aerosols particles (~1 μm) are transformed into the large, sand-sized particles (100-300 μm) on Titan's surface. We measured the interparticle forces and mechanical properties of Titan aerosol analogs (so called "tholin") to help better understand the formation of Titan sand and dunes.
We used atomic force microscopy (AFM) to measure the cohesion forces and tribocharging electrostatic forces between tholin-coated spheres and these forces between quartz spheres. We found the cohesion between the tholin-coated particles to be much larger than that between quartz spheres, and triboelectric charging could potentially induce more cohesion for tholin-coated spheres. This indicates that Titan's

sand could be formed by simple coagulation of small aerosol particles since the organics on Titan are much more stickier than silicate sand on Earth. The higher cohesion also indicates a higher threshold wind speed for transporting organic sand on Titan.
We also measured the mechanical properties of tholin and some common sands on Earth. We used nanoindentation to measure the elastic modulus, hardness, and fracture toughness of the laboratory produced tholin thin films. Tholin is shown to have much lower elastic modulus and hardness than even one of the softest sand on Earth, the white gypsum sand. Tholin also has low fracture toughness and is much more brittle compared to silicate sand. Being soft and brittle, the Titan sand may not be mechanically strong enough to transport for long distances on Titan. So the Titan sand is likely derived from where the sand dunes are located, near the equatorial regions of Titan. If sand formation is an ongoing process in the present day dunes, it is therefore unlikely to involve liquids, since the soft and brittle organic particles would be grind to dust before they reach the equator from the current lakes and seas in Titan's polar regions.
[1] Yu et al., (2017) JGR-planets, 122, 2610.
[2] Yu et al., (2018) JGR-planets, accepted.

Discussion Break

11:15 AM-11:25 AM
203.08 On the nature of Titan's north polar cap
Shannon MacKenzie[1], Elizabeth Turtle[1], Erich Karkoschka[2]
[1]Johns Hopkins Applied Physics Laboratory, Laurel, Maryland, United States, [2]University of Arizona Lunar and Planetary Lab, Tucson, Arizona, United States

Abstract
How Titan's lakes form remains a mystery. Several lake formation hypotheses (e.g. karsts) require organic sedimentary material at the poles as water ice bedrock is relatively resistant to fluvial erosion. Whether the north pole meets this requirement is not known, as the exact composition of the terrains is unknown. In this work, we characterize the near infrared properties of Titan's north polar terrain to provide new constraints on their nature. Specifically, we investigate the near infrared "cap" of material at Titan's north pole, in which many of the lakes are located. Both Cassini ISS and VIMS reveal distinct areas of higher albedo and reflectance that can be anticorrelated with RADAR backscatter. We will discuss the implications of the albedo, infrared color, and topography, and how they affect our understanding of lake formation.

11:25 AM-11:35 AM
203.09 Sunsets and Twilight as Viewed from the Surface of Titan
Jason W. Barnes[1], Shannon MacKenzie[2], Ralph Lorenz[2], Elizabeth Turtle[2]
[1]Physics, University of Idaho, Moscow, Idaho, United States, [2]JHU/APL, Laurel, Maryland, United States

Abstract
Titan's thick, hazy atmosphere leads to a complex radiative transfer environment that surface landers experience. We use a new 3D, spherical radiative transfer model, SRTC++, to calculate surface illumination as a function of solar incidence angle from noon, through sunset, and on into night twilight. Twilight illumination is highest at around 1 micron wavelength. At 0.65 microns (visible red), ambient illumination exceeds that of the Full Moon on Earth out to 30° beyond the terminator. Hence nighttime

imaging would be possible from the surface given long enough integration times. Sunsets (and sunrises) viewed in visible wavelengths on Titan resemble those in the dusty Arabian desert on Earth: the solar disk disappears well above the local horizon. Out into the infrared, the sunsets become more comparable to those typical on Earth. During the day, diffuse illumination filling in shadows maximizes at local noon owing to multiple scattering effects.

11:35 AM-11:45 AM

203.10 Characterization of Possible Two Liquid Layers in Titan Seas

Jennifer Hanley[1, 2], Jessica J. Groven[3, 2], William Grundy[1, 2], Logan A. Pearce[4, 2], Shy Dustrud[2], Gerrick E. Lindberg[2], Stephen C. Tegler[2]

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Abstract

The lakes and seas of Titan are composed primarily of methane and ethane, with the concentration of dissolved nitrogen from the atmosphere dependant on the ratio of methane to ethane, the temperature, and pressure. Previous models have predicted the existence of two liquid layers in equilibrium with the vapor phase under certain temperature and pressure conditions (e.g. Cordier et al., 2017, Nature Astronomy). Our previous experiments have confirmed the presence of the two liquid phase at colder temperatures and higher pressures than what exists on the surface of Titan. In the Astrophysical Ices Lab at Northern Arizona University, we have performed a new series of experiments to understand the conditions under which the two liquid layers will form. We have incorporated Raman spectroscopy to allow us to measure the composition of the samples. In all experiments performed so far, the lower layer is enriched in nitrogen and methane, while the upper layer is enriched in methane and ethane, although both layers have all three species present. The initial ratio of methane to ethane will control the relative volumes of the two liquids, though it does not appear to affect their compositions. Comparing to Cordier et al. (2017), we find the two liquid phase does not form at 85 K until a pressure of greater than ~1.83 bar is reached, compared to the 1.7 bar predicted. Our results show that at Titan surface pressure (1.44 bar), a mixture of methane, ethane and nitrogen will remain in one liquid down to 82 K, where it will then split into two liquids. We will present these experimental results detailing the conditions under which the two liquid phases form, as well as the composition of the liquids. These results can inform whether they might occur on Titan, and how that might impact understanding of previous mission results from Cassini, as well as future missions, and guide current theoretical models.

11:45 AM-11:55 AM

203.11 Experimental Studies of Evaporites on Titan

Ellen Czaplinski, Kendra Farnsworth, Vincent Chevrier

Space and Planetary Sciences, University of Arkansas, Fayetteville, Arkansas, United States

Abstract

Titan has an abundance of lakes and seas, as identified by Cassini. Major components of these liquid bodies include methane (CH_4) and ethane (C_2H_6), however, evidence indicates that minor components (ethylene (C_2H_4), benzene (C_6H_6), acetylene (C_2H_2)) also comprise the lakes. As the lakes and seas evaporate, 5-µm-bright deposits, resembling evaporite deposits on Earth, are left behind as “bathtub rings” structures [1]. Current studies focus on models and theoretical work of evaporites [2,3], observations of the 5-µm-bright regions, and experimental studies of evaporites [4-6], but much is still

unknown about their formation and composition.

Our work focuses on experimental investigations of evaporites in order to determine their composition and infrared spectra during evaporation. Gaseous hydrocarbons (CH_4 and C_2H_6) are condensed within our simulation chamber as solvents, while additional compounds (C_2H_4, C_6H_6, and C_2H_2) act as a solute. After dissolution and evaporation of various mixtures of these solvents and solutes at Titan surface conditions (~90 K, 1.5 bar N_2), the mixtures are then analyzed with FTIR spectroscopy (1 - 5 μm) for the appearance/persistence of new absorption bands.

We present results for three potential evaporite species: C_2H_4, C_6H_6, and C_2H_2. Spectra from C_2H_4 experiments show that at 90 K, evaporite formation only occurs with CH_4, indicating that C_2H_4 evaporites may be confined to CH_4-dominated lakes on Titan. We observe the appearance of a new absorption band in the C_2H_6/C_6H_6 spectra only when warming the mixture to ~120 K, then cooling back to 90 K. This band could represent the formation of a co-crystal [5,6], but is currently under further investigation. We have not observed the appearance of new bands in spectra from C_2H_2 experiments at 90 K, however we do observe three distinct ice phases of C_2H_2.

References:
[1] Barnes, J. et al. 2009a, Icarus, 201, 217-225
[2] Cordier, D. et al. 2013, Icarus, 226, 1431-1437
[3] Cordier, D. et al. 2016, Icarus, 270, 41-56
[4] Singh, S. et al. 2017, GCA, 208, 86-101
[5] Cable, M. et al. 2014, GRL, 41, 5396-5401
[6] Cable, M. et al. 2018, ACS Earth Space Chem. 2, 366-375

Acknowledgements:
This work was funded by NESSF grant 17-PLANET17F-0092

11:55 AM-12:05 PM
203.12D Constraining Ethane Concentration in Titan's Lakes and Seas
Kendra K. Farnsworth[1], Jason Soderblom[2], Sebastien Rodriguez[3], Vincent Chevrier[1]
[1]Space and Planetary Science, University of Arkansas, Fayetteville, Arkansas, United States, [2]Massachusetts Institute of Technology, Cambridge, Massachusetts, United States, [3]Universite Paris Diderot, Paris, France

Abstract
Titan has numerous hydrocarbon lakes and seas on its surface. Photochemical models predict that these bodies should contain significant amounts of ethane, along with methane and dissolved nitrogen. The precise composition of these lakes, however, is difficult to determine without in-situ measurements. Cassini VIMS spectra indicate the presence of ethane in Ontario Lacus (Brown et al., 2008, *Nature*) and at least some lakes/seas in the north (L. Soderblom, pers. comm.), though these studies were unable to estimate the amount of ethane. Cassini RADAR measurements of bulk liquid absorptivity coupled with laboratory measurements (Mitchell et al., 2015, GRL), contradict model predictions by suggesting many of Titan's larger seas are predominately methane, with small amounts of ethane (Mastrogiueppe et al., 2016, *IEEE Trans. Geosci.*; 2018, *Icarus*; 2018, *EPSL*). For example, RADAR estimates Ligia Mare, Punga Mare and Ontario Lacus to be 71/12/17%, 80/0/20%, and 51/38/11% methane/ethane/nitrogen mole percent, respectively.
Here, we provide constraint on the lower limit of ethane concentration in the lakes for which VIMS spectra have revealed infrared absorption features consistent with liquid ethane. These include Ontario

Lacus, the northern seas, and at least some of the northern lakes (the smaller lakes are difficult to investigate via VIMS spectra as multiple-scattering in Titan's atmosphere causes "cross-talk" between the small lakes and surrounding shore). These results will better constrain the concentration of ethane in Titan lakes, thereby furthering our understanding of Titan's hydrocarbon budget and lake evolution models.

Tuesday, October 23, 2018
10:00 AM-12:05 PM
Ballroom B (Knoxville Convention Center)

204 Comet Physical Characteristics: Comae
Chair(s): Alessondra Springmann, Adeline Gicquel

10:00 AM-10:10 AM
204.01 Strong emission of CO in comet C/2016 R2 (PANSTARRS)
Kacper Wierzchos, Maria Womack
Physics, University of South Florida, Ft Lauderdale, Florida, United States

Abstract
We report spectroscopic observations of comet C/2016 R2 (PANSTARRS) between 2017 December and 2018 January with the Arizona Radio Observatory 10m Submillimeter Telescope. A very strong CO (2-1) emission line was detected at 230 GHz with amounts high enough to drive the activity of the comet. The CO line was thin with $\Delta V_{FWHM} \sim 0.8$ km s^{-1} and was slightly blue-shifted by -0.1 km s^{-1}. We derived a CO gas expansion velocity of $v_{exp} = 0.50 \pm 0.15$ km s^{-1} and a production rate of Q(CO) = $(4.6 \pm 0.4) \times 10^{28}$ mol s^{-1} when the comet was at r ~ 2.9 au and Δ ~ 2.1 au. We note that this comet is very CO-rich, producing almost half the CO that comet C/1995 O1 (Hale–Bopp) produced at 3 au.
In comparison to Q(CO) values of C/1995 O1 (Hale-Bopp) and C/2006 W3 (Christensen) at 3 au, we derive an upper limit for the nucleus size of $R_{R2} \sim 15$ km, assuming that CO production scales with nucleus surface area. We derived a 3-sigma upper limit of Q(HCN) < 8×10^{24} mol s^{-1} from our observations, from which we derive Q(CO)/Q(HCN) > 5000, which is the highest value recorded for any comet. We also performed a CO (2-1) map of the coma and the data are consistent with CO arising from a combination of a sunward-side active area and an isotropic source.

10:10 AM-10:20 AM
204.02 The Volatile Composition of CO-Dominated Comet C/2016 R2 (PANSTARRS)
Adam McKay[1], Michael DiSanti[2], Michael S. Kelley[3], Anita Cochran[4], Neil Dello Russo[5], Geronimo Villanueva[2], Maria Womack[6], Kacper Wierzchos[6], Nicolas Biver[7], James Bauer[3], Olga Harrington[6], Ron J. Vervack[5], Boncho Bonev[8], Erika Gibb[9], Nathan Roth[9], Hideyo Kawakita[10]
[1]NASA GSFC/USRA, Silver Spring, Maryland, United States, [2]NASA GSFC, Greenbelt, Maryland, United States, [3]University of Maryland, College Park, Maryland, United States, [4]University of Texas at Austin/McDonald Observatory, Austin, Texas, United States, [5]Johns Hopkins Applied Physics Laboratory, Laurel, Maryland, United States, [6]University of South Florida, Tampa, Florida, United States, [7]Observatoire de Paris, Meudon, France, [8]American University, Washington, District of Columbia, United States, [9]University of Missouri St. Louis, St. Louis, Missouri, United States, [10]Kyoto Sangyo University, Kyoto, Japan

Abstract
In December 2017 we obtained spectra of comet C/2016 R2 (PanSTARRS) that were extremely atypical for comets observed at optical wavelengths. Usually dominated by neutral species such as CN and C_2, the optical spectrum of C/2016 R2 was devoid of these features and was instead dominated by ionic emissions from $CO^+$and N_2^+, with the N_2^+ detection being the most secure detection of N_2^+ in a comet obtained in the age of digital detectors (Cochran and McKay 2018). Sub-mm observations showed strong

CO emission (Wierzchos and Womack 2018, de Val Borro et al. 2018, N. Biver submitted), confirming the hypervolatile-rich nature of this comet suggested by the optical spectra.
We present additional observations of comet C/2016 R2 (PanSTARRS) obtained with the IRAC instrument on the Spitzer Space Telescope, iSHELL on the NASA IRTF, ARCES at Apache Point Observatory (APO), and the Tull Coude Spectrograph and the Prime Focus Corrector (PFC) at McDonald Observatory aimed at characterizing the volatile composition of this unusual comet. We report detections of four species (CO, CH_4, CO_2, and N_2^+) and provide sensitive upper limits on six other species (C_2H_6, CH_3OH, H_2CO, CN, NH_2, and OH). CN is employed as a proxy for HCN, NH_2 for NH_3, N_2^+ for N_2, and OH for H_2O. For all detected species, we measure strong enhancements relative to our derived H_2O upper limit by one to two orders of magnitude compared to other comets observed to date. All species are heavily depleted relative to CO compared to other comets, except N_2, which is enhanced. Unlike all other comets for which constraints on HCN, NH_3, and N_2 are available, N_2 seems to be the dominant nitrogen-bearing volatile in C/2016 R2. We will discuss our measured abundances of key species and discuss implications for the chemistry in the early Solar System.
This work makes use of Director's Discretionary Time observations obtained on Spitzer, IRTF, and APO, and we thank these observatories for granting our group DDT time to conduct these observations. This work is funded through the NASA NPP program, administered by USRA, as well as the National Science Foundation and the NASA Solar System Observations Program.

10:20 AM-10:30 AM
204.03 Multi-epoch CO mapping of the hypervolatile-rich comet C/2016 R2 (PanSTARRS)
Martin Cordiner[1], Chunhua Qi[2], Iain Coulson[3], Stefanie N. Milam[1], Yi-Jehng Kuan[4], Steven Charnley[1]
[1]NASA Goddard Space Flight Center, Greenbelt, Maryland, United States, [2]Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts, United States, [3]East Asian Observatory, Hilo, Hawaii, United States, [4]NTNU, Taipei, Taiwan

Abstract
Comet C/2016 R2 (PanSTARRS) is one of the most chemically unusual comets ever observed. Optical and radio observations during the comet's 2017-2018 apparition have revealed some of the strongest outgassing rates for hypervolatiles in any comet to-date, including N2+, CO+ and CO, providing a rare opportunity for detailed mapping of the (usually weak) CO rotational emission. Here we present the results of our campaign to characterise the CO distribution in the coma of R2/PanSTARRS on large (100") spatial scales using the single-dish JCMT and SMT mm/sub-mm facilities, and on small (5") spatial scales using the SMA interferometer. Multi-epoch observations of the CO J=3-2 and 2-1 lines were carried out during the period 2018 Jan 10 to Feb 21, allowing the temporal evolution of the CO emission to be monitored. High spectral resolution facilitated the derivation of accurate outflow velocities, with CO production rates calculated using a newly-developed Monte Carlo radiative transfer model. Upper limits were obtained for the HCN, H2CO, CS and CH3OH production rates. The unusual, CO-rich nature of this comet will be discussed with respect to theories regarding the origin and evolution of cometary ices during the earliest history of the Solar System.

10:30 AM-10:40 AM
204.04 A coordinated ground- and space-based observing campaign to measure CO_2 and CO emission in C/2016 R2 (PANSTARRS)
Olga Harrington Pinto[1], Adam McKay[2, 3], Michael A. DiSanti[2], Michael S. Kelley[4], Anita Cochran[5], Neil Dello Russo[6], Maria Womack[1], Kacper Wierzchos[1], Nicolas Biver[7], James Bauer[4], Ron J. Vervack[6], Boncho Bonev[8], Erika Gibb[9], Nathan Roth[9], Hideyo Kawakita[10]

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Abstract
Comets are similar to time capsules in that they give hints as to how the solar system looked when it was forming. They are composed of rock, dust, water ice, frozen carbon dioxide, carbon monoxide, methane, and ammonia, where there is typically more carbon dioxide than carbon monoxide. Comet C/2016 R2 was a special example of a comet that produced an unusual chemical composition profile: a great deal of CO, CO+, N_2+ with very little else (McKay et al. 2018; Wierzchos & Womack 2018; Biver et al. 2018). In order to measure both the CO and CO_2 production rates, we carried out a coordinated observing campaign using the Arizona Radio Observatory Submillimeter 10-m telescope, the IRAC instrument on the Spitzer Space Telescope, iSHELL on the NASA IRTF, and the Institut de Radioastronomie de Millimetrique 30-m telescope during January-February 2018. While CO can be studied from the ground, CO_2 can only be observed from space because of heavy telluric interference. CO was strongly detected from the ground-based spectra and there is a very strong presence of gaseous emission in the 4.5 micron IRAC channel, which is sensitive to both CO_2 and CO emission. We completed a comprehensive analysis of the SMT, iSHELL, and IRAM observations of CO in order to estimate the CO contribution to the observed Spitzer 4.5 micron channel fluxes, which is crucial to derive the CO_2 abundance from the Spitzer imaging. We will discuss our derived abundances of CO and CO_2 and our plan to determine whether there is any heliocentric variation evident in the ratio of the two species over the next year.

This work makes use of Director's Discretionary Time observations obtained on Spitzer, IRTF, ARO, and IRAM, and we thank these observatories for granting our group DDT time to conduct these observations. This work is funded through the NASA NPP program, administered by USRA, by NSF grant AST-1615917 to M.W. and a Genshaft Fellowship to O.H.P.

10:40 AM-10:50 AM
204.05 CO+CO_2 Production with the Reactivated NEOWISE Mission
James Bauer[1], A. Mainzer[2], Emily Kramer[2], Tommy Grav[3], Joseph Masiero[2], Yanga Fernandez[4], Michael S. Kelley[1], Silvia Protopapa[5], Timothy Spahr[6], Karen Meech[7], Dave G. Milewski[8], E. Wright[9]
[1]Astronomy, University of Maryland, College Park, Maryland, United States, [2]Jet Propulsion Laboratory, Pasadena, California, United States, [3]Planetary Science Institute, Tucson, Arizona, United States, [4]Dept. of Physics, University of Central Florida, Orlando, Florida, United States, [5]Southwest Research Insititute, Boulder, Colorado, United States, [6]NEO Sciences, Malborough, Massachusetts, United States, [7]University of Hawaii, Institute for Astronomy, Manoa, Hawaii, United States, [8]Dept. of Earth, Planetary, and Space Sciences, University of California, Los Angeles, Los Angeles, California, United States, [9]Dept. of Physics and Astronomy, UCLA, Los Angeles, California, United States

Abstract
The WISE spacecraft was launched on December 14, 2009, and from January 20 through August 4 of 2010, during the "fully-cryogenic" phase of the WISE mission, the spacecraft surveyed the entire sky simultaneously at four wavelengths: 3.4, 4,6, 12, and 22 μm. Over the course of the prime survey conducted in 2010 and 2011, over 164 comets were detected, providing flux measurements that yielded values of CO+CO_2 production, dust production, and comet nucleus sizes for the majority of comets

observed [1].
In November of 2013, the WISE spacecraft was re-activated, renamed NEOWISE, and began again to survey the sky at roughly 6 month intervals. Now in its 5th year of the reactivated mission, the survey continues to the present. As it continues into its 10th coverage of the sky in the WISE spacecraft's two shortest wavelength channels, and the reactivated NEOWISE spacecraft has detected over 150 comets, approaching a comparably large census number of cometary bodies as the prime mission. The reactivated mission data differ in several key aspects from the kind of comet data provided over the course of the cryo phases of the prime mission. Though nearly as sensitive as the post-cryo mission phase [2], the reactivated NEOWISE data span 9 complete sky coverages and provide multiple visits of most of the comets observed. The fraction of the detections that provide constraints on $CO+CO_2$ production is larger [3,4].
We will provide an overview of the reactivated mission comet $CO+CO_2$ production rate analyses, with focus on the first two years of the mission, while placing constraints on activity of particular comets of interest that have been detected by NEOWISE, like the long-period comet C/2016 R2 (PANSTARRS) and the hyperbolic comet C/2017 K2 (PANSTARRS). We will also discuss what future analyses will provide.
References: [1] Bauer et al. 2017. AJ, .154, 53 [2] Mainzer et al. 2014. ApJ 792, 30. [3] Rosser et al. 2018, AJ 155, 164. [4] Bauer et al. 2015. ApJ, 814, 85. [5] Masiero et al. 2017. AJ 154, 168.

10:50 AM-11:00 AM
204.06 Constraining the Physical Properties and Activity of 3 Unique Comets: 2009 MS9, C/2016 VZ18, and C/2016 R2
Erica Bufanda[1], Karen Meech[1], Charles Schambeau[2], Gal Sarid[2], Olivier Hainaut[3], Jan T. Kleyna[1], Jacqueline V. Keane[1], James Bauer[4], Larry Denneau[1], Bhuwan Bhatt[5], Devendra Sahu[5]
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Abstract
We will report on an investigation of the physical characteristics of three unique, dynamically different small bodies: 2009 MS9, C/2016 VZ18 (PANSTARRS), and C2016 R2 (PANSTARRS), in order to understand their origins, evolution, and roles in solar system growth. We characterize each comet's physical properties and investigate potential ice sublimation using several methods including analysis of dust and coma dynamics with composite images, quantifying changes in photometry with sublimation and thermodynamic models, and calculating spectral reflectivity to determine surface material composition and likely asteroid class. 2009 MS9 has q = 10.99 au, Q =707.17 au and passed perihelion in Feb. 2013. Broadband photometry suggested that it might be brighter after perihelion than would be expected from geometry and rotation alone. Data from NEOWISE estimates a radius of 11.5 km for 2009 MS9. We did not detect any significant activity and can place strong upper limits on the amount of outgassing. With q = 0.91 au and Q = 388.3, C/2016 VZ18 is classified as a long period comet. However at the time of its discovery it was inactive (r=5.8 au) and did not develop noticeable coma until it was inside 1 au. We thus considered it a Manx candidate, or a long period comet with no or with unusually low sublimation activity. Manxes have the potential to help us constrain solar system formation models. We will present a thermal model of the activity of C/2016 VZ18 around 1 au, which suggests that the volatiles were at some depth beneath the surface. C/2016 R2 is a long period comet, apparently rich in CO or CO2. Our models of the activity for this comet can be used to help constrain the nucleus size and relative abundances of H2O, CO and CO2. We will report on the results of this analysis and discuss how it can be used to provide insight about the distribution of volatiles in the early solar system. This work is supported by NSF grants AST1413736 and AST1617015.

11:00 AM-11:10 AM

204.07 Ultra-Distant Activity in Comet C/2017 K2 (PANSTARRS)

Man-To Hui
Earth Planetary and Space Sciences, UCLA, Los Angeles, California, United States

Abstract

C/2017 K2 (PANSTARRS; hereafter "K2") is an inbound Oort cloud comet exhibiting activity at least from 23.7 AU, a record heliocentric distance. We are studying the development of the activity using the Hubble Space Telescope and data scoured from the electronic archives. Our HST observations since 2017 June reveal a circularly symmetric dust coma ~10^5 km in radius, with a total effective cross-section ~10^5 km^2. The coma logarithmic surface brightness gradient is -1.01±0.01, consistent with the value expected for steady-state mass loss. The absence of a radiation-pressure caused tail suggests that the average ejected dust size is very large. Our Monte Carlo simulations indicate a mean dust diameter of ~1 mm, and an ejection speed of only a few m/s. We estimate the nucleus to be several kilometers in radius. Activity in K2, which we find is losing mass at ~10^2 kg/s, cannot be driven by the sublimation or crystallization of water ice. Instead, the sublimation of supervolatiles including CO and CO_2 is suspected. Our numerical integrations show that the previous perihelion occurred >1 Myr ago, and therefore no heat from the prior orbit can be retained. Continuing observations will probe the development of activity as K2 approaches the Sun.

This work has been published as:

Jewitt et al. (2017). A Comet Active Beyond the Crystallization Zone. Ap.J.Lett., 847, L19.

Hui et al. (2018). Prediscovery Observations and Orbit of Comet C/2017 K2 (PANSTARRS). AJ, 155:25.

11:10 AM-11:20 AM

204.08 Temporal Evolution of the Sunward Dust Feature of Comet 41P/Tuttle–Giacobini–Kresák

Cassandra Lejoly[1], Nalin H. Samarasinha[2], Beatrice E. Mueller[2], Walter Harris[1], Alessondra Springmann[1], Ellen Howell[1], Erin Ryan[3], Julia Bodnarik[1], Adriana M. Mitchell[1], Zachary Watson[1]
[1]University of Arizona, Tucson, Arizona, United States, [2]Planetary Science Institute, Tucson, Arizona, United States, [3]NASA Goddard, Greenbelt, Maryland, United States

Abstract

We observed 41P/Tuttle–Giacobini–Kresák (41P/TGK), as part of a larger Jupiter Family Comet campaign, in the spring of 2017, at a geocentric range of 0.14-0.20 au. We used visible continuum filters at the Bok 90" telescope and Vatican Advanced Technology Telescope as a proxy for dust measurements. Data from April 6th, 2017 to May 5th, 2017 were analyzed to characterize the sunward dust feature of 41P/TGK surrounding perihelion (April 12th, 2017). Obtaining data at such close geocentric distances allows us to probe the inner coma features of 41P/TGK, an opportunity rarely achieved from ground-based measurements.

The sunward feature of 41P/TGK was monitored through time and analyzed for position angle (PA) changes to characterize the sunward feature's spatial and temporal variations. From preliminary results of data from the Bok 90" data taken April 6-11, 2017, we see only minor changes in the PA of the sunward feature with respect to the sun. The PA of the sunward feature appears to be nearly aligned with the sunward direction with the PA offsets with the sunward direction ranging from -2° to 20°. Additionally, there does not appear to be strong periodical oscillations over the observed PAs. This feature has minimal curvature. These observations suggest a feature originating from a small sunward source region with

spatial smearing of the feature due to radial velocity dispersion (which effectively erase most if not all rotational signatures), or possible outgassing from a much larger region on the sunward hemisphere of the nucleus. We will present further analysis of the possible source region.

11:20 AM-11:30 AM

204.09 Continuous Monitoring of Spatial Variations in 103P/Hartley 2's Volatiles from Deep Impact

Carrie Holt, Jessica Sunshine, Lori Feaga, Tony Farnham
Astronomy, University of Maryland, College Park, Maryland, United States

Abstract

During its extended mission, the Deep Impact spacecraft flew by the hyperactive comet 103P/Hartley 2 on November 4th, 2010. Spectral maps of the innermost coma were created from the High Resolution Instrument infrared spectrometer (HRI-IR; 1-5 µm) data. The dominant detected volatile species, water (2.7 µm) and carbon dioxide (4.3 µm), were found to have different spatial distributions near closest approach, suggesting the source of the volatiles are distinct (A'Hearn *et al.*, *Science*, 2011). Expanding on previous closest approach studies (Sunshine *et al.*, DPS, 2013 and Feaga *et al.*, ACM, 2014), spatial and temporal variations of water and carbon dioxide in the coma are examined throughout the 23 days of continuous observations around closest approach from scans collected every 15 minutes to every hour. Both of the volatiles vary over a primary rotational period of ~18 hours and the complex rotational period of ~55 hours (Belton *et al.*, *Icarus*, 2013) resulting in triple-peaked light curves. However, the water and carbon dioxide light curves differ. The spatial distributions of the volatiles are used to interpret the light curves and better constrain Hartley 2's rotation. Correlations of varying volatile activity with respect to sources on the nucleus and in the coma with the shape and features of the nucleus, rotation, and illumination are also investigated. This unique data set provides continuous monitoring of Hartley 2 over very short timescales for an extended period of time. The Deep Impact Hartley 2 data therefore have implications for the interpretation of observations of other comets, which are snapshots acquired less frequently and thus cannot resolve rotational variations as seen here.

11:30 AM-11:40 AM

204.10 Modeling the large-grain (>2 cm) coma of comet 45P/Honda–Mrkos–Pajdušáková from Arecibo Observatory radar observations

Alessondra Springmann[1], Ellen Howell[1], Michael C. Nolan[1], Cassandra Lejoly[1], Patrick A. Taylor[2], Edgard G. Rivera-Valentin[2], Anne Virkki[3, 4], Luisa Zambrano-Marin[3, 4], Walter Harris[1], John Harmon[5], Carolina Rodriguez Sanchez-Vahamonde[6]
[1]Lunar & Planetary , University of Arizona, Tucson, Arizona, United States, [2]Lunar and Planetary Institute, Houston, Texas, United States, [3]Arecibo Observatory, Arecibo, Puerto Rico, United States, [4]University of Central Florida, Orlando, Florida, United States, [5]Retired, Spokane, Washington, United States, [6]Western University, London, Ontario, Canada

Abstract

Comet 45P/Honda–Mrkos–Pajdušáková (45P), a Jupiter family comet, passed within 32 lunar distances of Earth on 11 February 2017. This close approach to Earth enables measurement of the dust particle sizes in multiple wavelengths from ground-based telescopes as part of a coordinated observing campaign. Visible wavelength observations provide size information for micron-scale particles in the coma and radar observations can constrain the distribution of particles larger than 2 cm in diameter in the inner coma region. We will present radar observations of comet 45P, taken 9-16 February 2017 at Arecibo Observatory. A polarized, 12.6-cm wavelength continuous radio wave was transmitted at the comet and

returned echoes observed. Analysis of the radar echoes showed 15% depolarization, consistent with scattering off of 2 cm and larger particles in the coma. Modelling large grains ejected from the surface of 45P (using the methods of Harmon et al. 1989) will constrain the size-frequency distribution of large grains in the coma as well as constrain particle ejection direction and velocities.

11:40 AM-11:50 AM

204.11 Quantifying the Evolution of Molecular Composition of comet 21P/Giacobini-Zinner

Sara Faggi[1], Michael Mumma[1], Geronimo Villanueva[1], Lucas Paganini[1, 2], Manuela Lippi[1, 3]

[1]Solar System Exploration Division, Code 690, NASA Goddard Space Flight Center, Greenbelt, Maryland, United States, [2]Catholic University of America, Washington , District of Columbia, United States, [3]American University, Washington, District of Columbia, United States

Abstract

21P/Giacobini-Zinner has been described as one of the brighter comets of Jupiter's dynamical family. Optical observations of free radicals showed that 21P/G-Z was severely depleted in C_2relative to CN, leading to a dichotomy in the carbon chemistry of Jupiter family comets and identifying 21P as the prototype of depleted comets (A'Hearn et al. 1995).

21P/G-Z has been observed previously at infrared wavelengths, but a characterization of its volatile composition is far from complete (Weaver et al. 1999; Mumma et al. 2000; DiSanti et al. 2013). We present here the evolution of high-resolution spectra of 21P/GZ acquired as it approached perihelion using iSHELL - the near-IR high resolution immersion echelle spectrograph on NASA/IRTF (Mauna Kea, Hawaii). The individual iSHELL settings cover very wide spectral range with very high accuracy, eliminating many sources of systematic errors when retrieving molecular abundances.

We targeted many cometary emission lines across 4 customized instrument settings (L1-c, L3, Lp1-c and M1) in the (2.9 – 5) mm range. The bright and peculiar composition of comet 21P/GZ combined with the capabilities of iSHELL provided interesting results.

We searched fluorescence emission from HCN, C_2H_2, water, prompt emission from OH, and many other features in L1-c (2.85 – 3.1 mm). Methane, ethane and methanol were targeted both in L3 and Lp1 settings. These species are relevant to astrobiology, owing to questions regarding the origin of pre-biotic organics and water on terrestrial planets.

In M1 (near 5mm), we targeted multiple ro-vibrational lines of H_2O, CO and the (X-X) system of CN. We will report quantitative abundances for CN and will address its origin by comparing with quantitative production rates for HCN. The ability to quantify both primary and product species eliminates systematic error that may be introduced when measurements are acquired with different astronomical techniques and instruments.

A'Hearn et al. 1995. Icarus 118, 223.

DiSanti et al. 2013. ApJ 763:1 (19pp).

Mumma et al. 2000. ApJ 531:L155.

Weaver et al. 1999. Icarus 142, 482.

11:50 AM-12:05 PM

204.12D Characterizing Comets in the Centaur-to-Jupiter Family Transition

Charles Schambeau[1], Yanga Fernandez[1], Laura Woodney[2], Nalin Samarasinha[3], Karen Meech[4], Matthew Knight[5], Maria Womack[6], Gal Sarid[1], Iris Hernandez[2], John Montano[2], Brynn Presler-Marshall[7]

[1]Physics, University of Central Florida, Winter Park, Florida, United States, [2]California State University San Bernardino, San Bernardino, California, United States, [3]Planetary Science Institute, Tucson, Arizona, United States, [4]Institute for Astronomy, Honolulu, Hawaii, United States, [5]University of Maryland, College Park, Maryland, United States, [6]University of South Florida, Tampa, Florida, United States, [7]Agnes Scott College, Decatur, Georgia, United States

Abstract
We present results from an ongoing observing campaign to characterize activity patterns and nucleus properties of Jupiter Family comets (JFCs) with perihelion distances $q > 4.5$ au and active Centaurs by acquiring long-baseline visible imaging and millimeter wavelength spectra. The active lifetimes of JFCs often start when they are still in the Centaur region [1, 2, 3], yet the transition from Centaur to JFC happens in a region where water sublimation cannot be the driver of the activity [4]. The presence of cometary activity beyond the historically established distance for strong water sublimation near 3 au has been well documented [3, 5], but the observational dataset for most distantly active comets has been sparse, limiting our ability to fully understand the transition region from the outer to inner Solar System. We have acquired nightly broadband imaging during 6 week-long observing runs over the course of two years for JFCs 158P, P/2011 U2, and P/2016 A3 and Centaurs C/2013 C2, P/2015 M2, and C/2016 Q4 using the KPNO WIYN 0.9-m and CTIO SMARTS 0.9-m telescopes. Objects P/2011 U2, P/2015 M2, and P/2016 A3 were active between heliocentric distances 5.53-5.63 au, 5.96-6.56 au, and 4.79-5.17 au respectively and we report their absolute magnitudes, dust-production rates, active fractions, and coma morphology. For objects 158P, C/2013 C2, and C/2016 Q4 no activity was detected between heliocentric distances 4.81-4.88 au, 9.18-9.84 au, and 7.08-7.73 au respectively and we report nucleus size measurements, surface spectral slopes, and spin-period measurements. We additionally present preliminary thermophysical modeling results for the sample of objects to constrain plausible volatile species that could be driving the distant activity.

[1] Mazzotta Epifani et al. 2007, *MNRAS*, **381**, 713-722. [2] Jewitt, D.: 2009, *ApJ*, 137:4296-4312. [3] Meech, K.J., et al.: 2009, *Icarus*, **201**, 719-739. [4] Meech, K.J. & Svoren, J.: 2004, *Comets II*, Univ. AZ Press, 317-335. [5] Kelley, M., et al.: 2013, *Icarus*, **225**, 475-494. Based on observations at CTIO and KPNO, NOAO, which is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation.

Tuesday, October 23, 2018
10:00 AM-12:00 PM
Ballroom C (Knoxville Convention Center)

205 Historical Astronomy
Chair(s): Jay Pasachoff, Catherine B. Olkin

10:00 AM-10:25 AM
205.01 Cassini/Huygens Mission to Saturn: from Dream to Reality
Linda J. Spilker
Jet Propulsion Laboratory, Monrovia, California, United States

Abstract
Cassini's story was shaped by two Voyager flybys of Saturn in the early 1980's. Voyager performed detailed observations of the Saturn system and Voyager 1 flew close to the giant moon Titan. Unfortunately, none of the Voyager instruments were able to pierce through Titan's thick photochemical haze and view its surface, one of Voyager's key goals at Saturn. Almost immediately, a group of scientists began to plan a return trip, including a Saturn orbiter and a probe to parachute through Titan's atmosphere and land on its surface. Toby Owen, Daniel Gautier and Wing Ip formed a special collaboration to push for this new mission.

The international collaboration between NASA, the European Space Agency (ESA) and the Italian Space Agency (ASI) resulted in the Cassini/Huygens mission, a complex technological achievement with shared investment and participation. Science instruments were selected in 1990 and Cassini/Huygens was launched in 1997. After a 7-year, 2.2 billion-mile journey from Earth, Cassini arrived at Saturn and dropped a parachuted probe named Huygens to study the atmosphere and surface of Titan.
For 13 years Cassini circled Saturn, making astonishing discoveries about the planet, moons and rings. Cassini examined the Saturn system in greater depth than ever before and shed light on many of the mysteries uncovered by Voyager. Navigators carefully crafted a series of orbital tours for each of Cassini's mission phases. Scientists debated and decided on key science goals for the mission, and implemented them. Low on fuel, the mission ended with a fiery plunge into Saturn's atmosphere on September 15, 2017.

The history of the Cassini/Huygens mission will be discussed.

The research described in this paper was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

10:25 AM-10:50 AM
205.02 The history of the Cassini-Huygens Mission from historical origins until its successful launch in 1997.
Darrell F. Strobel
Earth and Planetary Sciences/ Physics and Astronomy, Johns Hopkins University, Baltimore, Maryland, United States

Abstract
The historical origins of the Cassini mission can be traced back to the Space Science Board (SSB) [Space Studies Board as of 1989] of the National Research Council (NRC) and its Committee on Planetary and Lunar Exploration (COMPLEX), which recommended in its 1975 report an in-depth exploration of the Saturnian system subsequent to the Pioneer and Voyager flyby encounters. The Cassini mission was a complex undertaking involving 16 European countries and the United States in supplying technology, hardware, software, and engineering and scientific expertise. To carry out this cooperative venture, a number of agreements were formalized, including (1) an MOU between NASA and ESA signed on December 17, 1990, and (2) an MOU between NASA and ASI signed on June 14, 1993 (an agency-to-agency agreement); to secure funding, this was elevated to a government-to-government agreement via the exchange of diplomatic notes in mid-1994, for design, development, and delivery of four Cassini orbiter components. The Cassini mission in its sink-or-swim-together mode generated strong "lobbying and support" efforts on both sides of the Atlantic. This partnership ensured that the importance attached to this cooperative enterprise was communicated to individual space agencies, ESA, and the U.S. government. In particular, the European lobbying and support effort was extremely important and effective in attaining a new U.S. start for Cassini in FY 1990 and averting near cancellation of the Cassini mission during FY 1994. The letter from ESA Director General Luton to U.S. Vice President Gore was an essential action at a crucial stage in the mission and illustrates the potential, importance of international cooperation for mission success. The successful launch of Cassini-Huygens was regarded as a miracle by some involved in the mission: The mission was very ambitious and its implementation was risky.

10:50 AM-11:15 AM
205.03 Huygens: Sending a probe to the unknown surface of an icy moon
Jonathan Lunine
Cornell University , Ithaca , New York, United States

Abstract
The Huygens Probe part of the Cassini-Huygens mission involved the atmospheric entry and descent to Titan's surface of a well-instrumented spacecraft designed and built by the European Space Agency (ESA). This was a remarkable accomplishment; not since the early Soviet and US entry probe missions to the surface of Venus was so little known about the environment within which a probe would have to function. Discussion of a mission to Saturn, with a Titan surface probe relaying data to the main spacecraft, goes back at least to the 1970's, before the basic nature of Titan's atmosphere was revealed by the 1980 close flyby of Voyager 1. That flyby, which indicated a thick nitrogen atmosphere replete with methane and layers of organic haze, overlying an as yet mysterious surface, energized scientific interest in an entry probe as well as a general examination of Titan as part of a Saturn system mission. This would come to be by the end of the 1980's as the Cassini-Huygens mission, with NASA responsible for the Saturn Orbiter, ESA for the Huygens probe, the Italian Space Agency (ASI) for large parts of the Orbiter telecomm system, and trans-Atlantic consortia for each of the instruments on Saturn Orbiter and Huygens probe.

Development of the Huygens probe and its instruments was remarkable in a number of respects: (a) it required close international cooperation not only in instruments but in spacecraft development as well, since significant Huygens hardware was included on the U.S.-built Saturn orbiter; (b) scientists were heavily involved in various aspects of the engineering of the Huygens probe and its mission design because so much depended on understanding of Titan's atmosphere, which was in flux during development; (c) interest in Titan surface science from Huygens resulted in a constant tension between scientists and project engineers, the latter committed to returning data from the atmosphere with no guarantee of surface survival.

11:15 AM-11:25 AM
205.04 Science planning for the Cassini mission.
Philip D. Nicholson
Astronomy, Cornell University, Ithaca, New York, United States

Abstract
The joint NASA/ESA Cassini mission to Saturn, which completed its 13-year orbital tour on 15 September 2017, was one of the most complex planetary missions ever attempted, involving 293 orbits of the ringed planet, 125 flybys of its giant moon Titan, and several tens of flybys of the smaller satellites. It was also the first NASA mission where distributed operations played a major role, i.e., where the science planning was carried out not at a central facility such as JPL but by a world-wide network of science team members and operations engineers. This was done, in part, as an experiment but primarily because of the sheer size and duration of the planning effort. Since 2001, the author has served as co-chair of one of the five Cassini Target Working Teams, each of which was responsible for the development of plans for a subset of the several thousand segments into which the orbital tour was divided. One of the keys to the success of this scheme of parallel planning was to pre-allocate each segment to a specific area of science, such as Titan, the rings, an icy satellite, Saturn itself or the magnetosphere. I will recap the reasons for this approach, why it was so successful (despite a rather rocky start), and some of the pitfalls along the way.

11:30 AM-11:40 AM
205.05 Edmund Halley: Discoverer of the Oort Cloud
Jordan K. Steckloff[1, 2]
[1]Aerospace Engineering and Engineering Mechanics, University of Texas at Austin, Whitmore Lake, Michigan, United States, [2]Planetary Science Institute, Tucson, Arizona, United States

Abstract
In this talk, I will discuss the forgotten story of the Oort Cloud's discovery, a story that spans centuries and involves the most famous names in comet science (e.g., Newton, Halley, and Whipple). The Oort Cloud, the reservoir of the Long Period Comets, is: 1.) an isotropic cloud of comets surrounding the Solar System, 2.) stretches from ~10,000 – 100,000 AU (0.2 – 2 ly), and 3.) can send its members toward the Sun, where we can observe them as comets, via gravitational perturbations (e.g., from passing stars). Jan Oort, for whom the Oort cloud is named, only discovered the last of these properties: the mechanism by which the Oort Cloud, replenishing the comets of the Solar System [1]. However, decades earlier, Ernst Öpik discovered that passing stars would limit the extent of the Oort Cloud [2]. Nevertheless, the first quantitative description of the Oort Cloud appeared centuries earlier.

In 1705, Edmund Halley discussed the obits of several prominent comets, which he computed using Issac Newton's (then new) laws of motion and gravity. Halley noted that the orbits of comets "are dispos'd in no manner of Order (…) but move indifferently every Way, as well Retrograde as Direct (…) the Distances in their Perihelium's are sometimes greater, sometimes less; which makes me suspect, there

may be a far greater Number of them, which moving in Regions more remote from the Sun, become very obscure; and wanting Tails, pass by us unseen(.)" Halley concluded "since they appear frequently enough, and since none of them can be found to move with an Hyperbolick Motion, (…) 'tis highly probable they rather move in very Excentrick Orbits, and make their Returns after long Periods of Time(…) Besides, the Space between the Sun and the fix'd Stars is so immense, that there is Room enough for a Comet to revolve, tho' the Period of its Revolution be vastly long."[3]

Halley's description of a largely unseen isotropic swarm of comets with orbits that can span lightyears is the first accurate description of the Oort Cloud.

References:
[1] Oort, J.H. (1950) *Bull. Asto. Inst. Neatherlands* **408**, 91-110
[2] Öpik, E. (1932) *Proc. Am. Ac. Art. & Sci.* **67**, 169-183
[3] Halley, E. (1705) London, 22

11:40 AM-11:50 AM
205.06 The Habitable Zone and the Drake Equation : Anticipation by Maunder in 1913 "Are the Planets Inhabited"
Ralph Lorenz
Johns Hopkins Applied Physics Lab, Laurel, Maryland, United States

Abstract
The term 'Habitable Zone' to denote the region around a star that might support temperatures allowing liquid water and life is sometimes attributed to Su-Shu Huang in 1959, although similar concepts with a different label were mentioned by Hubertus Strugholz and Harlow Shapley earlier in that decade. Estimates of the number of civilizations in the universe, obtained by multiplying the number of stars by a series of factors, were introduced in the same period by Shapley and others, most famously (for the specific estimate of civilizations with whom contact by radio telescopes might be possible) by Frank Drake in 1961.
In fact, both the term 'Habitable Zone', and the estimation of inhabited planets by successive fractions of the number of stars, were both presented in a popular book "Are the Planets Inhabited" by Edward Walter Maunder (most famous for the historical drop in sunspot numbers that bears his name), published in 1913. In common with many other works of this period, it challenges Lowell's interpretation of telescopic observations of Mars, and his estimate of temperatures there. It also considers the wider question of habitability in a thoroughly modern way :
"If we assume that there are a hundred million stars within the ken of our telescopes, we may well believe that not more than one in a hundred of these would fulfil the condition of being a single and stable sun, such as ours. Of the planets revolving round these million suns - stable and efficient suns - can we expect that in more cases than one in a hundred there will be a planet in the habitable zone fulfilling all the other conditions of habitability, of size, mass, inclination of axis, circular orbit, and rotation ? ..... Out of a hundred million of planetary systems throughout the depths of space, can we suppose that there are even one hundred worlds that are actually inhabited at the present moment ? These numbers and proportions certainly are not, and cannot be, based on knowledge ; they are given as illustrations only ; but, vague as they are, they suggest that our Earth may be neither one of many inhabited earths, nor yet unique, but one of a few, indeed of a very few."

11:50 AM-12:00 PM

205.07 History of the Planetary Science Workforce: Why does the DPS need a subcommittee on Professional Climate and Culture?

Julie Rathbun[1], Nancy J. Chanover[2], Serina Diniega[3], Sarah M. Horst[4], Kathleen Mandt[5], Franck Marchis[6], Jennifer Piatek[7], Edgard G. Rivera-Valentin[8], Cristina Thomas[9], Matthew S. Tiscareno[6]
[1]Planetary Science Institue, Tucson, Arizona, United States, [2]New Mexico State University, Las Cruces, New Mexico, United States, [3]Jet Propulsion Laboratory, Pasadena, California, United States, [4]Johns Hopkins University, Baltimore, Maryland, United States, [5]Johns Hopkins University - Applied Physics Laboratory, Laurel, Maryland, United States, [6]SETI, Mountain View, California, United States, [7]Central Connecticut State University, New Britain, Connecticut, United States, [8]Lunar and Planetary Institute, Houston, Texas, United States, [9]Northern Arizona State University, Flagstaff, Arizona, United States

Abstract

The AAS Division for Planetary Sciences (DPS) Professional Culture and Climate Subcommittee (PCCS) was formed in 2016 in an effort to explore the broad issues surrounding inclusion in planetary science. For the 50th DPS, we examine some of the data on the history of the planetary science workforce and the changes that have occurred over the past several decades.

Currently, the planetary science workforce is not as diverse as the population from which its membership is drawn and from which the majority of our funding comes. The most recent survey of the planetary science workforce, conducted in 2011 [1] showed that only 25% of responding planetary scientists were women and, by ethnicity, 87% white, 7% Asian, and 1% each Black and Hispanic. (Compare to 64, 5, 13, and 16% in the US population in 2010 [2].) The percentage of women in planetary science has increased from ~15% in the late-1990s to >25% by the early 2010s [3]. While there have been no studies of the participation of members of racial and ethnic minority groups in planetary science over time, a study of earned geoscience doctorates in the US and found no improvement in racial and ethnic diversity in the past 40 years [4]. Even once they are in the field, women are still lagging behind in some measures of success, such as involvement in spacecraft mission science teams, which has been stagnant at 15% for the past 15 years [3, 5-6].

These studies demonstrate that further work is necessary "to promote a broadly inclusive professional community characterized by respect, honesty, and trust, so that people of diverse backgrounds are – and perceive themselves to be – safe, welcome and enabled", as stated in the PCCS mission. The subcommittee is currently pursuing activities in support of this mission.

[1] White et. al., 2011 (https://tinyurl.com/y9bald4f)[2] 2010 US Census Brief (https://tinyurl.com/3gdko8e)[3] Rathbun, J.A., et al., 2015, *DPS*, 312.01 [4] Bernard & Cooperdock, 2018, *Nat Geoscience*, **11**, 292-295 [5] Rathbun, J.A., et al., 2016, *DPS*, 332.01 [6] Rathbun, J.A., 2017, *Nat. Ast.,* **1,**id 0148

Tuesday, October 23, 2018
02:15 PM-03:00 PM
Ballroom F-G (Knoxville Convention Center)

207 Harold C. Urey Prize: The Compositional Medley of Asteroids, Francesca DeMeo (MIT)
Chair(s): Catherine Olkin

02:15 PM-03:00 PM
207.01 The Compositional Medley of Asteroids
Francesca DeMeo
MIT, Cambridge, Massachusetts, United States

Abstract
Asteroids and other small bodies are markers, like tiny beacons, relaying information about the initial temperature and composition conditions of our Solar System revealed by their surface compositions. All-combined, the asteroids expose details of the Solar System's evolution fossilized in their orbital and compositional distribution. Large-scale asteroid discovery and characterization efforts have revolutionized our understanding of these distributions. There are now over 3/4 of a million known asteroids, more than 100,000 of which have some measurement of physical characterization. This explosion of data has allowed us to create a compositional map of the main asteroid belt at a level of detail never before achieved. This new view allows us to explore some of the most fundamental questions we have about asteroids and their role in the Solar System such as: How do we interpret the distributions of the most populous asteroid classes in terms of formation locations and delivery to the main belt? How much differentiated material exists in the main belt and what are the implications for the timing and extent of differentiation? In this talk, I will review the compositional diversity of asteroids, the compositional gradient of major asteroid classes across the main belt, and the observational details among the more rare and exotic classes that complete the picture. I will explore how this data fits in context with complementary meteorite studies and modern dynamical scenarios.

Tuesday, October 23, 2018
03:00 PM-03:45 PM
Ballroom F-G (Knoxville Convention Center)

208 Gerard P. Kuiper Prize: The Transneptunian Belt. Past, Present and Future, Julio Fernandez (Universidad de la Repúblicain Montevideo)
Chair(s): Catherine Olkin

208.01 The Transneptunian Belt. Past, Present and Future
Julio A. Fernandez
Astronomy, Facultad de Ciencias, Universidad de la República, Montevideo, Uruguay

Abstract
We present an overview of the early ideas about the existence of a transneptunian (TN) population (1930-1990), the discovery stage (since 1992) and a summary of what we have learned and some unsolved questions. The first ideas about a TN belt or ring were based on cosmogonic models that assumed that it was the leftover at the edge of a protoplanetary disk where densities were too low for the planetesimals to grow into a single planet. Attempts to constrain the mass enclosed in a putative belt were based on the perturbations that it could cause on the motions of Uranus, Neptune, or comets that penetrate the TN region like 1P/Halley. The lack of observed perturbations allowed to set an upper limit to the mass of the TN belt (up to distances ~ 50 au) of less than about one Earth mass. The following step was to show that Jupiter family comets should come from such a belt, giving thus an observational support to its existence. Jupiter family comets became the "smoking gun" that uncovered the existence of a large population of TN bodies arranged in a flat near-ecliptic distribution. We will next describe the discovery of TN objects (TNOs) and how they started to challenge Pluto's status as the "ninth" planet of the solar system, that led to the revision of the definition of planet, settled in a rather traumatic way at the Prague IAU General Assembly in 2006. Since then Pluto and other massive TNOs in hydrostatic equilibrium were placed in a new category of solar system bodies called ``dwarf planets''. Finally we will briefly describe our current understanding of the population and nature of TNOs and some of the hot issues under discussion, including the possible existence of planet-size objects in the region between the TN belt and the Oort cloud.

Tuesday, October 23, 2018
03:35 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

209 Comets: Dynamics, Origins, and Theory Posters

209.01 New emerging chemical taxonomy of comets observed in the IR between 1999 and 2016

Manuela Lippi[1, 2], Geronimo Villanueva[1], Michael Mumma[1], Sara Faggi[1]
[1]NASA - GSFC, Goddard center for Astrobiology, Greenbelt, Maryland, United States, [2]Department of Physics of the College of Arts and Science, American University, Washington, District of Columbia, United States

Abstract
We present molecular abundances, rotational temperatures and mixing ratios for 10 comets (from a database of 60) employing our latest analytical methods.

Since 1996, many comets have been observed mostly through ground-based observations, targeting the 3-5 μm infrared spectral region and using different high-resolution spectrometers (e.g., NIRSPEC, CSHELL, CRIRES). In this region, it is possible to observe and quantify primary volatiles (released directly from the nucleus), as for example H_2O, CO, CH_4, CH_3OH, C_2H_6, C_2H_2, HCN, NH_3, H_2CO. Several of these may also have distributed sources. So far, our archive collects high-resolution infrared data of 60 comets, making this one of the most rich and extensive database on comets currently available.

During this period, we have greatly improved our ability to observe and analyze cometary spectral features, building more and more advanced data processing routines and realistic fluorescence models. In addition, we improved the telluric atmospheric models, and developed automation schemes that allow us to process our extensive cometary database in a systematic and accurate manner. Using a robust and common set of analytical tools we can now correct for unevenness related to evolution of data reduction tools, and by extracting robust abundance ratios, spin temperatures and deuterated fractions we can finally investigate their interrelationships and their true cosmogonic significance.

We observe significant improvements in the confidence limits and differences in the retrieved abundances, especially for comets observed before the advent of the new developed atmospheric and quantum models. Moreover, we were able to complement the old results with primary and secondary molecules that were not identified and/or studied in the past due to the lack of molecular models (e.g., NH_3, NH_2, CN, C_3H_8, C_2H_5D).

In this presentation, we present the results for these 10 comets in the context of their significance for understanding processes affecting material in protoplanetary system formation and the origins of our planetary system.

209.02 The Relationship of HCN, NH_3, C_2H_6, H_2O, and Ammoniated Salts in Comets: A Key Clue to Origins?

Michael J. Mumma[1], Steven Charnley[1], Martin Cordiner[1, 2], Geronimo Villanueva[1], Sara Faggi[1, 3], Lucas Paganini[1, 2], Manuela Lippi[1, 4], Michael A. DiSanti[1]
[1]Solar SYstem Exploration Division, NASA Goddard Space Flight Center, Greenbelt, Maryland, United States, [2]Catholic University of America, Washington, District of Columbia, United States, [3]NPP Fellow,

NASA GSFC, Greenbelt, Maryland, United States, [4]American University, Washington, District of Columbia, United States

Abstract
We consider HCN, NH_3, C_2H_6, H_2O in 26 comets characterized at infrared wavelengths, along with seasonal and evolutionary behavior and evidence for salts and multiple ice phases within the cometary nucleus. We will present integrating themes that largely reconcile the seemingly divergent data.

Background: Several puzzling lines of evidence raise issues about the origin of HCN and NH_3:
a. The production rates of HCN measured through rotational (radio) and vibrational (infrared) spectroscopy agree in some comets, but in others the infrared rate exceeds the radio rate substantially. Is prompt emission from vibrationally excited HCN responsible?
b. With its strong dipole moment and H-bonding character, HCN should be linked more strongly in the nuclear ice to other molecules with similar properties (H_2O, CH_3OH), but instead its spatial release in some comets seems strongly coupled to volatiles that lack a dipole moment and thus do not form H-bonds (methane, ethane).
c. The nucleus-centered rotational temperatures measured for H_2O and other species (C_2H_6, CH_3OH) usually agree within error, but those for HCN are often slightly smaller. Is HCN production not yet fully developed in the warm near-nucleus region?
d. ALMA maps of HCN and the dust continuum show a slight displacement in their centroids. Is this the signature of extended production of HCN?
e. NH_3 and HCN are often enhanced in disrupting comets within 1 AU of the Sun and sometimes show evidence of a distributed source.
f. both amino-acetic acid (aka glycine) and acetic acid were detected in 67P and displayed evidence for production from distributed sources.
g. Ammoniated salts (NH_4CN & NH_4COOH) are produced at 10-15 K in lab simulations of ISM acid-base reactions; once formed such salts will survive until warmed to 200K and higher.

We will present and discuss these and other points and suggest ways to reconcile the seemingly divergent mixing ratios of HCN, NH_3, C_2H_6, and H_2O in comets.

The NASA Astrobiology Institute supported this work through funding awarded to the Goddard Center for Astrobiology under CANs 3, 5, and 7 (proposal 13-13NAI7-0032).

209.03 The Lyapunov spectrum of Halley's comet
Jorge A. Perez-Hernandez, Luis Benet
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Abstract
We compute the Lyapunov spectrum of comet 1P/Halley, for a Newtonian model of the Solar System. Our approach consists in solving the equations of motion simultaneously with the first-order variational equations, using automatic differentiation techniques. We take initial conditions from JPL's Horizons online ephemerides system, and integrate the equations of motion and the associated variational equations for 100 Kyr. We find the Lyapunov time (i.e., the inverse of the maximum element of the Lyapunov spectrum) of Halley's orbit to be around 183±6 yr. Furthermore, we explore the contribution of post-Newtonian as well as non-gravitational effects over the long-term stability of the comet's orbit.

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210 Comet Physical Characteristics: Comae Posters
Chair(s): Stefanie N. Milam, Silvia Protopapa

210.01 Sunward Dust Production from Cometary Nuclei
Nalin H. Samarasinha[1], Beatrice E. Mueller[1], Carl Hergenrother[2]
[1]Planetary Science Institute, Tucson, Arizona, United States, [2]Univeristy of Arizona, Tucson, Arizona, United States

Abstract
We investigate whether the sunward dust production observed in many comets is due to a source region in the sunward direction or due to dust outflow from the entire sunward side. Our previous Monte Carlo coma models are capable of simulating the dust outflow from a source region on the nucleus. Additionally, we developed a model that simulates dust outflow from the entire sunward side. Using these two models, we explore the sunward dust production for different scenarios. We compare model simulations with observations of many comets having the same observer-comet-sun geometry. We will discuss the results based on this investigation and will explain the origin of sunward dust outflow in comets.

We gratefully acknowledge the NASA Solar System Workings Program for funding this investigation.

210.02 Decimeter-Scale Coma Particle Characterization of Comet 73P/Schwassmann-Wachmann 3 Using Dual-Wavelength Radar Observations
Anne Virkki[1], Evgenij Zubko[2], Michael C. Nolan[3], Ellen Howell[3], Lance Benner[4], John Harmon[1]
[1]Arecibo Observatory, Arecibo, Puerto Rico, [2]School of Natural Sciences, Far Eastern Federal University, Vladivostok, Russian Federation, [3]Lunar and Planetary Laboratory, Tucson, Arizona, United States, [4]Jet Propulsion Laboratory, Pasadena, California, United States

Abstract
We investigate the large-scale coma-particle size distribution using radar observations of Comet 73P/Schwassmann-Wachmann 3 obtained at the Arecibo Observatory (S band: 2380 MHz or 12.6 cm) and the Goldstone Observatory (X band: 8560 MHz or 3.55 cm) shortly after the comet's disintegration in May 2006. 73P has one of the radar-brightest comae ever detected.

In dual-polarization radar observations, the radar system transmits a powerful circularly-polarized signal at a target and detects the echo in the same-circular (SC) and the opposite-circular (OC) polarizations. The detected echo power in each polarization provides information on the physical properties of the target. We introduce a novel method to derive the particle size distribution power-law index and maximum particle sizes of centimeter-to-decimeter-scale particles using the radar cross sections (the apparent, integrated radar-reflectivity of the target in the OC polarization) and the circular-polarization ratios (the SC echo power divided by the OC echo power) and show day-to-day changes in the number of particles. The radar scattering properties depend on the particle size relative to the wavelength, and therefore analyzing both S- and X-band observations simultaneously allow us to constrain the particle

sizes more reliably than using only one wavelength.

We test three irregular particle morphologies in order to study the effect of the particle shape on the particles' scattering properties but find that the particle shape plays a relatively minor role. We test various power-law indices (from 2.5 to 5.5) and find that power-law indices from 4.0 to 4.8 and particle major-axis diameters of up to about 30 cm provide the best fits to the radar observations of 73P fragments B and C, the values depending on the particle shape and velocity. The maximum particle sizes and the number of particles increase progressively toward smaller Doppler shift values, which suggests that the larger particles remain close to the nucleus whereas the smaller particles get accelerated by external forces such as the solar radiation pressure. The method can be utilized for any comet with a coma that is detectable at two different radar wavelengths.

210.03 Kepler Lightcurve of Comet C/2013 A1 (Siding Spring)

Michael S. Kelley[1], Tony Farnham[1], Jian-Yang Li[2]
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Abstract
On 2014 October 19, comet C/2013 A1 (Siding Spring) passed Mars with a closest approach distance of only 140,000 km. The flyby presented not only a potential hazard to Mars-orbiting spacecraft, but also two unique opportunities: (1) an up-close study of a dynamically new Oort cloud comet, and (2) the possibility to observe the interaction between a terrestrial planet atmosphere and fresh cometary material. More typical observing assets at Earth and elsewhere were used to characterize the comet, and help place it in context with all other comet observations.

Just 16 hours after the closest approach to Mars, comet Siding Spring entered the *Kepler* space telescope field of view. At that time, *Kepler* had begun its K2 mission, staring at ecliptic plane fields for approximately 80 days each. Comet Siding Spring continued moving though the K2 Campaign 2 field and was continuously observed over three time periods (23, 47, and 6 hr each), between -4.8 and 2.5 days from perihelion. Apertures filling the Siding Spring ephemeris were saved every 30 min, which, due to the comet's motion, resulted in its smearing.

We present the Kepler lightcurve of comet Siding Spring. The background field, within 20 degrees from the Galactic Center is complex and crowded. We discuss our approach to background subtraction, and time series extraction. For the latter, we employ two methods: (1) summing the entire flux within a specified aperture for each image, and (2) measuring the coma brightness along the smear direction, to potentially extract a lightcurve on timescales shorter than the series cadence. The lightcurve is compared to contemporaneous data, and phased with the 8.0-hr period measured by Li et al. (2016, ApJL 817, L23) using the *Hubble Space Telescope* during the Mars flyby.

210.04 Rotational Tmperature Modeling of the Swan Band Δv = 0 Sequence in comet 122P/de Vico

Tyler Nelson, Anita Cochran
Astronomy, University of Texas at Austin, Austin, Texas, United States

Abstract
We modeled observations of the C_2 $d^3\Pi_g$-$a^3\Pi_u$ (Swan) Δv = 0 sequence observed in spectra of comet 122P/de~Vico obtained with the 2.7m Harlan J. Smith Telescope and Tull Coude spectrograph of

McDonald observatory on 10/03/1995 and 10/04/1995 . The data used spanned 4783-5169 Å at $R=\lambda/\Delta\lambda=60,000$. We used the PGOPHER molecular spectra model to generate and fit synthetic spectra with the $d^3\Pi_g$ having one, two, and three rotational temperatures. We found the excited state had a two component rotational temperature, similar to Lambert et al 1990. The modeled spectrum was sufficiently high quality that local perturbations were important to include. The large perturbation, $b^3\Sigma^-_g(\nu=10)$, was added to our fits and some new estimates on its molecular constants were found.

210.05 Volatile Composition of Comet C/2015 ER61 (PanSTARRS)
Mohammad Saki[1], Erika Gibb[1], Boncho Bonev[2], Michael A. DiSanti[3], Neil Dello Russo[4], Nathan Roth[1], Ron J. Vervack[4], Hideyo Kawakita[5], Lori Feaga[6]
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Abstract
Comets are thought to retain volatiles from the time of their formation, therefore characterizing their composition should provide insights into the conditions in the early solar system. Roughly 25 Oort cloud comets have been sampled in the near IR and within that population, differences in composition have been noted. However, such a small sample size has made development of a classification system difficult. C/2015 ER61 (PanSTARRS) is an Oort cloud comet whose relatively close approach to Earth (~1AU) in spring of 2017 provided a great opportunity to help understand the distribution of volatiles in the early solar system. Spectra were acquired with iSHELL at the NASA Infrared Telescope Facility on April 16-17, shortly after its April 4 outburst, and between May 11-13. We used three settings to sample ten primary volatiles (H_2O, CO, OCS, CH_4, C_2H_6, CH_3OH, H_2CO, NH_3, C_2H_2, HCN) and three product species (OH, NH_2 and CN). We detected H_2O, CN, OH, HCN, NH_2, CH_4, C_2H_6, CH_3OH, CO and report upper limits for OCS, NH_3 and H2CO. Several of these molecules are underrepresented in comet studies; in particular, OCS has been measured in only four Oort cloud comets so far. This work was supported by the NASA Earth and Space Science Fellowship, Solar System Workings, Solar System Observations, and Astrobiology Programs, and NSF Solar and Planetary Research Grants.

210.06 The Extremely Active Comet C/Hale-Bopp (1995 O1): Production Rates from Nearly Five Years of Narrowband Photometry
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Abstract
Comet C/Hale-Bopp (1995 O1) was an intrinsically bright object that exhibited the highest continuous gas and dust production rates ever measured for a comet. We will report on our extensive narrowband photometry observations of H-B, including 332 individual sets of photometry obtained on a total of 98 nights at Lowell and Perth Observatories. Our observations span nearly 5 years, beginning with inbound measurements on 1995 July 25 (heliocentric distance, *r*, of 7.14 AU), continuing through perihelion (1997 April 1; perihelion distance of 0.91 AU), then extending outbound until 2000 March 3 (*r* of 10.58 AU).

A thorough analysis of this dataset has been delayed for numerous reasons, including the long timeline of post-perihelion observations and the calibrating of our then-new HB comet filter set (Farnham et al. 2000,

Icarus 147, 180). We additionally discovered that, due to its extremely high production rates, the size of the collision zone for H-B was much larger than normal, especially near perihelion, requiring an adjustment to our standard scalelengths and an empirical adjustment to the derived water production rates.

From our first observations, it was clear that H-B was unique. The dust production, even at 7.14 AU, had an *Afρ* of 50,000 cm – much higher than that measured for any comet in our database at any heliocentric distance. H-B's highest production rates were measured near perihelion, where *Afρ* peaked at 1.2×10^{6} cm and the water production rate, also by far our highest value measured for any comet, reached 3.59×10^{31} molecules s^{-1}. The effective active area required to produce the measured water production is 2100 km^2, implying a minimum nucleus diameter of 26 km; however the existence of isolated jets strongly indicates that the entire surface of the nucleus is not active, which means the actual size is likely to be at least 2× as large. These and other results from this unique comet will be presented. This research has been supported by NASA's Planetary Astronomy Program.

210.07 Observed Behavior of Jupiter-Family Comets Beyond 4 AU

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Abstract

Jupiter-family comets (JFCs) are generally highly-evolved members of the comet population. The JFCs typically recede to an aphelion near ~5 AU from the Sun where it is more difficult for sunlight to drive activity via the sublimation of water. Yet it is clear that many JFCs still show extended emission and activity while very distant (e.g. [1]). More extensive characterization of JFCs while far from the Sun has been lacking since it is more challenging to observe them there. However more systematic coverage could address questions of how energy flow through the surface and interior of an evolved, compositionally-layered nucleus drives activity. To this end, we present a summary of our ongoing visible-wavelength observations of JFCs as part of the SEPPCoN project (Survey of Ensemble Physical Properties of Cometary Nuclei). All data were obtained at the 3.5-meter Astrophysical Research Consortium Telescope at Apache Point Observatory. We have detected 71 JFCs, the vast majority of which were observed beyond 4 AU from the Sun. Many JFCs were also visited at multiple epochs. In many of our observations, a comet appears bare, but a significant fraction of the visits show a comet with extended emission from a dust coma, and in some cases a dust tail as well. For the bare comets, the photometry can be used in combination with the known radius from our Spitzer work [2] to derive the geometric albedo; we present an update on the JFC albedo distribution [3]. For the comets with extension, the photometry can be used to estimate dust production rate with the Afρ formalism, and imaging of tails can be used to constrain grain properties by employing a Finson-Probstein analysis. We present some of these preliminary results on these comets with ostensible activity at high heliocentric distances, and, where possible, compare the behavior to what is seen with these same comets at smaller distances from the Sun and closer to perihelion. References: [1] Kelley et al. 2013, Icarus 225, 475. [2] Fernandez et al. 2013, Icarus 226, 1138. [3] Fernandez et al. 2015, DPS #47, id 415.07.

210.08 Monitoring the Activity of 29P/Schwassmann-Wachmann 1

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Abstract
We present lightcurve data from monitoring of 29P/Schwassmann-Wachmann 1 during its 2018 apparition, beginning in June 2018 and extending up to within the weeks before this meeting. 29P is an enigmatic object in a near circular orbit at 6 AU that puts it at the borderline between Jupiter Family Comet and Centaur. At this distance it is clearly beyond the water sublimation zone, yet it has nearly continuous activity with semi-regular outbursts of material that increase its brightness by up to four magnitudes. The source of these outbursts remains unknown. While CO has been observed, so far, no clear connection between CO and outbursts has been made.

Our data are being obtained at the Great Basin Observatory, an automated 0.7 m telescope with access to the excellent dark skies within Great Basin National Park in Nevada. Our program runs every clear night, and depending on scheduling pressure from partner programs, obtains 1 to 6 hours of data. By the time of this meeting we should have monitoring of the evolution of at least one outburst. The intent of this project is to better understand the nature of comet outbursts, distant activity, and to inform our observing partners of when to trigger spectroscopic observations at larger observatories to characterize the gas composition at the time of outburst.

210.09 Comet 66P/du Toit: A Near Earth Main Belt Comet?
Bin Yang[1], Cyrielle Opitom[1], Emmanuel Jehin[2], Damien Hutsemekers[2], Youssef Moulane[2], Francisco POZUELOS-ROMERO[2], Henry Hsieh[3]
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Abstract
We obtained medium-resolution and high-resolution spectra of the near-Earth Jupiter family comet (JFC) 66P/du Toit from 300 to 2500 nm with X-shooter/VLT and UVES/VLT on 2018 July 01, 07 and 13, respectively. In addition, we obtained a series of narrow-band images of 66P between 2018 May and July with TRAPPIST-South. Comet 66P is one of the weakly active JFCs that were identified by Fernandez & Sosa (2015) as having the highest probability of coming from the Main Belt. Our main goal is to investigate the composition of this comet via measuring the gaseous species in the UV and visible and to study its dust properties via measuring the continuum over a broad wavelength range. Additionally, we aim to measure the ortho-to-para abundance ratio of NH2 to constrain the formation conditions of this comet. I will present our spectroscopic observations as well as the photometric observations of 66P. I will discuss whether this comet shows any clear difference in terms of its volatile profile or its dust profile compared to other typical JFCs.

210.10 Origin of Peculiar Comet 21P/Giacobini-Zinner: Volatiles and Crystalline Silicates
Hideyo Kawakita[1], Takafumi Ootsubo[2], Yoshiharu Shinnaka[1], Neil Dello Russo[3], Ron J. Vervack[3], Boncho Bonev[4], Michael DiSanti[5], Erika Gibb[6], Nathan Roth[6], Adam J. McKay[5], Anita Cochran[8], Yuki Sarugaku[1], Mitsuhiko Honda[7]
[1]Koyama Astronomical Observatory, Kyoto Sangyo University, Kyoto, Kyoto, Japan, [2]JAXA, Sagamihara, Kanagawa, Japan, [3]Johns Hopkins Univ. APL, Baltimore, Maryland, United States, [4]American Univ., Baltimore, Maryland, United States, [5]NASA GSFC, Baltimore, Maryland, United States, [6]University of Missouri St. Louis, St. Louis, Missouri, United States, [7]Fukuoka Univ., Fukuoka, Fukuoka, Japan, [8]University of Texas, Austine, Texas, United States

Abstract
Comet 21P/Giacobini-Zinner (G-Z) is a Jupiter-family comet that displays a peculiar nature for both volatiles and dust grains; e.g., chemical abundances depleted in carbon-chain molecules (C_2 and C_3) and NH_2 and a negative wavelength gradient of linear polarization indicative of organic grains. This peculiar nature might be evolutionary and not primordial. Here we present spectroscopic observations by the 8m-Subaru telescope with IRCS (in *L*-band) and COMICS (in *N*-band).
Hypervolatile (CH_4 and CO) abundances in 21P/G-Z provide clues to the origin and the evolution of the comet. For CO, an abundance of ~10 % with respect to water was reported (Mumma et al. 2000) during the 1998 apparition. However, Weaver et al. (1999) reported an upper limit of <3% during the same apparition. Although a chemically inhomogeneous nucleus of 21P/G-Z might yield such conflicting results, CH_4 has never been detected in the comet and could provide valuable insight into the comet's evolution and possible heterogeneity of the nucleus. Therefore, we concentrate on detecting CH_4 during the observations by IRCS in late July 2018. Simultaneously, H_2O, C_2H_6, CH_3OH and other organic species are also targeted.
Mid-infrared (*N*-band) spectra were taken during the 2005 apparition of 21P/G-Z. In the observed spectra, both crystalline olivine and crystalline pyroxene features are clearly detected. This is evidence that 21P/GZ has a high crystalline-to-amorphous ratio of silicate grains compared to other observed comets. This high fraction of crystalline silicate grains indicates that the birthplace of 21P/G-Z was closer to the proto-Sun than the other comets as these grains likely formed in the inner hot region of the solar nebula before transport to the cold comet-forming region by turbulent mixing in the solar nebula.
We discuss the birthplace of 21P/G-Z and whether the current properties of gas and dust grains suggest nature or nurture.

210.11 Probing the Evolutionary History of Comets: An Investigation of the Hypervolatiles CO and CH_4 and Parent Volatile Abundances in the Jupiter-family Comet 21P/Giacobini-Zinner

Nathan Roth[1], Erika Gibb[1], Neil Dello Russo[2], Michael DiSanti[6], Boncho Bonev[3], Ron J. Vervack[2], Mohammad Saki[1], Adam McKay[4], Hideyo Kawakita[5]
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Abstract
Jupiter-family comet (JFC) 21P/Giacobini-Zinner (G-Z) is the prototypical carbon-chain depleted comet as inferred from measurements of fragment species. Its parent volatile composition has also been studied in two previous apparitions (1998 and 2005; Weaver et al. 1999, Mumma et al. 2000, DiSanti et al. 2013). We observed G-Z with the new high-resolution, near-infrared iSHELL spectrograph at the NASA IRTF on July 25, 2018 and found clear, simultaneously measured detections of CO and H_2O. As of writing this abstract, we are preparing for six more scheduled observing dates of G-Z with iSHELL (between July 28-31 and September 7-11, 2018). Our planned observations include a suite of parent species with emphasis on the hypervolatiles CO and CH_4, whose abundances might be sensitive to both natal conditions and post-formative evolution, but for which measurements in JFCs are especially sparse. We also emphasize searches for both short-term (days to months) and long-term (apparition-to-apparition) compositional variability. Additionally, our observations will target fluorescent emission from hydrocarbon parent species, including C_2H_2, which has not yet been measured in G-Z but is crucial for comparison with the highly depleted C_2H_6 reported from previous apparitions, as well as for tying parent volatile abundances to the observed carbon-chain depletion in fragment species. We will present rotational temperatures, production rates, and mixing ratios (with respect to H_2O), discuss the implications of the CO/H_2O content of G-Z for the evolution of JFCs, and place our results in the context of findings from the *Rosetta* mission

and ground-based studies of comets. This work was supported by the NASA Earth and Space Science Fellowship, Solar System Workings, Solar System Observations, and Astrobiology Programs, and NSF Solar and Planetary Science Grants.

210.12 Narrowband Observations of Comet 21P/Giacobini-Zinner During Its Excellent 2018 Apparition

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Abstract

During its last excellent apparition in 1985, Comet 21P/Giacobini-Zinner was discovered to have a highly unusual composition, with C_2 and C_3 each depleted by about a factor of six compared to either OH or CN (Schleicher et al. 1987), making G-Z the prototype of what would become the carbon-chain depleted compositional class (A'Hearn et al. 1995). The comet also exhibited an odd pre-/post-perihelion asymmetry, with all production rates dropping by a factor of several in the six weeks surrounding perihelion. The current apparition, with very similar circumstances to that of 1985, presents an exceptional opportunity to further study this interesting object. The goals of our multi-instrument observing campaign from Lowell Observatory include greatly extending the heliocentric distance range over which we measure production rates, obtaining narrowband images to study expected jet morphology, and obtaining high resolution spectroscopy to measure isotopic ratios when the comet is brightest in September (though spectroscopic results are not expected to be available in time for presentation).

Thus far we have obtained a total of 21 sets of photometry over five nights beginning May 17 (1.82 AU), and imaging on 11 nights beginning June 13 (1.57 AU). Based on the strong asymmetry in production rates about perihelion that we measured in 1985, along with successful studies of seasonal effects in several other comets in recent years, we predicted that G-Z was likely to have a single dominant jet whose source was in summer inbound and rapidly changed to winter near perihelion. Indeed, our new imaging exhibits a broad feature towards the northeast having about 120° width that shows little rotational variation. This is consistent with a mid-to-high latitude source region perpetually in sunlight producing a filled corkscrew of material. How this feature evolves during this apparition, a preliminary model of G-Z's jet morphology, along with associated photometric results, will be presented.

This research is supported by NASA Planetary Astronomy Program grant NNX14AG81G and Solar System Observations Program grant 80NSSC18K0856.

210.13 **Comet C/2013 V5 (Oukaimeden): Evidence for Depleted Organic Volatiles and Compositional Heterogeneity as Revealed through Infrared Spectroscopy**

Michael A. DiSanti[1], Boncho Bonev[4], Erika Gibb[3], Nathan Roth[3], Neil Dello Russo[2], Ron J. Vervack[2]
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Abstract

We present results from high-resolution (lambda/Delta lambda ~ 25,000) pre-perihelion spectra of Oort cloud Comet C/2013 V5 (Oukaimeden), obtained on UT 2014 September 5–6 using NIRSPEC at Keck 2 and on September 11–13 using CSHELL at the NASA-Infrared Telescope Facility. Altogether our observations spanned a range in heliocentric distance R_h = 0.789 – 0.698 AU. We report water production rates, and production rates and abundance ratios relative to simultaneously measured H_2O for eight trace molecules in the coma: CO, H_2CO, CH_3OH, CH_4, C_2H_2, C_2H_6, HCN, and NH_3. These trace molecules were depleted relative to their respective median abundances found among comets, excepting NH_3, which was consistent with its median abundance. Most surprising were pronounced increases in abundance ratios for two trace volatiles between September 5 and 6, especially for C_2H_6 but also for CH_3OH. On September 5, C_2H_6 was severely depleted, consistent with its lowest abundance yet measured for any comet. It also tracked the spatial profile of H_2O, suggesting C_2H_6 was associated with a polar ice phase dominating gas production. On September 6, C_2H_6 was moderately depleted and was spatially distinct from H_2O, suggesting both polar- and nonpolar-dominated ice phases contributed to the activity then. Our results are consistent with a non-homogeneous volatile composition for C/2013 V5. Possible implications will be discussed.

210.14 Characterization of CO and H_2O During the Outburst of C/2015 ER61 with iSHELL

Jacqueline V. Keane[1], Karen Meech[1], Sara Faggi[2], Geronimo L. Villanueva[2], Michael J. Mumma[2]
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Abstract
On April 05, 2017, C/2015 ER61 was reported as undergoing an outburst with magnitude estimates between 7.4 and 6.5, up from a pre-outburst level of 8.4 mag. Observations from the TRAPPIST-South telescope showed that the gas production rates increased by a factor of 7 compared to observations made on 2017 March 31, and the dust mass-loss rate increased by at least a factor of 4. Prior to the outburst, C/2015 ER61 was already an intriguing target. Discovered by the Pan-STARRS1 telescope in March 2015, it has the most eccentric orbit and the fourth-largest aphelion of any known minor bodies in the Solar System. It was coming from the inner Oort cloud but appeared as an asteroidal object of magnitude of 20.7 upon discovery. By 2015 June, when 7.7 au from the Sun, a faint coma was detected for the first time by the Gemini telescope. C/2015 ER61 brightened significantly when it passed inside 6 au. We used iSHELL at the IRTF on UT 2017 April 05 (R_h = 1.18 au) to obtain high resolution spectra of volatiles released immediately during the outburst. Here we report production rates for CO and H_2O and compare the abundance ratios with those measured for other comets. Support for this work was obtained from NSF grants AST-1617015 and AST-1413736. The IRTF is operated by the University of Hawaii under contract NNH14CK55B with the National Aeronautics and Space Administration.

210.15 A high resolution spetrum of comet C/2016 R2 (PanSTARRS) with the ESO VLT

Emmanuel Jehin[1], Cyrielle Opitom[2], Damien Hutsemekers[1], Philippe Rousselot[3], Francisco José Pozuelos Romero[1], Jean Manfroid[1], Youssef Moulane[1]
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Abstract
The returning long period comet C/2016 R2 (PanSTARRS) was discovered on September 7, 2016 at 6.3 au from the Sun. While it was already showing a 20" coma at this large distance (Weryk and Wainscoat 2016), it is only in December 2017 that it was found that this comet had a very unusual composition. From radio observations the comet appeared to be very rich in CO and very poor in HCN (Wierzchos and Womack 2018) and its optical spectrum was dominated by CO^+ and more surprisingly N_2^+ emission bands (Cochran and McKay 2018), while most of the emission bands usually detected in the optical spectrum of comets were not detected.

In order to investigate in detail its coma in the optical, we obtained a total of 6 hours of Director Discretionary Time on C/2016 R2 with UVES, the high resolution optical spectrograph of the ESO Very Large Telescope, between February 11 and 16, 2018. We used two different settings to optimally cover the whole optical spectrum (326-1060 nm) with a resolving power of 80.000. We report on those observations.

We detect strong emissions of the ions CO^+ and N_2^+ , and also several CO_2^+ bands, but no H_2O^+ . We detect emission lines of the radicals CN, C_2 and C_3 but they are very weak. We computed from these spectra the N_2^+ / CO^+ / CO_2^+ ratios in the coma of the comet which put some constraints on the comet formation models, and compared those values to other comets. The forbidden oxygen [OI] lines are detected, allowing to measure the ratio between the green line and the red doublet which provides a way to determine the abundance of CO and CO_2 relative to H_2O. For the first time we report the detection of the nitrogen [NI] forbidden doublet at 5197.9 and 5200.2 Å in the coma of a comet, confirming the high abundance of nitrogen in this comet. Interestingly we also detect a line at 9850 Å which could be one of the carbon [CI] forbidden lines but we do not detect the other line of the doublet at 9823 Å. Because of the strong N_2^+emissions, it was also a unique opportunity to measure the $^{14}N/^{15}N$ isotopic ratio directly in N_2 , the main nitrogen reservoir in the solar nebula.

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211 Education and Outreach Posters
Chair(s): Padma Yanamandra-Fisher

211.01 Trick-or-Treat and Telescopes
Bonnie J. Buratti
NASA Jet Propulsion Laboratory, Pasadena , California, United States

Abstract
Based on an activity that DPS member Richard Schmude Jr. has been doing for years, with over 5000 children reached, DPS initiated in 2016 a pilot program entitled "Trick-or-Treat and Telescopes." DPS encouraged its members to put out their telescopes during trick-or-treat time on Halloween, in their own lawns or in a neighbor's lawn with better viewing (or more traffic). The program will be continued in 2018. This year Halloween occurs during a dark sky and will offer good viewing of Mars, offering an additional opportunity to discuss the latest findings from NASA's Mars missions. The program is also advertised though the Night Sky Network, a consortium of astronomy clubs. The following website gives advice and connections to resources.

https://dps.aas.org/education/trick-or-treat-and-telescopes

211.02 The Public Science of the James Webb Space Telescope
Joel Green, Alexandra Lockwood, Emma Marcucci, Bonnie Meinke, Denise Smith, Christine Pulliam, Hussein Jirdeh
Office of Public Outreach, Space Telescope Science Institute, Baltimore, Maryland, United States

Abstract
It is crucial to engage subject matter experts (SMEs, ie. YOU the reader) to share solar system science from the James Webb Space Telescope (JWST, or Webb for public audiences). STScI and the Office of Public Outreach are committed to bringing awareness of the future science of this great observatory to the public prior to launch. We must lay the proper groundwork, particularly in the broad categories of infrared light, coronagraphy, and spectroscopy, in a non-technical and compelling fashion. Scientist participation helps us engage the public using a variety of high impact, memorable initiatives, in combination with modern technologies to extend reach and convey information in novel ways. Webbtelescope.org, the public hub for scientific information related to Webb, is open. Webb Virtual Reality is being released to museums and science centers as well as the general public. We have injected Webb-specific content into ongoing outreach programs. But the stories and challenges emerge from the discoveries Webb will make, and the input from subject matter experts begins each story we tell. Here we begin to engage the scientific community to tell their scientific stories.

211.03 Astronomy Outreach and Education in India
Henry Throop
Planetary Science Institute, Mumbai, India

Abstract
India is one of the world's largest and densest countries. It is a country of contrasts. India has developed and successfully flown a mission to Mars, but its higher education system is unable to accommodate more than a small fraction of the country's potential students. While some successful Indian students move abroad and play leading roles in science and other fields, the vast majority of Indians learn at schools which have not kept pace with modern development.

I have spent the last three years living and working in India. During this time, I have given over 70 talks at schools, science centers, research labs, engineering colleges, planetariums, and art and science festivals. I have taught at the university level, judged science fairs, and and worked with schools, journalists, government groups, and research centers across the country. India and its students and scientists are largely enthusiastic about improving science literacy and participating in modern research, but many of these efforts are hampered by the country's sheer size, and the economic and educational disparities between India and the west.

In this poster, I will present a summary of my education and outreach work in India from 2015 - 2018, working with students and the public across the country. I will discuss the state of scientific literacy and awareness in the country, as well as the role of international cooperation in building India's current scientific capability.

211.04 AstroBetter Rumor Mill Hiring data (Fall 2011-Spring 2016): subtle gender barriers in hiring?
Margaret McAdam
Physics and Astronomy, Northern Arizona University, Flagstaff, Arizona, United States

Abstract
As of 2010 [1], women represented 26% of the new faculty hires in Astronomy. With the rates of women obtaining PhDs in astronomy ever increasing (e.g., [2]), I was curious if there has been any appreciable change in hiring since 2010. Using the AstroBetter Rumor Mill archival pages for faculty hires for the academic years of 2011-2012 through 2015-2016, I investigated this question. In addition to looking for trends in gender, I also determined if ‘pedigree’ or relative prestige of the hired person’s PhD-granting institution affected their chances of being hired. Using American Institute of Physics reports on graduation rates and gender representation of the field, I could compare the hiring rates to the rates of PhDs graduating in astronomy, including from ‘prestigious’ universities. Hires were confirmed by searching institutional websites’ ‘Faculty’ pages or lines on CVs. Gender of the hired-person is assumed based on stereotypical interpretation of names or interpretations of gender based on images on Faculty pages (this may erase gender non-conforming and transgender people from representation in this work). Racial, ethnic and other identities (e.g., LGBTQ identity, ability status, etc.) are not considered despite their importance to hiring experiences. Based on AIP reports [2] Women represent 34+/-10% of the overall graduates and they represent 36+/-9% of the hires in the Rumor Mill dataset. Therefore, women are being hired at the same rate they are graduating with PhDs. However, when the pedigree of the hired women is considered, an unfortunate trend appears. It is assumed that prestigious universities are admitting and conferring degrees at the same rate as the rest of the field. Using this assumption, women

with degrees from prestigious institutions represent 31+/-6% of the field of women-candidates (based on AIP reports). In the Rumor Mill data, women with degrees from prestigious institutions represent 63+/-16% of the hired women. This may represent a subtle barrier for women similar to [3].
[1] Ivie et al (2013) Focus On Report: Women among Physics & Astronomy Faculty. [2] Mulvey and Nicholson (2014) Focus On Report: Astronomy Enrollments and Degrees. [3] Wennerås and Wold (1997) *Nature 387*, 341–343

211.05 From Citizen Science to Citizen Chatter: Where Users Congregate

Sanlyn Buxner[1], Pamela Gay[2], Anya Glushko[2], Ben C. Azubuike[3], Susan N. Murph[2], Maya Bakerman[1]
[1]Planetary Science Institute, Tucson, Arizona, United States, [2]Astronomical Society of the Pacific, Edwardsville, Illinois, United States, [3]SIUE, Edwardsville, Illinois, United States

Abstract

The CosmoQuest facility launched in January 2012 as a place where people can learn, do science, and be part of an animated community. Since its launch, we have provided ongoing social media communications and blog posts to communicate out our projects and related science. In this paper, we study how people have engaged overtime, both by doing science, talking to one another, and coming and going from the community over time. This detailed behavioral analysis will be coupled with a look into the project twitter accounts, and how having individual twitter accounts per project did or didn't benefit engagement more than having a single project related twitter account.

211.06 Undergraduate Astronomy Research and Education through Observation of Jupiter Impact Flashes to Characterize Small-Body Populations in the Outer Solar System

Kunio M. Sayanagi[1], Paul Gueye[1], Kabir Al Amin[1], Jacob L. Gunnarson[1], Matthew Miller[1], Aaron Essex[1], Katiso Mabulu[1], Angelina R. Gallego[1], Ryan M. McCabe[1], Justin Garland[1], Malinga Rathnayake[1], Benito Loyola[2], Marc Delcroix[3], Ricardo Hueso[4]
[1]Atmospheric and Planetary Sciences, Hampton University, Hampton, Virginia, United States, [2]Loyola Enterprises, Inc., Virginia Beach, Virginia, United States, [3]French Astronomical Society (SAF), Tournefeuille, France, [4]Escuela de Ingeniería de Bilbao, UPV/EHU, Bilbao, Spain

Abstract

We report observation of Jupiter to detect impact flashes at a student-operated observatory at Hampton University. Our project is motivated by impacts recorded by amateur astronomers; if enough flashes are observed, the measurements will reveal the size distribution of those impactors, which may help us understand how the outer solar system has evolved since its formation. National Science Foundation provided funding to construct a roof-top observatory to be operated by undergraduate students to develop a telescope system for such observations, and to conduct long-term monitoring of Jupiter to detect impact flashes. The project will also provide locally-generated science content for education and public outreach, which will make STEM more relevant on a historically black university campus, and help increase representation of African Americans in scientific research and broader STEM disciplines.

The project's objective is to measure the size distribution of Jovian impactors, which are thought to be members of the Jupiter Family Comets (JFC) that originate beyond Neptune's orbit. Most JFCs are too dim for direct telescopic observation from Earth, so the project will observe Jupiter impacts to measure the sizes of objects that are otherwise impossible to observe. If the JFC size distribution shows signs of numerous collisions in the past, it would be consistent with the hypothesis that Uranus and Neptune violently migrated outward early in the solar system history and scattered primordial planetesimal objects. If the JFC population contains more small fragments than expected from collisions, it would reveal that most comets eventually break up during their repeated close encounters with the sun. If the JFC population contains few small objects, it would indicate that at least some JFCs have been left undisturbed since the formation of the solar system. The main technical challenge here is to detect a sufficient number of impacts to build a statistically significant size distribution. The goal of the current student-led exploratory project is to reduce uncertainties regarding the number of impacts per year to enable a larger impact survey in the future.

Our project is supported by NSF EAGER Award 1649878.

211.07 Ascertaining the Needs and Thoughts of DPS Membership Related to Education, Outreach, and Communication

Jennifer Grier, Sanlyn Buxner
Planetary Science Institute, Columbia - 21046, Maryland, United States

Abstract

As part of an ongoing effort to better meet the needs of the DPS membership, we are continuing to gather information from DPS scientists and educators to understand successes and barriers in doing education, outreach, and communication. Additionally, we are determining the resources that DPS members are looking to effectively engage with a variety of audiences. This poster will gather will present data collection to date as well as major finding and will offer the membership an opportunity to add their thoughts and needs. Please join us for a conversation!

211.08 1AU (One Accessible Universe): A program to increase the usability and accessibility of NASA space science education resources

Louis Mayo
NASA Goddard Space Flight Center, Greenbelt, Maryland, United States

Abstract

The NASA Science Mission Directorate operates an extensive space and Earth science education program comprised of 27 lead organizations, each with a myriad of government, academia, and industry partners and a wealth of education programs and products. 1AU, One Accessible Universe is a program designed to increase the accessibility, usability, reach, and impact of these many excellent science education initiatives. Its focus audiences are broad in scope encompassing accessibility for disabled populations, underserved populations, web designers, scientist communicators, and the many formal and informal institutions that serve the public.

The NASA Space Science Education Consortium (NSSEC) has adopted 1AU as a primary, overarching thematic element of our program. This presentation outlines some of the efforts we are making to address accessibility for NASA space science education products and programs and our ideas for a 1AU conference in 2019.

211.09 Assembling a Low-Cost Portable Planetarium with Crowd-Funding

Wesley Sandidge, Brian Jackson
Physics, Boise State University, Boise, Idaho, United States

Abstract

Crowdfunding is the practice of funding a venture by raising (usually small) monetary contributions from a large number of people, often via the internet. Several universities across the US have adopted this model to support small-dollar, high-profile projects and provide the seed money for research efforts. By contrast with traditional scientific funding (e.g., external grants), crowdfunding provides a novel way to engage the public in the scientific process, and such campaigns sometimes involve rewards to donors in the form of acknowledgments in publications or direct involvement in the research itself. Boise State University recently engaged the services of ScaleFunder to launch the PonyUp platform (https://ponyup.boisestate.edu/), inaugurated Fall 2015 with requests of support for projects ranging from the health effects of organic food during pregnancy to censuses of hummingbirds.

In this presentation, we will discuss our own crowdfunding project to assemble a mobile inflatable planetarium. Our approach mimics the set-up designed by the University of Washington's Astronomy Program (http://depts.washington.edu/astron/outreach/uw-mobile-planetarium/) and will use a first-surface mirror and specialized software to format images to the dome's hemispherical shape. This planetarium costs a fraction of what a traditional planetarium does ($18k instead of > $40k), and its primary uses will be outreach events and teaching, encouraging the public and prospective students to pursue their interest in science and astronomy. The planetarium will also provide a connection to the universe, enhancing the public's understanding of what is out there.

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212 Earth as a Planet Poster Session
Chair(s): Devon Burr

212.01 Characterization of tephra spectra by VSWIR spectroscopy
CJ Leight, Molly McCanta, Bradley Thomson
University of Tennessee, Knoxville, Tennessee, United States

Abstract
Explosive-style volcanism is common on Earth and evidence for it has been found on Mercury, the Moon, and Mars. Explosive eruptions can spread pyroclastic material over a large area, and can be visually indistinguishable from the under- and overlying sediment. Thus, spectroscopic methods are a useful source for non-destructive identification, particularly in places where orbital-based observations are the only option (e.g., Mars). However, tephra is not well characterized spectrally due to its highly variable composition, consisting of mixtures of mineral fragments, glass shards (i.e., melt), and fragmented rock and lava from previous eruptions. Glass specifically is difficult to characterize spectrally due to its amorphous structure and variable chemistry. Here we studied sixteen tephra samples from a variety of eruptive sources on the Earth's surface. The samples vary in source locality and composition (basaltic-rhyolitic). The samples were ground, sieved into five size fractions, (>2 mm, 2 mm–250 µm, 250–125 µm, –63 µm, and <63 µm) and dried under a heat lamp. An ASD Fieldspec 4 spectrometer equipped with a contact probe was used to gather VSWIR (350-2500 nm) reflectance spectra of each sample size fraction in the lab, provided there was enough of the size fraction to cover the field of view. The spectra were processed in MATLAB. We have measured the spectra's 1-micron band, which is used by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) to indicate the presence of olivine, pyroxene, or Fe-bearing glass, as well as other identified CRISM parameters. Samples were additionally characterized using the 1.9 and 2.2 micron bands to identify OH-bearing minerals (e.g., amphibole). We found that the 1-micron band depth decreases with particle size, but not all bands show this relationship. Samples will be characterized by optical microscopy and with an SEM to determine the presence and abundance of minerals and phases suggested by their VSWIR spectral characteristics.

212.02 The Great American Eclipse Weather Phenomena
Anthony Papol[1], Vincent Papol[2]
[1]Physics, Brown University, Pendleton, Oregon, United States, [2]NOAA/NWS, Pendleton, Oregon, United States

Abstract
For the first time in nearly 40 years, a total solar eclipse passed over the continental United States on August 21, 2017. Using observations gathered while on-site in Long Creek, Oregon, and from over seven hundred other sites within the path of totality from across the United States, it was determined that the total solar eclipse caused a decrease in temperature of 5.8 °F 10.2 minutes after totality ended. These observations also showed that the wind speed decreased by 1.6 mph 25.1 minutes after totality ended, and that if a change in wind direction occurred, it shifted 7.4 minutes before totality began.

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213 Historical Astronomy Posters
Chair(s): Jay Pasachoff

213.01 Cassini's Legacy: Preserving History While Making Data Accessible
Scott G. Edgington[1], Reta Beebe[2], Barbara Streiffert[1], Andrea Connell[1], Rob Tapella[1], Shawn Boll[1], Shawn Brooks[1], Kathryn Weld[1]
[1]Jet Propulsion Laboratory/Caltech, Pasadena, California, United States, [2]New Mexico State University , Pasadena, California, United States

Abstract
Over thirteen years of exploring Saturn, two decades from launch to end of mission, and nearly three decades since inception, Cassini's mission spanned the career of many of the scientists and engineers who would come to work on the spacecraft. During that time period, much work went into the building and operating of the spacecraft and its instruments. Given Cassini's long history, preserving its scientific and engineering data and the processes by which they were attained can be daunting. Partnering with the Planetary Data System, the Cassini Program has developed documentation and an architecture to engage the science community in an effort to ensure a lasting legacy for an amazing spacecraft .

This presentation gives an overview of efforts to preserve and make assessible the knowledge that is unique to missions of this scope. Here, we focus on the efforts of the Saturn Working Group , one of the Cassini Program's five science disciplines. We present our solutions to tackling accessibility of complex data sets with many instruments and modes, diverse targets, and science objectives.

The research described in this paper was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

213.02 Documenting the Legacy of Cassini's Instrument Teams in NASA's Planetary Data System
Shawn M. Brooks[1], Barbara Streiffert[1], Andrea Connell[1], Rob Tapella[1], Reta Beebe[2], Kathryn Weld[1], Shawn Boll[1]
[1]JPL/Caltech, Pasadena, California, United States, [2]New Mexico State University, Las Cruces, New Mexico, United States

Abstract
In September 2017, the Cassini mission to Saturn concluded its unprecedented thirteen-year exploration of that system with a dramatic end-of-mission impact into the planet. In addition to data collected en route to Saturn, Cassini returned over five terabits of data on the Saturn system collected by its twelve science instruments. This science data, which is available to the planetary science community and the general public via NASA's Planetary Data System archives, represents the legacy left by Cassini for decades to come. Ancillary and engineering data also provide key information that supports the interpretation of Cassini's science data and potentially serve as the basis for other scientific analyses (*e.g.*Lorenz et al. 2018).

Beyond archived data, the PDS also provides a wealth of information about the missions that collected it. The PDS Atmospheres Node, where the Cassini archive is stored, hosts webpages that contain information about the Cassini project and the science instruments that were onboard Cassini. To enhance the value of this archive, the Cassini Project embarked upon an effort to revamp the pages associated with the Cassini project. The upgraded Cassini mission page contains additional overview material on the project, including resources used by project members during spacecraft operations. Each Cassini mission science discipline has its own page featuring general information pertinent to that discipline, links to reference documents that describe archived data and links to higher order data products.

This poster will focus on the enhanced Cassini PDS webpages for the individual instrument teams. These instrument webpages were designed for consistency among each of the dozen pages and intended to provide users with an introduction to each instrument and its dataset. We will explain how our design principles for these webpages are meant to facilitate access to the PDS Cassini archives for future scientists and propagate Cassini's legacy into the future.

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Government sponsorship acknowledged.

213.03 Cassini Project's Strategy to Organizing Science Data Now and in the Future

Andrea Connell[1], Barbara Streiffert[1], Rob Tapella[1], Shawn Brooks[1], Kathryn Weld[1], Reta Beebe[2]
[1]Jet Propulsion Laboratory/California Institute of Technology, Pasadena, California, United States, [2]New Mexico State University, Las Cruces, New Mexico, United States

Abstract

The Cassini Spacecraft toured the Saturn System for thirteen years equipped with twelve instruments, each with multiple sensors that enabled scientists to make observations and perform investigations. The instruments included a wide array of scientific investigations including imaging, spectrometry, magnetic field, plasma and particle analysis, RADAR mapping of surfaces, and radio science. During the mission, teams were also organized into several science areas: Saturn, Titan, Rings, Icy Satellites, and Magnetospheric Science.

The resulting five terabits of science data have been stored in the Planetary Data System (PDS) for scientists to continue to analyze. The Cassini Project realized that future scientists would need science support data in order to find and analyze the data and continue to add to the knowledge of the Saturn System. These data include, but are not limited to:

- Science Observation Intent
- List of Instrument Observation Times
- Calibrations
- Visualization of Observations
- Trajectory Information
- Other Data Impacting the Science Return

The project started by working with PDS to create Web-based science support pages with User's Guides in the early 2010s. However, the project realized that these pages and the associated support data needed to be updated and enhanced based on new discoveries and additional data that has been obtained. This presentation discusses the approaches taken by the Cassini Project, in conjunction with PDS representatives, to provide support to enable scientists to find and analyze Saturn System data so that the Cassini Legacy of science discovery will continue.

213.04 Accessing Cassini Titan Data Made Easier

Trina L. Ray[1], Reta Beebe[2], Barbara Streiffert[1], Andrea Connell[1], Rob Tapella[1], Rudy A. Boehmer[1], Shawn M. Brooks[1], Kathryn Weld[1]
[1]Jet Propulsion Laboratory, Pasadena, California, United States, [2]New Mexico State University, Las Cruces, New Mexico, United States

Abstract
Our knowledge and understanding of Titan, Saturn's largest moon, has increased significantly as a result of data obtained over the 13 years of the Cassini-Huygens Mission to Saturn. 127 targeted Titan flybys by the Cassini spacecraft and hundreds of distant Titan observations, as well as the Huygens descent to the surface is overwhelming to the uninitiated.

Titan is a complex multi-disciplinary object which required significant coordination and tremendous effort to plan an observational campaign, and the structure developed by the Cassini science community is an excellent framework to navigate the rich Cassini dataset. Organizing along the lines of Titan's Interior, Surface, Atmosphere, and Magnetospheric Interactions is intuitive to the planetary science community.

Partnering with the Planetary Data System, the Cassini Program has developed documentation and an architecture to engage the science community, with a discipline focus, in an effort to ensure a lasting legacy for an amazing spacecraft.

This presentation gives an overview of efforts to preserve and make accessible the knowledge that is unique to missions of this scope. Here, we focus on the efforts of the Titan Orbiter Science Team, one of the Cassini Program's five science discipline groups.

The research described in this paper was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

213.05 Introducing the DPS Professional Culture and Climate Subcommittee (PCCS)

Sarah Horst[1], Edgard G. Rivera-Valentin[2], Julie Rathbun[3], Nancy J. Chanover[4], Serina Diniega[5], Kathleen Mandt[9], Franck Marchis[6], Jennifer Piatek[7], Cristina Thomas[8], Matthew Tiscareno[6]
[1]Earth and Planetary Sciences, John Hopkins University, Baltimore, Maryland, United States, [2]USRA/Lunar and Planetary Institute, Houston, Texas, United States, [3]Planetary Science Institute, Tucson, Arizona, United States, [4]New Mexico State University, Las Cruces, New Mexico, United States, [5]Jet Propulsion Laboratory, Pasadena, California, United States, [6]SETI Institute, Mountain View, California, United States, [7]Central Connecticut State University, New Britain, Connecticut, United States, [8]Northern Arizona University, Flagstaff, Arizona, United States, [9]John Hopkins University Applied Physics Lab, Baltimore, Maryland, United States

Abstract
The PCCS was established in 2016 "to work towards making the community of planetary scientists an

environment in which professional merit is the only criterion that determines each person's success". The group's work builds from efforts of several AAS committees that have and continue to pursue the broad issues surrounding diversity and inclusion, such as the Committee on the Status of Women in Astronomy (1979), the Committee on the Status of Minorities in Astronomy (1997), the Committee for Sexual Orientation and Gender Minorities in Astronomy (2012), and the Working Group on Accessibility and Disability (2016). These groups have worked to discuss issues related to diversity and towards tasks that enable inclusion.

The PCCS works towards these goals for the Planetary Science community, which is composed of many fields, each with their own diversity challenges. For example, though the geosciences have seen the representation of women increase to 45%, the field has shown no growth in terms of ethnic and racial minorities [1]. On the other hand, the representation of women is still far below parity (~20%) in physics; however, physics doctoral degrees earned by ethnic and racial minorities have shown some increase [2].

The PCCS is charged with promoting "community values and cultural norms" through mechanisms that enable inclusion guided by the diversity challenges within each community and ongoing inclusion efforts. Several of our recommendations have led to improvements in DPS including having a plenary lecture during the annual meeting on diversity and inclusion issues, facilitating networking events for underrepresented groups, working with session chairs to promote diversity and inclusion, and training for the DPS committee and prize committee on implicit bias.

We will discuss ways in which individuals and organizations can promote diversity and inclusion, such as Bystander Intervention training, and paying attention to multiple axes of underrepresentation.

[1] Bernard & Cooperdock, 2018, *Nat Geoscience*,**11**, 292-295. [2] Women, Minorities, and Persons with Disabilities in Science and Engineering, NSF, https://goo.gl/SxN4YY.

213.06 Voyager 2 Saturn Encounter Pointing Issue: The Lost Satellite Images

Tilmann Denk[1], Heike Rosenberg[1], Candice Hansen[2]
[1]Freie Universitaet, Berlin, Germany, [2]PSI, Tucson, Arizona, United States

Abstract

During the Voyager 2 encounter with Saturn, two problems affected the acquisition of data [1]. One was a temporary cessation of operation of the science instrument platform which pointed the imaging cameras, two spectrometers, and the photopolarimeter; it occured about 110 minutes after Saturn closest approach. The other was a gyroscope calibration error resulting in a roll attitude offset of about 1°, lasting from Saturn closest approach (C/A; 26 Aug 1981 03:24 UTC) until about C/A+5 hours. For the satellite images planned after Saturn C/A, this meant that almost all were lost due to mispointing until the scan platform motion was partially restored at about C/A + 2.8 days. The lost data included the best Enceladus and Tethys observations of the Voyager era with imaging resolutions better than 850 m/pxl for both moons -- compared to the obtained data with 1.1 km/pxl (Enceladus) and 2.6 km/pxl (Tethys). Only a small area at the edge of Tethys was captured [2] during the second of three mosaics, all other images were blank. With the data from the Cassini mission in hand, it is now possible to a certain degree to reconstruct the images lost by Voyager 2. While the Cassini data do mainly not offer similar illumination conditions (sub-observer and sub-solar points), coverage of the areas visible to Voyager 2 is now available. In the poster, we show Cassini mosaics reprojected to the lost Voyager images. They give a good impression on what people in the early 1980's would have seen without the pointing problems. For Tethys, the spatial resolution would have tripled. The southern end of Ithaca Chasma would have been visible, and many more small craters might have been counted. At Enceladus, the lost images would have shown more

plains with highly complex tectonics at low- and mid-southern latitudes on the sub-Saturn hemisphere (near Cashmere Sulci). A set of seven high phase images taken about 14 h after C/A (6.4 km/pxl; 126° phase; lat. -37°) might have shown the plumes, although it remains speculative if a correct data interpretation would have been possible.

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214 Giant Planet Atmospheres Posters
Chair(s): Glenn Orton, Kunio M. Sayanagi

03:35 PM-03:35 PM
214.01 Photochemistry in Saturn's Atmosphere: Ring Shadow and Ring Reflection
Scott G. Edgington[1], Sushil Atreya[2], Eric Wilson[2], Kevin H. Baines[1, 3], Robert A. West[1], Gordon Bjoraker[4], Leigh Fletcher[5], Thomas W. Momary[1]
[1]Jet Propulsion Laboratory/Caltech, Pasadena, California, United States, [2]University of Michigan, Ann Arbor, Michigan, United States, [3]University of Wisconsin, Madison, Wisconsin, United States, [4]Goddard Space Flight Center, Greenbelt, Maryland, United States, [5]University of Leicester, Leicester, United Kingdom

Abstract
After over thirteen years in Saturn orbit, Cassini observed for half a Saturnian year. During this epoch, the ring shadow moved from its northernmost extent to its southernmost. Acting like Venetian blinds, the rings would modulate both ultraviolet and visible sunlight penetrating through the rings. At the same time, both visible and ultraviolet light would be reflected from the sunlit side of the rings on the already sunlit hemisphere. Total insolation at any particular latitude would vary depending on Saturn's axis relative to the Sun, the optical thickness of each ring system, and ring reflectivity. These factors effectively magnify seasonal effects due to axial tilt alone, further influencing photochemical cycles and haze generation. This effect was observed with the transformation of the northern hemisphere from a relatively clear, blue Rayleigh-scattering atmosphere in 2004 to a smoggy, salmon color over the mission. We report on insolation over Saturn's disk accounting for axis tilt, ring transmission and reflectance, and solar cycle over Voyager and Cassini epochs. Impact on photolysis of key hydrocarbons in Saturn's thermosphere, stratosphere, and troposphere are explored and limits on production-loss rates and abundance of long-lived photochemical products leading to haze formation are placed. We assess the impact of insolation on a disequilibrium species (e.g. phosphine) whose presence in the upper troposphere can be used as a tracer of convective processes in the deeper atmosphere.
Analysis of Cassini's CIRS, UVIS, and VIMS datasets are used to provide constrains on evolving haze content. Comparison of hazes at mid-latitudes will be contrasted to those within Saturn's hexagonal jet stream to understand evolution from a hazeless atmosphere to a hazy one. We explore how this jet stream acts like a barrier to transport, isolating the north polar region from photochemical hazes generate outside of it.

The research described in this paper was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

03:35 PM-03:35 PM
214.02 Evolution of Saturn's Great Storm Anticyclone as seen by Cassini/VIMS from 2011-2017
Thomas W. Momary[1], Kevin H. Baines[2], Sarah Badman[6], Robert H. Brown[3], Bonnie J. Buratti[1], Roger N. Clark[4], Philip D. Nicholson[5], Christophe Sotin[1]

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Abstract
The Great Storm that erupted on Saturn at 34° N. in late 2010 obliterated the String of Pearls feature that had persisted for years in that region and gave birth to a massive lone long-lived anticyclone. This spot drifted along in an NH_3-dry 5 µm-bright "desert" Storm Zone spanning the entire Saturnian globe at that latitude. We observed the evolution of this oval spot with Cassini/VIMS from 2011 through our highest resolution views during the Grand Finale orbits in late 2017. It bobbed around in Saturn's zonal currents: it was at 35.9° planetocentric latitude in May 2011, drifted northward to 37.8° in 2012, hovered near 37° through 2013, sagged as far south as 36.5° in 2014, rose northward to 37° in 2015, and then sank back to about 36.3° in 2016 and 2017. It periodically bumped up against the dark band above it, spinning off material in 2013, 2015, and 2017. We measured a prograde zonal drift speed of 22 m/s in 2012, increasing 60% through 2013, then relaxing to a more moderate 15 m/s in 2014 and 2015. It slowed considerably in 2016 to 4.7 m/s and was drifting slightly faster at 8.5 m/s in late 2017. There appears to be a direct correlation of longitudinal drift speed with latitudinal drift of the spot center. The spot also varied in size over time, spanning 4.9° x 3.2° in 2011, elongating to 7.3° x 2.9° by 2013, contracting to 5.5° x 2.9° in 2014, enlarging again to 9° x 4° in 2015, and contracting to 7.0° x 3.2° (6100 x 3200 km) in 2017. The shape ratio, a measure of the elongated shape of the spot, correlates directly with the latitude drift of the spot center as well. The anticyclone varied in terms of cloudiness, being 90% 5 µm dark (obscured) in 2011, whereas by 2013 it was mostly bright (clear) with a thin dark edge. It was 90% dark in 2015, and in 2017 was about 65% obscured, with a bright central eye. Utilizing night observations to isolate thermal flux, we have found that the mean 5 µm flux coming from the anticyclone diminished steadily by about 75% after 2013, as did the 5 µm flux from the entire storm latitude of ~34° N itself as it fills in over time. A quantitative record of the evolution of this feature from formation to the last looks by Cassini/VIMS will be presented.

03:35 PM-03:35 PM
214.03 High-altitude Haze in the South-Polar Regions of Saturn

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Abstract
We derived vertically-resolved spectral structures of polar haze between 375 and 925 km altitude analyzing the 3-micron emission spectra of Saturn's southern auroral atmosphere observed by Visual Infrared MappingSpectrometer (VIMS)/Cassini. In order to carry out this task, we employed a new formulation of radiative transfer equations including scatterings and absorptions of haze particles as well as molecular line emissions and absorptions because the 3-micron spectra of Saturn contain molecular line emissions and absorptions over significant haze continuum. We will present this formulation as well as model fits which yield extracted polar haze spectra. A comparison of the derived polar haze spectra with those of the relative low-altitudes (257– 520km) and low-latitudinal haze reported by Kim et al. (2012) indicates that the high-altitude polar haze is dominated by aromatic hydrocarbons while the haze at lower latitudes mostly consists of aliphatic hydrocarbons. We will present discussions on the possibility of aging processes during the latitudinal advection and diffusion from the polar atmosphere to the low latitudinal regions (Courtin, Kim, and Bar-Nun, 2017), during the vertical precipitation process (Courtin,

Kim, and Bar-Nun, 2015), or during both the horizontal and vertical migrations.

Reference

Courtin, R., Kim, S., Bar-Nun, A. 2015. Astron. Astrophys. 573, A21.
Courtin, R., Kim, S., Stallard, T.S., Bar-Nun, A. 2017. EPSC2017-282.
Kim, S., Sim, C., Lee, D., Courtin, R., Moses, J., Minh, Y. 2012. Planet. Space Sci. 65, 122–129.

03:35 PM-03:35 PM

214.04 The formation of benzene and complex hydrocarbons in the auroral and non-auroral regions of Saturn

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Abstract

Recent infrared and ultraviolet observations from *Cassini* reveal an enhancement in the abundance of benzene at high latitudes on Saturn and indicate the presence of high-altitude hazes in Saturn's upper stratosphere (Guerlet et al. 2015, *A&A 580*, A89; Koskinen et al. 2016, *GRL 43*, 7895; Kim et al. 2012, *PSS 65*, 122). In contrast, photochemical models that include neutral photochemistry initiated by solar ultraviolet radiation alone (i.e., no auroral chemistry and no ion chemistry) predict a maximum in the benzene abundance at low latitudes, with related haze production deeper in the stratosphere (e.g., Moses & Greathouse 2005, *JGR 110*, E09007). This model-data mismatch supports the hypothesis that refractory high-molecular-weight organics are synthesized in Saturn's auroral regions as a result of ion chemistry driven by the precipitation of energetic magnetospheric particles into the upper atmosphere. Using a coupled ion-neutral photochemical model, we investigate the production of benzene, polycyclic aromatic hydrocarbons (PAHs), and other complex organic molecules in Saturn's high-latitude stratosphere and thermosphere and compare predictions with *Cassini* CIRS and UVIS observations. We identify the key chemical mechanisms involved, discuss the relative roles of auroral chemistry and solar photochemistry in producing refractory organics across the planet, better define the vertical profiles of benzene and other hydrocarbons as a function of latitude, and describe the differences between the hydrocarbon chemical pathways on Titan and Saturn.

This work was supported by the NASA Solar System Workings program, grant number NNX16AG10G.

03:35 PM-03:35 PM

214.05 Jupiter’s Cloud Morphology Spatial Structure and Cloud-top Wind Fields from New Horizons and Juno

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Abstract
We present a preliminary analysis of horizontal spatial-scales contained in Jupiter's cloud morphology and cloud-top wind fields as captured by the New Horizons and Juno missions. Our analysis calculated spatial scales of cloud reflectivity in multiple wavelengths as a function of latitude using fast Fourier transforms of the 2D autocorrelation fields of images taken with the LORRI, MVIC, LEISA, and JunoCam instruments. JunoCam images cover small portions of Jupiter's disk in high spatial resolution, while LORRI, MVIC, and LEISA images show a large portion of Jupiter's dayside in moderate resolution; thus, our analysis of these multiple datasets produce complementary results that sense a wide range of spatial scales. Our particular focus is on the transition from the banded structure characteristic of Jupiter's mid-latitudes to the chaotic structure of the polar region. We also use our group's previously calculated zonal wind field from LORRI data to provide context to the autocorrelation distances in our spatial-scale analysis. Together, these measurements explore the turbulent forcing of Jupiter's zonal jets and eddy dissipation in its atmosphere. Our work has been supported by the following grants: NASA PATM NNX14AK07G, NASA MUREP NNX15AQ03A, and NSF AAG 1212216.

03:35 PM-03:35 PM
214.06 Analysis of Wind and Clouds on Jupiter using the Cassini Spacecraft Visible and Near-Infrared Camera Images
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Abstract
We present preliminary results on cloud tracking wind measurements as well as morphology of atmospheric cloud bands and vortices on Jupiter. We use images captured by the Imaging Science Subsystem (ISS) onboard the Cassini spacecraft during the spacecraft's flyby in 2000. Our primary objective is to demonstrate the scientific utility of images captured in broad-band color filters such as red (RED on ISS), green (GRN) and blue (BL1 and BL2). Our work can be applied to preparation for missions like the Europa Clipper currently planned for launch in 2022 or later. The Clipper's main imaging camera, Europa Imaging System (EIS), is expected to image Jupiter as a calibration target; however, the camera is equipped only with broadband filters. The filter performance of EIS is similar to those of ISS. Thus, our project lays the groundwork in preparation for analyzing the broadband color images of Jupiter to be captured by Clipper.

We analyze images captured using the aforementioned broadband filters, as well as the narrow-band CB2 and MT2 filters on the Wide- and Narrow-Angle Cameras. In our wind measurements, we apply a 2-dimensional correlation imaging velocimetry, which determines the motion of clouds between a pair of images by searching for a peak in two-dimensional correlation coefficient as a functional of horizontal displacement from a given point. In our cloud morphology analysis, we visually inspect and document the shapes and colors of cloud bands and vortices so that they can be compared against results of current and future missions like Juno and the Europa Clipper.

03:35 PM-03:35 PM
214.07 A High-performance Atmospheric Radiation Package: with applications to the radiative energy budgets of giant planets
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Abstract
A High-performance Atmospheric Radiation Package (HARP) is developed for studying multiple-scattering planetary atmospheres. HARP is an open-source program written in C++ that utilizes high-level data structure and parallel-computing algorithms. It is generic in three aspects. First, the construction of the model atmospheric profile is generic. The program can either take in an atmospheric profile or construct an adiabatic thermal and compositional profile, taking into account the clouds and latent heat release due to condensation. Second, the calculation of opacity is generic, based on line-by-line molecular transitions and tabulated continuum data, along with a table of correlated-*k* opacity provided as an option to speed up the calculation of energy fluxes. Third, the selection of the solver for the radiative transfer equation is generic. The solver is not hardwired in the program. Instead, based on the purpose, a variety of radiative transfer solvers can be chosen to couple with the atmosphere model and the opacity model.

We use the program to investigate the radiative heating and cooling rates of all four giant planets in the Solar System. Our Jupiter's result is consistent with previous publications. Saturn has nearly perfect balance between the heating rate and cooling rate. Uranus has the least radiative fluxes because of the lack of CH_4 and its photochemical products. Both Uranus and Neptune suffer from a severe energy deficit in their stratospheres. Possible ways to resolve this issue are discussed. Finally, we recalculate the radiative time constants of all four giant planet atmospheres and find that the traditional values from (Conrath BJ, Gierasch PJ, Leroy SS. Temperature and Circulation in the Stratosphere of the Outer Planets. Icar. 1990;83:255-81) are significantly overestimated.

03:35 PM-03:35 PM

214.08 Comparison of the spatial extent of the QQO from observations and GCM modeling

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Abstract
The Quasi-Quadrennial Oscillation (QQO) in Jupiter's atmosphere is a wave-driven jet stream that changes direction every 4-5 years. Depending if the jet stream is heading towards the east or towards the west, relative maximum and minimum temperature anomalies are created and track the location of the jet as it vertically descends. Observations using the Texas Echelon cross-dispersed Echelle Spectrograph (TEXES), mounted on the NASA Infrared Telescope Facility (IRTF), were used to characterizemore more than a complete cycle of the QQO between January 2012 and July 2017. In March 2017, TEXES was mounted on the Gemini North Observatory to carry out a similar Jupiter observation, but achieving nearly 3 times better spatial resolution than that of the NASA IRTF. We compared the retrieved thermal structure of Jupiter's atmosphere from both facilities and found similar spatial extents of the temperature anomalies associated with the QQO. The maximum amplitude of the anomalies is about 5 K from the ambient mean temperature and they spatially span around 4 degrees in latitude. We used the EPIC Global Circulation Model (GCM) to investigate the effect of jet spatial structure and the extent of gravity wave forcing on reproducing temperature anomalies that best match observations. The best tuned parameters are reported with statistical analysis of both observations and GCM outputs.

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214.09 Wave activity in Jupiter's North Equatorial Belt from near-infrared reflectivity observations

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Abstract
In 2017, Jupiter's North Equatorial Belt underwent a periodic expansion event, which coincided with a period of increased wave activity in this part of the planet's atmosphere. Between December 2016 and June 2018, a series of high spatial resolution (~0.1 arcsec) images of Jupiter were made using the NIRI imager at Gemini North, in support of the Juno mission. These images were made in six discrete filters between 1.59 and 2.28 μm, allowing us to study the wave pattern using near-infrared reflected sunlight. The six wavelength filters together probe the ~0.1-2 bar region in the upper troposphere and provide a measure of the aerosol opacity profile. The observations show the amplitude of the wave increases in the early part of 2016, reaching a maximum in May-July 2016 before returning to a relatively quiescent state when Jupiter was next observed in May 2018. The observed wave pattern has a wave number of ~17, which is similar to the thermal wave activity observed by Fletcher et al. (2017, doi10.1002/2017GL073383) in early 2016, during the 'failed' NEB expansion that preceded the full expansion in 2017. While wave features can be seen at all longitudes, they are consistently more prominent at longitudes of 180-360°W. Individual wave features can be tracked in the NIRI images, showing that the wave is quasi-stationary on a timescale of several weeks. By stacking together the observations from the six filters, we are able to create image cubes, which can then be used to retrieve the aerosol opacity in the upper troposphere. We will present maps showing the vertical and horizontal aerosol distribution within the wave pattern, and will compare these results to the temperature retrievals performed by Fletcher et al. (2017).

03:35 PM-03:35 PM

214.10 Modeling the CH_4 3.3 μm non-LTE emissions in Jupiter and Saturn

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Abstract
The homopause divides planetary atmospheres into the high-pressure region where chemical species are well mixed by eddy diffusion and the low-pressure region where molecular diffusion separates species according to their individual masses. In Jupiter and Saturn, the homopause pressure level controls the methane abundance vertical profile, as methane is heavier than the two dominant species, H_2 and He. Methane plays a critical role in establishing the thermal structure on these planets. It is the prime near-infrared absorber that warms the Jovian and Kronian upper atmospheres, and its photolysis by solar UV radiation triggers the production of ethane, acetylene, and heavier hydrocarbons that are the prime far-infrared coolants in these upper atmospheres. Hence the homopause level drives the heating rates, and, as ethane is mainly produced by the three-body methyl recombination ($2CH_3$+ M --> C_2H_6 +M) whose reaction rate highly varies with pressure, the homopause level also controls the cooling rates. The determination of the methane homopause level in Jupiter and Saturn through solar occultations has been notoriously difficult as different studies and authors led to different results (see Moses et al. (2004), Fouchet et al. (2009) for reviews). Greathouse et al. (2010) even suggested that the Jovian homopause might vary spatially and/or temporally.

Here we present a detailed non-LTE model of CH_4 3.3 μm emissions for Jupiter and Saturn's atmosphere. The model accounts for various mechanisms of non-thermal excitation of CH_4molecules as well as inter- and intra-molecular vibrational-vibrational (VV) and vibrational-translational (VT) energy exchanges. With the help of this model, we studied the sensitivity of $CH_4$3.3 μm emissions to the temperature and methane abundance vertical profiles and compared integrated radiances with the corresponding Infrared Space Observatory (ISO) observations. We will discuss implications of these results to the interpretation of the homopause pressure level as well as opportunities the JWST telescope will provide to map the homopause across both planets.

03:35 PM-03:35 PM

214.11 Episodic cloud activity in Uranus and Neptune

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Abstract

In the hydrogen-rich atmospheres of gas and ice giants, a decrease with radius in the mixing ratio of a heavy species (e.g. He, CH_4, H_2O, H_2S) will produce a density stratification that is convectively stable if the heavy species is sufficiently abundant. Stably stratified layers can potentially be produced in the condensation zones of methane, hydrogen sulfide, and water in the atmospheres of Uranus and Neptune. However, if a stably stratified layer forms adjacent to an active region of convection, it will be susceptible to progressive erosion as the convection intrudes and entrains fluid into the unstable envelope. I discuss the principal factors that control the rate of entrainment and associated erosion and apply the results to examine whether these processes engender episodes of enhanced internal heat release and convective cloud activity in these planets and to estimate the relevant time interval between active cycles. This research is supported by a grant from the NASA Solar System Workings Program.

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214.12 Longitude resolved maps of Jupiter during Juno's Perijove 3

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Abstract

On December 11th, 2016 Juno completed its third Perijove Pass, probing a narrow swath of the Jovian atmosphere with its Microwave Radiometer (MWR). The vicinity of the spacecraft allows for retrieval of the deep atmosphere at great spatial resolution, however, at the cost of a relatively narrow field of view. We will present observations of the Very Large Array (VLA) that were taken concurrently with the passage of Juno, and provide a global context for the spacecraft.

Our VLA X-band observations (8-10 GHz) overlap with the Channel 5 and 6 observations of Juno's MWR and probe the level just below the cloud deck on Jupiter (0.7 - 3 bars). Using specialized software we construct longitude resolved maps, that highlight ammonia abundance variations across the disk. We superpose the Juno footprints on the VLA map and compare the VLA brightness temperatures with the Juno data along the Juno track.

We specifically focus on the shearing zone between the zones and belts and the equatorial zone, where

Juno allows for studying their deep vertical profile.

Based on these retrieved maps, we show the ammonia distribution derived through radiative transfer calculations across the planet. The variations are compared with the atmospheric cut derived by Juno to establish a link between the upper layer probed by the VLA and the deeper layer probed by the Juno spacecraft.

03:35 PM-03:35 PM

214.13 Long-term tracking of circumpolar cyclones on Jupiter's poles.

Fachreddin Tabataba-Vakili[2], Glenn Orton[2], Candice Hansen[1], John Rogers[3], Gerald Eichstädt[4], Thomas W. Momary[2], Michael Caplinger[5], Michael Ravine[5], Scott J. Bolton[6]

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Abstract

The Juno spacecraft has discovered constellations of circumpolar cyclones (CPCs) around the poles of Jupiter. These CPCs have been characterized as mostly stable configurations of eight and five cyclones, spread around the geographical north and south poles, each with a central cyclone located in close proximity to the pole.

The shape of these constellations has remained largely stable over the last 2 years of observation. However, an in-depth, long-term analysis of the location and characteristics of the circumpolar cyclones is necessary to compare the observed phenomenon with existing theories. For this purpose, we used SPICE-kernels and citizen-scientist derived images to map the CPCs on polar JunoCam images. Individual cyclones change their appearance over the observed time period in terms of cloud cover and color. However, the cyclones remain identifiable between perijove measurements. At the south pole, individual cyclones move around the centre to a limited extent, and there is a gap of variable width between one pair of them. Pairs of consecutive perijove measurements show both clock-wise and counter-clock-wise rotation. However, initial investigations of the first 8 perijove measurements of the south pole show a long-term systematic drift rate of ~1 degree per 53 days.

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214.14 In Search of Longitudinal Variations in the Stratosphere of Uranus

Naomi Rowe-Gurney[1], Leigh Fletcher[1], Glenn Orton[2], Amy Mainzer[2], Julianne Moses[3]

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Abstract

NASA's Spitzer Infrared Spectrometer (IRS) acquired mid-infrared (5-37 micron) spectra of the ice giants between 2004 and 2007. Uranus was observed in November 2004 (Burgdorf et al., 2006, doi: 10.1016/j.icarus.2006.06.006), in July 2005 and again very near its equinox in December 2007. The mean of the four observed longitudes in 2007, spaced equally around the planet, have provided the opportunity for the most comprehensive characterisation of Uranus' temperature and composition ever obtained (Orton et al., 2014, [1] doi: 10.1016/j.icarus.2014.07.010; [2] doi: 10.1016/j.icarus.2014.07.012). The Spitzer spectroscopy lacked spatial resolution, meaning that the results of Orton et al. should be

considered as global averages. However, in this work we analyse the four separate hemispheres to shed light on the longitudinal variability of Uranus' stratosphere in 2007. The IRS acquired a similar set of spectra for Neptune in May 2004 (Meadows et al., 2008, doi: 10.1016/j.icarus.2008.05.023), November 2004 and November 2005, which gives us a unique opportunity to compare the longitudinal variability of the two planets for the first time. We present initial findings that include the discovery of a longitudinal variability occurring across the spectrum on Uranus at equinox. The emission as a function of longitude from the tropospheric H_2-He continuum looks to be relatively constant but the stratospheric hydrocarbon species appear to vary by around 10% from the mean in a sinusoidal fashion. The hydrogen quadrupoles vary by up to 5% though it is not yet known whether the variation in these stratospheric thermometers is enough to cause those seen in the hydrocarbon emissions. The 2005 Neptune data have been directly compared to the 2007 Uranus data and are found to have less than a 2% variability in all measured species. This is despite Neptune typically being considered the more active planet. Building on the forward-modelling analysis of Orton et al., we will present full optimal estimation inversions (using the NEMESIS retrieval algorithm) of the Uranus-2007 spectra at each longitude to distinguish between thermal and compositional variability.

03:35 PM-03:35 PM
214.15 Retrieving a universal chromophore to constrain visible changes in Jupiter's appearance between 2014-2018
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Abstract
Several sets of hyperspectral observations of Jupiter were obtained from the VLT/MUSE instrument between 2014-2018, covering a wavelength range of 0.48-0.93µm. These spectra were inverted using the NEMESIS radiative transfer and retrieval algorithm in order to characterise tropospheric cloud structure and the absorption spectrum of Jovian chromophore, together with ammonia gas abundances at the level of the visible clouds. We were unable to fit the most recent observations of the Great Red Spot using the chromophore optical constants of Carlson et al. (2016), however we were able to directly retrieve a more blue-absorbing chromophore absorption spectrum using limb darkening observations that was able to fit the spectra of both the belts and the Great Red Spot. This was consistent with a universal chromophore that was most likely produced just above the visible cloud layers or in the upper tropospheric haze. We applied this chromophore spectrum as part of a cloud model to track observed visual changes in the northern hemisphere between 2014-2018 relating to the NTBs revival event that took place during that period, as well as to the observed shrinkage and reddening of the Great Red Spot. We found that the formation of the bright red haze layer in the NTBs in 2017 coincided with substantial upwelling of cloud from deeper altitudes.

03:35 PM-03:35 PM
214.16 Mapping Saturn's differential rotation
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Abstract
The rings are a great source of information on the interior of Saturn. Based on the ring occultation

parameters of the waves that we have detected in previous work, we will estimate the depth and latitude of the mass anomalies inside the planet, which will allow us to generate a map of the planet's differential rotation. The products of this work should complement other efforts to understand the giant planets' internal structure, especially the detailed maps of Saturn's gravitational fields.

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214.17 Preliminary Radiative Transfer Analysis of Hyperspectral Image Cubes of Jupiter Acquired During *Juno*'s 13th Perijove Pass

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Abstract

Jupiter's atmosphere is a complex and dynamic system. The spacecraft *Juno* arrived at the planet in July 2016, and has since measured the atmosphere with a powerful suite of instruments, including its infrared spectrometer and microwave radiometer. As a part of the ground-based observing campaign in support of the *Juno*mission, we collected hyperspectral image cubes of Jupiter in the visible wavelength regime during *Juno*'s close perijove passes. To obtain these data, we used the New Mexico State University Acousto-optic Imaging Camera with the Astrophysical Research Consortium 3.5-m telescope at Apache Point Observatory in Sunspot, NM. Our image cubes range from 470-950 nm, with an average spectral resolution ($\lambda/d\lambda$) of 242. Such measurements taken in the visible regime probe the uppermost ammonia cloud deck of Jupiter's atmosphere and are highly complementary to *Juno*'s measurements of infrared and microwave radiation from deeper in the atmosphere. Using the Non-Linear Optimal Estimator for Multi-variate Spectral Analysis (NEMESIS) radiative transfer package and spectra from Juno's 13th perijove pass on May 24th, 2018, we have developed preliminary models of representative atmospheric features such as the Equatorial Zone, and the Northern and Southern Equatorial Belts. These models are sensitive to the aerosol density at a range of different altitudes between approximately 0.1-1.5 bar, the ammonia gas volume mixing ratio at ~1 bar, and the scattering properties of the particles that make up the clouds in these regions. Such properties of Jupiter's uppermost cloud deck can provide important context for the *Juno* measurements made during the respective perijove pass, and for other ground-based observations in different wavelength regimes. This work will also inform conclusions about the relationships between the vertical structure of Jupiter's uppermost cloud deck and the mechanisms and processes taking place in the atmospheric regions below it. This work is supported by Research Support Agreement 1569980 from the Jet Propulsion Laboratory, as a subaward of a NASA/Solar System Observations grant.

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214.18 Juno's (illustrated) Mission Plan for achieving science in 53-day orbits at Jupiter

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Abstract

This poster illustrates the story of Juno's mission at Jupiter, starting in 2016 and planned until 2021. We show Juno's orbital trajectory, its spacecraft and instruments, the orientations used for primary science

observations near perijove, and how variations in orbital geometry affect science. Our main purpose is to show in a graphic way how the 53-day orbit period and other aspects of the mission plan have contributed to the science achieved after 16 of 35 planned orbits, and how we expect them to influence the remaining mission.

03:35 PM-03:35 PM

214.19 The effect of magnetic field on Jupiter's deep zonal flows at low and high latitudes

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Abstract

It has long been speculated that magnetic field is responsible for preventing strong differential rotation (zonal flow) in the highly conducting deep interior of Jupiter. The luminosity of Jupiter and recent Juno gravity measurements are consistent with strong (10 ~ 100 m/s) differential rotation in the non-conducting outer layer of Jupiter but substantially weaker differential rotation (0.1 m/s or less) in the electrically conducting deeper layer of Jupiter. Here we present an investigation of interaction between Jupiter's magnetic field and deep zonal flows in simplified set-ups. First, we show that without thermal/entropy perturbations, magnetic field alone cannot directly truncate high-latitude zonal flows and yet satisfy the Ohmic dissipation constraint at Jupiter. Second, we show that magnetic truncation of differential rotation at low-latitude is of a different nature. At low-latitude, magnetic field mostly likely shepherd strong zonal flows away from the highly conducting region via regulating the low-latitude Reynolds stress. Third, we show that small-scale, non-axisymmetric magnetic perturbations (rather than axisymmetric magnetic field) are more likely to balance the Reynolds stress when integrated on cylinders co-axial with the spin-axis (a modified Taylor's state).

03:35 PM-03:35 PM

214.20 Hydrogmagnetic dynamo models of an ice giant planet

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Abstract

The topology of the magnetic field of a planet is determined by the internal dynamics of that planet. The difference between the dipolar magnetic field of Jupiter, for example, and the multipolar magnetic fields of Uranus and Neptune indicate that there is also a difference between these planets in terms of physical composition. Over the past few decades, advances in both computational capabilities and understanding of the materials that constitute the giant planets have improved our ability to apply numerical models that are able to reproduce the physical conditions that exist at the outer planets. The properties of planets that consist of water have been investigated; however, these properties are expected to be sensitive to the relative abundance of other ices, such as ammonia and methane. Here we present a parameter study of Uranus- and Neptune-like dynamos in the magnetohydrodynamics code MagIC, including stratification of electrical conductivity based upon reasonable assumptions of the chemical composition of the interiors of ice giant planets.

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215 Titan: Atmosphere Posters

215.01 A search for complex molecules on Titan with ALMA

Conor Nixon[1], Martin Cordiner[2, 1], Steven Charnley[1], Alexander Thelen[3], Maureen Palmer[4], Patrick Irwin[5], Nicholas A. Teanby[6], Zbigniew Kisiel[7], Yi-Jehng Kuan[8]
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Abstract
Titan has long been a focus of astrobiological interest, dating back to the Voyager mission, which gave the first glimpse of the complex atmospheric chemistry via infrared spectroscopy. Subsequent laboratory work by Sagan, Khare, Thompson and others showed that much more complex molecules can be generated by reacting methane and nitrogen, the two most abundant molecules in Titan's atmosphere. Therefore, we should expect to find a multitude of heavy molecules increasing in mass, and eventually culminating in haze particles. Cassini's INMS and CAPS instruments further pulled back the curtain on the atmospheric chemistry, revealing a shower of heavy molecular ions and neutrals in the upper atmosphere, although much of the molecular structure remains ambiguous. In the last several years, new eyes have turned to Titan, in particular the ALMA sub-millimeter telescope array that has successfully confirmed two new nitriles: ethyl cyanide (C_2H_5CN) and vinyl cyanide (C_2H_3CN). Recent observations by our group with ALMA has focused on the search for even heavier molecules, including cyclic molecules pyridine (C_5H_5N) and pyrimidine ($C_4H_4N_2$), which are of high astrobiological interest. In this presentation we will discuss the current results, and conclude with an assessment of the future directions for Titan molecule hunts from ground and space-based observatories.

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216 Titan: Surface and Interior Posters
Chair(s): Orkan Umurhan

216.01 A Global Geomorphologic Map of Titan
Rosaly M. Lopes[1], Michael J. Malaska[1], Ashley M. Schoenfeld[2, 9], Anezina Solomonidou[3], Samuel Birch[4], Alexander G. Hayes[4], David A. Williams[5], Alice LeGall[6], Elizabeth Turtle[7], Jani Radebaugh[8]
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Abstract
We investigated the geologic history of Titan through mapping and analyzing the distribution of observed geomorphic features using a combination of Cassini data collected by RADAR, VIMS, and ISS. Determining the spatial and superposition relations between geomorphologic units on Titan leads to an understanding of the likely time evolution of the landscape and gives insight into the process interactions that drive its evolution. We have used all available datasets to extend the mapping initially done by Lopes et al. [1]. We now have a global map of Titan at 1:800,000 scale in all areas covered by Synthetic Aperture Radar (SAR). We have defined six broad classes of terrains following Malaska et al. [2], largely based on prior mapping [1]. These broad classes are: craters, hummocky/mountainous, labyrinth, plains, lakes, and dunes. We have found that the hummocky/mountainous terrains are the oldest units on the surface and appear radiometrically cold, indicating icy materials [3]. Dunes are the youngest units and appear radiometrically warm, indicating organic sediments. VIMS analysis shows that compositional variations can also exist within the same class of unit [4, 5]. Using correlations between different data sets, we have extended the map to regions not covered by SAR to produce a global 1:2,000,000 scale map.

References: [1] Lopes, R.M.C., et al.: Icarus, 205, 540-588, 2010; [2] Malaska, M., et al., Icarus, 270, 130-161, 2016; [3] Janssen et al., 2016 Icarus 270, 443-459, 2016. [4] Solomonidou, A., et al.: Icarus 270, 85–99, 2016, [5] Lopes, R.M.C., et al, Icarus, 270, 162-182, 2016.

216.02 A Global Mosaic of Titan's Surface Albedo using Cassini Images
Erich Karkoschka[1], Alfred McEwen[1], Jason Perry[1], Elizabeth Turtle[2]
[1]Lunar and Planetary Lab, University of Arizona, Tucson, Arizona, United States, [2]Johns Hopkins University, Baltimore, Maryland, United States

Abstract
We present a global mosaic of Titan's surface albedo made from 9873 Cassini ISS (Imaging Science Subsystem) images at 938 nm wavelength. It covers Titan without image seams, gives calibrated normal

albedos, and shows small features with relatively high signal-to-noise ratios due to averaging many images. The scale is 16 pixels per degree or 2.8 km in latitude.

Our mosaic helps in the interpretation of the global distributions of key terrains such as dark dunes, lakes, large river channels, and tectonic structures in connection with existing data by RADAR, VIMS, and DISR. The absolute albedo calibration makes our mosaic useful for deriving compositional constraints. In some areas, the new mosaic has higher spatial resolution than Cassini data at other wavelengths.

The mosaic has some deficiencies that we are working to address within the next year. It contains cloud features at some locations that we will identify and remove. It also contains minor camera artifacts that are 50 times enhanced since only 2 % of the detected light probes Titan's surface. Light scattered from aerosols in the atmosphere is most of the remaining 98 %. The absolute geometric calibration onto Titan's coordinate system of currently 5-10 km accuracy will also be improved.

The mosaic captures averages from many images taken over 13 years of Cassini operations at Saturn. We found some systematic variations between different observations of the same surface area. Based on the correlation with observational parameters, we divide them into atmospheric contributions from clouds and seasonal haze variations and surface contributions from variations in the phase coefficient and temporal changes.

We hope to detect surface changes due to methane rainfall, subsequent dryout, evaporite deposits, shrinking and expanding lakes, and perhaps unexpected processes. Titan's thick haze at 938 nm hides its surface well, but the large data set of ~20,000 ISS images has the power to reveal tiny variations with high statistical significance. We will even examine ISS data at a shorter wavelength, 750 nm, where the haze is even thicker.

This work was supported by the Cassini project.

216.03 Initial analyses of terrestrial rivers as possible analogs for radar-bright fluvial features on Titan

Anthony D. Maue, Devon Burr
University of Tennessee, Knoxville, Tennessee, United States

Abstract

The surface of Saturn’s moon Titan has been reworked through sedimentological processes including fluvial erosion. Despite significant environmental differences from Earth, observations and models indicate sediment may be weathered, transported, and deposited similarly to terrestrial detritus. Liquid hydrocarbons carry fragments of a mainly water ice crust (likely with some fraction of complex organic solids) across Titan’s surface. Fluvial morphologies that are bright at the Cassini RADAR wavelengths of 2.2 cm are interpreted to contain clasts of several cm radius that act as spheroidal retroreflectors. This sediment may resemble cobbles imaged at the Huygens landing site, but with greater number density. With significantly less backscatter expected from finer or very coarse sediment, changes in radar backscatter as a function of distance downstream can be related to changing grain size, shape, and sorting. To understand how these complex changes influence radar signals, we analyze terrestrial radar images of possible Titan analogs at 3, 6, and 24-cm wavelengths. Radar-bright fluvial features near Xanadu on Titan have been compared to desert washes or wadis on Earth with infrequent, severe flows that deposit gravel-rich beds. We examine radar-bright fluvial morphologies in arid environments with intermittent flows for direct relation between radar return and sediment properties. With an improved understanding of Titan’s radar signals, interpretations can be made regarding the downstream sedimentological changes that occur due to abrasion, selective transport/deposition, and/or sediment addition/extraction. This analysis of

terrestrial analog sites, in combination with on-going experimental constraints on rounding and fining rates for Titan-like sediments, will provide data to support interpretations of how fluvial sediments evolve on Titan. Determining limits for transport distances in Titan's fluvial features and possible methods of sand production will help elucidate Titan's sediment cycle from its brightest radar-rough sources to its darkest radar-smooth sandy basins and lacustrine sinks.

216.04 Titan Trek and IcyMoons Trek: New Online NASA Visualization and Analysis Portals for Saturn's Moons

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Abstract
Saturn's moons are the focus of two new online visualization and analysis tools produced by NASA. The Solar System Treks family of online portals provides a suite of interactive visualization and analysis tools. These enable mission planners, lunar scientists, engineers, students, and the general public to access mapped data products from past and current missions for a growing number of planetary bodies. They integrate data from a variety of instruments aboard a number of missions. This presentation will introduce two new portals in the Solar System Trek suite. Titan Trek highlights Saturn's largest moon, and IcyMoons Trek features a number of Saturn's other moons as studied by the Cassini mission.

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217 Trojan Asteroids Posters

217.01 Dynamical Applications of the Full Two-Body Problem
Alex Davis, Daniel J. Scheeres
Aerospace Engineering Sciences, University of Colorado at Boulder, Boulder, Colorado, United States

Abstract
With the increasing number of missions which have or will target binary systems and the continued study of translationally and rotationally coupled planetary satellites, it is of interest to explore the dynamical behaviors of these gravitationally coupled systems. We approach this challenge by exploring the dynamics of the full two-body problem (F2BP) which describes the translational and rotational motion of two gravitationally coupled bodies. This model describes each body as a distribution of infinitesimal mass elements which impart a mutual gravitational force and torque on each other. Beginning from the energetically-relaxed doubly-synchronous equilibrium of the F2BP, or tidally locked system, we map the excited response of the bodies as they are perturbed along their fundamental degrees of freedom. By mapping these responses, we describe dynamical manifolds, or periodic cycles, of the system which can be combined to describe a binary systems' complex motion. Through this methodology several analytical tools for planetary science arise; amongst these is an alternative description of the Cassini states which places no constraints on the elongation or mass distribution of the bodies. Once the mass distribution of each body is accounted for, the frequencies of the excited system responses can also be used as a predictive tool for their mass properties as a result of the highly coupled system behaviors. Such a predictive tool has applications to measurements of the Pluto-Charon system made by New Horizons, the libration of Phobos which will be measured by the JAXA MMX mission, and NASA's LUCY mission, which will fly by the 617 Patroclus system in 2033.

217.02 Temporal stability of the Jovian Trojan Asteroids.
Timothy R. Holt[1], David Nesvorny[2], Jonti Horner[1], Christopher Tylor[1], Brad Carter[1]
[1]University of Southern Queensland, Boulder, Colorado, United States, [2]Southwest Research Institute, Boulder, Colorado, United States

Abstract
The Jovian Trojans are two swarms of asteroids, set at the Lagrange points of Jupiter. To date over 6800 have been discovered. The current paradigm is for these objects to be captured during an early Solar system instability, with most having stable orbits on the age of the Solar system. Though the majority of the object are stable, long term modeling of the Jovian Trojans has indicated that at least some of these captures are temporary. Within each swarm several dynamical families have been identified.
The aim of this work is to examine the temporal range of stabilities in the Jovian Trojan swarm, in the context of these dynamical families. Our simulations extend those of previous work by including all identified Jovian Trojans, roughly doubling the number of objects.
Each of the Jovian Trojans that have been identified to date were simulated for the age of the Solar system, 4.5 Gigayear, using the REBOUND n-body integrator. We used a high resolution time step of 100,000 years for each simulation. To account for uncertainties in the ephemeris, each asteroid was

simulated with eight clones along the 1 sigma errors. Asteroids were monitored for when they escaped the Lagrange point stable regions, as well as Solar system ejection. We followed members of previously identified dynamical families to establish their temporal stabilities.
The results are that several of the outlying Jovian Trojans show stabilities on varying timescales. The short term stability of some of the Jovian Trojans is indicative of temporary captures. Prior to ejection, some of the ex-Jovian Trojans participate in other asteroid groups. This leads leads to a much more active participation between asteroid populations.

217.03 Light Curves of Trojan and Hilda Binary Asteroids Candidates

Sarah Sonnett[1], Tommy Grav[1], A. Mainzer[2], Joseph Masiero[2], Vishnu Reddy[3], James Bauer[4], Emily Kramer[2], Cassandra Lejoly[3]
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Abstract
Jovian Trojan asteroids (hereafter, Trojans) lie in stable orbits at Jupiter's L4 and L5 Lagrange points. Hilda asteroids are in 3:2 mean-motion resonance with Jupiter inwards of Jupiter's orbit. The dynamical origin of Trojans and Hildas differs between competing solar system evolution models, making them excellent targets of study for understanding solar system history. The Nice model predicts that Trojans formed in the outer solar system and were implanted into their present orbits during a scattering episode ignited when Jupiter and Saturn reached 2:1 orbital resonance. Earlier models of gentler giant planet migration predict Trojans to have formed in situ, and models of early solar system mixing predict Hildas and Trojans to have a common origin. One physical property that could test these models is bulk density, which differs significantly between established outer vs. inner solar system asteroids. A statistically meaningful collection of densities can only reasonably be obtained by studying the mutual orbits of binary asteroids. Several direct imaging searches best for identifying widely separated Trojan binaries have produced three discoveries, and other surveys that could identify tight binaries by their characteristic rotational light curves have yielded roughly a dozen strong binary candidates. In Sonnett et al. (2015), we identified dozens of possible binary Trojans and Hildas. We have since been obtaining densely sampled rotational light curves of these candidates at primarily Las Cumbres Observatory, NOAO, and Steward Observatory telescopes in order to search for light curve features diagnostic of binarity. We will present preliminary results from our ongoing light curve campaign and shape modeling efforts.

217.04 Deep Search for Satellites of Lucy Trojans with HST

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Abstract
We report on the first deep satellite search of the Trojan asteroids that are targets of NASA's *Lucy* mission. This search was carried out using the Hubble Space Telescope in a 10 orbit program in cycle 25. The observations were obtained from February – September 2018. The primary goal of the observations is to search for faint companions to the Trojans that will be visited by the *Lucy* spacecraft.

Deep imaging was accomplished using WFC3 UVIS in standard imaging mode with the F555W filter

which delivers good PSF quality and high sensitivity. The observations were designed to reach S/N=5 for a limiting magnitude of V≤25.5 at separations ≥0.2 arcsec from the primary object which approximates the Lucy spacecraft encounter distance. The search can detect satellites at least five magnitudes fainter than the faintest target, Polymele. At closer separations PSF fitting is required to search for close-in any satellites. The UVIS2-C1K1C subarray was used for all observations and covers the entire stable region of the Hill spheres of our targets.

The *Lucy* mission was selected by NASA in January 2017 and is planned for launch in October 2021. Early discovery of any satellites will enable early planning for observations and significantly enhance the scientific return of the mission. Orbiting material is also a potential spacecraft hazard and a deep search for any evidence of bound material is a necessary precaution for the mission. At the time of the Abstract deadline two of the five targets have been observed with HST – all are scheduled to be observed by the end of September. We will report on the latest results.

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218 Mercury Posters
Chair(s): Petr Pokorny

218.01D Identifying source(s) of circum-Caloris lavas through mapping, Mercury

Keenan B. Golder, Devon Burr
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Abstract
Vast expanses of smooth plains deposits on Mercury have been identified, characterized by sparse cratering, level or gently rolling terrain, distinct geomorphic boundaries with adjacent landforms, and embayment of older units. These deposits were interpreted to have been emplaced by regional-scale effusive volcanism. Smooth plains units are concentrated in three locations, the northern smooth plains (NSP), Caloris basin interior plains (CIP), and circum-Caloris exterior plains (CEP). The CEP form a nearly continuous annulus around the Caloris basin.

The emplacement sequence for the various smooth plains was derived from crater size frequency distributions. The NSP and CIP ages are statistically indistinguishable, whereas the CEP are younger, except for a deposit south of Caloris. Previous age estimates for the CEP were based on the average across the entire unit, partial coverage of the northwest CEP, or dispersed segments to the east, west, and south of Caloris. Color variations among smooth plains deposits suggest compositional differences and different lava sources. Two spectral unit types, the high-reflectance red plains (HRP) and low-reflectance blue plains (LBP) are present NW of Caloris. These interleaved CEP units are apparently younger based on previous crater counts, and the CIP, CEP, and NSP are spectrally distinct. However, the interleaved HRP and LBP units in the NW CEP may share characteristics with either the CIP or NSP, and potential flow pathways from either the CIP or NSP reach into the NW CEP. These factors suggest a possible genetic relationship between the CEP, CIP, and/or NSP.

To explore possible CEP lava source location(s) we delineated the NW CEP exposure using geomorphic and color-based mapping, and performed crater counts across representative HRP and LBP units in the NW CEP. Our overlapping model ages suggest contemporaneous emplacement of the two units, subsequent to the Caloris impact. Analyses of surface textures and reconnaissance for flow structures, coupled with comparison of the unit spectral characteristics to the CIP and NSP, will be performed to identify a potential source area for this CEP exposure.

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219 Planet and Satellite Dynamics Posters

219.01 Dynamics of multiple bodies in a corotation resonance
Joseph A'Hearn, Matthew Hedman
Physics, University of Idaho, Moscow, Idaho, United States

Abstract
Saturn's moons Aegaeon, Anthe, and Methone and their surrounding ring arcs are in corotation resonances with Saturn's moon Mimas that cause their semi-major axes to oscillate stably every few years. These resonances also longitudinally confine debris launched from these moons into arcs. How these moons became trapped in these resonances is still not well understood. Also, it is unclear why Aegaeon is the closest to exact resonance. We simulate orbits of multiple massive bodies in a corotation resonance in order to better understand these systems. In these simulations, the bodies exchange angular momentum and energy during close encounters, altering their orbits. Nevertheless, since a typical encounter occurs on a timescale that is short compared to the synodic period of Mimas, the relationships between the energy transferred by the encounter and the locations of the objects relative to the sites of exact corotation is more complex than one might expect. It is at least clear that more massive bodies are more likely to remain in the corotation resonance, while less massive bodies are more likely to exit it. This can explain why Aegaeon has remained in the corotation resonance with Mimas, but does not explain why it is so close to exact resonance. Further investigation of these interactions may be relevant to understand denser systems like the arcs in Neptune's Adams ring and how they can be maintained despite frequent inelastic collisions.

219.02 Losing moons: The gravitational influence of close encounters on satellite orbits
Jeremy Brooks, Seth A. Jacobson
Department of Earth and Planetary Sciences, Northwestern University, Evanston, Illinois, United States

Abstract
The early solar system was a period of ubiquitous collisions and close encounters between protoplanetary masses; all coalescing to form our current four terrestrial planets. Earth and Mars have satellites formed by giant collisions, but Venus and Mercury do not, despite the pervasive collisions that favor moon formation. In particular, it is curious why Venus and Earth are different in this respect despite their similar mass and orbital characteristics.
One possible reason for this discrepancy is that moons formed from giant impacts may later be orbitally altered or lost as a consequence of extended exposure to gravitational perturbations from protoplanetary collisionless encounters. These perturbations are thought to be responsible for the Moon's orbit being inclined five degrees from Earth's equatorial plane, in contrast to the physically-expected alignment of the orbit with the plane (Pahlevan & Morbidelli, 2015). However, with enough exposure to gravitational perturbations, a satellite may be liberated from its orbit around a planet or driven into a collision with the planet. This phenomenon presents a plausible explanation of Venus' planetary history: during early solar system formation, it may have had a moon formed from a giant collision earlier than the formation of the Earth's Moon. If so, this would expose the Venusian moon to a greater number of collisionless

encounters, potentially leading to the moon's removal. Here, we test this possibility using n-body integration to model the behavior of satellite orbits in response to collisionless encounters. Then, we quantify the efficiency of moon retention in the late terrestrial disk. The results demonstrate the importance of the length of exposure to gravitational perturbations for moon retention.

219.03 Ephemerides of the Small Saturnian Satellites after *Cassini*

Robert A. Jacobson
Jet Propulsion Laboratory, Pasadena, California, United States

Abstract

Shortly after the arrival of *Cassini* at Saturn Spitale et al. (2006) published the orbits of the small Saturnian satellites based on a fit to Earth-based, *HST, Voyager,* and early *Cassini* observations. Subsequently, Jacobson et al. (2008) and Cooper et al. (2015) determined revised orbits as more *Cassini* observations became available. This paper presents new orbits and mass estimates for the satellites incorporating the remaining *Cassini* imaging observations collected through 2017 May~28. The model for the orbits of Janus, Epimetheus, Atlas, Prometheus, Pandora, Pan, Methone, Pallene, Anthe, and Aegaeon is a numerical integration of their equations of motion. The gravitational forces acting on the satellites include their mutual interactions and the perturbations due to the major Saturnian satellites, Saturn's rings, the Sun and solar system planets, and the asphericity of Saturn. Saturn's gravity field and the ring mass were previously determined from data collected during the *Cassini* Grand Finale orbits. Mimas was integrated together with the small satellites to properly account for the Mimas--Pandora resonant interaction that induces a signicant periodic perturbation in the Mimas orbit. Mimas observations are included in the fit to constrain its orbit. A statistically significant change was found in the orbit of Pan, but only small changes have been found in the orbits of the other satellites. The knowledge of the masses of Janus and Epimetheus improved slightly as a result of their close encounter observed in 2014.

219.04 How do collisions shape the orbits of irregular satellites?

Zeeve Rogoszinski, Douglas Hamilton
University of Maryland, College Park, Maryland, United States

Abstract

Irregular satellites differ from their regular counterparts by orbiting at great distances, by following highly eccentric and inclined orbits, and, for most of them, by orbiting backwards. They are thought to have formed initially in heliocentric orbits, but were captured by the planets early in Solar System history. These satellite systems were once very collisionally active (Bottke et al. 2010), and these collisions may have shaped their orbital architectures. For instance, the prograde and retrograde satellites around Jupiter revolve in nearly distinct radial regions; although two transitional moons at Jupiter, Carpo and another announced in the summer of 2018, orbit prograde but transit into the retrograde region. While their high inclinations extend their collisional lifetimes, a once well-mixed population would have yielded frequent head-on collisions that lead to annihilation. As orbital velocities around Saturn, on the other hand, are slower, collisions are less frequent and less violent and it is no surprise that its irregular satellite system is more varied. At Jupiter, the largest irregular moon Himalia is prograde while Saturn's largest is Phoebe, which orbits retrograde. These large moons have low inclinations and eccentricities, and are positioned closer to the central planet than the other irregular moons. These similarities may imply a shared genesis (Hamilton 2001, 2003), and we are investigating the significance that collisions have on their formation.

Our focus here concerns how the satellites' orbits evolve as a result of prograde-prograde and prograde-

retrograde collisions. For prograde-prograde collisions we show that semi-major axes increase and eccentricities and inclinations decrease, while the opposite occurs for prograde-retrograde collisions. We tested the significance of these effects for a satellite doubling its initial mass by accretion, and discovered that changes to eccentricities and semi-major axes are very sensitive to collisions, while inclinations vary systematically and only by about 20%. We are investigating this and other effects in greater detail and will report on our findings.

219.05 Daphnis' Change of orbit

Radwan Tajeddine[1], Thamiris De Santana[2], Philip nicholson[1]
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Abstract
Cassini mission made tremendous discoveries that changed our views of the system of Saturn. Among those discoveries is the change of Daphnis' orbit that happened twice. Cassini moved into an equatorial orbit on both times, which prevented us from witnessing the moment of change of orbit. Some speculations were made to explain this change of orbit, including an impact. We discuss the possibility that Daphnis may be on a chaotic orbit due the large accumulation of satellite resonances in that part of the rings of Saturn, and that those two changes of Daphnis' orbit are part of regular changes separated by a Lyapunov time in the order of years.

219.06 Formation of Centaur Rings from Binary Collapse

David A. Minton[1], Andrew Hesselbrock[1], Julie Brisset[2]
[1]Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, Indiana, United States, [2]Florida Space Institute, Orlando, Florida, United States

Abstract
Small body binary systems are common throughout the solar system and are typically comprised of two similar mass bodies orbiting their mutual barycenter. Binary systems are particularly common in sub-populations of Kuiper Belt Objects (KBOs), and the prevalence of binaries may correlate with the dynamical excitation level of the sub-population. Observations suggest that the Centaurs Chariklo and Chiron may have rings. Here we investigate mechanisms by which binaries collapse. We explore the conditions necessary for tidal torques to cause the mutual orbit of a binary system to completely decay until the bodies become attached, forming a contact binary. We also investigate how this collapse process may provide source material for the rings observed around Centaurs, and possibly also satellites at the asteroid 216 Kleopatra.

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220 Laboratory Research Posters
Chair(s): Bryana Henderson

220.01 Electron Stimulated Desorption from Icy and Rocky Surfaces - Where Is It Safe to Keep Ignoring It, and Where Could It Play an Important Role?
Christopher J. Bennett[1, 2], Michael Poston[3], Micah Schaible[2], Brant Jones[2], Thomas Orlando[2]
[1]University of Central Florida, Orlando, Florida, United States, [2]Georgia Institute of Technology, Atlanta, Georgia, United States, [3]Southwest Research Institute, San Antonio, Texas, United States

Abstract
Traditionally, the dominant processes responsible for the desorption of (volatile) species from surfaces are thought to be thermal sublimation, micrometeorite bombardment, sputtering by ions, or photon-stimulated desorption. Despite the fact that many airless rocky/icy bodies are exposed to energetic electrons, the yields commonly reported for electron stimulated desorption (ESD) have been too low to consider their contribution to the sputtering significant.
Here, we present some recent work reporting the *absolute yields* of positively-charged species released during ESD experiments on methanol and water ices, as well as Apollo lunar samples investigated using time-of-flight (ToF) spectrometry. The yields of all species observed are presented as a function of electron energy (12.5 eV - 2 keV). At higher energies, water clusters (e.g., $[H_2O]_4$-H^+) dominate the total yield removed, while several species of interest to planetary science and astrochemistry are observed directly (including H_3^+, O^{2+}, $H_2O_2^+$, O_2^+). The deposition coniditons, composition, surface morphology, and underlying substrate composition are shown to have a measurable effect on the observed yields.
We discuss the implications of these results in regions where ESD could play a significant role, and where it is probably safe to ignore it. Such regions include interstellar icy grains, the exospheres of rocky airless bodies in the inner Solar System, as well as icy moons and rings in the outer Solar System.

220.03 Light Scattering Properties of Exoplanet Clouds in the Lab
Alexandria Johnson[1, 2], Maria Zawadowicz[3], Sara Lance[4], Daniel Cziczo[1]
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Abstract
A lack of strong atmospheric spectral features when observing exoplanets may suggest the presence of a high, optically thick cloud layer and poses great challenges for atmospheric characterization. As a result there are many outstanding questions about the clouds, and more generally particulates, present in exoplanet atmospheres. This work aims to address the following: How do substances representative of exoplanet clouds scatter incident radiation from the host star? What type of 'identifying signal', if any, can be obtained from light scattered by these cloud particles?

We approach these questions through the use of terrestrial based knowledge and instrumentation, which

has proven a useful resource for studying and understanding the cloud-laden atmospheres of our own solar system. More specifically we have modified the design of a vapor diffusion electrodynamic balance (EDB) used to study water clouds on Earth for the study of cooler Exoplanets. In the EDB we levitate single particles in an environmental cell for testing. The system is capable of sustained operation at 500K, has two independent temperature reservoirs for precise control of vapor and temperature gradients across the cell, and an optical ring enclosing the cell for the collection of scattering phase functions by a photomultiplier.

Here we will discuss the development of the EDB scatterometer, validation experiments with spherical particles (polystyrene latex spheres), and preliminary results on non-spherical exoplanet cloud analog particles. Although single particle studies allow for the precise control of a sample and its environment, their relevance to atmospheres and the complexity therein can be questioned. To address this we will discuss the relationship between single particle and bulk sample (or particle ensemble) scattering phase functions through comparison with data collected in our lab and that from the Amsterdam-Granada Light Scattering Database. Future work will be done towards expanding the system to include the collection of polarized light with the ultimate goal of retrieving Muller matrix elements for a full description of scattering on the single particle basis.

220.04 How space weathering may change the directional and polarization reflectance of surface regolith of airless bodies?

Hao Zhang[1], Te Jiang[1], Yazhou Yang[1], Yuxue Sun[1], Pei Ma[1], Daniel Britt[2]
[1]China University of Geosciences, Wuhan, Hubei, China, [2]University of Central Florida, Orlando, Florida, United States

Abstract
Airless bodies exposed to space environment are subject to constant space weathering (SW) alterations including solar wind irradiations, micrometeorite bombardment and thermal fractures. It is well known that SW produces nano-phase iron (npFe) and amorphous layers that redden and darken visible and near-infrared (VIS-NIR) reflectance spectra. To understand how SW may change the directional reflectance and polarization properties of the surface regolith, we performed pulsed laser irradiations of analog materials to simulate micrometeorite bombardment and measured the bi-directional reflectance and polarization phase curves of the samples. We irradiated olivine, orthopyroxene, anorthosite, and JSC-1A Lunar Regolith Simulant (LRS) placed in a vacuum chamber with a 1064 nm Nd: YAG pulsed laser with a pulse width of 6-8 nano-second. The pulse energy was fixed at 25 or 50 mJ per shot and the number of shots was varied from 2 to 8 for different samples, depending on the difficulty level of weathering. All irradiated samples show significant darkening and reddening in the VIS-NIR reflectance spectra except for the LRS irradiated at 50 mJ * 6 shots which shows spectral bluing. For directional reflectance, all samples except the LRS show both enhanced backscattering and forward scattering after irradiations, meaning the particle scattering becomes more anisotropic after SW. The LRS shows enhanced backscattering but decreased forward scattering, in contrast to the other 3 samples. The polarization phase curves of irradiated samples show larger degree of linear polarizations, in accordance with the Umov law. No significant changes of the polarization inversion angle α_{inv} and the minimum polarization P_{min} were found for irradiated samples. We performed vector radiative transfer calculations for olivine grains with amorphous layers and npFe with various concentrations. The computations show that increased concentrations of the npFe causes both enhanced backscattering and forward scattering. It would be interesting to understand why the LRS has a different behavior compared to pure minerals upon irradiations.

Tuesday, October 23, 2018
03:35 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

221 Tuesday Afternoon Break with iPoster and Poster Viewing

03:35 PM-03:35 PM
221.01 The Ammonia Absorption in the Great Red Spot on Jupiter
Victor Tejfel
Fessenkov Astrophysical Institute, Almaty, Kazakhstan

Abstract
In 2017 and 2018 we carried out a number of cycles of spectral observations to study some optical features of the Jovian Great Red Spot (GRS); Recording the CCD spectrograms of Jupiter's central meridian in each cycle was performing consistently for two hours in the 240^0 - 310^0 longitude ranges in steps of about 2^0 each - before, during and after passage the GRS across the CM. The main objective was to investigate the behavior of the 645 and 787 nm ammonia (NH_3) absorption bands in the GRS region, which before was studied quite a little. The measurements of the profiles and equivalent widths of these bands showed explicitly that ammonia absorption in the GRS is decreased; the decrease is comparable with the NH_3 depression in the Northern Equatorial Belt (NEB) that we discovered in 2004. A comparison with the results of the studies of Jupiter in the ranges of thermal infrared and millimeter radiation allowed concluding that the causes of the ammonia absorption decrease are not the same for the NEB and GRS. In the NEB, according to the radio astronomical observations, the gaseous ammonia concentration is really lowered. In the GRS, the NH_3 absorption decrease is caused by the increased cloud volume density. As a consequence of this, the absorption equivalent optical path decreases due to multiple scattering. That is also manifested in the near infrared ammonia and methane absorption bands. Quantitative interpretation requires some further complex studies because of the multiparametric nature of the models that are will be taken. This research was carried out in accordance with the grants of MES RK 0073 / GF4 and AP05131266.

03:35 PM-03:35 PM
221.02 Keck Observatory Exoplanet Imaginarium: Where Science and Imagination Meet
Carlos Alvarez[1], Adam Makarenko[2], Mari-Ela Chock[1]
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Abstract
W. M. Keck Observatory is bringing alien worlds to life, embarking on a deep space visual journey to exoplanets that have either been discovered or characterized using Keck Observatory data. Serving as an interface between science, technology, and the arts, this project is designed to fulfill the ultimate dream of anyone who has ever wondered what extrasolar planets look like, to imagine ourselves on board a spacecraft flying by a strange world, or standing on an alien moon's surface looking at a giant planet rising above the horizon.

The *Exoplanet Imaginarium* (www.keckobservatory.org/imaginarium) is the result of a collaboration between Keck Observatory and award-winning exoplanet artist Adam Makarenko. Together, we create a science-based artistic rendering of an exoplanet scene every month; our mission is to visit 12 different

exoplanets throughout 2018.

We are inspired by scientific facts about these extraordinary worlds, which are published in peer-reviewed journals. Published values of the separation between exoplanets and their host stars, combined with stellar radii and measured or inferred planet radii, are used to estimate the angular size of the planets and host stars as seen by a privileged observer located close to the exoplanets. Other planetary data extracted from the literature, when available, such as effective temperature, density, atmospheric composition, and classification, are also used to create photo-realistic scenes.

Since science facts can only go so far in revealing the full nature of exoplanets, we explore the 'unknowns' with creativity and imagination by way of artistic conceptions.

This artistic work is comprised of hand crafted planetary models made from half spheres of plaster, plastic, or foam. The models are painted with a variety of different paint mixtures to achieve the desired effect, e.g. a gas giant, or a rocky world. Afterwards, the completed planets are suspended in front of a black backdrop, illuminated by a single light source, and then photographed.

The result of this technique gives the work a tangible quality, instantly transporting the viewer to a distant world outside of our solar system.

03:35 PM-03:35 PM

221.03 DPS Planetary Science Programs Databases for Students and Advisors

David R. Klassen[1], Catherine Gosmeyer[2], Anthony Roman[3], Sanlyn Buxner[4]
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Abstract

The task of navigating the extremely diverse graduate school programs in planetary science is often overwhelming not only for the student, but also for many undergraduate advisors. Seeing the need for a consolidated catalog of programs, the DPS Education committee has been maintaining for several years a Graduate Schools for Planetary Science database and web site. Anecdotal feedback on this resource has been uniformly positive and the use of the web site has continued to increase.

Last year we expanded into the realm of Research Experiences for Undergraduates (REU) Programs for Planetary Science and have compiled a small, but significant, database of such programs.

We present here a walk-through of the basic features of the two sites as well as some usage statistics from the collected web site analytics. We continue to ask for community feedback on additional features to make the system more usable for them. We also call upon those mentoring and advising undergraduates to use this resource, and for program admission chairs to continue to review their entry and provide us with the most up-to-date information.

The URLs for our sites are http://dps.aas.org/education/graduate-schools and https://dps.aas.org/education/reu-programs.

03:35 PM-03:35 PM

221.04 Observation of the motion of major satellites of Saturn, Uranus and Neptune: A practice in astrodynamics.

Teresa Del Rio Gaztelurrutia, Jorge Hernandez-Bernal, Victor Almendros, Iker Otxoa, Asier de Ormaetxea, Agustin Sanchez-Lavega
Física Aplicada I, UPV/EHU, Bilbao, Bizkaia, Spain

Abstract

We present a study of the motion of the principal satellites of Saturn (Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Iapetus), Uranus (Miranda, Ariel, Umbriel, Titania and Oberon) and Neptuno (Triton) as a practice in solar system astrodynamics. The study is based in images captured with a telescope Celestron 11 (Ø28 cm) of the Aula Espazio Gela [1], a facility of the University of the Basque Country (UPV/EHU) dedicated to teach Space Sciences at Master and Doctorate level, and impulse its development both in the public and private sectors. The images were captured along several campaigns (2014-2017), and are used to calculate basic orbital parameters of the satellites, and in the case of Saturn, study their gravitational resonances. We describe the techniques used in observation and analysis of the images, and the methodology followed in the determination of the orbital parameters and the resulting uncertainties. This study is presented as a practice for the students of the Master in Space Science and Technology taught in the Aula Espazio Gela, and complements similar practices dedicated to the orbital analysis of Jupiter Galilean satellites [2].

[1] A. Sánchez-Lavega et al. Eur. J. Eng. Edu., 39, 518-526 (2014). [2] I. Ordoñez et al. Eur. J. Phys., 35, 045020 (2014); I. Ordoñez-Etxeberría et al, Eur. J. Phys., 37, 065601 (2016); J. F. Rojas, A. Sánchez-Lavega, Eur. J. Phys., 38, 065601 (2017)

03:35 PM-03:35 PM

221.05 A combined study of the gas productivity of Comet 103P/Hartley 2

Daniel Boice[1], D. T. Sanzovo[2], G. C. Sanzovo[3], Amaury A. de Almeida[4]
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Abstract

To complement the diversity of methods available in the literature to estimate the gas productivity of comets, we make a combined study on the coma activity of Comet 103P/Hartley 2 for the 1991, 1997, and 2010 returns. We quantify the presence of the gas though its water production rate (in molecules s^{-1}) using the Semi-Empirical Method of Visual Magnitudes, and its conversion into gas mass production rate (in g s^{-1}). This method also allows an analysis of the minimum nuclear size and active surface area. Near perihelion of the 2010 return, a mean surface area of 0.6±0.3 km^2 is obtained. For the three returns analysed, we verify that water (and gas) production rates increase with decreasing heliocentric distance r (au) inbound to perihelion with exponents [-6.21 (1991), -5.86 (1997), and -5.45 (2010)]. These rates decrease with increasing r (au) post-perihelion with exponents [-4.75 (1991), -2.33 (1997), and -3.29 (2010)]. From our power laws at perihelion we verify that Hartley 2 loses gas mass at rates of about (4200 to 5260), (1200 to 1440) and (340 to 405) kg s^{-1} in the 1991, 1997, and 2010 returns, respectively. Our water production rates are combined with standard water sublimation theory to evaluate a minimum effective radius of ~0.17 km for the nucleus of Hartley 2.

03:35 PM-03:35 PM

221.06 The Origin of Trojan Asteroids from Spectral Analysis

Audrey C. Martin, Joshua Emery, Sean Lindsay
University of Tennessee, Knoxville, Tennessee, United States

Abstract

Asteroid origins provide effective constraints on the events that dynamically shaped the Solar System. Jupiter's Trojan asteroids (hereafter Trojans) are particularly diagnostic of the amount of radial mixing that occurred during giant planet migration. Previous studies aimed at characterizing surface composition show that Trojan surfaces likely contain fine-grain silicates and have thermal infrared (TIR; 5 – 35 μm) spectra similar to Jupiter Family Comets (JFCs). In the near infrared (NIR; 1 – 2.5 μm) Trojans fall into two spectral slope groups: red and less-red. JFCs and Trojans have both been linked to the primordial Kuiper Belt region within the Nice model, and so it is expected they share spectral and compositional characteristics. We hypothesize that the two Trojan spectral groups and JFCs have similar compositions (silicate mineralogy), consistent with a common Kuiper Belt origin. With TIR spectra from the Spitzer Space Telescope, we identify spectral and mineralogical features from the surface of 11 Trojan asteroids; five red and six less-red, as well as five JFC nuclei. The 10 μm region exhibits strong features due to Si-O fundamental molecular vibrations. Fine-grain mixtures of crystalline pyroxene and olivine exhibit a broad flat plateau in the 10 μm region. Amorphous silicate phases, when present, smooth the sharp emission features, resulting in a dome-like shape. A relatively high spectral contrast (percent above the continuum) can be indicative of a high ratio of crystalline to amorphous silica. Preliminary results of the spectral analysis indicate less-red Trojans have more rounded 10 μm features as compared to red Trojans and JFCs. Additionally, the JFC spectral contrast in the 10 μm region is larger than either Trojan group. If the spectral analysis in the TIR reinforces the NIR spectral slope dichotomy, it is possible that Trojans were sourced from distinct regions of the Solar System. Similarly, if JFCs do not prove a match, it would be inconsistent with the common origin hypothesis. These results will provide new constraints for dynamical models that explain giant planet migration.

03:35 PM-03:35 PM

221.07 Ammonia on Pluto: its detection and implications

Cristina M. Dalle Ore[1, 2], Dale Cruikshank[2], Silvia Protopapa[5], Francesca Scipioni[1, 2], Jason Cook[3], Will Grundy[4], Alan Stern[5], Catherine B. Olkin[5], Leslie A. Young[5], Harold A. Weaver[6], Kimberly Ennico[2]
[1]SETI Institute, Mountain View, California, United States, [2]NASA Ames Research Center, Moffett Field, California, United States, [3]Pinhead Institute, Telluride, Colorado, United States, [4]Lowell Observatory, Flagstaff, Arizona, United States, [5]South West Research Institute, Boulder, Colorado, United States, [6]Johns Hopkins University Applied Physics Laboratory , Laurel, Maryland, United States

Abstract

Pluto was observed at high spatial resolution during the New Horizons flyby on July 14th, 2015 by the near-infrared spectral imager (Linear Etalon Imaging Spectral Array, LEISA, ~2700 m/pixel) and CCD camera (Multi-spectral Visible Imaging Camera, MVIC, ~650 m/pixel) system. In the striking diversity of the surface, Virgil Fossae, part of Cthulhu Macula, stands out as uniquely red. This is a region of past extensional tectonics, whose pattern appears to radiate away from Sputnik Planitia and the basin in which it lies. A detailed analysis of this geographical area unveils a spectral signature characteristic of ammonia in water ice, its hydrate, ammoniated salts, or a combination of the above. Ammonia is an important molecule both as a tracer of chemical evolution in the Solar System and as a modifier of the physical properties of bedrock water ice. Lowering the freezing point of water ice, ammonia potentially allows for liquid water to be present in the interiors of icy bodies with a core heated by radioactive decay. On Pluto, we find that the presence of ammonia provides evidence of past and possibly geologically recent activity, supporting the hypothesis of a subterranean body of water and cryovolcanic activity. We present a detailed analysis of the near-IR spectrum of Pluto leading to the discovery of this important feature.

03:35 PM-03:35 PM

221.08D The Pluto System story told by resonances

Thamiris De Santana[1], Douglas Hamilton[2], Othon C. Winter[1]

[1]Sao Paulo State University (UNESP), Guaratingueta, SP, Brazil, [2]University of Maryland, College Park, Maryland, United States

Abstract

The Pluto-Charon system is very interesting due its complex dynamics. Its four small satellites Styx, Nix, Kerberos and Hydra were discovered close to, but not in, the 1:3, 1:4, 1:5, and 1:6 mean motion resonances with Charon, respectively (Cheng et al. 2014). Later, Styx, Nix, and Hydra were found to be in a three body resonance, a special configuration not so common among satellites and that provides clues to the origin of the system (Showalter and Hamilton 2015).

In this work, we propose and seek evidence for a path to explain the satellites' current positions. Our idea is to start with an early Charon migrating under tidal forces from Pluto, and the initial resonant capture of one or more of the small satellites into two-body resonance with Charon. Perhaps the most likely situation is that Styx was first captured into the 3:1 mean motion resonance. Subsequently, Styx would move outward while simultaneously having its eccentricity raised by the resonance. We hypothesize that additional captures of Hydra and Nix into mean motion resonances can, when activated together, turn on the three-body resonance. If the three body resonance takes control, Styx could, in principle, be adiabatially removed from its resonance with Charon and its eccentricity driven back toward zero. We are in the process of testing this and similar scenarios with numerical simulations.

Initial results indicate that in some cases it is easier to capture a satellite in a higher order resonance with Charon, especially the 4:1, than for pairs of the smaller satellites to capture into resonance. Thus, we are also exploring alternative possible histories.

03:35 PM-03:35 PM

221.09 Modeling the Phase Diagram and Properties of Titan's Lakes via Molecular Dynamics

Shyanne Dustrud[1], Gerrick E. Lindberg[1], Will Grundy[2], Jennifer Hanley[2], Stephen C. Tegler[1], Jessica J. Groven[1, 3]

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Abstract

Nitrogen, methane, and ethane are abundant on Titan. The ternary system of these three compounds is present as liquids in lakes and seas. Knowledge of their phase behavior and thermodynamic properties is crucial for understanding the behaviors of Titan's fluid bodies and their interaction with the surface and atmosphere. The development of a full phase diagram is of fundamental importance in the understanding of how the bodies of liquid behave on the surface of Titan; additionally, the material properties such as, densities, heat capacities, or viscosity are vital to better the understanding of the stability of the liquids and their bulk behavior. Utilizing a thermodynamic approach that assumes ideality of the system, phase behavior can be predicted. Molecular dynamics simulations (MD) offer a unique insight to the harsh conditions of the outer solar system, enabling the real effects of non-ideal interactions to be quantified. Material properties can then be calculated from the results of MD simulations for a variety of

compositions and conditions. MD offers not only common observables, but it also provides an understanding at the atomistic level of what occurs in a mixture. Combining a theoretical approach with experimental, the exact boundaries of the predicted phase transitions can be elucidated and the theoretical approach validated. The Astrophysics Ice Lab at Northern Arizona University is home to a laboratory apparatus capable of cooling samples to 30K, and designed with windows to allow for spectroscopy of a bulk sample. Raman spectroscopy in particular is a powerful tool in evaluating the interactions between molecules within a mixture and allows for a more in-depth study of the systems in question. We will present on our findings and material properties calculated from MD simulations of the ternary mixture under conditions relevant to Titan.

03:35 PM-03:35 PM

221.10 Aeolian sediment mechanics on Titan: Insights from the Titan Wind Tunnel

Stephen L. Sutton[1], Emily Nield[1], Devon Burr[1], Joshua Emery[1], Jasper Kok[2], Francis Turney[2], Kirby D. Runyon[3], James K. Smith[4]

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Abstract

The presence of dunes on Titan is evidence that aeolian transport is of significant geomorphic importance on the Saturnian moon. However, atmospheric and sedimentological conditions differ significantly from terrestrial aeolian and fluvial systems, the two analogous sediment transport environments that exist on Earth. Specifically, differences in the fluid viscosity, fluid-sediment density ratio, and the submerged weight of the grains appear to change some fundamental aspects of sediment transport system behaviour.

Recently hardware simulation of Titan transport processes has been conducted in the Titan Wind Tunnel (TWT), located in the Planetary Aeolian Laboratory (PAL) at NASA Ames Research Center, using high pressure to alter kinematic viscosity and fluid density to approach Titan conditions. Video recorded during threshold of motion experiments show grains moving with unusual modes of both entrainment and transport. Specifically, grains are entrained through rotational, translational, or skipping motions, as opposed to near vertical ejections under ambient Earth conditions. Further, the grains are transported with greater horizontal translation than expected, deviating from the characteristic aeolian saltation trajectory. We speculate that these differences arise from a change in the relative importance of two controlling thresholds: 1) the fluid threshold, where grain ejection is controlled primarily by fluid forces; and 2) the impact threshold, where grains are ejected via forces exerted through collision with grains already in transport. This change then alters the systems response, and has implications for modelling bulk transport fluxes.

03:35 PM-03:35 PM

221.11 Integrated Laboratory, Modeling and Observational Investigations of the Condensation of Benzene on Titan's Stratospheric Aerosols

Ella M. Sciamma-O'Brien[1], Laura T. Iraci[1], Erika Barth[2], Farid Salama[1], Sandrine Vinatier[3]

[1]Space Science and Astrobiology Division, NASA Ames Research Center, Moffet Field, California, United States, [2]South West Research Institute, Boulder, Colorado, United States, [3]LESIA, Observatoire de Paris, Meudon, France

Abstract
Aerosols in Titan's atmosphere play an important role in determining its thermal structure and can act as condensation nuclei for the formation of clouds. The global circulation of Titan's atmosphere reversed within the two years following the northern spring equinox in August 2009, increasing the mixing ratios of benzene (C_6H_6) and other species at the South pole. A simultaneous strong cooling above the south pole (dropping temperatures below 120 K) resulted in conditions where molecules could condense at unusually high altitudes (>250 km). C_6H_6 and HCN ices have been detected by the Composite Infrared Spectrometer (CIRS) and the Visible and Infrared Mapping Spectrometer (VIMS), respectively, in the South polar cloud system, but the existing laboratory data is insufficient to allow models to reproduce the formation of the observed cloud system.
We will present the preliminary results and the overall scope of a newly funded NASA SMD Cassini Data Analysis Program (CDAP) project which proposes to combine laboratory, modeling and observational studies to investigate the condensation of benzene on Titan's aerosol as an important component of the cloud system that appeared during the autumn at 300 km above Titan's South pole.

The project goals are:
1) (lab) to measure the vapor pressure of benzene at Titan-relevant temperatures using the Ames Atmospheric Chemistry Laboratory[1],
2) (lab) to produce analogs of Titan's aerosols using the Titan Haze Simulation experiment developed on the NASA Ames COSmIC facility[2] and investigate the conditions required for condensation of benzene on them using the ACL,
3) (model) to use the experimental data to constrain nucleation and condensation in microphysical models[3], in order to determine expected cloud altitudes and particle sizes, and
4) (observation) to compare our experimental data and modeling output with observations from CIRS in the 9-17 µm spectral region[4], in order to better understand the molecular composition of this cloud system.

References:
[1] Iraci, L. T. et al., *Icarus* **210**(2), 985-991, 2010.
[2] Sciamma-O'Brien, E. et al., *Icarus* **289**, 214-226, 2017.
[3] Barth E. L., *Planet. Space Sci.* **127**, 20-31, 2017.
[4] Vinatier, S. et al., *Icarus* **310**, 89-104, 2018.

Wednesday, October 24, 2018
08:30 AM-09:30 AM
Ballroom A (Knoxville Convention Center)

300 Mars: Climate, including Surface-Atmosphere Interactions
Chair(s): Nadine G. Barlow, Matteo M. Crismani

08:30 AM-08:40 AM
300.01 Mapping Mars' Southern Springtime Winds and Seasonal Polar Fans with Planet Four
Megan E. Schwamb[1], K-Michael Aye[2], Ganna Portyankina[2], Candice Hansen[3], Chris J. Lintott[4], Adam McMaster[4], Grant R. Miller[4], Brian Carstensen[5], Christopher Snyder[5], Michael Parrish[5], Stuart Lynn[5], Chuhong Mai[6], David Miller[5], Robert J. Simpson[4], Arfon M. Smith[7]
[1]Northern Operations Center, Gemini Observatory, Hilo, Hawaii, United States, [2]Laboratory for Atmospheric and Space Physics, Boulder, Colorado, United States, [3]PSI, Tucson, Arizona, United States, [4]University of Oxford, Oxford, United Kingdom, [5]Adler Planetarium, Chicago, Illinois, United States, [6] ASU, Tempe, Arizona, United States, [7]STScI, Baltimore, Maryland, United States

Abstract
Mars' south pole region is sculpted by the seasonal cycle of freezing and thawing of exposed carbon dioxide (CO2) ice. In the Spring, CO2 jets loft dust and dirt through cracks in the thawing CO2 ice sheet to the surface where it is thought that local surface winds blow the material into the hundreds of thousands of dark fans visible from orbit. Understanding the direction, frequency, and appearance of these fans (a proxy for the jets) and how varying factors impact these properties, we can better understand the Martian climate.

It is difficult if not impossible for computer algorithms to accurately identify the hundreds of thousands of individual fans visible within orbital imagery, but these features are easily spotted by the human eye. The Planet Four project has recently released a catalog of 159,558 fans and 250,164 blotches (ellipses - deposits with less clear direction) identifying locations of seasonal fans produced by the CO2 jet process. The catalog was generated by combining the assessments made by over 80,000 volunteers reviewing a set of 42,904 tiles derived from 221 HiRISE observations obtained over 2 Martian Years (MY 29 and 30 spring seasons) and spanning 22 targeted locations across the south polar region.

This catalog serves as the largest reporting of locations, sizes, and directions of seasonal fans (and wind direction and strength by proxy) on the Martian surface. Using south polar fans as regional wind markers, the Planet Four catalog can provide tests for and input to global and regional atmospheric circulation models. We present the Planet Four project and our seasonal fan and blotch catalog, including estimates of the total area of the ice cap covered by these seasonal deposits. We will examine the inter-annual variability of the fans (wind direction) over the Martian south polar region and and preliminary comparisons to global climate models.

Acknowledgements: This work uses data generated via the Zooniverse.org platform, development of which was supported by a Global Impact Award from Google, and by the Alfred P. Sloan Foundation. We also thank the HIRSE and MRO Teams for their support.

08:40 AM-08:50 AM
300.02 Constraints on Mars Aphelion Cloud Belt Phase Function and Ice Crystal Geometries

Brittney Cooper[1], John E. Moores[1], Douglas J. Ellison[2], Jacob L. Kloos[1], Christina L. Smith[1], Charissa L. Campbell[1], Scott D. Guzewich[3]
[1]Earth and Space Science and Engineering, York University, Toronto, Ontario, Canada, [2]NASA JPL, Pasadena, California, United States, [3]NASA GSC, Greenbelt, Maryland, United States

Abstract
This work extends that of Kloos et al. (2016) to constrain the lower bound of the scattering phase function of Martian water ice clouds (WICs) with the implementation of a new observation aboard the Mars Science Laboratory (MSL). The Phase Function Sky Survey (PFSS) was designed to allow for the derivation of the phase function over a scattering angle range of 18.3° to 152.61°, in both morning and evening observations. It was executed on a weekly basis aboard MSL during the Aphelion Cloud Belt (ACB) season of Mars Year 34, spanning a solar longitude range of Ls = 61.4° − 156.5°. The phase function was then derived over our observed scattering angle range and compared with 9 modeled phase functions: seven ice crystal habits and two Martian WIC phase functions currently being implemented in models. Hexagonal plates, hollow columns, solid columns, and bullet rosettes were found to be possible ice crystal geometries dominating Martian WICs, while spheres, aggregates, and droxtals were not. Better understanding the ice crystal habit and phase function of Martian water ice clouds directly benefits Martian climate models which currently assume spherical and cylindrical particles.

08:50 AM-09:00 AM
300.03 Estimating the Altitude of Martian Clouds at the Mars Science Laboratory Rover Landing Site
Charissa Campbell[1], Alexandre Kling[2], Christina L. Smith[1], Jacob L. Kloos[1], John E. Moores[1], Scott D. Guzewich[3], Mark Lemmon[4], Casey Moore[1], Brittney Cooper[1], Robert M. Haberle[2]
[1]York University, Toronto, Ontario, Canada, [2]NASA-AMES Research Centre, Mountain View, California, United States, [3]NASA Goddard Spaceflight Center, Greenbelt, Maryland, United States, [4]Space Science Institute, College Station, Texas, United States

Abstract
The Mars Science Laboratory (MSL), also known as Curiosity, has captured images of clouds and created several types of atmospheric movies to understand winds and moisture aloft. A Zenith Movie (ZM) consists of eight images and are taken at an elevation of 85° using the Navigation Camera (Navcam). Wind direction can be measured using these products, but without a lidar the altitude of the features is still unknown. The Mars Regional Atmospheric Modelling System (MRAMS) is used to correlate these values. The Navcam has a field of view (FOV) of 45° x 45° and a ZM is 512 pixels x 512 pixels. This creates an angular distance of 0.08789° per pixel. Cloud features are followed to determine their change in angular space over time. The angular wind velocity and wind direction can be correlated for each altitude point from 0-50 kilometers above Gale Crater using MRAMS. Diurnal and seasonal patterns can be identified by evaluating results over an entire Martian Year (MY).

Uncertainties in our models requires confirmation of our results. The Mars Climate Sounder (MCS) onboard the Mars Reconnaissance Orbiter (MRO) provides the altitude of clouds by measuring ice extinction through limb measurements, but this is limited to high clouds above 5 km altitude or even higher depending on opacity. At lower altitudes, atmospheric movie pointing towards Aeolis Mons show shadows caused by overhead clouds. The shadow's velocity can be determined through geographical referencing. Pairing a shadow movie with a ZM provides cloud velocity and cloud altitude. Using these methods will refine our estimate the altitude of clouds above Gale Crater.

09:00 AM-09:10 AM

300.04 Mapping the vertical distribution of water ice clouds on Mars with NOMAD/TGO

Giuliano Liuzzi[1, 2], Geronimo Villanueva[1], Matteo M. Crismani[1], Michael Mumma[1], Michael D. Smith[1], Ann Carine Vandaele[3], Ian Thomas[3], Frank Daerden[3], Bojan Ristic[3], Manish R. Patel[4, 5], Giancarlo Bellucci[6], Jose Juan Lopez-Moreno[7], Valerie Wilquet[3], James A. Holmes[4], Yannick Williame[3], Stephen Lewis[4], Fabrizio Oliva[6], Will Hewson[4]

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Abstract

We present profiles of water ice clouds retrieved from the data collected by the high-resolution Nadir and Occultation for MArs Discovery (NOMAD) instrument onboard the ExoMars / Trace Gas Orbiter (TGO). The NOMAD spectrometer is the first IR instrument capable of producing vertical profiles of aerosols with high spatial resolution of the order of ~1 km. This is possible analyzing the data acquired in Solar Occultation geometry, which sample the atmosphere at different altitudes, hence permitting to quantify the extinction of the incoming direct solar radiation.

Running a full retrieval of gases and aerosol opacity on the available Solar Occultation data, we have reconstructed several vertical profiles of ice clouds, and disentangled them from dust at each altitude. Looking at the spectral properties of ice extinction, we also provide a first characterization of the microphysical properties of ice crystals, and constrained the particle size and their vertical variation. This allows us to create a detailed 3-D map of ice clouds near the Martian terminator.

Such a study opens a pathway to investigate in great detail the water condensation processes that occur in the Martian atmosphere, which can be more fully understood by the simultaneous retrieval of water ice, H_2O and HDO profiles. This particular analysis is ongoing with NOMAD data. In addition, given the capability of NOMAD to map water ice clouds at very high vertical sampling, a precise quantification of the vertical boundaries of clouds are a key aspect in improving the current understanding of their radiative effect and the induced heating rate.

Following its successful orbital insertion in early 2018, we retrieved unique vertical profiles of several gas species and aerosols with ExoMars/TGO/NOMAD. In this paper, we report initial retrievals of water ice derived during this initial observational period (April-May 2018).

This work was supported by the Mars Exploration Program Office, NASA HQ, under NOMAD WBS 604796.01.12.01 to the Goddard Space Flight Center.

09:10 AM-09:20 AM

300.05 **Clouds in the night side of Mars: an analysis using Mars Express VMC**

Teresa Del Rio Gaztelurrutia[1], Jorge Hernandez-Bernal[1], Agustin Sanchez-Lavega[1], Ricardo Hueso[1], Alejandro Cardesin-Moinelo[2], Abel de Burgos-Sierra[2], Dmitri Titov[3], Simon Wood[4], Miguel Dias Almeida[5]

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Abstract
The Visual Monitoring Camera (VMC) on-board Mars Express is a simple webcam that was initially designed to confirm the separation of the Beagle-2 probe. In 2007 it started taking routine images of Mars, initially intended for outreach, and it has been recently promoted to a scientific instrument [1]. At present, VMC image database contains ~20000 images in series of images taken with different exposure times. When the spacecraft is at apoapsis, VMC provides context images of Mars, with the whole planet visible and in which large and middle scale atmospheric features can be appreciated. The database covers over five Martian years (MY30- MY34), and therefore allows the study of the seasonal evolution of atmospheric phenomena. In this work, we describe the appearance of illuminated clouds in the night side of the planet close to the terminator. To this end, we have automatically navigated the approximately 958 series of images using python software based on SPICE kernels, and developed a cloud-search algorithm, that has allowed us to detect at least 350 events of high-clouds with minimum altitudes between 10 and 90km, corresponding to the period from October 2009 to April 2018. In order to perform a statistical analysis of the results, we have determined the sample space of parameters: aerographic longitude and latitude, area coverage, cloud top height, orbital longitude Ls and Martian Year (MY). With this aim, every night pixel closer than 30º from the terminator has been registered and the minimum height that would allow direct sunlight to reach a cloud at that position, and consequently make the corresponding pixel brighter in the Martian night has been calculated. We find that high clouds appear most often in two belts between latitudes 30º and 60º North and South, mainly at the end of the corresponding winter season, and at Terra Cimmeria and Terra Sirenum during autumn and winter in the Southern Hemisphere.
[1] Sánchez-Lavega et al., Icarus 299, 194-205, (2018)

09:20 AM-09:30 AM
300.06 A study of cloud and dust phenomenology in MAVEN/IUVS data
Kyle Connour[1], Nicholas Schneider[1], Franck Lefevre[2], Justin deighan[1], Sonal Jain[1], Michael J. Wolff[3]
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Abstract
The Imaging Ultraviolet Spectrograph (IUVS) instrument on the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft takes mid-UV spectral images of the Martian surface and atmosphere. From these apoapse images, a variety of cloud morphologies and local time variability can be seen and comprise the only MAVEN observations of water ice aerosols. Measuring local time variability of large-scale recurring cloud features is made possible with MAVEN's ~4.5-hour elliptical orbit, something not possible with sun-synchronous orbits.

We have examined two Martian years' worth of data and present an overview of IUVS cloud observations. Topographic clouds are one of the most visually striking types of clouds observed in our data, which are seen throughout northern hemisphere summer (Ls = 90°) and persist into northern fall (Ls = 180°). These clouds are generally localized to Tharsis volcanoes and show streaks, waves, and spirals. From northern spring into late summer we also see the presence of aphelion cloud belt (ACB) clouds, a longitudinally continuous band of clouds that forms near equatorial regions. Throughout the year we see the presence of polar hoods. Sometimes these clouds are simply an amorphous structure centered around the pole; other times we see the presence of single and double vortices as well as cyclonic features that appear and diminish on the timescale of several hours. Finally, we have observed clouds above the 2018 dust storm. Some clouds are wispy---reminiscent of cirrus clouds---while other times we see the presence

of gravity waves in the clouds and a “terminator cloud band.” We present observations of these cloud morphologies and preliminary retrievals of aerosol properties.

Wednesday, October 24, 2018
08:30 AM-09:35 AM
Ballroom B (Knoxville Convention Center)

301 1I/`Oumuamua
Chair(s): Tony Farnham, Beatrice E. Mueller

08:30 AM-08:40 AM
301.01 Discovery, Characterization and Origin of Interstellar Object ‘Oumuamua
Karen Meech[1], Michael J. Belton[6], Marc W. Buie[7], Kenneth C. Chambers[1], Davide Farnocchia[4], Olivier Hainaut[5], Robert Jedicke[1], Jacqueline V. Keane[1], Jan T. Kleyna[1], Eugene Magnier[1], Marco Micheli[2, 3], Beatrice E. Mueller[9], Dina Prialnik[8], Norbert Schorghofer[9], Richard J. Wainscoat[1], Harold A. Weaver[10], Robert Weryk[1]
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Abstract
On October 19, 2017 the Pan-STARRS1 telescope discovered a rapidly moving object. By October 30, its orbital eccentricity was determined to be 1.196±0.006 making this the first detection of an interstellar object. Designated 1I/2017 U1 (‘Oumuamua), it passed perihelion on September 9, 2017 and made its Earth close approach at 63 lunar distances on October 14. Because it was receding rapidly from the Earth and Sun, within a week of discovery the brightness dropped by a factor of 10 and in less than a month it had dropped by a factor of 100 so there was only a short period available for characterization. Deep images of ‘Oumuamua showed no cometary activity, with limits on the amount of micron-sized dust at < 1 kg (within 750 km) that could be present. The light curve showed an instantaneous rotation period of 7.34 hours with a brightness range of 2.5 magnitudes, implying an extremely elongated axis ratio of ~10:1. Assuming a low albedo typical of comets (4%) the estimated dimensions were 800x80x80 m. However, as more time series data were obtained, it was evident that ‘Oumuamua was in an excited spin state with the long axis precessing around the total angular momentum vector with an average period of 8.67±0.34 h. The timescale for damping an excited spin in a body this size is very long, so the spin state may reflect the violent process of ejection of ‘Oumuamua from its host planetary system. ‘Oumuamua’s surface reflectivity was red with a spectral slope of 23%±3% per 100 nm, consistent with comet surfaces, the dark side of Iapetus, and other minerals. Hubble Space Telescope and ground-based data were combined for a detailed study of the orbit. Our analysis of 207 astrometric positions showed that the orbit could not be fit by a gravity-only trajectory, but could be fit (at the 30-sigma level) with the addition of a radial non-gravitational acceleration. We explored several explanations for the non-gravitational motion, and found that cometary outgassing is the most physically plausible, but requires that ‘Oumuamua has a somewhat different nature from solar system comets. Support for this work was obtained from NSF grants AST-1617015 and AST-1413736.

08:40 AM-08:50 AM
301.02 Detailed Photometric Characterization of ‘Oumuamua with Gemini North
Michal Drahus[1], Piotr Guzik[1], Waclaw Waniak[1], Barbara Handzlik[1], Sebastian Kurowski[1], Siyi Xu[2]

[1]Jagiellonian University, Krakow, Poland, [2]Gemini Observatory, Hilo, Hawaii, United States

Abstract
‘Oumuamua is the long-awaited first bridge between extrasolar planetary systems and our own Solar System. The body was discovered with the Pan-STARRS telescope on UT 19 October 2017 and became intensively observed immediately after. Our team was awarded 12 hr of observation time on the Gemini North telescope in Hawaii - the longest run ever allocated to observations of ‘Oumuamua on a telescope of this class. On UT 27 and 28 October 2017, we obtained over 400 images suitable for accurate time-resolved photometry, having an effective integration time of 3.58 hr and spanning a total of 8.06 hr (Drahus et al. 2018, NatAs 2, 407). A combined ultra-deep image of ‘Oumuamua shows no signs of cometary activity, providing the most compelling evidence that the object is morphologically an asteroid — thus adding to the mystery of the remarkably strong non-gravitational acceleration detected in the object’s orbital motion (Micheli et al. 2018, Nature 559, 223). An accurate light curve reveals an enormous range of brightness variation with a full range reaching 2.6±0.2 mag, suggesting a highly elongated shape of the body with the long-to-short axis ratio of >4.9. We also determined the effective rotation period to be 7.56±0.1 hr, estimated the equivalent size to be about 150 m, and we found that - contrary to previous reports by other teams - the requirement of rotational stability allows for the body to be strengthless and have a bulk density of typical Solar System asteroids. Most significantly, our light curve does not repeat exactly from one night to another, implying that ‘Oumuamua is in a non-principal-axis rotation state. ‘Oumuamua’s tumbling is consistent with an ancient collision in the body’s home planetary system, but might have also been caused by the mysterious non-gravitational forces during ‘Oumuamua’s passage through the Solar System.

08:50 AM-09:00 AM
301.03 Spectral Variability of 1I/`Oumuamua
Barbara Handzlik[2], Sebastian Kurowski[2], Waclaw Waniak[2], Michal Drahus[2], Piotr Guzik[2], Siyi Xu[1]
[1]Gemini Observatory, Hilo, Hawaii, United States, [2]Jagiellonian University, Krakow, Poland

Abstract
1I/`Oumuamua is a small extrasolar body discovered by PanSTARRS and the first probe of exoplanetary matter seen in our Solar System. Its appearance resulted in many observational campaigns, which allowed the determination of several interesting properties of this remarkable body, such as large brightness variations (e.g. Meech et al. 2017, Nature 552, 378), tumbling motion (Drahus et al. 2018, NatAs 2, 407; Fraser et al. 2018, NatAs 2, 383) and temporal color variations (Bannister et al. 2017, ApJL 851, L38; Fitzsimmons et al. 2018, NatAs 2, 133; Fraser et al. 2018, NatAs 2, 383). Although the light curve variability is well resolved, the spectral and color variations are not as obvious. We will present the highest sensitivity spectra of 1I/`Oumuamua obtained with the Gemini North Multi-Object Spectrograph (GMOS-N) on UT 27 October 2017, and discuss them in the context of potential slope variability confronting our results with published data.

09:00 AM-09:10 AM
301.04 Spitzer observations of `Oumuamua and `Oumuamua's density and shape
David Trilling[1], Andrew McNeill[1], Michael Mommert[1, 2], Joseph Hora[3], Davide Farnocchia[4], Paul Chodas[4], Jon Giorgini[4], Howard Smith[3], Sean Carey[5], Carey M. Lisse[6], Michael Werner[4], Steve Chesley[4], Joshua Emery[7], Giovanni Fazio[3], Yanga Fernandez[8], Alan Harris[9], Massimo Marengo[10], Michael Mueller[11, 12], Alissa Roegge[1], Nathan Smith[1], Harold A. Weaver[6], Karen Meech[13], Marco Micheli[14, 15]

[1]Northern Arizona University, Flagstaff, Arizona, United States, [2]Lowell Observatory, Flagstaff, Arizona, United States, [3]Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, United States, [4]JPL/Caltech, Pasadena, California, United States, [5]IPAC/Caltech, Pasadena, California, United States, [6]JHU/APL, Laurel, Maryland, United States, [7]University of Tennessee, Knoxville, Knoxville, Tennessee, United States, [8]University of Central Florida, Orlando, Florida, United States, [9]DLR, Berlin, Germany, [10]Iowa State University, Ames, Iowa, United States, [11]Kapteyn Astronomical Institute, Groningen, Netherlands, [12]SRON, Groningen, Netherlands, [13]University of Hawai`i, Honolulu, Hawaii, United States, [14]ESA -- SSA/NEO Coordination Centre, Frascati, Italy, [15]INAF, Monte Porzio Catone, Italy

Abstract
1I/`Oumuamua is the first confirmed interstellar body in our Solar System. Here we report on 4.5 micron observations of `Oumuamua made with the Spitzer Space Telescope on 2017 November 21--22. We did not detect the object and place an upper limit on its flux. This implies an effective spherical diameter upper limit and albedo lower limit, with a range of values that depends on what value of the thermal beaming parameter is used. We also place upper limits on the amount of dust, CO, and CO2 that are emitted from this object that are lower than previous results; we are unable to constrain the production of other gas species. We also present our estimate of `Oumuamua's density and aspect ratio (elongation). There is no description of the suite of `Oumuamua's physical properties that corresponds to any population of bodies in our Solar System. Our results extend the mystery about `Oumuamua's origin and evolution.

09:10 AM-09:20 AM
301.05 1I/`Oumuamua - Probably Too Small To Ever be An Active Comet
Piotr Guzik, Michal Drahus
Jagiellonian University, Kraków, Poland

Abstract
Immediately upon its discovery, the first interstellar object 1I/`Oumuamua was thought to be a comet because of its highly eccentric orbit. Soon after, deep images revealed that it did not show the characteristic cometary activity, and thus it was reclassified as an asteroid. However, according to model calculations, many more comets than asteroids were ejected from the early Solar System, making the lack of `Oumuamua's activity very surprising. This, and the familiarly reddish color, suggested it might in fact be a (significantly devolatilized) comet (Fitzsimmons et al. 2017, NatAs 2, 133) – a hypothesis apparently further supported by the detection of non-gravitational forces in the orbital motion of the body (Micheli et al. 2018, Nature 559, 223).
However, the hypothesis of cometary nature of `Oumuamua must be confronted with two important evolutionary processes of comets: (1) rotational changes in response to outgassing torques and (2) rotational breakup resulting from those. The former is especially efficient for small nuclei (e.g. Bodewits et al. 2018, Nature 553, 186). We found that for a typical comet having the same dimensions as the expected dimensions of `Oumuamua sublimation of a layer as thin as 1 meter is enough to accelerate the rotation to the point that the nucleus breaks apart, even if it has a non-negligible tensile strength. This fact, combined with the estimated parameters of `Oumuamua, impose strict restrictions on the physical properties of the body. Furthermore, the amount of the sublimated material needed to explain the observed non-gravitational effects seems to be large enough to drive the body to rotational instability during its passage through the Solar System, if only `Oumuamua's physical properties are similar to those of typical active comets.
We conclude that: (1) `Oumuamua is supposedly so small that if it were ever an active comet, it would

spin up and disrupt before losing a sufficiently deep layer to devolatilize and (2) if `Oumuamua was sublimating while close to the Sun, its physical properties must be far from anything we know from our Solar System.

09:20 AM-09:30 AM

301.06D The Galactic Orbit of 1I/2017 U1 `Oumuamua

Bryce Bolin[1, 2], Rory Barnes[2], Thomas Quinn[2], Alessandro Morbidelli[3]
[1]B612 Asteroid Institute, Seattle, Washington, United States, [2]University of Washington, Seattle, Washington, United States, [3]Obs. de la Cote d'Azur, Nice, France

Abstract

The existence and detection of interstellar objects (ISOs) have been hypothesized in recent literature. Current models predominately describe the kinematics of the population of ISOs to be consistent with local stars in the Milky Way, however these models do not distinguish between a variety of different origins for ISOs from local to more distant stars. The first known ISO 1I/2017 U1 `Oumuamua was discovered in October 2017 after it reached perihelion on September 9, 2017, and presents the first opportunity for understanding the origin and size of the ISO population. While numerous studies have examined the occurrence of 1I/2017 U1 and its hyperbolic heliocentric orbit, a convincing origin for this object has not been found. We present the galactic orbit of 1I/2017 U1 in order to understand its orbital evolution in the Galaxy prior to encountering the Solar System and its subsequent scattering due to its encounter with the Sun. Using the latest heliocentric orbital solution for 1I/2017 U1, we find that the galactic orbit 1I/2017 U1 prior to encountering the sun had an eccentricity of ~0.08, compatible with the possibility of 1I/2017 U1 having experienced significant radial migration in its galactic orbit as a result of resonant scattering with spiral arms. The orbit of 1I/2017 U1 may have radially migrated >1 kpc from its original system given the likely possibility that 1I/2017 U1 has not encountered any other stars prior to the Sun due to the large time scale for relaxation in the Galaxy. We find that the post-encounter galactic orbit of 1I/2017 U1 is much hotter and is on the border between the thin and thick disk components of the Milky Way with a maximum height above the midplane of ~0.4 kpc. In addition, we present some possible ejection scenarios of 1I/2017 U1 out of its home system based on N-body experiments using an equivalent model of the Solar System as the home system of 'Oumuamua and its subsequent evolution in the Galaxy.

Wednesday, October 24, 2018
08:30 AM-09:35 AM
Ballroom C (Knoxville Convention Center)

302 Centaurs/TNOs I: Observational Surveys
Chair(s): Michele T. Bannister, José Peña Zamudio

08:30 AM-08:40 AM
311.01 OSSOS observes planet-formation structure in the main Kuiper Belt
Brett Gladman[1], Michele T. Bannister[2], J. Kavelaars[3], Jean-Marc Petit[4], Kathryn Volk[5]
[1]Physics and Astronomy, University of British Columbia, Vancouver, British Columbia, Canada, [2]Queen's University, Belfast, United Kingdom, [3]National Research Council, Victoria, British Columbia, Canada, [4]Observatoire de Besancon, Besancon, France, [5]University of Arizona, Tucson, Arizona, United States

Abstract
The Outer Solar System Origins Survey (OSSOS) has now completed its detailed search for moving objects in the transneptunian region. For the main Kuiper Belt, the survey tracked 100% of the detected objects to high-precision orbits (typical fractional semimajor axis uncertainties of 0.01 - 0.10 percent). This accuracy allows us to observe previously undiscussed structure in the classical Kuiper Belt's orbital distribution. During the early-release OSSOS data analysis, we found that the a/q/I structure (semimajor axis/perihelion/inclination) of the Kuiper Belt could still be matched adequately with that previously found by the Canada-France Ecliptic Plane Survey (CFEPS) : a hot inclination component and then a cold component split into a 'stirred' component and a concentrated 'kernel' near 44 au. With the abundant full set of OSSOS detection (extending down past 25th magnitude in r band), the data now no longer permit this simple two-component structure for the cold component. In fact, there are small-scale features of great interest in the belt, and there are new trends visible which require a more complex model. We will present these features and discuss how current models of planetary migration may explain some of them.

08:40 AM-08:50 AM
302.02 OSSOS: The Missing Small Members of the Haumea Family
Rosemary Pike[1], Darin Ragozzine[2], Benjamin Proudfoot[2], Steven Maggard[2], Mike Alexandersen[1]
[1]ASIAA, Taipei, Taiwan, [2]Brigham Young University, Provo, Utah, United States

Abstract
The Outer Solar Systems Origins Survey Ensemble detected three Trans-Neptunian objects (TNOs) with orbital parameters consistent with the Haumea family. These three objects have Delta-V<160 m/s; the majority of TNOs discovered within this space are Haumea family members. 2013 UQ15 is conclusively a Haumea family member, with a Delta-V=37 m/s and solar colors, and is the largest of the three family member candidates. Although OSSOS is sensitive to Haumea family members to a limiting Hr absolute magnitude of 9.5, the smallest of these three objects is Hr=7.9. If these objects share an absolute magnitude distribution with the other dynamically excited populations in the Kuiper belt, small Haumea family members Hr>8 should account for ~50% of the detections. This requires that the Haumea family be characterized by a single shallow H-distribution slope; our preferred slope is alpha=0.3 (q=2.5), although we find that slopes of alpha=0.1-0.7 are statistically consistent with the detections. This single

slope of alpha=0.3 is also found to be consistent with the Haumea family members detected in Pan-STARRS, which also favor a shallow H-distribution. Assuming that Haumea family members have high albedos (~80%) independent of size, this shallow slope extends down to sizes of d=20 km. Using the three OSSOS Ensemble detections and survey characteristics with this H-distribution and a model of the Haumea family orbital distribution, we determine that the stable non-resonant Haumea family has 450 (-390 +720) members with Hr<9.5 and Delta-V<160 m/s. With the shallow H-distribution, most of the mass is in the largest (known) objects. Assuming a density of water ice, an albedo of 80%, and estimating the loss due to unstable or resonant family members, we estimate that the cumulative mass of the original Haumea family (within Delta-V of 160 m/s) was about 10-20% of the present mass of Haumea.

08:50 AM-09:00 AM

302.03 OSSOS exposes the complex size-frequency distribution of the main Kuiper Belt

J. Kavelaars[1], Jean-Marc Petit[4], Brett Gladman[2], Michele T. Bannister[3], Wes Fraser[3]
[1]NRC Canada, Victoria, British Columbia, Canada, [2]University of British Columbia, Vancouver, British Columbia, Canada, [3]Queen's University Belfast, Belfast, Northern Ireland, United Kingdom, [4]Universite Bourgogne Franche Comte, Besancon, Franch Comte, France

Abstract

We present a determination of the H-magnitude (absolute magnitude) distribution for the main classical Kuiper belt based primarily on the Outer Solar System Origin Survey (OSSOS) catalog, but also draw inferences based on other published information where characterization of detection and orbital information was available. In particular, we show that for r-band H magnitudes from 7 to 9 the exponential distribution still has an exponent steeper than the Donanyi steady-state value down to the OSSOS limit.

Based on our analysis we find that the distribution between r-band H-magnitudes 2 to 12 is not well represented by an exponential function with two or even three slope components and a more complex form, with perhaps four distinct slopes, is statistically demanded. We will present our evidence for the claim of a multiple-sloped H-magnitude distribution in the main classical Kuiper belt with particular focus on the low-inclination members of the population. We will also discuss the implication for the formation processes of objects in different size ranges with particular emphasis on the possible history expected for the New Horizons fly-by target 2014 MU69.

09:00 AM-09:10 AM

302.04

Col-OSSOS: The Compositional Structure of the Protoplanetesimal Disk

Wesley C. Fraser[1], Michele T. Bannister[1], Michael Marsset[1], Rosemary Pike[2], Megan E. Schwamb[3], J. Kavelaars[4], Susan Benecchi[5], Matthew Lehner[2], Shiang-Yu Wang[2], Audrey Thirouin[6], Nuno Peixinho[7]
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Abstract
The surfaces of trans-Neptunian objects (TNOs) are poorly understood. Small TNOs fall into at least three classes of object based on their surface colours and albedo. Despite nearly two decades of gathering TNO surface information, a taxonomy has still not been agreed upon. The development of a robust taxonomy is one of the goals of the Colours of the Outer Solar System Origins Survey (Col-OSSOS). After a quick overview of the program, we present taxonomic results from Col-OSSOS. From u, g, r, z and J photometry of a sample of 79 TNOs, we find evidence for only three separate taxons based on their colours. One of the taxons consists entirely of a single dynamical population, the so-called cold classical TNOs, which stand out in colour space, possessing unique (r-z) compared to similarly optically red dynamically excited TNOs. The other two taxons are the known neutral and red classes of dynamically excited TNOs, which are approximately divided by optical colour at (g-r)=0.75. These classes exhibit a broad continuum in colour, rather than occupying similar mean colours for all class members. From albedo considerations, we demonstrate that in the dynamically excited populations, the neutral class outnumbers the red class by at least a factor of 4, but could be as numerous as 11:1. The minimal number of detected taxons argues for a moderately homogenous protoplanetary disk, with only a pair of substantive compositional divisions spanning roughly 20-45 AU, and a disk which is heavily dominated by the neutral class of object.

09:10 AM-09:20 AM
302.05 Lightcurves of the Dynamically Cold Classical Trans-Neptunian Objects
Audrey Thirouin[1], Scott S. Sheppard[2]
[1]Lowell Observatory, Flagstaff, Arizona, United States, [2]Carnegie Institution for Science-DTM, Washington, District of Columbia, United States

Abstract
The dynamically Cold Classical trans-Neptunian objects (TNOs) have low inclination, low eccentricity, and are not in Neptune resonances. Because they have likely remained far from the Sun, and formed near where they exist today, these TNOs are thought to be primordial and thus important to understand our Solar System's formation and evolution.

Even though more than 600 Cold Classicals (CCs) are known, only 19 have been studied for rotational lightcurves. In addition to this low number, most of the studied CCs are the larger objects and known wide binary systems and thus our understanding of this population is highly biased. Therefore, in order to improve our knowledge of the CCs and give context to the next flyby of the NASA's New Horizons mission, we started a survey of the CCs with the Discovery Channel and the Magellan telescopes for lightcurves and colors. Our survey is the first entirely dedicated to the study of the rotational and physical properties of this population. Over the past three years, we observed some 40 non-binary CCs with absolute magnitudes from 5 to 7.2 mag.
Sparse and complete lightcurves obtained through our survey are used to constrain the contact binary fraction, the shape and rotational frequency distributions of the CCs. By comparing the properties of the Cold Classicals to the other dynamical groups, we aim to extract the primordial characteristics of the trans-Neptunian population. We also report the discovery of the first two likely contact binaries detected through lightcurves in this dynamical group. Using our results and the literature, we estimate that only about 10% of the CCs could be contact binaries, which is significantly lower than our estimate of contact binaries in the Plutino population of some 40-50%. This low population of CC contact binaries is also surprising given that the CC have a larger fraction of equal-sized wide-binary systems while the Plutinos have very few known wide binaries. This suggests the different scattering histories of the TNO populations affected the formation of contact binaries. Finally, a new equal-sized wide binary, 2014 LQ28, was identified from our observations.

This work is supported by the National Science Foundation, grant #1734484.

09:20 AM-09:35 AM

302.06D A Combined Study of Extreme Trans-Neptunian Objects From Three Surveys and Implications for Planet Nine

Stephanie Hamilton, Kevin Napier, David Gerdes, Hsing-Wen Lin
Physics, University of Michigan, Ann Arbor, Michigan, United States

Abstract
We present careful studies of the effects of observational bias on the apparent orbital clustering of the most distant trans-Neptunian objects (TNOs) discovered to date, the $a > 250$au and $q > 30$au objects now known as "extreme" TNOs. Recent studies attempting to quantify the impact of observational bias on the observed orbital clustering of the ETNOs have led to conflicting conclusions (M. Brown, arXiv:1706:04175; and C. Shankman et. al., arXiv:1706:05348). We present a third, independent study of the effects of observational bias on the observed orbital clustering of ETNOs using the dataset and survey simulator of the Dark Energy Survey (DES). DES is entering its sixth and final year of operation on the 4m Blanco telescope in Chile and is imaging 5000 sq. deg. in the *grizY* passbands to a limiting magnitude of r~23.8. We additionally extend the study to other TNO surveys that have reported characterized discoveries of ETNOs -- namely, the Outer Solar System Origins Survey (OSSOS) and the survey of Sheppard & Trujillo (S&T). We present a combined, global analysis of the 14 ETNOs discovered by all three surveys (DES, OSSOS, and S&T) since the initial proposal of a distant, unseen planet in the solar system by Batygin & Brown in 2016. We evaluate the significance of the observed orbital clustering of these 14 objects, taking into account the observational biases of each survey. With more objects considered than any individual survey, this study of the impact of observational bias on the apparent orbital clustering of ETNOs has important implications for the Planet Nine hypothesis.

Wednesday, October 24, 2018
10:00 AM-12:00 PM
Ballroom A (Knoxville Convention Center)

303 Mars: Atmosphere
Chair(s): Robert Novak, Yuni Lee

10:00 AM-10:10 AM
303.01 Regolith Adsorptive-diffusive Control of the Methane Seasonal Cycle at Gale Crater, Mars
John E. Moores[1], Raina Gough[2], German Martinez[3], Pierre-Yves Meslin[4], Christina L. Smith[1], Sushil Atreya[3], Paul Mahaffy[5], Claire Newman[6], Chris Webster[7]
[1]Earth and Space Science and Engineering, York University, Toronto, Ontario, Canada, [2]University of Colorado, Boulder, Colorado, United States, [3]University of Michigan, Detroit, Michigan, United States, [4]Universite Paul Sabbatier, Toulouse, Toulouse, France, [5]NASA-Goddard Space Flight Center, Greenbelt, Maryland, United States, [6]Aeolis Research, Pasadena, California, United States, [7]Caltech-JPL, Pasadena, California, United States

Abstract
Recently, Webster et al (doi: 10.1126/science.aaq0131) reported a repeating seasonal cycle of atmospheric methane concentration at the Mars Science Laboratory (MSL) landing site as detected by the SAM-TLS instrument. This amplitude of this annual cycle, varying between 0.23 and 0.65 ppbv, is considerably smaller than previously reported methane spikes at Gale and does not correlate in a simple way with any measured environmental parameter. Such a cycle was unexpected as previous modeling of methane in the Martian atmosphere found that seasonal differences would likely be small due to the relatively low enthalpy of adsorption assumed for Martian regolith and an absence of known subsurface sources of methane.

A 1-D model was prepared to explore the effect of changing the enthalpy of adsorption and to allow subsurface outgassing and diffusion. In the model, a deep and constant seep source of methane is considered, with this methane continuously seeping upwards via a combined diffusive and adsorptive regolith. Meanwhile, the upper surface of the regolith stack remains in contact with the atmosphere and able to exchange methane molecules via adsorption and these methane molecules may also diffuse downwards into the regolith stack.

The best fit to the SAM-TLS data corresponds to a subsurface seep of 2.8×10^{-16} kg m^{-2} s^{-1}, an Effective Atmospheric Dissipation Timescale of 30 sols, a surface methane enthalpy of 32 kJ mol^{-1} and a γ/η (uptake to evaporation coefficient ratio) of 1. This fit results in a χ^2 statistic of 0.05, indicating that the model replicates the data with a probability of 82%. These thermophysical properties differ significantly from lab values. We will discuss the fit dependence on the chosen adsorptive properties of the surface (methane adsorption enthalpy) and compare results to laboratory studies using simulant materials.

10:10 AM-10:20 AM
303.02 ExoMars Trace Gas Orbiter – Selected First Results
Hakan Svedhem[1], Jorge L. Vago[1], Daniel Rodionov[2]
[1]ESA/ESTEC, Noordwijk, Netherlands, [2]IKI, Moscow, Russian Federation

Abstract
The ExoMars programme is a joint activity by the European Space Agency and ROSCOSMOS, Russia. It consists of the ExoMars 2016 mission, launched 14 March 2016, with the Trace Gas Orbiter, TGO, and the Entry Descent and Landing Demonstrator, EDM (Schiaparelli), and the ExoMars 2020 mission, to be launched in July 2020, carrying a Rover and a surface science platform.
TGO arrived at Mars on 19 October 2016 and was inserted into a near equatorial, highly elliptical 4 sol period capture orbit. Two orbits in late November were dedicated to instrument calibration and initial science observations, where an excellent performance of all instruments could be confirmed. In January 2017 the orbital plane was changed to its final inclination of 74 degrees and the period was reduced to one Sol. Subsequently, in early March 2017, an additional two orbits of instrument tests and observations took place, after which a long period of aerobraking commenced with the objective of reducing the orbital period to 2 hours. The aerobraking phase was running very smoothly but was suspended for two months during the solar conjunction in the summer of 2017 and finished on 20 February 2018 with an orbit with an apocentre just above 1000km. After this a series of thruster firings brought the apocentre further down to 400 km. The final near circular 400km altitude orbit was reached on 7 April 2018, after which a full check out of the spacecraft and the instruments was performed in a Commissioning and Verification Phase.
Since 21 April TGO is performing limited nominal science operations using all four instruments, including nadir pointing and solar occultation measurements with the two spectrometers. Full nominal science operation will start in September 2018.
The TGO scientific payload consists of four instruments. These are: ACS and NOMAD, both being spectrometers for atmospheric measurements in solar occultation mode and in nadir mode, CASSIS, a multi-colour camera with stereo imaging capability, and FREND, an epithermal neutron detector for search of subsurface hydrogen.
This presentation will cover a selection of the first results, a brief description of the Trace Gas Orbiter mission, the present status, and the planned future activities.

10:20 AM-10:30 AM
303.03 Martian upper-atmosphere circulation and tides revealed through MAVEN/IUVS observations of nitric oxide nightglow.

Zachariah Milby[1], Arnaud Stiepen[2], Nicholas Schneider[1], Sonal Jain[1], Emilie Royer[1], Justin deighan[1], Francisco Gonzàlez-Galindo[3], Jean-Claude Gérard[2], Franck Lefevre[4], Ian Stewart[1]
[1]Laboratory for Atmospheric and Space Physics, Boulder, Colorado, United States, [2]Université de Liège, Liège, Belgium, [3]Instituto de Astrofísica de Andalucía, Granada, Spain, [4]LATMOS, Paris, France

Abstract
The nitric oxide δ and γ bands are ultraviolet emissions which reflect the production-rate of nitric oxide (NO) from the recombination of excited nitrogen and oxygen atoms. We use it as a tracer of the dynamics between Mars's upper- and middle-atmospheres, particularly of day-to-night and summer-to-winter pole circulation. We analyse this rate as it varies over Mars's surface in mission-long aggregations and local-time divisions. Our data were gathered by the Mars Atmosphere and Volatile Evolution (MAVEN) mission's Imaging Ultraviolet Spectrograph (IUVS) and span different seasonal conditions and latitudes. The data span allows a limited comparison between two subsequent Mars years.

In our previous study of atmospheric limb scans from a limited dataset (Stiepen 2017, doi:10.1002/2016JA023523), we discovered a wave-3 structure to the nightglow at equatorial latitudes. For this study, we use scans taken of the full disk of Mars as seen at apoapse over 1.25 Mars years. We observe the same wave-3 structure, but find seasonal and local-time dependencies on position and brightness. We also discovered a wave-2 structure in northern polar regions that persists through all observed local times and seasons. We compare this to a similar feature observed in polar ozone. We compare our observations to model calculations from the LMD-MGCM. We find the model generally under-predicts the brightness of the nightglow at all sub-polar latitudes, suggesting it over-estimates the efficiency of atomic transport to the poles. However, we also find that the model reproduces the observed equatorial wave-3 and polar wave-2 structures. We identify the dominant atmospheric tide component of the equatorial wave-3 structure and analysis of the local-time dependencies of the wave structures and the brightness across all latitudes.

Acknowledgements
A. Stiepen is supported the Fund for Scientific Research (F.R.S.-FNRS). The MAVEN mission is supported by NASA through the Mars Exploration Program in association with the University of Colorado and NASA's Goddard Space Flight Center.

10:30 AM-10:40 AM
303.04 Global Aurora on Mars During the September 2017 Space Weather Event
Nicholas Schneider, Sonal Jain, Justin deighan, Camella-Rose Nasr
LASP, U. Colorado, Boulder, Colorado, United States

Abstract
We report the detection of bright aurora spanning Mars' nightside during the space weather event occurring in September 2017. The phenomenon was similar to diffuse aurora detected previously at Mars, but 25 times brighter and detectable over the entire visible nightside. The observations were made with the Imaging UltraViolet Spectrograph (IUVS), a remote sensing instrument on the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft orbiting Mars. Images show that the emission was brightest around the limb of the planet, with a fairly uniform faint glow against the disk itself. Spectra identified four molecular emissions associated with aurora, and limb scans show the emission originated from an altitude of ~60 km in the atmosphere. Both are consistent with very high energy particle precipitation. The auroral brightening peaked around 13 September, when the flux of solar energetic electrons and protons both peaked. During the declining phase of the event, faint but statistically significant auroral emissions briefly appeared against the disk of the planet in the form of narrow wisps and small patches. These features are approximately aligned with predicted open field lines in the region of strong crustal magnetic fields in Mars' southern hemisphere.

10:40 AM-10:50 AM
303.06 Propagation of Transient Perturbations into a Planet's Exosphere: Molecular Kinetic Simulations
Ludivine Leclercq[1], Robert johnson[1], Hayley Williamson[1], Orenthal J. Tucker[2]
[1]MSE, University of Virginia, Charlottesville, Virginia, United States, [2]NASA, Greenbelt, Maryland, United States

Abstract
The upper atmospheres of Mars and Titan, as well as those on many other planetary bodies, exhibit significant density variations vs. altitude that are interpreted as gravity waves as shown by MAVEN and Cassini (e.g. Yigit et al. 2015, Terada et al. 2017, Snowden et al. 2014). Such data is then used to extract vertical temperature profiles, even when such perturbations propagate through the transition region from a collision dominated regime and into a planet's exosphere, where the gas is collisionless. Since the

temperature profile is critical for describing the upper atmospheric heating and evolution, we use molecular kinetic simulations to describe transient perturbations in a Mars-like atmosphere. We show that the standard methods for extracting the temperature profile (Snowden et al. 2014) can fail dramatically so that molecular kinetic simulations, calibrated to observed density profiles, are needed in this region of a planet's atmosphere where perturbations occur.

10:50 AM-11:00 AM

303.07 Localized Ionization Hypothesis for Transient Ionospheric Layers

Matteo M. Crismani[1], Justin deighan[1], Nicholas Schneider[1, 2], John M. Plane[3], Paul Withers[4], Jasper Halekas[5], Michael Chaffin[1], Sonal Jain[1]
[1]Laboratory for Atmospheric and Space Physics, Boulder, Colorado, United States, [2]CU Boulder, Boulder, Colorado, United States, [3]University of Leeds, Leeds, United Kingdom, [4]University of Boston, Boston, Massachusetts, United States, [5]University of Iowa, Iowa City, Iowa, United States

Abstract
The long-lived two-peaked vertical structure of the Martian ionosphere is created by extreme and far ultraviolet radiation whose energies respectively determine their ionization altitude. A third low-altitude transient layer (previously referred to as M3 or Mm) has been observed by radio occultation techniques and attributed to meteor ablation. However, new spectral and in-situ observations rule out a meteoric origin. Here we propose an alternative hypothesis for these apparent layers associated with impact ionization from penetrating solar wind ions, previously observed by IUVS as proton aurora. Localized ionization breaks the symmetry assumed by radio occultation techniques, and creates apparent layers lower in the ionosphere. This may occur when the upstream bowshock is altered by a radial interplanetary magnetic field configuration, which allows the solar wind to penetrate directly into the thermosphere. This localized ionization hypothesis provides an explanation for the apparent layer's wide variation in heights, their transient behavior in the absence of a global dynamo. This hypothesis also explains the correlation of transient layers with Mars' southern summer, when penetrating protons are enhanced due to an enhanced hydrogen corona. Moreover this hypothesis is testable by new observations by the MAVEN ROSE experiment for the ongoing southern summer season. This hypothesis has implications for Venus and Titan' ionospheres, where similar transient layers have been observed.

11:00 AM-11:10 AM

303.08 The Impact of SIRs on Mars Upper Atmosphere: Past and Present

Shannon Curry[1], Janet Luhmann[1], Chuanfei Dong[2], Arcadi Usmanov[3], Vladimir Airaptian[4], Yingjuan Ma[5]
[1]Space Sciences Laboratory, University of California, Berkeley, Berkeley, California, United States, [2]Princeton University, Princeton, New Jersey, United States, [3]University of Delaware, Newark, Delaware, United States, [4]NASA Goddard, Greenbelt, Maryland, United States, [5]University of California, Los Angeles, Los Angeles, California, United States

Abstract
The Sun's activity plays a critical role in the evolution of terrestrial atmospheres, with extreme EUV and X-ray fluxes, as well as a more intense solar wind and higher occurrences of powerful solar transient events. The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission has been observing the upper atmosphere and magnetic topology of Mars, and has made numerous measurements of solar transient events such as Interplanetary Coronal Mass Ejections (ICMEs) and Stream Interaction Regions (SIRs) since November 2014. These events are characterized by dramatic changes in dynamic pressure, magnetic field strength and substantial increases in escaping and precipitating planetary ions. However, as solar

cycle 24 continues to decline, the frequency of ICMEs also declines while the frequency of SIRs remains steady. This is a significant trend because the early sun, while much more active, would have produced more powerful and more continuous SIRs within the inner heliosphere. In this study, we will present MAVEN observations of SIRs and compare those to a global MHD and test simulation of a specific observed SIR at Mars, including the response of Mars' upper atmosphere to the compression region and rarefaction region as it propagates past the planet. Additionally, we will use an Alfvén wave driven solar wind model to simulate the conditions for SIRs from the early Sun at 0.7 Gyr and 2 Gyr. We will discuss how SIRs from each of the three epochs influence atmospheric escape at Mars. The extreme space weather conditions in the Sun's early history may have had a significant influence on the evolution of the Martian atmosphere and may also have implications for exoplanets interacting with the stellar winds of younger, more active stars.

11:10 AM-11:20 AM

303.09 Following water (and its isotope HDO) as it escapes the Martian atmosphere with ExoMars/NOMAD

Geronimo L. Villanueva[1], Giuliano Liuzzi[1], Matteo M. Crismani[1], Michael Mumma[1], Michael D. Smith[1], Ann Carine Vandaele[2], Ian Thomas[2], Shohei Aoki[2], Severine Robert[2], Frank Daerden[2], Bojan Ristic[2], Manish R. Patel[3], Giancarlo Bellucci[4], Jose Juan Lopez-Moreno[5]
[1]Planetary Systems Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland, United States, [2]Institut Royal d'Aeronomie Spatiale, Brussels, Belgium, [3]Open University, Milton Keynes, United Kingdom, [4]INAF, Istituto di Astrofisica e Planetologia Spaziali, Rome, Italy, [5]Instituto de Astrofisica de Andalucia, Granada, Spain

Abstract
We present unprecedented vertical profiles of H_2O, HDO and D/H collected by the high-resolution Nadir and Occultation for MArs Discovery (NOMAD) instrument onboard the ExoMars/Trace Gas Orbiter (TGO). TGO is the first spacecraft at Mars specifically tailored to search for trace constituents, with the NOMAD instrument providing high spectral resolution (RP~20,000) over the 2-5 µm spectral region. These capabilities allow us to probe with unprecedented accuracy and sensitivity a multitude of organic species (e.g., CH_4, CH_3OH, H_2CO, C_2H_6, C_2H_2) and to map isotopic signatures (e.g., D/H, $^{13}C/^{12}C$) across the whole planet.

Isotopic ratios are among the most valuable indicators for the loss of volatiles from an atmosphere. Because the escape rates for each isotope are mass dependent, historical loss enriches the atmosphere with heavy isotopes relative to the lighter ones. By probing current isotopic ratios, one can infer the volatile reservoir lost to space over the planet's evolution. Deuterium fractionation also reveals information about the current cycle of water and informs us of its stability on short and long-term scales, including its release from active regions on Mars.

Upon its successful orbital insertion in early 2018, we acquired unique vertical profiles of several species with ExoMars/TGO/NOMAD. In this paper, we report initial retrievals of water and D/H derived during this initial observational period.

This work was supported by the Mars Exploration Program Office, NASA HQ, under NOMAD WBS 604796.01.12.01 to the Goddard Space Flight Center.

11:20 AM-11:30 AM

303.10 Water Escape from Mars During the June 2018 Global Dust Storm

Dolon Bhattacharyya[1], John T. Clarke[1], Majd Mayyasi[1], Jean-Yves Chaufray[2], Frank Montmessin[2], Michael Chaffin[3], Justin deighan[3], Sonal Jain[3], Nicholas Schneider[3]
[1]Center for Space Physics, Boston University, Boston, Massachusetts, United States, [2]LATMOS, Paris, France, [3]LASP, Boulder, Colorado, United States

Abstract
The martian exosphere has been observed to undergo substantial dynamical changes as Mars approaches perihelion in its orbit around the Sun. Both hydrogen and deuterium escape, tied to water and atmospheric escape from Mars, show significant variations with the peak escape occurring close to martian southern summer solstice (solar longitude L_s = 270°). These changes are theorized to be brought about by atmospheric heating due to increase in dust in the atmosphere of Mars in combination with seasonal effects. Dust storm season at Mars is prevalent between solar longitude L_s = 180° - 330°. It is difficult to separate the effects of dust in the atmosphere of Mars from seasonal changes. The 2018 global dust storm presented a unique opportunity to study the effects of substantial amounts of dust in the martian atmosphere on water/atmosphere escape. The onset of the dust storm occurred when Mars was at L_s = 186°, far from southern summer solstice where the seasonal effects reach their peak. Lyman α photons from hydrogen and deuterium atoms present in the martian exosphere were observed with the MAVEN-IUVS Echelle spectrograph and the Hubble Space Telescope (HST). We will present the results of these observations and provide insight into the effects of a martian global dust storm on the atmospheric/water escape from Mars.

11:30 AM-11:40 AM
303.11 Modeling Martian Atmospheric Losses over Time: Implications for (Exo)Planetary Climate Evolution and Habitability
Chuanfei Dong[1], Yuni Lee[2], Yingjuan Ma[3], Manasvi Lingam[4], Stephen Bougher[5], Janet Luhmann[6], Shannon Curry[6], Gabor Toth[5], Andrew Nagy[5], Valeriy Tenishev[5], Xiaohua Fang[7], David Mitchell[6], Dave Brain[7], Bruce Jakosky[7]
[1]Princeton University, Princeton, New Jersey, United States, [2]NASA GSFC, Greenbelt, Maryland, United States, [3]UCLA, Los Angeles, California, United States, [4]Harvard University, Cambridge, Massachusetts, United States, [5]University of Michigan, Ann Arbor, Michigan, United States, [6]UC Berkeley, Berkeley, California, United States, [7]LASP, CU Boulder, Boulder, Colorado, United States

Abstract
Mars has always represented an important target from the standpoint of planetary science, especially on account of its long-term climate evolution. One of the most striking differences between ancient and current Mars is that the former had a thicker atmosphere compared to the present-day value, thereby making Noachian Mars potentially more conducive to hosting life. This discrepancy immediately raises the question of how and when the majority of the Martian atmosphere was lost, as well as the channels through which it occurred. There are compelling observational and theoretical reasons to believe that the majority of atmospheric escape must have occurred early in the planet's geological history, when the extreme ultraviolet (EUV) flux and the solar wind from the Sun were much stronger than today. Our understanding of present-day Martian atmospheric escape has improved greatly thanks to observations undertaken by, e.g., the MAVEN in conjunction with detailed theoretical modeling.

In this study, we adopted the one-way coupled framework, which has been employed to study the ion and photochemical losses at the current epoch. We adopted the 3-D Mars thermosphere from the Mars Global Ionosphere Thermosphere Model (M-GITM) and the hot atomic oxygen density from the Mars exosphere Monte Carlo model Adaptive Mesh Particle Simulator (AMPS) as the input for the 3-D BATS-RUS Mars

multi-fluid MHD (MF-MHD) model. The Mars AMPS hot oxygen corona and the associated photochemical loss rate were calculated based on the thermospheric/ionospheric background from M-GITM. Our simulations indicate that the total photochemical and ion atmospheric losses over the span ~0-4 Ga are approximately equal to each other, and their sum amounts to ~0.1 bar being lost over this duration. If we assume that the oxygen lost through a combination of ion and photochemical escape mechanisms was originally derived from surface water, we find ~3.8 × 10^17 kg of water has been lost from Mars between 0 and ~4 Ga; this mass corresponds to a global surface depth of ~2.6 m. This study offers fresh insights concerning the long-term climate evolution and habitability of the increasing number of exoplanets discovered yearly due to atmospheric losses.

11:40 AM-11:50 AM
303.12 CO_2 Inventory for Mars
Bruce Jakosky
Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder, Boulder, Colorado, United States

Abstract
Major questions for Mars center on how much CO_2 was present early in history and where it went. With the recent addition of MAVEN, MSL, and MRO observations, we now can address these issues both qualitatively and quantitatively. Supply of CO_2 to the atmosphere subsequent to the time of the onset of the observable geological record comes from early degassing, volcanic outgassing, and impact supply. Loss comes from impact ejection, solar-wind and solar-EUV stripping, formation of both shallow and deep carbonates, adsorption into the regolith, freezing as ice in the polar regions, and possibly formation of clathrates. Each of these processes now can be constrained, providing an inventory of the likely sinks for CO_2. Carbon isotopic enrichment requires loss of a large fraction of the C to space – a best estimate of approximately 75 %. The loss processes together can account for 1-2 bars of CO_2 from the early atmosphere. Impact ejection, solar stripping, and formation of deep carbonates are the major sinks for CO_2. Together, they appear able to account for the major contributions to the transition from an early, warm, wet environment to the colder, drier environment that we see today.

Wednesday, October 24, 2018
10:00 AM-12:00 PM
Ballroom B (Knoxville Convention Center)

304 Asteroids: Observational Surveys I
Chair(s): Michael Mueller, Melissa J. Brucker

10:00 AM-10:10 AM
304.01 NEO Search Using a Cluster of Small Synthetic Tracking Telescopes
Michael Shao, navtej saini, russle trahan, chengxing zhai
Jet Prop Lab, Pasadena, California, United States

Abstract
Synthetic tracking (ST) is a technique that uses low noise cmos focal planes along with teraflop computing to increase sensitivity for the detection of moving objects. Multiple images in a video sequence are combined with a shift/add algorithm to increase the SNR of objects that would otherwise produce a streaked image. ST offers order of magnitude improvements in sensitivity and astrometric accuracy for moving objects. We descibe a small robotic observatory that has begun operating at a dark site, using a 28cm telescope and 16Mpix cmos camera that has sensitivity to 20.6~21.0 mag with a 2 sqdeg FOV. By using consumer and amateur astronomy hardware, the cost of one such telescope/sensor is < $8,000. The multi-teraflop computation can be performed with low cost graphics cards used in video games or crytocurrency mining. This naturally leads one to consider building a cluster of a half dozen such telescopes that could roughly equal all current ground based facilities for NEO search.
We will present preliminary results from the operation of this robotic telescope, which was primarily constructed to test real time ST data processing for a near future upgrade of the USAF's GEODSS network of telescopes for space situational awareness.
While a modest cluster of small telescopes could roughly equal all current NEO search telescopes for near Earth asteroids, ST offers order(s) of magnitude increase in the discovery rate of faster moving objects such as interstellar asteroids and very small (10m) and very nearby (few million km) objects in orbits that are suitable for future human or robotic visits.
We will also briefly discuss the concept of "saturation". Saturation is when adding a 2nd or 3rd large 8m class telescope dedicated to NEO search would not increase the number of H<22mag NEO discovered, because every NEO detected by the 2nd and 3rd telescope would have been detected by the 1st. A logical follow on quesetion is what does it take to saturate using many small telescope spread over the planet?

10:10 AM-10:20 AM
304.02 Near-Earth-Object Orbit Determination using Accurate Astrometry and Parallax
Chengxing Zhai[1], Michael Shao[1], navtej saini[1], russle trahan[1], Philip Choi[2]
[1]Jet Propulsion Laboratory, Pasadena, California, United States, [2]Pomona College, Claremont, California, United States

Abstract
Orbit determination is a necessary step towards cataloging Near-Earth-Objects (NEOs). With more than 90% completeness in surveying 1 km size asteroids, NASA NEO Observation program is now focusing on finding NEOs down to size of 100 m, whose population is significantly larger than that of the 1 km size NEOs. NEOs can only be conveniently observed during their close approaches and smaller size

NEOs have shorter time windows of observation. It is crucial to determine the orbit accurate enough during the close approach so that the NEO can be unambiguously identified at its next apparition. Therefore, performing efficient follow-up observations becomes extremely important. Traditional wisdom requires follow-up observations over a time window of at least three weeks to yield an orbit of sufficient accuracy for cataloging a NEO. Here we present the potential of using highly accurate astrometry (from using the synthetic tracking technique) and parallax in NEO orbit determination to show the possibility of determining orbit based on measurements over time windows much shorter than three weeks.

10:20 AM-10:30 AM

304.03 On-going work to link the Isolated Tracklet File (ITF)

Robert Weryk[1], Richard J. Wainscoat[1], Gareth Williams[2], Robert Jedicke[1]

[1]Institute for Astronomy, University of Hawaii, Honolulu, Hawaii, United States, [2]Minor Planet Center, Cambridge, Massachusetts, United States

Abstract

We discuss our on-going work to link astrometry found in the Isolated Tracklet File (ITF) from the Minor Planet Center (MPC) : a rich, always growing repository of 15+ million unlinked detections, dominated by submissions from Pan-STARRS1 (F51) and the Catalina Sky Survey (G96).

The main goal of our work is to find Near-Earth Objects (NEOs), especially those at low 'digest' score. To accomplish this, we must first identify all unknown objects on Hungaria-like orbits, which often post to the NEO Confirmation Page and consume valuable telescope follow-up time which could have been better spent confirming the true new candidate NEOs. In addition, identifying unlinked main-belt objects will improve the efficiency of asteroid surveys as future detections of these objects can then be identified and batch submitted without review. Our first large submission of linkages to the MPC was in August 2017, which identified more than 60 000 distinct objects, most of which are on main-belt orbits, with half being previously undesignated.

Our method uses a brute-force computational technique which compares tracklets with similar predicted motion (but offset in position) suggesting they are the same object, with many optimisations made to vastly reduce comparisons of tracklets which are clearly not related. Linkages are easily found across multiple oppositions and can also be identified against existing designations. We plan on making regular submissions of linkages to the MPC to reduce the ITF to the point where it is computationally feasible to identify the more interesting (but difficult to link) objects, such as NEOs. We will also discuss how our search method applies to separate detection catalogues from the F51 telescope to link new Trans-Neptunian Objects (TNOs), and how it might be extended to work with catalogues from third party sources in an automated manner.

10:30 AM-10:40 AM

304.04 HelioLinC: A Novel Approach to the Minor Planet Linking Problem

Matthew J. Holman[1], Matthew J. Payne[1], Paul Blankley[2], Ryan Janssen[2], Scott Kuindersma[2]

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Abstract
Our heliocentric transformation-and-propagation algorithm, HelioLinC, clusters tracklets at common epochs, allowing for the efficient identification of tracklets that represent the same minor planet. This algorithm scales as O(N log N), with the number of tracklets N, a significant advance over standard methods, which scale as O(N^3). This overcomes one of the primary computational bottlenecks faced by current and future asteroid surveys. We apply our algorithm to the Minor Planet Center's Isolated Tracklet File, establishing orbits for more than 200,000 new minor planets. A detailed analysis of the influence of false detections on the efficiency of our approach, along with an examination of detection biases, will be presented in future work.

10:40 AM-10:50 AM
304.05 A Bayesian-Based Method for Inferring Asteroid Properties from Sparse Light Curves
Christina W. Willecke Lindberg[1, 3], Daniela Huppenkothen[3, 4], Bryce Bolin[2, 1], Lynne Jones[1, 3], Mario Juric[1], Zeljko Ivezić[1], Andrew Connolly[1]
[1]Astronomy , University of Washington, Kenmore, Washington, United States, [2]B612 Asteroid Institute, Mill Valley, California, United States, [3]DIRAC Institute , Seattle, Washington, United States, [4]eScience Institute, University of Washington, Seattle, Washington, United States

Abstract
Light curve data from asteroids can provide constraints on their rotation periods, shape, and spin states, and when fitting with multi-band data, can also constrain colors and phase curves. The distribution of these parameters provides information on the structural properties of asteroids and constrains models of the collisional history of the asteroid belt. With ZTF and LSST set to make first light in the next decade, there is a precedent for developing new asteroid modeling methods that overcome these sparse sampling limitations. We present the use of Gaussian Process regression to develop a flexible modeling framework for parameter inference and data extrapolation of asteroid time series. We show on both simulated and real asteroid light curves that the new method is capable of reliably deriving periods and physical parameters from sparsely sampled asteroid light curves with better precision relative to previous methods, as well as providing rigorous estimates of the parameter uncertainties.

10:50 AM-11:00 AM
304.06 Probing the Populations of Very Small NEOs with ATLAS and Subaru
Aren Heinze, John Tonry, Larry Denneau, Heather Flewelling
Institute for Astronomy, University of Hawaii, Honolulu, Hawaii, United States

Abstract
We simulate the detectability of very small (absolute magnitude 25-30; diameter 5-50 m) NEOs by the ATLAS survey and by mini-surveys we have conducted with Subaru/Hyper Suprime-Cam. We discuss our preliminary results on the relative efficiency of ATLAS vs. Subaru for such objects -- a comparison that spans virtually the entire range of telescope apertures currently being used for NEO discovery. Based on actual detections with both ATLAS and Subaru, we find the total population of small NEOs is probably significantly larger than some recent estimates. We estimate the fraction of close (0.01 AU) Earth encounters that go completely undetected, and we suggest that all surveys have a strong bias against small asteroids with large encounter velocities. Although we have assumed in our simulations that the orbital distribution of very small NEOs is the same as for their larger counterparts, we note that if in fact the orbital distributions differ in a sense that causes small NEOs to have statistically higher relative

velocities during Earth encounters, this bias probably would not be detectable with current data -- and would cause additional underestimation of the total number of small NEOs.

11:00 AM-11:10 AM

304.07 NEOZTF: Using the Zwicky Transient Facility to Find New Near-Earth Objects

Emily Kramer[1], Quanzhi Ye[2, 3], Frank Masci[3], Thomas A. Prince[2], George Helou[3]
[1]Jet Propulsion Laboratory, Caltech, Pasadena, California, United States, [2]Division of Physics, Mathematics, and Astronomy, California Institute of Technology, Pasadena, California, United States, [3]Infrared Processing and Analysis Center (IPAC), California Institute of Technology, Pasadena, California, United States

Abstract

The Zwicky Transient Facility (ZTF, P.I. Shri Kulkarni) is an optical survey using the 1.2-m Oschin Schmidt telescope at Palomar Observatory. A 47 deg^2 field of view camera with a fast read out and a median R-band limiting magnitude of 20.4 allows ZTF to quickly and deeply scan the sky, searching for transient sources including small solar system bodies.

ZTF achieved first light November 1, 2017, completed commissioning and started its science survey in April 2018. Since February 2018, ZTF has been building reference images of the sky, critical for accurate image differencing to identify transient sources, including point-like and trailed asteroids. Exploratory NEO searches were started in February 2018, using two different modes: (1) ZMODE, a pipeline for linking multiple point-like transients into a tracklet; and (2) ZSTREAK, a pipeline for identifying trailed objects in difference images.

Wide area surveys at moderate depth such as ZTF can be particularly effective for discovery of small NEOs, defined here as those with diameters d < 140 meters. NEO surveys in the past have appropriately emphasized discovery of Potentially Hazardous Asteroids (PHAs) with d > 140 m (see https://www.nasa.gov/sites/default/files/atoms/files/2017_neo_sdt_final_e-version.pdf for the NEO Science Definition Team Report). However, even a small NEO can cause significant regional devastation on impact – the 1908 Tunguska event was thought to have a diameter of about 50 m and flattened about 2,000 km^2 of forest; the 18-m Chelyabinsk asteroid caused significant regional disruption. Surveys such as ZTF will help characterize the population of small NEOs, important for NEO science and for assessing risk.

We present here some preliminary results to illustrate ZTF's capability to search for new NEOs, including the discovery of over a dozen objects using ZTF's unique ZSTREAK pipeline.

11:10 AM-11:20 AM

304.08 The Pan-STARRS search for Near-Earth Objects

Yudish Ramanjooloo, Richard J. Wainscoat, Robert Weryk, Kenneth C. Chambers, Eugene A. Magnier
Institute for Astronomy, University of Hawaii (Manoa), Honolulu, Hawaii, United States

Abstract

Both Pan-STARRS telescopes, located on Haleakala, Hawaii, are now operational. Whilst Pan-STARRS2 [See K. Chambers abstract] is still in its fine-tuning phase, it has begun to contribute to the NEO discovery and follow-up efforts. Despite long-lasting inclement weather and unplanned downtime in early 2018, Pan-STARRS has contributed one-third of the NEO discoveries this year. In past years, Pan-STARRS has set itself as one of the leading discovery surveys producing high-precision astrometry and photometry for almost half the annual NEO discovery rate. The Pan-STARRS1 telescope boasts a 3 degree FOV allowing the survey to cover approximately 1000 square degrees per night. Under optimal observing conditions, the survey can reach as faint as V=23. In 2017, the survey discovered ~900 NEOs and over half of the PHAs, continuing to lead the discovery effort of the remaining 10% of estimated PHAs to completion. The survey also yielded important solar system discoveries such as 1I/2017 U1 ('Oumuamua) [See K. Meech abstract] and C/2017 S3 (Pan-STARRS). The combined discovery rate from both telescopes during new moon often overwhelm external follow-up efforts. In future, a self-follow up strategy will be implemented.

11:20 AM-11:30 AM
304.09 ATLAS: First year of full operations
Heather Flewelling, John Tonry, Larry Denneau, Aren Heinze, Henry Weiland
Institute for Astronomy, University of Hawaii, Honolulu, Hawaii, United States

Abstract
The Asteroid Terrestrial-impact Last Alert System (ATLAS) has been fully operational since 2017. ATLAS consists of 2 robotic 0.5 meter telescopes located on Maunaloa, Hawaii and Haleakala, Maui. These 2 telescopes survey all of the accessible sky every 2 nights, with a limiting magnitude of about 19.5. In this talk we will give an update on the status of ATLAS, details about the types of near earth asteroids we've detected, and our future plans. We also discuss 2 recent enhancements - automated self followup and our 'puma' orbit fitting software. Our automated self followup is used to automatically schedule followup observations of ATLAS NEOCP objects on both telescopes, specifically to help recover objects which will likely be lost without same night self-followup. Position Using Motion under Acceleration (puma) reads observations and fits an orbit to them, based on a linear approximation to the accelerated trajectories of the object and observer. It is very fast (milliseconds) and quite accurate for nearby and fast objects.

11:30 AM-11:40 AM
304.10 Astronomical Research Institute Near-Earth Asteroid Observations
Tyler Linder[1, 2], Robert Holmes[1]
[1]Astronomical Research Institute, Sullivan, Illinois, United States, [2]University of North Dakota, Grand Forks, North Dakota, United States

Abstract
The Astronomical Research Institute (ARI) has conducted near-Earth astrometry observations from the northern hemisphere since 2007 and from the southern hemisphere since 2011 (H21/807). Operating seven telescopes ranging from 0.61m to 1.3m requires successful planning and execution each night. Sharing ARI's standard operating procedures ARI hopes to help other observers take advantage of new efficient methods to increase their production as well as develop a similar outlook on collecting large volumes of near-Earth astrometry.

ARI is currently developing techniques to conduct large uncertainty recovery with a multiple telescope approach. Currently, the NEA astrometry community has an individual group priority where everyone's goal is to produce the highest number of observations per year. ARI has switched to a "What Observations are Needed" approach. Although, the number of observations per year decreases one can show the value of conducting fainter and more difficult observations.

11:40 AM-11:50 AM

304.11 Measuring the Minor Planets: Additional Diameters and Albedos for Asteroids Derived from WISE/NEOWISE Infrared Survey Data

Amy Mainzer[1], James Bauer[2], Jana Chesley[1], Roc Cutri[3], John Dailey[3], Tommy Grav[4], Emily Kramer[1], Joseph Masiero[1], Edward L. Wright[5]

[1]JPL, Pasadena, California, United States, [2]University of Maryland, College Park, Maryland, United States, [3]IPAC/Caltech, Pasadena, California, United States, [4]Planetary Science Institute, Tucson, Arizona, United States, [5]UCLA, Los Angeles, California, United States

Abstract

The vast majority of the ~800,000 minor planets identified to date in our solar system have little information about them known except for their orbital parameters and visible brightness. Measurements of physical properties such as size distributions and albedos can provide insight into the origins of small bodies, including membership in collisional families; origins within inner or outer solar system populations; and composition. With NASA's Wide-field Infrared Survey Explorer (WISE) mission, now known in its reactivated mission phase as NEOWISE, a large archive of infrared survey data is now publicly available for small bodies, allowing diameters and albedos to be derived for two orders of magnitude more small bodies than were previously available. Previously published diameters and albedos of minor planets from WISE/NEOWISE used detections bright enough to appear in individual exposures. However, since the spacecraft collects an average of ~10-12 exposures per visit on most minor planets, it is possible to shift-and-stack these exposures along an asteroid's orbital path to recover detections of objects that are too faint to appear in some or all individual exposures. We have completed stacking of all ~800,000 known minor planets that have passed through the WISE/NEOWISE fields of view, resulting in the recovery of additional detections of objects with previously unpublished diameters and albedos. These data will be publicly released, increasing the number of asteroids with well-determined basic physical characterizations.

11:50 AM-12:00 PM

304.12 NEOWISE diameter uncertainties as told by asteroid families

Joseph Masiero[1], A. Mainzer[1], E. Wright[2]

[1]NASA JPL, Pasadena, California, United States, [2]UCLA, Los Angeles, California, United States

Abstract

Asteroid diameters can be determined from infrared observations by comparing models of the thermal emission from the surface to measured fluxes. However, it is necessary to calibrate these models, and verify the level of accuracy they can achieve. We present a new method for characterizing the quality of NEOWISE diameter measurements using information gleaned from asteroid families. We show the characteristic 1-sigma random error for the Main Belt population must be less than 17.5%, and is approximately 10% when a typical H magnitude uncertainty of 0.2 mags are assumed.

Wednesday, October 24, 2018
10:00 AM-12:05 PM
Ballroom C (Knoxville Convention Center)

305 Centaurs/TNOs II: Dynamics, Origins, Theory
Chair(s): Kathryn Volk, Simon B. Porter

10:00 AM-10:10 AM
305.01 Tightly-bound transneptunian binaries have prograde mutual orbits
Will Grundy[1], Keith Noll[2], Henry Roe[3], Marc W. Buie[4], Simon B. Porter[4], Alex Parker[4], David Nesvorny[4], Harold F. Levison[4], Susan Benecchi[5], D.C. Stephens[6], Chadwick A. Trujillo[7]
[1]Lowell Observatory, Flagstaff, Arizona, United States, [2]NASA GSFC, Greenbelt, Maryland, United States, [3]Gemini Observatory, Santiago, Chile, [4]SwRI, Boulder, Colorado, United States, [5]PSI, Tucson, Arizona, United States, [6]BYU, Provo, Utah, United States, [7]NAU, Flagstaff, Arizona, United States

Abstract
We report on our continuing efforts to determine the orbits of transneptunian binaries (TNBs), using data from Hubble Space Telescope and adaptive optics systems on large ground-based telescopes. We have expanded the sample of TNBs with fully determined orbits to around 40% of the known TNBs, with another ~20% having known periods, eccentricities, and semimajor axes, but ambiguous orientations. Excluding planet-sized objects where the satellites could be more likely to have formed through giant impacts, the smaller TNBs show a stark contrast in orbital orientations between tightly bound binaries (with semimajor axes less than around 5% of the Hill radius) and more loosely bound binaries. Among the tight binaries, prograde mutual orbits vastly outnumber retrograde orbits. This imbalance is not attributable to any known observational bias. We argue that it is a key clue to the formation environment of outer solar system planetesimals, favoring gravitational collapse from regions enriched in solids via mechanisms such as the streaming instability. Unlike the tight binaries, wider binaries are evenly distributed between prograde and retrograde orbits, but with mutual orbits favoring alignment or anti-alignment with their heliocentric orbits. This pattern is consistent with expectation from Kozai-Lidov cycles coupled with tidal evolution eliminating initially high inclination wide binaries.

10:10 AM-10:20 AM
305.02 K2 light curves of eight Centaurs
Gábor Marton[1], László Molnár[1], Csaba Kiss[1], Andras Pal[1], Thomas G. Müller[2]
[1]Konkoly Observatory, Budapest, Hungary, [2]Max-Planck-Institut für extraterrestische Physik, Garching, Germany

Abstract
As has been demonstrated by some recent papers, the K2 mission (Howell et al. 2014, PASP, 126, 398) provides an excellent opportunity to obtain rotational properties of Centaurs and trans-Neptunian objects (Pál et al. 2015, ApJL, 804, 45, Pál et al. 2016 AJ, 151, 117, Kiss et al. 2016, MNRAS, 457, 2908). Here we report on K2 observations of eight Centaurs: (250112) 2002 KY14, 2010 GX34, 2010 JJ124, (499522) 2010 PL66, (471931) 2013 PH44, (463368) 2012 VU85, 2016 AE193 and 2009 YD7. We obtained light curves and derived rotational periods for 5 targets. We give an assessment on light curve interpretation of contact binary vs. shape effects. The results suggest that at least one of our targets could be a contact binary, the first among Centaurs.

10:20 AM-10:30 AM

305.03 Exploring Gravitational Collapse of a Pebble Cloud - A Route to TNO Binaries

James E. Robinson[1], Wes Fraser[2]
[1]Queen's University Belfast, Belfast, United Kingdom, [2]Queen's University Belfast, Belfast, United Kingdom

Abstract

A large fraction of the icy trans-neptunian objects are found in binary pairs, 30% in the cold classical population, which generally have similar size and colour components on widely separated orbits. Understanding what mechanisms can produce such a high binary fraction will inform us of planetesimal formation in general. Gravitational instability (GI) is an efficient mechanism for producing these trans-neptunian binaries. In GI, planetesimals and binaries form directly from the gravitational collapse of a gravitationally bound pebble cloud, which was formed via particle concentration mechanisms in the gaseous disk. Merging collisions and conservation of angular momentum naturally lead to the formation of similar mass binary components with strong preference for prograde binary orbits, and equal composition between both components due to having been formed from the same cloud of material. We demonstrate this using the REBOUND n-body integrator to model a spherical, rotating cloud of particles collapsing under its own gravity. Past efforts made use of a particle radius inflation factor to artificially enhance accretion rates. We investigate a new collision routine, where we consider an impacting particle to be composed of many small pebbles. These small merging impacts cause a random walk of the target particle's linear momentum, and the resultant post-collision momentum is reduced, somewhat analogous to a Brownian motion. We compare and contrast the simulation results of both collision routines. Initial results indicate that the overall loss of momentum in our collision model leads to preferential formation of single objects.

10:30 AM-10:40 AM

305.04

Bayesian Modeling of the Formation of the Haumea Family

Benjamin Proudfoot, Darin Ragozzine
Brigham Young University, Provo, Utah, United States

Abstract

The Haumea family is the only known collisional family known in the outer Solar System and an important prototype for outer solar system collisions. Although many Haumea formation models have been proposed, none are able to fully explain all of the observed features of the Haumea family. The main challenge is identifying a plausible collision that can explain the surprisingly compact size of the family, Haumea's near-breakup spin,and the distant orbits of the satellites. Using synthetic families and a Bayesian methodology, we compare the results of Haumea family formation models to the actual Haumea family in a-e-i-H space, i.e., the three-dimensional ejection velocity distribution as a function of size. This results in posterior distributions of our model parameters that best fit the Haumea family. In our previous work, we used triple the number of Haumea family members than other studies (Proudfoot & Ragozzine, DPS49, DDA48). In this work, we extend these results while self-consistently inclulding the effects of interlopers in the data set, additional formation models, and improved modeling of the absolute magnitude distribution. Using our statistical methods and family creation models, we find that a strongly planar family (as predicted by Leinhardt et al. 2010) cannot dynamically explain the Haumea family. A satellite collision (Schlichting and Sari 2009), also cannot fully explain the Haumea family.

10:40 AM-10:50 AM

305.05 Equilibrium Figure of a Rapidly Rotating, Differentiated Haumea

Emilie T. Dunham[1], Steven Desch[1], Sarah Sonnett[2]
[1]Arizona State University, Tempe, Arizona, United States, [2]Planetary Science Institute, Tucson, Arizona, United States

Abstract
Haumea is a unique Kuiper Belt Object (KBO) that suffered a large collision in the past, generating moons and a collisional family, stripping Haumea's icy mantle and spinning it up to a period of 3.9 hours [1]. Haumea has a uniformly icy surface but a pronounced light curve implying a triaxial ellipsoid [2]. Previous analyses have suggested a Jacobi ellipsoid with semi-axes 960 x 768 x 496 km, and average density 2600 kg m^{-3} [2, 3]. However, the recent observation of Haumea during an occultation not only revealed a thin ring, but an ellipsoidal shadow with semi-axes 852 x 569 km [4]. Very different semi-axes, 1161 x 852 x 513 km, and bulk density 1885 kg m^{-3}, were inferred [4]. Resolving these discrepant results is needed to understand collision processes, KBO internal structure, and thermal evolution.

We have written a code, based on [5], that calculates the non-axisymmetric figure of equilibrium of a non-homogeneous body in solid body rotation. We fix the density at 921 kg m^{-3} at pressures < P_{cmb}, and ρ_{rock} at pressures > P_{cmb}. We vary P_{cmb} and ρ_{rock} and find a family of equilibrium configurations consistent with Haumea's mass and period. We find P_{cmb} = 18 MPa and ρ_{rock} = 2599 kg m^{-3}, yielding semi-axes 1000 x 825 x 523 km, and average density 2216 kg m^{-3}, are an equilibrium solution. With a rotational phase 22° and inclination 14°, these parameters yield an shadow consistent with observations [4]. Haumea is consistent with an equilibrium fluid, and its core density is consistent with a prior period of hydrothermal circulation and alteration [6].

[1] Brown, ME et al. (2007) *Nature* 446, 294.
[2] Rabinowitz, DL et al. (2006) *Ap.J.* 629, 1238.
[3] Lockwood, AC et al. (2013) *EM&P* 111, 127.
[4] Ortiz, JL et al. (2018) *Nature* 550, 219.
[5] Hachisu, I (1986) Ap.J.S. 62, 461.
[6] Desch, SJ & Neveu, M (2015) LPSC 46, #2082.

10:50 AM-11:00 AM

305.06 Searching for More Collisional Families in the Kuiper Belt

Darin A. Ragozzine, Nathan Benfell, Steven Maggard
Physics and Astronomy, Brigham Young University, Provo, Utah, United States

Abstract
Kuiper Belt (KB) collisional families cannot be efficiently detected using the techniques common for asteroid family detection because KB families are not nearly as clustered compared to the background population. We provide an update on other methods that can be used to search for KB families, particularly using direct backwards integration. Through a careful and independent propagation of astrometric detection uncertainties through to uncertainties on orbital elements 5 GYr ago, we find that most KBOs currently do not have orbits sufficiently well known for backwards integration GYrs into the past. We study whether this can be improved and find that expected improvements in observational

uncertainties afforded by GAIA stellar catalogs and LSST discoveries should provide the opportunity for successful family discovery by backwards integration, as long as the integration techniques are well chosen. We test the feasibility of finding new families by applying these techniques to the known Haumea family and place constraints on its age.

11:00 AM-11:10 AM

305.07 Finding a Lower Bound on the Ring Limit for Planetary Close Encounters with Ringed Centaurs

Jeremy Wood[3, 1], Jonti Horner[3, 4], Tobias Hinse[2], Stephen C. Marsden[3]
[1]Hazard Community and Technical College, Hazard, Kentucky, United States, [2]Korea Astronomy and Space Science Institute, Daejeon, Yuseong-gu, Korea (the Republic of), [3]University of Southern Queensland, Computational Engineering and Science Research Centre, Toowoomba, Queensland, Australia, [4]Australian Centre for Astrobiology, Sydney, New South Wales, Australia

Abstract
Rings have recently been discovered around the TNO 136108 Haumea and the Centaur 10199 Chariklo. Rings are also suspected around the Centaur 2060 Chiron. As planetary close encounters with ringed small bodies can affect ring longevity, we previously measured the severity of such encounters of Chariklo and Chiron using the minimum encounter distance, d_{min}.
The value of d_{min} which separates noticeable encounters from non-noticeable encounters we call the "ring limit". In this work, we seek to find a lower bound on the ring limit. To accomplish this, we use numerical integration to simulate close encounters between each giant planet and fictitious ringed Centaurs in what is in effect the three-body planar problem. The masses of the fictitious ringed Centaurs range from 2 x 10^{20} kg to 1 Pluto Mass (1.309 x 10^{22} kg). Ring orbital radii range from 25,000 km to 100,000 km.
The results show that the ring limit has a lower bound of approximately 1.8 tidal disruption distances and that this distance is independent of the ring orbital radius but slightly dependent on the planet mass. The small body mass has no noticeable effect on the lower bound.

11:10 AM-11:20 AM

305.08 Searching for KBO Binaries in the HST Archive

Richard D. Smith, Wesley C. Fraser
School of Maths and Physics, Queen's University Belfast, Belfast, United Kingdom

Abstract
Binary Kuiper Belt Objects (KBOs) can provide valuable insights into the history and properties of the Kuiper Belt, including dynamical history and object compositions. Inconsistent methods have been used to search for binary companions in Hubble Space Telescope (HST) data. We aim to address this by reprocessing the data of the 518 KBOs available in the HST archive using a consistent point spread function-fitting algorithm to search for unidentified companions. The algorithm uses the Markov Chain Monte Carlo sampler emcee to find best fit image parameter values for the KBO in the image. The best fit values are then used to produce an artificial source image which is subtracted from the image, revealing any hidden sources. We present the preliminary results of applying this process to Wide Field Camera 3 observations of 38 KBOs. No new binaries have been found thus far, however 4 known binaries have been confirmed using the algorithm and 2 binary candidates have been identified: 1999KR16 and 1999RY215. The results for 1999KR16 show an unusual fan-like residual, warranting further investigation. The algorithm will be expanded to process images taken with other HST instruments and to allow for characterisation of the binary candidates found, for example taking colour measurements of

primary and secondary components. The algorithm's sensitivity to binary component separation and brightness ratios will also be examined. With well understood sensitivity biases, we will be able to produce unbiased distributions of binary properties, such as size ratio distribution and component separation distribution.

11:20 AM-11:30 AM

305.09 A Saturnian horseshoe coorbital & predictions for temporary coorbitals of the giant planets

Mike Alexandersen[1], Sarah Greenstreet[3], Brett Gladman[2]
[1]Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), Taipei City, Taiwan, [2]University of British Columbia, Vancouver, British Columbia, Canada, [3]B612 Foundation / University of Washington, Seattle, Washington, United States

Abstract

Temporary coorbitals are objects that, while scattering around in the planet region, are temporarily captured into an unstable 1:1 mean motion resonance with a planet. The recent Outer Solar System Origins Search (OSSOS) has increased the sample of Trans-Neptunian Objects (TNOs) and Centaurs with well known orbits discovered in well characterised surveys by more than a factor of 4. This includes 25 scattering objects (including Centaurs and Jupiter coupled objects) with semi-major axis less than 34 AU, one of which is of particular interest.

We present here the exciting discovery of a Saturnian coorbital in a horseshoe configuration and simulations demonstrating that it likely originated in the trans-Neptunian region. Using dynamical simulations of the scattering TNOs to create a Centaur model, we have measured the rate at which Centaurs of TNO origin get captured as temporary coorbitals of Neptune, Uranus, Saturn and Jupiter. We have also estimated the orbital distribution that these populations of temporary coorbitals would have and the fraction of objects in each libration island (L4 Trojans, L5 Trojans, horseshoes and quasi-satellites). Lastly we have used the characterisation of OSSOS and previous well characterised surveys to estimate the expected rate of detections of temporary coorbitals, which is heavily biased towards finding nearer objects, and compare with the real sample.

11:30 AM-11:40 AM

305.10 Exploring the Kuiper Belt Close to Home: A Mission to Explore Centaurs

S. Alan Stern[1], Kelsi N. Singer[1], Keith Noll[2], Anne Verbiscer[4], Harold F. Levison[1], William F. Bottke[1], Daniel Stern[3]
[1]Southwest Research Institute, Boulder, Colorado, United States, [2]NASA GSFC, Greenbelt, Maryland, United States, [3]NASA JPL, Pasadena, California, United States, [4]University of Virginia, Charlottesville, Virginia, United States

Abstract

The Kuiper Belt (KB) has been cited in Decadal Surveys (DSs), SMD roadmaps, and NRC reports as a treasure-trove of information about the origin and early evolution of our solar system and the accretion of the planets. New Horizons (NH) inaugurated KB exploration with its flyby of Pluto (2400 km diameter) in 2015 and will soon reconnoiter 2014 MU_{69} (~25 km diameter).

It is possible to conduct the next chapter in KB exploration at far lower cost than return missions to the KB itself by making reconnaissance flybys of the vast, escaped population of KB Objects (KBOs) called Centaurs. Centaurs are a scientifically critical, intermediate population—the big brothers to the short period comets that also derive from the KB, and the little brothers to the KB's dwarf planets. In addition,

because Centaurs are KBOs located between the giant planets, 3 to 10 times closer than the KB, they are far more accessible than KBOs in the Kuiper Belt itself.

The key goals for a first mission to Centaurs should be to: (i) bridge the two order of magnitude gap in the explored size range of KBOs between MU69 and Pluto, and (ii) sample the diversity of KBO evolution, geologies, compositions, satellite systems, rings, and—importantly—activity. All these objectives can be accomplished with a flyby spacecraft conducting just three investigations: Ralph (a medium-resolution color/panchromatic VIS imager and IR mapping spectrometer on New Horizons and Lucy), LORRI (a high-resolution imager on New Horizons and Lucy), and radio science.

By exploring Centaurs for the first time, such a mission can dramatically enhance knowledge of the KB, and address scientific objectives key to a broad suite of planetary science disciplines including the Kuiper Belt, dwarf planets, comets, origins, rings, and small bodies.

11:40 AM-11:50 AM

305.11 Evidence for Very Early Migration of the Solar System Planets

David Nesvorny[1], David Vokrouhlicky[2], William F. Bottke[1], Harold F. Levison[1]
[1]Southwest Research Institute, Boulder, Colorado, United States, [2]Charles University, Prague, Czechia

Abstract
The orbital distribution of trans-Neptunian objects provides strong evidence for the radial migration of Neptune. A dynamical instability is thought to have occurred during the early stages with Jupiter having close encounters with a Neptune-class planet. As a result of these encounters, Jupiter acquired its current orbital eccentricity and jumped inward by a fraction of an au, as required for the survival of the terrestrial planets and from asteroid belt constraints. The timing of these events is often linked to the lunar Late Heavy Bombardment that ended some 700 Myr after the dispersal of the protosolar nebula (t_0). We show instead that planetary migration started shortly after t_0. Such early migration is inferred from the survival of the Patroclus-Menoetius binary, which is a pair of Jupiter Trojans with 113 and 104 km diameters. The binary formed within a massive planetesimal disk once located beyond Neptune. The longer the binary stayed in the disk, the greater the likelihood that collisions would strip its components from one another. The simulations of its survival indicate that the disk had to have been dispersed by migrating planets within 100 Myr of t_0. This constraint implies that the planetary migration is unrelated to the formation of the youngest lunar basins.

11:50 AM-12:05 PM

305.12D How KBO bulk density constrains their formation time

Carver Bierson, Francis Nimmo
Earth and Planetary Science, UC Santa Cruz, Santa Cruz, California, United States

Abstract
Telescopic observations have determined the bulk density of 17 Kuiper Belt objects (KBOs) [1]. These observations have found that larger KBOs have a higher bulk density. Importantly small KBOs have been found to have a bulk density less than that of pure water ice. The best constrained of these is 2002 UX_{25} which has a radius of ~325 km and a density of 820 ± 110 kg m–3 [2]. Previous work have suggested that this trend in density is due to larger KBOs being more rock rich. The mechanism to generate such a compositional gradient with size has however remained unclear. We propose that the change in density with size is driven instead by a difference in bulk porosity with larger bodies

experiencing more pore closure due to higher pressures and higher temperatures. We model the compression of porosity due to brittle failure and ductile creep. We track the thermal evolution of KBOs with heat production from long lived radioisotopes. We find that the majority of KBOs measured density values are well fit by a rock mass fraction of 70%.

There are two primary formation models for KBOs. The first is coagulation in which KBOs form via gravitational encounters over ~70 Myr [3]. Alternatively they may form via gravitational collapse [4]. In this model 'pebbles' are accumulated by the streaming instability with the gas disk until they reach a critical density. Because this mechanism requires the presence of the gas disk it must happen early in solar system history. A key reason small KBOs can maintain their low density is because the heat produced by long lived radioisotopes is quickly conducted to the surface keeping interior temperatures low. If however these objects formed with even small amounts of ^{26}Al they warm significantly and all the internal porosity is removed. We find that to maintain their high porosity small KBOs must have formed later than ~5 Myr after CAI. Given that the gas disk is not expected to last more than ~4-5 Myr into solar system formation this favors coagulation as the formation mechanism for KBOs.

[1] Brown, M. Annu. Rev. Earth Planet. Sci. 40, 467–494 (2012) [2] Brown, M. ApJ letters 778, 2 (2013) [3] Kenyon S. J., Publications of the ASP 114.793 (2002) [4] Nesvorný, D. et al., ApJ 140, 3 (2010)

Wednesday, October 24, 2018
02:00 PM-02:55 PM
Ballroom F-G (Knoxville Convention Center)

308 Plenary: New Views of the Evolution of the Early Solar System
Chair(s): Joshua Emery

02:05 PM-02:30 PM
308.01 Early Solar System Dynamics Constrained Using Cosmochemistry
Thomas Kruijer
Nuclear and Chemical Sciences Division, Lawrence Livermore National Laboratory, Livermore, California, United States

Abstract
Cosmochemistry, the study of chemical and isotopic signatures in meteorites, can provide direct constraints on the origin and evolution of our Solar System. As a discipline, it therefore, represents an important complement to fields like astronomy and astrophysics. Here I will review some recent developments in cosmochemistry, with a particular focus on early Solar System dynamics.
From a cosmochemist's viewpoint, the evolution of the solar protoplanetary disk started with the formation of the oldest dated solids, Ca-Al-rich inclusions (CAIs), which formed ~4567 billion years ago. The isotopic signatures of CAIs indicate that they derived from a solar disk reservoir that was genetically distinct from that of other planetary materials, implying that they either formed close to the Sun, or alternatively, in the outer Solar System.
A second important step in early Solar System evolution is the accretion of the first planetesimals. Recent W isotope studies of iron meteorites—metal samples of protoplanetary cores—demonstrate that core segregation in their parent bodies occurred within the first ~1-3 million years (Ma) after CAIs. Consequently, the accretion of iron meteorite parent bodies occurred even earlier, well within <1 Ma of Solar System formation, demonstrating that planetesimals formed very early.
The formation of Jupiter had a dramatic effect on the dynamics of the solar accretion disk. As no samples of Jupiter are available, its formation history can only be indirectly studied. Nevertheless, using the isotopic signatures of meteorites, it is possible to infer Jupiter's growth history. This is because meteorites exhibit a fundamental 'dichotomy' in their genetic heritage, separating non-carbonaceous (NC) and carbonaceous (CC) meteorites. The Mo and W isotope signatures of meteorites demonstrate that these NC and CC reservoirs must have formed very early and co-existed separately over several Ma. The only plausible mechanism for such an efficient spatial separation is the formation of a gas giant, most probably Jupiter, acting as a barrier between the reservoirs. Thus, Jupiter is the oldest planet of the Solar System and its solid core must have formed well within <1 Ma after CAIs.

02:30 PM-02:55 PM
308.02 Dynamical Models of Solar System Formation
André Izidoro[1], Sean N. Raymond[2], Rogerio Deienno[3]
[1]Department of Mathematics, Sao Paulo State University, Guaratingueta, Sao Paulo, Brazil, [2]Laboratoire d'Astrophysique de Bordeaux, France, France, [3]Southwest Research Institute, Boulder, Colorado, United States

Abstract
The dynamical origin of the inner solar system remains heavily debated. Models are constrained by the

masses and orbits of the terrestrial planets, the very low mass and structure of the asteroid belt, and the architecture of the outer solar system. It is well-accepted that the late stage of terrestrial accretion is characterized by giant collisions among Mars-mass planetary "embryos". Two contrasting views exist regarding the state of the inner system at this stage. The first view assumes a smooth mass distribution of terrestrial bodies with up to a few Earth masses in solids in the asteroid region. To match the current belt in this view, models must deplete the asteroid region by a factor of 100-1000. The classical model systematically fails to reproduce the large Earth/Mars mass ratio and and tends to strand Mars-mass embryos in the belt, which is inconsistent with the present-day belt. New models have been built taking into account the fact that matching Mars' small mass requires a severe mass deficit beyond 1 au. The Grand-Tack model invokes a specific migration history of the giant planets to deplete Mars' feeding zone, to deplete and excite the asteroid belt, successfully matching constraints. Yet uncertainties in the giant planets' growth and migration histories have motivated alternative scenarios that do not require large scale radial migration. Another viable model invokes also an early dynamical instability in the giant planet's orbits to deplete the asteroid belt and Mars' feeding zone. In the second, contrasting view the asteroid belt region was already strongly mass depleted before the late phase of terrestrial accretion. The low-mass asteroid belt model starts with a belt a few times more massive than the current one and naturally produces good Mars analogs. The giant planets can subsequently excite the asteroids' orbits to the current observed levels in a way that is consistent with models of the dynamical evolution of the outer solar system. In this talk we will review these scenarios and discuss their implications and potential ways to distinguish them.

Wednesday, October 24, 2018
02:55 PM-04:10 PM
Ballroom F-G (Knoxville Convention Center)

309 Plenary: New Views on Habitability Near and Far
Chair(s): Kathleen Mandt, Masatoshi Hirabayashi

02:55 PM-03:20 PM
309.01 The History of the Search for Life on Mars
Jennifer L. Eigenbrode
Code 699, NASA GSFC, Greenbelt, Maryland, United States

Abstract
The search for life on Mars extends back to the late 1950's when scientists started devising a strategy that laid the foundation for the 1975-76 Viking missions and planetary protection requirements. With the controversial results of Viking life detection and gas chromatography mass spectrometry (GCMS) experiments attention shifted towards the geology of Mars and technological demonstration of in situ exploration by a rover platform (Sojourner on Pathfinder). Around the same time, reported life signatures in the Allan Hills 84001 martian meteorite and formation of the NASA Astrobiology Institute reinvigorated the field of astrobiology. Together, these events opened the door to exploration rovers with science payloads and motivated reshaping of NASA's Mars exploration strategy with stepwise objectives: "follow the water", search for ancient habitability (and organic carbon), and search for ancient life. The recent in situ observations of organic matter in ancient rocks from a habitable lake environment supports the next step in this strategy—to search for signatures of ancient life.

Mission results have and will continue to profoundly reshape our perception of Mars, especially its past biological potential hidden below its dusty surface. The strategy for the search for recent or extant life on Mars is more tenuous, but mission concepts are emerging and ESA's 2020 ExoMars rover will take the first step in this exploration directive since Viking. The need for a recent or extant life search strategy is building urgency with the expectation that humans will land on Mars in decades to come, ushering in a new era of Mars ecology. The presentation will review the history of the search for life on Mars with regards to strategy, instruments, mission results, and expectations for future science exploration.

03:20 PM-03:45 PM
309.02 Searching for Pale Blue Dots: The Quest for Habitable Exoplanets
Courtney Dressing
Astronomy, University of California, Berkeley, Oakland, California, United States

Abstract
Although we have not yet detected life beyond Earth, astronomers have made remarkable progress towards the eventual goal of finding an inhabited planet orbiting another star. We now know that small, temperate planets are common and we are actively designing facilities capable of detecting life elsewhere in the galaxy. In celebration of the 50^{th} anniversary of the DPS annual meeting, I will review key milestones in the history of our exploration of exoplanet habitability and highlight recent achievements such as the discovery of multiple Earth-size planets orbiting within the habitable zones of nearby stars. I will also describe the statistical advances enabled by the NASA Kepler mission and the prospects for

finding dozens of new potentially habitable planets with NASA's recently launched Transiting Exoplanet Survey Satellite.

03:45 PM-04:10 PM

309.03 Hayabusa2 Has Kicked into Full Gear: Cosmochemical Significance of C-type Asteroids in the Solar System Formation

Hikaru Yabuta[1, 2]
[1]Hiroshima University, Hiroshima, Japan, [2]ISAS/JAXA, Sagamihara, Japan

Abstract

It has been hypothesized that the building blocks of the Earth-life and ocean, hence organic molecules and water, were provided to the early Earth by small bodies. Asteroids have been regarded as the most likely source of water to the terrestrial planets, but comets must also have contributed to the inventory of volatiles. The hypothesis of exogenous delivery has been supported by the Nice model, which is linked with the Grand Tack model in which C-type asteroids were scattered from beyond Jupiter to inward due to the tidal interaction between Jupiter and gas disk (Walsh et al. 2012). However, the material evidences to support the models have not been identified yet.

We have addressed this question through chemical analyses of primitive carbonaceous chondritic meteorites and Antarctic micrometeorites (AMMs), which are thought to be C-type asteroidal- and/or cometary origins. Our recent investigation on anhydrous and hydrous AMMs has revealed continuous variations at the submicron scale in mineralogy and organic materials, reflecting differences in the extent of aqueous alteration with the evolution from comets to hydrous asteroids. In particular, we characterized organic-mineral association possibly derived from icy asteroids, such as D-/P-type asteroids, where silicates are not affected by a very weak degree of aqueous alteration on the parent bodies but organic chemistry is sensitively changed. Ultracarbonaceous Antarctic micrometeorites (UCAMMs) commonly contain large amounts of organic material enriched in nitrogen-bearing functional groups. According to the presence of amorphous silicates so-called GEMS, UCAMMs are regarded as cometary origin, while similar chemical features have been observed from several primitive carbonaceous chondrites. Thus, UCAMMs could be related to the transition from a comet to a hydrous asteroid. These results imply that C-type asteroids may have been originally derived from comets. Hayabusa2, the first C-type asteroid sample return mission by JAXA, will link the chemical features of AMMs and meteorites with their sources and geology, in order to enhance our understanding of the reservoir and transport of organics and water.

Wednesday, October 24, 2018
04:10 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

310 Asteroids: Observational Surveys Posters
Chair(s): Amy Mainzer, Bryce Bolin

310.01 THOR: An Algorithm for Cadence-Independent Asteroid Discovery
Joachim Moeyens, Mario Juric
Astronomy, University of Washington, Seattle, Washington, United States

Abstract
Discovering Solar System small bodies involves linking the detections of moving objects over many different nights into orbits. At scale, this is a difficult problem for two reasons: there are many objects that generate detections, and orbit determination is computationally expensive. Asteroid-discovery surveys use an observing cadence designed to make this problem computationally feasible. Typically, the same field is revisited multiple times a night to create "tracklets": sky-plane vectors composed of at least two detections that constrain the position and velocity of an object. These are then relatively straightforward to link into discoveries (Kubica 2007, Jones et al. 2018, Holman et al. 2018). The need for a specialized cadence has the downside of making surveys that don't follow it, including archival datasets, unsuitable for asteroid searches. Conversely, for future multi-purpose missions such as the LSST, cadence restrictions reduce the ease with which other science drivers can be accommodated. It is therefore prudent to research the feasibility of Solar System object discovery methods that are independent of survey cadence. Here we present such an algorithm, which we name THOR: "Tracklet-less Heliocentric Orbit Recovery". We test its effectiveness on a toy simulated survey produced by an LSST-like telescope. We show that by sparsely covering regions of interest in the phase space with "test orbits", projecting and shifting nearby observations over a few nights followed by a generalized Hough transform, objects with orbits similar to the test orbit can be recovered at reasonable computational cost and at little to no constraints on cadence. Our present software implementation allows us to search out the majority of the Main Belt with a relatively small number of test orbits. Extensions are planned to generalize it to other populations (esp. NEAs), hopefully taking the hammer to the need for tracklets.

310.02 The Pan-STARRS2 facility and the Wide Area Survey for NEOs with Pan-STARRS
Kenneth C. Chambers, Peter Onaka, Richard Wainscoat, Eugene A. Magnier
Institute for Astronomy, University of Hawaii, Honolulu, Hawaii, United States

Abstract
The Pan-STARRS2 telescope and 1.5 gigapixel camera (GPC2) are now functioning and is actively discovering NEOs. The Pan-STARRS2 facility will be described, and the differences with the Pan-STARRS1 facility highlighted. The performance of PS2 will be described together with ongoing work to optimize it going forward. Together PS1 and PS2 make up the Pan-STARRS system for the discovery and characterization of the NEO population. The plan for the Wide Area Survey for NEOs with both facilities will be presented.

310.03 SPACEWATCH® Astrometry of Near-Earth Objects with Larger Telescopes

Melissa J. Brucker[1], Robert S. McMillan[1], Terry H. Bressi[1], Jeffrey A. Larsen[2], Ron A. Mastaler[1], Mike T. Read[1], Jim V. Scotti[1], Andrew F. Tubbiolo[1]
[1]LPL, University of Arizona, Tucson, Arizona, United States, [2]United States Naval Academy, Annapolis, Maryland, United States

Abstract
Spacewatch does follow-up astrometry of near-Earth objects (NEOs) with our 1.8m and 0.9m telescopes and with larger telescopes to improve accuracy of orbital elements and prevent loss of scientifically interesting NEOs. We will present an update on our use of larger telescopes including our Target-of-Opportunity (ToO) program to observe virtual impactors (VIs) beyond the reach of usual follow-up assets.

Our priorities are VIs, possible Yarkovsky effect objects, future radar and NHATS targets, and NEOs with characterization data. We use the Bok 2.3m and used the Mayall 4m on Kitt Peak to recover and measure NEOs too faint for smaller telescopes. We average 930 lines of astrometry of 212 priority NEOs per year.

VIs have uncertain orbital elements such that future Earth impacts are possible within 100 years. Though potentially hazardous, they frequently become lost due to insufficient astrometry. With inadequate follow-up, VIs accrue huge uncertainties in position during long intervals between apparitions. As they tend to return fainter, VI recovery can require extensive time and resources. Once all impact solutions are eliminated, a VI is removed from JPL's and NEODyS's impact prediction lists. A VI is 'lost' when its uncertainty is so large that it is more likely to be rediscovered by chance (Milani 1999). 86 (60%) of 143 VIs discovered in the 2017B semester remain potential impactors, 13 with uncertainties greater than 15 degrees as of July 2018.

Our ToO goal is to observe priority VIs, reducing orbital element uncertainty, to help rule in or out predicted impacts via timely observations with large telescopes. ToO interruptions provide access to objects unknown when proposals were due. For the 2018A semester, we received ToO time on DECam/Blanco, ODI/WIYN, SOI/SOAR, and LRIS/Keck to collect astrometry of one VI each. We triggered 2 of 4 ToOs with 1 successful recovery. Spacewatch, since its 1984 creation, has observed 2/3 of all NEOs ever on JPL's VI risk list.

This work is supported by NASA/NEOO, LPL, Steward Observatory, KPNO, the WIYN Observatory, CTIO, SOAR, the W.M. Keck Observatory, the Brinson Foundation of Chicago, IL, the estates of R.S. Vail and R.L. Waland, and the web services of JPL, MPC, and NEODyS.

310.04 Observations of Solar System Objects with K2

Jessie Dotson[1], Christina L. Hedges[2, 1], Geert Barentsen[2, 1]
[1]NASA Ames Research Center, Moffett Field, California, United States, [2]Kepler/K2 GO office, Moffett Field, California, United States

Abstract
The K2 mission utilizes the Kepler space telescope to perform high-precision, uninterrupted photometry of different fields along the ecliptic plane. Each ~ 100 square degree field is observed for ~ 80 days at a time. Data has been obtained for over 300 solar system objects over 18 pointings of the spacecraft. Only a small fraction of the Kepler photometer's pixels are stored and downlinked due to the limited size of the

on-board solid state recorder and the data downlink rate. For stationary targets like stars and galaxies, a small postage stamp of pixels centered around the object of interest are stored and downlinked. For moving objects, a track of pixels is stored and downlinked. This track covers a portion of the object's path during the campaign, usually centered around the stationary point. There are two possible data cadences – 1 minute and 30 minutes.

A range of solar system objects have been observed – including planets (e.g. Uranus and Neptune), moons (e.g. Titan and Enceladus), and various small bodies. Data has been obtained for over 200 asteroids, more than 60 TNOs and 19 comets.

In addition, numerous solar system objects have been observed by K2 serendipitously as the objects move through pixels stored in order to observe other objects. In particular, large 'superstamps' designed to observe clusters and planets have provided observations of high numbers of solar-system bodies. The investigation of fortuitously observed solar system objects has barely begun. Molnar (2017) has examined the region of the focal plane stored to observe Uranus during Campaign 8. Photometry was obtained for over 600 main belt asteroids which crossed this portion of the Kepler focal plane and rotation rates were estimated for 90 asteroids. Other superstamps have not been examined for serendipitous observations.

In order to efficiently use the limited resources on the spacecraft, the tracks which trace out the path of moving objects are stored a series of tiles. Pixel level data for each of these tiles is currently available at the Mikulski Archive for Space Telescope. We will describe a recent effort to develop an easier to access data format and python user tools as part of the lightkurve package.

310.05 The PRIMitive Asteroids Spectroscopic Survey Library: PRIMASS-L

Julia de Leon[1, 2], Noemi Pinilla-Alonso[3, 4], Humberto Campins[5], Javier Licandro[1, 2], David Morate[6], Vania Lorenzi[7, 1], Mario De Prá[3], Juan Rizos[1, 2]
[1]Instituto de Astrofisica de Canarias, La Laguna, Santa Cruz de Tenerife, Spain, [2]Departamento de Astrofisica, Universidad de La Laguna, La Laguna, Santa Cruz de Tenerife, Spain, [3]Florida Space Institute, Orlando, Florida, United States, [4]Arecibo Observatory, University of Central Florida, Esperanza, Puerto Rico, [5]Physics Department, University of Central Florida, Orlando, Florida, United States, [6]Observatorio Nacional, Rio de Janeiro, Brazil, [7]Fundacion Galileo Galilei - INAF, La Palma, Santa Cruz de Tenerife, Spain

Abstract
The study of primitive asteroids is relevant to understanding the origin and evolution of our Solar System. These asteroids contain valuable information about volatile and organic compounds present during the prebiotic stages of Earth and other terrestrial planets. Interest in the main-belt asteroids that are the likely sources of primitive near-Earth asteroids (NEAs) has increased in anticipation of the two sample-return missions that reached their targets in 2018 and will bring samples to Earth within a few years. Concurrently, the discovery of water ice on the surfaces of two primitive asteroids (24 Themis and 65 Cybele) placed the focus on the outer-belt, where more asteroids could harbor water ice on, or below the surface.

In 2010 we started our PRIMitive Asteroids Spectroscopic Survey (PRIMASS) with the goal of studying the surface of primitive asteroids at different locations in the main belt, by means of visible and near-infrared spectroscopy. Here we present PRIMASS-L, a spectral library that contains the results of PRIMASS. As of July 2018, this library gathers spectra of about 500 asteroids from 10 families and two dynamical groups of asteroids that had been sparsely studied before. PRIMASS uses a variety of ground-based facilities, including the 3.0-m NASA Infrared Telescope Facility (IRTF) on Mauna Kea (Hawai, USA) and the 4.1-m Southern Astrophysical Research Telescope (SOAR, participated by NOAO), at Cerro Pachón (Chile). We also use the 10.4-m Gran Telescopio Canarias (GTC), and the 3.6m Telescopio Nazionale Galileo (TNG), both located at the El Roque de Los Muchachos Observatory (ORM, La Palma,

Spain) and the 3.6m New Technology Telescope (NTT), located at la Silla Observatory. This survey is on-going and aims to contain a thounsand of spectra by 2019.

Making PRIMASS-L publicly available at the Small Bodies Node of the Planetary Data System (SBN-PDS, NASA) will enable synergies with other data sets containing physical parameters (e.g. polarymetric properties and geometric albedo) and family affiliation. This will push the characterization of the families and of primitive material to a new level and improve our understanding of the evolution of our Solar System and other planetary systems.

310.06 Initial Results from Near-infrared Spectroscopy of the Klio and Sulamitis Primitive Inner-belt Families: a New "Klio-like" Compositional Group

Anicia Arredondo[1], Noemi Pinilla-Alonso[2], Humberto Campins[1], Andrew Malfavon[1], Vania Lorenzi[3, 4], Julia de Leon[4, 5], David Morate[4, 5]
[1]University of Central Florida, Winter Park, Florida, United States, [2]Florida Space Institute , Orlando, Florida, United States, [3]Fundacion Galileo Galilei, Brena Baja, La Palma, Spain, [4]Instituto de Astrofisica de Canarias, La Laguna, Tenerife, Spain, [5]Departmento de Astrofisica, Universidad de la Laguna, La Laguna, Tenerife, Spain

Abstract
The PRIMitive Asteroid Spectroscopic Survey (PRIMASS) is a visible and near-infrared study of primitive asteroids throughout the asteroid belt. Nesvorny et al. 2015 defined 6 primitive families in the inner asteroid belt: Polana-Eulalia, Erigone, Sulamitis, Clarissa, Chaldaea, and Klio. PRIMASS has already characterized Polana in visible and NIR, and Erigone, Sulamitis, and Clarissa in the visible (de Leon et al. 2016; Pinilla-Alsonso et al. 2016; Morate et al. 2016, 2018). Our published results show that inner-belt primitive asteroids fall into at least two distinct compositional groups: Polana-like (spectrally homogenous and no 0.7-micron absorption) or Erigone-like (hydrated and spectrally diverse). Objects in the Sulamitis family are Erigone-like in the visible (Morate et al. 2018). No work has been published on the Klio family in the visible, but there are multiple published spectra of the parent body (84) Klio.
In this work, we present near-infrared spectra of 15 objects in the Kilo family and 5 objects in the Sulamitis family, obtained with NASA's InfraRed Telescope Facility (IRTF) and the Telescopio Nazionale Galileo (TNG) between August 2017 and June 2018. Our initial results show clear differences between the Klio and Sulamitis families in the NIR, evident even in a small sample size. Within the uncertainties, Kilo objects are identical to each other and show essentially flat spectra with no slope and no features. In contrast, Sulamitis objects are more spectrally diverse which agrees with what is seen in the visible. Asteroid (84) Kilo shows a clear 0.7-micron feature, associated with hydrated material (Fornasier et al. 2014), which suggests that there is a third compositional group of inner belt families that are Klio-like (hydrated and spectrally homogeneous). These three spectral groups occur at three different inclinations: Polana-like are at low inclination ($i<3°$), Erigone-like are at mid inclination ($3°<i<6°$) and Klio-like are at high inclination ($i>8°$); i.e., there are similar compositions among three groups with distinct inclinations.

310.07 Olivine-dominated A-type asteroids in the Main Belt: Distribution, Abundance and Relation to Families

Francesca DeMeo[1], David Polishook[2], Benoit Carry[3], Brian Burt[4], Henry Hsieh[5], Richard P. Binzel[1], Nicholas Moskovitz[4], Thomas Burbine[6]
[1]MIT, Cambridge, Massachusetts, United States, [2]Weizmann Institute of Science, Rehovot, Israel, [3]Observatoire de la Côte d'Azur, Nice, France, [4]Lowell Observatory, Flagstaff, Arizona, United

States, [5]Planetary Science Institute, Tucson, Arizona, United States, [6]Mount Holyoke College, South Hadley, Massachusetts, United States

Abstract
Differentiated asteroids are rare in the main asteroid belt despite evidence for ∼100 distinct differentiated bodies in the meteorite record. We have sought to understand why so few main belt asteroids differentiated and where those differentiated bodies or fragments reside. Using the Sloan Digital Sky Survey (SDSS) to search for a needle in a haystack we identify spectral A-type asteroid candidates, olivine-dominated asteroids that may represent mantle material of differentiated bodies. We have performed a near-infrared spectral survey with SpeX on the NASA IRTF and FIRE on the Magellan Telescope. The success rate for confirming A-types from SDSS candidates is 33% - 20 of the 60 objects observed.

We report results from having doubled the number of known A-type asteroids. We deduce a new estimate for the overall abundance and distribution of this class of olivine-dominated asteroids. We find A-type asteroids account for less than 0.16% of all main-belt objects larger than 2 km and estimate there are a total of ~600 A-type asteroids above that size. They are found rather evenly distributed throughout the main belt, are even detected at the distance of the Cybele region, and have no statistically significant concentration in any asteroid family. We conclude the most likely implication is the few fragments of olivine-dominated material in the main belt did not form locally, but instead were implanted as collisional fragments of bodies that formed elsewhere.

310.08 Impact Probability Evolution of Virtual Impacting Asteroids Observed by the Large Synoptic Survey Telescope

Clark R. Chapman[1], Bryce Bolin[2], Edward Lu[2], Mike Loucks[2], John Carrico[2]
[1]B612 Foundation, Mill Valley, California, United States, [2]B612 Asteroid Institute, Mill Valley, California, United States

Abstract
The Large Synoptic Survey Telescope (LSST) will discover more than 10 times as many Near Earth Asteroids (NEAs) as all other telescopes combined (Ivezić et al., 2008, Jones et al., 2018). Among the more than 100,000 expected newly discovered NEAs, will be hundreds of asteroids with a worrisome chance (more than 10^-4) of hitting Earth. The probability of impact of any given asteroid is a function of the uncertainty in the orbit determination, and evolves as the knowledge of the orbit of the asteroid is refined by repeated observations. Eventually, the probability drops low enough to know that a collision with Earth can be ruled out, or in rarer cases the probability rises large enough to consider the asteroid a serious threat.

The goal of our study is to understand how the impact probabilities evolve with time prior to potential impact. This is critical because the danger posed by an asteroid may not be fully apparent because the uncertainty in the knowledge of the orbit may be large enough that the estimated impact probability is still small. As a result, the warning time for a threatening asteroid may be too short for mitigation efforts which can take years to execute and plan.

To understand the warning times that are likely to result for impacting asteroids, we have simulated decades of operation of LSST in observing an ensemble of 100,000 asteroids which are chosen to be representative of Earth impacting asteroids. From these series of observations, we carry out the orbit determination process and examine the evolution of the estimated asteroid orbits and their uncertainties to

understand the evolution of impact probability as a function of time before impact. The tools for studying asteroid observations, including the calculation of asteroid impact probabilities, developed as part of this study will eventually become part of the Asteroid Decision and Mapping project (a program of the Asteroid Institute). These tools are intended to be public and open-source for use by the scientific community for orbit determination of NEA discoveries by LSST and other observatories in the coming decade.

310.09 Demonstration Run for Near-Earth Objects Follow-up with the TMO 1-m Telescope

Jana Pittichova[1], Marc Buie[2], Steven Chesley[1], Heath A. Rhoades[1]
[1]JPL, Pasadena, California, United States, [2]SWRI, Boulder, Colorado, United States

Abstract
We are reporting observations of Near-Earth Objects using the 1-meter telescope at the Table Mountain Observatory (TMO), JPL's dedicated astronomical observing facility. Construction and installation of the TMO 1-meter telescope was completed in 2015 and, as we show below, the telescope is ideal for faint follow-up of NEOs.
Our demonstration run covers a five-week period in April-May 2018. We observed on 12 partial nights to demonstrate the telescope's performance capability. During these test and demonstration nights, we detected a total 42 objects (40 distinct objects, with two objects observed on two nights), including 5 radar targets and 37 NEOCP targets. Among the 37 NEOCP targets, 28 were eventually published as new NEOs with our astrometry posted in associated MPECs. The other nine NEOCP targets turned out to be new discoveries, but of main-belt or trojan asteroids.
The faintest object detected (or even attempted) during this demonstration was the Jupiter trojan 2018 JF3, which was detected at V=22.1 mag with SNR=3 in a stack of three 600-sec images for a total exposure time 1800 sec. The results indicate that with dark sky in typical seeing of 2 arcsec, we can detect a V~21 mag target in less than 5 minutes of cumulative exposure time, and a V~22 mag target can be detected with 15-30 minutes of exposure. These exposure times must be doubled to collect the minimum of two independent detections needed to form an MPC submission.
The follow-up of NEOs at the time of discovery is crucial and oftentimes this period also presents the best characterization opportunity (e.g., for radar) if the trajectory can be refined expeditiously enough. Many promising candidate NEOs posted to the NEOCP are not confirmed and become lost. Our proposed NEO follow-up observation program at TMO will contribute orbital tracking data for about 800 objects per year, including confirmation follow-up for many recently discovered objects and an appropriate tracking cadence for objects already announced.

310.10 Status of The Catalina Sky Survey for Near Earth Asteroids

Eric Christensen, Brian Africano, Greg Farneth, David Fuls, Alex Gibbs, Al Grauer, Hannes Groeller, Jess Johnson, Richard Kowalski, Stephen Larson, Greg Leonard, Robert Seaman, Frank Shelly
The University of Arizona, Tucson, Arizona, United States

Abstract
The University of Arizona's Catalina Sky Survey (CSS) is beginning its third decade of operations, and continues to be the most productive Near Earth Object (NEO) survey to date. CSS has discovered 46% of the known NEO catalog, including over a third of NEOs with a diameter of approximately 140 meters or larger. Recent upgrades to both survey instruments (the 1.5 meter and Schmidt telescopes) have

significantly increased CSS's annual discovery rate, which is on track to exceed 1,000 by year's end. In June, CSS also discovered another small asteroid (2018 LA) prior to Earth impact. We have also increased our focus on NEO follow-up in support of the community's discovery efforts, by remotely operating the CSS 1.0-m telescope a full 24 nights per lunation, and by operating the Steward Observatory Kuiper 61" telescope up to 9 nights per lunation. We will discuss improvements to the planning and scheduling software, ongoing efforts to coordinate community follow-up, and progress toward reprocessing archival data and making it publicly available through NASA's Planetary Data System.

Catalina Sky Survey gratefully acknowledges sustained support from NASA, currently under grant #80NSSC18K1130.

Wednesday, October 24, 2018
04:10 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

311 Centaurs/TNOs Posters
Chair(s): Darin A. Ragozzine

311.01 The 2017 occultation by Vanth: a revised analysis
Amanda S. Bosh[1, 2], Amanda A. Sickafoose[3, 1], Stephen E. Levine[2, 1], Carlos A. Zuluaga[1], Anja Genade[3], Karsten Schindler[4], Tim Lister[5], Michael J. Person[1]
[1]Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, Massachusetts, United States, [2]Lowell Observatory, Flagstaff, Arizona, United States, [3]South African Astronomical Observatory, Cape Town, South Africa, [4]Deutsches SOFIA Institut, Stuttgart, Germany, [5]Las Cumbres Observatory, Goleta, California, United States

Abstract
In March 2017, we observed an occultation by members of the Orcus system. Two chords were obtained, along with three negative detections (Sickafoose et al. 2017; Sickafoose et al. 2018, submitted). Initial geometric analysis of these data was consistent with an occultation by Orcus and Vanth, of a single star (Bosh et al. 2017). Subsequent speckle imaging of the occultation star using DSSI on Gemini-South (Horch et al. 2009) revealed a double star with a separation of 252 mas and a magnitude difference of 0.93 at 692 nm. Reanalysis of the geometry of this event with this new stellar information shows that the two positive detections are consistent with occultations by Orcus' satellite Vanth at both the 3-m IRTF (chord length 434.39 ± 2.36 km) and the 1-m Las Cumbres ELP telescope at McDonald Observatory (chord length 291.1 ± 124.9 km; larger uncertainty due to deadtime uncertainty). These observations suggest that the IRTF chord was close to being central on Vanth; in fact, it must be near central because a non-detection at Sierra Remote Observatories (0.6-m ATUS) constrains the geometry. We are not able to determine if there is any deviation from sphericity due to the uncertainty in the chord length of our second chord, from ELP, however it is consistent with a spherical shape for Vanth.

Initial estimates of the size of Vanth from thermal measurements (Brown et al. 2010; Fornasier et al. 2013) are approximately 280 km, with an albedo of approximately 0.25. Later observations of Orcus/Vanth made with ALMA give a diameter for Vanth of 475 ± 75 km, with an albedo of 0.08 ± 0.02 (Brown & Butler 2018). Our occultation measurement agrees with this new measurement for Vanth's size, and further constrains the size. Vanth is therefore darker than Orcus, implying either a difference in origin or in subsequent evolution. As reported in Sickafoose et al. (2018, submitted), neither atmosphere nor rings were detected in the occultation data.

311.02 The mass and density of the dwarf planet 2007 OR10
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Abstract
The satellite of 2007 OR10 was discovered on archival Hubble Space Telescope images in 2017. With new observations taken with the WFC3 camera of the HST in late 2017 we were able to confirm the presence of the satellite and determine the orbit. The orbit's notable eccentricity, e=0.31, may be a consequence of an intrinsically eccentric orbit and slow tidal evolution, but may also be caused by the Kozai mechanism. Dynamical considerations also suggest that the moon is small, D < 100 km. Based on the newly determined system mass of 1.75×10^{21}kg, 2007 O10 is the fifth most massive dwarf planet after Eris, Pluto, Haumea and Makemake. We also revisited the radiometric size estimate of the primary using the assumption that the moon orbits in the equatorial plane of the primary. This approach provides a size range of 1210 km < D < 1295 km, and a bulk density of 1.72±0.16 g cm^{-3} for the primary. A previous size estimate that had assumed an equator-on configuration (D = 1535^{+75}_{-225} km) provides a density of $0.92_{-0.14}^{+0.46}$ g cm^{-3}, unexpectedly low for a 1000 km-sized dwarf planet. 2007 OR10 and the satellite have the larest color difference, Δ(V-R)=0.43±0.17 among binary transneptunian objects.

311.03 Searches for KBO Binaries using New Horizons LORRI

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Abstract
The New Horizons (NH) spacecraft is currently traversing the densest portion of the Kuiper belt (r ~ 43 AU), enabling observations of known Kuiper belt objects (KBOs) at unique geometries, including at large phase angles not possible from the inner solar system and at ranges that provide higher spatial resolution than available from Earth, or Earth-orbiting, facilities. New Horizons carries a large aperture (20.8 cm) visible light imaging system, the LOng Range Reconnaissance Imager (LORRI), whose resolution (IFOV=1,4 arcsec for 1x1 and 4x4 modes, respectively) permits searches for binaries at finer spatial scales than available from the Hubble Space Telescope (HST). We have already scheduled observations of 13 KBOs (1 Plutino, 1 Hot Classical, 1 Scattered Disk, and 10 Cold Classicals) that pass within 1 AU of the NH spacecraft, and we are actively searching for additional candidates using ground-based telescopes. Five of the KBOs pass within 0.2 AU of the NH spacecraft, including two with ranges of ~0.1 AU (73 km/pix for 1x1 mode). LORRI's photometric sensitivity for these satellite searches (V~16.3 in 1x1 mode after co-adding ~125 0.5s exposures; V~21 in 4x4 mode after co-adding ~50 30s exposures) is comparable to, or exceeds, that available from HST. Five of the six highest resolution (1x1 mode) NH KBO satellite searches are being conducted during the latter half of 2018, although most of the data will not be downlinked to Earth until 2019. Here we report on the binary search limits achieved for the five NH distant KBO observations already obtained and our plans for the upcoming searches.

311.05 A New, Unusual, and Diagnostic Band in Near-Infrared Spectra of Laboratory Ice Samples and Triton

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Abstract
We present near-infrared spectra of carbon monoxide (CO) and nitrogen (N_2) ice mixtures obtained in the Northern Arizona University Astrophysical Ice Laboratory. We confirm the existence of an unidentified band at 4466 cm^{-1} (2.239 μm) in these mixtures that was first reported by Quirico and Schmitt (1997, Icarus, 128, 181-188). A systematic laboratory study of the band has led us to some surprising results. Specifically, the band is strongest for a sample with near equal amounts of CO and N_2; however, the band is not present in a pure CO ice sample nor a pure N_2 ice sample. Nor is the band present in a CO and argon (Ar) mixture. Furthermore, the 2.239 μm band shifts for ^{13}CO in an N_2 ice sample and for $C^{18}O$ in an N_2 ice sample, but not for $^{12}C^{16}O$ in a $^{14}N_2$ enriched ($^{15}N^{14}N$ depleted) ice sample. We looked into the solid state phase behavior of the mixtures, and found CO and N_2 are fully miscible in one another. We mapped the temperature and composition dependence of the alpha – beta N_2 phase transition and found the band in both N_2 phases. Our experiments suggest the band arises from some sort of interaction between individual CO and N_2 molecules in the solid state.

In addition to laboratory spectra, we present a recently obtained near-infrared spectrum of Triton taken with the 8-meter Gemini Telescope in Chile and the IGRINS spectrograph. The 2.239 μm band weakly appears in the spectrum. Besides laboratory and telescope spectra, we present the results of our theoretical efforts to better understand the interaction between the CO and N_2molecules giving rise to this band.

Our work shows the 2.239 μm band has important applications for remote sensing of icy outer system objects. In particular, its detection on icy bodies like Triton, and perhaps future detections on Pluto, Eris, and Makemake, demonstrates the CO and N_2 molecules are intimately mixed together. Perhaps spectrographs on future spacecraft could exploit this band to better understand the chemical makeup of the ice on this class of bodies.

311.06 Commissioning of the Transneptunian Automated Occultation Survey (TAOS II)

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Abstract
The Transneptunian Automated Occultation Survey (TAOS II) will aim to detect occultations of stars by small (~1 km diameter) objects in the Kuiper Belt and beyond. Such events are very rare (0.001 events per star per year) and short in duration (~200 ms), so many stars must be monitored at a high readout cadence in order to detect any events. TAOS II will operate three 1.3 meter telescopes at the Observatorio Astronómico Nacional at San Pedro Mártir in Baja California, México. With a 2.3 square degree field of view and a high speed camera comprising CMOS imagers, the survey will monitor 10,000 stars simultaneously with all three telescopes at a readout cadence of 20 Hz. Construction of the site began in the fall of 2013, and the telescopes were installed in 2017 October. In this poster, we present the status of the commissioning of the survey and the plans to begin science operations.

311.07 Searching for activity on 15 Centaurs discovered in the Pan-STARRS detection catalog
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Abstract
We present the observations and search for distant activity among 15 Centaurs discovered in the Pan-STARRS1 detection catalog (Weryk, R.J., et al. 2016, eprint arXiv:1607.04895). The observations were made with the Gemini N telescope in R-band, as a set of three 120-second exposures per target, over the observing semester 2017B. This setting allowed for detecting faint activity down to surface brightness of 25.5 mag/arcsec^2.
Centaurs originate in the trans-Neptunian region and are known to exhibit comet-like activity way past Jupiter's orbit, which source and triggers are still poorly understood. The active Centaurs are known to exhibit a wide range of activity patterns not necessarily associated with the perihelion passage, and often at large heliocentric distances. To increase the chances of detecting such a random outburst our chosen targets occupied heliocentric distances 7.9 AU – 25.4 AU at the time of observations and varying mean anomalies. One of the objects – 2015 BD518, was passing the perihelion three weeks after the observations were made, three other targets were less than a year after the perihelion passage.

We will present the results of analysis of the coma contribution to the targets' brightness in the context of our ongoing survey for activity on Centaurs at large heliocentric distances, and our estimates of the nuclei sizes.

311.08 Search for a Pluto-like Satellite System Around Eris
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Abstract
The most massive trans-Neptunian object, (136199) Eris, has one known satellite, Dysnomia. While some uncertainty surrounds the origin of Dysnomia, the favored mechanism for the formation of satellites among the large trans-Neptunian objects is giant impacts. Numerical modeling strongly favors the formation of the Pluto system by giant impact, and the system contains one large satellite, Charon, as well as four smaller satellites orbiting in near mean-motion resonances with Charon. The existence of minor satellites in the Eris/Dysnomia system was examined using images obtained with WFC3/HST in January and February 2018 (program 15171). These images were taken through the F606W filter and visits were

scheduled to capture Dysnomia at different orbital phases. Aperture photometry was performed on Eris and a synthetic PSF inserted into median-stacked images from each orbit to determine the detection limit for a hypothetical minor satellite. We find that we are able to detect objects 9.7±0.2 magnitudes fainter than Eris at the 3-σ level. We assumed that any potential minor satellites would orbit in the same plane as Dysnomia and projected orbits for hypothetical satellites in mean-motion resonance with Dysnomia onto each image. Aperture photometry, centered on each pixel that fell on the projected orbit paths, was performed to search for 3-σ outliers. We then compared the position of the outliers across multiple images to determine if the motion is what would be expected for a satellite on that orbit. This method is also applicable for minor satellite searches in other large TNO binary systems.

311.09 A New Inner Oort Cloud Object

Chadwick Trujillo[1], Scott S. Sheppard[2], David J. Tholen[3], Nathan Kaib[4]
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Abstract
We report the discovery of v302126, the third known Inner Oort Cloud (IOC) object after Sedna and 2012 VP113. With its perihelion of 65 au and semi-major axis of 1190 au, it is the most eccentric and distant of the IOCs. It was discovered as part of our ongoing survey for Extreme Trans-Neptunian Objects (ETNOs) and IOCs which has covered over 2,000 square degrees to at least magnitude 25 using Hyper Suprime-Cam on the Subaru 8m telescope on Mauna Kea, Hawaii and the Dark Energy Camera (DECam) on the Blanco 4m telescope at the Cerro Tololo Inter-American Observatory in Chile.

v302126's longitude of perihelion is similar to that of Sedna, 2012 VP113 and nearly all of the other ETNOs. Using our observational bias simulator to analyze this trend for the IOCs and ETNOs discovered in our survey, we find the longitude of perihelion clustering significance at the 97\% level, or about 2.2 sigma assuming Gaussian statistics, which we interpret as extremely interesting but not yet formally statistically significant without more detected objects. In addition, the high semi-major axis of v302126 suggests that the semi-major axis distribution of the IOCs increases roughly as the third power of distance, suggesting that the volume distribution of the IOCs is roughly uniform with increasing distance. This indicates that there are probably many IOCs that remain undiscovered at large distances, perhaps even outnumbering the TNOs, as discussed in Sheppard and Trujillo (2016).

We used dynamical simulations to assess v302126's stability including the effects of the known giant planets, the Galactic tide, passing stellar encounters and a hypothetical 10 Earth mass distant undiscovered giant planet (i.e. Planet X or Planet 9). We find v302126's orbit generally stable to all of these effects, although its stability against stellar encounters and Planet X depend on the specific scenarios chosen. Interestingly, the Planet X scenarios which are stable for v302126 are also stable for the other known ETNOs and IOCs, adding weight to the Planet X hypothesis.

311.10 The Wavelet theory applied to the study of spectra of Trans-Neptunian objects

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Abstract
Reflection spectroscopy in the Near Infrared (NIR) is used to investigate the surface composition of Trans-Neptunian objects (TNOs). In general, these spectra are difficult to interpret due to the low apparent brightness of the TNOs, causing low signal-to-noise ratio even in spectra obtained with the

largest telescopes available on the Earth, making necessary to use filtering techniques to analyze and interpret them.

The purpose of this poster is to present a methodology to analyze the spectra of TNOs. Specifically, we aim at filtering these spectra in the best possible way: maximizing the remotion of noise, while minimizing the loss of signal. To do this, we use the wavelets technique. The wavelets are a mathematical tool that decomposes the signal into its constituent parts, allowing to analyze the data in different areas of frequencies with the resolution of each component tied to its scale. To check the reliability of our method, we compare the filtered spectra with spectra of water and methanol ices to identify some common structures between them.

Of the 50 TNOs of our sample, we identify traces of the presence of water and methanol ices in the spectra of several of them, some with previous reports, while some of these objects there were no previous reports. Through the analysis of TNO spectra with wavelets, many data that were previously neglected because they did not present sufficient signal to noise to be analyzed, can now be re-evaluated, even the smallest TNOs. Therefore, we conclude that the wavelet technique is successful in filtering TNOs spectra and in this edition of DPS, we will show how to use this powerful tool for the community.

Wednesday, October 24, 2018
04:10 PM-06:40 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

312 Asteroid Physical Characteristics: NEOs Posters
Chair(s): Michael Mueller

312.01 Archived Spitzer Observations of (3200) Phaethon: an aqueously altered asteroid.
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Abstract
(3200) Phaethon is a perplexing object. It is the progenitor of the Geminids meteor stream, yet activity observed at perihelion is not sufficient to be the sole source of the meteors observed at Earth (e.g.,[1], [2]). It has been argued that Phaethon has a cometary origin but has been degassed due to many close solar passages (e.g., [3]). Phaethon has also been suggested to be related to asteroids based on near-infrared spectral similarity (e.g., [4]) and dynamical association between Phaethon's orbit and (2) Pallas (e.g., [5]). Here we present archived, mid-infrared *Spitzer* spectroscopy of (3200) Phaethon to investigate if Phaethon is spectrally similar to cometary nuclei or asteroids. Phaethon was observed by Spitzer with the IRS instrument on January 14, 2005 using the short-low and long-low modes of the IRS instrument with wavelength ranges of 5.5-13.2-µm and 14.0-38-µm, respectively. The integration time was 58.7 s. Its heliocentric distance was 1.1 AU and distance from Earth was 0.7 AU with a phase angle of 60.3 degrees. We first fit Phaethon's infrared spectrum with the Near Earth Asteroid Thermal Model [6] finding a best fit diameter of 7.4 +/-0.79 km, an albedo of 0.041(+0.003, -0.004) and an eta parameter of 2.30 (+0.05, -0.04). Cometary nuclei are known to have distinct spectral signatures from asteroids in the mid-infrared (especially between 5.5-13.2-mm; e.g., [7]). Phaethon appears to be asteroid-like in this wavelength region, lacking the characteristic cometary spectral signature. Furthermore, we find that Phaethon appears to be most similar to intermediately altered carbonaceous chondrites in the CM and CI chemical groups. This indicates that Phaethon has 75-80% hydrated minerals on its surface, despite frequent close passages to the Sun.

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312.02 Benchmarking Asteroid-Deflection Simulations: Basalt Spheres
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Abstract
Near-Earth asteroids pose a low-probability yet potentially high-consequence risk to Earth. We simulate mitigation techniques to deflect asteroids in preparation for future threats. Code validation, an important aspect of asteroid-deflection research, provides guidance for selecting appropriate material models for use

in deflection simulations. Here we compare results from the 1991 Nakamura and Fujiwara hypervelocity two-stage light gas-gun experiment to our simulation results using Spheral, an Adaptive Smoothed-Particle Hydrodynamics code. This particular experiment used a 0.7-cm nylon projectile, launched at ~3 km/s, to fragment a 6-cm basalt sphere. We find that our results are sensitive to the selected strain and strength models, as well as material parameters utilized by the strength and damage models. We describe the best constitutive model and material parameter selections in Spheral determined from this research and discuss the possible range of applications. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-JRNL-751961-DRAFT.

312.03 Rotation Rates of Near-Earth Asteroids

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Abstract

It is widely accepted that Near- Earth Asteroids (NEAs) represent a global hazard for human civilization. They have impacted many bodies in the Solar System, including the Earth. More notorious was the NEA with an estimated diameter of 17 meters that exploded over Chelyabinsk in Russia with an energy of about 470 kilotons in 2013 and injured over 1,500 people. Due to the possible devastating consequences of such impacts, Congress has assigned NASA the task of finding 90% of all of the asteroids with sizes greater than 140 meters by 2020. While is of vital importance and priority to detect these objects, it is also of vital importance to characterize them in order to develop a correct deflection strategy in case of an imminent impact.

An asteroid photometry campaign has been initiated with the intent of obtaining lightcurves of NEAs in order to determine their rotation periods and lower limits. The rotation rate distribution of NEAs can give us important information about their material strength and composition. NASAcam, a 2K x 2K thermoelectrically cooled CCD camera, is used on the 31-inch National Undergraduate Research Observatory (NURO) telescope at the Lowell Observatory in Flagstaff, Arizona to obtain the photometric data. Twenty five NEAs have been observed using an R-band filter typically for no more than four hours in one night. The data reduction and analysis of the data is conducted at the University of Puerto Rico at Humacao (UPRH) Astronomical Observatory using the Minor Planet Observer (MPO) Canopus software, the Image Reduction and Analysis Facility (IRAF) software, and a suite of Interactive Data Language (IDL) routines.

312.04 Physical Characterization of 4 Near-Earth Asteroids

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Abstract

The Arecibo S-band radar system (2380 MHz, 12.6 cm) is an ideal method for studying the decimeter scale surface features of near-Earth asteroids. In all dual-polarization radar experiments, the echo from the asteroid is recorded in both the same circular (SC) and opposite circular (OC) sense as the transmitted

wave. The ratio of these numbers, the circular polarization ratio (CPR), is an indicator of surface roughness on approximately wavelength scales. We present here preliminary results of a radar-image analysis regarding the surface feature characterization of 4 asteroids observed using the 305 meter Arecibo telescope during the past six years. Targets include the recently discovered equal mass binary system 2017 YE5, the Destiny$^+$ mission target 3200 Phaethon, the triple system 3122 Florence and 2005 GO_{21}. Targets were selected based on their imaging resolution and number of observations (minimum two days). The backscattered power was then fit with a Bragg scattering model for both the SC and OC polarizations, which gives an indication of both the near-surface bulk density and surface roughness. To ensure enough data points for the fit, we added the additional criterion of at least 30 distinguishable pixels in both the vertical and horizontal axes (echo delay and Doppler shift, respectively) , which gives sufficient coverage of incidence angles (the angle between the direction of propagation of the incident signal and the normal of the surface at the point of interest). We also consider the CPR as a function of time, looking for variation in roughness as the object rotates, and the changes in CPR mapped across the surface of the asteroid.

312.05 Wide phase-polarization curve of asteroid (3200) Phaethon during December 2017

Yoshiharu Shinnaka[1, 2], Toshihiro Kasuga[2], Daniel Boice[3], Tsuyoshi Terai[2], Reiko Furusho[4], Hirotomo Noda[2], Noriyuki Namiki[2], Jun-ichi Watanabe[2]
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Abstract
A linear polarization degree (referred to the scattering plane, P_r) as a function of the solar phase angle, α, of solar system objects is a good diagnostic to understand the scattering properties of its surface materials. We report $P_r$of Phaethon over a wide range of α from 19°.1 to 114°.3 in order to better understanding properties of its surface materials. The polarimetric survey of Phaethon was performed for 13 consecutive nights from UT 2017 December 9 to December 21 using the Polarimetric Imager for Comets (PICO; Ikeda et al. 2007) mounted on the 50-cm Telescope for Public Outreach at Mitaka Campus of National Astronomical Observatory of Japan. We used the standard Johnson-Cousins R_C-band filter for all observations of Phaethon. Due to favorable weather conditions, we obtained a high-quality data set in the range of solar phase angle from 19°.12 through 114°.30. The ranges of heliocentric and geocentric distances of Phaethon were 1.13-0.94 au and 0.15-0.07 au, respectively. The elevation of all observations was over 28°.
The derived phase-polarization curve shows that the maximum of P_r, P_{max}, is >42.4% at α>114°.3, a value significantly larger than those of the moderate albedo asteroids (P_{max}~9%). The phase-polarization curve classifies Phaethon as B-type in the polarimetric taxonomy, being compatible with the spectral property. We compute the geometric albedo, p_v, of 0.14 ± 0.04 independently by using an empirical slope-albedo relation, and the derived $p_v$is consistent with previous results determined frommid-infrared spectra and thermophysical modeling (0.122 ± 0.008; Hanuš et al. 2016). We could not find a fit to the period in our polarimetric data in the range from 0 up to 7.208 *hr*(e.g., twice the rotational period) and found significant differences between $P_r$during December 2017 (this work) and that of the 2016 (Ito et al. 2018). These results imply that Phaethon has a region with different properties for light scattering on the surface.

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312.06 Rounded and Subrounded Boulders on Asteroid 433 Eros

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Abstract

Impact cratering is well known to be one source of many surface features on small bodies. While impacts cause craters, they also produce ejecta which may remain on the surface in the form of various sized rootless positive relief features, or “boulders”, which are then potentially shaped by weathering. Different from Earth, weathering on airless bodies is thought to be caused by, meteorite and micrometeorite impacts, interactions with cosmic rays and solar-wind particles, and thermal cycling. Boulders on airless bodies are generally thought to be eroded by thermal cycling and micrometeorite impacts. On comets and asteroids with semi-major orbit axes close to 1 AU, all of these mechanisms may have significant effects on the rounding of boulders. On more distant asteroids, it is not clear that thermal cycling is a large enough effect to be a dominant cause of boulder rounding.

On Asteroid Eros there is a lack of boulders at larger scales and a low amount of rounded boulders overall. Other Near Earth Asteroids such as Itokawa have rounded and subrounded boulders. While most of the rounding on Itokawa is explained by its formation mechanism, there are still processes that can cause boulders to lose their sharpness over the lifetime of the body. These mechanisms should in theory affect Eros and lead to rounded boulders on its surface. An unanswered question is why Eros’s boulders have not been significantly rounded.

The terrestrial sedimentology community’s definition of roundness is a ratio of the average radius of curvature of the edges or corners to the radius of curvature of the maximum inscribed sphere. Marshall and Rizk 2015 defined rounding as a ratio between the weathered edge and the diameter of the boulder. By using the different rounding criteria such as these, we can compare the effectiveness of different methodologies at determining the true roundness of boulders on these small bodies, and characterize how round the boulders on Eros are. Finding the amount of rounding can also determine if there are sub-rounded boulders, which can mean that erosion of these boulders through some mechanism either occurred in the past or are slowly occurring over time.

312.07 The Mission Accessible Near Earth Object Survey (MANOS): Spectrophotometric Characterization of Small NEOs

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Abstract

The Mission Accessible Near Earth Object Survey (MANOS)
Spectrophotometric Characterization of Small NEOs

The Mission Accessible Near Earth Object Survey (MANOS) was designed to characterize sub-km, low delta-v, newly discovered near-Earth objects (NEOs). A subset of MANOS includes collecting color

photometry in the Sloan Digital Sky Survey (SDSS) filter set, which can be used to produce rough taxonomic assignments for our targets. Such information is critical for (1) understanding how the Solar System formed as NEOs are remnants from the epoch of planet formation, (2) the interpretation of meteorites as NEOs are their primary producers, and (3), resource extraction missions in space; which are soon to become reality with future manned missions expected to extend beyond low earth orbit.

MANOS utilizes 4-m (Lowell Observatory's Discovery Channel Telescope, SOAR) and 8-m (Gemini North and South) telescopes which enables traditional spectroscopy down to an apparent visual magnitude of 19.5 and 20.5 respectively. The NEOs observed by MANOS have an average absolute magnitude of H > 21, corresponding to objects with a mean diameter in the 100m range. These relatively small targets are most often discovered near peak brightness around V~20-21 mag, with follow up observations during subsequent apparitions being infeasible as targets return on average 100 times fainter (Galache et al. 2015). By performing coarse spectrophotometry, we are offered a unique opportunity to characterize particularly small NEOs, a currently under sampled portion of the NEO population.

Our comprehensive data set contains spectrophotometric results for over 100 targets. These data will be compared to the Sloan Digital Sky Survey Moving Object Catalog, which contains a similar size sample of km-scale NEOs. It is understood that while more than 80% of meteorites have origins traced to S-type asteroids (Harvey & Cassidy 1989), only 60% of the large NEOs are designated as such (Binzel et al. 2018). Our sample bridges the gap between meteorites and large NEOs, and thus can provide insight into this discrepancy.

This work is supported by the NASA NEOO program, grant number NNX17AH06G.

312.08 A Shape-based Thermophysical Model of (433) Eros

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Abstract
Characterizing the regolith of a broad sample of near-Earth asteroids (NEAs) is necessary to understand their ensemble properties and evolution. Our team combines high-fidelity shape models and near-IR spectroscopic data obtained over multiple viewing geometries and rotational phases with our thermophysical model to describe the global and local properties of NEA surfaces in more detail than possible with simpler approaches. Our technique, which samples both the thermal emission and reflectance simultaneously, allows for the thermal and scattering properties of different regions on the surface to be investigated, thus enabling a better understanding of the heterogeneity of an object's surface in addition to its global properties. We present results from our investigation of (433) Eros, a particularly interesting object given the availability of detailed information from the NEAR Shoemaker spacecraft mission. We obtained near-IR spectra of Eros using the NASA/IRTF SpeX instrument on 5-6 November 2009 and 6 December 2011. These data probed sub-Earth latitudes of –85 degrees and +75 degrees, giving us views of Charlois Regio on November 5, Eros's South rotation pole on November 6, and Psyche Crater on December 6. The shape, topographic, and albedo properties revealed by NEAR allow us to connect our thermal spectra to thermal properties of specific locations, as well as to constrain the global-average thermal properties. We will show results from our thermophysical modeling of Eros using our

code SHERMAN (Magri et al. 2018, Icarus 303, 203-219) and will discuss how Eros's thermal emission varies over the surface and what that implies for the heterogeneity of Eros's surface properties.

312.09 Radar Observations and Characterization of Binary Near-Earth Asteroid (35107) 1991 VH

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Abstract
Binary near-Earth Asteroid (35107) 1991 VH approached Earth in August 2008 at a distance of 0.045 au. We used this opportunity to obtain an extensive set of radar observations between Jul. 29 and Aug.12 with Arecibo (2380 MHz, 13 cm) and Goldstone (8560 MHz, 3.5 cm). The range-Doppler images have resolutions as fine as 15 m that spatially resolve both components in the system. Arecibo images show that the primary is roughly spheroidal with a visible range extent of 650 m. The images contain clear signatures of an equatorial ridge with longitudinal variations in its appearance. A concavity ~100 meters in extent is present along the ridge. A radar-bright linear feature that casts a radar shadow down-range is visible in some of the images, and occurs at mid- to high-latitudes.

A preliminary shape model fit to images of the primary reveals a top-shaped object with a volume equivalent diameter of roughly 1.2 km similar in shape to the (66391) 1999 KW4 primary (Ostro et al. 2006, Science 314, 1296). The mutual orbit determined from the radar data has an orbital period of ~32 hours, a semimajor axis of 3.26 km, an eccentricity of 0.05, and a system mass of 1.5e12 kg. These values are consistent with those estimated by Pravec et al. (2006, Icarus 181,63). The orbital fits yield a primary to secondary mass ratio of ~12 and a density of the primary of about 1500 kg/m^3. The range extents of the secondary echoes vary from less than 100 m to more than 200 m indicating that it is highly elongated. Echo bandwidths of the secondary also vary by a factor of two and are consistent with an elongated shape. Attempts to model the shape of the secondary using a single spin vector have so far yielded poor fits, hinting that the secondary might be spinning in a chaotic manner due to its elongation and eccentric mutual orbit, as suggested by numerical simulations in Naidu & Margot (2015, AJ 149, 80).

312.10 Constraining Ordinary Chondrite Composition via Near-Infrared Spectroscopy

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Abstract
Near-Infrared spectroscopy is a powerful tool for remotely characterizing surface composition of asteroids and identifying meteorite analogs based on their composition. To accurately determine the mineral compositions and abundances of the observed asteroids the relationship between the telescopic spectra and laboratory spectral calibrations must be well understood. Ordinary chondrites are the most abundant meteorites that fall on the Earth. We compare four popular methods that are used for constraining the surface composition of S-type asteroids to determine which process best resembles the

laboratory-measured values. We also analyze the effect of the polynomial order, used to calculate band parameters, on the precision of olivine and pyroxene chemistry and abundance from laboratory spectra of ordinary chondrite meteorites. Our work is important because S-type asteroids dominate both the main belt and near-Earth asteroid populations and hence understanding the patterns in the interpretation of their spectra is vital. This work was funded by NASA NEOO Grant NNX17AJ19G (PI: Reddy).

312.11 A WISE Radiometric Diameter of Icarus

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Abstract
1566 Icarus [1949 MA] is a Near Earth Asteroid on a highly elliptical orbit. Recently there have been a number of inconsistent determinations of its size, including 1.3-1.54 km from 3-band cryo WISE data, 0.99-1.07 km from 2-band post-cryo WISE data, and 1.18-1.70 km from radar data. In this paper we report on a combined analysis of 5 epochs of WISE data using a tri-axial ellipsoid thermophysical model based on Wright (2007). The 5 epochs include the two previous epochs, plus a single detection during the close pass on 18 Jun 2015, and 2 epochs where image stacking was necessary to detect a signal: one during full cryo operation and one during 2 band post-cryo operation. This modeling gives a volume equivalent diameter of 0.95-1.02 km, a small axis ratio b/a of 0.93-0.98, and a fairly well determined rotation pole at ecliptic longitude=110 and latitude=-74 degrees, and a thermal inertia of 66-91 sec^{1/2}W/m^2/K. This IR radiometric result agrees fairly well with the 2015 radar observations with regard to the axis ratio and rotation pole, but is two sigma smaller in diameter. The radar diameter would more than double the infrared flux, which is unlikely. However, the radar model found a very large specularity which leads to a smaller echo extent, and a smaller diameter along with a smaller specularity might be an acceptable fit to the radar data.

312.12 SHERMAN-Based Thermophysical Model of (101955) Bennu

Jenna Crowell[1], Ellen Howell[1], Joshua Emery[2], David Trilling[4], Carl Hergenrother[1], Joseph Hora[3], Lucy F. Lim[6], Michael Mueller[5], Marco Delbo[5], Alan Harris[7], Antonella Barucci[8], Dante S. Lauretta[1]
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Abstract
We apply our thermophysical model to derive regolith properties of (101955) Bennu constrained by Spitzer observations taken in 2007 (Emery et al. 2014) and 2012, before the arrival of the OSIRIS-REx spacecraft. From these observations, we will create a thermal curve and compare with photometric lightcurves, investigating physical characteristics. Our thermophysical model is described in detail by Magri et al. (2018) and treats surface roughness using a fractional coverage of hemispherical craters on each facet. In some cases we find that the thermal inertia in our models is lower than that calculated by other thermal models. This may be due to capturing inhomogeneity in our observations, or to observations at particular observing geometries (Crowell et al., 2017). (101955) Bennu, target of the OSIRIS-REx mission, will provide us with “ground-truth”, allowing us to compare the results of our thermal model

with the spatially resolved spacecraft measurements. This work will also allow us to interpret nonphysical parameters like crater fraction and relate them to the highly resolved measurements of the surface, soon to be available. References: Emery et al. 2014, Icarus 234, 17-35.; Magri et al. 2018, Icarus 303, 203-219; Crowell et al. 2017 ACM.

312.13 Robotic Spectroscopy for Moving Objects:
Making the bots do all the work with the LCO NEO Follow-up Network

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Abstract
Las Cumbres Observatory (LCO) is a network of automatically scheduled robotic telescopes that has been performing observations of Solar System objects since the network became operational in 2014. Over the last few years the LCO NEO follow-up program has been very productive in providing both astrometry and photometry for newly discovered NEO candidates as well as characterization of radar targets and other objects of interest. We have now begun extending these characterization capabilities to spectroscopic observations using the FLOYDS spectrograph on the two LCO 2m telescopes on Haleakala (FTN) and in Australia (FTS). Automated scheduling, acquisition, and analysis of spectra of moving objects on a robotic telescope network come with certain hurdles and difficulties that need to be overcome. Here we will discuss some of these difficulties and limitations, as well as demonstrate the first successful results of this newly established capability.

312.14 **Landslides on Didymos Alpha caused by the Ejecta of the DART Mission**

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Abstract
The NASA Double Asteroid Redirection Test (DART) mission will be launched in 2020. Its target is the binary asteroid Didymos and the spacecraft will have a close encounter with this asteroid in late 2022. The mission will test the possibility of changing the trajectory of a small body with a kinetic impactor. For this, the S/C will launch a 300 kg artificial projectile towards the surface of Didymos Beta at hypervelocity and measure the resulting change in its orbit about the primary.

Given the available observational data, it is believed that both members of the binary system are granular in nature. This would imply that the planned impact could produce a sizeable ejecta field. The ejecta particles could have 3 possible fates: 1. escape the system, 2. fall back to the secondary or, 3. impact the primary. The question we address is whether or not the particles in this last group could cause landslides on the surface of the primary.

To study this scenario, we have performed a number of soft-sphere granular mechanics simulations. In our simulations we model Didymos as a perfectly spherical body and, due to its symmetry, we consider only a semi-lune that runs from the north pole down to the equator. This sphere has a diameter of 775 m and a rotation period of 2.26h just like Didymos. Due to the large size of the body, we do not simulate the entire surface, but we place granular test beds that are subjected to a gravitational field, centrifugal and Coriollis forces corresponding to different latitudes on the surface. The falling projectiles (10 cm in size) are assumed to impact the primary perpendicular to the axis of rotation, with impact speeds between 1-5 m/s plus a tangential component, which varies with the latitude of the impact, due to the rotation of the

primary.

Our simulations show that the calculated cohesive strength of Didymos of 25 Pa prevents the falling particles from penetrating the surface more than a few centimeters and prevent surface failure via landsliding. The impacts do cause an ejecta field that remains in orbit above the surface and which could eventually escape. Variations in the cohesive strength of the aggregates are expected to change this behavior and will be presented at the conference.

312.15 The Absolute Magnitude Distribution of Near Earth Objects (NEOs)

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Abstract
The distribution of asteroid absolute magnitudes (*H*) for the near earth objects (NEOs) observable near opposition -- i.e. Armors, Apollos, and Atens (A^3) -- is derived from the set of **ALL** currently known NEOs. The result is based only on common sense assumptions of uniformly random distributions and that the orbital phase space and H-magnitude distribution of known NEOs is representative of the total population. There is no population or other modeling and no assumption on albedo except in interpreting the result as a size-frequency distribution (SFD). The analysis is based on the 18355 A^3 NEOs cataloged by the MPC as of June 2018. The observations from 9 of the top programs, in terms of distinct NEOs observed, and the smaller but deeper DECam NEO Survey are used comprising 74464 measurements of 13430 NEOs observed within 30° of opposition. The only parameter in the analysis is an estimate of the detection magnitude limits for each program.

A single power-law slope for the cumulative distribution, **log(N)=0.53*H***, for $H < 27$ is found with no evidence for additional structure. A turn-over fainter than 27th magnitude may occur, but the population of known NEOs is dropping off rapidly because they are difficult to detect and so is likely to be a completeness effect. Connecting to the nearly complete census of the brightest/biggest NEOs (diameter > ~2Km) provides a normalization that estimates ~10^8 A^3 NEOs with $H <$ ~27 corresponding to NEOs greater than ~10m in diameter for reasonable typical albedos.

312.16 **Spin parameters and shape model of Mars-crossing asteroid (2078) Nanking**

Dong-Heun Kim[1, 2], Jung-Yong Choi[3], Myung-Jin Kim[2], Hee-Jae Lee[1, 2], Hong-Kyu Moon[2], Young-Jun Choi[2, 4], Yonggi Kim[1]
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Abstract
We present the analysis of the spin parameters and shape model of the Mars-crossing asteroid (2078) Nanking. Mars-crossing asteroids (MCAs, $1.3 < q < 1.66$ AU) are asteroidal objects that cross the orbit of Mars and regarded as one of the primary sources of near-Earth asteroids due to the unstable nature of their orbits. The lightcurve of (2078) Nanking was first reported by Mohamed et al. in 1994 (Planetary and Space Science). Subsequently Warner et al. published new observational data in 2015 (Minor Planet Bulletin). We conducted Cousins_R-band time-series photometry of this asteroid for 2 nights from

November 26, 2014 to January 17, 2015 at the Sobaeksan Optical Astronomy Observatory (SOAO) and for 25 nights from March 2016 to April 2016 using the Korea Microlensing Telescope Network (KMTNet) to reconstruct its physical model with our dense photometric datasets. Using the lightcurve inversion method (Kaasalainen and Torppa 2001; Kaasalainen et al. 2001), we determine the pole orientation and shape model of this object based on our lightcurves with the archival data obtained from the literatures. We derived rotational period of 6.461 h and the preliminary ecliptic longitude and latitude of its pole (8, -52) which indicates a retrograde rotation of the body. From the apparent W UMa-shaped lightcurve and its location in the rotation frequency-amplitude plot of Sheppard and Jewitt (2004), we suspect the contact binary nature of the body (Choi 2016).

312.17 Near-Surfaces Bulk Densities of Near-Earth Asteroids using Radar Observations

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Abstract
Meter-scale particles can appear in radar image as brightness speckles, ubiquitously distributed on the surface of asteroids in the inner Solar System. They are indicative of the presence of centimeter-to-decimeter scale particles (“cobble”). Their spatial and size distribution give us indications of the geological evolution and the outcome of the collision event history. The abundance of cobbles can be suggestive of whether the asteroid is monolithic or a rubble pile. We use radar observations by the Arecibo Observatory Planetary Radar Program. Arecibo radar system transmits a powerful circularly polarized signal using a frequency of 2380 MHz (wavelength of 12.6 cm) and receives the echo in the opposite circular (OC) polarization and same circular (SC) polarization. The quasi-specular reflection from a layer of fine-grained regolith and diffuse scattering by and between the wavelength-scale particles compose the OC polarized part of the echo. The intensity and the polarization are suggestive of the physical properties of the target’s near-surface. Wavelength-scale particle distribution and near-surface densities of Near-Earth Asteroids (NEAs) are derived from the radar albedos in the SC and OC polarization states. We analyze the radar albedos in order to obtain wavelength-scale particles shape and size distribution as well as the effective near-surface bulk density of the underlying layer of sub-centimeter-scale particles. Here we investigate the physical properties of NEAs, specifically analyzing 1998 WT24, 1998 CS1, 1950 DA, and 2006 AM4 using state-of-the-art methodology of interpreting radar scattering. We derive the Fresnel reflection coefficient using a linear least squares fit to separate the diffuse-scattering part from the quasi-specular part of OC radar albedo, to calculate the electric permittivity. We use laboratory measurements of rocky lunar regolith and our measurements of the electric permittivity, to calculate the near-surface bulk densities. We obtain bulk densities of 2.6 ± 0.54 g/cm^3, 2.54 ± 0.2 g/cm^3, 3.0 ± 1.7 g/cm^3, and 2.86 ± 0.1 g/cm^3 for 1998WT24, 1998 CS1, 1950 DA, and 2006 AM4, respectively.

312.18 Spectral clustering tools applied to Ceres in preparation for the NASA OSIRIS-REx images of (101955)

Juan Rizos[1, 2], Julia de Leon[1, 2], Javier Licandro[1, 2], Humberto Campins[3]
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Abstract
NASA's OSIRIS-REx mission is currently on its way to the asteroid (101955) Bennu. Bennu is a

primitive asteroid, characterized by a dark surface composed mainly of carbon compounds, organic, and silicates altered by the presence of water. In addition, due to its proximity to the Earth, is classified as a potentially dangerous asteroid (PHA). Among several instruments, the mission OSIRIS-REx has OCAMS, a set of three cameras (PolyCam, MapCam and SamCam) with different configurations to capture images in the visible and map the entire surface. Specifically, MapCam has a set of four filters centered at 0.44, 0.55, 0.70 and 0.85 microns respectively, with which it will be possible make color maps. The last three filters are particularly well designed for detect the absorption band at 0.7 microns produced by the silicates altered by the presence of liquid water (phyllosilicates). In addition, color maps will make it possible to detect the existence of hydrated minerals on the surface of Bennu more quickly and with much better spatial resolution than the spectra provided by the OVIRS instrument (infrared spectrograph), also aboard the ship. This communication presents the results obtained from the analysis of the images of the asteroid (1) Ceres taken by the Framing Camera of NASA's Dawn mission. This camera has a set of 7 filters in the visible range, so the techniques used for the spectral clustering analysis of the (1) Ceres images will serve as preparation for the analysis of the Bennu images obtained with OCAMS.

Wednesday, October 24, 2018
04:10 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

313 Mars Posters
Chair(s): Edgard G. Rivera-Valentin

313.01 Morlet wavelet analysis of planetary atmospheres.
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physics, gustavus adolphus college, Saint Peter, Minnesota, United States

Abstract
This study investigated the use of Morlet wavelet analysis in the detection of gravity wave structure in the atmosphere of terrestrial bodies, primarily Mars, Venus, and Titan. Atmospheric profiles from data collected by planetary probes and satellites were processed to generate 2D images of wave structure in each analyzed atmosphere. The analysis shows a correlation between vertical wave structure at altitudes and wavelengths to those previously found using other methods such as comparing temperature gradient profiles to the dry adiabatic lapse rate. This suggests the use of Morlet wavelet analysis as a viable alternative to previously used methods for detection of small-scale variability.

313.02 Dynamical Explanation for a Warm Early Mars
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Abstract
We offer a new explanation for how an early Mars was warmer than it is today under a faint Sun. The idea is that Mars was formed nearer the Sun and that it was captured by Venus ~4.5 Ga. It would have remained in orbit around Venus for tidal-evolution timescales lasting 0.5-0.7 Gyr. Under certain conditions, Mars successfully escapes Venus and returns to a heliocentric orbit. Our orbital simulations then show that Mars wanders chaotically through the inner Solar system before ending up near its present orbit, approximately 13% of the time. Here I will discuss both the challenges and benefits of a possible Mars migration.

313.03 Nitrogen Fixation on Early Mars
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Abstract
The nitrogen cycle of early Mars is one of the many outstanding mysteries surrounding the Red Planet's past, especially with regards to its habitability and potential for an emergence of life during the Pre-Noachian, Noachian, and Hesperian epochs (roughly 4.5–3.3 Ga). Recently, the Mars Science Laboratory discovered nitrate in sediments at Gale Crater: of particular interest is the 70–260 and 330–1,100 ppm

nitrate in John Klein and Cumberland mudstone deposits, respectively, which sample the Noachian-aged sediments of Yellowknife Bay (Stern et al., 2015). These deposits are likely due to nitrogen fixation in Mars's early CO_2–N_2 atmosphere.

Here, we seek the conditions on early Mars that could produce the measured concentrations of nitrate in the Noachian rock record. To do this, we evaluate the nitrogen fixation rates and pathways on early Mars via a suite of atmospheric modeling, primarily using the Caltech–JPL chemistry–transport model, Kinetics. The present study builds upon the work of Wong et al. (2017), which evaluated the lightning-induced photochemical production of nitrogen oxides (NOx) on early Earth. NOx production depends on the relative concentrations of CO_2 and N_2 (Nna Mvondo et al., 2001), the amount of water vapor in the atmosphere, the frequency of high-energy events via lightning or coronal mass ejections (Airapetian et al., 2016), and the temperature profile of the atmosphere. The composition of the atmosphere is our central free parameter. For any given atmospheric composition, we can solve for the temperature profile by coupling Kinetics to a radiative–convective equilibrium model, and we will be able to estimate the lightning flash rate via GCM simulations. Thus, we will be able to back out a range of atmospheric states that can explain the fixed nitrogen in Mars's rock record.

313.04 The Search for Organic Molecules in Mars' Atmosphere

Robert Novak[1], Willow Held-Pistone[1], Michael Mumma[2], Geronimo Villanueva[2], Sara Faggi[2]
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Abstract
For several years, we have been searching for organic molecules (such as CH_4, CH_3OH, H_2CO, C_2H_6, C_2H_2, C_2H_4) in the atmosphere of Mars [1], [2]. We have identified methane [3] and have obtained upper limits for the other molecules listed. We took data using the L3 setting on iSHELL (NASA-IRTF) on January 29 and 31, 2018 (L_s~122°). iSHELL is a cross-dispersed echelle-grating spectrograph (1.1 - 5.3 μm) with a resolving power of ~ 70,000. The L3 setting consists of thirteen orders ranging from 3.20 – 3.48 microns. This spectral range includes absorption bands of the molecules listed before along with bands of water. Data were continuously taken with the slit positioned N/S on Mars along the meridian (~14.3 Local Time) as the planet rotated by the slit. The longitude range covered was from 156°W to 256°W. Sufficient flats and darks were taken at the same spectral setting to increase the signal to noise level. Approximate thirty minutes of data were stacked into one file. Spectral extracts were then taken at 0.6 arc-sec intervals in the latitudinal direction. The Mars atmospheric spectrum was isolated from the solar and the Earth atmospheric spectra. Atmospheric models generated for Mars were created to match the observed spectrum. For some molecular species, such as CH_4 and H_2O, column densities were obtained. For others, upper limits were measured. Results of these measurements will be presented and compared to results from previous observations.

This work was partially funded by a grant from NASA's Mars Fundamental Research Program (11-MFRP11-0066). The NASA Astrobiology Institute supported this work through funding awarded to the Goddard Center for Astrobiology under proposal 13-13NAI7-0032. We thank the administration and staff of the NASA-IRTF for awarding observing time and for coordinating our observations. [1] Mumma et al., DPS 2015, [2] Villanueva et al., Icarus 2013, [3] Mumma et al., Science 2009.

313.05 Sensible Ozone on Mars Based on 2-D Maps of $O_2(a\ ^1\Delta_g)$ Emission for L_s=122° Using iSHELL (NASA-IRTF)

Willow Held-Pistone[1], Mathias Zurbiggen[1], Robert Novak[1], Michael Mumma[2], Geronimo Villanueva[2], Sara Faggi[2]
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Abstract
We report 2-D maps of the $O_2(a\ ^1\Delta_g)$ emission rate (a tracer for high-altitude ozone) taken during mid-Northern Summer on Mars (L_s=122°, 30 Jan 2018) using iSHELL, a cross-dispersed echelle-grating spectrograph (1.1 - 5.3 µm) with a resolving power of ~ 70,000, at the NASA-IRTF. The J2 setting encompasses 29 orders (1.2 to 1.3 µm). The (0-0) band of the $O_2(a\ ^1\Delta_g)$ emission is measured in three of these orders. The entrance slit was positioned N-S on Mars and stepped E-W at 1.0 arc-sec increments. Spectral extracts were taken at 0.6 arc-sec intervals. A model consisting of the solar continuum with Fraunhofer lines, the two-way transmission through Mars' atmosphere, and the one-way transmission through Earth's atmosphere was used to isolate and analyze the emission of individual a-X lines from Mars. The line-of-sight emission intensities were converted to vertical emission rates and $O_2(a\ ^1\Delta_g)$ column densities after geometric correction. 2-D longitude-latitude maps of $O_2(a\ ^1\Delta_g)$ were constructed from the stepped measurements. The map of sensible O_3 column implied by these data will be compared with maps of total O_3 in Mars standard atmosphere models. Our iSHELL 2-D map shows $O_2(a^1\Delta_g)$ emissions concentrated in the Southern region and reduced detectible emissions in the tropical and Northern latitudes. These 2-D maps will be compared to previously reported CSHELL maps taken during early (L_s=102°) and late northern summer (L_s=155°). This work was partially funded by a grant from NASA's Mars Fundamental Research Program (11-FRP11-0066). The NASA Astrobiology Institute supported this work through funding awarded to the Goddard Center for Astrobiology under proposal 13-13NAI7-0032. WHP was support by a summer grant from the Clare Booth Luce Foundation. We thank the administration and staff of the NASA-IRTF for awarding observing time and for coordinating our observations.

313.06 Effects of a Solar Flare on the Martian Hot O Corona and Photochemical Escape

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Abstract
An X8.2-class solar flare occurred on September, 10th 2017, peaking at approximately 16:12 UT. In this study, we examined for the first time the flare-induced effects on the Martian hot O corona and resulting photochemical loss of O. We performed integrated one-way couplings of three numerical models, AMPS, M-GITM, and MF-MHD coupled with a custom spectral irradiance model. Our modeling study is designed to investigate the effects of the flare only and better capture the important atmospheric variability during the flare. We conducted simulations for four model cases, which are the time snapshots representing the flare phases. The rapid ionospheric response to the increase in the soft X-ray flux

(~800%) facilitates more hot O production at altitudes below the main ionospheric peak, but almost all of these atoms are thermalized before escape to space. In response to the simultaneous increase in the EUV flux (~170%), the overall upper ionospheric and thermospheric densities are enhanced, and the peak thermospheric responses are found about 1.5 hours later. The photochemical escape rate increases by ~20% with the abrupt increases in the soft X-ray and EUV fluxes but decreases rapidly by ~13% about 2.5 hour later before recovering the pre-flare level. Since the escaping hot O atoms are mostly produced at high altitudes where ionization by the EUV flux is the greatest, the main contributor to the 20% increase in escape rate is the enhancement in the EUV flux.

313.07 An Important Dust Storm Track in the Southern Hemisphere of Mars

Joseph Battalio, Huiqun Wang
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Abstract
Eight Mars years of Mars Daily Global Maps (MDGMs) are used to identify dust storms and dust storm sequences. The data are analyzed within the context of the Martian dust cycle and atmospheric circulation. Results show that the Aonia-Solis-Valles Marineris (ASV) region (0-115W, 0-46S) is a unique, yearly dust storm track that links high latitude with low latitude dust storm activity in the southern hemisphere. It is active during Ls=0-180 with a solstitial pause between Ls=90 and Ls=120. It is most active during Ls=120-180 when larger and more vigorous dust storms form dust storm sequences. These sequences contribute to the annual dust cycle and correspond to the most significant dust activity outside the conventional dust storm season. In some cases, the ASV sequences can influence the large-scale thermal structure of the atmosphere. During the peak season, the ASV track is strongly influenced by a combination of several circulation components. The observed ASV sequences exhibit distinct clusters. The characteristics and effects of the ASV dust activity will be presented.

313.08 Estimating the pressure ceiling of the June 2018 Mars global dust storm

Timothy A. Livengood[1, 3], John R. Kolasinski[2], Tilak Hewagama[1, 2], Theodor Kostiuk[2]
[1]Astronomy, University of Maryland, College Park, Maryland, United States, [2]NASA GSFC, Greenbelt, Maryland, United States, [3]NASA GSFC/CRESST, Greenbelt, Maryland, United States

Abstract
We observed the spectrum of a single rovibratinal transition of carbon dioxide in Mars atmosphere within the 10.6 micron lasing band, using the Goddard Space Flight Center (GSFC) Heterodyne Instrument for Planetary Winds and Composition (HIPWAC) from the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii. Observations were acquired on June 9-13, 2018. The measurements were acquired targeting 42°, 37°, or 47° south latitude on the region of Hellas Planitia at several local times from late morning through nearly dusk. The measured spectrum differed significantly from previous Mars apparitions, in that a hot band transition of normal isotope CO2 and a transition of O18 CO2 that primarily form near the surface did not appear due to the reduced atmospheric path length and opacity above the areographic surface. The major absorption feature at the normal isotope transition of CO2 was greatly reduced in breadth and depth, indicating that the dust cloud became optically thick at high altitude at a relatively warm temperature. We will infer the altitude at which dust rendered the atmosphere optically thick, and explore effects on the thermal profile.

313.09 Martian atmospheric dust-particle-size distributions from MER Navcam observations

Jason Soderblom[1], Michael D. Smith[2]
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Abstract

Dust suspended in a planetary atmosphere affects the atmosphere's dynamics by absorbing sunlight that is in turn deposited as energy into the atmosphere (Gierasch and Goody, 1972, J. Atmos. Sci.). Critical to modeling this effect is accurate characterizing of efficiency by which dust absorbs energy, which depends primarily on its size and single-scattering albedo. Herein we describe work to use MER Navcam observations (described below), to constrain the size of dust suspended in the Martian atmosphere.

A common technique to interrogate dust size in an atmosphere is to study the light-scattering properties of the dust, specifically the forward-scattering (i.e., low scattering angles) portion of the single-scattering phase function, which is primarily influences by the size of the particles and is less sensitive to particle shape, albedo, or density (optical depth) (Hansen and Travis, 1974, Space Sci. Rev.). Several studies have done just this, using near-sun observations of the sky acquired from the martian surface by the Viking Landers, Mars Pathfinder, and MER Pancams.

In this work, we utilize MER Navcam observations. These data are unique in that these cameras suffer from very little internal instrumental scattered light during near-Sun imaging (Soderblom et al., 2008; JGR). This allows us to characterize the scattering function down to lower scattering angels (<5°) than is possible with other data. This is significant in that the forward-scattering peak the atmospheric phase function is the most sensitive to particle size. We discuss methods to use Pancam observations to provide better constraint on the absolute calibration of the Navcam data (which were never intended to be used as scientific data). We discuss constrains offered by these data over a wide optical depths and times of year.

313.10 Present-day frost-driven geomorphic changes on martian northern dunes

Serina Diniega[1], Jacob Widmer[2], Joseph Plumitallo[3], Fan Wu[4], Candice Hansen[5]
[1]Jet Propulsion Laboratory, Pasadena, California, United States, [2]University of Maryland, College Park, Maryland, United States, [3]Fordham University, Bronx, New York, United States, [4]UC Santa Barbara, Santa Barbara, California, United States, [5]Planetary Science Institute, St. George, Utah, United States

Abstract

Recent observations have shown that many small-scale geomorphological changes on martian sandy slopes occur annually. In sites where the timing of activity is constrained to a < 1 Mars year, feature formation appears tied to when frost is accumulating or sublimating. This, together with other data such as location of these features within areas covered seasonally by frost, strongly suggests that *martian CO_2 frost and ice, especially when interacting with a granular surface, is an effective geomorphic agent* and should be considered, with wind and impacts, when interpreting modern martian geomorphology and climate records. Additionally, some estimates of present-day rates of activity have led to the suggestion that CO_2-driven processes may account for many features that have previously been hypothesized to be 'fluvial' features.

This work will summarize current results and ongoing studies of martian landforms found on dunes in the northern hemisphere (i.e., dune alcoves and 'troughs') observed to be active over seasonal-to-decadal-timescales and hypothesized to have activity connected to the accumulation and/or sublimation of seasonal frost. *Alcove-apron* features have been observed to form annually in north polar and mid-latitude

dune fields, potentially during early autumn. *'Troughs'* are also found to form annually, extending from the crests of the north polar dunes. It is not yet clear if these features are more similar to *linear gullies* which form due to sliding/rolling of a CO_2 ice block downslope or if they are more similar to *dune furrows* extending from the margins of north polar dunes or *araneiforms* seen in the southern hemisphere, both of which are hypothesized to form due to gas flow beneath a translucent CO_2 ice slab.

In our study, we are monitoring and measuring dune alcove and furrow activity within polar and mid-latitude dunes. Comparing these results to those studies to active landforms in the southern hemisphere, we seek to identify latitude-variations in the timing/magnitude of frost formation and use these to constrain the relevant frost environment for causing the observed geomorphic changes.

313.11 Martian Pancake Ejecta Craters: Erosional Landforms or Primary Morphology?

Nadine G. Barlow
Physics & Astronomy, Northern Arizona University, Flagstaff, Arizona, United States

Abstract
Viking Orbiter analysis revealed the presence of pancake (Pn) craters whose layered ejecta deposits terminate in a convex shape with no obvious distal rampart. Analysis of the distribution and general morphology of Pn craters led Costard (1989) to propose that the Pn morphology was simply the inner ejecta layer of double layer ejecta (DLE) craters where the outer layer was destroyed or below Viking image resolutions. Barlow (2015) used THEMIS daytime IR images and MOLA topography to show that the morphologic and morphometric characteristics of Pn craters were similar to the inner DLE ejecta deposit. That study also found examples of highly eroded outer ejecta layers around craters classified as Pn in lower resolution Viking images. This seemed to confirm that Pn craters are eroded DLE craters. Recently the Mars crater community has realized that there are two distinct types of DLE craters: the high-latitude ("Type 1") craters and the lower-latitude ("Type 2") versions. The inner ejecta layer of Type 1 DLE craters is characterized by low-sinuosity, greater thickness, a topographic moat just outside the crater rim, a broad terminal rampart, and radial grooves which are distinct in shape and width from grooves found on lower-latitude crater ejecta. Type 2 DLE craters have highly sinuous inner and outer ejecta layers, no moat, similar thicknesses of the two layers, and narrow prominent ramparts terminating both layers. Single layer ejecta (SLE) and multiple layer ejecta (MLE) craters have traditionally been reported at lower latitudes and with the Type 2 characteristics. However, we have identified examples of high-latitude MLE craters which are morphologically and morphometrically similar to Type 1 DLE craters. Therefore there are two types of both DLE and MLE craters on Mars. Pn craters display many of the same distinctive morphologic and morphometric characteristics of Type 1 DLE and MLE craters except for the single ejecta layer. We have found some very fresh Pn craters with no evidence of an eroded outer ejecta layer in CTX images. Therefore at least some Pn craters are primary morphologies and are Type 1 SLE craters.

313.12 Exospheric Density Waves Observed by MAVEN

Hayley Williamson[1], Ludivine Leclercq[1], Robert johnson[1], Meredith Elrod[2]
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Abstract
Multiple recent studies have analyzed density perturbations found in the MAVEN Neutral Gas and Ion

Mass Spectrometer data, assumed to be propagating gravity waves (Yigit et al. 2015, England et al. 2015, Terada et al. 2017). As gravity waves are understood to be ubiquitous in planetary atmospheres, their detection in the upper thermosphere is unsurprising. However, we examine 252 MAVEN passes through the Martian atmosphere where NGIMS data show wave-like density structures with amplitudes larger than 40% of the background density present above the nominal exobase, where the atmosphere transitions from collisional to ballistic. In this region of a planet's atmosphere the continuum physics typically used to describe gravity waves is not applicable. Here we present the profiles of these wave-like structures as a function of atmospheric column density rather than altitude, as this removes the dependence of altitude-density profiles on composition, scale height, and local solar time. This allows us to construct an average wave amplitude profile as a function of total atomic column density, which shows a sharp peak above the nominal exobase as defined by the O+CO_2 cross section and then a decaying amplitude with decreasing column density. As continuum models break down in this region of the atmosphere, we use molecular kinetic simulations (Leclercq et al. 2018) to describe the propagation of such features to these altitudes, as well as the causes of their eventual dissipation, as the methods of dissipation differ from the wave saturation that occurs at higher densities (e.g. D.C. Fritts 1984). Such density structures are of interest as the wave-like activity can affect the local heating rate (Charney and Drazin 1961, Hunsucker 1982) and possibly the escape rate (Walterscheid et al. 2013).

313.13 6 Years on Mars: The Sample Analysis at Mars (SAM) Investigation by the Numbers

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Abstract
The Sample Analysis at Mars (SAM) investigation, onboard the Curiosity rover, has been studying Gale Crater, Mars since landing on August 5th, 2012. In our six years of exploring the Red Planet, we have discovered many surprises, performed many 'firsts', and helped advance the understanding of Mars' habitability, both past and present. There have been numerous publications, talks, and presentations which cover the scientific discoveries SAM has accomplished; here we focus on some of the numbers which have been accumulated over 6 years of operations on Mars, and how they may serve as guidelines for future missions to improve on.

SAM has completed 493 power cycles in 2160 Sols, ranging in complexity from simple electrical checkouts to in situ wet chemistry on a dune sample. Each SAM experiment involves various subsystems in the instrument suite, and significant effort is made during the design of each experiment to minimize the use of consumable resources, while maximizing the science return. A typical SAM experiment is roughly 6 hours, during which SAMs 52 microvalves are opened and closed dozens of times, the two turbomolecular pumps are run at 100k RPM for several hours, and many of SAMs 60 heaters are used to keep the instrument isothermal. This presentation looks at the timeline of the past 6 years, and how SAMs hardware has been used on the Red Planet.

Wednesday, October 24, 2018
04:10 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

314 Pluto System Posters
Chair(s): Carly Howett, Orkan Umurhan

314.02 The highest spatial resolution compositional maps of Pluto and what they tell us about surface composition and geology
Alissa M. Earle[1], Will Grundy[2], Carly Howett[3], Catherine Olkin[3], Alex Parker[3], Francesca Scipioni[4], Richard P. Binzel[1], Ross A. Beyer[4], Jason Cook[5], Dale Cruikshank[4], Cristina M. Dalle Ore[4], Kimberly Ennico[4], Briley Lewis[6], Silvia Protopapa[3], Paul M. Schenk[7], Bernard Schmitt[8], S. Alan Stern[3], Harold Weaver[9], Leslie A. Young[3]
[1]EAPS, Massachusetts Institute of Technology, Dover, New Hampshire, United States, [2]Lowell Observatory, Flagstaff, Arizona, United States, [3]SwRI, Boulder, Colorado, United States, [4]NASA Ames, Moffett, California, United States, [5]Pinhead, Telluride, Colorado, United States, [6]Columbia, New York, New York, United States, [7]Lunar and Planetary Institute, Houstan, Texas, United States, [8]University Generoble Alpes, Grenoble, Grenoble, France, [9]JHU-APL, Laurel, Maryland, United States

Abstract
NASA's New Horizons spacecraft has given us an unprecedented, detailed look at the Pluto system. New Horizons' Ralph/MVIC (Multispectral Visible Imaging Camera) is composed of 7 independent CCD arrays on a single substrate, including a red channel (540-700 nm), near-infrared channel (780-975 nm), and a methane channel (860-910 nm). The ratios of these channels were compared to produce high-resolution methane equivalent width (E.W.) (based on the 890 nm band) and spectral slope maps of Pluto's surface (originally published in Earle et al., 2018. DOI: 10.1016/j.icarus.2018.06.005). These maps provide a means for quantitatively studying the relationships between methane distribution, surface redness, latitude, elevation, and geology. Earle et al. 2018 explored the global trends between latitude, elevation, and surface composition, finding that MVIC E.W. showed dependence on both latitude and elevation (with the broadest MVIC E.W.s appearing near the equator and at altitudes greater than 2 km), while redness showed some relationships with latitude but very little dependence on elevation. It was also noted that in addition to the global trends, there appeared to be complex, smaller-scale relationships between surface composition and geologic features, like craters and mountains. In this talk we will build on the work of Earle et al. 2018 by taking a deeper, quantitative look at the localized trends that occur between surface composition and geologic features on Pluto's surface. We will also look at how topography can affect the local insolation over various timescales leading up to the New Horizons observations of Pluto and consider how this influences the volatile distribution and could potentially be used to constrain the timescales over which volatile transport occurs.

314.03 Pluto's atmosphere with ALMA: disk-resolved observations of CO and HCN, and first detection of HNC
Emmanuel Lellouch[1], Mark Gurwell[2], Raphael Moreno[1], Panayotis Lavvas[5], Bryan Butler[6], Darrell Strobel[3], Thierry Fouchet[1], Arielle Moullet[4], Dominique Bockelée-morvan[1], Nicolas Biver[1]
[1]LESIA, Observatoire de Paris, Meudon, France, [2]Smithsonian Astrophysical Observatory, Center for Astrophysics, Boston, Massachusetts, United States, [3]The Johns Hopkins University, Baltimore, Maryland, United States, [4]NASA/Ames, Palo Alto, California, United States, [5]Université de Champagne-Ardenne, Reims, France, [6]NRAO, Socorro, New Mexico, United States

Abstract
Following our detection of HCN(4-3) and CO(3-2) in 2015 (Lellouch et al. 2017), we pursued our exploration of Pluto's atmosphere with ALMA. On July 30, 2017, we obtained maps of these CO and HCN emissions, with a 96 x 54 mas beam providing some spatial resolution of the Pluto disk in the North-South direction. On April 27, 2017, we explored portions of the 256.1-259.1 and 271.9-273.8 GHz spectrum, searching for HNC, CH3CN, and H13CN in disk-averaged observations. The highlight of this search was the detection of the HNC(3-2) line at 271.98 GHz, which appears as a narrow emission with a ~15 mJy contrast. This first identification of HNC in Pluto's atmosphere reinforces the similarity to Titan's upper atmosphere, where HNC has been also observed (Moreno et al. 2011). Data interpretation in terms of (i) the spatial distribution of CO and HCN emissions (ii) the HNC abundance/vertical distribution, including comparison with photochemical models, will be presented.

Wednesday, October 24, 2018
04:10 PM-06:05 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

315 Wednesday Afternoon Break with iPoster and Poster Viewing

315.01 Discovering Asteroids
Alberto Q. Vodniza, Mauricio Portilla, Daniel Ruiz, Andres Martinez, Mario Pantoja
Physics, University of Narino Observatory, Pasto, Nariño, Colombia

Abstract
We have recently participated in the Project "INTERNATIONAL ASTRONOMICAL SEARCH COLABORATION-IASC" [1] in the group "ALL COLOMBIA ASTEROID SEARCH CAMPAIGN" from April 8th to May 6th 2018. We analyzed the photographies provided by IASC through Astrometrica software [2]. The images were captured by the observers N. Primak, A. Schultz, S. Watters, J. Thiel, T. Goggia, employing the 1.8-m f/4.4 Ritchey-Chretien telescope at Pan-STARRS 1-Haleakala-Hawaii (Observatory code F51) [3]. We have obtained the finding of twelve asteroids which, for the time being, have the status of PRELIMINARY in the IASC. We have calculated the orbital parameters for 7 asteroids and we've found of great interest the asteroids OUN0016 and OUN0025. On April 8/2018 the asteroid OUN0016 was closer from the Earth's orbit and we estimate it will remain so until roughly July 25/2018; then it will begin to move away. It won't intercept at any point the Earth orbit; it has the lowest period which is very similar to the Earth's, also it has the smallest diameter. The estimated parameters for this asteroid are: eccentricity = 0.0298241, semi-major axis = 1.06548180 A.U, orbital inclination = 0.24475 deg, longitude of the ascending node = 167.32683 deg, argument of perihelion = 61.40650 deg, mean motion = 0.89615888 deg/d, perihelion distance = 1.03370473 A.U, aphelion distance = 1.09725887 A.U, absolute magnitude = 28.1, diameter = 10.2 meters, orbital period of 1.10 years. The asteroid OUN0025 stays in the zone of the asteroid belt most of the time, but due to its greater eccentricity, it will intercept Mars orbit about March 2021, and it will move away from there about June the same year. The estimated parameters for this asteroid are: eccentricity = 0.278261, semi-major axis = 2.20000031 A.U, orbital inclination = 5.99999 deg, longitude of the ascending node = 59.19277 deg, argument of perihelion = 112.55702 deg, mean motion = 0.30204382 deg/d, perihelion distance = 1.58782591 A.U, aphelion distance = 2.81217472 A.U, absolute magnitude = 19.4, diameter = 557.1 meters, orbital period of 3.26 years.
[1] http://iasc.hsutx.edu/index.html
[2] http://iasc.hsutx.edu/Astrometrica.html?
[3] http://newton.dm.unipi.it/neodys/index.php?pc=2.1.0&o=F51

315.02 CANA: A Python package for the analysis of hydration in asteroid spectroscopic and spectrophotometric data
Mario N. De Pra[1], Jorge Carvano[2], David Morate[2], Noemi Pinilla-Alonso[1], Javier Licandro[3]
[1]FSI / UCF, Orlando, Florida, United States, [2]Observatorio Nacional, Rio de Janeiro, RJ, Brazil, [3]IAC, Tenerife, Tenerife, Spain

Abstract
Primitive asteroids are considered transitional objects between rocky and icy small bodies. They are expected to contain volatile-rich materials, such as hydrated silicate minerals. The hydration level can be

derived from the analysis of an absorption band centered at ~0.7 microns in an asteroid reflectance spectrum. Mapping the presence of this feature in asteroids' spectra enables the study of the distribution of phyllosilicates on the surface of these bodies and allows localization of zones in where the aqueous alteration process occurred across the main belt. Such capability is a powerful tool to constrain evolutionary models and to shed light into the history of the Solar System.

The CANA toolkit (Codes for ANalysis of Asteroids) is a Python package specifically developed to facilitate the study of hydration features in asteroids spectroscopic and spectrophotometric data. More precisely, we discuss the different methodologies for this analysis. We will also present other features of the toolkit, such as: tools to handle both types of data, spectral slope calculations, taxonomic classification, and parameterization of absorption features. In the future, this package will be extended to perform meteorite comparison and compositional modeling.

Finally, we will discuss a practical case study in which PRIMASS data (see Pinilla-Alonso et al. 2017, 49th DPS and de Leon et al. 2018 DPS poster), collected through spectroscopic observations, is be used to compare and validate CANA implemented methods for the study of hydration on primitive bodies with spectrophotometric data (i.e., ECAS, SDSS and J-PLUS). The ability to extend the analysis of hydration bands from the typically small samples covered by spectroscopy to the large data sets resulting from photometric surveys represents a significant step into the study of the population of small bodies as it enables statistical analysis.

315.03 Applications of the AAVSO Photometric All-Sky Survey (APASS) to observations of objects in our Solar System

Stephen Levine[1, 6], Arne Henden[2], Dirk Terrell[3], Doug Welch[4], Brian Kloppenborg[5]
[1]Lowell Observatory, Flagstaff, Arizona, United States, [2]AAVSO, Cambridge, Massachusetts, United States, [3]SwRI, Boulder, Colorado, United States, [4]McMaster Univ., Hamilton, Ontario, Canada, [5]Pratum Labs, Boulder, Colorado, United States, [6]MIT, Cambridge, Massachusetts, United States

Abstract
The AAVSO Photometric All-Sky Survey (APASS) is designed to provide photometric standards over the entire sky in the magnitude range 6.5 < V < 17.5mag in B, V, u, g, r, i, z and Y filter passbands. For the magnitude range, APASS is well matched to optical telescopes from 8-cm up to 2- to 3-meters in diameter. The survey was originally conceived to facilitate variable star observations. However, having photometric standards in every image taken can be of great utility to the Solar System community as well. Not only does this make it easier to combine extended time series photometry of observations of objects like asteroid and comets that move appreciably, it also makes it possible to recover photometry at the few percent level for data taken under non-photometric conditions (e.g. as demonstrated with SDSS data by Ivezic et al 2007, AJ, 134, 973).

APASS data have been taken between 2010 and 2018 with twin ASA 20-cm astrographs installed at northern and southern hemisphere sites. Over the course of the survey, we have accummulated over 500,000 images, each 2.8 x 2.8 degrees in size. We present initial results of our work to compile a catalogue of all the serendipitous observations of asteroids and comets in those images. For the bulk of the survey data, we have contemporaneous five color (B,V,g,r,i) imaging.

315.04 Signatures of a low perihelion Planet 9 on the classical Kuiper belt and distant TNOs

Rodney Gomes, Jessica Cáceres

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Abstract
We investigate the effect of a putative low perihelion distant planet in the Solar System on the orbits of TNOs, to check (1) its influence on the clustering of angular orbital elements of distant TNOs, (2) its influence on the ratio of observable detached to scattered objects and (3) its influence on the orbital distribution of the classical Kuiper belt. We find that (1) confinements in longitude of the perihelion of distant TNOs are better defined by the perturbation of low perihelion distant planets as compared to large perihelion planets, (2) confinements in longitude of nodes for TNOs perturbed by a low perihelion distant planet are also produced, (3) the ratio of observable detached to scattered objects is compatible with the presence of such a planet and (4) the structure of the classical Kuiper belt is preserved for planets with q >~ 80 au. We conclude that low perihelion planets (q >~ 80 au) should not be discarded in principle based on the signature it may produce on the classical Kuiper belt as well as the scattered and detached objects.

315.05 Rings under close encounters with the giant planets: Chariklo vs Chiron
Rafael Sfair, Rosana Araujo, Othon C. Winter
UNESP, Guaratingueta, São Paulo, Brazil

Abstract
In 2014, the discovery of two well-defined rings around the Centaur (10199) Chariklo were announced. This was the first time that such structures were found around a small body. In 2015, it was proposed that the Centaur (2060) Chiron may also have a ring. In a previous study, we analyzed how close encounters with giant planets would affect the rings of Chariklo. The most likely result is the survival of the rings. In the present work, we broaden our analysis to (2060) Chiron. In addition to Chariklo, Chiron is currently the only known Centaur with a presumed ring. By applying the same method as Araujo, Sfair & Winter (2016), we performed numerical integrations of a system composed of 729 clones of Chiron, the Sun, and the giant planets. The number of close encounters that disrupted the ring of Chiron during one half-life of the study period was computed. This number was then compared to the number of close encounters for Chariklo. We found that the probability of Chiron losing its ring due to close encounters with the giant planets is about six times higher than that for Chariklo. Our analysis showed that, unlike Chariklo, Chiron is more likely to remain in an orbit with a relatively low inclination and high eccentricity. Thus, we found that the bodies in Chiron-like orbits are less likely to retain rings than those in Chariklo-like orbits. Overall, for observational purposes, we
conclude that the bigger bodies in orbits with high inclinations and low eccentricities should be prioritized.

315.06 A Database of Fluxes and Albedos of Kuiper Belt Objects at 3.6 and 4.5 μm from Observations with the Spitzer Space Telescope
William Perkins[1], Joshua Emery[1], Dale Cruikshank[2], Cristina M. Dalle Ore[3], Yanga Fernandez[4], Keith Noll[5], Noemi Pinilla-Alonso[6, 7], John Stansberry[8], David Trilling[9]
[1]University of Tennessee, Knoxville, Tennessee, United States, [2]NASA Ames Research Center, Mountain View, California, United States, [3]SETI Institute, Mountain View, California, United States, [4]University of Central Florida, Orlando, Florida, United States, [5]NASA Goddard Spaceflight Center, Greenbelt, Maryland, United States, [6]University of Central Florida, Orlando, Florida, United States, [7]Arecibo Observatory, Arecibo, Puerto Rico, United States, [8]Space Telescope Science Institute, Baltimore, Maryland, United States, [9]Northern Arizona University, Flagstaff, Arizona, United States

Abstract
Kuiper Belt objects (KBOs) are distant (~30-50 AU) primitive planetary bodies. Due to their distance from the Sun, KBOs have endured little to no surface thermal alteration and are therefore are presumed to retain their original complement of volatiles. Observations at visible and near-infrared (0.4 to 2.4 μm) wavelengths have revealed significant spectral diversity, but detailed composition of most KBOs remains uncertain. Spectral reflectance information at longer wavelengths provides strong constraints on volatile and organic compositions. Using the NASA Spitzer Space Telescope, we observed over 200 objects at 3.6 and 4.5 μm, and a few of the brightest objects were also observed at 5.8 and 8.0 μm. Flux from KBO is reflected sunlight at all these wavelengths, but the 5.8 and 8.0 μm channels have strong thermal component for some Centaurs. Images were reduced and aperture photometry performed using Interactive Data Language (IDL). Geometric albedos at 3.6 and 4.5 μm were calculated from the measured fluxes using published sizes of the KBOs. In cases where the object was not clearly detected, an upper limit on flux and albedo is reported. The objects in the study come from a variety of dynamical classifications including Hot, Cold, Scattered, Detached, and Centaurs. This diverse population of objects spans six Spitzer observational programs (20769, 40389, 60155, 60184, 70115, 80116). With the majority of the observations deemed reliable, we were able to compile a large database of KBOs with up-to-date albedos at wavelengths never before observed for these objects. The albedo database of KBOs will enable researchers to conduct spectral analyses to identify absorption features of the key compositional components on the surfaces of KBOs. The fluxes will be useful for planning observations with JWST. The improved understanding of the surface composition of objects in the outer Solar System enabled by these data will give insight into the early Solar System formation and enable trends to be identified among the various classifications of KBOs.

315.07 Effects of Snowfall on the Albedo and Emissivity of Mars' Seasonal Ice Caps

Carlos E. Bicas, Paul Hayne
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Abstract
The existence of the residual Carbon Dioxide (CO_2) cap near the south pole of Mars is enabled at least in part by its higher albedo than seasonal CO_2deposits in northern polar region. Previous studies have suggested that a feasible reason for this contrast in albedos is the different amounts of snowfall at the poles. Snowfall may increase summertime albedo, at the same time it lowers the infrared emissivity of the surface, due to scattering by optically thick clouds and granular surface deposits. Direct observations of the emissivities of the poles can help to understand the possible effects of seasonal snowfall on the polar cap albedo. Snowfall may therefore be an important consideration for modelling the CO_2cycle on Mars, as well as the planet's long-term climate variations.

We used Mars Climate Sounder (MCS) data from the Mars Reconnaissance Orbiter (MRO) to constrain the albedo and emissivity (and in turn snowfall amount) of the seasonal CO_2 deposits in both hemispheres at latitudes > 60° to investigate whether snowfall may be responsible for the higher albedo in the south polar cap. We produced binned polar maps at a resolution of 10 km per pixel for Mars Years 29-33, for emissivity and albedo, and identified all locations with condensed CO_2 on the surface. Using these maps, we quantified the relation between summertime albedo and average wintertime emissivity (as a proxy for snowfall) for each hemisphere. Comparisons between the northern and southern hemispheres revealed important differences.

Based on our results, we found that snowfall amount is well-correlated with springtime albedo in within

the south polar region, but not in the north polar region. In particular, the highest albedo location on the planet is the south polar residual cap, which also has the greatest snowfall amount in the south polar region. However, there is no such correlation between snowfall and albedo in the northern hemisphere. Indeed, the northern seasonal cap shows significantly greater snowfall amounts than the south, yet lower albedo. Therefore, snowfall is not likely to be the primary factor controlling the hemispheric dichotomy of seasonal cap albedo on Mars.

315.08 Sedimentary Deposits in Partially Exhumed Impact Craters in the Aeolis Dorsa Region: Rivers, Lakes, and Wind

Samantha Peel, Devon Burr
Earth and Planetary Sciences, University of Tennessee, Knoxville, Knoxville, Tennessee, United States

Abstract
West of Tharsis and east of Gale Crater, the Medusae Fossae Formation (MFF) on Mars is a sedimentary deposit transitionally located between the southern highlands and northern lowlands. In its westernmost extent the MFF exhibits two high-standing plana (Aeolis and Zephyria) between which are found a suite of six craters containing enigmatic geologic units. As part of a geologic map of this region, we mapped these deposits using images from the Context Camera and High-resolution Imaging Science Experiment instruments. Some of these units show areal exposures with knobby or pitted textures. Other areal units show undulating surfaces with cuspate, cliff-forming edges. Other units, having more limited areal extent, form sinuous ridges. Two high-standing units, one mounded and one cliff-forming, are also observed. Lastly are smoother units with lineations that appear to be formed by alternating albedo. We interpret the pitted and undulating units as lacustrine in origin. The pitted surface of the pitted unit is interpreted to have formed from differences in diagenesis within the unit followed by aeolian erosion. The undulating unit is interpreted as formed by wave action with its >1km elongate raised-edge features interpreted as ice keel scours. The unit comprised of sinuous ridges is likely inverted fluvial deposits, which are pervasive along the margins of this interplana depression and give the local region its name of Aeolis Dorsa ('ridges of Aeolis'). The high-standing, mound unit is interpreted as aeolian, formed by abrasion of a sedimentary substrate to produce extensive yardangs, characteristic of the MFF as a whole, with amphitheater-style erosion observed locally. The high-standing, areal units with cliff-forming boundaries are interpreted at deltaic. The smooth surfaced units with lineations are interpreted as exposed strata of alternating grain size or chemistry of unknown depositional origin. These unit interpretations – specifically, the undulating unit interpreted as lacustrine and the cliff-forming unit interpreted as deltaic -- imply standing bodies of water in the AD region. If correct, they expand our understanding of the complex interplay of aqueous processes at this equatorial region of Mars.

315.09 Effect of variations in temperature and water vapor profiles in photochemical modeling of H and D escape from Mars

Eryn Cangi[1, 2], Michael Chaffin[2], Justin deighan[2], Ian Stewart[2], Nicholas Schneider[1, 2]
[1]Astrophysical & Planetary Sciences, University of Colorado Boulder, Boulder, Colorado, United States, [2]Laboratory for Atmospheric and Space Physics, Boulder, Colorado, United States

Abstract
Mars was once a much wetter world, but most of its water has been lost over time. Quantifying this loss and its evolution are critical to understanding how Mars lost its atmosphere. Key to this quantification is the ratio of deuterium to hydrogen (D/H), as H preferentially escapes compared to D. Also important are seasonal variations of atmospheric water vapor, which have been shown to have significant short-term

effects on escape rates (Chaffin 2017). In this work, we expand the 1D photochemical model of Chaffin et al. to study the combined effect of D and variations in temperature and water vapor profiles on Martian atmospheric escape. To the model, we add the deuterated species D, HD, HDO, HDO_2, DO_2, OD, and CO_2D, using the globally averaged Martian D/H ratio of 5.5×SMOW (the terrestrial value, 1.6×10^{-4}). After converging the model atmosphere to equilibrium over ~10 million years, we catalogue the outgoing flux of both H and D, as well as the fractionation factor $F=(\Phi_D/\Phi_H)/([HDO]/2[H_2O])$. We performed this numerical experiment for 30 different vertical profiles of temperature and water vapor drawn from the Mars Climate Database that represent general atmospheric averages for different latitudes, seasons, and times of day. Preliminary results show that the flux of H and D out of the atmosphere varies within 1% of the average value, while the fractionation factor *F* varies between 0.0-0.02. Though horizontal transport and changes in temperature profiles over simulation time are neglected, the results can still be used to inform understanding of the equilibrium chemistry, define general bounds on the parameter space, and quantify the feasible range for H+D escape flux and fractionation. Future work will address the inclusion of dynamic temperature profiles, as well as the effect of fractionation of HDO and H_2O due to climatology.

315.10 Generating Synthetic Spectra from Ames Mars GCM for Direct Comparisons to Observations

David R. Klassen[1], Melinda A. Kahre[2], Michael J. Wolff[3], Robert M. Haberle[2], Jeffery L. Hollingsworth[2]
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Abstract
In the field of martian cloud science, the observing and modeling communities have worked to create intercomparisons with the goal of improving results from both areas. In general, these comparisons happen at the derived end-product stage, such as maps of column-integrated cloud optical depth. Differences in derived product lead to changes in computations, model parameters, or even some base assumptions, until the end products are in the best possible agreement. While this appears to work well, it is really only an implicit confirmation of agreement; there is the possibility that even as end-points are converging, starting points could be diverging, leading to different interpretations of the underlying processes. We have begun a project of testing the NASA Ames Mars GCM and key aerosol model assumptions more directly by taking the model output and creating synthetic TES-spectra from them for comparison to actual raw-reduced TES spectra. We will present GCM spectra from more complex GCM runs to investigate the degree to which a fundamental observation is affected, and compare to TES retrieved spectra.

315.11 Mars D/H Evolution from 3 Ga to present

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Abstract
Mars D/H today is enriched by a factor of ~6 relative to terrestrial values, suggesting that large amounts of H from water have been lost to space. Loss of H occurs more efficiently than loss of D, so the remaining gas becomes enriched in D. By tracking the supply and loss of H and D in the atmosphere, using D/H, we can constrain the history of water on Mars. We examined the evolution of water and D/H

from 3 Ga to the present, using the measured D/H in a 3 Ga sediment and in the present atmosphere as boundary conditions. We included supply of water from outgassing and loss of H and D to space, using the present-day inventory of exchangeable water ice primarily in the polar caps as a constraint. Key uncertainties include the amount of water present at the surface early in history, the supply of water to the surface from catastrophic flooding and its subsequent history, and the ability of water to move into potentially non-exchangeable reservoirs such as mid/high latitude dense ground ice. The factor of two enrichment in D/H in the last 3 Ga can be produced if loss to space outstrips outgassing — that is, if the present-day 20-45 m water global equivalent layer (GEL) is a residual of an initial inventory at 3 Ga of 45-110 m GEL, combined with 5-50 m outgassed and 20-150 m lost to space. We conclude that given the processes we believe are dominant in water loss, we are able to explain the 2x enrichment in D/H from 3 Ga to the present, and the escape rate we measure today is within the range of values needed to achieve that enrichment.

315.12 Outer Planets Unified Search (OPUS): Status and Future Plans

Robert S. French, Mark R. Showalter, Debra J. Stopp, Mitch K. Gordon, Matthew S. Tiscareno
SETI Institute, Mountain View, California, United States

Abstract

Outer Planets Unified Search (OPUS) is a comprehensive search tool provided by the PDS Ring-Moon Systems node of NASA's Planetary Data System. It currently hosts 1.5 million images and spectra from Cassini, Voyager 1 and 2, Galileo, New Horizons, and the Hubble Space Telescope and provides a sophisticated, web-based user interface that allows cross-mission and cross-instrument searches. In addition to the standard metadata provided by the instrument teams, OPUS adds searchable metadata describing surface geometry and lighting of all planets and satellites in the field of view as well as ring plane geometry and lighting where applicable. We will report on the current status of OPUS, including the recent addition of new Hubble cameras, updates to Cassini and New Horizons data, and refinements to the user interface, as well as plans for the near future, including the addition of ring occultation profiles from the Cassini VIMS, UVIS, and RSS instruments.

315.13 Cohesive Aggregation of Dust in Free-Floating Parabolic Flight Experiments

Akbar Whizin[1], Daniel Durda[1], Con Tsang[1], Stan Love[2]
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Abstract

The fundamental mechanical properties of the dust that makes up protoplanetesimals in the solar nebula are critical to understand in order to inform accretion hypotheses regarding early stage terrestrial planet formation (Blum, J., and Wurm, G., 2008, *Annu. Rev. Astron. Astrophys.* 46:21-56). The mineralogy of this dust is similar to the surfaces of primitive asteroids and comets and it's critical to exploration science to characterize properties such as cohesion, aggregation, porosity, and coefficient of restitution in order to better inform both the design and operation of spacecraft, ISRU technology implementation, and the characteristics of small body surfaces. To this end, we have designed a parabolic flight experiment to study the dependence of fundamental properties of different relevant analog minerals on the growth of porous clusters (aggregates) in microgravity. The objectives of the experiments described here are to determine the effects of particle size, number density, and composition on the accretion of dust-scale grains in microgravity conditions. Our dust aggregation experiments are a follow-up to free-float experiments performed by astronaut Don Pettit aboard the ISS (Love, S., Pettit, D., Messenger, S.,

2014, *Meteoritics & Plan. Sci.* 49:732-739), and parabolic flight experiments by co-author Durda. In the Pettit experiments bags of finely grained materials like coffee and sugar were agitated and left to free-float immediately showing the aggregation of the highly cohesive materials. The clusters that formed did so due to surface forces such as van der Waals electrostatic forces. In a low-gravity environment these and other secondary forces dominate over self-gravity; this is the case in the nascent protoplanetary disk during the stage of planet formation where small mm to cm-sized protoplanetesimals grow. We will use two 4k HD cameras, advanced 3D rendering, and tracking software to both record as well as analyze the aggregation of the clusters en masse during each 20 second parabola. The results of the microgravity experiments will allow for further understanding of the aggregation rates of 0.1 - 10 mm dust clusters, their strengths, sticking thresholds, and porous compaction.

315.14 A New Look at Pluto's Small Satellites: Observations with HST in 2018

Mark R. Showalter[1], Anne Verbiscer[2], Marc Buie[3], Paul Helfenstein[4]
[1]SETI Institute, Mountain View, California, United States, [2]University of Virginia, Charlottesville, Virginia, United States, [3]Southwest Research Institute, Boulder, Colorado, United States, [4]Cornell University, Ithaca, New York, United States

Abstract
We recently began a new two-year program to observe the Pluto system with the Hubble Space Telescope. Our goals are (1) to obtain photometry of the system as it passes through almost exact opposition in July 2018 and again in July 2019, and (2) to refine the orbits and rotation states of the four small moons Styx, Nix, Kerberos and Hydra. We will present the latest observations, giving particular emphasis to the second topic. New astrometry should help us to refine our understanding of the many near-resonances in the system and to test the one proposed exact resonance, a three-body interaction between Styx, Nix and Hydra. We will infer the current rotation periods and orientations of the moons via their light curves. We will tie together these results with HST observations from 2010-2015 in order to study the moons' spins, obliquities, and precession rates. Our goal is to evaluate the evidence for spin-orbit couplings and/or chaotic rotation in the Pluto system.

Thursday, October 25, 2018
08:30 AM-09:30 AM
Ballroom A (Knoxville Convention Center)

400 Satellite Geology and Geophysics
Chair(s): Cesare Grava, Michael Bland

08:30 AM-08:40 AM
400.01 Simulating Icy Impacts using Adaptive Smoothed Particle Hydrodynamics
Dawn Graninger, Megan Bruck Syal, J. M. Owen, Paul L. Miller
Lawrence Livermore National Laboratory, Livermore, California, United States

Abstract
Interpretation of the cratering record on icy bodies can be informed by modeling of planetary-scale impacts into ice. The accuracy of these impact simulations depends upon the quality of the material models implemented, including the equation of state, strength, and damage models. Here we benchmark strength and damage models for water ice against laboratory hypervelocity impact experiments, which have studied cratering in ice at small scales (e.g. Harriss and Burchell 2017, Shrine et al. 2002). These experiments provide a necessary test-bed to validate numerical simulations, which we rely on to model the larger impacts that occur in our Solar System. We validate our Adaptive Smoothed Particle Hydrodynamics (ASPH) code, Spheral, using the knowledge obtained from previously published experiments, attempting to replicate both crater width and depth as well as general fracture patterns. Sensitivities to the water ice equation of state as well as the intrinsic flaw distribution employed will be discussed. These numerical results demonstrate the efficacy of the ASPH technique for simulating icy impacts and provide a stepping stone for future large-scale studies of cratering in ice.
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS- 755228

08:40 AM-08:50 AM
400.02 Origins of Dark Material in Crater Ejecta on Europa
Tara Tomlinson, Paul Hayne
LASP - University of Colorado, Boulder, Colorado, United States

Abstract
The origins of low-albedo hydrate material on the surface of Europa have been a source of great curiosity since Voyager first returned close-up images of the icy moon. Sulfur originating from Io is known to contribute an exogenic flux of dark material, primarily to Europa's trailing hemisphere. At regional and local scales, hydrated salt compounds are concentrated within chaos, ridges, and pits, suggesting an endogenic source. Many of Europa's impact craters also exhibit dark ejecta, the origins of which are unknown.
We used imaging data from NASA's Galileo mission and models to investigate impact features and their possible contributions to the exogenic deposition of dark material. Our study examines the ejecta of large impact craters to determine whether intrinsically dark impactors could be responsible for this low-albedo component in the crater's ejecta. Using Galileo images, we identified a number of craters with this dark ejecta characteristic. Using crater scaling laws, we then estimated the impactor size for each crater and, using a radiative transfer model, determined the contribution of the dark ejecta due to the impactor.

Our preliminary results show that, by comparing the ratio of dark vs light material in the ejecta to the ratio of impactor mass vs ejecta mass, the concentrations of dark material found in the ejecta of these craters cannot be solely attributed to the impactor itself. This result indicates that dark crater ejecta on Europa must be at least partly endogenic; subsurface material excavation and/or chemical or physical alteration due to impact forces are likely sources. Further study is planned to consider these alternate mechanisms as they relate to the relatively limited number of impact sites found on the surface today.

08:50 AM-09:00 AM
400.03 A unified framework for the formation of Ganymede's diverse terrains
Michael Bland[1], William B. McKinnon[2]
[1]Astrogeology, USGS, Flagstaff, Arizona, United States, [2]Washington University in Saint Louis, St. Louis, Missouri, United States

Abstract
To first-order, the surface of Ganymede can be divided into young, bright, tectonically modified terrain, and older, dark, cratered terrain; however, this division belies the diversity of observed terrain types. Dark terrains contain numerous viscously relaxed craters that indicate elevated heat flow, and extensional fracturing has resulted in dark lineated terrains that may be transitional with bright terrain. The bright terrain is a resurfacing unit, as evidenced by its lower crater density relative to the dark terrain, but its morphology is highly varied, ranging from swaths of relatively smooth material to deeply tectonized sets of ridges and troughs. Reticulated terrains and Europan-like bands are also observed. The mechanism(s) responsible for bright terrain emplacement (tectonic or cryovolcanic), and the relationships between Ganymede's terrain types, remains uncertain. Here we discuss recent numerical simulations of lithospheric extension and impact crater relaxation that clarify how Ganymede's resurfacing occurred, and provide a unified framework for understanding the formation of its diverse terrains. We show that viscous relaxation of impact craters before or during extension enables "tectonic resurfacing" during groove formation. Such concomitant relaxation is actually unavoidable given the high heat fluxes that accompany groove terrain formation. Tectonism need only erase relatively low-amplitude, relaxed topography, rather than deep craters. We posit that Ganymede's diverse terrains result from spatial variations in heat flux and strain magnitude. In regions where both heat flux and strain was large, complete resurfacing occurred and Ganymede's iconic "grooved terrain" was formed. Where the heat flux was large but strain was low, extensive viscous relaxation occurred without tectonism. Large strains but low heat fluxes resulted in tectonism without resurfacing, such as in the dark lineated terrains. Ancient, largely unmodified terrains persist only where both strain and heat flux were low. This simplified framework does not preclude either cryovolcanism or Europa-like band formation, and may be tested by ESA's JUICE mission.

09:00 AM-09:10 AM
400.04 Tortured Ridges: Investigating Potential Ridge and Lenticulae Interactions on Europa
Chase J. Chivers[1], G W. Patterson[2], Britney E. Schmidt[1]
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Abstract
Europa's young surface has been highly modified by a diverse set of geologic processes. One such process is represented by quasi-elliptical shaped surface features collectively known as lenticulae that appear as ~10 km diameter depressions (pits), disruptions (small chaos), or uplifts (domes) and may be

entirely unique to Europa. Double ridges – cracks flanked by raised ridges extending linearly for 10s to 1000s of km – represent the surface expression of some other process within the shell. Current models suggest lenticulae are formed by endogenic processes such as warm ice diapirs or saucer-shaped pockets of liquid water within the brittle shell. The formation of ridges is less constrained; models have suggested both endogenic processes such as liquid water sills, exogenic processes such as tidal stresses, or a combination of both. Here, we investigate ridge morphology in association with lenticulae in high resolution Galileo SSI images. We observe a distinctive transition in ridge morphology, from a generally linear trend to a tortuous one, associated with regions that include a high concentration of lenticulae. This relationship implies some interaction between the lenticulae and fracture propagation and we suggest possible formation mechanisms based in a linear elastic fracture mechanics framework. Additionally, we observe clear fracture deflection by lenticulae, similar to those of crack and crater interactions observed on Enceladus, implying a similar mechanism and thermal anomaly beneath the lenticulae. These two phenomena are likely related and will provide insight to lenticulae formation processes and local and temporal ice shell properties

09:10 AM-09:20 AM

400.05 Variations in Surface/Subsurface Processes on Europa

Maya D. Yanez[1], Morgan Cable[2], Cynthia Phillips[2]
[1]Astrophysical and Planetary Sciences, University of Colorado, Boulder, Boulder, Colorado, United States, [2]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States

Abstract
Interest in Europa has steadily increased since the first close-up images from the *Voyager* spacecraft in 1979. Its global subsurface ocean, as well as the surface geology of its ice shell, have launched many inquiries into its potential for harboring life. We are in an era where it is possible we will have two missions to Europa (including a lander mission concept) within the next two decades. It is becoming more and more imperative to maximize our understanding of Europa (especially its surface and subsurface) in order to properly prepare for these potential missions. Therefore, we provide a synthesis of the processes governing Europa's surface to a depth of one meter and a lateral area of ~two square-meters (i.e., typical lander workspace-scale). As the highest resolution data of Europa does not permit this scale of understanding, we performed various qualitative analyses of analogue environments (Mars, Moon, etc.) where we do have *in situ* data. We also begin to quantify the vertical and horizontal variation to be expected within a workspace area. We present the results of this search and analyses, and comment on the potential of various surface processes to destroy or preserve biosignatures.

09:20 AM-09:30 AM

400.06 Comprehensive spherical harmonic analysis of Io's volcanoes, mountains, heat flow, and other geologic phenomena

James T. Keane[1], Katherine de Kleer[1], Julie Rathbun[2]
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Abstract
Io is the most tidally heated world in the solar system—as evidenced by the hundreds of continually erupting volcanoes dotting its surface. Many previous studies have attempted to identify patterns in the spatial distribution of these volcanoes and link those patterns to tidal heating processes at depth. While

trends have been observed in some datasets, the link to interior processes remains inconclusive. In this work, we present a spherical harmonic analysis of the most comprehensive suite of Io datasets ever compiled, including: thermal hot spots observed by Voyager, Galileo, and New Horizons (Rathbun et al. 2004, Lopes et al. 2007, Tsang et al. 2014, Veeder et al. 2015, Davies et al. 2015), thermal hot spots measured by ground-based observatories (de Kleer & de Pater 2016, de Kleer et al. 2018, Rathbun et al. 2018), volcanic features and paterae mapped by Voyager and Galileo (Williams et al. 2011, Hamilton et al. 2013), mountains and tectonic structures mapped by Voyager and Galileo (Turtle et al. 2007), topography derived from Galileo stereo imagery and limb profiles (Thomas et al. 1998, White et al. 2014), and more. Spherical harmonics are a natural basis function for examining structures and patterns on a sphere, and the resulting analyses are more directly comparable to other geophysical datasets (e.g., gravity and topography), and analytical and numerical models of interior processes (which are often solved spectrally). Spherical harmonic expansion of Io's geologic phenomena have only been attempted once before for a more limited dataset (Kirchoff et al. 2011). Beyond the larger dataset, we extend this methodology in several key ways, including improved error analysis, regional spectral analyses, and cross-correlation analyses. We confirm several previously identified trends, and identify several new trends in the data—including hemispheric dichotomies, latitudinal trends, and more. Our work also highlights several deficiencies in existing Io datasets, including latitudinal and longitudinal biases arising from observation geometry. Many of these biases and uncertainties will remain until we revisit Io.

Thursday, October 25, 2018
08:30 AM-09:30 AM
Ballroom B (Knoxville Convention Center)

401 Asteroids: Observational Surveys II
Chair(s): Quanzhi Ye, Sarah Sonnett

08:30 AM-08:40 AM
401.01 Colors for Small Asteroids in the High cadence Transient Survey
José Peña Zamudio, Cesar Fuentes, Francisco Förster, Jorge Martínez
Departamento de Astronomía, Universidad de Chile, Santiago, Chile

Abstract
We report the discovery of thousands of asteroids in the High cadence Transient Survey (HiTS) 2015 campaign. This builds on our HiTS 2014 campaign (Peña, Fuentes, Förster et al. 2018, AJ 155 135) that yielded ~7000 new asteroids as small as the bulk of the NEO population (H~18.8). HiTS 2015 surveyed an area of 150 square degrees with a cadence of 5 exposures per night during 6 nights, now delivering g-r colors for asteroids brighter than g~22.5 (H~17.8), enabling a comparison with the brightest NEOs and exceeding the limiting magnitude of previous surveys with colors by >=1 magnitude (such as the SDSS, WISE or PS-1).

08:40 AM-08:50 AM
401.02 Asteroid Phase Curves Seen by Pan-STARRS1
Michele T. Bannister[1], Alan Fitzsimmons[1], David Young[1], Serge Chastel[2, 3], Richard Wainscoat[4]
[1]Queen's University Belfast, Belfast, United Kingdom, [2]University of Hawaii at Manoa, Honolulu, Hawaii, United States, [3]Research Corp. Univ. of Hawaii, Honolulu, Hawaii, United States, [4]University of Hawaii Institute for Astronomy, Honolulu, Hawaii, United States

Abstract
The Pan-STARRS1 survey made 19 million optical observations of more than half a million main-belt asteroids in 2010-2016, creating an exceptionally rich imaging dataset for understanding asteroid reflectivity. Phase curves provide critical information about the surface reflectance properties and sizes of minor planets, which are typically unresolved in observations. Deriving measurements of the absolute magnitude H and slope parameter G (or G1,2) from well-sampled phase curves for large sets of asteroids has only become possible with the advent of systematic wide-field surveys. On the scale of populations, the relationships between H, slope parameter and orbital parameters can provide insight into the formation and evolution of minor planet populations.
We consider the asteroid photometry from both the 3pi and the Solar System Survey datasets of Pan-STARRS1, measured in the grizy and wide-band w filters. We are calculating phase curve information sampled over a seven-year span for more than half a million $H_r > 13$ asteroids with well-determined orbits. The number of asteroids in our dataset doubles that of Veres et al. (2015), who considered the first 15 months of PanSTARRS1 data. We are deriving absolute magnitudes and slope parameters, and will map these against the precisely-known dynamical populations of the main belt. Asteroids with $m_r < 15.8$ will saturate in the imaging of the upcoming LSST survey; thus, this dataset of physical parameters will remain useful in that era, complementing the phase curves that will be measured with Gaia.

08:50 AM-09:00 AM

401.03 Searching for Super-Fast Rotators Using the Pan-STARRS 1

Chan-Kao Chang[1], Hsing-Wen Lin[1], Wing-Huen Ip[1, 2], Wen-Ping Chen[1], Ken Chambers[3]

[1]Institute of Astronomy, National Central University, Taiwan, Taoyuan City, Taiwan, [2]Space Science Institute, Macau University of Science and Technology, Macau, Macao, Macao, [3]Institute for Astronomy, University of Hawaii, Manoa, Hawaii, United States

Abstract

The properties and features of super-fast rotators (SFRs) is important to understand their formation and asteroid interior structure as well. Therefore, we carried out a survey for asteroid rotation period using the Pan-STARRS 1 during October 26-31, 2016 to search for SFRs. 876 reliable rotation periods were obtained, from which we found eight of them having a rotation period of P < 2 hours. Considering their kilometer/sub-kilometer sizes and super-fast rotations, the rubble-pile structure is difficult to explain these eight objects except using a relatively high bulk density. Consequently, we named them as the PS1-SFRs, including one candidate. The colors of these eight PS1-SFRs are diverse, and their locations spread throughout the main asteroid belt. This rules out the possible taxonomic tendency and location preference perviously found among the six known SFRs. However, it is interesting that six out the eight PS1-SFRs locate in the mid main asteroid belt. Combining with the results from the pervious studies (Chang et al., 2015, 2016), the chance of detecting a SFR in the inner main asteroid belt seems to be relatively low that probably suggests less SFRs in the inner main belt than the mid main belt. However, this need further confirmation in the future observations.

09:00 AM-09:10 AM

401.04 Light curves of 200 solar system objects from Kepler/K2 are now available to the community, and more will follow!

Christina L. Hedges[1, 2], Jessie Dotson[1, 2], Geert Barentsen[1, 2]

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Abstract

The K2 mission has completed more than four years of observations in the ecliptic plane, observing solar system objects with unprecedented precision and cadence. Now entering its 17th campaign, K2 has observed hundreds of asteroids, trojans, planets and moons to enable better estimates of rotation rates and measurements of asymmetry. Until now, producing light curves for this dataset has been difficult, owing to data products designed for exoplanet hunting and complications from spacecraft motion. In this talk I will present 1) a new method for building asteroid light curves using Kepler/K2 data, 2) a new tool to produce these light curves that is freely available to the community, and 3) the first of several High Level Science Products, which will include more than 200 light curves of solar system objects from Kepler/K2 with a uniform processing. The community will have access to asteroid light curves from the MAST archive, as easily as stellar and exoplanet light curves.

09:10 AM-09:20 AM

401.05 Near Earth Object studies from the Spitzer Space Telescope

Andrew McNeill[1], Joseph Hora[2], Annika Gustafsson[1], Michael Mommert[3], David Trilling[1]

[1]Department of Physics and Astronomy, Northern Arizona University, Flagstaff, Arizona, United States, [2]Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts, United States, [3]Lowell Observatory, Flagstaff, Arizona, United States

Abstract

We present an overview of the Near Earth Object (NEO) studies carried out using IRAC on the Spitzer Space Telescope. Over 2000 NEOs have been observed in several programs since the start of the Spitzer Warm Mission. Thermal modelling has been used to estimate the albedos and diameters of the NEOs.

In the absence of dense photometry for a large population of NEOs, the best method of obtaining a shape distribution comes from sparse photometry and partial lightcurves. We have used 824 partial lightcurves obtained by Spitzer to determine a shape distribution for NEOs. From this data we find a best fit average elongation $\frac{b}{a}=0.72 \pm 0.08$. We compare this result with a distribution obtained from Pan-STARRS 1 and find it to be in excellent agreement. We also derive periods and amplitudes for a subset of 38 NEOs, many of them having no previously reported rotation periods. For objects where the period observed did not sample the full rotational period, we derived lower limits to these parameters. We also identify an object with rapid spin and diameter D = 519^{+227}_{-116} m and find that for this object a cohesive strength of about 225 Pa is necessary to avoid fission.

Major NEO surveys return a small fraction of high albedo objects which do not have clear analogs in the current meteorite population. About 10% of Spitzer-observed NEOs have nominal albedo solutions greater than 0.5. This may be a result of lightcurve variability leading to an incorrect estimate of diameter or inaccurate absolute visual magnitudes. We performed a Monte Carlo analysis on 1500 NEOs observed by Spitzer, sampling the visible and thermal fluxes of all targets in an amplitude range of 0.1 to 1.0 magnitudes to hold the high albedo targets within albedo cutoffs of 0.4, 0.5, and 0.6. Our results suggest that an amplitude of >1.0 magnitudes is required to duplicate the observations. Implementing the mean lightcurve amplitude obtained from the shape distribution we obtained, we provide an upper-limit on the geometric albedo based on composition.

09:20 AM-09:30 AM

401.06 Gaia asteroid astrometry in Data Release 2

Paolo Tanga[1], Federica Spoto[2, 1]

[1]Observatoire de la Côte d'Azur, Nice, France, [2]IMCCE, Observatoire de Paris, Paris, France

Abstract

Solar System observations by Gaia come in two flavours: daily alerts, triggered by the discovery of unidentified moving sources; and high-accuracy observations of known asteroids. We discuss both aspects with a particular emphasis on the astrometric observations published in the Data Release 2 (DR2) on April 25, 2018.

For the first time, DR2 has made available to the community sub-mas astrometry of minor planets at visible wavelengths. Nearly 2 million epoch positions, for a total of 14,099 selected asteroids, have been released. The data have been processed at the CNES facilities of Toulouse (France), one of the centres of the Data Processing and Analysis Consortium (DPAC) of Gaia.

Processing includes the rejection of clearly anomalous astrometric positions and fluxes, and a validation phase. This last task has involved a careful orbital fitting on Gaia data only, and an analysis of the residuals. For objects brighter than V~18 the single-epoch astrometry is in general better than 1 mas, except at the bright end where size effects can play a role.

At the faint end (V~20.7) the accuracy decreases to a few mas. Photometry is in general accurate at a few

mmag.
Such unprecedented performance opens the door to new applications, such as more precise Yarkovski force measurements among NEOs, the direct detection of Yarkovsky in the Main Belt and a completely renewed approach to stellar occultations.
We will briefly discuss all these aspects, illustrate the main recommendations for the appropriate exploitation of Gaia accuracy, and present the plans for the future releases.

Thursday, October 25, 2018
08:30 AM-09:30 AM
Ballroom C (Knoxville Convention Center)

402 Extrasolar Planets and Systems: Giant Planet Atmospheres
Chair(s): Ingo Waldmann, Konstantin Batygin

08:30 AM-08:40 AM
402.01 Using Jupiter's Light Curves from the UV to the Mid-IR to Study the Light Curves on Brown Dwarfs and Direct-Imaging Planets
Huazhi Ge[1], Xi Zhang[1], Leigh Fletcher[3], Glenn Orton[2], James Sinclair[2], Josh Fernandes[2], Thomas Momary[2], Ari Warren[1], Yasumasa Kasaba[4], T. M. Sato[5], Takuya Fujiyoshi[6]
[1]Earth and Planetary Sciences, University of California Santa Cruz, Santa Cruz, California, United States, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States, [3]Department of Physics Astronomy, University of Leicester, Leicester, United Kingdom, [4]Dep. Geophysics, Tohoku University, Sendai, Japan, [5]ISAS/JAXA, Sagamihara, Japan, [6]Subaru Telescope, National Astronomical Observatory of Japan, National Institutes of Natural Sciences, Hilo, Hawaii, United States

Abstract
It is suggested that the rotational modulations on brown dwarfs and direct-imaging planets are driven by the temperature perturbations and patchy clouds, but the underlying mechanism is not well understood. Here we analyze Jupiter's rotational light curves constructed from its global maps at 12 wavelengths from the UV to the mid-IR. The peak-to-peak amplitude of Jupiter's light curves at most wavelengths ranges from sub-percent level to 4%, but that at 5 μm exceeds 20%. The multi-wavelength light curves exhibit various kinds of shapes, time evolution and phase shifts between wavelengths. We find that Jupiter's rotational modulations are mainly caused by discrete patterns in the belts instead of in the zones. The light curve amplitude is dominated by the size and the brightness contrast of the Great Red Spot (GRS), the North Equatorial Belt (NEB) expansion, patchy clouds in the North Tropical Belt and the train of hot spots in the NEB. The reflection brightness contrast of the local patterns is controlled by distributions of tropospheric haze and clouds and chromophores in the clouds. The thermal emission brightness contrast is produced by distributions of temperature, tropospheric gas and clouds. Light curves in the methane absorption band at 0.89 μm exhibit significant phase shift compared with the UV and visible wavelengths. This phase shift is caused by the brightness change of the GRS at different wavelengths. At visible wavelengths, the GRS is a dark spot because of the chromophores in the GRS; In the CH_4 band, the GRS is a bright spot because there is less CH_4 above the GRS. This work sheds light on the underlying mechanism of the rotational modulations on brown dwarfs and direct-imaging planets. We suggest that distributions of the temperature, gas, and clouds are essential for the rotational modulations on brown dwarfs and exoplanets. At the wavelengths that the sensitive pressure level is above the cloud top, the opacity of the inhomogeneously distributed gas and temperature distributions are essential to the rotational modulation. The patchy cloud opacity is more likely to produce large photometric variability at the wavelengths of atmospheric windows. This project is supported by the NESSF.

08:40 AM-08:50 AM
402.02 Exoplanet Cloudscapes: Metallicity, Mixing, and Mass Effects
Peter Gao
Astronomy, University of California, Berkeley, Berkeley, California, United States

Abstract
Clouds have been readily inferred from observations of exoplanet atmospheres, and a trend is beginning to emerge where hotter planets appear "clearer" than cooler ones, though there is significant scatter in the data and a local minimum in cloudiness can be discerned at ~1300 K. Equilibrium condensation calculations suggest a myriad of cloud species - salts, sulfides, silicates, and metals - could condense on these worlds, but how they form and evolve as clouds is uncertain. The behavior of clouds - their formation, evolution, and equilibrium size distribution - is controlled by cloud microphysics, which includes processes such as nucleation, condensation, and evaporation. In this work, we explore the cloudy exoplanet phase space by using a cloud microphysics model to simulate a suite of cloud species ranging from cooler condensates such as KCl/ZnS, to hotter condensates like iron and corundum. We investigate how the cloudiness and cloud particle sizes of exoplanets vary due to temperature, metallicity, gravity, and eddy mixing, and how these changes may be reflected in current and future observations. We show that a reduction in cloud mass can explain the decrease in cloudiness with increasing temperature, while the clearing near ~1300 K suggests that sulfide clouds may play minimal role in transmission. In addition, we make predictions on the magnitude of cloud spectral features at JWST MIRI wavelengths to investigate how we can use these features to characterize exoplanet clouds.

08:50 AM-09:00 AM
402.03 Aggregate Hazes in Exoplanetary Atmospheres
Danica Adams[1], Peter Gao[1], Imke de Pater[1], Caroline Morley[2]
[1]UC Berkeley, Berkeley, California, United States, [2]Harvard-Smithsonian Center for Astrophysics, Boston, Massachusetts, United States

Abstract
Photochemical hazes have been frequently used to interpret exoplanet transmission spectra that show an upward slope towards shorter wavelengths and weak molecular features. While previous studies have only considered spherical haze particles, photochemical hazes composed of hydrocarbon aggregate particles are common throughout the solar system. We use an aerosol microphysics model to investigate the effect of aggregate photochemical haze particles on transmission spectra of warm exoplanets. The depth of unit nadir optical depth depends on wavelength, and we find that this wavelength dependence is steeper for spherical hazes than for aggregates since aggregates grow to larger radii. At short wavelengths (~0.4 microns), unit optical depth occurs at comparable pressures for spherical and aggregate hazes, but at long wavelengths (~10 microns), unit optical depth occurs at a pressure ~7 scale heights lower for aggregates than spheres. As a result, while spherical haze opacity displays a scattering slope towards shorter wavelengths, aggregate haze opacity is gray in the optical and NIR, similar to those assumed for condensate cloud decks. We further find that haze opacity increases with increasing production rate, decreasing eddy diffusivity, and increasing monomer size. Furthermore, we generate synthetic exoplanet transmission spectra to investigate the effect of these hazes on spectral features. For a given set of parameter values, aggregate hazes lead to flat, nearly featureless spectra, while spherical hazes produce sloped spectra with clear spectral features at long wavelengths. Finally, we generate synthetic transmission spectra of GJ 1214b for aggregate and spherical hazes, and will show model fits to the transit spectra measured by Spitzer and HST.

09:00 AM-09:10 AM
402.04 On the Dayside Atmospheric Structure and Composition of WASP-12b
Michael D. Himes, Joseph Harrington

University of Central Florida, Orlando, Florida, United States

Abstract
The atmospheric structure and composition of WASP-12b has been hotly contested for years, with disagreements in the presence of a thermal inversion as well as the C/O ratio (Madhusudhan et al. 2011 Nature 469, 64-67; Crossfield et al. 2012 ApJ 760, 140; Swain et al. 2013 Icarus 225, 432-445; Line et al. 2014 ApJ 783, 70; Stevenson et al. 2014 ApJ 791, 36). Previously, these difficult-to-diagnose discrepancies have been suggested to be due to the data used in the retrieval and/or model differences. Assumptions in these models, such as the included molecules, were thought to possibly drive retrievals towards different answers. We present an investigation into this controversial planet by replicating previously-published retrievals and permutations of their setups using the Bayesian Atmospheric Radiative Transfer (BART) code and find that the retrieved results are largely data-driven and are generally unaffected by model assumptions. We also propose a new physically-motivated model that takes into consideration the dissociation of methane and the formation of other hydrocarbons at the temperatures reached in the dayside atmosphere of WASP-12b. This work was supported by NASA Astrophysics Data Analysis Program grant NNX13AF38G and NASA Exoplanets Research Program grant NNX17AB62G.

09:10 AM-09:20 AM
402.05 Using laboratory methods under extreme conditions to better understand refractory cloud formation in exoplanet atmospheres
Erika Kohler, Frank Ferguson
NASA Goddard Space Flight Center , Greenbelt, Maryland, United States

Abstract
The high number of extrasolar planets found in recent years has challenged our knowledge of solar system sciences. These recently discovered planets show a large diversity in their masses, temperatures, orbital periods, and other properties. With such a diverse mix of planetary parameters, it is safe to assume that the atmospheric properties are just as varied. Evidence suggests the presence of silicate and metal condensates in their atmospheres. This has led to new insights into the physics of cloud formation, and new observational data will help test and validate theoretical models. However, these models are fundamentally limited by the insufficiencies of laboratory data on the properties of atmospheric constituents; new laboratory data is desperately needed to advance state-of-the-art of exoplanet atmospheric models.
A laboratory verification of the condensation and vaporization predictions of refractory materials is critically needed in order to inform and improve atmospheric and spectral models. The stability of forsterite (Mg_2SiO_4) and iron (Fe) were tested in a thermogravimetric balance at NASA Goddard Space Flight Center. The minerals were pumped under vacuum for twenty-four hours at room temperature and then heated to a predetermined high temperature, dependent on the expected vaporization temperature of that material. After observing mass loss, the temperature is lowered at preset durations and mass measurements are taken in similar measured increments. The data is processed by a computer program in order to calculate the mass loss as a function of temperature.
The direct output of these experiments is the actual measured vapor pressures of minerals at high temperatures, which are used to predict the temperature regimes for stable cloud formation. These temperature regimes are then used as inputs to atmospheric models that predict cloud condensates. Presently, inputs for models of exoplanet atmospheres depend heavily upon extrapolations from terrestrial pressures and atmospheres. This work will lead to significant improvements in the accuracy of exoplanet atmospheric models by eliminating the need to extrapolate data from terrestrial conditions.

09:20 AM-09:30 AM

402.06 Searching for Eclipse Variability for Kepler-76 b in the Kepler Dataset

Brian Jackson[1], Elisabeth Adams[2], Wesley Sandidge[1], Steven Kreyche[3], Jennifer Briggs[1]
[1]Physics, Boise State University, Boise, Idaho, United States, [2]Planetary Science Institute, Tucson, Arizona, United States, [3]University of Idaho, Moscow, Idaho, United States

Abstract

Secondary eclipses of transiting exoplanets (when a host star occults its planet) are diagnostic of atmospheric composition, meteorology, and can even potentially reveal geophysical activity. Indeed, volcanic activity has been suggested to explain year-to-year variability in infrared eclipses of the hot super-Earth 55 Cnc e. Variations in visible eclipses observed by the Kepler mission were also recently reported for the hot Jupiter HAT-P-7 b, with credit given to changes in wind speed and cloud coverage in the atmosphere. Kepler's very long observational baseline, spanning hundreds of days for some planets, makes its datasets especially well suited to search for eclipse variability.

For this presentation, we will discuss our search for variability in eclipses of Kepler-76 b, a 2 Jupiter-mass gas giant in a 1.5-day orbit around an F-star. Throughout each orbit, Kepler-76 b induces observable ellipsoidal variations (EVs), periodic brightness oscillations resulting from motion of tidal bulges in the stellar figure. For this system, EVs should remain constant from orbit to orbit, as opposed to the planet's phase curve and eclipse which may vary. Thus, we can leverage EVs to assess the robustness of variability detected in the planet's phase curve and eclipse, leading to new insights into the meteorology of Kepler-76 b. We will also discuss prospects for observing secondary eclipses among targets from the TESS mission. For example, TESS's increased sensitivity in red wavelengths as compared to Kepler means that planetary eclipses observed by TESS will probably be more sensitive to thermal emission from the planets, likely probing conditions deeper in their atmospheres.

Thursday, October 25, 2018
10:00 AM-12:00 PM
Ballroom A (Knoxville Convention Center)

403 Satellite Atmospheres, Plumes, Particles, and Fields
Chair(s): Katherine de Kleer, Fran Bagenal

10:00 AM-10:10 AM
403.01 Eclipse Observations of the Galilean Satellite Atmospheres
Katherine de Kleer[1], Michael E. Brown[1], Imke de Pater[3], Mate Adamkovics[2]
[1]California Institute of Technology, Pasadena, California, United States, [2]Clemson, Clemson, South Carolina, United States, [3]UC Berkeley, Berkeley, California, United States

Abstract
The galilean satellites host atmospheres that are all extremely tenuous yet vary in composition and source between bodies, providing opportunities to study the generation of near-surface gas populations on small icy and rocky worlds located within intense particle environments. The oxygen-based atmospheres of Europa and Ganymede are sourced from the sputtering of surface ices, while Io's sulfur-based (SO2/SO) atmosphere is produced by a combination of volcanic outgassing and the sublimation of surface frosts. Studying these atmospheres is challenging from Earth because sunlight reflected off the satellites' high-albedo disks typically obscures the faint gas signatures. We present new observations of Io, Europa, and Ganymede made when the satellites were in eclipse by Jupiter and emissions from their tenuous atmospheres were therefore visible. The observations were made at the Keck and Hubble Space Telescopes on more than 10 occasions in 2015-2018. We present detections of the visible-wavelength oxygen aurorae of Europa and Ganymede, including the first detection of Europa's 6300 Angstrom oxygen aurora. Using these data, we derive column densities and place constraints on auroral morphology and variability. At Io we measure emission from volcanic SO gas at 1.7 microns; the factor of ten improvement to spectral resolution over all previous detections motivates detailed modeling, which indicates the presence of excited SO gas populations at both high and low temperatures. Together these observations form part of an ongoing campaign to investigate the composition and variability of the atmospheres of the galilean satellites.

10:10 AM-10:20 AM
403.02 The Spatial Distribution of Callisto's Oxygen Atmosphere
John R. Spencer[1], Nathaniel J. Cunningham[2], Paul Feldman[3], Oliver Hartkorn[4], Lorenz Roth[5], Joachim Saur[4], Darrell Strobel[3]
[1]Southwest Research Institute, Boulder, Colorado, United States, [2]Nebraska Wesleyan University, Lincoln, Nebraska, United States, [3]Johns Hopkins University, Baltimore, Maryland, United States, [4]University of Cologne, Cologne, Germany, [5]Royal Institute of Technology, Stockholm, Sweden

Abstract
It has long been suspected that Callisto has a significant O_2atmosphere, in addition to the CO_2atmospheric component detected by Galileo, based on Galileo's detection of an ionosphere, as well as theoretical expectations. However, the low level of magnetospheric excitation at Callisto makes its atmospheric emissions fainter than those of Ganymede and Europa, and emission from atmospheric $O_2$was not detected until 2010/2011, using the unprecedented sensitivity of the Cosmic Origins Spectrograph (COS)

on HST (Cunningham et al. 2015). Those observations, which implied an O_2column abundance of ~2 x $10^{15}cm^{-2}$, were all obtained on the leading hemisphere of Callisto. However, Galileo saw a stronger ionospheric signature when Callisto's trailing hemisphere faced the sun, suggesting the possibility of a denser atmosphere on the sunlit trailing side. In 2017 we therefore obtained new COS spectra of Callisto, covering both the leading and trailing hemispheres, in order to improve observational constraints on the longitudinal distribution of the atmosphere. In addition, Callisto was offset in the COS aperture in some observations, to follow up on indications of off-disk emission in the 2011 data. We will report on the results of the new observations, and their implications for understanding one of the least-known atmospheres in the solar system.

Cunningham, N.J., J.R. Spencer, P.D. Feldman, D.F. Strobel, K. France, and S.N. Osterman (2015). Detection of Callisto's oxygen atmosphere with the Hubble Space Telescope. *Icarus*, 254, 178-189.

10:20 AM-10:30 AM

403.03 O_2 Outgassing at Icy Satellites and Comets

Apurva V. Oza[1], Robert johnson[2], Martin Rubin[1], Andre Galli[1]
[1]Physikaliches Institut, Universitat Bern, Bern, Switzerland, [2]Engineering Physics, University of Virginia, Charlottesville, Virginia, United States

Abstract
The production of atmospheric molecular oxygen beyond Earth has been an enigma for decades after being discovered at the icy Galilean satellites as well as the large icy Saturnian satellites (Hall et al. 1995, 1998; Teolis & Waite 2016). O_2 was also observed in surprisingly abundant quantities in the comas of comet Halley (Rubin et al. 2015) and comet 67P/C-G (Bieler et al. 2015 ; Keeney et al. 2017). The recent observation and modeling of a diurnal O_2 cycle on Europa and Ganymede suggest that radiolytically produced O_2 is being thermally outgassed from O_2 trapped in the ice at dangling hydrogen bonds with an activation energy ~1.5 times that of pure O_2 sublimation (Leblanc et al. 2017 ; Oza et al. 2018 ; Johnson et al. 2018). The O_2 volatiles are also observed to be much more strongly trapped in bubbles in the irradiated icy surfaces of Europa and Ganymede (Spencer et al. 1995, 2002). Due to the much higher surface temperatures and several meters of mass loss per orbit (Keller et al. 2015), the in-situ observations of O_2 at 67P/C-G by Rosetta/ROSINA and Rosetta/ALICE are not likely to be due to weakly bound O_2, but rather due to the release of the O_2 trapped in bubbles, observed in the solid phase in the low-temperature regoliths (< 150K) of the icy Galilean satellites. Because the radiolytic formation of O_2 in the gas phase is inefficient, the modeling at Europa suggests that the ice grains in the solar nebula were likely irradiated forming O_2 in the solid phase prior to their assembly in comets. Identifying the thermal mechanism of O_2 outgassing is critical to being able to describe the observed O_2 column density on any airless icy body.

10:30 AM-10:40 AM

403.04 Multi-epoch Mid-infrared Spectroscopy of Io at the Large Binocular Telescope with LMIRcam and the ALES Integral Field Spectrograph

Michael Skrutskie[1], Al Conrad[2], Philip Hinz[3], Katherine de Kleer[8], Jordan Stone[3], Ashley Davies[4], Imke de Pater[5], Jarron Leisenring[3], Andrew Skemer[6], Christian Veillet[2], Charles Woodward[7], Steve Ertel[3]
[1]Astronomy, University of Virginia, Nederland, Colorado, United States, [2]Large Binocular Telescope Observatory, Tucson, Arizona, United States, [3]University of Arizona, Tucson, Arizona, United States, [4]Jet Propulsion Laboratory - California Institute of Technology, Pasadena, California, United

States, [5]University of California, Berkeley , Berkeley, California, United States, [6]University of California, Santa Cruz, Santa Cruz, California, United States, [7]University of Minnesota, Minneapolis, Minnesota, United States, [8]California Institute of Technology, Pasadena, California, United States

Abstract
The Arizona Lenslet for Exoplanet Spectroscopy (ALES) is an enhancement to the Large Binocular Telescope's mid-infrared imager, LMIRcam, that permits low-resolution (R~20) spectroscopy between 2.8 and 4.2 µm of every diffraction-limited resolution element in a 2.5"x2.5" field-of-view on a 2048x2048 HAWAII-2RG 5.2 µm-cutoff array. The 1" disk of Io, dotted with powerful self-luminous volcanic eruptions, provides an ideal target for ALES, where the single 8.4-meter aperture diffraction-limited scale for Io at opposition ranges from 240 kilometers (80 milliarcseconds) at 2.8 µm to 360 kilometers (120 milliarcseconds) at 4.2 µm. ALES provides the capability to assess the color temperature of each volcanic thermal emission site as well as map broadband absorbers such as SO2 frost. A monitoring campaign in the Spring 2018 semester provided global snapshots of Io's volcanic activity including charactization of spatially-resolved changes in the distribution of thermal emission from Loki Patera.

10:40 AM-10:50 AM
403.05 New Views of Europa’s Atmosphere from Hubble: Water Vapor Plume Campaigns and Other Species
Kurt D. Retherford[1, 2], Lorenz Roth[3], Tracy Becker[1], Joachim Saur[4], Darrell Strobel[5], Paul Feldman[5], Mykola Ivchenko[3], Denis Grodent[6], Lucas Paganini[7], Philippa Molyneux[1], Aljona Bloecker[3]
[1]Southwest Research Institute, San Antonio, Texas, United States, [2]University of Texas at San Antonio, San Antonio, Texas, United States, [3]Royal Institute of Technology, Stockholm, Sweden, [4]University of Cologne, Cologne, Germany, [5]Johns Hopkins University, Baltimore, Maryland, United States, [6]Universite de Liege, Liege, Belgium, [7]Catholic University of America, Washington, District of Columbia, United States

Abstract
Numerous advances in our understanding of Europa’s atmosphere and auroral features have been accomplished in the last several years as a result of robust Hubble Space Telescope (HST) observing campaigns dedicated to searches for water vapor plumes. The most recent sets of observations started on March 28, 2018 as part of Hubble’s Mid-Cycle 25 Europa Campaigns. In addition to continued Space Telescope Imaging Spectrograph (STIS) instrument long-slit far-UV auroral Lyman-alpha and oxygen line emission and Lyman-alpha Jupiter transit spectral data sets reported previously, we will describe our observations using three new modes: i) STIS/NUV G230L spectroscopy, off-limb, ii) STIS/CCD G750M spectroscopy in eclipse, and iii) WFC3/UVIS imaging in eclipse. Improved constraints to the relative abundance of molecular and atomic oxygen have been provided using the far-UV emission datasets. Exospheric atomic hydrogen is detected by absorption in the Lyman-alpha transit spectral data set, when Europa is silhouetted by Jupiter's bright Lyman-alpha dayglow. A confirmation of the initial detection using the technique of H and O auroral emissions released by electron impact dissociation of water vapor has not yet been achieved. The current HST campaign program led by our group has another ~1/3rd of the program yet to come, with these observations deferred until the next Jupiter opposition period in 2019. We’ll discuss our early assessments of the successfulness of the various techniques used to search for plumes and how this informs our plans for Europa Clipper and JUICE mission ultraviolet spectrograph observations.

10:50 AM-11:00 AM

403.06 A Closer Look at Galileo Thermal Data from Possible Plume Sources near Pwyll, Europa

Julie Rathbun[1], John Spencer[2]
[1]Planetary Science Institue, Tucson, Arizona, United States, [2]Southwest Research Institute, Boulder, Colorado, United States

Abstract

Observations by Sparks et al (2016; 2017) suggested a plume originating from an area north of Pwyll on Europa. Reanalysis of Galileo magnetometer and plasma data also suggest a plume source about 1000 km NE of the Sparks location (Jia et al., 2018). Thermal data give a clear signature of recent or current activity, as demonstrated by Cassini CIRS data (Spencer etl al., 2006), so we have reanalyzed Galileo Photopolarimeter-Radiometer (PPR)thermal observations of these two locations. Rathbun et al. (2010) determined observational limits on the PPR thermal observations and determined that PPR would have detected a 100 km^2 hotspot at the Sparks location if it had a temperature greater than 170 K and at the Jia location if it had a temperature greater than 140 K. Rathbun and Spencer (2014) determined the surface thermal properties of Europa from the PPR data and found that the Jia location has an albedo ~0.4 and a thermal inertia of ~100 in mks units. Temperatures at the Sparks location were more difficult to match to a thermal model because there were no observations at mid-day. We combined PPR observations of this location with the daytime observation by Trumbo et al. (2017) and found an albedo of 0.54 and thermal inertia of 133 in mks units. While the thermal inertia of the Jia location is similar to surrounding locations, the thermal inertia in the Sparks location is higher than in nearby locations, consistent with either fallout from a plume or Pwyll ejecta blanket. In neither location is endogenic heating necessary to match observed temperatures, but given the low spatial resolution, a single hotspot or tiger stripe in these location is less than ~10% of the observed thermal output. Nothing in the thermal data suggests that the Jia location is special and the differences at the Sparks location extend beyond the possible plume region to cover the Pwyll ejecta blanket.

Jia, X. et al. (2018) *Nature Astronomy*, **doi:**10.1038/s41550-018-0450-z
Rathbun, J. A. et al. (2010) *Icarus*, **210**, 763.
Rathbun, J. A. & Spencer, J. R. (2014) *Habit. Icy Worlds*, abs #1774.
Sparks, W. B. et al. (2016) *AJ*, **829**, 121
Sparks, W. B. et al. (2017) *AJ Lett.*, **839**, L18
Spencer, J. R. et al. (2006) *Science*, **311**, 1401.
Trumbo, S. K. (2017) *AJ*,**154**, 148

11:00 AM-11:10 AM

403.07 Measurements of Plume Activity on Europa using Ground-based Infrared Facilities

Lucas Paganini[1], Avi Mandell[2], Geronimo L. Villanueva[2], Lorenz Roth[4], Kurt D. Retherford[3], Terry Hurford[2], Michael J. Mumma[2]
[1]Solar System Exploration Division, NASA GSFC/CUA, Greenbelt, Maryland, United States, [2]NASA GSFC, Greenbelt, Maryland, United States, [3]Southwest Research Institute , San Antonio, Texas, United States, [4]KTH Royal Institute of Technology, Stockholm, Sweden

Abstract

While limited solar radiation might hinder activation of volatiles in some distant icy bodies beyond the snowline, recent observations have shown that water and organic volatiles are prevalent throughout our solar system, including many previously unexpected locations like the asteroid belt (Ceres) and several moons of the outer planets (e.g. Europa, Enceladus). These discoveries are leading to new strategies that aim better understanding (and confirmation) of key conditions that could permit habitability in Ocean Worlds, including the characterization of water environments and the search for plumes. While space-based assets, like Galileo, Cassini, and Hubble Space Telescope (HST), have provided unique insight to plume activity, ground-based observations represent a unique and complementary effort that permit measurements of water molecules directly (not its by-products H and O), whose excitation mechanisms are less dependent of electron and/or magnetic environments.

We aim to test plume activity, characterize Europa's terrain, and provide sensitive upper limits of water vapor at different Europan sub-longitudes. Ultimately, these global results can strategically inform possible localized measurements with spacecraft missions like the James Webb Telescope (JWST), Europa Clipper, and JUICE, and complement studies that are currently underway with HST at UV wavelengths as part of Hubble's Mid-Cycle 25 Europa Campaigns. Thus far, we have been able to acquire observations of Europa with Keck/NIRSPEC and IRTF/iSHELL in 2016 and 2017, covering ~60% of its surface (41 hr on-source). In this presentation we will discuss key aspects of our observing strategy, data analysis, and resulting sensitivities in the context of HST measurements.

This work is supported by NASA's Keck PI Data Award (PI L.P.) and Solar System Observation Program (PI L.P.), and by the NASA Astrobiology Institute through funding awarded to the Goddard Center for Astrobiology (PI M.J.M.).

11:10 AM-11:20 AM

403.08 Is Europa Producing a Neutral Torus? New Results Based on Observations and Modeling.

Howard T. Smith[1], Donald Mitchell[1], Robert johnson[2], Barry mauk[1]

[1]Space Sector, Johns Hopkins University Applied Physcis Laboratory, Laurel, Maryland, United States, [2]University of virginia, Charlottesville, Virginia, United States

Abstract

Neutral tori can provide key insight in large planet magnetospheres. These features form when particles escape and form a population that co-orbits with the moon. Tori distributions and compositions are a direct result of the satellite composition and source mechanisms. Thus, understanding the features can often provide critical insight into the source moons that might be difficult to directly observable.

The potential habitability of Jupiter's moon, Europa, is of particular interest. Detection of a Europa-generated neutral torus could provide important insight into this moon to include critical evidence of possible activity. The first indications of such a feature were reported by Lagg et al. (2003) who proposed the possible presence of a neutral torus in the vicinity of Europa's orbit based on the observed energetic electron population. Mauk et al. (2003) then reported the detection of a Europa neutral torus by imaging energetic neutral hydrogen atoms produced from charge exchange interactions with a neutral torus. However, unlike at Saturn's magnetosphere, where neutral particles dominate over charged particles, Jupiter's magnetosphere is dominated by charged particles. In such a high radiation environment, ENAs could also be produced as a result of charge exchange interactions between two ionized particles. In that case, the ENA's cannot be used to infer the presence of neutral particles because they could be produced by interactions with the more extended (and dominant) Io plasma torus.

For this presentation, we examine the viability that the Mauk et al. (2003) observations were actually generated from a neutral torus emanating from Europa. These results are then combined to reconstruct and place constraints on the Europa neutral torus.

11:20 AM-11:30 AM

403.09 Modeling the Flow of Mass Through the Io-Europa Space Environment

Fran Bagenal, Vincent Dols, Timothy A. Cassidy, Edward Nerney
LASP, University of Colorado, Boulder, Colorado, United States

Abstract

Ground-based observations in the 60s and 70s indicated Io was peculiar. The Voyager 1 flyby in 1979 discovered volcanism on Io, found strong UV emissions from an ionized torus, and measured the torus plasma in situ. On its way to Saturn the Cassini UVIS provided months of high-quality observations of the torus emissions, telling us the plasma composition and how the torus changed after a volcanic eruption. The Galileo spacecraft measured magnetic and particle perturbations near Io on several passes. When Thomas+2004 wrote the post-Galileo review of Io's neutral clouds and plasma torus in the Jupiter book we thought the main phenomena were explained – about 1 ton/s of sulfur and oxygen escapes Io, becomes ionized and trapped in Jupiter's magnetic field, moves out to fill the vast magnetosphere. In the meantime, new observations and models have emerged, and there is important science in the unexplained details.

(i) Models suggest ~90% of the plasma moves outwards from Io (e.g. Delamere+2005) but we see the peak density in a "ribbon" extending inside Io's orbit.

(ii) Ground-based observations and Voyager in situ data indicates there's a physical gap between the "ribbon" and the cold disc of the inner torus (Herbert+2008).

(iii) Adding to known neutral clouds of atomic O and S, Galileo observations and models show molecular SO2 and SO are also key (Russell+2003; Dols+2008, 2012).

(iv) JAXA's Hisaki satellite has monitored >3 years of Io torus spatial and temporal variations.

(v) Reanalysis of Voyager SO2
+ ions quantifies the distribution inside Io's orbit.

(vi) Focus on Europa raised ideas of iogenic species delivering useful chemicals to the surface.

(vii) Europa is unlikely a major plasma source, but the escaping neutrals absorb energetic particles moving inwards from the outer magnetosphere.

11:30 AM-11:40 AM

403.10 Search for variability between Enceladus jets erupting from different tiger stripes with UVIS

Ganna Portyankina[1], Larry Esposito[1], Candice Hansen[2], Geronimo Villanueva[3]
[1]Laboratory for Atmospheric and Space Physics, Boulder, Colorado, United States, [2]Planetary Science Institute, Tucson, Arizona, United States, [3]NASA Goddard Space Flight Center, Greenbelt, Maryland, United States

Abstract

Simultaneous observations of Cassini's Visual and Infrared Mapping Spectrometer (VIMS) and Ultraviolet Imaging Spectrograph (UVIS) of Enceladus jets during the Solar occultation in 2010 revealed that the jets above Baghdad and Damascus tiger stripes have different dust-to-gas mass ratio compared to the jets above Alexandria and Cairo [1]. Similar trends of spatial variability between the tiger stripes were previously noted by in-situ instruments [2]. The observed spatial variations between properties of the jets erupting from different tiger stripes might be attributed to differences in the inner structure of vents that connect water reservoir to the surface and/or to the differences of the water source itself. We use UVIS data together with precise geometry of observation to establish differences in the jet material observed over different tiger stripes.

We developed 3D DSMC model for water vapor jets to analyze UVIS occultation. The model traces test particles from jets' sources [3] into space and results in coordinates and velocities for a set of test

particles. We convert particle positions into the particle number density and integrate along UVIS line of sight (LoS) for each time step of the UVIS observation using precise observational geometry derived from SPICE [4]. This provides the ability to precisely distinguish which jets of the set contribute to the LoS signal at each observational timestep.
We used UVIS Solar occultation data from 2010 to generate separate spectra of material in the jets that erupt from different tiger stripes. The geometry of the observation does not allow for the clean separation between each of the four tiger stripes. Instead we can compare combinations of Alexandria+Cairo to Baghdad+Damascus, to Cairo+Baghdad. The evaluation of the observed spectral differences is complicated by the low signal-to-noise ratios however UVIS spectra show differences in spectral slopes as well as in depths of several absorption bands that may be attributed to the differences in water vapor column density along UVIS LoS.
[1] Hedman et al, Icarus 305 (2018) pp. 123–138. [2] Dong et al. 2015 JGR 120:915-937 [3] Porco et al. 2014 The Astronomical Journal 148, 4 [4] Acton, 1996 PSS 44, 65-70.

11:40 AM-11:50 AM

403.11 New Curtain-Based Maps of Eruptive Activity in Enceladus' South-Polar Terrain

Joseph Spitale[1], Mattie Tigges[1], Alyssa Rhoden[2], Terry Hurford[2]
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Abstract
In 2015, we introduced a curtain representation for eruptions near Enceladus' south pole (Spitale et al.; Nature 521; 2015). Compared to representing eruptions as discrete, narrow jets, the curtain representation has the advantage of being able to model the non-localized activity seen throughout the region. Even where the primary eruptive style is discrete, the jets spread out with altitude and may appear as broad sheets at the altitudes where the material emerges into the sunlight where it can be observed, causing difficulties for a discrete representation.

In Spitale et al. (2015), we used the curtain representation to map activity along the major fractures in the south-polar terrain at five epochs. We have since improved our methodology and map representation, and have mapped activity during a total of sixteen epochs, including re-examining the original five.

11:50 AM-12:00 PM

403.12 Interpreting Enceladus' D/H ratio in Light of the 'Jovian Gap'

William B. McKinnon[1, 6], Chris Glein[2], Jonathan Lunine[3], Olivier Mousis[4], Everett L. Shock[5], Steven D. Vance[6], J. H. Waite[2]
[1]Earth and Planetary Sciences, Washington University in St. Louis, St. Louis, Missouri, United States, [2]Southwest Research Institute, San Antonio, Texas, United States, [3]Cornell University, Ithaca, New York, United States, [4]Aix Marseille Université, CNRS, Marseille, France, [5]Arizona State University, Tempe, Arizona, United States, [6]Jet Propulsion Laboratory, Pasadena, California, United States

Abstract
Utilizing chemical and isotopic evidence from both Titan and Enceladus, a self-consistent argument can be made that the materials from which the saturnian satellites formed (water ice, icy volatiles, and heavy organics) were essentially protosolar, trapped in planetesimals that might have had a common origin with some classes of comets, and transported into the satellite feeding zone without significant subsequent chemical or isotopic interaction with saturnian subnebular gas. Regarding the rock component, gathering isotopic evidence that carbonaceous chondrites (CCs) formed beyond the position of proto-Jupiter in the

protosolar nebula (Kruijer et al. 2017, Scott et al. 2018) implies that planetesimals of similar composition contributed to the formation of Saturn's satellites (and may have dominated if CI chondrites formed beyond the position of Saturn as advocated by Desch et al. 2018). If so, we might expect the D/H in CI chondrites to reflect the high D/H values in cometary water and Enceladus plume vapor and surface ice as measured by Cassini INMS and VIMS, respectively. D/H measurements for CCs — that is, the D/H in water as opposed to that in the organic fraction (mostly IOM) — are actually depleted with respect to VSMOW (Alexander et al. 2012, 2017). During aqueous alteration in CC parent bodies, as well as in Enceladus' core today, there will be isotopic fractionation between pore water and the OH in hydrated silicates, but the δD shift is relatively small. Thus, there is an inconsistency between Enceladus' measured D/H and the presumption that CI chondrites are specifically representative of rock in the Saturn system. Possible explanations are 1) CC-type parent bodies were not able to form near or beyond Saturn (meaning planetesimals that did form remained unequilibrated mixtures of anhydrous grains and highly deuterated ices and organics), 2) CC-type meteorites with cometary $(D/H)_{H2O}$ did form near Saturn but are not yet recognized in our collections (unless CR chondrites are they), 3) Enceladus' water hydrothermally equilibrated with a similar mass of D-enriched primitive organics, and 4) Saturn's ultimate, outward "Grand Tack" migration pushed it (but not Jupiter) into colder, more D-rich icy realms.

Thursday, October 25, 2018
10:00 AM-12:00 PM
Ballroom B (Knoxville Convention Center)

404 Main Belt Asteroids: Physical Characteristics I
Chair(s): Zoe A. Landsman, Julia de Leon

10:00 AM-10:10 AM
404.01 Surface failure conditions for cohesive rubble piles
Daniel J. Scheeres, Paul Sanchez
Aerospace Engineering Sciences, University of Colorado Boulder, Boulder, Colorado, United States

Abstract
The presence of small amounts of cohesive strength has been predicted and documented in rubble pile asteroids. Even cohesive strengths on the order of 10's of Pascals can have a dramatic effect on the failure conditions and behavior of granular material on asteroid surfaces. In this presentation we report on a new analytical theory for failure of an asteroid surface that accounts for cohesive strength. The theory assumes that the interior of the asteroid does not fail before the surface and is validated with detailed numerical simulations on a spherical, rotating body.

The theory is expressed in terms of non-dimensional parameters and thus can be applied across a wide range of situations. Specifically, this theoretical understanding allows surface failure phenomenon to be predicted from fine regolith on small, rapidly spinning asteroids to meter-sized boulders on larger bodies with slower rotation rates.

The theory identifies three distinct regimes of granular matter failure as a function of the relative strength of cohesion, as defined by the bond number (the ratio of cohesive strength to a granular particle's weight). For bond numbers less than unity, failure occurs via landslides in two ways. First, for low cohesion, landslides start at a fixed latitude defined by the granular material angle of friction. For larger bond numbers, but less than unity, the initial failure point transitions to higher latitudes and lies at the boundary between fission and landslide failure. For a bond number greater than unity, failure first occurs at the equator by the fission of material from the surface. When in this regime, particles that fail will in general be placed on hyperbolic orbits and immediately escape. This demarcates the beginning of the "disaggregation" phase of rubble pile asteroids and occurs for bodies < ~300 m. It is also interesting to note that for any bond number, failure near the poles of a spinning body always occurs via landslides.

The presentation will describe the theory and its main predictions, review the numerical confirmation of the approach and present a number of implications for the interpretation of in situ observations of asteroids.

This work is supported by NASA grant 80NSSC18K0491.

10:10 AM-10:20 AM
404.02 The interaction between grain- and boulder-scale effects on thermally induced rock breakdown
Jamie Molaro[1, 2], Maurizio Pajola[3], Catherine Elder[2]

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Abstract
We investigate the multi-scale nature of diurnal, thermally induced rock breakdown on asteroid surfaces. Crack propagation is initiated at the grain scale, where stress fields develop at heterogeneous mineral grain boundaries that experience differential expansion and contraction. The stress amplitude is controlled by the diurnal temperature range and the elastic properties of the mineral constituents. Stresses are also amplified in regions where these fields interact due to the distribution of grains. These effects control the crack spacing and propagation path in different materials, which will ultimately influence the size and morphology of resulting regolith grains. At macroscopic scales, boulders undergoing thermal cycling have a bimodal response. During sunrise, stresses occur in their interiors associated with large-scale temperature gradients, driving surface-parallel crack propagation and contributing to exfoliation of planar fragments. During sunset, stresses occur at the boulders' exteriors due to the cooling and contraction of the surface, driving surface-perpendicular crack propagation and contributing to granular disintegration. It is unclear, however, how these boulder-scale effects influence grain-scale behavior and vice versa.

Ultimately, the interaction between micro- and macroscopic stress fields will determine the nature of boulder breakdown and the properties of resulting regolith fragments. We will perform 3D simulations of spherical boulders on asteroid surfaces with a range of compositions, and then impose their 3D macroscopic strain fields as background states onto 2D mineral-grain microstructures. In this way, we will characterize grain-scale behavior at the locations within boulders where macroscopic stresses are thought to drive breakdown, and analyze their effect on crack propagation paths throughout the thermal cycle. This will allow us to constrain the size and shape of resulting rock and regolith fragments, providing insight into the role thermal breakdown plays in evolution of different asteroid surfaces and their boulder size-frequency distributions.

10:20 AM-10:30 AM
404.03 Simulations and experiments of low-velocity collisions between agglomerated asteroids
Gonzalo Tancredi[1], Nestor Rocchhetti[2], Sergio Nesmachnow[2], Daniel Frascarelli[2], Thomas Gallot[3], Alejandro Ginares[1]
[1]Astronomia UdelaR, Montevideo, Uruguay, [2]INCO UdelaR, Montevideo, Uruguay, [3]Fisica UdelaR, Montevideo, Uruguay

Abstract
We present numerical simulations as well as laboratory experiments on the study of propagation of impact-induced seismic waves into the interior of an agglomerated asteroid and low-velocity collision of two agglomerates.
The numerical simulations are done with a parallel multithreading algorithms for self-gravity computation implemented in the package ESyS-Particle. ESyS-Particle applies the Discrete Element Method to simulate an ensemble of interacting particles under several contact and body forces. It was conceived to improve the computational efficiency of simulations involving large number of particles. Taking into account the different time scales of the process involved in the problem (gravitation interaction and contact among particles), a parallel mesh-based algorithm that speed up the self-gravity calculation is proposed, and it is integrated with the contact force calculation. We call this new package: ESyS-Gravity. One set of numerical experiments consist on a spherical asteroid, maintained by selfgravity which is impacted on the surface by a small projectile. The propagation of impact induced seismic waves into the interior is studied as well the ejection of low-velocity particles from the entire surface.

In another ser of experiments we consider two agglomerates colliding at low-velocity (hundreds m/s). The ejection of particles and the deformation of the interiors are analyzed.
The asteroids are modeled as agglomerates of individual spherical particles as well as agglomerates of irregular boulders formed by spherical particles.
In parallel we are performing laboratory experiments to study the propagation of impact induced seismic waves into granular materials. A cubic box (50x50x50cm), filled with different natural and artificial granular matter, is impacted with projectiles with velocities up to a few hundred m/s. The box is compressed to understand the dependence of the speed of the seismic wave with the internal pressure. The experiments are also compared with numerical simulations.
These results are relevant to understand the outcomes of impacts in rubble/gravel pile asteroids, as well as the formation of families.

10:30 AM-10:40 AM
404.04 Slow Impacts on Surfaces of Small Bodies: Coefficient of Restitution and Penetration Depth into the Regolith
Julie Brisset, Joshua Colwell, Adrienne R. Dove, Christopher Cox, Nadia Mohammed
Florida Space Institute, University of Central Florida, Orlando, Florida, United States

Abstract
Introduction: The dusty regolith covering the surfaces of asteroids and planetary satellites is subject to environmental conditions very different from those found on Earth. This regolith evolves at low ambient pressures and gravity levels. Its response to slow impacts, such as those occurring upon secondary impacts on small bodies or in planetary ring environments, may be completely different than what is intuitively expected. We carried out a series of impact experiments into simulated planetary regolith in zero- and reduced-gravity conditions using a range of microgravity platforms.
Coefficient of Restitution: For speeds >30 cm/s, impacts systematically produced an ejecta blanket and coefficients of restitution of the projectile were of the order of 10^{-2}. Below ~20 cm/s, only rebounds without ejecta were observed, with coefficients of restitution rising up to 0.3. Our results showed a similar power law index than the value of -1/4 found in 1*g*. This is twice as high as expected from the theory of an elastic sphere impacting a plane surface and indicates that energy absorption in a bed of granular material is not entirely captured by the mechanics of elastic surfaces.
Penetration Depth: We determined the maximum penetration depth of the projectile into the target (z_{max}). No correlation between z_{max} and the equivalent total drop distance (H) was observed. This is in contrast with the relation $z_{max} \sim H^{-1/3}$ observed in 1*g*. Instead, we showed that the penetration depth scales with the quantity $\mu^{-1}(\rho_p/\rho_g)^{0.1}D_p^{2/3}\ H^{-1/3}$, with μ the coefficient of friction of the target material, ρ the density of the target (g) and projectile (p), and D_p the projectile diameter.
Conclusion: Our experiments show projectile rebound off the target in microgravity ($<10^{-4}g$). None of the impacts in 1*g* and reduced gravity (0.05*g*) displayed a similar behavior. The projectile penetration depth into the target in microgravity was observed to depend more on the projectile size and energy and less on its density difference with the target than in 1*g*. These experiments show that the ambient gravity has a significant influence on the behavior of granular material on small bodies of the Solar System.

10:40 AM-10:50 AM
404.05
ESO/VLT/SPHERE Survey of D>100km Asteroids (2017-2019): First Results
Pierre Vernazza[1], Benoit Carry[2], Michael Marsset[3], Josef Hanus[4], Matti Viikinkoski[5], Franck Marchis[6]
[1]Laboratoire d'Astrophysique de Marseille, Marseille, France, [2]Université Côte d’Azur, Observatoire de la Côte d’Azur, Nice, France, [3]Astrophysics Research Centre, Queen’s University Belfast, Belfast, United

Kingdom, [4]Astronomical Institute, Faculty of Mathematics and Physics, Charles University in Prague, Prague, Czechia, [5]Department of Mathematics, Tampere University of Technology, Tampere, Finland, [6]SETI Institute, Mountain View, California, United States

Abstract
The vast majority of the geological constraints (i.e., internal structure via the density, cratering history) for main belt asteroids have so far been obtained via dedicated interplanetary missions (e.g., Rosetta, DAWN). The high angular resolution of SPHERE/ZIMPOL (one pixel represents 3.6 x 3.6 mas on sky), the new-generation visible adaptive-optics camera at ESO/VLT, implies that such science objective can now be investigated from the ground for a large fraction of D≥100 km main-belt asteroids (most of these bodies possess an angular diameter around opposition larger than 100 mas). The sharp images acquired by this instrument can be used to constrain accurately the shape and thus volume of these bodies (hence density when combined with mass estimates) and to characterize the distribution and topography of D≥30 km craters across their surfaces.

To make substantial progress in our understanding of the shape, internal compositional structure (i.e., density) and surface topography of large main belt asteroids, we are carrying out an imaging survey via an ESO Large program entirely performed in service mode with seeing constraints <0.8” (152h in total; PI: P. Vernazza; ID: 199.C-0074; the observations are spread over 4 semesters from April 1st, 2017 till March 30, 2019) of a statistically significant fraction of all D>100 km main-belt asteroids (~35 out of ~200 asteroids; our survey covers the major compositional classes) at high angular-resolution with VLT/SPHERE throughout their rotation (typically 6 epochs per target).
Here, we will present a summary of the results obtained after one year of observations.

10:50 AM-11:00 AM
404.06 Deciphering the cratering record of (7) Iris

Josef Hanus[1], Pierre Vernazza[2], Matti Viikinkoski[3], Benoit Carry[4], Michael Marsset[5], Franck Marchis[6, 7]
[1]Institute of Astronomy, Charles University, Prague, Czechia, [2]LAM, Marseille, France, [3]Tampere University of Technology, Tampere, Finland, [4]Observatoire de la Cote d’Azur, Nice, France, [5]Astrophysics Research Centre, Belfast, United Kingdom, [6]SETI Institute, Mountain View, California, United States, [7]Unistellar, Marseille, France

Abstract
As part of our ESO large program (ID 199.C-0074), we observed asteroid (7) Iris with the VLT/SPHERE/ZIMPOL instrument throughout its rotation during two consecutive nights in October 2017 (five different epochs). Iris, which is one of the four D>200 km S-type main belt asteroids along with (3) Juno, (15) Eunomia and (29) Amphitrite, is an exceptional target for an adaptive optics (AO) campaign due to its large angular size as seen from the Earth (0.35") during opposition. Considering the large size of Iris, one pixel represents 2.3 km at distance of Iris on our AO images.

We identified several topographic features in the ZIMPOL AO images that we interpreted as impact craters. Crater identification was performed manually on the images, by looking for circular features with a clear brightness contrast. Craters were first extracted on each of the five epochs. We compared all the images within a given epoch to confirm the genuineness of the identified features, removing the possibility that they are deconvolution artifacts. In the end, we checked the pairing of craters between the different epochs, that lead to a total number of six individual craters with diameters larger than 20 km. We compared the number and size of the identified craters to the cratering records on Ceres and Vesta.

We used the well established ADAM (All-Data Asteroid Modeling) inversion technique for the reconstruction of a highly-detailed 3D shape model (craters included), volume and the spin of Iris using its disk-integrated data (optical lightcurves) and disk-resolved images as inputs. We also estimated the bulk density to 2.4±0.3 g cm^{-3}. No moons were identified in our images.

This work was supported by the grant 18-09470S of the Czech Science Foundation.

11:00 AM-11:10 AM

404.07 Pallas's formation and internal structure: New insights from VLT/SPHERE

Michael Marsset[1, 2], Pierre Vernazza[3], Julie Castillo-Rogez[4], Nicolas Rambaux[5], Benoit Carry[6], Josef Hanus[7], Matti Viikinkoski[8], Franck Marchis[9], Alexis Drouard[3], Romain Fetick[3]

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Abstract

Large (D>100km) asteroids are the most direct remnants of the building blocks of planets. (2) Pallas is the third largest asteroid and the parent body of a small collisional family. Its spectral properties indicate a B-type surface, meaning Pallas is most likely linked to carbonaceous chondrite meteorites. Disc-resolved images have revealed a nearly hydrostatic shape overprinted by long-wavelength concavities (Schmidt et al. 2009, Carry et al. 2010). This was interpreted as evidence for an early phase of internal heating subsequent to Pallas's formation, followed by several large impact craters (Schmidt & Castillo-Rogez 2012). Recent estimates of Pallas's density, 2.40±0.25 g/cm3 (Schmidt et al. 2009), 3.40±0.90 g/cm3 (Carry et al. 2010) and 2.72±0.17 g/cm3 (Hanus et al. 2017), are rather inconsistent and prevent from differentiating among the various models proposed for its internal structure (Schmidt & Castillo-Rogez 2012). This currently limits our understanding of the formation and thermal evolution of Pallas.

We report new high-angular resolution observations of Pallas collected in the frame of the SPHERE large survey of the asteroid belt (see Talk by P. Vernazza) with the adaptive-optics-fed SPHERE+ZIMPOL camera on the VLT. 40 images acquired at 8 epochs provide a full longitudinal coverage of Pallas's southern hemisphere, with Pallas being resolved with ∼120 pixels along its longest axis. The optimal angular resolution of each image was restored with Mistral (Fusco et al. 2002), a myopic deconvolution algorithm optimised for images with sharp boundaries, which allows the identification of many craters and geological features on Pallas. A precise 3D-shape reconstruction was achieved with the ADAM software (Viikinkoski et al. 2015), providing a high precision estimate of Pallas's 3D shape, volume and hence density. Those are used to explore Pallas's early thermal evolution, its subsequent collisional evolution, and its current internal structure and composition.

[1] Carry et al. 2010, Icarus, 205, 460

[2] Fusco et al. 2002, SPIE, 4839, 1065

[3] Hanus et al. 2017, A&A, 601, A114

[4] Schmidt et al. 2009, Science, 326, 275

[5] Schmidt & Castillo-Rogez, Icarus, 218, 478

[6] Viikinkoski et al. 2015, A&A, 576, A8

11:10 AM-11:20 AM

404.08 (16) Psyche: A Mesosiderite-like Asteroid With No Moons?

Franck Marchis[1, 2], Matti Viikinkoski[3], Pierre Vernazza[4], Josef Hanus[5], Michael Marsset[6], Alexis Drouard[4], Herve Le Coroller[4], K. Tazhenova[4], Benoit Carry[7], Romain Fetick[4], Thierry Fusco[4], Josef Durech[5]

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Abstract

Asteroid (16) Psyche is the target of the NASA Psyche mission. It is considered as one of the few main-belt bodies that could be an exposed proto-planetary metallic core and that would thus be related to iron meteorites. Such association is however challenged by both its near- and mid-infrared spectral properties (e.g. Hardersen et al. Icarus 175, 2005; Takir et al. AJ, 153, 2017; Landsman et al. Icarus, 304, 2018).

We observed (16) Psyche with ESO VLT SPHERE/ZIMPOL as part of our large program (ID 199.C-0074, PI Vernazza) between April 24 and June 6 2018. We use the high-angular resolution of these observations to reconstruct the 3D shape model of Psyche. When combined with the most recent estimates of its mass, the volume that we derive led to a bulk density of 3.99 ± 0.26 g.cm^{-3} for Psyche. While such density is incompatible at the 3-sigma level with any iron meteorites ($\sim$7.8 g.cm^{-3}), it appears fully consistent with that of stony-iron meteorites such as mesosiderites (density $\sim$4.25 g.cm^{-3}).

Although our observations only covered the northern hemisphere of Psyche, they reveal the presence of two peculiar units in the front views, namely one low and one high brightness regions nicknamed Panthia and Meroe. Meroe unit is about 7% brighter than the surrounding region, whereas the Panthia unit is 8% fainter. Panthia is a depression with a width of ~90 km and a depth of ~10 km.

We did not detect any moons around Psyche and estimate the minimum radius of a moon to be detected around Psyche to 730 ± 100 m at 150 km (so 0.2% x R_{Hill}) of the primary and 400 ± 100 m at 2000 km from the primary corresponding to 3% x R_{Hill}) where most of the satellites of >100-km asteroids have been seen so far (Yang et al. AJL 820:L35, 2016).

Considering that the visible and near-infrared spectral properties of mesosiderites are similar to those of Psyche, there is merit to the initial hypothesis by Davis et al. (1999) that Psyche could be a plausible candidate parent body for mesosiderites (Viikinkoski et al. submitted to A&A, 2018).

This material is based upon work partially supported by the National Science Foundation under Grant No 1743015.

11:20 AM-11:30 AM

404.09 **Spectral properties and mineral compositions of acapulcoite-lodranite clan meteorites: Establishing S-type asteroid-meteorite connections**

Michael P. Lucas[1], Joshua Emery[1], Takahiro Hiroi[2], Harry Y. McSween[1]

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Abstract
In lieu of asteroid sample return missions, measurements of the spectral properties of both meteorites and asteroids offer the best possibility of linking meteorite groups with their parent asteroid(s). Visible plus near-infrared (VIS+NIR) spectra reveal distinguishing absorption features controlled mainly by the Fe^{2+} contents and modal abundances of olivine and pyroxene. Meteorite samples provide relationships between spectra and mineralogy. These relationships are useful for estimating the olivine and pyroxene mineralogy of stony (S-type) asteroid surfaces. Using a suite of 10 primitive achondrite samples from the acapulcoite-lodranite clan (ALC), we have developed new correlations between spectral parameters and mafic mineral compositions for partially-melted objects. A well-defined relationship exists between Band II center (*BIIC*) and the ferrosilite (Fs) content of orthopyroxene. Furthermore, because Fs in orthopyroxene and fayalite (Fa) content in olivine are well-correlated in these meteorites, the derived Fs content can be used to estimate Fa of the co-existing olivine. Our new equations for determining the mafic silicate compositions of S-type asteroid parent bodies that are analogous to ALC meteorites are: $Fs = 107.6 \, x \, BIIC - 189.5$ ($R^2 = 0.72$) and $Fa = 1.100 \, x \, Fs - 1.270$ ($R^2 = 0.86$). Stony meteorite spectra have previously been used to delineate meteorite analog spectral zones in Band I center versus band area ratio (BAR) parameter space for the establishment of asteroid-meteorite connections with S-type asteroids. However, the spectral parameters of the partially-melted ALC overlap with those of ordinary (H) chondrites in this parameter space. We find that Band I versus Band II center parameter space reveals a clear distinction between the ALC and the H chondrites. This work allows the distinction of S-type asteroids as nebular (ordinary chondrites) or geologically processed (primitive achondrites).

11:30 AM-11:45 AM
404.10D Inertia Parameter Statistics of An Uncertain Small Body Shape
Benjamin Bercovici, Jay McMahon
Aerospace Engineering Sciences, University of Colorado Boulder, Boulder, Colorado, United States

Abstract
This paper proposes an analytical formulation of the inertia parameters of Bezier shapes of arbitrary order. This formulation is linearized so as to yield the expressions of the first-variation in the inertia properties of interest. These expressions eventually provide the second-moment about the means of the inertia parameters (volume, center of mass, inertia tensor), given a description of the uncertainty in the control mesh of the considered shape model. The model was evaluated over the surface of asteroid Itokawa under the assumption of a normal error in the shape control points in the order of 4 meters, in addition to point-to-point correlations over a characteristic distance of 50 meters. The model exhibited good agreement with Monte-Carlo simulations as the moments of the data distribution matches the predicted ones. This uncertainty model should benefit astronomers and scientists in their assessment of the physical properties and orbital dynamics of distant objects whose shape models are only known within some accuracy.

11:45 AM-12:00 PM
404.11D Using Asteroid-Meteorite Connections to Quantify Space Weathering
Eric MacLennan, Joshua Emery
University of Tennessee, Knoxville, Tennessee, United States

Abstract

Solar wind exposure and micrometeoroid bombardment are known to cause mineralogical changes in silicate regolith grains on asteroid surfaces. These space weathering processes affect light-scattering properties of regolith by forming amorphous rims, which contain embedded nano-phase iron. The resulting asteroid spectral parameters (spectral slope and band depth) can be compared to meteorite spectral parameters in order to quantify the spectral alteration due to space weathering as a "space-weathering index". This index is used to investigate and characterize potentially influential factors relevant to space weathering: 1) the relative olivine/pyroxene abundance, 2) the amount of FeO within olivine and/or pyroxene, 3) heliocentric distance, and 4) regolith grain size. We hypothesize that space weathering would be enhanced for asteroids with more olivine, higher Fe contents, smaller mean heliocentric distance, and smaller average regolith grain size. This analysis is performed on olivine-dominated asteroids (relating to pallasites, brachinites, and R chondrites), pyroxene-dominated basaltic (HED-like) asteroids, and ordinary chondrite-like asteroids with the goal of determining the relevant factors that influence the amount of space weathering on asteroids.

The large (> 250) sample of asteroids we used is taken from public databases such as the PDS and the MITHNEOS project, which house visible to near-infrared reflectance spectra, as well as our own spectral survey carried out on the NASA IRTF. After performing a band parameter analysis on these spectra, we separated them into the compositional groups mentioned above. Meteorite and lab-irradiated meteorite and mineral samples, mostly sourced from RELAB, are used to quantify the amount of space weathering exhibited by the asteroid spectra. This space-weathering index is used to test the hypotheses across all the compositional groups. Corroborating laboratory experiments, we show that olivine-dominated asteroids are more affected by space weathering processes. Because this method relies on accurate asteroid-meteorite connections, we are able to estimate the average petrologic type (i.e., degree of metamorphism) of the population of ordinary chondrite-like asteroids.

Thursday, October 25, 2018
10:00 AM-12:00 PM
Ballroom C (Knoxville Convention Center)

405 Extrasolar Planets and Systems: Observations and Observational Modeling
Chair(s): Brian Jackson, Peter Gao

10:00 AM-10:15 AM
405.01D The search for radio emission from exoplanets using LOFAR beam-formed observations
Jake Turner[1, 2], Jean-Mathias Griessmeier[3, 5], Philippe Zarka[4, 5], Iaroslavna Vasylieva[6]
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Abstract
Detection of radio emission from exoplanets can provide information on the star-planet system that is very difficult or impossible to study otherwise, such as the planet's magnetic field, magnetosphere, rotation period, orbit inclination, and star-planet interactions. Such a detection in the radio domain would open up a whole new field in the study of exoplanets, however, currently there are no confirmed detections of an exoplanet at radio frequencies. In this study, we discuss our ongoing observational campaign searching for exoplanetary radio emissions using beam-formed observations within the Low Band of the Low-Frequency Array (LOFAR). To date we have observed three exoplanets: 55 Cnc, Upsilon Andromedae, and Tau Boötis. These planets were selected according to theoretical predictions, which indicated them as among the best candidates for an observation. Additionally, we observed Jupiter with LOFAR with the same exact observational setup as the exoplanet observations. The main goals of the Jupiter observations are to train the detection algorithm and to calculate upper limits in the case of a non-detection. Data analysis is currently ongoing. Conclusions reached at the time of the meeting, about detection of or upper limit to the planetary signal, will be presented.

10:15 AM-10:25 AM
405.02 Cassini Phase Curves of the Galilean Satellites and Implications for Direct-Imaging of Icy Exoplanets
Laura Mayorga
Harvard University, Cambridge, Massachusetts, United States

Abstract
Direct observation of the disk-integrated brightness of bodies in the Solar System, and the variation with illumination and wavelength, is essential for both planning imaging observations of exoplanets and interpreting the eventual datasets. In my previous work, I used the Imaging Science Subsystem cameras aboard Cassini to determine the disk-integrated and wavelength-dependent variations of Jupiter, which will serve to inform observations of gas-giant exoplanets. Here, I present the derived phase variations of the four Galilean satellites, which may be useful proxies for icy exoplanets with little or no atmosphere. The data span a range of wavelengths from 400 - 950 nm and predominantly phase angles from 0 - 20 degrees with some constraining observations near 120 degrees. Despite the similarity in size and density between the moons, surface inhomogeneities result in significant changes in the disk-integrated

reflectivity with planetocentric longitude and phase angle. This implies that future exoplanet observations could exploit this effect to deduce surface variations, determine rotation periods, and infer surface composition.

10:25 AM-10:40 AM

405.03D New integrated the Sun, Earth, Moon and observing instrument model using non-sequential ray tracing method for detection and characterization of the Earth-like exoplanets

Dongok Ryu[1], Robert P. Breault[2], Sug-Whan Kim[1]
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Abstract

This study presents a new integrated the Sun, Earth, Moon and observing instrument model using non-sequential ray tracing method for detection and characterization of the Earth-like exoplanets. Simultaneous imaging and spectroscopic results are provided using this system model with fully resolved spatial, spectral, and temporal coverage of sub-models of the Sun, Earth system (atmosphere, cloud, land, and ocean), Moon, and instrument. The sun sub-model is a Lambertian scattering sphere with a 6-h scale and about 300 lines of solar spectral irradiance in the wavelength region from visible to near infrared. The atmospheric sub-model has a 15-layer three-dimensional ellipsoid structure of molecular atmosphere including 3-layers of clouds and 3-layers of aerosol. The land sub-model uses 22 types of spectral bidirectional reflectance distribution functions (BRDF) defined by a semi-empirical parametric kernel model. The ocean is modeled with the ocean spectral albedo after subtracting the total integrated scattering of the sun-glint scatter model. The Moon is modeled as a sphere of 1.737×10^3 km in radius using four different albedo maps. The relative moon coordinate with respect to the observing instrument location was computed from 24-h from 28 May 2008 using "JPL HORIZONS" on-line solar system data and ephemeris computation. A hypothetical two mirror Cassegrain telescope with a 300-mm-diameter aperture and 21.504 mm×21.504-mm focal plane imaging instrument is designed. The simulated image results are compared with observational data from HRI-VIS measurements during the EPOXI mission for approximately 24 h from UTC Mar.18, 2008 and May 28, 2008. Next, the defocus mapping result and edge spread function (ESF) measuring result shows that the distance between the primary and secondary mirror increases by~50 μm from the diffraction-limited condition. The model shows the time- and disk-averaged synthetic spectrum for the case of a 24-h simulation from the line-by-line ray tracing computation using the earth system model. The simulated Earth light curves, obscured by the Moon, are calculated in non-sequential ray tracing environment.

10:40 AM-10:50 AM

405.04 Atmospheric Photochemistry Models of Habitable-Zone Exoplanets in the TRAPPIST-1 System

Renyu Hu[1, 2], Luke Peterson[1, 3], Eric T. Wolf[4]
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States, [2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California, United States, [3]Northwestern University , Evanston, Illinois, United States, [4]Laboratory for Atmospheric and Space Physics, Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder, Boulder, Colorado, United States

Abstract

Small exoplanets in the habitable zone of nearby red dwarf stars present a unique possibility to characterize habitable exoplanets within the next decade. TRAPPIST-1, an ultracool red dwarf star, was recently found to have seven Earth-sized exoplanets, and three are in its habitable zone. Constraints on the planetary masses from orbital dynamics and radii from transits indicate that most of these planets have a predominantly rocky composition. Climate models have shown that the planets e and f in the system can sustain a global liquid water ocean, for 0.2 bar CO_2 plus 1 bar N_2, and 2 bars CO_2, respectively. Observation and reconstruction of the Lyman-alpha emission of TRAPPIST-1 indicate that it has a moderately active chromosphere. Using an atmospheric photochemistry model, we investigate how the stellar irradiation drives chemical reactions in the atmospheres of TRAPPIST-1 e and f, where we assume habitable compositions predicted from the climate models. Our models show that substantial amounts of CO and O_2 must coexist with the CO_2, and in some cases, overtake CO_2 as the most abundant gases. The CO and O_2 are produced by photodissociation of CO_2, and they cannot recombine efficiently unless an unlikely direct recombination reaction in the ocean is assumed. Also, our models find that SO_2, one of the presumed gases from volcanic outgassing, cannot accumulate in the atmospheres. It is quickly oxidized in the atmosphere and then rained out as H_2SO_4. These findings indicate that CO and O_2 should be considered together with CO_2 as the primary targets in the search for atmospheric signatures from habitable-zone planets of TRAPPIST-1.

10:50 AM-11:00 AM

405.05 Target Selection for In-depth Follow-up Transit Observations

Robert Zellem

Jet Propulsion Laboratory - California Institute of Technology, Monrovia, California, United States

Abstract

The recently-launched TESS is predicted to discover thousands of transiting exoplanets ideal for in-depth characterization. However, target selection can prove to be troublesome. Here will present two figures of merit to identify targets for both transit and eclipse follow-up observations. These ranking metrics, originally developed for the FINESSE and CASE missions, provide a relative ranking between any transiting exoplanet, agnostic of the observing platform. Thus, one can quickly identify targets to more efficiently devise an observing campaign with ground- and space-based telescopes, such as Palomar, JWST, and ARIEL.

11:00 AM-11:10 AM

405.06 Retrieving Biosignatures in the Mid-Infrared

Luke Tremblay[1], Michael Line[1], Robert Zellem[2], Kevin Stevenson[3], Tiffany Kataria[2], Caroline Morley[4], Jonathan J. Fortney[5]

[1]School of Earth & Space Exploration, Arizona State University, Tempe, Arizona, United States, [2]Jet Propulsion Laboratory, Pasadena, California, United States, [3]Space Telescope Science Institute, Baltimore, Maryland, United States, [4]University of Texas at Austin, Austin, Texas, United States, [5]University of California - Santa Cruz, Santa Cruz, California, United States

Abstract

With the forecasted increase of temperate terrestrial exoplanets soon to be discovered by TESS, it is pertinent to begin questioning the nature and diversity of their atmospheres, as well as the plausibility of detecting signs of life. While previous studies have attempted to produce predictive models of plausible atmospheric compositions, very little work has been done to quantify the observational requirements necessary to probe the indicators of habitability on these planets. Through well-established atmospheric retrieval techniques, we obtain constraints on temperature structure and molecular composition using both transmission and emission spectra of an Earth-like atmosphere orbiting an M-dwarf. Specifically, we

explore the parameter spaces over spectral resolution, wavelength range, and aperture size on our ability to constrain apparent surface temperature and the abundances of six key molecules (H2O, CO2, CH4, O3, N2O, and CO) thought to impact habitability. In the context of JWST, we determine the optimal observational configuration for making definitive detections of biosignatures in an Earth-like atmosphere and ascertaining the atmospheric conditions conducive to life.

11:10 AM-11:20 AM

405.07 Comparative Terrestrial Exoplanetology in an Era of Space-Based Infrared Spectroscopy

Caroline Morley[1], Tiffany Kataria[2], Jonathan J. Fortney[3], Kevin Stevenson[4], Michael Line[5], Luke Tremblay[5]

[1]Astronomy, University of Texas at Austin, Austin, Texas, United States, [2]JPL, Pasadena, California, United States, [3]UCSC, Santa Cruz, California, United States, [4]Space Telescope Science Institute, Baltimore, Maryland, United States, [5]ASU, Tempe, Arizona, United States

Abstract

An exciting and imminent frontier of exoplanet science is the characterization of Earth-sized planets. The most amenable planets for characterization in the coming decades are transiting planets orbiting the smallest stars. During the past two years, nine planets close to Earth in radius have been discovered around nearby M dwarfs cooler than 3300 K. These planets include the 7 planets in the TRAPPIST-1 system and two planets discovered by the MEarth survey, GJ 1132b and LHS 1140b. A number of other such planets are expected to be found by the TESS mission and ground-based surveys like MEarth and SPECULOOS. Some of these planets orbit as distances potentially amenable to surface liquid water, though the surface temperatures will depend strongly on the albedo of the planet and the thickness and composition of its atmosphere. The stars they orbit also vary in activity levels, from quiet M dwarfs like LHS 1140 to more active stars like TRAPPIST-1. This set of planets will form the testbed for our first chance to study the diversity of atmospheres around Earth-sized planets. Here, we will present model spectra of the nine currently-known temperate terrestrial worlds amenable to atmosphere characterization. We also present model spectra of an additional set of simulated planets from the Barclay et al. 2018 catalog, which represent the best new planets that TESS will find. We show the distributions of planet radii, orbital periods, temperatures, host star temperatures, and distances for the predicted sample of TESS terrestrial planets that provide the best opportunities for measuring their atmospheres. We vary both composition and the surface pressure of the atmosphere, basing our elemental compositions on outcomes of planetary atmosphere evolution in our own solar system. We present both thermal emission spectra and transmission spectra for each of these objects, and we provide predictions for the observability of these spectra with JWST and with two different versions of the Origins Space Telescope mission concept. We show which big questions in terrestrial planet science are likely to be studied with JWST and which can be studied in the future.

11:20 AM-11:30 AM

405.08 Inferring the Composition of Disintegrating Planet Interiors from Dust Tails with Future JWST Observations

Eva Bodman[1], Jason T. Wright[3], Steven Desch[1], Carey M. Lisse[2]

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Abstract
Disintegrating planets allow for the unique opportunity to study the composition of the interiors of small, hot, rocky exoplanets because the interior is evaporating and that material is condensing into dust, which is being blown away and then transiting the star. Their transit signal is dominated by dusty effluents forming a comet-like tail trailing the host planet (or leading it, in the case of K2-22b), making these good candidates for transmission spectroscopy. To assess the ability of such observations to diagnose the dust composition, we simulate the transmission spectra from 5-14 mic for the planet tail assuming an optically-thin dust cloud comprising a single dust species with a constant column density scaled to yield a chosen visible transit depth. We find that silicate resonant features near 10 mic can produce transit depths that are at least as large as those in the visible. For the average transit depth of 0.55% in the Kepler band for K2-22b, the features in the transmission spectra can be as large as 1%, which is detectable with the JWST MIRI low-resolution spectrograph in a single transit. The detectability of compositional features is easier with an average grain size of 1 mic despite features being more prominent with smaller grain sizes. We find most features are still detectable for transit depths of ~0.3% in the visible range. If more disintegrating planets are found with future missions such as the space telescope TESS, follow-up observations with JWST can explore the range of planetary compositions.

11:30 AM-11:40 AM
405.09 Spitzer's Search for Proxima Centauri b Transits
Joseph Harrington[1], James Jenkins[2, 3], Ryan C. Challener[1], Nicolás T. Kurtovic[2], Ricardo Ramirez[2], José Peña Zamudio[2], Kathleen J. McIntyre[1], Michael D. Himes[1], Eloy Rodríguez[4], Guillem Anglada-Escudé[5], Stefan Dreizler[6], Aviv Ofir[7], Ignasi Ribas[8, 9], Patricio Rojo[2], David Kipping[10], R. Paul Butler[11], Pedro J. Amado[4], Cristina Rodríguez-López[4], Eliza M. Kempton[12, 13], Enric Palle[14, 15], Felipe Murgas[14, 15]
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Abstract
Proxima Centauri, the nearest star to the sun, hosts a habitable-zone planet (Anglada-Escude' et al. 2016 Nature 536, 437). Several teams have sought Proxima b's transits using ground-based photometry, and have reported tentative transit detections (Liu et al. 2018 AJ 155, 12; Blank et al. 2018 AJ 155, 228; others). Proxima, a modest-sized M-dwarf star, flares at the 0.5% level (the predicted Proxima b transit depth) 63 times per day, according to our team's prior analysis of optical photometry from the Microvariability and Oscillations of STars spacecraft (Davenport et al. 2016 ApJL 829, L31). This dramatically limits optical precision. However, the effect of flares is much reduced in the infrared. We observed the system with the Spitzer Space Telescope's Infrared Array Camera in November 2016. Our first observation was a 48-hour stare at 4.5 um. It was centered on the predicted transit and covered the 99% credible region for the transit time, based on the discovery radial-velocity (RV) data. Despite a transit-depth precision of ~0.01% for a 1 hour transit, we did not detect the predicted 0.5% transit. There was structure in the light curve, including some asymmetric transit-like features, that led us to conduct follow-up observations in May, June, July, and November 2017. None of these observations contained detections, once we accounted for a new manifestation of systematics due to spacecraft vibration. Our

improved methods for identifying and partly removing this effect is the topic of the next presentation.

This work is based on observations made with the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA. We acknowledge support from: NASA Planetary Atmospheres Program grant NNX12AI69G, NASA Astrophysics Data Analysis Program grant NNX13AF38G. CATA-Basal/Chile PB06 Conicyt and Fondecyt/Chile project #1161218 (JSJ). Spanish MINECO programs AYA2016-79245-C03-03-P (PJA, CRL, and ER) and ESP2017-87676-C05-02-R (ER).

11:40 AM-11:50 AM

405.10 Improved Methods for Spitzer Systematic Identification and Removal

Ryan C. Challener[1], Joseph Harrington[1], James Jenkins[2, 6], Nicolás T. Kurtovic[2], Ricardo Ramirez[2], José Peña Zamudio[2], Kathleen J. McIntyre[1], Michael D. Himes[1], Eloy Rodríguez[3], Guillem Anglada-Escudé[4], Stefan Dreizler[5], Aviv Ofir[7], Ignasi Ribas[8, 9], Patricio Rojo[2], David Kipping[10], R. Paul Butler[11], Pedro J. Amado[3], Cristina Rodríguez-López[3], Eliza M. Kempton[12, 13], Enric Palle[14, 15], Felipe Murgas[14, 15]
[1]University of Central Florida, Orlando, Florida, United States, [2]Universidad de Chile, Santiago, Chile, [3]Instituto de Astrofisica de Andalucia, Granada, Spain, [4]Queen Mary University of London, London, United Kingdom, [5]Institut fur Astrophysik, Gottingen, Germany, [6]Centro de Astrofisica y Tecnologias Afines, Santiago, Chile, [7]Weizmann Institute of Science, Rehovot, Israel, [8]Institut de Ciencies de l'Espai, Bellaterra, Spain, [9]Institut d'Estudis Espacials de Catalunya, Barcelona, Spain, [10]Columbia University, New York, New York, United States, [11]Carnegie Institution of Washington, Washington D.C., District of Columbia, United States, [12]Grinnell College, Grinnell, Iowa, United States, [13]University of Maryland, College Park, Maryland, United States, [14]Instito de Astrofisica de Canarias, Tenerife, Spain, [15]Universidad de La Laguna, Tenerife, Spain

Abstract

After the discovery of Proxima Centauri b in 2016, we observed the system with the Spitzer Space Telescope to look for transits. We confirmed that the planet does not transit. However, we observed three asymmetric, periodic, comet-like events. Unfortunately, we now understand these events to be systematic effects due to telescope vibration, which is occasionally temporally resolved with our 0.02 second frame time. This systematic has been previously identified as a spike in the number of pixels significantly contributing to photometry, but that metric can be misleading. We show that coherent, high-frequency activity in the point-spread function area, measured several ways, is more indicative of this systematic, and that the effect can be partially removed by a quadratic model dependent on point-spread function width. This systematic occurs at an exoplanet-signal level three times in our 80 hours, and more frequently at a lower level, which has implications for transits and eclipses of small and cool planets, respectively. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G.

Thursday, October 25, 2018
01:30 PM-03:30 PM
Ballroom A (Knoxville Convention Center)

407 Satellite Surfaces and Dynamics
Chair(s): Michael J. Person, Emilie Royer

01:30 PM-01:40 PM
407.01 Europa's surface radiation environment
Tom Nordheim[1], Leonardo H. Regoli[2], Camilla D. Harris[2], Xianzhe Jia[2], Chris Paranicas[3], Kevin P. Hand[1], Elias Roussos[4], Timothy A. Cassidy[5]
[1]Jet Propulsion Laboratory, Los Angeles, California, United States, [2]University of Michigan, Ann Arbor, Michigan, United States, [3]Applied Physics Laboratory, Laurel, Maryland, United States, [4]Max Planck Institute for Solar System Research, Gottingen, Germany, [5]Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, Boulder, Colorado, United States

Abstract
Jupiter's moon Europa is embedded deep within the Jovian magnetosphere and is thus exposed to bombardment by charged particles, from thermal plasma to more energetic particles at radiation belt energies. In particular, energetic charged particles are capable of affecting the uppermost layer of surface material on Europa, in some cases down to depths of several meters Examples of radiation-induced surface alteration include sputtering, radiolysis and grain sintering; processes that are capable of significantly altering the physical properties of surface material. Radiolysis of surface ices containing sulfur-bearing contaminants from Io has been invoked as a possible explanation for hydrated sulfuric acid detected on Europa's surface (Carlson et al., 2002, 1999) and radiolytic production of oxidants represents a potential source of energy for life that could reside within Europa's sub-surface ocean (Chyba, 2000; Hand et al., 2007; Johnson et al., 2003; Vance et al., 2016).

Accurate knowledge of Europa's surface radiation environment is essential to the interpretation of space and Earth-based observations of Europa's surface and exosphere. Furthermore, future landed missions may seek to sample endogenic material emplaced on Europa's surface to investigate its chemical composition and to search for biosignatures contained within. Such material would likely be sampled from the shallow sub-surface, and thus, it becomes crucial to know to which degree this material is expected to have been radiation processed (Nordheim et., al. 2018).

Here we will present modeling results of energetic electron and proton bombardment of Europa's surface, including interactions between these particles and surface material. In addition, we will present predictions for biosignature destruction at different geographical locations and burial depths and discuss the implications of these results for in-situ and remote sensing by future missions to Europa.

01:40 PM-01:50 PM
407.02 A Search for Signatures of Irradiated Chloride Salts in Spatially Resolved HST Spectra
Samantha K. Trumbo[1], Michael E. Brown[1], Kevin P. Hand[2]
[1]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California, United States, [2]Jet Propulsion Laboratory, Pasadena, California, United States

Abstract
We present spatially resolved visible-wavelength spectra of the surface of Europa, which we obtained using the Space Telescope Imaging Spectrograph (STIS) onboard the Hubble Space Telescope (HST). Our data cover the entire surface of Europa at wavelengths of 300 – 1000 nm with a nominal spatial resolution of ~ 200 km. At these wavelengths, our data are sensitive to the signatures of irradiation-produced color centers of hypothesized surface chloride salts as well as to signatures of the condensed O_2 previously detected in disk-integrated spectra. In our data, we identify a spectral feature near 450 nm, which may be consistent with irradiated sodium chloride on the surface. The feature is concentrated on the leading hemisphere, with the highest abundances falling within the chaos region Tara Regio. We map observed features across the surface and compare their spatial distributions with surface geology, particle bombardment patterns, and previous compositional maps.

01:50 PM-02:00 PM
407.03 MeV Electron Bombardment of Europa Surface Analogs
Murthy S. Gudipati[1], Bryana L. Henderson[1], Fred B. Bateman[2]
[1]Science Division, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States, [2]National Institute of Standards and Technology, Gaithersburg, Maryland, United States

Abstract
Europa's surface has strong dichotomy based on whether it is leading/trailing or whether it is equatorial or polar. Accordingly, Jovian magnetospheric radiation incidence dose changes significantly based on these regions. Eqatorial trailing hemisphere receives maximum dose of electrons and ions of energy below around 25 MeV.

Our goal is to understand how this electron radiation effects surface chemical composition focusing on organics and secondary X-ray (Bremsstrahlung) radiation penetration depths as well as how the physical properties are affected by the initial chemical composition.

We present analysis of our recent experiments conducted at the NIST Medical and Industrial Radiation Facility (MIRF) with electrons of energy between 10 MeV and 25 MeV.

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA). Funding from JPL internal (R&TD and Technology Enabling) as well as NASA through SSW and EW programs is acknowledged.

02:00 PM-02:10 PM
407.04 **Leeb Hardness of Salty Europa Ice Analogs Exposed to MeV Electrons**
Bryana Henderson[1], Murthy S. Gudipati[1], Fred B. Bateman[2]
[1]Jet Propulsion Laboratory, Pasadena, California, United States, [2]National Institute of Standards and Technology, Gaithersburg, Maryland, United States

Abstract
Europa is a key target for exploration of habitability in the Solar System. Due to the intense radiation impinging upon the surface, it is likely that future lander missions to Europa will need to gain access to subsurface material to obtain pristine samples that are unaffected by radiation. Since Europa's ice composition and surface structure are not yet fully characterized, technological requirements for mobility,

drilling, and caching mechanisms are also not well constrained.
To begin to understand the physical properties of ice under Europa's extreme environments, we have initiated a set of laboratory studies to examine the effect of temperature, composition, and MeV electron radiation on the hardness of ices that contain hydrated salts. By utilizing a commercially-available Leeb rebound hardness tester, we have determined that ices that contain salts such as NaCl and $MgSO_4$ exhibit increased hardness relative to pure water ices under temperatures that are relevant to Europa (which experiences average temperatures of ~80 K at the polar regions to ~120 K at the equator). However, exposure of these ices to 10-25 MeV electron radiation (such as is received by the trailing hemisphere of Europa) led to measurable softening, which indicates that the increases in hardness due to the presence of salt may be somewhat tempered by surface radiation effects. We found that hydrated $MgSO_4$ (close to 1:1 by mass with H_2O) is the hardest of these materials at Europa-relevant temperatures and ranges from 477 to 527 HL.

02:10 PM-02:20 PM
407.05 Europa's Unusual Surface
Robert Nelson[1, 2], Mark D. Boryta[2], Kenneth S. Mannatt[3], Yuriy Shkuratov[4], Vladimir Psarev[4], Bruce W. Hapke[5], Kurt Vandervoort[6], Victor Tishkovets[7], Elena Petrova[8], Morgan Palmer[2]
[1]Planetary Science Institue, Pasadena, California, United States, [2]Mount San Antonio College, Walnut, California, United States, [3]Jet Propulsion Laboratory, Pasadena, California, United States, [4]Karazin University, Kharkiv, Ukraine, [5]University of Pittsburgh, Pittsburgh, Pennsylvania, United States, [6]California Polytechnic University at Pomona, Pomona, California, United States, [7] Institute of Radio Astronomy of NASU, Kharkiv, Ukraine, [8]Space Research Institute (IKI) RAS, Moscow, Russian Federation

Abstract
Europa exhibits high albedo and distinctive polarization when observed near opposition. This characteristic is shared by many highly reflective atmosphereless solar system bodies (ASSBs) (1,2,3). Our laboratory goniometric photopolarimeter (GPP) measurements of wavelength-sized alumina (Al2O3) particulates find polarization-phase angle behavior that is strikingly similar to Europa's observed reflectance and polarization (4). Theoretical models of spherical particles of comparable size also replicate these telescopically observed effects (5).
We report new GPP measurements of well-sorted fractions of NaCl and of extremely uniform silica spheres. The reflectance phase curves of both materials are consistent with our previous Al2O3 results, but our polarization phase curves of the spheres show no polarization-phase angle dependence. We suggest that this is most likely due to the effect of irregularities (fractures, etc.) on the surfaces and in the interiors of the Al2O3 particles, which act as scattering centers; hence aggregates of small particles scatter like large ones. The silica spheres are extremely uniform in size and shape which may explain the absence of polarization effects.
The alumina samples are all highly porous (void space ~95%); efforts to design surface landers on high ASSBs such as Europa must accommodate such a regolith.
Our results have relevance to the field of terrestrial geo-engineering, particularly to proposals for modifying Earth's radiation balance by injecting Al2O3 particulates into the atmosphere to offset the effect of anthropogenic greenhouse gas emissions (6). NaCl would be a more effective scatterer, posing reduced threat to air breathing organisms.
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Kharkiv Ukraine, June 2018.
5. Tishkovets V. and Petrova E. (2013) *JQSRT 127*, 192-206. Int Conf ASSBs, Kharkiv Ukraine, June 2018.
6. Teller et al., 1997. UCRL-JC-128715.

02:20 PM-02:30 PM

407.06 Maps of Tethys' Thermophysical Properties

Carly Howett[1], John Spencer[1], Terry Hurford[3], Anne Verbiscer[2], Marcia Segura[3]
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Abstract

On 11th April 2015 Cassini's Composite Infrared Spectrometer (CIRS) made a series of observations of Tethys' daytime anti-Saturn hemisphere over a nine-hour time period. During this time the sub-spacecraft position was remarkably stable (0.3° S to 3.9° S; 153.2° W to 221.8° W), and so these observations provide an unprecedented coverage of diurnal temperature variations on Tethys' anti-Saturn hemisphere. In 2012 a thermal anomaly was discovered at low latitudes on Tethys' leading hemisphere, it appears cooler during the day and warmer at night than its surroundings (Howett et al., 2012) and is spatially correlated with a decrease in the IR3/UV3 visible color ratio (Schenk et al., 2011). The cause of this anomaly is believed to be surface alteration by high-energy electrons, which preferentially bombard low-latitudes of Tethys' leading hemisphere (Schenk et al., 2011; Howett et al., 2012; Paranicas et al. 2014; Schaible et al., 2017). The thermal anomaly was quickly dubbed "Pac-Man" due to its resemblance to the 1980s video icon. We use these daytime CIRS data, along with two sets of nighttime CIRS observations of Tethys (from 27 June 2007 and 17 August 2015) to make maps of bolometric Bond albedo and thermal inertia variations across the anti-Saturn hemisphere of Tethys (including the edge of its Pac-Man region). These maps confirm the presence of the Pac-Man thermal anomaly and show that while Tethys' bolometric Bond albedo varies negligibly outside and inside the anomaly (0.69±0.02 inside, compared to 0.71±0.04 outside) the thermal inertia varies dramatically (29±10 J m^{-2} K^{-1} $s^{-1/2}$ inside, compared to 9±4 J $m^{-2}K^{-1}$ $s^{-1/2}$ outside). These thermal inertias are in keeping with previously published values: 25±3 J m^{-2} K^{-1} $s^{-1/2}$ inside, and 5±1 J m^{-2} K^{-1} $s^{-1/2}$ outside the anomaly (Howett et al., 2012).

02:30 PM-02:40 PM

407.07 Dione and Helene's photometric characteristics

Emilie Royer[1], Amanda Hendrix[2], Carly Howett[3], Linda Spilker[4]
[1]LASP, University of Colorado, Boulder, Colorado, United States, [2]Planetary Science Institute, Tucson, Arizona, United States, [3]Southwest Research Institute, Boulder, Colorado, United States, [4]JPL, La Cañada, California, United States

Abstract

The icy satellites Dione and Helene share the same orbit, at 6.26 Saturn radii from Saturn, which is within its diffuse E ring. Helene is one of Dione's two Trojan moons, located in the leading Lagrangian point (L4) of Dione's orbit. We present here results on the investigation of the Dione-Helene duo in terms of origin, formation and evolution. Specifically, the key objectives are to retrieve the photometric properties and surface composition of the moons to answer questions such as: *Are the Dione and Helene surfaces made of the same material? Did they form in the same region of the Solar System? Is one satellite older than the other? Have they experienced the same amount of space weathering?*

To provide the most complete evaluation of the Dione and Helene surfaces and advance our understanding of how exogenic processes affect the surfaces of icy satellites, we use the synergy of four of the Cassini instruments: UVIS (Ultraviolet Imaging Spectrograph), ISS (Imaging Science Subsystem), VIMS (Visual and Infrared Mapping Spectrometer) and CIRS (Composite Infrared Spectrometer). Composite disk-integrated spectra of both moons have been produced to conduct spectral modeling over a large wavelength range from the ultraviolet to the infrared, from 111nm to 1mm. Until now, most investigations have focused only on one wavelength domain, telling only part of the story. A multi-wavelength analysis allows an in-depth investigation of the surfaces of the Saturnian satellites as each wavelength probes a different layer of the surface. Special attention is directed toward the search for correlations of basic properties (albedo, scattering properties, texture, grain size, composition, porosity, thermal properties) between Dione and Helene.

02:40 PM-02:50 PM

407.08 Do the Large Moons of Uranus have "Fluffy" Regoliths Dominated by Small Grains?

Richard Cartwright[1, 2], Dale P. Cruikshank[2], Joshua Emery[3], Noemi Pinilla-Alonso[4]
[1]SETI Institute, Mountain View, California, United States, [2]NASA Ames Research Center, Mountain View, California, United States, [3]University of Tennessee, Knoxville, Tennessee, United States, [4]Florida Space Institute, University of Central Florida, Orlando, Florida, United States

Abstract

The surface compositions of the large and tidally-locked "classical" Uranian moons Miranda, Ariel, Umbriel, Titania, and Oberon are dominated by a mixture of H_2O ice and a dark, spectrally-neutral constituent. This dark material contributes to the relatively low geometric albedos of these moons (~0.2 – 0.5) over visible (VIS) and near-infrared (NIR) wavelengths (~0.4 – 2.5 µm), weakens the 1.52-µm and 2.02-µm H_2O ice bands, and effectively masks H_2O ice bands at shorter wavelengths. In contrast, our analysis of longer wavelength spectra and spectrophotometry of these moons (L/L' bands, ~2.9 – 4.1 µm) demonstrates that they are relatively bright at longer NIR wavelengths.

We compared the continua shapes and albedos of these Uranian moon L/L' band datasets to those of H_2O ice-rich, mid-sized moons in the Saturnian system and the dark material-rich surfaces of Callisto and the leading hemisphere of Iapetus. This comparison demonstrates that the shapes of the Uranian moon continua are consistent with the H_2O ice-rich Saturnian satellites. However, the Uranian moon L/L' band albedos are significantly higher than the L/L' band albedos of the H_2O ice-rich Saturnian moons and the dark material-rich surfaces of Callisto and Iapetus.

We generated radiative transfer models of the Uranian moon L/L' band datasets, which suggest their exposed surfaces are dominated by small grains of H_2O ice and amorphous carbon (~0.2 – 1 µm diameters). These spectral modeling results are consistent with recent VIS polarimetric results for these moons, which indicate their regoliths are highly porous, with a "crumbly" structure dominated by sub-micron and micron grains [Afanasiev et al. 2014, *Astrophysical Bulletin 69, No. 2, p.211*]. Furthermore, analysis of thermal emission spectra collected by the Infrared Interferometer Spectrometer (~16 – 50 µm) onboard Voyager 2 suggests that the regoliths of Miranda and Ariel are dominated by strongly backscattering grains, with notably different scattering properties than the regoliths of the mid-sized Saturnian moons. We will present our longer NIR wavelength results and discuss their implications regarding the structure of the classical Uranian moons' regoliths.

02:50 PM-03:00 PM

407.09 Continued Volatile Transport on Triton

Bonnie J. Buratti, Michael Hicks, David Dombroski
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Abstract
The large Neptunian satellite Triton is one of at least three moons in the outer Solar System that exhibit volcanism. Triton's ice volcanoes appear to be driven by solar heating and to occur during the sublimation of the polar cap observed by Voyager 2 in 1989. During the small period of time covered by Voyager, there are plumes being generated within this cap, but long term seasonal transport of volatiles on Triton's surface requires ground-based or Earth-orbiting measurements. Volatile transport on Triton has been monitored by gathering historical and current rotational light curves though time and comparing these lightcurves to those expected from static frost coverage. For the few years after the encounter, no frost transport was detected. Triton reached southern summer solstice, when volatile transport should be near its maximum, in 2001. Lightcurves obtained from 2000-2004 show substantial seasonal transport of volatiles on Triton's surface (Buratti et al., 2011), and HST images of the moon confirm this result and identify regions where frosts are accumulating (Bauer et al. 2011). A dedicated program to obtain new data on Triton's lightcurve, including over 20 nights of observations in 2016 with the 24-inch telescope at Table Mountain Observatory, shows that the regions identified by Bauer et al. as brightening are continuing to accumulate frost. A full season on Triton is 84 years, and with long term monitoring approaching 38 years, these observed seasonal variations can be compared with models that make predictions on the global frost budget on Triton.
Funded by NASA.

03:00 PM-03:10 PM
407.10 Constraints on the impactor source for the Saturnian system from two independent tests
Edgard G. Rivera-Valentin[1], Michelle Kirchoff[2], Cristina M. DalleOre[3]
[1]USRA/Lunar and Planetary Institute, Houston, Texas, United States, [2]Southwest Research Institute, Boulder, Colorado, United States, [3]SETI Institute, Moffett Field, California, United States

Abstract
Early studies on the bombardment of the outer solar system found two distinct populations for the Jovian system and Neptune's Triton (Zahnle *et al*., 2003). Specifically, the Jovian moons were found to be deficient in small craters compared to Triton. Furthermore, recent work has also found the Uranian moons and the Pluto system have crater populations deficient in small craters (*i.e.*, Jupiter-like; Kirchoff and Dones, 2018; Singer *et al*., 2018). Here we investigate the potential impactor population for the Saturnian system, specifically analyzing Rhea and Dione, using two independent tests. First, we use a Monte Carlo impact model where we vary the slope of the cumulative power law describing the distribution of small impactors to generate model crater populations. These simulated populations were compared to the measured crater population on Dione and Rhea found from high resolution Cassini ISS images. We find that that the small crater population on Dione and Rhea is best reproduced with an impactor population following a cumulative power law ($N=kD^{-b}$) with a slope of b~1.9 and b~1.7, respectively. The second test involved dating the formation of young craters on Rhea using the relative distribution of crystalline to amorphous ice found from Cassini VIMS data (Dalle Ore *et al*., 2015). The measured crater density on the floor of the studied craters is then used to infer the impact rate. Applying the ice-inferred age for Rhea's Obatala crater and the measured crater density within its floor, we infer an impact rate on the order of 10^{-5} per 10^{6} km^2 per year for craters with diameters greater than 1 km, at least for the last 450 Ma. This impact rate agrees with the inferred rate if the impactor source followed a cumulative power law of b~1.7 for small craters (Zahnle *et al*., 2003). Therefore, for Saturn, our two independent tests would suggest an impactor population enhanced in small objects compared with the Jovian moons (*i.e.*, Triton-like). Furthermore, our inferred impactor population has a power law slope that agrees well with the

expected distribution of small projectiles in the cold Kuiper Belt Object (KBO) population, potentially suggesting the cold KBO as the impactor source for the Saturnian system.

03:10 PM-03:20 PM

407.11 Saturnian Moon's size distribution

Cesar I. Fuentes, Peña José
Astronomy, Universidad de Chile, Santiago, Chile

Abstract

The giant planets are orbited by a swarm of Irregular Satellites that exhibit orbits with chracteristic large semi major axis, high inclinations and/or high eccentricities. Many of these show retrograde orbits (Jewitt & Sheppard, 2005) further highlighting how different they are from Regular Moons in much closer in coplanar orbits. Because of their extreme orbits, there is a consensus model that requires their capture from a source population (Kuiper, 1956). The source of Irregular satellites is thought to be the region of bodies in their vicinity on the planetesimal disk during the phase of planet migration (Nesvorný 2007, 2014). The most obvious source is then, the Trans-neptunian object population, remnants of the primordial planetesimals on the outer regions of the Solar System that were scattered and captured during planet migration (Levison 2008, 2011; Lykawka 2008; Horner 2013, Nesvorný 2014) to their current location. Simulations have shown that Irregular Satellites could be captured during planet migration in similar numbers as the actual ones (Nesvorný, 2014). Studying the statistical properties of this population, like their size distribution, is an important test for the consistency of these theories.

We present new constraints on the size distribution of Irregular Moons of Saturn from a survey conducted on the Dark Energy Camera (DECam) onboard the Blanco telescope in Cerro Tololo. We survey its entire Hill Sphere over a three day period down to magnitude R~25. We compare their size distribution to other populations in the Solar System and provide further evidence for a Trans-Neptunian origin.

03:20 PM-03:30 PM

407.12 Long-term gravitational spreading of irregular satellite families

Daohai Li[1], Apostolos Christou[2]
[1]Department of Astronomy and Theoretical Physics, Lund University, Lund, Sweden, [2]Armagh Observatory and Planetarium, Armagh, United Kingdom

Abstract

All four giant planets have the so-called irregular satellites. Residing on wide, eccentric and inclined orbits, these moons did not form in-situ but were captured from heliocentric orbits in the early solar system. Jupiter has the largest irregular moon population of more than 60, among which several orbital families are identified. Members of the same family are fragments of the same parent bodies during collisions. Himalia, the largest irregular moon at Jupiter (with a mass ~10^{-9} of that of Jupiter), leads a prograde-revolving family. This family features a velocity dispersion of several 100s of m/s, well beyond that expected for family-creating collisions. Here we test if gravitational scattering by Himalia over the age of the solar system could explain the dispersion.

We generate a synthetic Himalia family with an initial dispersion < 100 m/s, consistent with a collisional formation. This family is numerically propagated for 1 Gyr under the gravitational perturbation of Himalia. We observe that Himalia induces significant orbital spreading in the family especially in a.

Extrapolating the dispersion over 4 Gyr we find that, while appreciable, it is not large enough to explain the observed orbital distribution of the family. Therefore, one must seek other explanations such as the disturbing action of planetary encounters during a solar system dynamical instability (Li & Christou 2017).

In addition to spreading out the family, Himalia creates its own network of secular resonances where ~90% of family members are captured into at least once over the course of our 1 Gyr simulation. This implies that members of the real family have been captured into such resonances in the past. Additionally, we estimate that Himalia has collisionally removed more than 60% of the smaller family members over the past 4 Gyr. Hence, the family likely had more members upon its formation.

Finally, we have performed a similar exercise for Saturn's satellite Phoebe, seeking to test that satellite's ability to spread out a hypothetical family, possibly beyond recognition. The results of this investigation will be reported at the meeting.

Thursday, October 25, 2018
01:30 PM-02:50 PM
Ballroom B (Knoxville Convention Center)

408 Main Belt Asteroids: Physical Characteristics II
Chair(s): Margaret McAdam, Eric MacLennan

01:30 PM-01:40 PM
408.01 Thermal properties of large main belt asteroids derived from Herschel PACS data
Victor M. Ali Lagoa[1], Thomas G. Müller[1], Anna Marciniak[2], Csaba Kiss[3], René Duffard[4], Przemyslaw Bartczak[2], Magda Butkiewicz-Bak[2], Grzegorz Dudzinski[2], Estela Fernández-Valenzuela[5], Gábor Marton[3], Nicolás Morales Palomino[4], Jose Luis Ortiz[4], Edyta Podlewska-Gaca[2], Dagmara Oszkiewicz[2], Toni Santana-Ros[2], Pablo Santos-Sanz[4], Robert Szakáts[3], Aniko Takácsné-Farkas[3], Erika Varga-Verebelyi[3]
[1]Max Planck Institute for extraterrestrial physics, Garching-bei-Muenchen, Germany, [2]Astronomical Observatory Institute, Faculty of Physics, A. Mickiewicz University, Poznan, Poland, [3]Konkoly Observatory, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, Budapest, Hungary, [4]Instituto de Astrofisica de Andalucia (CSIC), Granada, Spain, [5]Florida Space Institute, University of Central Florida, Orlando, Florida, United States

Abstract
One of the many aims of the Small Bodies: Near and Far project (SBNAF; see Müller et al. 2017arXiv171009161M) is to develop a database with IR observations taken from (space) observatories such as AKARI, IRAS, WISE, Spitzer, and Herschel. In some cases, Herschel PACS calibration data of asteroids required a more careful reduction strategy, and the resulting expert-reduced data products have been provided by SBNAF to the Herschel Science Archive. The IR data can then be used to derive physical and thermal properties from thermo-physical models (TPMs), which is yet another objective of the project.

Here we will present the TPM analysis of a set of ~10 main belt asteroids larger than 100 km in diameter with the aim of deriving their thermal inertias (so far, we know those of about twenty such objects). Some of our targets are so-called "Gaia perturbers", objects whose masses will become known thanks to the high precision of ESA's Gaia mission. We use available or newly derived shape models and benefit from the high photometric quality provided by the Herschel PACS 70-, 100- and 160-micron fluxes taken from the calibration program. Whenever available, we also use ground-based and AKARI, IRAS and WISE data. One key aspect we are interested in is how well TPM and shapes derived from inversion methods, including non-convex shape models from SAGE (Bartczak & Dudzinski 2018MNRAS.473.5050B) and/or ADAM (Viikinkoski et al. 2015A&A...576A...8V), can reproduce the highest-quality IR data and, conversely, to what extent we can use these data to assess the quality of the shapes models.

Acknowledgments: the research leading to these results has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under Grant Agreement no 687378.

01:40 PM-01:50 PM
408.02 A Grand Unified Theory of the M-Types? Interpreting Spitzer Space Telescope spectra of M-type asteroids in the context of previous observations and dynamical models
Zoe A. Landsman[1], Joshua Emery[2], Humberto Campins[1], Lucy F. Lim[3], Dale Cruikshank[4]

[1]Florida Space Institute, University of Central Florida, Orlando, Florida, United States, [2]University of Tennessee, Knoxville, Knoxville, Tennessee, United States, [3]NASA Goddard Space Flight Center, Greenbelt, Maryland, United States, [4]NASA Ames Research Center, Moffett Field, California, United States

Abstract
The M-type asteroid taxonomic class has long been associated with metal through spectral similarities with iron meteorites and the observation of high radar albedos among the M-types. If some of the M-types are truly metallic asteroids, they are likely to be the cores of differentiated protoplanets that were stripped of their silicate crusts and mantles by hit-and-run collisions. Studies of hypothetical remnant metal cores are valuable opportunities to constrain planetary formation and differentiation processes. As such, the upcoming NASA mission *Psyche* will target the M-type asteroid (16) Psyche, thought to be a candidate metal core. However, there is also evidence for compositional diversity within the M-type asteroid taxon. Many M-types have been reported to show weak VNIR spectral signatures of silicate materials such as pyroxene and/or olivine (λ~0.9, 1.9 μm), and of hydrated minerals (λ~3 μm). We are now investigating the mid-infrared (mid-IR; 5-35 μm) characteristics of 28 M-type asteroids using data collected with the Spitzer Space Telescope's Infrared Spectrograph. The mid-IR spectral region is potentially diagnostic of thermal characteristics and silicate mineralogy. Our preliminary results show that the Spitzer spectra of all M-type asteroids in our sample display silicate emission features in the 8-12 μm range. The 8-12 μm spectral contrast ranges from ~3 to 13%, indicating the silicates are fine-grained, with some variation in regolith texture among the sampled asteroids. There is no statistically significant difference in 8-12 μm spectral contrast between the high-radar albedo group and the low-radar albedo group. We are working to interpret silicate mineralogy from these data, and will determine whether relationships exist between mid-IR characteristics and previous observational results, including radar reflectivity, UV-through-near-infrared reflectance spectroscopy, and polarization parameters. We will also use our results to test dynamical hypotheses of M-type asteroid formation scenarios and collisional histories.

01:50 PM-02:00 PM
408.03 Hubble Observations of the asteroid (16) Psyche in the UV

Tracy Becker[1], Kurt D. Retherford[1], Lorenz Roth[2], Nathaniel J. Cunningham[3], Lori Feaga[4], Philippa Molyneux[1], Zoe A. Landsman[5], Lindy T. Elkins-Tanton[6], Jan-Erik Wahlund[7]
[1]Space Science and Engineering, Southwest Research Institute, San Antonio, Texas, United States, [2]KTH - Royal Institute of Technology, Stockholm, Sweden, [3]Nebraska Wesleyan University , Lincoln, Nebraska, United States, [4]University of Maryland, College Park, Maryland, United States, [5]Florida Space Institute, Orlando, Florida, United States, [6]Arizona State University, Tempe, Arizona, United States, [7]Uppsala University, Uppsala, Sweden

Abstract
The asteroid (16) Psyche is the target of the upcoming NASA Discovery Mission, *Psyche*. It is the largest asteroid designated as M-type in the Tholen taxonomic classification and is hypothesized to be the remnant metallic core of a differentiated body, stripped of its mantle through collisions. However, it has alternatively been suggested that Psyche accreted from highly-reduced, metal-rich material near the Sun early in the formation of the Solar System. Recent infrared and visible observations have also detected spectral features indicative of low-iron pyroxenes and hydroxyl or water on its surface. We seek to better constrain the asteroid's composition through a study of its surface in the ultraviolet (UV).

In April of 2017 we acquired the first UV Hubble Space Telescope observations of (16) Psyche. Using the Space Telescope Imaging Spectrometer (STIS), we measured Psyche's reflectance spectrum at

wavelengths between 160 nm – 310 nm and find that the spectrum is very red, with a reversal to a blue slope shortward of 200 nm. The spectrum is relatively featureless, with a few potentially weak absorption features in this bandpass. We will present the UV observational data, as well as our best-fit spectral models of the surface of (16) Psyche.

02:00 PM-02:10 PM

408.04 Spins and shapes of members of asteroid pairs

Josef Durech[1], Petr Pravec[2], Petr Fatka[2], Petr Scheirich[2], David Vokrouhlicky[1], Josef Hanus[1]
[1]Astronomical Institute, Charles University, Prague, Czechia, [2]Astronomical Institute, Academy of Sciences of the Czech Republic, Ondrejov, Czechia

Abstract

We present the results of our photometric observing campaign of members of asteroid pairs. Our sample consists of 93 asteroid pairs with estimated ages (times of separation of the pair components) between several 10^3 and 2×10^6 yr. We determined the rotation periods of all the primaries (larger pair members) and about 20 secondaries (smaller pair members). For 20 of the paired asteroids, we derived the directions of their spin axes with the lightcurve inversion method. For the cases where we have information on the spin axes of both components, their sense of rotation – prograde or retrograde – is always the same for a given pair, and their poles are mostly close one to each other. For selected asteroids with available thermal data measurements, we were able to derive their thermal inertia, surface roughness, and size using a thermophysical model. Our analysis of the derived physical properties of asteroid pairs allows us to constrain scenarios of the origin of the pairs. In general, our results agree with predictions of the theory of their origin by spin-up fission.

02:10 PM-02:20 PM

408.05 Mapping slopes of asteroid pairs to constrain break-up conditions

David Polishook, Oded Aharonson
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Abstract

Asteroid pairs had a single progenitor that split due to rotational-fission of a weak, rubble-pile structured body (Pravec et al. 2010). By constructing shape models of asteroid pairs from multiple-apparition observations and the lightcurve inversion technique (Durech et al. 2010), we mapped the gravitational and rotational accelerations on the surfaces of these asteroids. Together, these allow us to construct a map of local slopes on the asteroids' surfaces. In order to test for frictional failure, we determine the maximum rotation rate at which an area larger than half the surface area of the secondary member (assumed to be the ejected component) has a slope value larger than 40 degrees, the angle of friction of lunar regolith. We use this critical state to constrain the failure stress operating on the body and the rotation period at breakup.

Our current preliminary sample includes shape models of nine primary members of asteroid pairs, observed from the Wise Observatory in Israel in the last decade. In the studied parameter space we find that the shape models do not reach the observed spin barrier of 2.2-hour period and they break up at slower rates. We show how the critical rotation for breakup is not only highly dependent on the elongation but also on the flattening of the asteroid's shape. Pushing the critical spin rates towards the

spin barrier is also possible when the bulk density is larger than the ~2 gr cm^{-3} measured for the sub-km rubble pile-structured 25143 Itokawa, suggesting that km-sized asteroid pairs have density values similar to larger 433 Eros (effective diameter of 17 km, mean bulk density of ~2.7 gr cm^{-3}). Using secondary components that are larger than the real observed values (up to the maximal size allowing separation, <=20% of the primary asteroid mass), can also push the asteroid towards the spin barrier, supporting the theory of continuous disruption of the secondary (Jacobson & Scheeres 2011). In addition, cohesion level of hundreds of Pascals are also required (e.g. Holsapple 2007) to prevent these shape models from disrupting at spin rates slower than the 2.2-hour spin barrier, even at Eros-like densities.

02:20 PM-02:30 PM

408.06 The Reactivation and Nucleus Characterization of Main-Belt Comet 358P/PANSTARRS (P/2012 T1)

Henry Hsieh[1, 2], Masateru Ishiguro[3], Matthew M. Knight[4], Marco Micheli[5, 6], Nicholas Moskovitz[7], Scott S. Sheppard[8], Chadwick A. Trujillo[9]

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Abstract

We present observations of main-belt comet 358P/PANSTARRS (P/2012 T1) obtained using the Gemini South telescope from 2017 July to 2017 December (Gemini program IDs GS-2017A-LP-11 and GS-2017B-LP-11), as the object approached perihelion for the first time since its discovery. We find best-fit IAU phase function parameters of H_R=19.5+/-0.2 mag and G_R=-0.22+/-0.13 for the nucleus, corresponding to an effective radius of r_N=0.32+/-0.03 km (assuming an albedo of p_R=0.05). The object appears significantly brighter (by >1 mag) than expected starting in 2017 November, while a faint dust tail oriented approximately in the antisolar direction is also observed on 2017 December 18. We conclude that 358P has become active again for the first time since its previously observed active period in 2012-2013. These observations make 358P the seventh main-belt comet candidate confirmed to exhibit recurrent activity near perihelion with intervening inactivity away from perihelion, strongly indicating that its activity is sublimation-driven. Fitting a linear function to the ejected dust masses inferred for 358P in 2017 when it is apparently active, we find an average net dust production rate of 2.0+/-0.6 kg/s (assuming a mean effective particle radius of a_d=1 mm) and an estimated activity start date of 2017 November 8+/-4 when the object was at a true anomaly of 316+/-1 degrees and a heliocentric distance of R=2.54 AU. This work has been published in Hsieh et al. (2018, AJ, 156, 39). We will also present new observations of the object obtained after the submission of this Abstract
from 2018 August through 2018 October (Gemini program ID GS-2018B-LP-11), during which its previously-observed activity is expected to continue, and report whether we find any evidence of changes in activity strength between the object's 2012-2013 and 2017 active periods. The authors acknowledge support from NASA Solar System Observations grant NNX16AD68G and the State of Arizona Technology and Research Initiative Program.

02:30 PM-02:40 PM

408.07 Continuous Monitoring of Active Asteroid P/2016 G1 (Pan-STARRS)

Dave G. Milewski[1, 2], David Jewitt[1], Robert M. Rich[1]

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Abstract
We present a study of active asteroid P/2016 G1 (Pan-STARRS) ('G1') conducted between 2016 April and August. Our ground-based data were augmented by archival Hubble Space Telescope data as well as follow-up monitoring after G1 passed perihelion on UT 26 January 2017. The active asteroids are a subset of main belt asteroids that share the dynamical properties of asteroids but also the physical properties of comets such as the appearance of dust tails. By the use of the Jeanne Rich Centurion 28 0.7-m Telescope, the Keck-I 10-m telescope, and HST, data were obtained on 11 different epochs. We find that 1) G1's apparent R-band magnitude faded from ∼17.8 to ∼19.6 over a period of three months and steeply dropped between UT 2016 June and UT 2016 August, 2) the absolute magnitude (assuming a phase function $\beta = 0.02$ magnitudes per degree) varied from 14.7 ± 0.09 on UT 17 April 2016 to 15.9 ± 0.02 in our last useful observation on UT 2016 August 03, 3) our photometry suggests that about 10^7 kg dust was ejected, and 4) the likely mechanism of activation remains impact, as suggested earlier by Moreno et al.

02:40 PM-02:50 PM
408.08 astorb at Lowell Observatory: A comprehensive system to enable asteroid science
Nicholas Moskovitz[1], Robert Schottland[1], Brian Burt[1], Mark Bailen[2], Lawrence Wasserman[1]
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Abstract
astorb is a database of orbital elements for all known asteroids in the Solar System (780,489 objects as of 12 July 2018), has been hosted at Lowell Observatory for over 20 years, and is actively curated to be automatically updated as new objects are discovered. Front-end access to the database and associated tools are available at asteroid.lowell.edu. Modernization and upgrades to the astorb system are ongoing with expected completion by mid-2019. Upgrades currently implemented include the addition of physical properties, such as albedo and rotation period, and redesigned observational planning tools, such as ephemeris and finder chart generators. Data on physical properties are pulled from multiple sources including NASA's Planetary Data System (PDS), the asteroid Lightcurve Database (LCDB), and a number of project-specific online compilations. Future upgrades will include additional physical properties, enhanced query capabilities, and a system for credentialed user input to the database as a way to facilitate rapid dissemination of observational results. User feedback on desired additional functionality is invited.

The combination of physical properties and tools for observational prediction provides a powerful system for planning and conducting new science investigations. Through queries that execute in just a few seconds we can answer complex questions such as: which members of the Vesta dynamical family have measured albedos and are observable tonight? what is the lowest numbered asteroid without a measured albedo and when is it next observable? which Main Belt asteroids with known spectral types are passing through opposition this week? These examples highlight the type of queries for which astorb is optimized.

We will present the current state of the astorb system and highlight some of the novel tools available to the community.

This work is supported by the NASA PDART program, grant number NNX16AG52G.

Thursday, October 25, 2018
02:50 PM-03:40 PM
Ballroom B (Knoxville Convention Center)

409 Ceres
Chair(s): Jennifer Hanley, Andrew Rivkin

02:50 PM-03:00 PM
409.01 Ceres second extended mission: The final harvest
Carol Raymond[1], Julie Castillo-Rogez[1], Maria C. De Sanctis[2], Andreas Nathues[3], Thomas Prettyman[5], Christopher T. Russell[4]
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Abstract
NASA approved a second extended mission (XM2) at Ceres to obtain elemental concentrations with high sensitivity and spatial resolution, and further investigate the processes driving cryovolcanism, including sources of putative cryovolcanic deposits. To achieve these goals, Dawn maneuvered into a resonant, eccentric orbit with periapsis altitude of 35 km, enabling the Gamma Ray and Neutron Detector (GRaND) to measure the elemental composition of the regolith within the longitude corridor that includes the Occator and Urvara craters, with spatial resolution at least seven times better than the previous lowest altitude orbit. The data acquired in the elliptical orbit will improve our understanding of surface geochemistry, including the concentration and distribution of subsurface ice and the elemental composition of the ice-free regolith. High resolution imaging of the surface revealed new information on the emplacement of the bright deposits in Occator crater, the timing and nature of eruptive/effusive processes, structure and tectonics within the heterogeneous Cerean crust, and the nature of mass wasting processes. Extensive DSN doppler tracking of the spacecraft has improved the regional gravity field, illuminating subsurface structure. On the way to the low elliptical orbit, the VIS/IR spectrometer re-mapped the better-illuminated southern polar region, and new Framing Camera color imaging of high-priority targets was obtained. New infrared observations of Juling Crater were obtained to further monitor the previously observed increase in exposed ice. The combination of GRaND measurements, improved regional gravity, imaging and infrared data contribute to the goal of testing hypotheses of Ceres' origin and internal evolution, as well as understanding cyromagmatic and surface processes on this dynamic icy dwarf planet. By the time of the DPS meeting, it is expected that the spacecraft will have run out of hydrazine and will have ceased operations. Dawn will continue to orbit Ceres stably in the eccentric orbit for decades to come.

Acknowledgements: Part of this work is being carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

03:00 PM-03:10 PM
409.02 Carbon Sources and Sinks in Ceres
Julie Castillo-Rogez[1], Maria C. De Sanctis[2], Vassilissa Vinogradoff[2], Thomas prettyman[3], Marc Neveu[4], Simoni Marchi[6], Marc Hesse[5], Carol Raymond[1]
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Columbia, United States, [5]University of Texas, Austin, Texas, United States, [6]Southwest Research Institute, Boulder, Colorado, United States

Abstract
The Dawn mission has observed or inferred several types of carbon compounds on dwarf planet Ceres: various types of carbonates [1,2]; organics in narrow areas [3]; and clathrate hydrates of carbon dioxide and/or methane suggested for Ceres' low density, high strength crust [4,5]. Lastly, nuclear spectroscopy indicates Ceres' regolith contains higher concentrations of carbon than found in CI chondrites [6]. These results raise several questions about the nature and fate of carbon compounds in Ceres: Could organics form from scratch in Ceres? What is the fraction of CO_2 and CH_4 sequestered in clathrates? What is the nature of the relationship between carbonates and organics found together in the Ernutet region [3]? What is the fate of organics accreted from the solar nebula in Ceres' early ocean? The latter is expected to be alkaline and with abundant hydrogen, akin to that of Enceladus, as illustrated by the similarities in the salt compounds found at both objects [2,6].
A major difference between the two bodies is the mechanism of exposure of organics on the surface. In the open system of Enceladus, a diversity of organic material may be expelled with oceanic material when the Tiger Stripes open. On Ceres, the concentration of organics observed in the Ernutet region requires a concentration mechanism. As the densities and viscosities of organics vary with chain size, a possible concentration mechanism is density-driven stratification resulting from separation during early differentiation. The implication of this mechanism is the preferential segregation of low density organics in the crust. This paper will review the origins and evolution of organics in Ceres and likely exposure mechanisms.

Acknowledgements: Part of this work is being carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

[1] De Sanctis et al. (2015) *Nature* 528, 241-244. [2] De Sanctis et al. (2016) *Nature* 536, 54-57.12. [3] De Sanctis et al. (2017) Science 355, 719-722. [4] Ermakov et al. (2017) *JGR* 122, 2267-2293. [5] Fu et al. (2017) *EPSL* 476, 153-163. [6] Prettyman et al. (2018) Icarus, doi: 10.1016/j.icarus.2018.04.032. [7] Castillo-Rogez et al. (2018) MAPS, in press.

03:10 PM-03:20 PM
409.03 Occator Crater, Ceres, at 35 km Altitude: Nature and Origin(s) of Bright Carbonate Deposits and Lobate Floor Materials
Paul Schenk[1], Carol Raymond[7], Julie Castillo-Rogez[7], Christopher T. Russell[2], Debra Buczkowski[3], Simoni Marchi[4], Lucy McFadden[5], David O'Brien[6]
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Abstract
Dawn XM2 very-high-resolution imaging of the 92-km-diameter Occator crater reveals a wealth of detail on the terraces, central structures, bright carbonate deposits and floor deposits within. The lobate floor deposit is complex. Smoother plains on the crater floor are densely pitted and interrupted by conical to irregular-shaped knobs, massifs, scarps, and irregular rings of non-impact origin. Clusters of irregular pits occur in several locations and are clearly non-impact, suggesting collapse or volatile release. The knobs

and massifs could be impact debris (forming kipuka surrounded by flows) or post-emplacement pingo-like formations on top the floor deposit. Some of the knobs are capped by a cliff-forming resistant layer. Curvilinear scarps, 100-200 m high and often capped by a similar resistant layer, are observed in the terraces of the southeastern floor, and face inward. These scarps and cliff-forming units suggest partial withdrawal of cryolava beneath a refrozen carapace toward crater center, perhaps linked to cryolava break-outs to the north. These features have some resemblance to impact melt deposits on the Moon, but the distinct characteristics (rilles, pit clusters, ring structures, and possibly pingos) are likely related to Ceres' volatile rich crustal composition and lower impact velocities. Impact models indicate melting of water ice, which will mix with unmelted silicates, salts and carbonates to form floor deposit of "impact mud" or slurry. The observed features may be the result of the physical solidification and geochemical differentiation of this material, including possible hydrolaccolithic uplifts and localized venting.

03:20 PM-03:30 PM

409.04 Geomorphology and Distribution of Ground Ice-related Features in Occator

Kayla D. Duarte[1], Britney E. Schmidt[1], Hanna G. Sizemore[2], Izzy Burgess[3], Vivian N. Romero[1], Jennifer E. Scully[4], Paul Schenk[5], Kynan Hughson[6], Andreas Nathues[7], Julie Castillo-Rogez[4], Carol Raymond[8]
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Abstract
Dwarf planet Ceres, the largest body in the asteroid belt, has been explored by NASA's Dawn Mission. During Dawn's second extended mission (XM2), the spacecraft reached a closest range of 35 km altitude, achieving unprecedented resolution FC images at 5 m/px and providing the chance to observe features previously unresolvable. Occator crater, most notably recognized for its patches of bright material and varied geological features, is the main target of XM2. Other regions along the longitude swath sampled by the orbit have also been observed at similar resolution. Among the most numerous of the features we can now resolve within Occator crater are morphologically similar to those that signify ground ice on other planets. Candidate frost-heave features such as pingos, potentially effusive ridges, extensional fractures, small mounds, and quasi-polygonal topographic features are prominent in this region, and are commonly associated with the presence of water ice in terrestrial permafrost and periglacial settings. Examining regional placement and groupings of these features within Occator helps to mold our understanding of the potential interaction of ice and water within the subsurface of Ceres with its regolith. Preliminary analysis has shown small mounds present in clusters within Occator, many near its central dome, with typical diameters ranging from 100 to 500m. Polygonal topography and possible pingos with associated bright material have also been identified, potentially arising from freezing of ground water within the subsurface formed by emplacement of a melt sheet during Occator's formation. Fractures and ridges are in some cases associated with the presence of small mounds. Among the hypotheses these new data can address is the potential role of the thermal expansion of freezing water in facilitating cracking of the surface. Studying these features within Occator, a geologically young impact crater, helps supplement our understanding of other older features believed to have undergone similar processes as Occator, therefore uncovering clues pertaining to Ceres' geologic past and evolution.

03:30 PM-03:40 PM

409.05 What Can Surface Observations Tell Us About Ceres' Interior?

Scott King[1], Michael Bland[6], Julie Castillo-Rogez[2], Anton I. Ermakov[2], Roger R. Fu[3], Simoni Marchi[4], Carol A. Raymond[2], Jennifer E. Scully[2], Hanna G. Sizemore[4], Christopher T. Russell[5]
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Abstract

While we now know much about the volatile-rich world of Ceres from the Dawn mission, the deep interior of Ceres remains something of an enigma, shrouded by a crust composed of carbonates, salts, phyllosilicates, water ice, and organic material. Plausible compositions and evolutionary histories of Ceres predict strong, weak, or heterogeneous rheology for the silicate-rich interior of Ceres. Modeling topographic relaxation requires that the viscosity decrease by 10x for every 10-km increase in depth for at least 100 km depth, while admittance and hydrostatic modeling of the shape and gravity field require a clathrate-salt-ice-rock crust that is no more than 40 km in thickness overlying a silicate mantle. Thus, at least the uppermost 60 km of the silicate-rich mantle is mechanically weak (i.e., viscosity < 10^{21}Pa s). The viscosity below this depth depends strongly on the assumed degree of lithification.

A highly viscous interior is effectively rigid and cools by diffusion while an unlithified interior could deform by frictional sliding facilitated by pore fluids if there is sufficient water present. The intermediate viscosity regime (i.e., 10^{19}-10^{21}Pa s) leads to a single upwelling plume that carries the accumulated heat from deep within the interior to near the surface, followed by diffusive cooling. This plume event occurs as the internal temperature reaches the point where the Rayleigh number exceeds the critical value. Numerical modeling shows that a plume event produces sufficient lithospheric strain to erase a previous surface cratering record, possibly explaining the absence of large craters on Ceres. The hemispheric asymmetry of the upwelling explains the observed pit chains called the Samhain Catenae that have been interpreted as the surface expression of subsurface extensional fractures from an upwelling that formed beneath Hanami Planum. The topographic high and thickened crust of Hanami Planum could also be formed by the interaction between the warm upwelling and the lithosphere. The preferential location of the large domes (tholi)in this hemisphere is consistent with a warmer region of the interior due to the upwelling.

Thursday, October 25, 2018
01:30 PM-03:30 PM
Ballroom C (Knoxville Convention Center)

410 Extrasolar Planets and Systems: Atmospheric, Dynamical, and Evolutionary Models
Chair(s): Sarah Morrison, Christa Van Laerhoven

01:30 PM-01:40 PM
410.01 Photochemical Oxygen in Non-1-bar CO_2 Atmospheres of Terrestrial Exoplanets
Tre'Shunda James[1, 2], Renyu Hu[1, 3]
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, United States, [2]Occidental College, Los Angeles, California, United States, [3]Division of Geological and Planetary Science, California Institute of Technology, Pasadena, California, United States

Abstract
Atmospheric photochemistry models have shown that photochemically produced O_2 can build up on potentially habitable exoplanets having CO_2-rich atmospheres. However, existing models assume a surface pressure of 1 bar. We model terrestrial exoplanets with non-1-bar CO_2-dominated atmospheres. We use a one-dimensional photochemistry model to calculate the abundance of O_2 under surface pressures ranging from 0.1-10 bars and outgassing rates ranging from ~20x the present-day Earth's volcanic rate to the present-day Venus's volcanic rate. Our model shows that surface pressure is a controlling parameter in the photochemical stability of CO_2 atmospheres and molecular oxygen buildup. At higher-than-Earth outgassing rates, the abundance of abiotic oxygen monotonically decreases as the surface pressure increases. The opposite trend occurs at lower outgassing rates. No detectable level of oxygen can build up under Earth or high-than-Earth outgassing rates, despite the surface pressure. In atmospheres with lower-than-Earth volcanic rates, abiotic oxygen can build up to the detectable level (10^{-3} in volume mixing ratio) for surface pressures larger than ~1 bar. Our results highlight the need to understand the atmospheric context in the search for biological activities via atmospheric O_2 on exoplanets.

01:40 PM-01:50 PM
410.02 Photochemistry Producing Haze particles in Cool Exoplanet Atmospheres: Insight from Laboratory Simulations
Chao He[1], Sarah M. Horst[1], Nikole Lewis[2], Xinting Yu[1], Patricia McGuiggan[1], Julianne Moses[3]
[1]Earth and PlanetarySciences, Johns Hopkins University, Baltimore, Maryland, United States, [2]Cornell University, Ithaca, New York, United States, [3]Space Science Institute, Boulder, Colorado, United States

Abstract
Photochemical hazes are present in atmospheres of many Solar System bodies (such as Venus, Earth, Jupiter, Saturn, Titan, Triton, and Pluto), and photochemical processes could also produce haze particles in atmospheres of exoplanets. Transit observations show signs of aerosols (clouds or hazes) in atmospheres of a number of small planets (radius smaller than Neptune) with cool temperatures (Teq <1000 K). There are no solar system analogues in both size and equilibrium temperature for these planets, and the atmospheres are expected to have various compositions. In order to understand the photochemistry and haze formation in these atmospheres, we performed laboratory simulation experiments for a range of exoplanet atmospheres (100×, 1000×, and 10000× solar metallicity at three temperatures, 300, 400, and 600 K) using the PHAZER (Planetary Haze Research) chamber at Johns

Hopkins University (He et al. 2017). The experiments started with H_2, H_2O, and CO_2dominated atmospheres and used one of two energy sources (AC glow plasma and UV photons) to initiate chemical reactions. We find that all simulated atmospheres resulted in haze formation with both energy sources, but the production rates vary a lot with different conditions (He et al. 2018a, 2018b; Hörst et al. 2018). We also investigated the gas phase chemistry and the properties of haze particles. The result indicates that the precursors and chemical processes responsible for haze formation are different in different simulated atmospheres, and the resulted haze particles exhibit distinct physical and chemical properties. Our laboratory results can help to guide exoplanet atmosphere modeling, and to interpret current and future atmospheric observations of exoplanets.

Ref:

He, C., Hörst, S. M., Riemer, S., Sebree, J. A., Pauley, N., Vuitton, V. 2017, APJL, 841, L31
He, C., Hörst, S. M., Lewis, N. K., et al. 2018, ApJL, 856, L3
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Hörst, S. M., He, C., Lewis, N. K., et al. 2018, Nat. Astron., 2, 303

01:50 PM-02:05 PM
410.03D Bayesian Inference of Giant Exoplanet Physics

Daniel P. Thorngren, Jonathan J. Fortney
Physics, University of California, Santa Cruz, Santa Cruz, California, United States

Abstract

The many giant planet discoveries of recent decades provides a valuable dataset for population-level analysis complementary to the detailed study of solar-system giants. By constructing interior models of observed warm giant planets, we have been able to estimate their bulk metallicity and uncover a relationship between planet mass and bulk metallicity. Applying this relationship to hot Jupiters, we estimated the heating required to inflate them to their observed radii as a function of incident flux. This knowledge allows us to make complete Bayesian models of giant planets at a broad range of temperatures, yielding estimates of their anomalous heating and bulk metallicity. Of particular interest is the upper limits this places on atmospheric metallicity, which is observable by transit and emission spectroscopy. Finally, we investigated whether hot Jupiters inflate further as a result of their parent stars' main sequence brightening; whether this occurs depends strongly on the mechanism causing the radius inflation effect.

02:05 PM-02:20 PM
410.04D Flying Exomoons on Jumping Jupiters

Yu-Cian Hong[1], Jonathan I. Lunine[1], Philip D. Nicholson[1], Sean N. Raymond[2]
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Abstract

Planet–planet scattering is the leading mechanism to explain the broad eccentricity distribution of observed giant exoplanets. Here we study the orbital stability of primordial giant planet moons in this scenario. We use *N*-body simulations including realistic oblateness and evolving spin evolution for the giant planets. We find that the vast majority (~80%–90% across all our simulations) of orbital parameter space for moons is destabilized. There is a strong radial dependence, as moons beyond 0.1 R_{Hill} are systematically removed. Closer-in moons on Galilean-moon-like orbits (<0.04 R_{Hill}) have a good (~20%–40%) chance of survival. Destabilized moons may undergo a collision with the star or a planet, be ejected from the system, be captured by another planet, be ejected but still orbiting its free-floating host planet, or survive on heliocentric orbits as "planets." The survival rate of moons increases with the host planet mass but is independent of the planet's final (post-scattering) orbits. Based on our simulations, we predict the existence of an abundant galactic population of free-floating (former) moons.

02:20 PM-02:30 PM

410.05 The resilience of *Kepler* systems to stellar obliquity

Christopher Spalding[1], Noah Marx[2], Konstantin Batygin[3]

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Abstract

The Kepler mission and its successor K2 have brought forth a cascade of transiting planetary systems. Whereas many of these systems exhibit multiple transiting members, an unexpectedly large fraction possess only a single transiting planet. This high abundance of singles has been hypothesized to arise from significant mutual inclinations between orbits in multi-planet systems. However, the primary mechanism driving these large mutual inclinations in single-transiting systems remains unresolved. In this work, we propose that planetary systems typically form with a coplanar, multiple-planetary architecture, but that quadrupolar gravitational perturbations, arising from their rapidly-rotating host star, subsequently disrupt this primordial coplanarity. Given sufficient stellar obliquity, even systems beginning with 2 planetary constituents are susceptible to dynamical instability soon after planet formation as a result of the stellar quadrupole moment. This mechanism stands as a widespread, yet poorly explored pathway toward planetary system instability. Moreover, we are able to place upper limits on the stellar obliquity in systems such as K2-38 (obliquity < 20 degrees), where other methods of measuring spin-orbit misalignments are not currently available.

02:30 PM-02:40 PM

410.06 The Origin and Evolution of the Kepler-36 System

Thomas Rimlinger, Douglas Hamilton

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Abstract

We examine origin scenarios for the Kepler-36 system, which features two very different planets: the inner body, Kepler-36 b (ρ= 7.46 g cm^{-3}) and the outer body, Kepler-36 c (ρ= 0.89 g cm^{-3}). They are separated by just ~0.01 AU and orbit their host star at ~0.1 AU. In our origin scenario, Kepler-36 c, a gaseous sub-Neptune, and Kepler-36 b, a rocky super-Earth, form beyond and within the ice line, respectively. The more massive Kepler-36 c quickly migrates inward and captures its slower neighbor into its 2:1 mean-motion resonance; the pair then moves inward through a swarm of smaller bodies. Subsequent collisions with these objects raise Kepler-36 b's mass and density (via self-compression), strip its atmosphere, and occasionally knock it out of resonance. While such impacts have an equal chance of moving Kepler-36 b radially towards or away from its outer neighbor, Kepler-36 c's faster migration rate ensures that the planets always recapture into *some* resonance. If Kepler-36 b is kicked away from Kepler-36 c, they recapture into the original resonance, but otherwise, they are captured into a closer one. In this way, their orbital separation gradually shrinks.

We also investigate how much mass an impactor needs to eject its target from resonance. For Kepler-36

b, we find that an object with mass ~ a few M_{Moon} is sufficient. This allows us to estimate a range for how many resonance-ejecting collisions Kepler-36 b might experience, given a mass distribution for the planetesimal swarm. In addition, this critical mass has bearing on the formation and longevity of resonant chains as the two planets move inward. In principle, nothing prevents other objects from getting trapped in resonance with Kepler-36 b. However, as smaller bodies are dislodged by even smaller and more numerous impactors, we expect that such resonant chains would not persist long. We are in the process of quantifying this with targeted numerical integrations.
We performed over 3,000 simulations of our scenario; several reproduced the observed masses and period ratio for Kepler-36 b and c, although these successes were rare. However, since the Kepler-36 system is unusual amongst exoplanets, this is perhaps not a bug but a feature.

02:40 PM-02:50 PM
410.07 Gas flow around a planet embedded in a protoplanetary disc: the dependence on the planetary mass
Ayumu Kuwahara[1], Hiroyuki Kurokawa[2], Shigeru Ida[2]
[1]Tokyo Institute of Technology, Ookayama, Meguroku, Tokyo, Japan, [2]Earth-Life Science Institute, Ookayama, Meguro-ku, Tokyo, Japan

Abstract
The ubiquity of short-period super-Earths remains a mystery on the planet formation, as these planets are expected to become gas giants via runaway gas accretion within the lifetime of protoplanetary disc. Super-Earths cores should be formed in the late-stage of the disc evolution to avoid the runaway gas accretion.
The three-dimensional structure of the gas flow around a planet is thought to influence the accretion of both gas and solid materials. Especially, the outflow in the mid-plane region may prevent the accretion of the solid materials and delay the formation of super-Earths cores. However, it has not been understood how the nature of the flow field and outflow speed change as a function of the planetary mass. In this study, we investigate the dependence of gas flow around a planet embedded in a protoplanetary disc on the planetary mass and discuss the implication for the formation of super-Earths.

Assuming the isothermal, inviscid gas disc, we perform three-dimensional hydrodynamical simulations on the spherical polar grid in which a planet is located at the centre. We find that, gas enters the Bondi or Hill sphere at high latitudes and exits it through the mid-plane region of the disc regardless of the assumed dimensionless planetary mass $m=R_{\mathrm{Bondi}}/H$, where R_{Bondi} and $H$are the Bondi radius of the planet and disc scale height, respectively, which is consistent with previous studies. The topology of the flow field does not significantly change as a function of m. However, the altitude from where gas predominantly enters the envelope varies with the planetary mass. From an analytical estimation, the outflow speed can be expressed as $|u_{\mathrm{out}}|=\sqrt{(3/2)}mc_{\mathrm{s}}(R_{\mathrm{Bondi}}\leq R_{\mathrm{Hill}})$ or $|u_{\mathrm{out}}|=\sqrt{(3/2)}\ (m/3)^{1/3}\ c_{\mathrm{s}}\ (R_{\mathrm{Bondi}}\geq R_{\mathrm{Hill}})$, where c_{s} is the isothermal sound speed and R_{Hill} is the Hill radius. Our results suggest that the flow in the vicinity of proto-cores would delay the formation of super-Earths cores and, consequently, help them to avoid the runaway gas accretion within the lifetime of gas disc.

02:50 PM-03:00 PM
410.08 Transit Duration Variations in Multi-Planet Systems
Christa Van Laerhoven, Aaron Boley, Agueda Paula Granados Contreras
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Abstract
As a planetary orbit evolves, changes in the inclination and eccentricity vectors can cause the duration of a planet's transit to vary. For nearly circular orbits, these Transit Duration Variation (TDVs) are dominated by the inclination vector, in which the duration is set by the projection of the planet's orbit onto the star (i.e., the chord length). Because it is a projection, the observed chord length is determined by the magnitude of the orbital inclination, as well as the location of the ascending node. TDVs can thus be the result of changes in only the magnitude of the inclination, only the location of the ascending node, or both. We use secular theory to create a ranked list of planetary systems that are expected to produce the largest observable Transit Duration Variations (TDVs) on decade timescales. Select systems are also explored using direct n-body calculations, using an ensemble of initial conditions that are consistent with the current transit durations and explore the allowed parameter space of the full inclination vector. Simulations of Kepler-11, Kepler-442, K2-132, and TRAPPIST-1 demonstrate that, when the full inclination vector is considered, large, observable TDVs are likely in such systems and that planets are able to go from transiting to non-transiting states.

03:00 PM-03:10 PM
410.09 Obliquity Variations of a Potentially Habitable Kepler-62f
Billy Quarles[1], Jason W. Barnes[2], Jack Lissauer[3], John Chambers[4]
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Abstract
The Kepler mission discovered a few exoplanets that may be habitable assuming Earthlike atmospheric conditions and one such planet resides in the Kepler-62 system. We explore the obliquity, or axial tilt, evolution of the outermost planet, Kepler-62f, using N-body simulations to identify the sensitivity to assumptions on the planetary masses and perturbations due to long period (> 1000 days) gas giant companions. Changes in obliquity are typically small when long period gas giants are neglected, unless overlap occurs with the rotational precession and the orbital secular frequency. However, large obliquity variations (up to 60°) can occur when gas giant planets on long period orbits are included. The implications of this obliquity variation, along with changes in orbital eccentricity, on the potential habitability of the exoplanet will also be discussed.

03:10 PM-03:20 PM
410.10 Ultimate Thule vs Comets vs Pluto: Placing New Horizons' Next Flyby Target in a Solar System & Exosystem Context
Carey M. Lisse[1], Alan Stern[2], Susan Benecchi[3], Richard P. Binzel[4], Pontus Brandt[1], Bonnie J. Buratti[5], Andrew Cheng[1], Dale Cruikshank[6], Mihaly Horanyi[7], William B. McKinnon[8], Ralph McNutt[1], Jeffrey M. Moore[6], Catherine Olkin[2], Alex Parker[2], Joel Parker[2], Andrew Poppe[11], Kirby D. Runyon[1], John Spencer[2], Michael E. Summers[12], Orkan Umurhan[9], Anne Verbiscer[10], Harold Weaver[1], Leslie A. Young[2]
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Abstract
Kuiper Belts, thought to be the edge of a star's original protoplanetary disk, are common, perhaps ubiquitous processes of planetary systems - at least 30% of all stars have them according to Spitzer and Herschel surveys. New Horizons is the first spacecraft to ever survey our Kuiper Belt, making measurements on its smallest dust particles up to its largest body, Pluto, and on a number of bodies in between. For example, the *New Horizons* encounter with *Ultima Thule* on 1 January 2019 will be the first time a spacecraft has ever closely observed one of the small free-orbiting denizens of the Kuiper Belt. Potentially related, via inward scattering from the Kuiper Belt through the Centaur region and into the inner solar system, to the short period comets explored by spacecraft such as *Giotto, Deep Impact, Stardust*, and *ROSETTA*, *Ultima Thule* will also be the largest, most distant, and most primitive body yet visited by spacecraft.

In this paper we attempt to put the results from these measurements in a planetary system formation and evolution context. We argue that while the Kuiper Belt may have some dynamical similarities to our inner relic planetesimal asteroid belt (e.g., pronounced resonances with a giant planet and scattered disk objects), stable massive inner Gyr-old asteroid belts may be rare. By contrast, all stellar systems must form from edge-truncated disks which produce Kuiper Belts with a unique history at the outer edge of their solar systems. This unique history may or may not involve systems that are in slow, frustrated collisional equilibrium interrupted by planetary perturbations, judging from the reported frequency of our system's KBO binaries and bilobate inner system cometary nuclei and the distribution of mass in the known KBO population.

03:20 PM-03:30 PM
410.11 Magnetic Effects Determine the Spin Rates of Giant Planets
Konstantin Batygin
Division of Geological & Planetary Science, California Institute of Technology, Pasadena, California, United States

Abstract
Within the general framework of the core-nucleated accretion theory of giant planet formation, the conglomeration of massive gaseous envelopes is facilitated by a transient period of rapid accumulation of nebular material. While the concurrent build-up of angular momentum is expected to leave newly formed planets spinning at near-breakup velocities, Jupiter and Saturn, as well as super-Jovian long-period extrasolar planets, are observed to rotate well below criticality. In this talk, I will argue that the large luminosity of a young giant planet simultaneously leads to the generation of a strong planetary magnetic field, as well as thermal ionization of the circumplanetary disk. The ensuing magnetic coupling between the planetary interior and the quasi-Keplerian motion of the disk results in efficient braking of planetary rotation, with hydrodynamic circulation of gas within the Hill sphere playing the key role of expelling spin angular momentum to the circumstellar nebula. These results place early-stage giant planet and stellar rotation within the same evolutionary framework, and motivate further exploration of magnetohydrodynamic phenomena in the context of the final stages of giant planet formation.

Thursday, October 25, 2018
03:30 PM-06:00 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

411 HAYABUSA2 Special Session Posters
Chair(s): Deborah Domingue

411.01 A first look of boulders on asteroid Ryugu: Comparison with other small asteroids.
Tatsuhiro Michikami[1], Chikatoshi Honda[2], Masaki Kawamura[1], Kiichi Sugimoto[1], Eri Tatsumi[3], Hideaki Miyamoto[3], Masatoshi Hirabayashi[4], Tomokatsu Morota[5], Takaaki Noguchi[6], Yuichiro Cho[3], Shingo Kameda[7], HIROSHI KIKUCHI[3], Toru Kouyama[8], Masahiko Hayakawa[9], Ryodo Hemmi[3], Naoyuki Hirata[10], Naru Hirata[2], Rie Honda[11], Moe Matsuoka[9], Naoya Sakatani[9], Hidehiko Suzuki[12], Yasuhiro Yokota[9], Manabu Yamada[13], Kazuo Yoshioka[3], Hirotaka Sawada[9], Seji Sugita[3]
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Abstract
The existence of boulders on asteroids provides an opportunity to study the physical properties and the geological evolution of asteroid surfaces and, in particular, their collisional history. The surface of asteroid Ryugu is covered with numerous boulders although gravity is small. Here we report on the preliminary data for the boulders on the entire surface of Ryugu based on the images (1 pixel ~ 2 m) obtained by the Hayabusa 2 spacecraft.
The boulders are formed by impact cratering and/or catastrophic disruption of the parent asteroid. The number density of the boulders reflect their origin. For instance, the boulders on the two asteroids Ida and Eros are attributed to impact cratering because of relatively low number densities of the boulders. On the other hand, the boulders on the asteroid Itokawa are the fragments ejected from the disruption of the larger parent body of Itokawa because of relatively high density of the boulders. The number density of the boulders on Ryugu is at least twice as large as Itokawa. Thus, from the point of view of the number density, the boulders on Ryugu are considered to be the fragments ejected from the disruption of its larger parent body. Besides, two observational evidences support this as follows. First one is that, in the case of Ryugu, the relatively size of the largest boulder to the largest (candidate) crater is higher compared with Itokawa and Eros. That is, the largest boulder on Ryugu could not be produced by impact cratering. Second one is that, the shape distribution of the large boulders on Ryugu is similar to that on Itokawa. According to Michikami et al. (2016), this means that these boulders are produced by catastrophic disruptions. Therefore, we conclude that most boulders are surviving fragments from the parent body of Ryugu, accreted after its breakup.

411.02 Color Maps of Asteroid Ryugu from ONC-T Camera Onboard *Hayabusa2*: Correlations Between Color Units and Topography to Understand its Formation and Evolution
Lucille Le Corre[1], Adriana M. Mitchell[2], Jian-Yang Li[1], Eri Tatsumi[3], Seiji Sugita[3], Naoyuki Hirata[4], Naru Hirata[5], Carolyn M. Ernst[6], Rie Honda[7], Tomokatsu Morota[8], Shingo Kameda[9], Yasuhiro Yokota[10], Toru Kouyama[11], Hidehiko Suzuki[12], Manabu Yamada[13], Naoya Sakatani[10], Chikatoshi Honda[5],

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Abstract
The *Hayabusa2* spacecraft arrived at the Apollo-type near-Earth Asteroid (NEA) Ryugu on June 27, 2018. The main goal of the mission is to return regolith samples to Earth at the end of 2020. Ryugu is a ~900-m Earth-crossing NEA with a rotation period of about 7.6 h. During its operations in the vicinity of the asteroid, the spacecraft will characterize the surface using several scientific instruments and deploy four rovers, one lander, and an impactor. During the science observations and sampling phase, the Optical Navigation Camera - Telescopic (ONC-T) will map the surface of the asteroid using seven color filters (0.4-1.0 microns) and a broadband clear filter at a resolution of at least ~2 meters/pixel. Ryugu is a C-type NEA thought to be rich in carbonaceous material and hydrated silicates. Some ground-based observations suggest the presence of a 0.7-microns absorption feature similar to carbonaceous chondrite meteorites. This meteorite type, being very dark, is a good analog for Ryugu given the very low albedo of the surface. We will present our color image mosaics using ONC-T filters and how they can be used to constrain the surface composition of Ryugu. In particular, we will look at the correlation between surface color and topography. Finally, we will explain how our higher-level data products, generated in near real time, help characterize potential landing and sample sites on Ryugu.

Acknowledgements: NASA *Hayabusa2* Participating Scientist program, the OSA Paul Anthony Bonenfant Memorial Scholarship*,* JSPS program International Planetary Network.

411.03 Initial results of 3D mapping of lineaments on Ryugu

HIROSHI KIKUCHI[1], Goro Komatsu[2], Hideaki Miyamoto[1], Ryodo Hemmi[1], Naoyuki Hirata[3], Naru Hirata[4], Chikatoshi Honda[4], Tatsuhiro Michikami[5], Yuichiro Cho[1], Tomokatsu Morota[6], Rie Honda[7], Shingo Kameda[8], Eri Tatsumi[1], Yasuhiro Yokota[9], Toru Kouyama[10], Hidehiko Suzuki[11], Manabu Yamada[12], Naoya Sakatani[9], Masahiko Hayakawa[9], Kazuo Yoshioka[1], Moe Matsuoka[9], Olivier S. Barnouin[13], Sho Sasaki[14], Masatoshi Hirabayashi[15], Hirotaka Sawada[9], Seiji Sugita[1]
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Abstract
Lineaments are features commonly observed on many asteroids such as (951) Gaspra, (433) Eros, (21) Lutetia, and (4) Vesta. These lineaments are identified in variable forms including ridges, troughs, grooves and pit crater chains. For understanding their formation processes, three-dimensional analysis can be important especially when they are found on an irregularly-shaped small bodies, such as Ryugu; we note that, although Ryugu at distance appeared to be quite symmetric, at higher-resolutions Ryugu exhibits many irregularities in its shape due to large depressions and uplifts. On its boulder-rich surface,

we identified various types of lineaments including the prominent equatorial ridge, trough-like depressions, narrow depressions, and aligned ridges which may host boulders. Based on these observations, we mapped all the observable lineaments directly on a shape model while considering the influence of solar incidence angle. These mapped lineaments were then analyzed statistically and categorized into various morphological types. In this presentation, we report the initial results regarding the morphology and distribution of the various kinds of lineaments on the 3D Ryugu shape model.

411.04 Initial report of Hayabusa2 LIDAR

Noriyuki Namiki[1, 2], Hiroki Senshu[3], Hirotomo Noda[1, 2], Koji Matsumoto[1, 2], Yoshiaki Ishihara[4], Ryuhei Yamada[5], Hiroshi Araki[1], Keiko Yamamoto[1], Naru Hirata[5], Shinsuke Abe[8], Fumi Yoshida[3], Arika Higuchi[1], Hideaki Miyamoto[6], Hitoshi Ikeda[4], Fuyuto Terui[4], Sho Sasaki[7], Shoko Oshigami[1], Seiitsu Tsuruta[1], Kazuyoshi Asari[1], Seiichi Tazawa[1], Makoto Shizugami[1], Hirohide Demura[5], Jun Kimura[7]
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Abstract

After the arrival at Ryugu on June 27, Laser Altimeter of Hayabusa2, LIDAR, is continuing to collect topography data of the asteroid. On the occasion of scan mapping on July 11, LIDAR successfully measured the global topography except for the two polar areas. The measurement shows a good agreement with shape models which have been developed from camera images independently thus indicating an excellent performance of LIDAR even after two-year suspension during transfer phase. The LIDAR data are used to adjust a scale of the shape models
Space craft orbits with respect to the asteroid are refined using LIDAR data. While an orbit of the Hayabusa2 space craft in an inertial reference system is determined from range and range rate data taking by the ground stations, the space craft position in the asteroid-center reference system is subject to an ambiguity of the orbit of Ryugu which exceeds 10 km. The distance from the space craft to the asteroid surface is essential to spectrometer images of NIRS3 and TIR.
We have measured cross sections of 7 craters on Ryugu using LIDAR data. The diameters and depths are between 100 and 250 m, and between 16 and 45 m, respectively, corresponding to depth/diameter ratios between 0.11 and 0.2. These values are consistent with those measured on other small bodies. The shape of four craters appear conical while other three craters show flat floor. The slope of crater wall is about 22 degrees. The flat floor and the slope close to an angle of repose may be suggesting mass wasting within craters.
The cross sections also show crater rims whose height is between 0 and 5 m. This observation is a notable difference from that of Itokawa craters which has little crater rim. Rimmed craters have been found on other small bodies, for example, Lutetia, however, are not common. Although Ryugu is said to be a rubble pile body on the basis of numerous boulders at the surface, physical properties of Ryugu could be different from those of Itokawa.

411.05 Crater size distribution and surface age of Ryugu

Tomokatsu Morota[1], Yuichiro Cho[2], Masanori Kanamaru[3], Rie Honda[4], Shingo Kameda[5], Eri Tatsumi[2], Yasuhiro Yokota[6], Toru Kouyama[7], Hidehiko Suzuki[8], Manabu Yamada[9], Naoya Sakatani[6], Chikatoshi Honda[10], Masahiko Hayakawa[6], Kazuo Yoshioka[2], Moe Matsuoka[6], Tatsuhiro Michikami[11], Hideaki Miyamoto[2], HIROSHI KIKUCHI[2], Ryodo Hemmi[2], Masatoshi Hirabayashi[12], Carolyn M. Ernst[13], Olivier S. Barnouin[13], Naoyuki Hirata[14], Naru Hirata[10], Hirotaka Sawada[6], Seiji Sugita[2]

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Abstract
Using high-resolution images of Ryugu obtained by Optical Navigation Camera (ONC-T) onboard Hayabusa2, we identified more than 50 craters larger than 20 m in diameter on the whole surface of Ryugu. The observed density of craters larger than 100 m in diameter approximates to the empirical saturation level, but the slope of size distribution is steeper than the saturation slope (power-law index of -2), implying that the large craters are under-saturated. The density of smaller craters is much less than that expected from the density of large craters and impactor population. The deficiency of the small craters suggests that some crater erasure processes such as seismic shaking are active on Ryugu. Using Ryugu cratering chronology model developed by combining the size distribution models of main-belt asteroids, collision probability and mean collision velocity in the main belt, and crater scaling laws, the surface age of Ryugu was estimated to be 0.1 to 1 billion years from the density of craters larger than 100 m in diameter. Also, we found that the crater density has a regional variation: the western bulge appears to have a lower crater density than the other area, suggesting different geologic history, including crater erasure processes.

411.06 Morphological features of craters on asteroid Ryugu

Yuichiro Cho[1], Tomokatsu Morota[2], Masanori Kanamaru[3], Rie Honda[4], Shingo Kameda[5], Eri Tatsumi[1], Yasuhiro Yokota[6], Toru Kouyama[7], Hidehiko Suzuki[8], Manabu Yamada[9], Naoya Sakatani[6], Chikatoshi Honda[10], Masahiko Hayakawa[6], Kazuo Yoshioka[1], Moe Matsuoka[6], Tatsuhiro Michikami[11], Hideaki Miyamoto[1], HIROSHI KIKUCHI[1], Ryodo Hemmi[1], Masatoshi Hirabayashi[12], Carolyn M. Ernst[13], Olivier S. Barnouin[13], Naoyuki Hirata[14], Naru Hirata[10], Hirotaka Sawada[6], Seiji Sugita[1]
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Abstract
The Hayabusa 2 spacecraft arrived at its target asteroid Ryugu on June 27, 2018. Images of the surface of Ryugu were acquired with the Optical Navigation Camera. A series of images were taken at a distance of 20 km from the asteroidal surface. We observed crater morphologies and distributions on Ryugu using 120 images sequentially taken from this position. The pixel scale of the images was 2 m. We have identified more than 50 crater candidates with varying morphologies so far. Crater diameters ranged from ~20 m to ~270 m. Many craters overlap with one another, forming clusters. A number of craters contain boulders of tens of meters in size on their floors [Honda et al., this meeting]. Among the crater candidates observed on Ryugu, more than 30 exhibited clear circular depressions. Some of the crater candidates have well-defined circular rims, while others show more degraded and obscure rims. These candidates were classified as circular depressions (CD). Less than 10 crater candidates have partially circular rims, potentially modified by subsequent geological processes, such as impacts or mass movements. We classified these candidates as quasi-circular depressions (QCD). Approximately 10 crater candidates

showed little to no depression, but exhibit circular features defined by the arrangement of boulders (quasi-circular features, QCF).

411.07 Geomorphological characteristics of asteroid Ryugu; initial results

Hideaki Miyamoto[1], Ryodo Hemmi[1], HIROSHI KIKUCHI[1], Goro Komatsu[2], Chikatoshi Honda[3], Tatsuhiro Michikami[4], Tomokatsu Morota[5], Yuichiro Cho[1], Olivier S. Barnouin[6], Sho Sasaki[7], Naoyuki Hirata[8], Naru Hirata[3], Rie Honda[10], Shingo Kameda[11], Eri Tatsumi[1], Yasuhiro Yokota[12], Toru Kouyama[13], Hidehiko Suzuki[14], Manabu Yamada[15], Naoya Sakatani[12], Masahiko Hayakawa[12], Kazuo Yoshioka[1], Moe Matsuoka[12], Masatoshi Hirabayashi[9], Hirotaka Sawada[12], Seiji Sugita[1]
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Abstract
Optical Navigation Camera (ONC-T) onboard Hayabusa2 spacecraft has started its proximity observation of Ryugu from June 2018. Already, some intriguing geomorphic characteristics of Ryugu have been identified. For example, while a diamond-like overall profile (a perfect north-south and a west-east symmetrical silhouette) is observed when viewed from the equatorial plane, Ryugu shows a perfect circular profile when viewed from either pole due to the existence of the equatorial circular ridge. The ridge is cut by some craters with relatively distinct rims. Ryugu has tens of circular depressions and numerous boulders, whose sizes range from less than a meter to more than 100m. We also identified relatively large trough-systems and many lineaments, which are mostly aligned boulders. We developed several types of equidistant cylindrical projection maps including orthographic image, digital elevation model, and shaded relief map based on the elevation model, which are used to map these geomorphological features in two dimensions. We map them on a three-dimensional shape model as well depending on the purpose of mapping. By using these geomorphological maps of Ryugu, we found that the spatial distributions of these features are not uniform over the surface of Ryugu, implying that Ryugu has at least two mappable units, which is also supported by subtle but non-negligible color and brightness variations.

411.08 Spectral comparison between asteroid (162173) Ryugu and carbonaceous meteorites

Moe Matsuoka[1], Tomoki Nakamura[2], Takahiro Hiroi[3], Kohei Kitazato[4], Takahiro Iwata[1], Masanao Abe[1], Kana Amano[2], Shiho Kobayashi[2], Takahito Osawa[5], Makiko Ohtake[1], Shuji Matsuura[6], Takehiko Arai[7], Yusuke Nakauchi[1], Hiroki Senshu[8]
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Abstract
Near-infrared Spectrometer (NIRS3) onboard Hayabusa2 successfully measured infrared spectra of the target asteroid Ryugu, at an altitude of 20 km from Ryugu. We compared the Ryugu spectra to carbonaceous chondrite spectra from RELAB and Tohoku University. The NIRS3 data obtained from

Ryugu surface has very low reflectance and no large absorption bands, ranging from 1.8 to 3.2 micrometer in wavelength, which makes data interpretation even challenging. We found that any reflectance spectra of hydrous carbonaceous chondrites such as Murchison CM do not match perfectly with Ryugu spectra. Our study indicated that the most similar spectra to Ryugu spectra are: (1) the spectra of carbonaceous chondrites heated and dehydrated moderately, and (2) the spectra of those having experienced impact and compression; those two types of altered chondrites showed that the hydrous silicate is dehydrated, and in terms of their spectra, albedo becomes lower and absorption band depth changes shallower. Further NIRS3 observation at a lower altitude with higher spatial resolution will improve the spectral interpretations.

411.09 Clustering analysis of visible spectra of asteroid Ryugu

Rie Honda[1], Yasuhiro Yokota[2], Eri Tatsumi[8], Ryo Hayashi[1], Antonella Barucci[11], Davide Perna[12], Deborah Domingue[13], Tomokatsu Morota[7], Shingo Kameda[3], Toru Kouyama[4], Hidehiko Suzuki[5], Manabu Yamada[6], Naoya Sakatani[2], Chikatoshi Honda[9], Masahiko Hayakawa[2], Kazuo Yoshioka[8], Moe Matsuoka[2], Yuichiro Cho[8], Yukio Yamamoto[2], Naru Hirata[9], Naoyuki Hirata[10], Yuki Fujii[1], Hirotaka Sawada[2], Seiji Sugita[8]
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Abstract
The Japanese asteroid exploration spacecraft, Hayabusa2, has arrived at asteroid Ryugu on June 27th, 2018 and started observing its surface morphology and the distribution of material across its surface. One of the optical navigation cameras on-board Hayabusa2, ONC-T, obtained multi-band spectra by imaging Ryugu with seven broadband filters ranging from 0.39- 095 µm. In order to extract representative reflectance spectra on Ryugu's surfaces and examine the spatial distribution of spectral properties for selecting landing site candidates, we conducted spectra clustering analysis as a part of our initial data examination efforts. Since the spectra on Ryugu has been found to be basically flat and there are only small deviations up to several percent among the bands, we carefully examined multiple methods of clustering, such as k-means, k-means++, x-means, and statistical methods focusing on the selection of the optimal number of the components, together with experiments using the artificial test spectra with noise. Preliminary results indicate that multiple clusters can be extracted from the Ryugu spectra. More detailed results will be shown in the presentation.
Acknowledgements: This study was supported by JSPS International Planetary Network.

411.10 Simulation of proximity imaging of Ryugu's surface during Hayabsua2 touch-down sequence

Akira Miura[1], Naoya Sakatani[1], Yasuhiro Yokota[1], Rie Honda[2], Chikatoshi Honda[3], Tomokatsu Morota[4], Manabu Yamada[5], Tatsuhiro Michikami[6], Naoko Ogawa[1], Hirotaka Sawada[1], Seiji Sugita[7]
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Abstract
Hayabusa2 spacecraft arrived at asteroid Ryugu (1999JU$_3$), and is going to land on the surface for sampling surface materials on October in this year. We have chance to obtain the surface proximity images by optical camera (ONC-W1) from a few meters altitude, before and after the touch down. These images will tell us about the surface physical condition, such as grain size and small-scale topography. Also, these proximity images are important for estimating the amount of the collected samples.

In this study, we constructed an imaginary 3-dimensional polygon model of a touch down candidate of the Ryugu's surface. Boulder size distribution and photometric function are considered based on the observations during the landing site selection. Then, we simulated the images that will be taken by ONC-W1 during the touch-down sequence. Shadow by the spacecraft and indirect illumination mainly from the spacecraft, and effect of flash lamp are included in the simulation. Using these simulated data, we discuss about strategy for analyzing the proximity observation data, which will soon be acquired.

411.11 Photometric Correction of Ryugu Multiband Visible Image Data

Yasuhiro Yokota[1], Rie Honda[3], Eri Tatsumi[2], Deborah Domingue[4], Tomokatsu Morota[5], Seiji Sugita[2], Shingo Kameda[6], Toru Kouyama[7], Hidehiko Suzuki[8], Manabu Yamada[9], Naoya Sakatani[1], Chikatoshi Honda[10], Masahiko Hayakawa[1], Kazuo Yoshioka[2], Moe Matsuoka[1], Yuichiro Cho[2], Hirotaka Sawada[1]
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Abstract
The multi-band visible camera (ONC-T) onboard the Hayabusa2 spacecraft is now observing the asteroid 162173 Ryugu. The ONC-T has 7 broadband filters ranging in wavelength from 0.39–0.95 μm. Since the measured radiance of the asteroid surface depends on the observation geometry, a photometric correction is needed to remove effects due to variations in illumination and viewing geometry, but preserve variations due to composition or physical properties. To apply an accurate correction, the selection of a photometric model and the derivation of the model parameters are crucial. After the arrival at Ryugu on June 27, 2018, we used the approach data set to derive a photometric correction and are now applying this correction to the ONC-T image data. We use a Hapke model and a parameter set for Ryugu derived from the combined dataset of the ground based observations, and approach phase disk-integrated and disk-resolved ONC-T data. Our analyses of the disk-resolved data also provide understanding of the variations in surface properties across this asteroid. We will present the current status of our analyses in this presentation.

411.12 The first report of observation of sodium cloud around Ryugu

Shingo Kameda[1], Seiji Sugita[2], Rie Honda[3], Eri Tatsumi[2], Yasuhiro Yokota[4], Toru Kouyama[5], Hidehiko Suzuki[6], Manabu Yamada[7], Naoya Sakatani[4], Chikatoshi Honda[8], Masahiko Hayakawa[4], Kazuo Yoshioka[2], Moe Matsuoka[4], Yuichiro Cho[2], Takahiro Sawada[4]
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Abstract
Mercury and Moon have a thin sodium exosphere. It is suggested that sodium atoms are released by interaction between the surface and its environment. Sodium depletes at the surface after heated to the temperature of ~ 630°C. If an asteroid has not been heated at the temperature, the surface should contain sodium atoms and it forms the exosphere. We discuss the effect of solar wind impact to the surface of Mercury on the formation of sodium exosphere and the plan to detect sodium emission from the C-type asteroid's exosphere.
We performed observation of the sodium exosphere on the C-type asteroid. *Hayabusa2*is the sample-return mission to the C-type asteroid, Ryugu. Emission from exospheric sodium around Ryugu would be detectable by Optical Navigation Camera (ONC) with the 0.59μm filter if the Na source rate on Ryugu is comparable with that on Mercury. Because Na is one of the most volatile metallic elements, it would be lost upon heating; Na depletion would occur at ~ 630°C. This Na depletion temperature is much higher than disappearance temperatures 400°C for 0.7μm and comparable to 600°C for 3 μm absorption bands, respectively. Moreover, the exospheric Na of planetary bodies is supplied from centimeters depth of subsurface, while the reflectance spectroscopy of solid surfaces is controlled by only a sub-millimeter thick surface layer. Thus, if the cm's-deep subsurface on Ryugu has not been heated at temperatures > 630°C, its Na abundance is probably higher than Mercury and Moon. Then, a tenuous but detectable Na atmosphere could be formed around the asteroid. If the heating of Ryugu surface is not uniform, exospheric Na distribution would exhibit nonuniformity. Such observations are useful for understanding the devolatilization state of Ryugu and helpful for selecting the touchdown site.

411.13 Spatial distribution of boulders on Ryugu

Chikatoshi Honda[1], Tatsuhiro Michikami[2], Yuichiro Cho[3], Tomokatsu Morota[4], Rie Honda[5], Shingo Kameda[6], Eri Tatsumi[3], Yasuhiro Yokota[7], Toru Kouyama[8], Hidehiko Suzuki[9], Manabu Yamada[10], Naoya Sakatani[7], Masahiko Hayakawa[7], Kazuo Yoshioka[3], Moe Matsuoka[7], Hideaki Miyamoto[3], HIROSHI KIKUCHI[3], Ryodo Hemmi[3], Masatoshi Hirabayashi[11], Hirotaka Sawada[7], Seji Sugita[3]
[1]The University of Aizu, Aizuwakamatsu, Japan, [2]Kindai University, Higashihiroshima, Japan, [3]The University of Tokyo, Tokyo, Japan, [4]Nagoya University, Nagoya, Japan, [5]Kochi University, Kochi, Japan, [6]Rikkyo University, Tokyo, Japan, [7]JAXA/ISAS, Sagamihara, Japan, [8]AIST, Tokyo, Japan, [9]Meiji University, Tokyo, Japan, [10]Chiba Institute of Technology, Narashino, Japan, [11]Auburn University, Auburn, Alabama, United States

Abstract
On June 27th, 2018, the Hayabusa2 spacecraft arrived at the destination, a tiny C-type asteroid 162173 Ryugu. The onboard Optical Navigation Camera - Telescopic (ONC-T) scrutinized the surface from the Home Position (HP, about 20 km sunward of Ryugu) and mid-altitude position. One of the most curious characteristics is the numerous boulders which are similar to the Itokawa surface. However, we cannot identify the "smooth terrains" observed on Itokawa. It's important to find out the site of the lower number of boulders on Ryugu for the safe landing of Hayabusa2 spacecraft.
Regarding to spatial distribution of boulders on Ryugu, we recognized an obvious deficiency of large boulders at the equatorial area. We examine the boulder diameter which is defined as the maximum dimension. As a result, the magnitude of boulder size-frequency distribution around the equatorial area is smaller than that at higher latitude region. The larger boulders at equatorial area seem to be covered by Ryugu's regolith migrated from higher latitude area. On the other hand, it seems to be difficult to accumulate even regolith from the topographic low at middle latitude to the topographic high at the equatorial area. This trend of the observation of boulder spatial distribution may be one of the key characteristics to solve the Ryugu's origin or evolution such as the orbital mechanism including its spin rate.

Thursday, October 25, 2018
03:30 PM-06:00 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

412 Ceres Posters
Chair(s): Paul Schenk

412.01 ALMA Thermal Mapping of Ceres: Search for Subsurface Water Ice
Jian-Yang Li[1], Timothy N. Titus[2], Arielle Moullet[3], Mark V. Sykes[1], Henry Hsieh[1]
[1]Planetary Science Institute, Tucson, Arizona, United States, [2]US Geological Survey, Flagstaff, Arizona, United States, [3]SOFIA/USRA, Moffett Field, California, United States

Abstract
Previous observations suggested that Ceres may host the largest amount of water in the inner solar system other than Earth. The Dawn mission mapped the whole surface of Ceres. While the detection of hydrated minerals is ubiquitous, only a few sites of areas up to a few km^2 host exposed water ice. The elevated abundance of hydrogen within a meter of the top surface indicates water ice or a high degree of hydration. Therefore, the thermal conditions at the surface and within a few annual thermal skin depths are critical for understanding the existence, status, history, and transportation of water ice beneath the surface of Ceres. While the Dawn near-infrared instrument maps Ceres at spatial resolutions down to ~100s m/pix, it can only measure temperatures >~180 K, which is confined in low-to-mid latitudes during the mid-day. Dawn thermal observations are also restricted in Ceres' season due to the mission duration, preventing the generation of accurate thermal models for Ceres down to annual thermal skin depths. For a complete mapping of the thermal conditions on Ceres, we observed Ceres with Atacama Large Millimeter/submillimeter Array at 1.3 mm wavelength in three epochs in October/November 2015, September 2017, and October 2017, each covering one full Ceres rotation. The spatial resolution at Ceres is about 100 km/beam for the first epoch, and 40-60 km/beam for other epochs. The goal is to map the thermal inertia and roughness down to 0.5-1 meter beneath the surface in order to identify regions with favorable thermal conditions for hosting water ice, and possible high thermal inertia areas that could be enriched in water ice. The modeling based on the first epoch of data indicate that Ceres has an overall low thermal inertia of less than a few tens of thermal inertia unit. The thermal inertia maps show high thermal inertia subsurface layer in the north polar region. The boundary of the ice table is between 50 and 70 deg north Latitude. These results are consistent with Dawn results. Detailed modeling and mapping process and results will be reported. This work is supported by the NASA Solar System Observations Pro-gram NNX15AE02G.

412.02 Using Millimeter/Submillimeter Spectra to Investigate the Potential Transient Exosphere of Ceres
Maxwell Parks, Conor Nixon, Martin Cordiner, Steven Charnley, Alexander Thelen, Maureen Palmer
NASA Goddard Spaceflight Center, Richmond, Virginia, United States

Abstract
The presence of a rarefied atmosphere around Ceres has been possibly indicated by observations over the past 30 years, but its consistency and pervasiveness has not yet been determined. The International Ultraviolet Explorer (IUE) failed to detect OH in 1990, but in 1991 observed the presence of OH around Ceres. Follow-up investigations in the mid 2000's by the Very Large Telescope (VLT) yielded no confirmation, nor did subsequent submillimeter observations by the Herschel Space Observatory (HSO)

in 2011. In late 2012 and 2013, however, strong signals of OH were detected by Herschel.

Modelling water vapor around Ceres show that thermal collisions around Ceres create velocities close to the escape velocity, indicating that any H2O is on the borderline between being bound gravitationally and not bound. Any heavier elements, however, would be more strongly bound. This research uses spectra from the Atacama Large Millimeter/submillimeter Array (ALMA) to investigate the possibility of a transient exosphere and detect its composition. We have searched for absorption lines of species including HCN, HCCCN, CO, and CCCN, without any conclusive evidence to date. Further analysis of additional data sets, molecules, and transition lines is ongoing, in order to cover more observational epochs and probe the temporal nature of any possible atmosphere.

412.03 Proposed Names for 74 Surface Features Associated with Ice on Ceres

Vivian N. Romero[1], Britney E. Schmidt[1], Kayla D. Duarte[1], Hanna G. Sizemore[2], Carol Raymond[3], Julie Castillo-Rogez[3]
[1]EAS, Georgia Tech, New Orleans, Louisiana, United States, [2]Planetary Science Institute, Tucson, Arizona, United States, [3]JPL, Pasadena, California, United States

Abstract

NASA's Dawn mission has been orbiting dwarf planet Ceres since 2015. Multiple lines of evidence support the presence of water ice in the subsurface, such as landslides, flow-like features, large domes, linear features, depressions, and bright spots. We have selected a subset of these features and have proposed names to the IAU for the ease of discussing ice related morphological features and surface interactions in future work.

Currently named Cerean features are large and morphologically varied craters, Ahuna Mons, Occator's faculae, and large fractures. However, other diagnostic features within craters thought to indicate a cryosphere include fracture systems, pitted materials, and central domes/pits. As the most numerous feature on the dwarf planet, craters are a useful reference point when discussing surface morphologies, thus we suggest that features clustered within these 27 craters can be referred to by crater name and feature type. More than 170 landslides have been identified on Ceres, with three distinct sub-types, spanning tens of kilometers and exposing tens of meters of Ceres' subsurface (Schmidt et al 2016). We have selected 16 of the largest landslides for naming as "*Labes*".

Sizemore et. al. (2018, in review) identified two classes of potentially ice-related domes, defined by their size and morphology, and named these as "*Montes*" for large features or "*Tholi*" for small domical mountains or hills. We suggested names for 10 prominent large domes, which exhibit 1-6km relief with diameters of 30-120km. Most of these features appear to be relatively geologically old. The small mounds feature class is comprised of over 200 morphologically diverse features (Buczkowski 2016) less than 10km in diameter with sub-kilometer topographical relief. We proposed the naming of 5 clusters of mounds and two solo small mounds.

Faculae seen in Occator led to the search for more effusive material with high albedo. The faculae have a distinct composition-- composed of mostly sodium carbonate and are proposed to be the solid residues of crystallized brines (Scully 2018). We selected 2 of these features for naming as "*Facula, faculae*" to continue the discussion of bright effusive material on Ceres' surface.

412.04 Arecibo radar observations of dwarf planet Ceres during the 2018 Apparition

Sriram S. Bhiravarasu[1], Edgard G. Rivera-Valentín[1], Patrick A. Taylor[1], Luisa F. Zambrano Marin[2], Betzaida A. Hernandez[1], Sean E. Marshall[2]
[1]USRA, Lunar and Planetary Institute, Houston, Texas, United States, [2]Arecibo Observatory, University of Central Florida, Arecibo, Puerto Rico, United States

Abstract
We report dual-polarization, Doppler-only radar observations of dwarf planet (1) Ceres that were obtained using the Arecibo planetary radar system (2380 MHz, 12.6 cm) during 2018 February 20 - 27. Each evening's observations comprised two runs, each consisting of a continuous-wave (CW), circularly polarized transmission lasting ~27 min. This was followed by receiving the Doppler-shifted echoes for an equal time, simultaneously in the same sense of circular polarization (SC) as transmitted and the opposite (OC) sense. The total of 9 runs yielded six valid echo power spectra. The weighted average of the individual spectra obtained at different asteroid rotation phases yielded an OC radar cross section of 2.52 ± 0.2×10^4 km^2, radar albedo of 0.036, and Circular Polarization Ratio (CPR) of 0.024, consistent with the 1986 Arecibo radar observations of Ceres [1]. A variation of ~10% in radar cross section was observed over the approximately 210° of apparent rotation phase. The Dawn spacecraft has gathered important data about the surface composition, internal structure, and geomorphology of Ceres. Ground-based radar observations compared with orbiter-based data may reveal insights to the near surface of Ceres.

References: [1] Mitchell et al., 1996, Icarus, 124, 113-133

Thursday, October 25, 2018
03:30 PM-06:00 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

413 Extrasolar Planets and Systems: Posters
Chair(s): Apurva V. Oza

413.01 Characterizing Extrasolar Planets from Transit Light Curves obtained at the Universidad de Monterrey Observatory – Part 3
Pedro V. Sada
Física y Matemáticas, Universidad de Monterrey, Shavano Park, Texas, United States

Abstract
At the Universidad de Monterrey Observatory (MPC 720) we carried out a program for observing exoplanet transits and registering their light curves using telescopes of modest aperture and standard photometric filters between 2005 and 2016. In our archives we have over 340 transits of over 75 known systems. Our goal is to combine individual transit light curves of the same system taken at different times but with the same equipment. We then analyze the combined light curves in conjunction with the radial velocity information available from the literature in order to confirm, improve or revise the main parameters that characterize the transiting system. It is important to systematically continue observing these systems not only to improve and refine our understanding of them, but also to record any possible transient phenomenon and monitor for possible period changes, as reflected in the mid-transit times.
We report our observations of 48 individual exoplanet transit light curves and the results from successfully combining 7 light curves for GJ 436 (Ic), 7 for HAT-P-20 (Ic), 5 for WASP-14 (Rc), 4 for WASP-26 (Ic), 5 for WASP-43 (Ic), 6 for WASP-50 (Ic), 6 for XO-2 (Ic), 4 for XO-3 (Ic), and 4 for XO-4 (Ic). From these we then derive planet sizes (R_p/R_*), orbital distances (a/R_*) and orbital inclinations (i) for these systems using standard modeling software such as EXOFAST and TAP. In most cases we confirm the parameters reported in the literature. For the GJ 436, WASP-50 and XO-2 systems we derive planet sizes which are marginally larger than literature values. For the WASP-43 and GJ 436 systems we derive slightly higher inclinations accompanied by slight increases in orbital distance compared with HST results. Our WASP-26 results show an anomalous 20% larger planet size, but we suspect that to be an artifact of light contamination in the light curve due to a nearby star. From our mid-transit times and those of the literature we do not find any statistically significant deviations from a fixed orbital period for these systems.
Our results validate the presented methodology and show that college observatories with small telescopes are able to adopt usefull extrasolar planet transit follow-up observing programs.

413.02 Obliquity Evolution of Simple Systems
Steven Kreyche[1], Jason W. Barnes[1], Billy Quarles[2], Jack Lissauer[3], John Chambers[5], Elisa Quintana[4]
[1]Physics, University of Idaho, Moscow, Idaho, United States, [2]University of Oklahoma , Norman, Oklahoma, United States, [3]NASA Ames Research Center, Moffett Field, California, United States, [4]NASA Goddard Spaceflight Center, Greenbelt, Maryland, United States, [5]Carnegie Institution of Washington, Washington DC, District of Columbia, United States

Abstract
Understanding how a terrestrial planet's obliquity, or axial tilt, varies over time is essential when judging its potential habitability, as it largely governs changes in the planet's climate. We numerically explore the obliquity variations of three synthetic systems that were generated in previous work (Quintana and Lissauer, 2014, ApJ). Each system contains a solar-type star, a Jupiter-mass planet at ~5.2 AU, and a handful of terrestrial planets with at least one potentially habitable planet. Complementing previous work that involved single planet, intensive case studies (Lissauer et al., 2012, Icarus; Barnes et al., 2016, Astrobiology), this study serves as an attempt to gain broad insight into our understanding, which could potentially be translated to real systems. Early results show surprisingly complex obliquity behavior for these simple systems, where varying initial conditions result in distinct and sometimes dramatic regimes of variation, corresponding to Lyapunov timescales of just ~10^5 - 8 x 10^5 years, forewarning the sensitivity to our set initial conditions. Among these results include habitably suitable regimes where the obliquity varies only ~1-3 degrees over timescales of at least 10^8 years, similar to the present day Earth (~2.4 degrees); retrograde obliquities show an overall trend of reduced variation compared to prograde obliquities, although factors such as the planet's eccentricity can influence this.

413.03 VPLanet: A Simple Model for Planetary System Evolution
Rory Barnes[1], Rodrigo Luger[1], Russell Deitrick[2], Peter Driscoll[3], David Fleming[1], Hayden Smotherman[1], Thomas Quinn[1], Diego McDonald[1], Caitlyn Wilhelm[1], Benjamin Guyer[1], Victoria Meadows[1], Shawn Domagal-Goldman[4], John Armstrong[5], Pramod Gupta[1]
[1]University of Washington, Seattle, Washington, United States, [2]University of Bern, Bern, Switzerland, [3]Carnegie Institute for Science, Washington, District of Columbia, United States, [4]Goddard Space Flight Center, Greenbelt, Maryland, United States, [5]Weber State University, Ogden, Utah, United States

Abstract
Planetary systems evolve due to a myriad of processes, often non-linearly, which complicates simulating exoplanetary systems. The relevant physical processes have often been modeled and explored within sub-disciplines of science, so a universal model of planetary system evolution must unite theories developed in multiple scientific disciplines. We present a new interdisciplinary model of planetary system evolution that self-consistently couples stellar, orbital, tidal, rotational, atmospheric, internal, magnetic, climate, and galactic evolution for generic planetary systems, but focusing on systems with habitable worlds. We have combined all these processes into a single open source software package called VPLanet.

413.04 A statistical exploration of the dynamical stability of Kepler and K2 multi-planet systems
Kathryn Volk, Renu Malhotra
Lunar and Planetary Laboratory, The University of Arizona, Tucson, Arizona, United States

Abstract
Exoplanet detection and confirmation pipelines now routinely check whether the planetary systems they discover are dynamically stable. It is also increasingly recognized that observed planetary architectures are often quite close to the edge of dynamical instability. This tension motivates our present study of the dynamical evolution and potential for instabilities of the discovered Kepler and K2 multi-planet systems. We have performed an extensive suite of numerical integrations of these systems, with input parameters sampling the uncertainties in their masses and orbits, for integration times of ~5 billion orbital periods of the innermost planet (corresponding to ~20-100 Myr). We find that dynamical instabilities are not

uncommon for these observed planetary architectures. We will report on the common features of the stable versus unstable configurations for these systems, with a focus on identifying the triggers for dynamical instability. For a subset of the individual exoplanet systems, we will present refined estimates of the planet masses and eccentricities that allow stability on a variety of timescales up to the estimated stellar age based on a combination of numerical modeling and theoretical analysis.

413.05 Looking for Exoplanets in the TAOS-II Data Set

Joel H. Castro Chacón[1], Fernando Alvarez Santana[2], Mauricio Reyes-Ruiz[2], Benjamin Hernandez[2], Matthew Lehner[3]
[1]CONACYT - IA UNAM, Ensenada, Baja California, Mexico, [2]Instituto de Astronomía, Ensenada, Mexico, [3]ASIAA - SINICA, Taipei, Taiwan

Abstract
The TAOS-II project, soon to begin operation at the San Pedro Martir observatory, will monitor approximately 10,000 stars simultaneously to obtain in excess of 10^7 high cadence lightcurves, with the purpose of detecting serendipitous occultations by small transneptunian objects. As an additional use of these voluminous data set, we will be looking for long period temporal variations in the lightcurves that are consistent with the transit of exoplanets around the stars being monitored. In this poster we describe the algorithms to be used: a) to increase the SNR of the light curves when looking for low frequency phenomena in comparison to the sampling time; b) to identify exoplanet transit candidate events and c) to estimate the properties of the transiting exoplanet and its orbit for further followup. We estimate that a few hundreds of Hot-Jupiter planet candidates could be detected in the database with the methodology here described.

413.06 Internal Structure and CO2 Reservoirs of Habitable Water-Worlds

Nadejda Marounina, Leslie A. Rogers
University of Chicago, Chicago, Illinois, United States

Abstract
Water worlds are water-rich (>1% water by mass) exoplanets. They may form from volatile-rich material beyond the snow line but never attain masses sufficient to accrete or retain large amounts of H2/He nebular gas. This pathway for producing low-mass water-rich planets has played out as a robust prediction of planet formation simulations, and may produce planets with comet-like compositions having up to 50% of their mass in astrophysical ices. If located at an appropriate orbital separation from their host star, water worlds may possess a global surface water ocean. Habitable (liquid ocean-bearing) water worlds are especially timely because their larger sizes relative to terrestrial planets make them more amenable to observations with current and upcoming telescopes such as Hubble Space Telescope (HST) and James Webb Space Telescope (JWST).
The classic calculations of the habitable zone consider Earth-like planets, where the amount of CO2 in the atmosphere is stabilized by the carbonate-silicate cycle. Due to their important oceanic mass, the hydrostatic pressure at the oceanic floor of water worlds reaches the stability field of high pressure polymorphs of water ice, hindering chemical interactions between the liquid water and the silicates. In the absence of a carbonate-silicate cycle, the solubility of CO2 in the ocean and the formation of CO2-rich clathrates determine the concentration of CO2 in the water world's atmosphere.
We use GERG-2008 equation of state for CO2-H2O mixture and coupled models of planet interior structure, clathrate formation, liquid-vapor equilibrium, and atmospheric radiative transfer to constrain the atmospheric and interior CO2 abundances of habitable water worlds. We show that for a habitable water

world with more than 11 wt% volatiles, the vast majority of its CO2 needs to be trapped in the interior of the planet. In order for these planets to have a cometary, CO2-rich composition and remain habitable, we propose that they may possess a significant fraction of CO2 trapped as CO2 ice inside of the high-pressure water ice mantle.

413.07 ExoGAN: Retrieving Exoplanetary Atmospheres Using Deep Convolutional Generative Adversarial Networks

Tiziano Zingales[1, 2], Ingo Waldmann[1]
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Abstract
Atmospheric retrievals on exoplanets usually involve computationally intensive Bayesian sampling methods. Large parameter spaces and increasingly complex atmospheric models create a computational bottleneck forcing a trade-off between statistical sampling accuracy and model complexity. This is especially true for upcoming JWST and ARIEL observations.
We introduce ExoGAN, the Exoplanet Generative Adversarial Network, a new deep learning algorithm able to recognise molecular features, atmospheric trace-gas abundances and planetary parameters using unsupervised learning. Once trained, ExpGAN is widely applicable to a large number of instruments and planetary types. The ExoGAN retrievals constitute a significant speed improvement over traditional retrievals and can be used either as a final atmospheric analysis or provide prior constraints to subsequent retrieval.

413.08 The PHOENIX ExoplaneT Retrieval Algorithm (PETRA) and a New Look at Ultra-Hot Jupiters

Joshua Lothringer, Travis Barman
Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona, United States

Abstract
We introduce the PHOENIX ExoplaneT Retrieval Algorithm, or PETRA, a new atmosphere retrieval analysis code built around the well-tested and widely-used PHOENIX atmosphere model. This new retrieval suite offers varying levels of complexity in its forward model and is capable of interpreting observations of both transiting and self-luminous exoplanets and brown dwarfs. PETRA is designed to be flexible with respect to spectral resolution, chemistry, observational geometry, cloud treatment, and the molecular line lists used. We use PETRA to develop a novel technique to probe the ion chemistry in ultra-hot Jupiters (> 2000K). Retrieving the abundances of select ions would provide insight into the importance of MHD effects in shaping the circulation of ultra-hot atmospheres.

413.09 ExoAI: Deep learning in exoplanet spectroscopy

Ingo Waldmann
Physics & Astronomy, UCL, London, United Kingdom

Abstract
The field of exoplanetary spectroscopy is as fast moving as it is new. Analysing currently available observations of exoplanetary atmospheres often invoke large and correlated parameter spaces that can be difficult to map or constrain. This is true for both: the data analysis of observations as well as the

theoretical modelling of their atmospheres. Modelling both sets of correlations in data and modelling is key to understanding the nature of exoplanet atmospheres.

In recent years, bayesian atmospheric retrieval algorithms have become the norm in exoplanet characterization.
Traditional atmospheric retrievals are limited by the sampling time required to fully map the likelihood space of the solution. Such large sampling processes do consequently require the atmospheric forward model to be fast, and hence simplistic. Whilst simple forward models are sufficient for the resolution and signal-to-noise of currently available Hubble data, this will not be the case in the era of JWST or Ariel. Though, more complex forward models require more computation time, making them the paramount bottleneck of next generation atmospheric retrievals.

In this talk I will discuss how these improvements in deep learning can be applied to solve correlations in the models as well as speeding up the statistical sampling.

By designing deep neural networks, we can significantly speed up data analysis and interpretation and allow our current models to ‘learn from experience’. Such AI driven systems will help to resolve model correlations, and allow us to incorporate complex forward models in the atmospheric retrieval of extrasolar planets.

413.10 Discovering Ultra-Short-Period K2 Exoplanets

Samantha R. Johnson[1], Brian Jackson[1], Elisabeth Adams[2], Michael Endl[3]
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Abstract
The K2 Mission, an extension of NASA’s Kepler Mission, collects the light curves of stars with the aim of finding transiting planets. Our group, the Short-Period Planets Group (SuPerPiG), focuses on finding transiting planets very close to their host stars. Our search scheme involves considerable data conditioning to remove longer-period signals due to astrophysical and instrumental effects, followed by a robust analysis for periodic signals. However, even after these processing steps, it is still expedient to examine each of these light curves by hand to weed out objects that are obviously not planets, such as eclipsing binary stars and light curves that are clearly sinusoidal. For the candidates whose light curves pass this level of scrutiny, further follow-up observations, such as low-precision radial velocity and adaptive optics observations, as well as spectral characterization of the host star, are necessary to weed out false positives. Radial velocity observations allow us to ensure that the candidates are not instead stellar companions in binary systems. Using data from the K2 Missions Campaigns 6, 7, 8, and 10, we have discovered dozens of ultra-short-period planetary candidates through this process.

413.11 On the origin of free-floating planets: The effect of planet migration

Jordan Jubeck[1], Nader Haghighipour[2], Aaron Do[2]
[1]Duquesne University, Pittsburgh, Pennsylvania, United States, [2]Institute for Astronomy, Honolulu, Hawaii, United States

Abstract
Many free-floating planets have been detected through the microlensing technique, however very little has been done to determine their origins. In this study, we explored the possibility that planets may be ejected into interstellar space during the process of terrestrial planet formation in systems with migrating giant planets. We simulated the late stage of terrestrial planet formation while varying the mass, number and rate of giant planet migration, and determine the efficiency of the scattering and ejection of objects to large distances. Results indicated that less than half of all planetary embryos or larger bodies can be potentially ejected into interstellar space. While many exoplanets have super-Earth or sub-Neptune masses, the objects that we found to be ejected are much closer to Mars size. We present the results and our study and discuss their implications for future research.

413.13 Fundamental Parameters of ~30,000 M dwarfs in LAMOST DR1 Using Data-Driven Spectral Modeling

Brianna Galgano[1, 2], Keivan Stassun[1], Barbara Rojas-Ayala[3]
[1]Physics & Astronomy, Vanderbilt University, Nashville, Tennessee, United States, [2]Fisk University, Nashville, Tennessee, United States, [3]Andrés Bello National University, Santiago, Chile

Abstract
We present new effective temperatures, masses, radii, and solar luminosities for 28,263 early-type M dwarfs (M0–M8) from the first data release (DR1) from the Large Sky Area Multi-Fiber Spectroscopic Telescope (LAMOST) derived from data-based spectral modeling program the Cannon. The data used to train the Cannon model were obtained from 1,388 dwarfs of the Transiting Exoplanet Survey Satellite Cool Dwarf Catalog (TCD) also in LAMOST DR1. We discuss methods for selecting a training set of spectra to produce an accurate model that predicts these four stellar characteristics from low-resolution, optical LAMOST DR1 observations. We conclude that the Cannon can accurately characterize spectra that have relatively low signal-to-noise, and is a viable tool for automated M dwarf spectral analysis.

Thursday, October 25, 2018
03:30 PM-06:00 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

414 Main Belt Asteroids: Physical Characteristics Posters
Chair(s): Franck Marchis, Gonzalo Tancredi

414.01 The Small Body Geophysical Analysis Tool

Jay McMahon, Benjamin Bercovici
Smead Aerospace Engineering Sciences, University of Colorado Boulder, Boulder, Colorado, United States

Abstract
The Small Body Geophysical Analysis Tool (SBGAT) currently under development at CU Boulder aims at providing scientists and mission designers with a comprehensive, easy to use, open-source analysis tool. SBGAT is meant for seamless generation of valuable simulated data originating from small bodies shape models, combined with advanced shape-modification properties. The SBGAT software architecture revolves around polyhedral shape models from which can be computed mass properties (volume, center of mass, inertia,...), synthetic observations (lidar, lightcurves,...) and be used within dynamical models (spherical harmonics, polyhedron gravity model, ...) The software architecture was implemented in the form of two distinct packages: a dynamic library SBGAT Core containing the data structure and algorithm backbone of SBGAT, and SBGAT Gui which wraps the former inside a VTK, Qt user interface to facilitate user/data interaction. This modular development facilitates maintenance and addition of new features. Note that SBGAT Core can be utilized independently from SBGAT Gui. SBGAT now incorporates a number of functionalities: generation of spherical harmonics expansions from constant-density polyhedra, (exportable to JSON), the evaluation of the spherical harmonics expansions, the ability to generate YORP coefficients, multi-threaded Polyhedron Gravity Model gravity and potential evaluation, as well as synthetic light-curve and radar observations for single/primary asteroids SBGAT is available on MacOS and Linux. MacOS users can readily retrieve SBGAT and its dependencies through the Homebrew package manager. SBGAT's repository is public and can be accessed at https://github.com/bbercovici/SBGAT. The code documentation is constently updated in order to reflect new functionalities. SBGAT's user's manual is available at https://github.com/bbercovici/SBGAT/wiki. Some of the upcoming development goals are now detailed. First, SBGAT GUI will soon be augmented with shape-interaction functionalities to enable editing of the shape model using VTK methods. SBGAT will also eventually be able to generate more extensive data products, like zero-velocity maps around small bodies of arbitrary shapes

414.02 Influence of the particle size distribution on the cohesive strength of granular asteroids

Jeremy Sautel[1, 2], Paul Sanchez[2], Daniel J. Scheeres[2]
[1]Physics, Ecole Normale Supérieure Lyon, Lyon, Rhône, France, [2]The University of Colorado in Boulder, Boulder, Colorado, United States

Abstract
Small granular asteroids, due to their size, mass and rotation, have gravitational fields in the order of milli- to micro-g with respect to Earth's gravity. Grain-grain cohesive forces on the other hand, do not escale with asteroid size and thus the cohesive forces between

different particles forming an asteroid play a non-negligible role, which can be quantified by the cohesive strength of the medium. Moreover, the size distribution of these particles can be quite wide and this will also have an influence on the cohesive strength. One simple way to measure cohesive strengths is the direct shear test, which is well-known method in Soil Mechanics. In order to precisely control the investigated size distributions we have chosen to use a simulation code that implements a numerical method for the simulation of granular media in this study. We found that in general, cohesive strength scales proportionally with the strength of the cohesive bonds. When large particles are embedded in the medium, the cohesive strength remains steady as long as failure happens through the region of the medium that is formed by the smaller particles. Then, if the volume fraction occupied by the large particles becomes greater than 50%, the cohesive strength of the medium decreases. These results, along with a theoretical interpretation, further numerical tests and their implications for the structural strength of asteroids will be discussed during the conference.

414.03 Asteroid Lightcurves: Can't Tell a Contact Binary from a Brick

Alan W. Harris, Brian Warner
MoreData!, La Canada, California, United States

Abstract
Over the last couple decades, numerous papers based on lightcurve observations of asteroids have derived shapes that were claimed to represent "contact binary" or fluid equilibrium figures. From these shapes, the authors then presumed to derive densities, or density limits, on such bodies. In this paper we remind that it is well established, theoretically as well as observationally, that lightcurve analysis alone cannot establish concavities of a figure, i.e., the resultant shape inversion is a convex hull, not an actual shape. Therefore, it is not possible to infer "bilobed" or "contact binary" shapes from lightcurve analysis alone, let alone infer densities from such analysis. We also show that even "rubble pile" strength overrides fluid equilibrium for all but the very largest asteroids or TNOs. As a result, supposing Jacobi ellipsoidal or Roche near-contact figures and inferring densities therefrom is not justified. As an example, we present lightcurves of the asteroid (3169) Ostro fitted to models of a near-contact binary and a convex hull "brick", showing that the quality of the fits to lightcurves are indistinguishable.

414.04 Methods for improved photometric and spectroscopic calibration of asteroid observations

Tim Lister
Las Cumbres Observatory, Goleta, California, United States

Abstract
In order to support calibration of observations of Solar System bodies (asteroids and NEOs) taken with the Las Cumbres Observatory global telescope network, we have developed methods for "forward calibration" of data. This makes use of a computed atmospheric transmission model and a generalized telescope and instrument model to allow the prediction of the number of photons at the detector for a given source's spectral energy distribution (SED). This can be used to predict the expected signal-to-noise ratio of proposed observations or to calibrate observations that have been taken to higher accuracy than with classical standard star photometry.
We have developed code to retrieve the time-variable parameters that affect the atmospheric transmission at our distributed observing sites such as the amount of precipitable water vapor, ozone and aerosols from ground-based and satellite sources. These can then be used to compute a library of reference atmospheric transmission functions. These in turn can be combined with the SED and the more stable telescope and instrument throughputs to synthesize spectra or integrated across the filter bandpass to synthesize

photometric measurements. We illustrate this use with observed spectra of NEOs and calibrated multi-epoch photometry of members of the (4) Vesta family.

414.05 NEOWISE: The Cybele population

Tommy Grav[1], Amy Mainzer[2], Joseph Masiero[2], Emily Kramer[2], Roc Cutri[3], James Bauer[4], Edward L. Wright[5], Sarah Sonnett[1]
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Abstract
The Nice model is currently favored as the leading hypothesis for quantitatively explaining many of the characteristics seen in the current Solar System, from the giant planet orbits, the Jovian and Neptunian Trojan populations, the Kuiper Belt, and the origin of the late heavy bombardment (Tsiganis et al., 2005; Morbidelli et al., 2005; Nesvorny et al., 2007). The insertion of primitive trans-Neptunian objects into the outer main belt using the Nice model can reproduce the general aspects of both the taxonomic and size distributions seen in the outer main belt, Hilda, and Jovian Trojan populations. Deeper understanding of the current taxonomy, sizes, and physical properties of these populations is needed to better constrain the Nice model. In previous papers we have reported on these properties for the Hilda and Jovian Trojan populations based on mid-infrared observations of the NEOWISE extension of the Wide-field Infrared Survey (WISE) mission (Grav et al., 2011a, 2011b, 2012). Here we report on the results of the NEOWISE observations of the Cybele population.

The Cybeles are asteroids that occupy the region just beyond the edge of the main asteroid belt, with semi major axis between the 2:1 (at ~3.27AU) and 5:3 (at ~3.7AU) mean motion resonances with Jupiter. The Cybeles currently consist of over 3000 known objects. Generally thought of as a breakup of a large asteroid in the early part of the formation of the Solar System, the Cybeles are dominated by the primitive C, P and D taxonomic classes from the Tholen taxonomic system (Tholen & Barucci, 1989). To test whether the Cybele population has experienced significant shattering events after insertion it is important to determine the size distribution of this population. Here we present the thermal observations of over 1200 objects from the Cybele population, using the WISE satellite during its cryogenic phase. The thermal model fits show a mostly homogeneous population. A vast majority of the Cybeles are dark, with albedos of less then 10%. Preliminary results show that the mean albedo of the Cybeles is 5±3%, which is similar to that of the Hilda population (5.5±1.8%; Grav et al. 2012), and darker than the Jovian Trojan Population (7±3; Grav et al., 2011).

414.06 Slope trends within Main Belt asteroid families using the SDSS Moving Object Catalog

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Abstract
Past work has shown that the space weathering process has different effects on the observed spectral slope of an asteroid depending on the spectral type (e.g., Nesvorny et al. 2005). To investigate the range of spectral slope trends in families of various taxonomic types, we used the Sloan Digital Sky Survey

(SDSS) Moving Object Catalog 4 (MOC4, Ivezic et al 2002). Work by Thomas et al. (2012) demonstrated that the SDSS could be used to investigate the spectral change associated with space weathering within a single asteroid family. We used a similar process to study many other families within the SDSS MOC4. Family members were identified using the Nesvorny (2015) lists of dynamical family membership. We implemented a number of rejection criteria (including error flags and cutoffs for known unreliable apparent magnitudes) to ensure the photometric accuracy of each observation included in our study. We will present the trends in spectrophotometric slope with respect to size for each family in our sample and discuss how these trends vary by taxonomic type.

414.07 Infrared Spectroscopy of Large, Low-Albedo Asteroids: Is Ceres an Archetype or Outlier?

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Abstract
Telescopic and spacecraft measurements point to Ceres having had a dynamic geological history. The leading interpretation for its surface composition includes carbonates and ammoniated minerals along with limited exposures of water ice and organics [1]. Photogeological imaging revealed bright spots (now termed “faculae”) whose origin may be related to brine extrusion and at least one feature attributed to cryovolcanic origin [2]. Ceres is the largest object in the main asteroid belt but there are additional low-albedo objects larger than 200 km, likely to be intact from the time of their formation [3]. Understanding the nature of these objects, including in comparison to Ceres, will be necessary to get a full understanding of early solar system history. These types of comparisons are particularly necessary because Ceres has no known dynamical family and there are no known meteorites derived from Ceres [4].

We have identified eight objects that are larger than 200 km, members of the C spectral complex, and have 3-µm band shapes unlike what is seen in the meteorite collection. We will present the results of mixing models and band depth/band center calculations and discuss how these objects compare to Ceres and Themis, as well as the possibility of spectral variation across their surfaces.

[1] McCord, Thomas B., and Francesca Zambon. "The surface composition of Ceres from the Dawn mission." *Icarus* (2018).
[2] Scully, Jennifer EC, Christopher T. Russell, Julie C. Castillo-Rogez, Carol A. Raymond, and Anton I. Ermakov. "Introduction to the special issue: The formation and evolution of Ceres’ Occator crater." *Icarus* (2018).
[3] Morbidelli, Alessandro, William F. Bottke, David Nesvorný, and Harold F. Levison. "Asteroids were born big." *Icarus* 204, no. 2 (2009): 558-573.
[4] Rivkin, Andrew S., Erik Asphaug, and William F. Bottke. "The case of the missing Ceres family." *Icarus* 243 (2014): 429-439.

414.08 Extending UV Spacecraft Spectra of Primitive Asteroids with Ground-based Spectra: Spectral and Space Weathering Effects

Faith Vilas
Division of Astronomical Sciences, National Science Foundation, Alexandria, Virginia, United States

Abstract
We extend UV C-complex asteroid studies of International Ultraviolet Explorer spectra of 13 C-complex asteroids in the ~210- to- 320-nm wavelength range (Roettger & Buratti, 1994) to spectra of 6 main-belt C-complex asteroids (41, 54, 165, 253, 326, 3507) that were obtained using the MMT 6.5-m telescope facility Blue Channel spectrograph, covering the 320- to- 640-nm wavelength range. These asteroids likely contain iron and phyllosilicates and vary in levels of aqueous alteration. The results of our studies in the UV/blue spectral region address two questions: (1) Are there UV/blue spectral attributes that suggest compositional information? The UV dropoff is subdued for C-complex asteroids compared to CI and CM meteorite types. Differences exist in the spectral properties at wavelengths lower than 400 nm for asteroids whose VNIR spectra appear the same at longer wavelengths. (2) Can UV/blue data be used to discern space weathering effects on a C-complex asteroid's surface? Space weathering in the S-complex asteroids is evident in the UV/blue spectral region before it is apparent in the VNIR; this is an effect of the presence of iron in olivines. Our modeling supporting the S-complex research, based upon UV/blue observational data, suggests that the effect of adding small amounts of SMFe to particles from both a hypothetical mineral and a terrestrial basalt affects the reflectance at UV/blue wavelengths before the VNIR reddening and diminution of absorption features associated with space weathering. Can space weathering be the root of the differences between C-complex asteroid and CI/CM meteorite reflectance spectra? Most CM2 carbonaceous chondrites have chondrules containing ~ 20 volume % olivines (e.g., Howard, K. T. et al., 2015); no spectrum of the chondrule contents of CM2 meteorites has been obtained. We report our most recent results.

414.09 The Red Edge Problem in Asteroid Band Parameter Analysis

Sean Lindsay[1], Tasha Dunn[2], Joshua Emery[1], Neil Bowles[3]
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Abstract
The analysis of visible plus near-infrared (Vis+NIR; 0.4 – 2.5 μm) spectra of S-type asteroids that are analogous to ordinary chondrite-like mineralogies is a powerful tool in determining the mineralogy and composition of asteroids. The Vis+NIR spectra of these asteroids and meteorites contain two diagnostic absorptions centered near 1 μm (Band I) and 2 μm (Band II). Analyses of these absorption features often are used to determine the abundance ratio of olivine and pyroxene (ol ratio) and the mol% FeO. Such analyses, however, rely upon ordinary chondrite (OC) calibration equations that link the mineralogy to band parameters (e.g., Band I center and the band area ratio; or BAR = Area BII/BI). The most widely used calibration study by measures the Band II Area by setting the terminal wavelength, the "red edge"), of Band II at 2.50 μm. Due to limitations of NIR instruments, spectral data for asteroids are typically only reliable out to 2.45 μm, and in some cases, only to 2.40 μm, which leads to an underestimation of the Band II Area compared with the calibration study. We refer to this discrepancy as the "Red Edge Problem." Here we evaluate the uncertainties caused by this problem using band parameters determined for the same sample of OCs used in the calibration study. The band parameters are determined using our Spectral Analysis Routine for Asteroids (SARA) for red edges set to 2.40, 2.45, and 2.50 μm. We find that BAR and ol ratio errors associated with the Red Edge Problem often are less than the uncertainties inherent the calibration equations when the red edge is set to 2.45 μm (45/48 cases). For a 2.40 μm red edge, however, the Red Edge Problem is frequently the dominate source of error (28/48 cases). In cases dominated by red edge error, investigators may incorrectly determine the ol ratio and meteorite analog. Of the three OC subgroups, the choice of red edge most strongly affects the H chondrites. In response to these findings, we provide: 1) equations to adjust BAR values measured from one red edge to different red edge; and 2) new ol ratio calibration equations for red edges set at 2.40 and 2.45 μm.

414.10 Spin State of (5247) Krylov

Hee-Jae Lee[1, 2], Josef Durech[3], Myung-Jin Kim[2], Hong-Kyu Moon[2], Chun-Hwey Kim[1], Young-Jun Choi[2, 4], Adrian Galad[5, 6], Donald Pray[7], Anna Marciniak[8], Murat Kaplan[9], Orhan Erece[9, 10], René Duffard[11], Leonard Kornos[6], Stefan Gajdoš[6], Jozef Vilagi[6]
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Abstract
The spin states of asteroids are regarded as critical evidence for their evolutionary processes. In particular, the spin states of NPA (Non-Principal Axis) rotators offer significant clue to the evolutionary processes of these asteroids because their excited spin states are thought to be caused by internal and/or external forces in the past. The NPA rotation of asteroid (5247) Krylov was confirmed by Lee et al. (2017) based on photometry data in 2016. We also conducted observations of the body during the 2006 and 2017 apparitions using 0.5-2.1m telescopes. Incorporating the datasets obtained from the three apparitions, we constructed its spin state and shape model of Krylov. We found that the asteroid is rotating in Short Axis Mode (SAM) with rotation and precession periods of 68.15 h and 396.30 h, respectively. The ecliptic longitude and latitude of the angular momentum vector is 182 ° and 59 °, respectively. The largest and intermediate principal inertia moments are nearly the same: $I_b/I_c = 0.98$. However, the smallest principal inertia moments is less than the half of the others: $I_a/I_c = 0.23$. In this presentation, we will discuss the spin state and shape model of Krylov, and elaborate on the possible evolutionary processes which led to the observed spin state.

414.11 Compositional Diversity of Inner-Belt Primitive Asteroid Families as Constraints on Giant Planet Instabilities

Vanessa Lowry
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Abstract
We propose to use the spectroscopic characteristics of primitive asteroids in the inner-belt to constrain models of giant planet instabilities during the formation of our Solar System. Our ongoing Primitive Asteroid Spectroscopic Survey (PRIMASS) has yielded results on five inner-belt primitive families and so far, these fall into at least two distinct spectral groups with hints of a third one (Arredondo et al. 2018). The first group includes the Polana, Eulalia and Clarissa families, which show considerable spectral homogeneity and no evidence of a 0.7-µm hydration feature. In contrast, the Erigone and Sulamitis families are spectrally diverse and most of their members show clear 0.7-µm hydration features (e.g., Pinilla-Alonso et al. 2017; Morate et al. 2016, 2018; Campins et al. 2018; de León et al. 2016, 2018). The first three families have very similar orbital inclinations near 2 degrees, while those of the Erigone and Sulamities families cluster tightly near 5 degrees. However, the mean eccentricities of families of similar spectrum are significantly different. It has been previously shown that some giant planet evolutions

during the instability phase, lead to a strong dispersion of asteroid eccentricities, but not of their inclination (Brasil et al. 2015). Our proposed interpretation of the observations is that the parent bodies of families with similar spectra and inclination, but different eccentricities are fragments of a common progenitor at that inclination; during the giant planet instability these parent bodies acquired different eccentricities but preserved their original common inclination. Finally, they fragmented during the subsequent history of the Solar System, generating the families that we see today. We seek to model this scenario including the dynamical instability and the subsequent evolution, with the Yarkovsky effect, in the current configuration of the planets over the last ~4Gy. If our scenario is confirmed by our dynamical models, it will provide strong observational constraint on the actual evolution of the giant planets during their instability.

Thursday, October 25, 2018
03:30 PM-06:00 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

415 Satellite Geology and Geophysics Posters

415.01 The Europa Clipper Mission: Science Objectives, Working Group Structure, and Mission Status Update

Christina Richey[1], Robert T. Pappalardo[1], David A. Senske[1], Haje Korth[2], Kate L. Craft[2], Rachel L. Klima[2], Cynthia Phillips[1]
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Abstract
The overarching science goal of the Europa mission is to explore Europa to investigate its habitability. Following from this goal are three Mission Objectives: (1) Ice Shell and Ocean:characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange; (2) Composition:understand the habitability of Europa's ocean through composition and chemistry; and (3) Geology:understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities. The current structure of the Thematic Working Groups within the Project Science Group includes an over-arching Habitability Working Group as well as a Composition Working Group, a Geology Working Group, and an Interior Working Group. In addition, three Focus Groups have been formed: a Radiation Focus Group, a Plumes Focus Group, and a Recon Focus Group.

A highly capable scientific payload of nine instruments was selected by NASA. This includes five remote-sensing instruments that observe the wavelength range from ultraviolet through radar: *Europa Ultraviolet Spectrograph (Europa-UVS)*, *Europa Imaging System (EIS), Mapping Imaging Spectrometer for Europa (MISE),Europa Thermal Imaging System (E-THEMIS), and Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON);* and four *in situ*instruments that measure fields and particles: *Interior Characterization of Europa using Magnetometry (ICEMAG), Plasma Instrument for Magnetic Sounding (PIMS), MAss Spectrometer for Planetary Exploration (MASPEX)*, and *SUrface Dust Analyzer (SUDA)*. In addition, a gravity science investigation can be conducted using the spacecraft's telecommunication system, combined with radar altimetry. Valuable scientific data could also come from the spacecraft's planned radiation monitoring system. Working together, the Europa mission's robust investigation suite can be used to test hypotheses and enable discoveries relevant to the interior, composition, geology and potential current activity of Europa, thereby addressing the question of habitability of this intriguing ocean world.

415.02 Measuring Lava Eruption Temperatures Remotely with a Novel Infrared Detector and Readout Circuit

Ashley G. Davies[1], Alexander Soibel[1], David Z. Ting[1], William R. Johnson[1], Sarath D. Gunapala[1], Paul Hayne[2], Megan Blackwell[3]
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Abstract
Only certain styles of volcanic activity are suitable for thermally constraining the eruption temperature of Io’s dominant silicate lavas using remote sensing data, those where thermal emission is only from a restricted range of surface temperatures close to eruption temperature. Such processes include lava fountain events, from fissures and within lava lakes [1,2], lava tube skylights [3], and recently-discovered transient eruptions [4]. Other problems that must be overcome are: (1) the cooling of the lava between data acquisition at different wavelengths; (2) the unknown magnitude of thermal emission, which in the past has led to detector saturation; and (3) thermal emission changing on a shorter timescale than the observation integration time. We can overcome these problems by using a novel imager that features a faceted mirror design and digital focal plane array where the latter utilizes the HOT-BIRD detector [5] and digital readout circuits [6]. We have created an instrument model that allows different instrument parameters (including mirror diameter, number of signal splits, exposure duration, filter band pass, and optics transmissivity) to be tested to determine eruption detectability. We find that a short-wavelength infrared instrument on an Io flyby mission can achieve simultaneity of observations by splitting the incoming signal for all relevant eruption processes and obtain data fast enough to remove uncertainties in accurate determination of the highest lava surface temperatures exposed. Lava temperature determinations are also possible with a visible wavelength detector [3] so long as data are obtained at different wavelengths very quickly. References: [1] Davies et al., 2001, JGR, 106, 33079-33104. [2] Davies et al., 2011, GRL, 38, L21308. [3] Davies et al., 2016, Icarus, 278, 266-278. [4] Davies et al., 2017, AGU FM Abstract P31E-02. [5] Ting et al., 2012, Barrier infrared detector, U.S. Pat. No. 8217480. [6] Kelly et al., 2005, Proc. SPIE, 5902. This work was performed at the Jet Propulsion Laboratory–California Institute of Technology, under NASA contract.

415.03 Coupled Models of Mantle Convection and Tidal Heating on Io

<u>Walter Kiefer</u>
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Abstract
Jupiter's moon Io is presently undergoing a prodigious amount of volcanic activity. Understanding the interior dynamics that produces this volcanism is a fundamental problem in planetary geophysics. Io's volcanism is driven by tidal heating of its interior, and the magnitude of tidal heating at a given location depends in part on the viscosity and shear modulus of that material and thus on both the mantle temperature and the presence of magma. However, the thermal structure can evolve with time both due to convective flow in the mantle and by the production of magma. As the mantle temperature evolves, the viscosity will change, leading in turn to changes in the tidal heating rate. Changes in the tidal heating may in turn cause changes in the mantle flow. Thus, rigorous models of mantle convection on Io must consider the couplings among tidal heat generation, mantle convection, the rheology law, and the production and transport of magma. Existing models of mantle convection on Io have made the simplifying assumption that tidal heating can be imposed with a fixed spatial pattern and amplitude.

This presentation is the beginning of a multi-year project designed to better understand the couplings and feedback loops between tidal heating, rheology, magma production, and convective flow on Io. The viscosity of Io’s mantle is dominated by a combination of dry olivine and melt (at least 20% melt in places, based on electromagnetic induction studies from the Galileo spacecraft). The effect of small melt fractions on the rheology is moderate, but for peridotite, once a critical melt fraction of 20-30% is exceeded, the solid rock begins to rapidly disaggregate and the viscosity drops rapidly with increasing melt fraction. The initial tidal heating model is based on a Maxwell visco-elastic rheology, incorporating the effects of both temperature and melt on the shear modulus as well as the viscosity. Current modeling

focuses on incorporating these rheological considerations and the tidal heating model into the CitcomX and CitcomS finite element mantle convection codes.

415.04 Numerical Simulations for Convection in Europa: Tidal Heating and External Topography in Tridimensional Models

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Abstract
Existance of tidal heating is necessary for a subsurface ocean to persist on Europa to the present day. Also, recent investigations show that the yield stress from tides may exceed the rigidity of the external crust, and this may lead to fractures and weak zones along the ice shell. Researches evoke diffrerent processes like diapirism, shear heating of the crust and partial melting of shallow layers to explain the observed features, but a full consideration of the convective dynamics is required to rigorously model diapir formation, evolution, and surface manifestation as a function of the background thermal state. This study presents 2D and 3D numerical simulations for tidally driven convection in Europa. By associating the resulting normal stress from ascending and descending plumes with local surface weakining and considering the resistence from the different layers, our model was able to succsessfully reproduce Europa's topography.

415.05 Inspecting the Geochemical Flux of Europa from its Thermal Evolution

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Abstract
Europa poses novel questions regarding astrobiology and habitability due to its liquid water ocean. Defining the nature of geochemical fluxes within Europa in the context of the thermal evolution of the satellite is a necessary perspective in understanding the potential for habitability. While many theories and models exist for plausible Europa geochemical processes and interactions, few incorporate the non-static nature of heat production in the interior through time. Work on the thermal-orbital history of Europa show periods of oscillatory heat production rates due to tidal and radiogenic heating. These variations in heat production could have non-negligible effects on the geochemical systems within the interior of Europa.
Due to the complexity modeling geochemical cycles, the geochemical kinematics will be realized through a box model. Box models have been successfully used in modeling for Earth's ocean cycling and terrestrial exoplanets. Box-models divide the system into well-mixed reservoirs, or 'boxes', with fluxes between each box driven by mass-balance. The simplicity allows for realistically-solvable equations, enabling a focus on fundamental interactions while minimizing computational time. The thermal evolution of Europa is modeled through a one-dimensional, depth-dependent temperature profile. Radiogenic and tidal heat production are considered. Both conductive and convective scenarios are considered for the mantle and ocean.
The Europan box-model consists of five boxes (upper ice, lower ice, ocean, mantle, core) and iteratively calculates the chemical mass fluxes, incorporating the temperature profiles into the chemical species EOS, through time. Carbon, oxygen, and hydrogen fluxes will be demonstrated, and consequently the

production and circulation of carbon dioxide, carbon monoxide, and methane. These are important participants in water-rock reactions at varying temperatures and have likely played an important part in the evolution of the biosphere on Earth. Additionally, geothermal processes dependent on these species, such as serpentinization, hydro-thermalism, and H2 outgassing would create an effect on the long-term heat production in the interior.

415.06 Compositional variation within Europa's ice shell reflects thickening and geologic history

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Abstract
The surface of Europa records a storied history of tectonic deformation, including the exposure of new interior material at extensional bands and removal of surface material to the interior at inferred subsumption zones. These geologic processes are critical for transporting material through the brittle ice shell exterior, and therefore critical for understanding the redox state and astrobiological potential of the interior ocean. Some features are associated with the exposure of non-ice materials, indicating that spatial or temporal variations in non-ice abundance are recorded in the shell. The amount of non-ice material incorporated into the ice shell from the ocean depends to first-order on how quickly the ocean water freezes. Therefore, the distribution of non-ice materials may record the geologic evolution of the ice shell. We use the finite element code SiStER (Simple Stokes solver with Exotic Rheologies), extended to simulate the visco-elasto-plastic behavior of ice I and to include partial melting and freezing. Models include internal tidal heat generation and an imposed silicate heat flux to the ocean. For particles transitioning from the ocean to the ice shell, we record the maximum freezing rate ever experienced as an indicator of potential impurity abundance. Thus, by using freezing rate as an analog for non-ice incorporation, we use maps of freezing rate at the time of ice incorporation to infer the distribution of impurities within the ice shell. We investigate 3 scenarios: (1) An ice shell freezes in from an ocean exposed to space. (2) An initially 130 km thick shell that thins. (3) A frozen-in ice shell thickens in response to a decrease in heating. We find that non-ice distributions record geologic history and interior heat flux, and will help constrain whether the ice shell interior is convecting. Laboratory experiments quantifying the fractionation of expected non-ice materials as a function of freezing rate, within the range predicted by this study, will enable direct predictions of variations in ice shell composition on the surface and with depth.

415.07 Enceladus' Expanded Impact Crater Database

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Abstract
Enceladus' surface has been modified throughout its history by the formation of tectonic grooves and ridges and only a relatively small area – mostly in the northern latitudes – of ancient cratered terrain remains. Analyzing variation in impact crater density is currently the only way to constrain how old Enceladus' diverse terrains are. These analyses also provide insight into processes that may be modifying craters, such as burial by plume particles and viscous relaxation due to higher heat flow [e.g., 1,2]. Several new images from the Cassini Imaging Science Subsystem at resolutions of 100 m/pixel or better

have been released since the publication of our original Enceladus crater database [1]. In particular, there is now complete coverage of the leading hemisphere, which was not available during creation of the original database. Using these new images we have expanded our impact crater database to new areas of Enceladus' surface. We measured the diameter and location of craters with diameters 1 km and larger in these new areas. We have also aligned the original database to the new coordinate system [3], which has shifted a few degrees longitude to the east. Finally, we added the following information for all craters: crater morphology, crater degradation (or preservation) class, observer confidence that the feature is a crater, and if the crater is cut by tectonic features, which increases the scientific usefulness of the crater database. Preliminary analysis of the database indicates that the cratered terrain has a shallower crater size-frequency distribution than the tectonized terrains, but the reason has not yet been determined. We will report on more comprehensive analyses of the database, including comparisons to crater distributions derived in previous work [1,4-6].

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415.08 Cold Case: Fractional Crystallization in Cryomagmatic Environments

Jacob Buffo[1], Britney E. Schmidt[1], Catherine Walker[2], Christian Huber[3]
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Abstract

With a diverse array of putative hydrological features (dikes, sills, lenses, fractures, plumes) linked to geophysical and transport processes on a number of ocean worlds understanding and quantifying the multiphase physics that govern these unique systems is imperative in constraining their formation, evolution, and persistence. Akin to terrestrial volcanism, the thermo-compositional properties of the melt will likely dictate its density, eutectic point, reactivity, viscosity, and solidification dynamics; quantities and processes that will govern the transport, longevity, and astrobiological relevance of the melt, as well as the thermal and physicochemical characteristics of both the melt and the ice it forms.

A key process occurring in these ice-ocean/brine systems is fractional crystallization. While more commonly used to describe high temperature magmatic processes, perhaps the most familiar example of fractional crystallization is the freezing of water into ice. When an aqueous solution is depressed below its freezing point pure crystalline ice begins to form, rejecting impurities into the remaining, concentrated, solution. The result is a complex and ever evolving two phase system, governed by a combination of diffusive and advective heat and mass transport, ever seeking thermodynamic and chemical equilibrium. The complex physics governing these two-phase systems pose a significant hurdle to numerical representations of these environments, and thus they are frequently parameterized, if not wholly excluded from models.

Here we discuss the ubiquity and importance of these environments in our own polar oceans as well as the oceans and ice shells of other bodies in our solar system. We present a one-dimensional reactive transport model capable of simulating the solidification dynamics of these interfaces using both terrestrial and putative Europan ocean/brine chemistries. The model is validated against terrestrial sea ice and is applied to Europa; investigating the thermochemical evolution of its ice shell. The models applicability to other ocean worlds is discussed and future model improvements are outlined.

415.09 Ocean Dynamics of Outer Solar System Satellites

Krista Soderlund
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Abstract

Exploration of the outer solar system has shown that subsurface oceans may be relatively common in the interiors of icy satellites. The presence of liquid water makes these ocean worlds compelling astrobiological targets. However, the dynamics of these oceans also play a role in promoting habitable environments. Here, we focus on the convective ocean dynamics of Europa and Ganymede in preparation for the upcoming Europa Clipper and JUICE missions and of Enceladus and Titan given the abundance of data from the Cassini mission. We use theoretical arguments and numerical models to make predictions about ocean currents and heat transfer patterns. Our results show that oceans in the outer solar system are prone to dynamics that are not strongly constrained by the Coriolis force due to their relatively slow rotation rates. In addition, convective heat transfer is found to vary with latitude, which may have consequences for the thermophysical structure of the ice shell and be linked to surface deformation.

Thursday, October 25, 2018
03:30 PM-06:00 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

416 Satellite Surfaces, Atmospheres, and Observations Posters
Chair(s): Anne Verbiscer

416.02 The oxidants of Europa's surface induced by Europa's radiative environment
Jiazheng Li[1], Siteng Fan[1], Murthy S. Gudipati[1], Donald Shemansky[2], Yuk Yung[1]
[1]California institute of Technology, Pasadena, California, United States, [2]Space Environment Technologies, Pasadena, California, United States

Abstract
Europa, the second Galilean satellite of Jupiter, is embedded in Jupiter's magnetosphere and hence bombarded with high-energy electrons, protons, and ions accelerated in the Jovian magnetosphere. Europa's surface is mainly composed of water ice, but the ice is expected to be porous and known to be contaminated by molecules containing sulfur in the trailing hemisphere. It is generally understood that the porosity and non-ice material of Europa's surface is due to continuous bombardment by energetic ions of oxygen and sulfur, protons, and electrons. Major surface processes on Europa include: ion induced sputtering, ion implantation into the surface forming new molecules, electron and ion induced ionization and dissociation of surface molecules, MeV-electron induced secondary electrons and photons (Bremsstrahlung) generation, and radiation damage caused by radiative recombination of highly charged heavy ions and low-energy secondary electrons and photons. Although the flux of low energy (keV) particles is much higher than the flux of high energy (MeV) particles, high energy particles also play important roles in those surface processes. For example, highly charged particles deliver the energy directly to the surface in X-ray radiation. In this study, we analyze the damage and contamination of the ice on Europa's surface caused by different kinds of particles with different energy ranges. These results may improve our understanding of the microstructure of Europa's surface and the composition of Europa's tenuous atmosphere. Data from future missions like JUICE and Europa Clipper are needed to provide constraints on Europa's surface processes.

416.03 Ganymede's and Callisto's Surface Composition from Near-IR Spectral Modeling of SINFONI/VLT's Observations
Nicolas Ligier[1], François Poulet[2], John Carter[2], Colin Snodgrass[1]
[1] Science, Technology, Engineering and Maths, The Open University, Milton Keynes, United Kingdom, [2]Institut d'Astrophysique Spatiale, Orsay, France

Abstract
The icy Galilean satellites, Europa, Ganymede and Callisto, are known to be one of the high interest exobiological bodies insofar as they may help to better understand the emergence of life on Earth because of their respective subglacial oceans (Sotin et al. 2004). Significant discoveries have been made thanks to the Galileo mission in the late 90s, but many questions remain unanswered. Thus, ESA and NASA have decided that the Galilean moons, and especially the icy ones, will be visited during the next decade through two major space missions: JUICE (ESA) and Europa Clipper (NASA).

In preparation of these missions, and more specifically of the infrared (IR hereafter) imaging spectrometer

MAJIS onboard the JUICE mission (Langevin et al. 2014), multiple ground-based observations have been performed with SINFONI, a near-IR integral field spectrograph mounted on one of the four telescopes of the VLT. SINFONI's high spectral binning (~0.5 nm) and large signal to noise ratio (>1000) are adequate to detect sharp absorptions in the range 1.10 – 2.45 µm. In addition, the spectra acquired over 4 different epochs for both Ganymede and Callisto nearly cover the whole surface of the satellites with a pixel scale of 12.5 x 25 mas. This spatial resolution corresponds to ~40 x 80 km projected on satellites' surface, thus permitting a global scale study with a resolution good enough to differentiate the larger geomorphological structures.

We will be presenting new results about the surface composition of Ganymede and Callisto, such as: (1) non-icy species – that could be hydrated salts – are needed to model our spectra, (2) these species seem unevenly distributed on moons' surface, (3) the predominant form of water-ice is crystalline, at ~120K, based on the analysis of the 1.65 µm absorption, and (4) the abundance and the size of water-ice grains seem dominated by a latitudinal effect and the geomorphology. Spectra and the very first global composition maps ever produced for Ganymede and Callisto will be presented and discussed to emphasize our results.

416.04 Modeling Cassini VIMS Spectra of Saturnian Icy Satellites Using an Efficient and Accurate Technique for Light Scattering by Densely Packed Media

Ludmilla Kolokolova[1], Kirsten Mc Michael[2, 1], Gen Ito[3], Karly Pitman[4]
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Abstract
Retrieval of properties of planetary surfaces from remotely measured spectra often rely on physically realistic yet burdensome exact computer solvers or fast yet empirical models with debatable validity. Efficient and accurate analyses of spectra require a practical method that still strives to preserve physical legitimacy. With this motivation, we use a technique that is based on a radiative transfer equation enhanced by adding a correction for dense packing effects with the static structure factor (Mishchenko, JQSRT 52, 1994; Pitman et al., JGR 110, 2005; Ito et al., JGR 122, 2018). This factor counts on the spatial correlation among densely packed particles that substantially changes their single-scattering properties. The simulations start with calculating light scattering by a single particle; the output of this calculation is corrected for the static structure factor, and then is used in a radiative transfer code The advantage of this approach is that it uses only physical parameters of the particulate surface: size of particles, their refractive indices, and filling factor or porosity. With this technique we modeled the spectra acquired by Cassini's Visual and Infrared Mapping Spectrometer (VIMS) for saturnian icy satellites Tethys, Rhea, and Dione, and compared against previous models of the same data that were done with a numerically rigorous T-matrix technique for layers formed by spherical particles (Pitman et al., PSS, 149, 2017). Even in a simple, initial stage (spherical particles), we get a very good fit to the VIMS spectra and produce reasonable values of the surface characteristics. For example, we obtained particle radius 2 micron and porosity 90% for Tethys, and particle radius 1 micron and porosity 90% for Dione. The code used in this work is very efficient computationally; it can model a VIMS 1-4 micron spectrum in ~5 minutes on a single Dell Precision T7500 desktop. An important advantage of this approach is that it can be used for single particles of any shape and structure. Following Ito et al. (2018), we also apply this technique to model surfaces covered by icy aggregates, computing their scattering properties with the T-matrix method by Mackowski and Mishchenko (JOSA 13(11), 1996).

416.05 Assessing the Crystallinity of Water Ice on Europa's Leading Hemisphere

Jodi Berdis[1], Nancy J. Chanover[1], Murthy S. Gudipati[2], Jim Murphy[1]
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Abstract

Due to resurfacing from its sub-surface ocean, Europa's surface ice is likely less than 100 million years old (Pappalardo et al. 1999; Zahnle et al. 1998). At a temperature of ~100 K (Spencer et al. 1999), this young surface should be composed of water ice mostly in its crystalline form; however, vapor deposition of water from excavated material could increase the fraction of amorphous water ice on the surface. Presence of gas-phase water in Europa's exosphere could bear different sources, such as sputtering, plumes, or cryovolcanism.

In order to quantify the relative fraction of crystalline and amorphous water ice on Europa's surface, we obtained disk-averaged near-infrared (0.95-2.46 μm) spectra of Europa's leading hemisphere at a phase angle of ~0.67° on May 11, 2018, with the TripleSpec instrument (Wilson et al. 2004) on the Astrophysical Research Consortium's 3.5m telescope at Apache Point Observatory. In addition, we employ laboratory spectra that were obtained at the Ice Spectroscopy Lab at the Jet Propulsion Laboratory of water ice as the vapor deposition rate and temperature were varied.

The band strength ratio between the 1.5 and 1.65 μm bands can directly indicate the fraction of crystalline and amorphous water ice, as the 1.65 μm band is absent in pure amorphous water ice (Schmitt et al. 1998). We use laboratory spectra to aid in the classification of water ice crystallinity as observed on Europa's surface. We then assess the implications of vapor-deposited water ice due to plume material falling back onto Europa's surface. We compare these results to previous studies of Europa's water ice crystallinity (e.g., Hansen & McCord 2004; Ligier et al. 2016) in an effort to better understand icy surface formation and evolution in the outer solar system.

This work is performed at the Jet Propulsion Laboratory, California Institute of Technology under a contract from NASA, and supported by the NASA Harriett G. Jenkins Graduate Fellowship under Grant #80NSSC17K0408, issued through the NASA Education Minority University Research Education Project (MUREP) through the Aeronautics Scholarship & Advanced STEM Training and Research (AS&ASTAR) Fellowship activity.

416.06 Plume profile studies of nanosecond laser induced desorption of water ice
- amorphous versus crystalline -

Daniel Paardekooper, Bryana L. Henderson, Murthy S. Gudipati
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Abstract

Recently, macromolecular organic compounds have been detected from the depths of Saturn's Moon Enceladus by NASA's Cassini.[1] The Jovian Moon Europa is soon to be subject to close investigation by both NASA's upcoming Europa Clipper and ESA's JUputer ICy moons Explorer (JUICE). The ocean worlds are of particular interest for the search of extraterrestrial life within our solar system.

Both of these moons are covered with presumably active oceans below thick ice shells. Enceladus has

cryo-volcanic plumes that actively expel material from its subsurface ocean. Active plumes are also present on Europa, as has been confirmed by re-examining the data from the Galileo mission.[2-3] It is likely that in the future *in situ* investigation of these highly active locations, with fresh material from the ocean is required to determine if molecules associated with life are present. However, getting detailed insights of the composition of the ice is challenging. One of the possible instruments for investigation of these ices combines laser induced desorption with time-of-flight mass spectrometry.[4-6]

At NASA-JPL, we have used the two-color Laser Ablation Ionization Mass Spectrometer system to study such ice-surface analogs.[4] IR laser desorption combined with multiphoton ionization mass spectrometry, provides insights into the desorption dynamics of amorphous and crystalline ices and their propagation in the plume. By introducing different species in low abundances into the ice structure, we can study if these molecules follow the same trend in extraction time as the water molecules. These fundamental investigations are essential for understanding the processes at play.

Acknowledgements: This work has been carried out at JPL, Caltech under a contract with the NASA, and funded by JPL's R&TD Program and NASA Solar System Workings Program. DMP thanks NASA Postdoctoral Program (NPP) Fellowship.

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416.07 Investigating the Variability of Europa's Exosphere with Keck HIRES
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Abstract
We present the first data providing ongoing monitoring of sodium in Europa's exosphere. Europa's exosphere has rarely been observed so little is known about its variability. While sodium is one of the most easily detected species, it presumably is a tracer for the presence of many other species being sputtered from the surface of Europa.

We observed Europa's sodium exosphere 21 times over 7 months in 2018 using the high-resolution echelle spectrometer (HIRES) at the Keck Observatory. The observations were obtained in short 30-minute blocks on most of the nights when HIRES was scheduled to be on the telescope. Through these observations we investigate the intensity and distribution of sodium in Europa's exosphere as a function of time, orbital phase and magnetospheric orientation. We will assess the variability of Europa's exosphere, begin investigating its sources, and explore its connection to the internal ocean.

416.08 Jupiter and Mutual Satellite Occultations of Io for the NASA Planetary Data System
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Abstract
The brightness of individual volcanic hotspots on Io can be measured using occultations of Io by Jupiter and by other satellites. We are in the final stages of preparing for submission to the NASA PDS our record of such observations covering 1985 to the present. They provide a relatively uniform long-term record of the activity of multiple sources, and the satellite mutual events provide our highest resolution ground-based observations of the hotspots. The individual hotspots appear as discrete steps in the disappearance and reappearance occultation lightcurves and those lightcurves will be included in the PDS information. However correctly attributing individual steps to given hotspots requires accurate ephemerides and for the Jupiter events also requires an accurate effective Jovian radius at which the occultations occur. The available ephemerides have improved significantly since the earliest data was obtained, and we have refined the Jovian radii to use. As part of the PDS submission we are also preparing software tools to make it easy for users to convert between locations of potential hotspots on Io and times within the lightcurve, and conversely, to project onto a map of Io the limb of the occulting object at the time of any lightcurve steps of interest. Besides cataloging brightnesses of individual unresolved hotspots we are using the mutual events to determine the brightness distribution resolved within Loki during some of its periodic brightenings. We will discuss the state of the data set and the software tools, the accuracy of the ephemerides and Jovian radii, and the quality of the Loki reconstructions.

416.09 High-resolution Spectra of Lo's Neutral Clouds: Insights on Lo-plasma Interaction and New Escape Processes

Cesare Grava[1], Timothy A. Cassidy[2], Nicholas M. Schneider[2], François Leblanc[3], Jeffrey P. Morgenthaler[4], Valeria Mangano[5], Cesare Barbieri[6], Kurt D. Retherford[1]
[1]Space Science Directorate, Southwest Research Institute, San Antonio, Texas, United States, [2]University of Colorado, Boulder, Colorado, United States, [3]LATMOS/IPSL, Paris, France, [4]Planetary Science Institute, Fort Kent, Maine, United States, [5]IAPS/INAF, Rome, Italy, [6]University of Padua, Padua, Italy

Abstract
We present high resolution ground-based spectroscopic observations of Io's exospheric sodium environment taken at the TNG (Telescopio Nazionale Galileo) telescope in 2007 and 2009. Long-slit spectra of Na D-line emissions were obtained to determine sodium density profiles near Io within ~10 R_{Io} distance. Several nights of observations spanned the entire orbital longitude range of Io, and included pre- and post-eclipse periods to study the behavior of Io's atmosphere as the solar illumination changes [Grava et al. 2014]. A leading/trailing (or downstream/upstream) hemisphere asymmetry in the abundance of sodium atoms, first reported in Mendillo et al. [2007], is more clearly established, with the leading (downstream) region being more abundant in sodium. This asymmetry is likely consistent with Io's wake of denser and stagnated plasma flow being populated with faster Na atoms originating from dissociative recombination of sodium-bearing molecular ions (e.g. $NaCl^+$). A spectral asymmetry in the emission line profile is also observed, with a tail in the redshift direction for orbital dusk-side (Western sky) observations, and likewise a blueshift in the dawnside (Eastern sky). This deviation from a Gaussian was observed by Trafton & Macy [1977] and attributed to fast streaming of the sodium neutrals along the line of sight. We also observe a previously undetected emission feature, blueshifted of tens of km/s compared to the main Neutral Clouds, as well as a deep absorption on top of Io's disk.
We present preliminary results from models developed to explain these phenomena. Our models aim to reproduce the two-dimensional features of our data (in both spectral and spatial direction) by changing parameters such as the origin of the sodium atoms and their velocity distribution. Together with the

modeling, these observations will allow to understand the plasma environment parameters in the wake of Io's interaction region, source rates for the more distant Neutral Clouds, and new escape processes.

416.10 Airborne and Ground Observations of the Stellar Occultation by Triton on 5 October 2017

Michael J. Person[1], Karsten Schindler[2], Amanda S. Bosh[1, 3], Juergen Wolf[2], Stephen E. Levine[3, 1], Carlos A. Zuluaga[1], Enrico Pfueller[2], Daniel Caton[4], Alexander Patton[1], Jay Pasachoff[5], Terry Oswalt[6], Ted von Hippel[6], Timothy Brothers[1]
[1]Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, Massachusetts, United States, [2]Deutsche SOFIA Instituet, Stuttgart, Germany, [3]Lowell Observatory, Flagstaff, Arizona, United States, [4]Appalachian State University, Boone, North Carolina, United States, [5]Williams College, Williamstown, Massachusetts, United States, [6]Embry-Riddle Aeronautical University, Daytona Beach, Florida, United States

Abstract

On 5 October 2017, Triton occulted the 13th magnitude star UCAC4 410-143659 as seen from the Eastern US, North Atlantic, and Europe. Our collaboration observed this event from the Stratospheric Observatory for Infrared Astronomy (SOFIA) aircraft, as well as numerous (over two dozen) ground stations throughout the US and Europe. Here, we present the preliminary results of analyzing this dataset and highlight a number of features of Triton's atmosphere.

Initial reduction of the data indicates that the atmospheric pressure increases seen throughout the 90's have stabilized or perhaps begun to reverse, as the current pressures are more comparable to those measured during the earlier occultations of the 1990's than the later ones, although still greater than the pressure observed by Voyager 2 in 1989.

Careful calibration of the multi-wavelength observations made from SOFIA indicates a clear atmosphere at the levels to which we are sensitive (>35 km), with no signs of the various particulate dust plumes or cloud-like structures seen by Voyager 2 below 8 km altitude.

Data reduction is progressing and a final report is in preparation.

416.12 Observations of Saturn's Irregular Moons

Tilmann Denk[1], Stefano Mottola[2]
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Abstract

The irregular moons of Saturn [1] were observed with the ISS camera of the Cassini spacecraft at a large phase-angle range to obtain lightcurves [2]. About one-quarter of the observations has been executed at $\alpha < 30°$, while about one-third at $\alpha > 70°$.

The measured amplitudes vary between ~0.1 and ~2.6 mag and generally increase from low to high phase angles. For $\alpha < 30°$, most amplitudes of Saturn's irregulars were found to be below 0.5 mag. On the other hand, for $\alpha > 50°$, there are only very few lightcurves left with amplitudes smaller than ~0.5 mag. For high phase angles above ~80°, almost all amplitudes are >1 mag.

The shapes of the lightcurves vary considerably between different objects and even between observations of the same object, indicating that these moons are not just sort of "fluid equilibrium figures" (like the

small inner Saturnian moons Methone and Pallene), but very individual worlds with irregularly-shaped surfaces. With respect to extrema, almost all show either a 2-maxima/2-minima or a 3-maxima/3-minima pattern, indicating that they are likely shape-dominated.

The periods range from ~5.5 h to ~76 h. The results approximately triple the number of known spin rates of irregular moons in the Solar System. The average spin rate for 22 irregular moons of Saturn (all except Phoebe, Loge, Fornjot) is 2.10 d^{-1} (rotation period: 11.4 h). Remarkably, it appears that there exist dependencies between spin rates, object sizes, distances to Saturn, and orbit directions. The retrograde irregular moons of Saturn are on average rather small, far away from the planet, and have fast rotations, while the prograde satellites are mostly large, closer to Saturn, and rotate more slowly.

The presentation will report the current status of our work on irregular-moon physical properties from Cassini imaging data.

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[2] Denk, T., Mottola, S. (2018): Studies of Irregular Satellites: I. Lightcurves and Rotational Periods of 25 Saturnian Moons from Cassini Observations. Submitted to Icarus.

416.13 Mapping Cryovolcanic Activity from Enceladus' South-Polar Region
Mattie Tigges, Joseph Spitale
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Abstract
Using Cassini images taken of Enceladus' south polar plumes at various times and orbital locations, our goal is to determine which fractures are active and inactive at each time. Maps of activity at various orbital phases will help test the hypothesis that Tiger Stripe activity is affected by Enceladus' orbital position around Saturn via tidal forcing.

To produce our maps, we use simulated curtains of ejected material that are superimposed over Cassini images. The images are organized into sets representing various epochs and orbital longitudes, and view the plumes from multiple angles. Source fractures are determined either by triangulation, or by matching the shadows cast onto the erupted material by the terminator of the satellite.

416.14 A sensitivity study of Enceladus geysers outgassing parameters based on DSMC calculations
Arnaud Mahieux, David Goldstein, Philip Varghese, Laurence Trafton
Computational Fluid Physics Lab, The University of Texas at Austin, Austin, Texas, United States

Abstract
The two-phases water plumes arising from the Enceladus South pole of are a key signature of what lies below the surface. Multiple Cassini instruments (INMS, CDA, CAPS, MAG, UVIS, VIMS, ISS) measured the gas-particle plume over the warm Tiger Stripe region as there have been several close flybys. Numerous observations also exist of the near-vent regions in the VIS and IR. The most likely source for these extensive geysers is a subsurface liquid reservoir of somewhat saline water and other volatiles boiling off through crevasse-like conduits into the vacuum of space.

We used a DSMC code (Yeoh et al., 2017) to simulate the plume, as it exits a vent, under axisymmetric conditions, in a vertical domain extending up to 10 km (Mahieux et al., 2018). We performed a DSMC parametric study of the following parameters: vent diameter, outgassed flow density, water gas/ice mass flow ratio, gas and ice speed, ice grain diameter and vent exit angle. We constructed parametric expressions for the plume characteristics (number density, temperature, velocity) at the 10 km upper boundary. We use these parametrizations to propagate the plumes to higher altitudes, assuming free-molecular conditions. The density field at higher altitude is determined from the parametrizations described above and explicit analytical expressions for the various force fields that the plumes are experiencing (Enceladus and Saturn gravity fields, Coriolis and centripetal accelerations due to Enceladus rotation). This enables rapid numerical computations and tabulations of the density field in space.

We will explore a Bayesian sensitivity analysis of the vent parameters conditioned on the number density field measured by the INMS instrument in the E3, E5 and E7 geometry conditions, considering the eight vent geometry presented in Spitale and Porco (2007) and the hundred vent geometric parameters given in Porco et al. (2014).

Acknoledgments
We would like to thank NASA for funding (reference NNX16A152G).

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J. Spitale and C. Porco., Nature 449, 2007
C. Porcoet al., Astron. J., 2014

416.15 Tvashtar's Eruption during the Flyby of New Horizons

Laurence M. Trafton, Yasvanth K. Poondla, David Goldstein, Philip Varghese
McDonald Observatory, University of Texas at Austin, Austin, Texas, United States

Abstract

During the flyby of New Horizons, multlcolor images were obtained of Tvashtar by MVIC spanning 0.4 - 1 microns. Tvashtar's brightness increased by an order of magnitude due either to rising volcanic activity or to forward scattering particulates. Unlike LORRI, MVIC images constrain the plume particulate spectrum. By fitting a power law to the peak plume brightness, we found an exponent of -3.1, shallower than -4 for Rayleigh scattering. This implies that the plume particles are not small compared to visible wavelengths, in apparent contradiction to HST results in the UV based on Mie theory analysis (Jessup & Spencer 2012). The UV results yielded a particle size of 50 – 75 nm. The lack of wavelength dependence for this exponent suggests that the imaginary index of refraction may be negligible throughout the MVIC spectral range Finally, this exponent appears to be constant throughout the rise in plume brightness. Hence, if the brightening resulted from increasing volcanic activity, an exponentially increasing efflux would suffice, as opposed to changing eruption chemistry or plume composition. We considered the alternative case using Mie theory for non-absorbing dielectric spheres constrained by the LORRI flyby and HST UV observations. Conclusions: 1) Forward scattering by S_2 spheres in Tvashtar's plume is unlikely to contribute appreciably to the rise since the larger spheres (micron scale) do not have the correct dependence with scattering angle while the smaller spheres do not fit the wavelength dependence of the UV HST observations. 2) In agreement with MVIC, forward scattering by SO_2 spheres can qualitatively explain the magnitude of the steep brightness rise, and roughly fit the UV HST data, only if their size is significantly bigger than found in the UV from HST; i.e., the wavelength of visible light.

Perhaps the disagreement between the UV and visible results might be reconciled if the particle size distribution were bimodal; or if the particulates were aggregates of the smaller sized spheres. Further work is needed to determine whether volcanism or forward scattering dominated the brightness increase during the flyby. [NNX14A039G]

Thursday, October 25, 2018
03:30 PM-06:00 PM
Cumberland Concourse and Ballroom E (Knoxville Convention Center)

417 Thursday Afternoon Break with iPoster and Poster Viewing

417.01
Using ADS Bumblebee: Who is that Exoplanet Scientist?
Michael J. Kurtz
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Abstract
After several years of development the new, modern ADS (codenamed Bumblebee) has been released and will soon replace the venerable, quarter century old "Classic" ADS. The new system includes both expanded capabilities and expanded content. Of particular interest to the Planetary Community we are expanding coverage of journals and conferences which could be of interest to the study of exoplanets. Using the new ADS tools one can very quickly get a detailed overview of the people, projects and research directions involved in exoplanet research, and then dive deeply into the details.

417.02 The Continuing Conundrum of the Very Wide Binary Asteroids
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Abstract
The LCDB (Warner et al., 2009) currently lists more than 260 known binary or multiple asteroids and another 91 suspected binaries. Johnston (2018) gives similar numbers. The binary asteroids fall into three basic groups. The singly-asynchronous systems (e.g., 5905 Johnson) feature a primary with a short period and a satellite that is tidally locked to its orbital period, which generally ranges from 10 to 50 hours. The fully-asynchronous systems (e.g., 1509 Esclangona) feature different rotation periods for each body with neither tied to the orbital period. In fully-synchronous systems (e.g., 2017 YE5), the rotation periods of the primary, satellite, and orbit of the satellite are all the same. When the two bodies are similar in size, "binary" may be a better descriptor than "primary/secondary."

Among the fully-asynchronous systems is a rare subclass that we call "very wide binary asteroids" (VWBA). So far, less than 20 of these have been found among the NEA, main-belt, Hilda, and Jupiter Trojan asteroids. These systems have long primary periods (24 to >500 hours) and large lightcurve amplitudes. The secondary periods are mostly below 10 hours, often in the range of the primary periods (2-4 hours) of close-in singly-asynchronous binaries. The lightcurve amplitudes are usually <0.15 mag.

From only lightcurves, the best confirmation of a binary is seeing so-called "mutual events" (occultations and/or eclipses). Since the orbital periods of VWBAs are likely hundreds of hours or more, the chance of seeing mutual events is almost nil, as evidenced by the lack of any observed so far. Alternate means of confirmation could be AO resolution of the pair, stellar occultation showing two separate bodies, or radar.

Almost all of the very wide binary candidates have been found at the Center for Solar System Studies. This is mostly due to our being able to continue observing a potential candidate for days, even weeks, on-

end with dense lightcurve coverage to confirm the two periods. Many others cannot or are reluctant to commit their limited resources when the chances for success are rare. However, it is the rare and unusual object that can lead to an even better understanding of binary asteroid evolution.

417.03 The ALCDEF Database and the NASA SBN/PDS: The Perfect Merger

Robert Stephens, Brian D. Warner
MoreData! Inc., Rancho Cucamonga, California, United States

Abstract
When is 3.3 million asteroid time-series observations enough? NEVER! Ask the AAVSO, which now has 30 million variable star observations – and counting. The problem is not the volume of data but that they are presented in so many different formats and styles that it's nearly impossible to handle hundreds of observations with a simple import program. Instead, the data must be manually dissected or hours spent modifying and testing the import program. This is made worse when it's unclear if any corrections or adjustments were applied to the raw data.

To avoid uncertainty and manual processing of data, the Asteroid Lightcurve Data Exchange Format (ALCDEF) was created (Stephens et al., 2010). Since then, 3.3 million observations have been submitted via the alcdef.org web site where users can easily download selected data in the form of ALCDEF-compatible text files. The ALCDEF database has been used extensively by those doing asteroid spin axis and shape modeling (e.g., Hanus et al., 2011; 2012). That's just one of many potential uses for the data.

A subset of the ALCDEF database recently went through the NASA PDS review process and was very favorably received. Work is now in progress to upload and make regular updates to the PDS version of the ALCDEF database. This means that those doing time-series asteroid photometry can submit their data via the ALCDEF web site and, optionally, have the data automatically transferred to the PDS. Thus, a single operation will simplify meeting NASA requirements for making data freely available and distribute them to the widest possible audience.

In addition to these enhancements, the ALCDEF site will become part of NASA's Small Bodies Node and hosted on servers at the University of Maryland. This assures meeting requirements for long-term data archiving.

With the large mass of sparse asteroid time-series data coming from surveys such as Pan-STARRS and LSST, a standard but simple format for submitting and retrieving data is even more imperative. We urge all those producing asteroid time-series photometry data to submit their data to ALCDEF and help "Save the Lightcurves."

417.04 Volume uncertainty assessment method of asteroid models from disk-integrated visual photometry.

Przemyslaw Bartczak, Grzegorz Dudzinski
Astronomical Observatory Institute, Faculty of Physics, A. Mickiewicz University, Poznan, Poland

Abstract
The problem of asteroid models' uncertainty from photometric observations remained unaddressed, though we have witnessed astounding improvements in numerical methods concerning asteroid shape and spin axis modelling. Combined with the mass estimates of good quality, e.g. the ones Gaia mission will

provide for some asteroids, reliable volumes with realistic uncertainties are crucial when deriving the densities. In this work we propose a method of asteroid models' parameters uncertainty assessment leading to volume uncertainty. The method is based on creating the clones of the nominal model and accepting the ones inside the confidence level determined by the initial fit to observations. The clones population enables to convert deterministic asteroid models into stochastic ones. We applied the method to evaluate the uncertainty of available convex and non-convex models of (3) Juno, (9) Metis and (89) Julia.

417.05 Star occultations by asteroids
Grzegorz Dudzinski, Karolina Dziadura, Przemyslaw Bartczak
Astronomical Observatory Institute, Faculty of Physics, A. Mickiewicz University, Poznan, Poland

Abstract
An occultation occurs when an asteroid passes in front of a more distant object - a star - and covers the light that comes from it. By observing occultations of stars by asteroids we can directly determine the sizes of asteroids. Current methods take only the uncertainty of observation timings into account, whereas the new method aims to take into account model's uncertainties as well. To obtain an asteroid model with uncertainties clones of the nominal solution are created. Those clones are created by making small changes in model's parameters and are accepted or rejected based on the fit to the observations within a confidence level. The main goal of new method is to specify asteroid diameters with uncertainty, which takes into account the uncertainties from: observing time, rotational period, spin position and shape.

417.06 NEATM models for asteroids with well-characterized phase curves and with radar diameters
Diane H. Wooden, Jessie Dotson
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Abstract
The Near Earth Asteroid Thermal Model (NEATM) is a powerful tool that allows astronomers to understand a variety of important physical properties of asteroids, including diameter, geometric albedo, and IR beaming parameters (eta), which is a proxy for surface roughness and thermal inertia. Not all asteroids either venture close enough to Earth to allow radar observations or are visited by spacecraft. Thermal infrared observations are an important complement to the methods used by astronomers to study asteroids. Here we investigate how thermal data of asteroids taken by the WISE spacecraft can be used to quantify these physical parameters, especially diameters, by fitting the WISE data with the NEATM models.
We present NEATM models for a handful of asteroids that have high quality absolute magnitudes (H) and well determined phase curves and hence phase integrals (q), i.e., they have been well characterized in visible light (scattered light). The asteroids have all been measured by radar as well, and include 22 Kalliope, 50 Virginia, 83 Beatrix, and 444 Gyptis. The NEATM model assumes zero thermal inertia and is one of the simplest models applied to WISE data of asteroids. We follow different published modeling approaches for grooming the data or for restricting the parameter space and contrast the results of the model fits. The aim is to assess how these different modeling approaches affect the results and to compare the NEATM diameters with the radar diameters for these select asteroids.

417.07 Physical Properties of 2000 Observed Main-Belt Asteroids

Nicolas Erasmus[1], Andrew McNeill[2], Michael Mommert[3, 2], Amanda A. Sickafoose[1, 4], David Trilling[2, 1]
[1]South African Astronomical Observatory, Cape Town, South Africa, [2]Department of Physics and Astronomy, Northern Arizona University, Flagstaff, Arizona, United States, [3]Lowell Observatory, Flagstaff, Arizona, United States, [4]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States

Abstract

We present VRI spectrophotometry of 2238 main-belt asteroids (MBAs) observed with the Sutherland, South Africa node of the Korea Microlensing Telescope Network (KMTNet). Through our broadband spectrophotometry we are able to reliably distinguish among four asteroid taxonomies: S-, C-, X-, or D-type asteroids. We categorize 1964 of the 2238 observed targets as either a S-, C-, X-, or D-type asteroid by means of a machine learning algorithm that was trained with colors synthesized from spectra of observed MIT-UH-IRTF targets that have confidently identified taxonomies. Additionally, we report 0.35–5.5 hr (mean: 3.0 hr) light-curve data for each MBA which allowed us to resolve the complete rotation periods and amplitudes for ~1/5th of our targets. Of the ~400 targets with resolved rotation periods, 3 have rotation periods potentially below the theoretical zero-cohesion boundary limit of 2.2 hr. Using our determined taxonomies and rotation properties we also show preliminary results of further investigation into MBA family and non-family members within our target list.

417.08 Symplectic Integrators: T + V Revisited

John Chambers
Department of Terrestrial Magnetism, Carnegie Institution for Science, Washington, District of Columbia, United States

Abstract

Symplectic integrators are a popular tool for long-term orbital evolution calculations due to their efficiency and good energy conservation properties. These algorithms separate the Hamiltonian for a system into two or more parts, each of which can be solved easily. The parts are advanced alternately in several substeps that when combined approximate the complete system. For problems with a dominant central mass, such as the Sun in the Solar System, the Hamiltonian is usually separated into Keplerian orbits plus perturbations (mixed-variable symplectic or ``MVS'' algorithms). This separation typically leads to small errors when the secondary masses are much smaller than the primary. Here, I consider so-called ``T+V'' algorithms, where the Hamiltonian is separated into kinetic (T) and potential (V) energy terms instead. A simple implementation of T+V leads to much larger errors than MVS algorithms in systems with a dominant central mass. However, the error can be reduced greatly by splitting forces into strong and weak parts, with different step sizes. Further gains can be made by including force gradients. To first order, these are straightforward to include in T+V problems with a dominant central mass. I will describe several T+V algorithms and show that they can be competitive with MVS algorithms. I will also demonstrate how a simple modification can substantially reduce roundoff errors for T+V integrators.

417.09 The Current State of Spitzer Secondary Eclipse Analyses: HD 209458 b

Kathleen J. McIntyre, Joseph Harrington, Ryan C. Challener, Matthew Reinhard, Raechel Green, Zacchaeus Scheffer, Parker Jochum, Catherine Millwater
University of Central Florida, Winter Park, Florida, United States

Abstract
The Spitzer Space telescope has been the workhorse for exoplanet secondary eclipse observations for more than a decade. Despite this, we are still uncovering and understanding new methods for moderating systematics. One such systematic that can mimic the features of a secondary eclipse or small primary transit is vibrations of the spacecraft that manifest as changes in the point-spread function (PSF). Previously utilized metrics for identifying this "noise pixel" effect do not account for the systematic's presence when there is no accompanying increased contribution to the noise. This omission impacts published results. Here we present the test case of HD 209458 b, one of the most observed, published, and highest signal-to-noise exoplanets discovered to date. We compare the effect of different methods, for example, variable aperture photometry and decorrelating with PSF parameters, on the resulting light curves across all of Spitzer's IRAC channels. Spitzer is operated by the Jet PropulsionLaboratory, California Institute of Technology, under a contract with NASA. This work was supported by NASA Planetary Atmospheres grant NNX12AI69G and NASA Astrophysics Data Analysis Program grant NNX13AF38G.

417.10 Impact of Stellar UV Activity on Habitable Moist Terrestrial Exoplanet Atmospheres Around M dwarfs

Mahmuda Afrin Badhan[1, 2], Eric T. Wolf[3], Ravi Kopparapu[2], Giada Arney[2], Eliza M. Kempton[1], Drake Deming[1], Shawn Domagal-Goldman[2]
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Abstract
Transit spectroscopy of terrestrial planets around nearby M dwarf stars is a primary goal of space missions in the coming decades. 3D climate modeling has shown that slowly rotating terrestrial extrasolar planets, at the inner edge of M dwarf habitable zones (HZ), may possess significantly enhanced stratospheric water vapor compared to a rapidly rotating planet like Earth. For host M-dwarfs with Teff > 3000 K, synchronously rotating inner HZ planets have been shown to retain moist greenhouse conditions (stratospheric water mixing ratio $>10^{-3}$) despite low Earth-like surface temperatures. This is promising for H_2O detection in the atmospheres of habitable planets with the upcoming James Webb Space Telescope (*JWST*). In such slow rotators, strong vertical mixing is expected to loft H_2O high into the atmosphere. However, M dwarfs also possess strong UV activity, which may effectively photolyze stratospheric H_2O. Prior modeling efforts have not included the impact of high stellar UV activity on stratospheric H_2O abundance. Here, we employ a 1-D photochemical model with varied stellar UV, to assess whether H_2O destruction driven by high stellar UV would affect the detectability of H_2O in transmission spectroscopy. Temperature and water vapor profiles are taken from published 3-D climate model simulations for an inner HZ Earth-sized planet around a 3300 K M dwarf with a pure N_2-H_2O atmosphere; they serve as self-consistent input profiles for the 1-D model.
We find that as long as the atmosphere is well-mixed up to the 1 mbar pressure level, UV activity appears to not impact detectability of H_2O in the transmission spectrum. The strongest H2O features occur in the *JWST* MIRI instrument wavelength range and are comparable to the estimated systematic noise floor of ~50 ppm for a cloudless atmosphere. We also explore additional chemical complexity within the 1-D model by introducing other species into the atmosphere and discuss their impact on the transmission spectrum for both cloudy and cloudless cases.

Friday, October 26, 2018
08:30 AM-10:05 AM
Ballroom A (Knoxville Convention Center)

500 Giant Planet Atmospheres and Interiors
Chair(s): Cheng Li, Imke de Pater

08:30 AM-08:40 AM
500.01 Discovery and Infrared Characterisation of Jupiter's Equatorial Disturbance Cycle
Arrate Antuñano[1], Leigh Fletcher[1], Glenn Orton[2], Henrik Melin[1], John Rogers[3], Joseph Harrington[4], Padraig T. Donnelly[1], Naomi Rowe-Gurney[1], James S.D. Blake[1]
[1]Department of Physics, University of Leicester, Leicester, United Kingdom, [2]Jet Propulsion Laboratory, Pasadena, California, Afghanistan, [3]British Astronomical Association, London, United Kingdom, [4]University of Central Florida, Orlando, Florida, United States

Abstract
In this work, we use a ground-based infrared dataset spanning almost four decades, between June 1984 and August 2017, to report five rare events that completely changed the appearance of Jupiter's equatorial zone at 5 µm (1-4 bar region), leaving a cloud-free band at the equator, in addition to large, narrow, and bright festoons within the northern equatorial zone. Three of these five events were previously observed in ground-based images captured in June-November 1973, in March 1979 and in January-April 1992, but were not discussed at all. Here we characterize for the first time two new episodes of these equatorial zone disturbances at 5 µm, observed between August 1999 and August 2000, and between April 2006 and September 2007. These events exhibited large grey/bluish festoons and white plume-like features at the northern edge of the equatorial zone at visible wavelengths, and a brownish coloration of the southern equatorial zone. We find that these events can form within a month, have a typical lifetime of 12-18 months, and dissipation time-scales of 4 months or less. Comparing 5 µm data of these two events with visible wavelength images, we find that aerosols change first in the upper troposphere at the cloud tops (~700 mbar), before the disturbance propagates downwards and removes, months later, the aerosols in the cloud forming region at 1-4 bar. Analysing the brightness variability of the equatorial zone at 1.58 µm (ammonia cloud tops) and 2.12 µm (stratospheric hazes) during the 2006-2007 event, we see that the disturbances are confined to the cloud deck and do not appear to influence the stratospheric hazes. Finally, after analysing five equatorial zone disturbances, we conclude that they are periodic/stochastic with typical time intervals of 6-8 years or 13-14 years. This periodicity implies that a new event should occur in 2019-2020, permitting detailed characterization of an equatorial disturbance by the Juno spacecraft.

08:40 AM-08:50 AM
500.02 Superstorms on Jupiter: Convection, volatiles, clouds, and lightning near Juno's 4th orbit
Michael Wong[1], Gordon Bjoraker[2], Shannon T. Brown[3], John Rogers[4], Imke de Pater[1], Joshua Tollefson[1], Charles Goullaud[1], Chris Moeckel[1], Amy Simon[2], Cheng Li[5], Ko-ichiro Sugiyama[6], Kensuke Nakajima[7]
[1]ASTRONOMY DEPARTMENT, UC BERKELEY, Berkeley, California, United States, [2]NASA/GSFC, Greenbelt, Maryland, United States, [3]JPL, Pasadena, California, United States, [4]BAA, Cambridge, United Kingdom, [5]Caltech, Pasadena, California, United States, [6]Natl. Inst. Tech., Matsue, Japan, [7]Kyushu Univ., Kyushu, Japan

Abstract
A South Equatorial Belt (SEB) Outbreak---comprising a series of extremely large convective storms---began in the last few days of 2016. This was early in the Juno mission, and several ground-based programs targeted Jupiter in mid-January while the Outbreak was in full force. These January observations were intended to coincide with Juno's 8th orbit, under the original plan with 14-day orbits. Instead, due to a canceled main engine burn, there were no Juno atmospheric observations in January. Under the revised 53-day plan, Juno's 4th perijove pass fell in February 2017. The spacecraft flew in between convective superstorms associated with the SEB Outbreak. The February 2017 Juno data were accompanied by a suite of observations by ground-based and space-based observatories.

The wide range of complementary datasets will allow us to report on a comprehensive picture of the workings of individual superstorms, as well as the overall SEB Outbreak system that remained active for several months. Juno's path fell between convective centers, and the between-storm region sensed by MWR was locally depleted in ammonia gas at $P < 2$ bar. The MWR also revealed a cluster of lightning strikes as the spacecraft passed over the SEB. Time-lapse HST imaging will be used to generate velocity fields and estimate cloud-top divergence, at multiple stages of the Outbreak's evolution. HST methane-band data also show massive haze-depleted areas in between-storm regions, and HST-derived zonal wind profiles from January, February, and April reveal significant monotonic changes in wind speeds as the Outbreak evolved. High-resolution 5-micron spectroscopy with Keck/NIRSPEC and IRTF/iSHELL reveal spatially-variable volatiles and deep cloud opacity across the Outbreak. Microwave/millimeter maps are also sensitive to volatile abundances in and around the convective storms. The ultimate goal of assembling these observations is to understand the convective process on giant planets, particularly to test numerical models suggesting that episodic convection is controlled by vertical gradients of volatile species, and that major convective events produce stable conditions in their aftermath.

08:50 AM-09:00 AM
500.03 Water clouds and volatiles in a stormy portion of Jupiter's South Equatorial Belt
Gordon Bjoraker[1], Michael Wong[2], Imke de Pater[2], Mate Adamkovics[3], Tilak Hewagama[4], Glenn Orton[5]
[1]NASA/GSFC, Greenbelt, Maryland, United States, [2]UC Berkeley, Berkeley, California, United States, [3]Clemson U, Clemson, South Carolina, United States, [4]U Maryland, College Park, Maryland, United States, [5]JPL, Pasadena, California, United States

Abstract
We used NIRSPEC on the Keck telescope to obtain 5-micron spectra of Jupiter in support of Juno Perijove 4 and of a VLA mapping campaign in January and February 2017. Prior to our observations, amateur astronomers had observed an "Outbreak" or disturbance in Jupiter's South Equatorial Belt (SEB). As part of our mapping program we aligned the 24-arcsec slit east-west and stepped it from south to north to cover the disturbed portion of the SEB on January 23 and again on February 4, 2017. These spectra are sensitive to cloud structure as well as to volatiles such as NH_3 and H_2O. Preliminary results show evidence for deep clouds (around the 5-bar level) in the disturbed region near 13 South, while spectra taken at 8 South and 18 South indicate that the undisturbed SEB is largely free of clouds at this level. We attribute these deep cloud features to water clouds based on their pressure. We will report on retrieved abundances of H_2O and NH_3 and compare them with measurements from the microwave radiometer on Juno and ground-based maps of NH_3 from the VLA. Our evidence for deep clouds supports the idea that the disturbance in the SEB originates at the water-cloud level and is responsible for enhanced convection and lightning activity in the region.

09:00 AM-09:10 AM

500.04 The source of Saturn's stratospheric water

Thibault Cavalié[1, 2], Vincent Hue[3], Paul Hartogh[4], Emmanuel Lellouch[2], Raphael Moreno[2], Timothy A. Cassidy[5], Christopher Jarchow[4], Michel Dobrijevic[1]
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Abstract

Infrared Space Observatory observations demonstrated that water (H_2O) and other species like carbon monoxide (CO) are supplied in giant planet upper atmospheres by external sources: interplanetary dust particle, icy rings and/or satellites, large comet impacts. These sources have different spatio-temporal properties that we can use to discriminate them.

At Saturn, stratospheric CO was probably deposited by an ancient comet impact. For water, the situation remains unclear, even if Enceladus and its water geysers are promising candidates.

In this paper, we model altitude-latitude distributions of water in Saturn's stratosphere and compare them with Herschel PACS and HIFI observations to determine its source. Herschel observations have already enabled the detection of a water torus at the orbital distance of Enceladus. A fraction of this water is predicted to rain on Saturn. We test this prediction and compare it to other possible sources.

09:10 AM-09:20 AM

500.05 Reconciling Neptune's interior O/H and D/H abundances: new constraints from Herschel measurements of CO

Nicholas A. Teanby[1], Patrick Irwin[2], Julianne Moses[3]
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Abstract

Measurements of Neptune's atmospheric D/H combined with interior models suggest that the icy planetesimals which formed Neptune had D/H ratios of $5.1\text{-}7.7\times10^{-5}$ (Feuchtgruber et al., 2013). This is ~2-3 times less enriched that any known source material in the present day solar system. One potential solution is to reduce the ice content of pre-Neptune planetesimals to give Neptune a more rock-rich core and allow contribution from ices with D/H in the range of current comets ($1.5\text{-}3.0\times10^{-4}$). The reduced ice content would then suggest bulk O/H enrichment 50-150 times solar, which is comparable to the measured C/H enrichment from methane. However, a problem arises when comparing this potential formation scenario with thermochemical schemes for CO, which require highly enriched O/H ratios of 280-650 times solar to allow sufficient mixing of CO into the troposphere to explain previously inferred ~0.1 ppm deep abundances (e.g. Cavalié et al., 2017).

We propose a simple solution to this discrepancy - that there is in fact very little tropospheric CO for pressures greater than ~1 bar - and that the majority of Neptune's observable CO is externally sourced. We tested this hypothesis using Herschel's SPIRE instrument to constrain Neptune's CO profile. We find that nine independent CO bands can be simultaneously fitted using a step profile with a 0.2 ppm tropospheric abundance, a 1.0 ppm stratospheric abundance, and a step transition pressure of 0.1 bar - in broad agreement with previous studies. However, more importantly, we also find that CO spectral

features could be fitted to well within measurement errors with a profile that contains no tropospheric CO for pressure levels deeper than 0.5 bar. CO is in fact only required in the upper troposphere (0.1-0.5 bar) to adequately fit both SPIRE and previous sub-mm observations.

Therefore, we propose that while some CO is required in the upper troposphere to fit observations, it is not a requirement to have significant amounts at deeper pressures. This has important implications for the formation and composition of Neptune's deep atmosphere and could resolve some of the apparent discrepancies between CO and D/H measurements.

09:20 AM-09:30 AM

500.06 Microwave Sounding of Saturn and Uranus: Comparing Gas- and Ice-Giant Planets

Mark Hofstadter[1], Virgil Adumitroaie[1], Sushil Atreya[2], Bryan Butler[3]
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Abstract

Ground-based radio observations of the giant planets at millimeter to meter wavelengths probe the atmospheres from 0.1 bar to kilo-bars. We are sensitive to the abundances and distribution of NH_3, H_2O, and H_2S. These species are diagnostic of atmospheric dynamics and chemistry, and are potentially diagnostic of planetary formation models.

Observations of Saturn indicate the tropospheric NH_3 abundance is 5 to 10x a solar abundance. If NH_3 is near the bottom of that range, H_2O must be ≥10x solar. If NH_3 is near the top of that range, we cannot constrain water. These results are broadly consistent with earlier works (e.g. de Pater and Massie, *Icarus* 1985), though details have changed due to improved models of opacity and perhaps because of temporal variations. Favored planetary formation models for Saturn predict enrichments in these species comparable to what is observed (Atreya et al. 2018 and references therein). New observations currently being reduced may allow us to test the prediction by Li and Ingersoll (*Nature* 2015) that H_2O should be near 10x solar.

At Uranus, we find strong vertical variations in abundances indicative of cloud formation. Near pressures of 50 bar (just above the liquid water cloud) the NH_3 abundance is 0.2 to 0.6x solar, and H_2S is 1 to 2x solar. H_2O is not well constrained but is probably >3x solar. These results are consistent with earlier work on the upper troposphere (e.g. Gulkis et al., *Icarus* 1978), but are charting new territory at depth. If the retrieved abundances reflect bulk mixing ratios, they are inconsistent with most (but not all) formation models for Uranus, which favor mixing ratios >50x solar. Our preferred interpretation, however, is that a super-ionic water ocean deep within Uranus traps both NH_3 and H_2S.

Our results highlight three points. 1) The composition, chemistry, and interior structure of the gas giant planets are very different from the ice giants. 2) Microwave observations, both ground- and space-based, are useful probes of the dynamics, chemistry, and composition of the deep atmospheres of giant planets. 3) On Uranus, unknown chemical or dynamical processes are modifying the abundance of species, or the favored planetary formation models are incorrect.

09:30 AM-09:40 AM

500.07 Comparing the deep dynamics on Jupiter and Saturn in light of the Juno and Cassini gravity experiments

Yohai Kaspi[1], Eli Galanti[1], Luciano Iess[2], Daniele Durante[2]
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Abstract

Strong zonal flows dominate the atmospheres of both Jupiter and Saturn at cloud-level. Jupiter's flows consist of strong latitudinally alternating east-west zonal jets (up to 140m/s), with a significant asymmetric component between the northern and southern hemispheres. On Saturn, the wind pattern is a wide and mostly symmetric eastward flow of more than 400 m/s at the equatorial region, and smaller scale jets extending to high latitudes. How deep these winds penetrate into the planets' interior has remained a fundamental open question until recently, when both Juno at Jupiter and Cassini at Saturn enabled answering this decades-long question.

The gravity experiment, performed by both spacecrafts, provided measurements of the gravity harmonics with unprecedented accuracy, and showed substantial differences between the two planets. The Jupiter's even gravity harmonics were found to follow closely those predicted by rigid body models, and its odd harmonics are large, clearly above the measurement uncertainty level. Conversely, the even harmonics of Saturn deviate considerably from those predicted by rigid body models, for all harmonics larger than J4, and its odd harmonics turned out small with only J5 being substantially above the uncertainty level. Using the gravity measurement, together with an adjoint based inverse model of the flow dynamics, we show that on both planets the winds are very deep - reaching around 3,000km on Jupiter and 9,000km on Saturn. This points to some similarities and differences on both planets. On both planets the winds observed at the cloud level are a manifestation of deep flows extending thousands of kilometers deep, to the level where the electric conductivity is large enough that the flow may be dissipated by the magnetic field. With that, the winds on Saturn penetrate 3 times deeper and are more symmetric than the winds on Jupiter. These differences are likely the result of Saturn being 3 times less massive and having a much weaker magnetic field.

In the presentation we will discuss the gravity measurements, the depth of the winds analysis including the best fit vertical wind profile, and the implications to the characteristics of the two planets.

09:40 AM-09:50 AM

500.08 Probability based density profiles of Saturn from its measured gravity field

Naor Movshovitz, Jonathan J. Fortney, Daniel Thorngren, Christopher Mankovich
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Abstract

The external gravity field of a planetary body is determined by the distribution of mass in its interior. A measurement of the external field, if properly interpreted, can therefore tell us about the interior density profile, and the interior density can in turn inform on the composition in the deep interior and thereby possibly constrain formation theories for gas giants generally.

Recently, high precision measurements of Saturn's gravity have been made by the radio science instrument on Cassini during its Grand Finale orbits. The question of how best to relate these measurments to interior models is not trivial. In essentially all prior work on matching models to gravity field data inferences about planetary structure have rested on assumptions regarding the imperfectly known H/He equation of state and the assumption of an adiabatic interior. Here we wish to relax some of these assumptions. In the language of statistical inference, we wish to use them as *priors* rather than iron-

clad axioms.

We present our framework for sampling from all possible interior density structures of a Jovian planet, guiding the samples by a given set of gravity coefficients and their associated uncertainties, and assisted by physically motivated interior models as priors. We thus produce a random sample of $\rho(s)$ curves drawn from the underlying (and unknown) probability distribution of all curves, where ρ is the density on an interior level surface with mean radius s. Since the resulting set of density curves is a random sample, that is, curves appear with frequency proportional to the likelihood of their being consistent with the measured gravity, we can compute probability distributions for any quantity that is a function of ρ (e.g. pressure curves, oblateness, core mass). And using theoretical equations of state we can also derive quantities relating to composition, such as the heavy element total mass and distribution, and the uniformity of Helium abundance.

We present an application of this approach to Saturn based on recently published gravity data from Grand Finale orbits and discuss their implications.

09:50 AM-10:05 AM

500.09D Cassini Ring Seismology as a Probe of Saturn's Rotation

Christopher Mankovich[1], Mark S. Marley[2], Jonathan J. Fortney[1], Naor Movshovitz[1]
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Abstract
Seismology of the gas giants holds the potential to resolve long-standing questions about their internal structure and rotation state. We construct a family of Saturn interior models constrained by the gravity field and compute their adiabatic mode eigenfrequencies and corresponding Lindblad and vertical resonances in Saturn's C ring, where more than twenty waves with pattern speeds faster than the ring mean motion have been detected and characterized using high-resolution Cassini Visual and Infrared Mapping Spectrometer (VIMS) stellar occultation data. We present identifications of the fundamental acoustic modes of Saturn that appear to be the origin of these observed ring waves, and use their observed pattern speeds and azimuthal wavenumbers to estimate the bulk rotation period of Saturn's interior to be 10h 35m 42s (+2m 00 s / -1 m 42 s) (median and 5%/95% quantiles), significantly faster than magnetospheric periods measured by Voyager and Cassini radiometry. Structure in the resulting pattern speed residuals suggests the presence of differential rotation in Saturn's outer envelope.

Friday, October 26, 2018
08:30 AM-10:00 AM
Ballroom B (Knoxville Convention Center)

501 HAYABUSA2 Special Session
Chair(s): Faith Vilas, Masatoshi Hirabayashi

08:30 AM-08:40 AM
501.01 Overview of initial remote-sensing observations of asteroid Ryugu by Hayabusa2
Makoto Yoshikawa[1], Sei-ichiro Watanabe[2], Masaki Fujimoto[1], Satoshi Tanaka[1], Seiji Sugita[3], Kohei Kitazato[4], Noriyuki Namiki[5], Tatsuaki Okada[1], Hitoshi Ikeda[1], Naru Hirata[4], Naoya Sakatani[1], Tomokatsu Morota[2], Koji Matsumoto[5], Yoshiaki Ishihara[1], Hikaru Yabuta[6], Tomoki Nakamura[7], Yukio Yamamoto[1], Shota Kikuchi[1], Fuyuto Terui[1], Takanao Saiki[1], Satoru Nakazawa[1], Yuichi Tsuda[1]
[1]ISAS, JAXA, Sagamihara, Kanagawa, Japan, [2]Nagoya University, Nagoya, Aichi, Japan, [3]University of Tokyo, Tokyo, Tokyo, Japan, [4]University of Aizu, Aizuwakamatsu, Fukushima, Japan, [5]NAOJ, Mitaka, Tokyo, Japan, [6]Hiroshima University, Hiroshima, Hiroshima, Japan, [7]Tohoku University, Sendai, Miyagi, Japan

Abstract
Hayabusa2 is the second sample return mission from an asteroid after Hayabusa mission. The target asteroid is (162173) Ryugu, which is a C-type asteroid. The main science objective is to investigate organic matters and water at the beginning of the solar system. The technological purpose is to maturate the new technology developed by Hayabusa and to develop other new technology for space missions. Hayabusa2, which was launched December 3, 2014, arrived at Ryugu on June 27, 2018. Ryugu is a top-shaped asteroid about 900m in diameter. The shape is rather unexpected because the spin period of Ryugu is not so short as those of top-shaped asteroids known previously. The remote sensing observations were done from the distance of 20km at first by the four instruments, ONC (Optical Navigation Camera), LIDAR (Laser Altimeter), NIRS3 (Near Infrared Spectrometer), and TIR (Thermal Infrared Imager).
Up to now (end of July), we found that Ryugu has sharp ridge along its equator, and that there are about 50 crater candidates. The largest one is about 300m in diameter. The surface is covered by numerous boulders. The largest one is located near the one of the poles and the size is about 130m. We also found by the observation of TIR that the surface temperature is different between the north hemisphere and the south hemisphere, which shows the seasonal difference. The visible and infrared spectra were obtained by ONC-T (with 7 filters) and NIRS3. The visible spectrum is very flat and its variations are very small. But we observed small variation in both albedo and spectral slope on Ryugu. As for the near infrared spectrum by NIRS3, it showed homogeneous and featureless spectra between 1.8 and 3.2 microns, which indicates lack of hydrated minerals in the entire surface.
These features are very interesting from the science point of view and it is very important to decide where to touchdown and where to release the lander (MASCOT) and the rovers (MINERVA-II). The landing site selections will be done in August by considering these remote sensing observation data, shape model, and gravity measurements. The lander and rover releases will be done in September and October 2018, and the 1st touchdown will be done in October.

08:40 AM-08:50 AM
501.02 The First Detailed Look at Asteroid Ryugu with Visible Multi-band Camera on Hayabusa2
Seiji Sugita[1], Rie Honda[2], Tomokatsu Morota[18], Shingo Kameda[19], Hirotaka Sawada[3], Eri Tatsumi[1], Chikatoshi Honda[4], Yasuhiro Yokota[3], Manabu Yamada[5], Toru Kouyama[6], Naoya Sakatani[3], Hidehiko

Suzuki[7], Kazuo Yoshioka[1], Masahiko Hayakawa[3], Yuichiro Cho[1], Moe Matsuoka[3], Naru Hirata[4], Naoyuki Hirata[8], Deborah Domingue[9], Hideaki Miyamoto[1], HIROSHI KIKUCHI[1], Ryodo Hemmi[1], Tatsuhiro Michikami[10], Olivier S. Barnouin[11], Carolyn M. Ernst[11], Eric Palmer[9], Robert Gaskell[9], Patrick Michel[12], Masatoshi Hirabayashi[13], Jaumann Ralf[14], Katharina Otto[14], Nicole Schmitz[14], Stefan Schroeder[14], Takahiro Hiroi[15], Tomoki Nakamura[16], Goro Komatsu[17], Yuichi Tsuda[3], Makoto Yoshikawa[3], Satoshi Tanaka[3], Kei Shirai[3], Sei-ichiro Watanabe[18]
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Abstract
Upon the arrival of Hayabusa2 at Ryugu, we conducted multi-band visible imaging observations covering its globe. These observations revealed a number of important properties of Ryugu, most of which are unexpected before the arrival. These include: 1) a classic bi-cone top shape with upright spin axis, 2) equatorial ridge encircling the entire body, 3) the presence of large boulders particularly around the poles, 4) latitudinal decrease in number density of large boulders toward equator [1], 5) general uniformity in visible spectra on the entire globe [2], 6) bright spots and bright surfaces on a large boulder, which exhibit bluer spectra [2], 7) bowl-shaped circular depressions with raised rimes, consistent with impact craters [3], 8) the number density of these depressions being on the same order of magnitude as that of crater candidates on Itokawa [4], 9) preferential deficiency in small circular depressions with a similar size frequency slope as Itokawa and Eros, suggesting the presence of granular medium subject to seismic shaking and crater erasure.

The bowl-like shape of large (~200m in diameter) circular depressions, consistent with gravity-controlled craters, and the deficiency in small circular depressions suggest that Ryugu may be mantled with strengthless materials at least 10's meter of thickness. Such mobile interior in Ryugu may have played an important role in forming the circum-equatorial ridge belt [5] and clustering of large boulders around the poles. Furthermore, boulder size measurements indicate that they are too large to be impact ejecta from observed craters, suggesting that they may be direct fragments from Ryugu's parent body. Thus, the variations in spectroscopic properties of large boulders may reflect heterogeneity in Ryugu's parent body, its detailed spectroscopic characterization is of great importance for both uncovering the history of Ryugu.

Ref. [1] Honda, C. et al. (2018), DPS mtg [2] Tatsumi et al., (2018) DPS mtg, [3] Cho et al. (2018), DPS mtg, [4] Morota et al., DPS mtg, [5] Michel et al., DPS mtg. Acknowledgements: This study was supported by JSPS International Planetary Network.

08:50 AM-09:00 AM
501.03 Surface composition of asteroid (162173) Ryugu from Hayabusa2/NIRS3 observations
Kohei Kitazato[1], Takahiro Iwata[2], Masanao Abe[2], Makiko Ohtake[2], Shuji Matsuura[3], Takehiko Arai[4], Yusuke Nakauchi[2], Tomoki Nakamura[5], Moe Matsuoka[2], Hiroki Senshu[6], Naru Hirata[1], Takahiro Hiroi[7], Cedric Pilorget[8], Rosario Brunetto[8], François Poulet[8], Lucie Riu[2], Deborah Domingue[9], Driss Takir[10],

Ernesto Palomba[11], Ralph Milliken[7], Davide Perna[12], Antonella Barucci[12], Jean Pierre Bibring[8], Sei-ichiro Watanabe[13]
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Abstract
On 27 June 2018, JAXA's Hayabusa2 spacecraft arrived at a distance of 20 km from its target asteroid, 162173 Ryugu, and began the 1.5-year asteroid proximity operations. We have acquired near-infrared spectra of Ryugu using the NIRS3 instrument onboard Hayabusa2 to begin to characterize and map the surface composition. The asteroid Ryugu is a sub-km sized C-type asteroid in the near-Earth space. The initial data from NIRS3, obtained at a spatial resolution of about 35 m, shows homogeneous and featureless spectra between 1.8 and 3.2 microns, indicating possible lack of hydrated minerals across the entire surface. We will present results from the analysis of the NIRS3 data, including the high-resolution data to be obtained during the first descent operations.

09:00 AM-09:10 AM
501.04 Thermal Infrared Observations of C-type Asteroid 162173 Ryugu by Hayabsua2
Tatsuaki Okada[1, 2], Tetsuya Fukuhara[3], Satoshi Tanaka[1], Makoto Taguchi[3], Takehiko Arai[4], Hiroki Senshu[5], Naoya Sakatani[1], Yuri Shimaki[1], Hirohide Demura[6], Yoshiko Ogawa[6], Kentaro Suko[6], Tomohiko Sekiguchi[7], Toru Kouyama[8], Jun Takita[9], Tsuneo Matsunaga[10], Takeshi Imamura[2], Takehiko Wada[1], Sunao Hasegawa[1], Jorn Helbert[11], Thomas G. Müller[12], Axel Hagermann[13], Jens Biele[11], Mathias Grott[11], Maximiliam Hamm[11], Marco Delbo[14], Naru Hirata[6], Yukio Yamamoto[1], Fuyuto Terui[1], Takanao Saiki[1], Satoru Nakazawa[1], Makoto Yoshikawa[1], Sei-ichiro Watanabe[15, 1], Yuichi Tsuda[1]
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Abstract
Hayabusa2 [1] is the second asteroid sample return mission organized by Japan Aerospace Exploration Agency (JAXA), and has just arrived at the C-type near-earth asteroid 162173 Ryugu. Hayabusa2 performs remote sensing to characterize global features of the asteroid such as the shape, the rotation state, the gravity and density, the surface geology, the spectroscopic profiles, and the thermal properties. Thermal Infrared Imager (TIR) [2] is one of the remote sensing instruments to take thermal images for investigating thermo-physical properties of the asteroid. TIR is based on the uncooled micro-bolometer array of 328 x 248 effective pixels, with the FOV of 16° x 12°, and with a band pass filter of 8 to 12 μm. At the Home Position, 20 km earthward from the asteroid, TIR has taken images of Ryugu at every 6° for one rotation with about 20 m per pixel resolution. Higher resolved images are taken during descent operations. Those observed thermal images are converted to the brightness temperature images with the pipeline data handling and using the compiled ground calibration database for TIR called HEAT [3].

Using the asteroid shape model and the SPICE kernels, we map surface thermal inertia and consequently the grain size distribution [4] of the surface of Ryugu using the delay of peak temperature from the local noon and by the maximum temperature in rotation, compared with the thermo-physical model [5]. The surface temperature will be verified by *in situ* radiometry for day-night cycles by MARA [6] on MASCOT lander. The information of the surface physical state, grain size, boulder abundance, and the temperature predictions derived from TIR data will contribute to the landing site selection both from the scientific and mission purposes.

[1] Tsuda, Y., et al., *Acta Astronaut.* 127, 702-709 (2016), [2] Okada, T. et al, *SSR* 208, 255-286 (2017), [3] Endo, K. et al., *IEEE Xplore*, 16946502, pp.1-10 (2017), [4] Sakatani N. et al. *AIP Adv*, 7, 015310, (2017), [5] Takita, J., *SSR*, 208, 287-315, (2017), [6] Grott, M., et al., *SSR*, 208, 413-431, (2017).

09:10 AM-09:20 AM

501.05 Initial results of shape modeling on the asteroid Ryugu from observations by Hayabusa2 for landing site selection

Naru Hirata[1], Naoyuki Hirata[2], Sayuri Tanaka[2], Naoki Nishikawa[2], Takaaki Sugiyama[1], Robert Gaskell[4], Eric Palmer[4], Rina Noguchi[3], Yuri Shimaki[3], Koji Matsumoto[5], Hiroki Senshu[7], Yukio Yamamoto[3], Shinya Murakami[3], Yoshiaki Ishihara[3], Seji Sugita[8], Yuichi Tsuda[3], Sei-ichiro Watanabe[6]
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Abstract

The Hayabusa2 spacecraft arrived at the asteroid Ryugu in June 2018 and started its proximity observation to select candidates of landing sites for touch-down operations. The shape of the asteroid is one of the most important information not only for landing site selection but also for scientific discussions.

We successfully modeled the shape of Ryugu with images and ancillary data acquired during the approach phase and early proximity observations.

Two different methods are applied to model the shape; one is Structure-from-Motion (SfM) and another is stereophotoclinometry (SPC). SfM is a method to be able to estimate a shape of the target object from multiple images (e.g. multiple exposures of a moving camera). SfM is a popular shape modeling method in computer vision, and there are many open source and commercial implementations. SPC developed by R. Gaskell is a method combining stereo method photoclinometry and is adopted by many planetary missions including Hayabusa, NEAR Shoemaker, Dawn, Rosetta, and OSIRIS-REx. Two independent methods give the shape models of Ryugu with good consistency.

The spin axis and rate of the asteroid are also estimated as byproducts of shape modeling. The spin axis points to near the south ecliptic pole. This differs from the pre-mission best estimation by ground-based observations but still falls within the possible area of estimation. The spin rate is rather consistent with the estimation by ground-based observations.

The top-shaped form of Ryugu is clearly shown in the shape models. Possible origin and evolution of the asteroid will be discussed in the presentation as implications from the shape and other related geophysical properties.

09:20 AM-09:30 AM

501.06 In-situ investigation of asteroid (162173) Ryugu by the Mobile Asteroid Surface Scout (MASCOT) as part of the Hayabusa 2 Mission

Jaumann Ralf[2, 4], Jean Pierre Bibring[3], Karl-Heinz Glassmeier[5], Mathias Grott[1], Tra-Mi Ho[1], Stefan Ulamec[1], Nicole Schmitz[1], Stefan Schroeder[1], Katharina Otto[1], Christian Krause[1], Ulrich Auster[5], David Hercik[5], Jens Biele[1], Alexander Koncz[1], Cedric Pilorget[3], Vincent Hamm[3], Harald Michaelis[1], Stefano Mottola[1], Hajime Hano[6], Seiji Sugita[7], Hitoshi Kuninaka[6], Makoto Yoshikawa[6], Tatsuaki Okada[6], Sei-ichiro Watanabe[6], Masaki Fujimoto[6], Hikaru Yabuta[8]

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Abstract

Japan Aerospace Exploration Agency's (JAXA) Hayabusa 2 asteroid sample return mission has been launched to asteroid (162173) Ryugu on Dec 3rd, 2014. It arrived at Ryugu on June 27th 2018, and will return samples to Earth in 2020. The German Aerospace Center (DLR) developed the lander MASCOT in cooperation with the French Centre National d'Etudes Spatiales (CNES). Ryugu is classified as a probable volatile-rich Cg-type asteroid. Its visible geometric albedo is 0.07±0.01, its diameter 0.9 km. Remote sensing measurements indicate a cm-sized, gravel-dominated regolith surface layer. Ryugu rotates with a period of 7.63±0.01h, and spectral observations suggest iron-bearing phyllosilicates on parts of the surface. MASCOT will descend and land on the asteroid at the beginning of October 2018 and enable in-situ mapping of the asteroid's surface. MASCOT comprises a payload of four scientific instruments: a camera, a radiometer, a magnetometer, and a NIR hyperspectral microscope. After landing, MASCOT will change its position by hopping. The main scientific objectives are to investigate: 1) the geological context of the surface; 2) the global magnetization and any local magnetization at the landing positions; 3) the mineralogical composition and physical properties of the surface and near-surface material including minerals and organics; 4) the surface temperature over the entire expected temperature range for a full day-night cycle; 5) the regolith emissivity and thermal inertia; 6) the local morphology and in-situ regolith structure and texture. MASCOT will provide ground truth for the orbiter remote measurements as well as context for the returned samples by qualifying their generic value and processed/pristine state and thus support the laboratory analyses by indicating potential alteration during sampling and cruise First results of MASCOT on surface operations will be presented during the conference.

09:30 AM-09:40 AM

501.07 Hayabusa2 Landing Site Selection: Scientific Evaluation on Asteroid Ryugu

Hikaru Yabuta[1, 2], Sei-ichiro Watanabe[3], Tomoki Nakamura[4], Naru Hirata[5], Seiji Sugita[6], Tatsuaki Okada[2], Kohei Kitazato[5], Yoshiaki Ishihara[2], Tomokatsu Morota[3], Naoya Sakatani[2], Koji Matsumoto[7], Koji Wada[8], Shogo Tachibana[9], Mutsumi Komatsu[10], Eri Tatsumi[6], Moe Matsuoka[2], Chikatoshi Honda[5], Takahiro Hiroi[11], Hiroki Senshu[8], Rie Honda[12], Shota Kikuchi[2], Satoshi Tanaka[2], Akira Miura[2], Tomohiro Yamaguchi[2], Yukio Yamamoto[2], Takanao Saiki[2], Yuichi Tsuda[2]

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Abstract
On June 28, 2018, the spacecraft of the Japanese C-type asteroid sample return mission, Hayabusa2, has arrived at the asteroid Ryugu. During its 18-month stay, remote-sensing observations will be carried out with the on-board instruments, Optical Navigation Camera (ONC), Near Infrared Spectrometer (NIRS3), Thermal Infrared Imager (TIR), and Laser Altimeter (LIDAR). Hayabusa2 plans to collect asteroid samples from up to three sites. Based on the remote-sensing data, we will carry out the landing site selection (LSS) in the end of August 2018, for the first touch down (TD1) and for releasing a hopping lander, MASCOT, in the beginning of October 2018. Based on the mission's scientific goals, the most scientifically valuable site for TD1 will be a less altered region where carbon and/or water are abundant. Here we will present a methodology of LSS scientific evaluation.
The body of Ryugu is a top shape that has a radius of 0.44 km. The rotation period is 7.632 h. The albedo is homogeneously low. There are a number of boulders and large craters in an entire region of Ryugu. Fifteen potential landing sites were proposed based on spacecraft safety and boulder size-frequency by the system engineering team and ONC team. The data products will be obtained at 20 km, 5-7 km and at 5 km in altitude. Shape modeling team produced polygon shape models of Ryugu by two different methods; Shape-from-Motion (SfM) and Stereophotoclinometry (SPC). ONC produces the six types of spectral indices: (i) 0.7 μm absorption depth, (ii) spectral slope from 0.39 μm to 0.95 μm, (iii) spectral slope in ultraviolet, (iv) 0.95 μm absorption depth, (v) scores of PC1 to PC5. NIRS3 produces the spectral feature maps: (i) 3-μm band depth/center, (ii) spectral slope, and (iv) near-infrared albedo. TIR provides the maps of thermal inertia, grain size, and maximum temperature for TD1. Based on the data products, scientific evaluations on physical properties of the surface, carbon contents, mineralogical compositions, extents of dehydration, and extents of space weathering will be conducted for the individual zones. Summarizing the chemical and geological characteristics, we will select the regions that meet both the safety and scientific value for TD1.

09:40 AM-09:50 AM
501.08 Hayabusa2's first results on the visible spectroscopic properties of 162173 Ryugu
Eri Tatsumi[1], Seiji Sugita[1], Naru Hirata[2], Naoyuki Hirata[3], Deborah Domingue[4], Rie Honda[5], Tomokatsu Morota[6], Yasuhiro Yokota[7], Toru Kouyama[8], Hidehiko Suzuki[9], Shingo Kameda[10], Manabu Yamada[11], Naoya Sakatani[7], Kazuo Yoshioka[1], Chikatoshi Honda[2], Masahiko Hayakawa[7], Moe Matsuoka[7], Yuichiro Cho[1], Lucille Le Corre[4], Takahiro Hiroi[12], Takahiro Sawada[7]
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Abstract
This study presents the first report on the visible spectral properties of 162173 Ryugu as observed with the optical multi-band camera (ONC-T) on Hayabusa2 during its approach phase and the first series of global observations. The ONC-T spacecraft is equipped with 7 color filters at wavelength ranging from 0.39 – 0.95 micron (ul: 0.40 μm, b: 0.48 μm, v: 0.55 μm, Na: 0.59 μm, w: 0.70 μm, x: 0.86 μm, p: 0.95 μm). We have examined the spectral calibration accuracy using the approach phase images and found that the measurements are in good agreement with ground-based observations. Although a few ground-based observations reported absorptions in UV, we did not observe a strong UV absorption on Ryugu in the ONC-T images. We also mapped several global spectral properties, such as albedos, spectral slopes, and

absorption features. The average reflectance spectral shape of Ryugu is very flat over the entire ONC-T wavelength range, and spectral variations are very small (i.e., spectrally homogeneous). However, we do observe small variation in both albedo and spectral slope on Ryugu. The polar regions and the circum-equatorial ridge exhibit relatively bluer slopes, while the mid-latitude regions exhibit relatively redder slopes. Furthermore, the spectral properties apparently correspond to geological features, such as craters, boulders, and fossa. We will discuss the relationship of this spectral slope variation with gravitational potential and topographic slope, which is probably important for understanding how the spectrum evolves over the surface of Ryugu. Because spectral variations and albedo provide constraints on plausible surface materials, we will also discuss possible compositional properties for Ryugu's surface in comparison with meteorite spectra.
Acknowledgement: This work is supported by JSPS Core-to-Core program, "International Planetary Network".

09:50 AM-10:00 AM

501.09 Approach Phase Photometry of Ryugu from Hayabusa2's Multiband Imaging Campaign

Deborah Domingue[1], Eri Tatsumi[2], Yasuhiro Yokota[3], Seji Sugita[2], Rie Honda[4], Naru Hirata[5], Naoyuki Hirata[6], Yukio Yamamoto[3], Tomokatsu Morota[7], Shingo Kameda[8], Toru Kouyama[9], Hidehiko Suzuki[10], Manabu Yamada[11], Naoya Sakatani[3], Chikatoshi Honda[5], Masahiko Hayakawa[3], Kazuo Yoshioka[2], Moe Matsuoka[3], Yuichiro Cho[2], Hirotaka Sawada[3], Masateru Ishiguro[12], Lucille Le Corre[1], Faith Vilas[1]
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Abstract

During Hayabusa2's approach phase, prior to its arrival at the home position on 27 June 2018, the Optical Navigation Camera (ONC) observed its target, 162173 Ryugu, in all seven color-bands ranging in wavelength from 0.4 – 0.95 mm, over several rotational periods. These observations form the base of the approach disk-integrated observations that were compared with ground-based observations for calibration verification, rotational phase characterization, and initial photometric characterization of the asteroid's surface. The approach phase images together with ground-based telescopic observations were analyzed using Hapke's photometric model to provide an initial photometric standardization for the imaging data set in all seven filters. This photometric standardization is necessary for color analyses across images acquired under various illumination and viewing geometries, in addition for mosaic and map production. We present the rotational phase properties of Ryugu in all seven wavelengths, along with comparisons of the photometric phase curves in all seven color-bands with ground-based observations. We present the photometric modeling results in comparison with photometric analyses of other asteroids, especially those acquired for Itokawa, a similarly rocky, rough surface.
Acknowledgements: This study was supported by the JSPS International Planetary Network and the NASA Hayabusa2 Participating Scientist Program.

Friday, October 26, 2018
08:30 AM-10:00 AM
Ballroom C (Knoxville Convention Center)

502 Pluto System I: Atmosphere and Surfaces
Chair(s): S. Alan Stern, Michael J. Person

08:30 AM-08:40 AM
502.01 The 15-AUG-2018 stellar occultation by Pluto: evidence for and against changes in haze opacity and atmospheric oblateness
Eliot F. Young[1], Leslie Young[1], Brian A. Keeney[1], Jeffrey Regester[2], Anne Verbiscer[3]
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Abstract
Pluto will occult a bright star (V ~13) on 15-AUG-2018 at 5:32 UT. The shadow path prediction has a cross-track error of less than 100 km due to improved star positions from the Gaia DR2 catalog and recent astrometry from the New Horizons flyby. This level of error lets us reliably place observers in the central flash region. We are deploying several picket fences of observers (spanning about 140 km in the cross-track direction) to intersect the central flash caustic: in Mexico, in Texas and along the Eastern Seaboard. At least six of these stations will have two detectors in separate color channels to measure haze optical depths.

A single color lightcurve cannot distinguish between attenuation due to haze opacity or a particular thermal profile (i.e., due to differential refraction). Simultaneous occultation lightcurves were obtained in two colors during events in 2002, 2007, 2011 and 2015, with haze observed in 2002 and 2015, but no haze was detected in 2007 and 2011. The upper limit on the one-way haze optical depth at 0.73 μm in 2007 is 0.011, less than a tenth of the haze optical depth of 0.11 that we retrieve from the 2002 occultation lightcurves. The pattern of high haze vs low haze optical depths closely follows the solar cycle and suggests that the haze opacity in August 2018 - in the minimum between solar cycles 24 and 25 - should be lower than observed in 2015. The amplitude of the central flash peak is very sensitive to haze optical depth.

The shape of the central flash is also a function of Pluto's atmospheric oblateness: a larger oblateness produces a larger caustic pattern in the middle of Pluto's shadow on the Earth. A double-peaked central flash was observed in 2007, consistent with an equatorial radius that was 3% larger than the polar radius (at an altitude of a few 10s of km above Pluto's surface). Several central flashes were also observed in 2015, but all of those have single peaks. If the oblateness changes, it suggests that Pluto has zonal winds that come and go, or that there is a variable density field asymmetry - perhaps due to Charon tides or a plume above Sputnik Planitia.

08:40 AM-08:50 AM
502.02 Pluto's atmosphere after *New Horizons*: results from stellar occultations in 2017 and 2018
Amanda A. Sickafoose[1, 2], Stephen E. Levine[2, 3], Amanda S. Bosh[2, 3], Carlos A. Zuluaga[2], Michael J. Person[2], Karsten Schindler[4, 5]
[1]South African Astronomical Observatory, Observatory, Western Cape, South Africa, [2]Massachusetts Institute of Technology, Cambridge, Massachusetts, United States, [3]Lowell Observatory, Flagstaff,

Arizona, United States, [4]Deutsches SOFIA Institut, Stuttgart, Germany, [5]SOFIA Science Center, NASA Ames Research Center, Moffett Field, California, United States

Abstract
Stellar occultations have been employed for the last thirty years to characterize Pluto's atmosphere. The atmospheric pressure has increased between 1988 and 2015 (e.g. Bosh *et al.* 2013; Sicardy *et al.* 2015). Evolution in the shape of the occultation light curves over time has revealed waves in the upper atmosphere (e.g. Hubbard *et al.*2009; Person *et al.* 2008) and suggests a thermal gradient, possibly combined with extinction-generating events, in the lower atmosphere (e.g. Elliot *et al.* 2007; Olkin *et al.* 2014). Occultation data have been combined with volatile transport models (Hansen & Paige 1996; Young 2013) to predict Pluto's atmospheric properties during and beyond the 2015 flyby of NASA's *New Horizons* spacecraft. Some models indicate that Pluto's atmosphere should collapse over a relatively short timescale; however, recent results are consistent with models that have no atmospheric collapse, stemming from high thermal inertia and a permanent, northern cap (e.g. Olkin *et al.* 2015). Here, we report results from two stellar occultations by Pluto, in 2017 and 2018. A single chord was observed at each epoch.

The first occultation was on 2017 August 07, with a shadow path over the Pacific Ocean. The star had visible magnitude of 14.5, with relative velocity of 20.8 km s^{-1}. Observations were taken from NASA's 3-m Infrared Telescope Facility in Hawaii. The dataset includes 2.5-second, visible-wavelength images from MORIS (MIT Optical Rapid Imaging System), and low-resolution, near-infrared spectra from SpeX with 3-second integration time. The second occultation was on 2018 April 09, with a shadow path over the western United States. The star had visible magnitude of 17.9, with relative velocity of 6.4 km s^{-1}. Visible-wavelength images, at 10 Hz, were taken from the 4.3-m Discovery Channel Telescope in Arizona with a POETS (Portable Occultation Eclipse and Transit System). The 2018 observation was central, with half-light to half-light chord length of ~2280 km. The 2017 observation had half-light to half-light chord length of ~1650 km. The shape of both light curves is indicative of a body with an atmosphere. We present results for atmospheric model fits to these light curves and place them in context.

08:50 AM-09:00 AM
502.03 Retrieval of Haze Properties in Pluto's Atmosphere from New Horizons Observations
<u>Siteng Fan</u>[1], Peter Gao[2], Chao Liu[1], Yuk Yung[1]
[1]California Institute of Technology, Pasadena, California, United States, [2]University of California, Berkeley, Berkeley, California, United States

Abstract
One of the most amazing features seen in Pluto's atmosphere during New Horizons' historic close approach was its multi-layered haze. The haze was directly imaged at visible and near infrared wavelengths by the Long Range Reconnaissance Imager (LORRI), the Multispectral Visible Imaging Camera (MVIC), and the Linear Etalon Imaging Spectral Array (LEISA), and investigated in the ultraviolet by the Alice spectrograph using solar occultations. Cheng et al. (2017) showed, using simplified models, that neither spherical nor 2-dimensional aggregate particles could satisfy the set of observations. Preliminary analysis shows that the size of the aggregates and the number of monomers in each aggregate may exceed the capability of the scattering model (Tomasko et al. 2008) used for the haze in Titan's atmosphere, where aerosol particles are also products of photolysis and polymerization of organic molecules in a nitrogen dominated atmosphere. In this work, we present a joint retrieval of haze particle properties using LORRI, MVIC, LEISA, and Alice data, which examines various sizes and dimensions of aggregate particles using a new database of aggregate optical properties. This database

includes the possibility of hydrocarbons (e.g., C2H2, C2H6) on the aggregates. We map out the haze particles' phase function by simultaneously considering forward scattering and extinction across multiple wavelengths, allowing for the size and shape of the haze particles to be constrained.

09:00 AM-09:10 AM

502.04 Pluto's Minimum Pressure in the Current Season from a Thermophysical Model

Perianne Johnson[1], Leslie Young[2]
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Abstract

A model balancing solar insolation, substrate thermal inertia, and thermal emission (Young 2017, Icarus 284 433-476) is used to determine the volatile temperature and pressure at Pluto's surface over the course of its year. Our initial model assumes for simplicity that Sputnik Planitia, with borders defined by the New Horizons mapping of geologic units (White et al. 2017, Icarus 287 261-286), is the only volatile-covered region, and that the volatiles have spatially uniform albedo and emissivity. The reasoning for this volatile distribution is in part motivated by the GCM results of Bertrand and Forget (2016, Nature 540 86-89), which show all volatiles confined to a Sputnik Planitia-like basin after 10,000 Earth years. Thermal parameter values were varied over many runs in order to produce pressures consistent with existing stellar occultation measurements as well as the New Horizons measurement of 11 μbar in 2015. This work is motivated by a desire to learn the minimum pressure experienced at Pluto's surface. This can help determine if the atmosphere ever becomes non-global (Spencer et al. 1997, in Pluto and Charon p 435), and if the atmosphere ever becomes transparent to Lyman-α or EUV radiation. Transparency to radiation could help explain the puzzling lack of settled-out haze particles on the surface, by providing a method of disrupting haze production, which may be needed to explain Pluto's heterogeneity (Cheng et al. 2017, Icarus 290 112-133; Grundy et al. 2018, Icarus 314 232-245). Since our methodology is completely distinct from Bertrand and Forget (2016), the independent results can be used as means of checking both models.
This work was supported by NASA ROSES/SSW grant NNX15AH35G.

09:10 AM-09:20 AM

502.05 Haze formation on Pluto on million-year timescales

Leslie Young[1], Perianne Johnson[2]
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Abstract

Pluto's surface has an astounding variety of terrains (Moore et al. 2015, Icarus 287 320-333), which is in apparent conflict with the calculated production of haze. In the present-day atmosphere, the production is roughly ~316-500 g/cm^2/Gy (Cheng et al. 2017, Icarus 290 112-133; Grundy et al. 2018, Icarus 314 232-245), or roughly a micron per Pluto year. As discussed by Cheng et al. and Grundy et al., haze production can be modified over Pluto's orbit, both by the change in incident UV flux, but also because of seasonal variation in the column density of Pluto's N_2-CH_4 atmosphere. We investigated Pluto's haze production on million-year time scales with a simple thermophysical model, using constraints derived from the current season (Johnson and Young, this meeting). We find that the mean seasonal insolation onto Sputnik Planitia varies by a factor of only 1.6 over the last 10 million years, but the minimum insolation over a season varies by much more, varying by a factor of 3. Initial results show that (i) Pluto's gaseous N_2 and CH_4 are always opaque (p_{surf} > 0.1 to 1 nbar; Young et al. 2018), (ii) Pluto's atmosphere is always

global (p_{surf} > 50 nbar; Spencer et al. 1997, in Pluto and Charon p 435), and (iii) the minimum seasonal pressure drops below 500 nbar for some models. Similar results were shown in Bertrand et al. (2018, Icarus 309 277-296). Since the peak of haze production occurs at 500 nbar (Chang et al. 2017), this would affect net haze production on Pluto on million-year timescales. We will discuss how changes in Pluto's surface pressure affects the haze deposition vs. latitude on million-year timescale.
This work was supported by NASA ROSES/SSW grant NNX15AH35G.

09:20 AM-09:30 AM

502.06 Resolved Thermal Images of Pluto and Charon with ALMA

Bryan Butler[1], Will Grundy[2], Mark Gurwell[3], Emmanuel Lellouch[4], Raphael Moreno[4], Arielle Moullet[5], Leslie A. Young[6]
[1]VLA/VLBA Science Support Division, National Radio Astronomy Observatory, Socorro, New Mexico, United States, [2]Lowell Observatory, Flagstaff, Arizona, United States, [3]Harvard-Smithsonian Center For Astrophysics, Cambridge, Massachusetts, United States, [4]Observatoire de Paris, Paris, France, [5]SOFIA, Moffett Field, California, United States, [6]SWRI, Boulder, Colorado, United States

Abstract
We report on the first Earth-based observations of thermal emission from the surfaces of Pluto and Charon where the disks of each body are resolved. Observations at a wavelength of 1.2 mm were completed using the Atacama Large Millimeter/submillimeter Array (ALMA) on September 27 and 29, and October 14, 2017. The resolution of the observations was approximately 20 masec, while the sizes of Pluto and Charon were approximately 100 and 50 masec respectively, so both bodies were well-resolved individually. We have previously reported on observations from ALMA, the Submillimeter Array (SMA), and the Karl G. Jansky Very Large Array (VLA) where the two bodies are resolved from each other at these long wavelengths [1-4], but these are the first observations where the bodies are each resolved themselves. We know from New Horizons that both bodies have distinct surface features and ices which should result in temperature variations [5], and we will be able to correlate these with our thermal images. We note that our resolution is similar to that of the HST ACS and FOC maps, which were used to derive surface properties across both bodies [6]. We will also be able to derive disk-averaged brightness temperatures, which we can compare with our previous results: brightness temperatures of 33.0 K for Pluto and 43.5 K for Charon at these wavelengths. These low brightness temperatures, along with those from other icy bodies, have been examined in [7]. [1] Butler et al. 2015, BAAS #47, id.210.04. [2] Gurwell et al. 2011, DPS/EPSC, p271. [3] Butler et al. 2011, DPS/EPSC, p. 1670. [4] Butler et al. 2017 BAAS #49, id.102.02. [5] Schmitt et al. 2017, Icarus, 287, p.229. [6] Buie et al. 2010, AJ, 139, p.1128. [7] Lellouch et al. 2017, A&A, 608, id.A45.

09:30 AM-09:40 AM

502.07 Triton: Atmosphere and Surface Observed with ALMA and Comparison with Pluto

Mark Gurwell[1], Bryan Butler[2], Emmanuel Lellouch[3], Raphael Moreno[3], Arielle Moullet[4]
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Abstract
Our Atacama Large Millimeter/Submillimeter Array (ALMA) observations of the Pluto-Charon system confirmed the low Pluto mm/submm surface brightness temperature (T_B=33 K, [1]), measured atmospheric thermal structure to 400 km altitude, measured the CO abundance, and detected for the first time HCN, in extreme supersaturation in the upper atmosphere ([2], [3], [4]). They led to higher resolution ALMA studies of Pluto's atmosphere [5], and surface [6], and also motivated this new study of the atmosphere and surface of Triton using the same techniques.

Observations of Triton were obtained October 25 and 26, 2016 using ALMA for a total of 150 minutes on-source. At the time 40 ALMA 12-m antennas were available, providing baselines ranging from 19 m to 1.4 km. During the observations Triton ranged between 13.6" and 16.6" from Neptune, and was just over 127 mas in diameter. The spectral coverage was nearly identical to the 2015 observations of Pluto, allowing 60 kHz spectral resolution covering CO(3-2), HCN(4-3) and two HC_3N transitions, coarser observations of HCN isotopologues, and a thermal continuum band at 355.6 GHz. The FWHM of the ALMA primary beam is about 18" at these frequencies; thus Neptune (~1000 times the flux density of Triton) was not fully excluded, and significant sidelobes affected the imaging. Using a spatial high-pass visibility filter (using spatial frequencies >400 kλ), we effectively eliminated confusion from Neptune, providing high dynamic range imaging of Triton at 155 mas x 122 mas resolution.

The thermal continuum of Triton was 28.1±0.2 mJy at 355.6 GHz, equivalent to a mean T_B of 32.0+/-0.2 K (formal error, with absolute flux scale error ~5%, or 1.6 K). This is within the error of the T_B of Pluto measured in 2015 ([1],[6]). We also report the first mm/submm detection of CO in Triton's atmosphere. We will present a full analysis of the CO line emission, as well as limits on HCN and HC_3N, and compare and contrast to the similar observations of Pluto from 2015.

[1] Butler et al 2015, DPS #47, id.210.04. [2] Lellouch et al 2017, Icarus 286, 289 [3] Gurwell et al 2015, DPS #47 id.105.06 [4] Lellouch et al 2015, DPS #47, id.105.07D, [5] Lellouch et al, this meeting, [6] Butler et al, this meeting

09:40 AM-09:50 AM
502.08 Radiometric Polarization Anomalies on Pluto's Winter Night
Ivan Linscott[6, 2], Mike Bird[3], S. Alan Stern[2], Michael Vincent[2], Leonard Tyler[1], Chris Deboy[4], Rebecca Sepan[4], William B. McKinnon[6], Leslie A. Young[2], Martin Patzold[3], G. R. Gladstone[2], Catherine B. Olkin[2], Harold A. Weaver[4], Kimberly Ennico[5]
[1]Retired, Stanford University, Mountain View, California, United States, [2]Southwest Research Institute, Boulder, Colorado, United States, [3]Rheinisches Institut fur Umweltforschung, Universitat Koln, Cologne, Germany, [4]Johns Hopkins Applied Physics Laboratory, Laurel, Maryland, United States, [5]Ames Research Center, Mountain View, California, United States, [6]Washington University, St. Louis, Missouri, United States

Abstract
Radiometry at 4.2 cm, during the New Horizons Pluto Encounter observed two scan paths on Pluto's surface. Much of the scan was within the winter night, and unimaged regions. The high precision of the radio brightness temperature measurements reveal significant differences in the two X-band polarizations at the few percent level. The differences are anomalous from the perspective of conventional radiometry at normal incidence. However, the differences are found at angles, (or phase), of 45 degrees, or more, where the effects of Fresnel-like reflection and transmission coefficients play a role. Taking such effects into account, the nature of Pluto's topography and materials is inferred in relation to that found on the imaged and composition analyzed illuminated regions.

09:50 AM-10:00 AM

502.09 Ultraviolet Reflectance of Charon

Joel Parker[1], Alan Stern[1], Silvia Protopapa[1], Catherine Olkin[1], John Spencer[1], Anne Verbiscer[2], Harold Weaver[3], Leslie A. Young[1], Kimberly Ennico[4]
[1]Southwest Research Institute, Boulder, Colorado, United States, [2]University of Virginia, Charlottesville, Virginia, United States, [3]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, United States, [4]SETI Institute, Mountain View, California, United States

Abstract

During the New Horizons flyby of the Pluto system in July 2015, observations were made of Pluto and some of its satellites using the Alice ultraviolet spectrograph in the wavelength range of 520-1870 Å. Here we report the Alice observations made of Pluto's moon Charon. Since no atmosphere was detected around Charon (Stern et al. 2017, Icarus, 287, 124), the Alice UV observations of Charon provide direct measurements of the surface at FUV wavelengths where positive detections were made, allowing us to determine the FUV albedo and UV color slope of Charon. We compare these results with other airless icy bodies in the solar system and discuss implications. We also outline future work to produce FUV results for Pluto's surface reflectance and that of Pluto's satellite Nix.

Friday, October 26, 2018
10:30 AM-12:00 PM
Ballroom A (Knoxville Convention Center)

503 Giant Planet Atmospheres I
Chair(s): Padma Yanamandra-Fisher, Shawn Brueshaber

10:30 AM-10:40 AM
503.01 Fine-Scale Waves in Jupiter's Atmosphere Detected by JunoCam
Glenn Orton[1], Gerald Eichstaedt[2], Hamish Nicholson[3], Fachreddin Tabataba-Vakili[1], Candice Hansen[4], Thomas Momary[1], John Rogers[5], Andrew Ingersoll[6]
[1]Jet Propulsion Laboratory, California Institute of Technology, Arcadia, California, United States, [2]Independent Scholar, Stuttgart, Germany, [3]Harvard University, Cambridge, Massachusetts, United States, [4]Planetary Science Institute, Pasadena, California, United States, [5]British Astronomical Association, London, United Kingdom, [6]California Institute of Technology, Pasadena, California, United States

Abstract
Mesoscale waves have been detected previously from Voyager, New Horizons and Galileo images (see Table 1 of Simon et al., 2015, *Geophys. Res. Lett. 42*, 2612) with spacing between waves of 110 to 305 km. Larger waves have been detected by Hubble Space Telescope, as well as more recent 5-micron images from Juno's JIRAM experiment and the Very Large Telescope's VISIR experiment with wave spacings between 1200 and 1400 km. Here, we report the detection of smaller-scale waves in the atmosphere of Jupiter from the Juno mission's JunoCam imaging instrument, with the spacing between waves ranging from 55 to 270 km. These waves appear in all of Juno's close approaches to Jupiter (perijoves), starting with perijove 3, mostly in the form of wave trains that are narrow in latitude and extended in longitude. The majority of these waves appear within 5 degrees of latitude from the equator, except for a group at the northern boundary of the Great Red Spot. Most of the wave fronts appear to be perpendicular to their longitudinal extent, but some of the waves with more subtle features are tilted. It's not clear whether this is due to a horizontal wind shear or a varying layer thickness underneath the waves. There are no significant differences in wave properties as a function of color. We will discuss the constraints on the origin of the waves, in the absence of useful measurements of their associated phase speeds.

10:40 AM-10:50 AM
503.02 Results from a Multi-wavelength Observing Campaign of Jupiter in January 2017
Imke de Pater[1], Robert J. Sault[2], Chris Moeckel[1], Arielle Moullet[3], Bryan Butler[4], Leigh Fletcher[5], David deBoer[1], Michael Wong[1], Glenn Orton[6], Michael Janssen[6], Richard Cosentino[7], Eric Villard[8], Gordon Bjoraker[7]
[1]Astronomy & Earth and Planetary Science, University of California, Berkeley, Berkeley, California, United States, [2]Univ. Melbourne, Melbourne, Victoria, Australia, [3]Sofia, Mountain View, California, United States, [4]NRAO, Socorro, New Mexico, United States, [5]Leicester Univ., Leicester, United Kingdom, [6]JPL, Pasadena, California, United States, [7]NASA/Goddard, Greenbelt, Maryland, United States, [8]ALMA, Santiago, Chile

Abstract
In early January 2017, between Juno's perijoves 3 and 4 (near its originally planned perijove 8) many ground-based observatories participated in a *Juno*-support campaign, including ALMA and the VLA. In this talk we present the first ALMA observations of Jupiter in the continuum at 1- and 3-mm wavelength. Both longitude-smeared and longitude-resolved maps will be shown, and compared to VLA maps at 3.5 cm. These maps show numerous zones and belts, and unexpectedly detailed structure on the longitude-resolved maps. At these wavelengths, we probe regions in the atmosphere at ~0.5 – 3 bars (down to ~10 bars in ammonia-depleted regions). We will compare the data with radiative-transfer models that fit multi-frequency VLA observations from 2014 and the PJ1 *Juno*data from August 2016. A detailed comparison with contemporaneous HST, Gemini 5-micron, near-IR IRTF, and mid-IR VLT and Subaru data will be made.

10:50 AM-11:00 AM
503.03 The Juno Micowave Radiometer for the Investigation of Jupiter
Paul Steffes[1], Michael Janssen[2], Scott J. Bolton[3], Steven M. Levin[2], Shannon T. Brown[2], Virgil Adumitroaie[2], michael allison[4], John Arballo[2], Sushil Atreya[7], Amadeo Bellotti[1], Samuel Gulkis[2], Andrew Ingersoll[5], Cheng Li[5], Jonathan Lunine[6], sidharth misra[2], Glenn Orton[2], Fabiano Oyafuso[2], Daniel Santos-Costa[3], Fachreddin Tabataba-Vakili[2], Zhimeng Zhang[5]
[1]ECE/Center for Space Technology and Researchc, Georgia Institute of Technology, Atlanta, Georgia, United States, [2]NASA/JPL, Pasadena, California, United States, [3]SWRI, San Antonio, Texas, United States, [4]NASA GISS, New York, New York, United States, [5]California Institute of Technology, Pasadena, California, United States, [6]Cornell University, Ithaca, New York, United States, [7]University of Michigan, Ann Arbor, Michigan, United States

Abstract
The Juno MWR is designed to meet the unique environmental and observational challenges of measuring Jupiter's microwave emissions from an orbiting spacecraft. Its primary objective is to determine the composition and structure of the atmosphere deep beneath the clouds. The MWR instrument comprises six radiometric channels operating at wavelengths from 1.37 to 50 cm (0.6-22 GHz). These channels are sensitive to thermal emission from the atmosphere from the cloud tops at ~0.7 bar to well below the 100-bar pressure level. Remote sensing of microwave-absorbing atmospheric constituents has been a key objective. Secondary objectives include exploration of non-thermal emissions from the Jupiter radiation belts, and fortuitously, from atmospheric lightning, which dominate at the longer wavelengths. After two year's experience and 14 perijoves operating in Jupiter orbit, it is clear that the ambitious performance objectives in terms of calibration and stability have been met, and the MWR experiment is well on its way to achieving its scientific objectives. An overview of the MWR instrument and experimental approach along with current results will be presented.

11:00 AM-11:10 AM
503.04 Lightning on Jupiter: Correlations of lightning clusters observed by the Juno Microwave Radiometer with contemporaneously observed meteorological features obtained by the NASA/IRTF
Kevin H. Baines, Glenn Orton, Thomas W. Momary, Shannon T. Brown
Jet Propulsion Laboratory/Caltech, Pasadena, California, United States

Abstract
Clusters of lightning have been found by the Microwave Radiometer (MWR) onboard the Juno Jupiter orbiter (S. T. Brown et al., Nature, 2018, https://doi.org/10.1038/s41586-018-0156-5). The method for lightning detection utilizes a frequency of 600 megahertz, which - unlike visual imaging techniques - is unaffected by the opacity of overlying clouds, thus providing a more faithful record of where lightning occurs. Jupiter has been probed for lightning for several hours during each of Juno's perijove passes, when the spacecraft is within ~100,000 km of the cloud tops. The coverage varies from orbit to orbit, but generally extends from pole-to-pole and is more limited in longitudinal extent near the equator. Contemporaneously, our team has obtained near-infrared global maps of Jupiter at the IRTF with the SpeX instrument guide camera. Good global or near-global coverage occurred contemporaeneously with MWR during Juno perijoves 4, 6, 8, 13, and 14, the latter occurring recently on July 16, 2018. Here, we present initial results of mapping the observed lightning clusters over near-infrared maps obtained contemporaneously at 2.1, 1.6 and 5 microns, which are sensitive, respectively, to cloud features near 0.4,1.0 and 2-3 bar, to begin to determine correlations between the spatial/vertical morphology of cloud structures and the occurrence of lightning clusters on Jupiter.

11:10 AM-11:20 AM
503.05 Jupiter's Global Zonal Winds as Measured from New Horizons LORRI Images
John J. Blalock[1], Kunio Sayanagi[1], Julie Zhou[2], William B. Moore[1], Jacob L. Gunnarson[1], Justin Garland[1], Angelina Gallego[1]
[1]Atmospheric and Planetary Sciences, Hampton University, Hampton, Virginia, United States, [2]University of Virginia, Charlottesville, Virginia, United States

Abstract
We present a preliminary analysis of Jupiter's zonal winds utilizing New Horizons LORRI images captured during the 2007 Jupiter flyby. To measure the wind field, we utilize a two-dimensional correlation imaging velocimetry (CIV) technique. We compile together the wind measurements from 120 image pairs to measure ~1.7 million wind vectors and to produce a global zonal-mean wind profile, extending the record of Jupiter's global winds obtained from Voyager, HST, and Cassini. Furthermore, we perform wind measurements on Cassini ISS images of Jupiter capture in the CB2 (752 nm) filter during the 2000 flyby. These additional measurements allow us to analyze the temporal stability of Jupiter's winds between the Cassini and New Horizons. Our analysis finds that the winds in the equatorial jets are ~5 m/s faster during the 2007 New Horizons flyby than during the 2000 Cassini flyby. We also find that there is a greater degree of longitudinal variation in the winds at 24N during the 2007 New Horizons flyby than during the 2000 Cassini flyby. We discuss potential mechanisms for these variations, as well as how they fit into the context of other measurements of Jupiter's winds. Our work has been supported by NASA CDAP NNX15AD33G, NASA PATM NNX14AK07G, NSF AAG 1212216, and NASA NESSF NNX15AQ70H.

11:20 AM-11:30 AM
503.06 Changes in the Upper Clouds and Hazes of Jupiter following a North Temperate Belt Disturbance
Santiago Perez-Hoyos[1], Agustin Sanchez-Lavega[1], Jose F. Sanz-Requena[2], Ricardo Hueso[1], Jose F. Rojas[1], Inigo Mendikoa[1], Patrick Irwin[3], Naiara Barrado-Izagirre[1], Oscar Carrión-Gonzalez[4], Asier Anguiano[1]
[1]Fisica Aplicada I, University of the Basque Country UPV/EHU, Bilbao, Spain, [2]Universidad Europea Miguel de Cercantes, Valladolid, Spain, [3]University of Oxford, Oxford, United Kingdom, [4]Technische Universität Berlin, Berlin, Germany

Abstract
The banded aspect of Jupiter's atmosphere shows significant changes over time, sometimes even transforming in a few weeks the reflectivity of a whole latitudinal band, and staying for years with an aspect different from the usual one. The origin of some of these disturbances may be associated with the creation and destruction of the chromophore species that provides Jovian clouds its reddish coloration. In this work we have focused on the North Temperate Belt (NTB) disturbance detected during the second flyby of Juno mission (NASA) on October 2016 as a series of convective storms interacting with the zonal jet over months and leaving a quiet aspect characterized by an intense red coloration ("A planetary-scale disturbance in the most intense Jovian atmospheric jet from JunoCam and ground-based observations", Sánchez-Lavega et al., 2017, Geophys. Res. Lett. 44, 4679 – 4686). In order to determine the changes in the upper clouds and hazes we have used images taken in 2016 and 2017 with the Hubble Space Telescope Wide Field Camera 3 as well as with the lucky imager PlanetCam-UPV/EHU operating at the 2.2m telescope in the Observatory of Calar Alto (Almeria, Spain). Such images were acquired before and after the outbreak, showing an intense color change in a narrow latitude band. The images cover the wavelength range from 200 nm up to 1.7 μm including methane absorption bands of diverse depth, thus sensitive to a number of atmospheric levels from the lower stratosphere to the upper troposphere where the ammonia condensation cloud is expected to be located. Here we will report the reflectivity and the limb-darkening variations in all filters. We will use the NEMESIS radiative transfer and retrieval suite ("The NEMESIS planetary atmosphere radiative transfer and retrieval tool", Irwin et al., 2008, JQSRT 109, 1136 - 1150) to retrieve information on the vertical distribution of the upper clouds and hazes and on the optical properties of the particles in order to analyze the temporal evolution of the three-dimensional distribution of the aerosols that initiated the aspect change.

11:30 AM-11:40 AM

503.07 A Comparative Study of Ice Particle Formation and Evolution in the Atmospheres of Jupiter, Saturn, and Titan

Erika Barth
Southwest Research Institute, Boulder, Colorado, United States

Abstract
Photochemical processes operating within the atmospheres of the outer solar system create a number of trace vapor species which are sufficiently abundant temperature levels where they are likely to condense into optically thin ice layers. On Titan more than a dozen trace species, including hydrocarbons, nitriles, and CO_2 can condense between about 50 and 100 km. Hydrocarbon condensation deep in Saturn's stratosphere includes butane and diacetylene. Condensable species in Jupiter's stratosphere include hydrazine, naphthalene, and other PAHs. The Community Aerosol and Radiation Model for Atmospheres (CARMA) has been updated to simulate cloud microphysics in the atmospheres of the solar system outside of Earth. CARMA is a coupled aerosol microphysics and radiative transfer model and includes the processes of nucleation, condensation, evaporation, coagulation, and vertical transport. PlanetCARMA has been applied to the stratospheres of Jupiter, Saturn, and Titan to model the microphysics of hydrocarbon and nitrile ices. Expected condensation altitudes and particle sizes will be presented and compared, as well as the implications for the optical properties of outer planet stratospheric aerosol particles. The altitudes of the individual ice layers are sensitive to a number of factors, including the temperature profile, vapor pressure equation, volatile abundance, nucleation critical saturation, and coagulation efficiency. Additionally, some ices are likely to serve as condensation nuclei for others.

11:40 AM-11:50 AM

503.08 Simulations of large scale cloud features on Outer Solar System planets

Ramanakumar Sankar[1], Nathan Hadland[1], Chloe Klare[1], Abigail Flom[1], Noah Nodolski[1], Csaba Palotai[1], Raymond LeBeau[2], Kevin Farmer[2]
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Abstract

In recent years, observations of solar system objects have skyrocketed, and we have high resolution maps of surface and atmospheric features. Ubiquitous among these are clouds, especially in the gas giant planets, e.g., Juno's observations of the Great Red Spot as well as multiple smaller vortical features and recent discoveries of companion clouds around new Dark Spots on Neptune (Wong et al, 2015), to name a few. With this explosion in data, there is more potential than ever to understand the underlying phenomenon that drive the atmosphere of these giant planets. In this work, we use the updated Explicit Planetary Isentropic-Coordinate (EPIC) model coupled with active, multi-species cloud microphysics, which has previously been used to study the Great Red Spot and Oval BA (Palotai et al, 2014), to simulate the 24-degree north jet on Jupiter and the Great Dark Spot of 1989 on Neptune. We present results from our 3-dimensional hydrodynamic simulations with the addition of water and ammonia condensation on Jupiter, and a methane cycle on Neptune to model the effects of cloud on large scale vortical systems.

On Jupiter, we introduce small scale perturbations randomly throughout the jet region. These perturbations evolve to form distinct cloud features whose vertical structure varies significantly within and outside the jet. We test the effect of different bulk abundance of the condensibles on the stability and progression of these features. We see that the ammonia cloud layer is generally higher in altitude inside the jet, and also the inception of warm, dry areas which are lacking in clouds.

On Neptune, Voyager 2 observed the Great Dark Spot in 1989, and its oscillation in shape and equatorward latitudinal drift. We analyze the effect of different deep abundance values and initial supersaturation of methane on the stability and the drift rate of the vortex, and its influence on the formation of companion clouds. Our initial results show that the deep abundance strongly impacts both the drift rate and the stability of the vortex, with higher values being more stable and some cases showing strong agreement with the observed drift rate.

11:50 AM-12:00 PM

503.09 Rationalizing the great springtime storms on Uranus

Stephen Markham, Dave Stevenson
Caltech, Los Angeles, California, United States

Abstract

Observations of Uranus from 2014 showed record breaking storm activity at northern latitudes despite predictions that convective activity in the Northern Hemisphere should have diminished after equinox in 2007. In this work, we seek to understand the unexpected weather using a simple 1D model which accounts for the important effect of volatile mass loading and inhibition of convection in hydrogen/helium dominated atmospheres. The deep mixing ratio of methane in Uranus is expected to exceed 2%. This is large enough that saturated parcels of hydrogen/helium gas can actually increase density with increasing temperature, as the exponential effect of larger methane abundance overwhelms the linear effect of the ideal gas law. This consideration fundamentally changes the convective behavior of the system. This work seeks to demonstrate with a concrete example the general importance of this mechanism in

hydrogen/helium rich atmospheres, and to contribute to our understanding of Uranus' high obliquity climate.

Friday, October 26, 2018
10:30 AM-11:10 AM
Ballroom B (Knoxville Convention Center)

504 Laboratory Research
Chair(s): Murthy S. Gudipati, Keeyoon Sung

10:30 AM-10:40 AM
504.01 Near Ultraviolet and Optical Emission Features of Electron Impact on Water Vapor
Dennis Bodewits[1], Juraj Orszagh[2], John Noonan[3], Štefan Matejčík[2], Michal Durian[2], Joel Parker[4]
[1]Physics Department, Auburn University, Auburn, Alabama, United States, [2]Comenius University, Bratislava, Slovakia, [3]Lunar and Planetary Laboratory, Tucson, Arizona, United States, [4]SWRI, Boulder, Colorado, United States

Abstract
Auroral emission from electron impact processes can provide a remote window on the physical properties of plasma and neutral gases surrounding small bodies such as comets, main belt asteroids, and moons (Galand & Chakrabarti, 2002; Roth et al. 2014).

Surprisingly, Rosetta found that outside 2 AU pre-perihelion, atomic and molecular emission featuresin the inner coma were predominantly caused by dissociative electron impact excitation (Feldman et al. 2015). When the comet came within 2 au of the Sun, fluorescent emission became the dominant process, as water densities in the inner coma could effectively cool the electron population below the appearance energy of the relevant electron impact dissociative excitation processes (Bodewits et al. 2016). Further quantitative interpretation of the Alice and OSIRIS images of the coma is constrained by the limited published lab measurements of excitation cross sections of electron impact reactions with the gases present in cometary comae.

We will present the results of a series of experiments where we characterized the energy dependence of NUV-visible emission features of electrons colliding with H_2O vapor between 2 – 100 eV. The experimental set up is located at the Comenius University in Bratislava, Slovakia, and consists of a crossed-beam configuration combining an electron monochromator and a gas beam (Danko et al. 2013). We have measured the appearance energies of a large number of reactions leading to the emission of OH, the H balmer series, and OH+ and H_2O+ ions. Future experiments will focus on gases such as CO_2, CO, O_2, and HCN and emission features at shorter wavelengths.

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10:40 AM-10:50 AM

504.02 Laboratory Reflectance Spectroscopy Measurements of Planetary Analogs in the UV-IR under Relevant Conditions

Charles Hibbitts, Karen Stockstill-Cahill
Space, JHUAPL, Laurel, Maryland, United States

Abstract

The interpretation of remote measurements of planetary surfaces often requires referencing to and comparison with laboratory measurements of analogous materials under relevant environmental conditions, such as pressure and temperature. Spectral reflectance measurements from the ultraviolet through infrared enable direct comparison with observations as well as the ability of derive fundamental optical properties that through application of theory can reproduce spectral signatures observed for other bodies. In the LabSPEC facility at the JHU-APL we focus on the ability to obtain reflectance measurements from the UV through mid-IR (~ 7 um) of particulate and cohesive samples at vacuum, temperature, and radiation conditions relevant to the surfaces of Mercury to the icy satellites of Jupiter and Saturn. Obtaining spectra over this full wavelength range while conditions remain static enables valuable spectral correlations, such as the 3 um, 6 um and potential UV water features; as well as the transition metal related NIR crystal field band and the UV-Vis oxygen-metal charge transfer band. The LabSPEC also possesses a 40 keV electron source and 20 keV ion source, including mass selection, that enables simulating the monoatomic ions of the solar wind and giant planet magnetospheres. The moderately high energies of the electrons and protons ensure sufficiently deep penetration of the particles into samples to affect the NIR portion of the spectrum as well as the UV-Visible region; the longer wavelengths are of particular interest to Jovian satellite studies. These capabilities also come with challenges in design and operation, of which the greatest is ensuring measurement repeatability given switching out multiple detectors and light sources over a range of conditions from ambient pressure and temperature to ultra-high vacuum and temperatures from 100K to 600K. Even though the sample remains undisturbed in process, repeatability is affected by subsequent small shifts in the alignment of the entire system. Experimental results along with these and other challenges will be discussed.

10:50 AM-11:00 AM

504.03 Lunar Dayside Hydration Measurements by LRO LAMP

Amanda Hendrix[1], Dana Hurley[2], Kurt D. Retherford[3], Steve Liu[4], Michael Poston[3], Joshua T. Cahill[2], Faith Vilas[1], Thomas Greathouse[3], Kathleen Mandt[2]
[1]Planetary Science Institute, Tucson, Arizona, United States, [2]Applied Physics Lab/JHU, Laurel, Maryland, United States, [3]SwRI, San Antonio, Texas, United States, [4]zz, Ax, Alabama, United States

Abstract

Dayside, non-polar lunar hydration signatures have been observed by a handful of instruments and present insights into the lunar water cycle. In this study, we utilize the unique measurements from the current Lunar Reconnaissance Orbiter (LRO) mission to study the phenomenon of diurnally-varying dayside lunar hydration. The Lyman Alpha Mapping Project (LAMP) onboard LRO senses a strong far-ultraviolet water absorption edge indicating surficial hydration in small abundances in the permanently shadowed regions [Gladstone et al., 2012] and potentially on the lunar dayside [Hendrix et al., 2012].

In this study, application of a new FUV photometric function, with individual terms for mare and highlands terrains (Liu et al., 2018), results in a more robust determination of surficial hydration and its diurnal variability as sensed in the far-UV. We discuss implications for surface hydration.

11:00 AM-11:10 AM

504.04 The Rings of Pluto, Titan, Comets, and other Solar System Bodies: Laboratory Investigations into a Neglected Set of Cyclic Molecules

Reggie Hudson[1], Ella Mullikin[2], Christopher K. Materese[1], Perry Gerakines[1]
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Abstract

Over the past few decades, laboratory astrochemists have generated a large amount of data on cyclic compounds at low-temperature, low-pressure conditions. The overwhelming majority of such data concerns aromatic organic compounds ranging from the nucleobases of DNA to polycyclic aromatic hydrocarbons (PAHs). However, this work has come at the expense of *non*-aromatic cyclic molecules, which belong to the general class known as aliphatics. In this DPS presentation we consider some of the simplest such cyclic aliphatics, starting with the C_3 prototype: cyclopropane. Reasons for its non-detection will be addressed as will a subtle bias against such molecules (starting with a 1905 Nobel Prize!). New laboratory data comparing radiolytic stabilities of several C_3 compounds with those of known planetary and interstellar molecules will be presented. Suggestions for future investigations will be made. -- This work was supported by the NASA Astrobiology Institute through funding awarded to the Goddard Center for Astrobiology under proposal 13-13NAI7-0032. Support also was received from NASA's Planetary Science Division Internal Scientist Funding Program through the Fundamental Laboratory Research (FLaRe) work package at the NASA Goddard Space Flight Center.

Friday, October 26, 2018
11:10 AM-12:00 PM
Ballroom B (Knoxville Convention Center)

505 Asteroid Physical Characteristics: NEOs I
Chair(s): Sean Marshall, Cristina Thomas

11:10 AM-11:20 AM
505.01 Using Bayesian Optimization to Find Asteroids' Pole Directions
Sean Marshall[1, 2], Adam Cobb[3], Chedy Raïssi[4], Yarin Gal[3], Agata Rozek[5], Michael W. Busch[6], Grace Young[3], Riley McGlasson[7]
[1]Planetary radar, Arecibo Observatory, Arecibo, PR, Puerto Rico, [2]University of Central Florida, Orlando, Florida, United States, [3]University of Oxford, Oxford, United Kingdom, [4]Inria, Villers-les-Nancy, France, [5]University of Kent, Canterbury, United Kingdom, [6]SETI Institute, Mountain View, California, United States, [7]Macalester College, Saint Paul, Minnesota, United States

Abstract
Near-Earth asteroids (NEAs) are being discovered much faster than their shapes and other physical properties can be characterized in detail. One of the best ways to spatially resolve NEAs from the ground is with planetary radar observations. Radar echoes can be decoded in round-trip travel time and frequency to produce two-dimensional delay-Doppler images of the asteroid.
Given a series of such images acquired over the course of the asteroid's rotation, one can search for the shape and other physical properties that best match the observations. However, reconstructing asteroid shapes from radar data is, like many inverse problems, a computationally intensive task. Shape modeling also requires extensive human oversight to ensure that the fitting process is finding physically reasonable results.
Even though only a small fraction of NEAs are observed by radar, and not all of those have observations that are of sufficient quality for detailed shape modeling, radar observations are being acquired more quickly than the modeling can be done. Developing a shape model from radar data currently takes several months for each asteroid, even for an experienced researcher.
A critical part of shape modeling is the determination of the asteroid's spin state: its rotation period and the direction of its rotation axis. For some radar-targeted NEAs, there are existing lightcurve observations that provide a good estimate of the period. However, even if such information is available, finding the pole orientation is generally difficult and time-consuming. A grid search over the full range of possible pole directions often takes about one week.
Building upon the work of Raissi, Lamee, Mosiane, et al. (2016), we sped up and automated this task by implementing Bayesian optimization with Spearmint (Snoek, Larochelle, and Adams, 2012), on a spherical coordinate system (Carr, Garnett, and Lo, 2016). With Bayesian optimization, the results from previous models are used to choose optimal subsequent test points. Pole searches with Bayesian optimization are about three times faster and require less human supervision.
This work was supported by NASA, IBM, NVIDIA, and the SETI Institute as part of the NASA Frontier Development Lab program.

11:20 AM-11:30 AM
505.02 What is the Minimum Size of a Near Earth Object Impactor which Can Cause Ground Damage?
Peter Brown[1, 2], Nayeob Gi[1, 2], Michael Aftosmis[3]

[1]Physics and Astronomy, University of Western Ontario, London, Ontario, Canada, [2]Western University, Centre for Planetary Science and Exploration, London, Ontario, Canada, [3]Computational Aerosciences, NASA Advanced Supercomputing Division, NASA Ames Research Center, Moffet Field, California, United States

Abstract
The impact danger from Near Earth Objects (NEOs) has been examined in detail for several decades. However, emphasis has tended to focus on quantifying impact effects from the largest, but most infrequent, NEO impacts. The Feb 15, 2013 Chelyabinsk airburst has drawn attention to the extreme small end (~10 m) of the impactor spectrum. Window blast damage is the dominant damage modality at the smallest sizes (ignoring kinetic effects from direct meteorite impacts on ground objects) as seen at Chelyabinsk. This leads naturally to the question: what is the smallest NEO impactor for which we can expect economically significant window damage due to airblast? Clearly, this is smaller than Chelyabinsk (~0.5 MT) but how much smaller? Here we attempt to answer this question by first estimating the overpressure needed to damage windows at a level causing economically significant window breakage in urban areas. We then estimate the areal footprint of overpressure exceeding these limits caused by airbursts of different energies and impact geometries. We use the Triggered Progressive Fragmentation (TPFM) entry model of ReVelle (2005) conditioned by empirical limits on fragmentation height and energy to generate physically realistic height-energy deposition profiles. We will present estimates of the threshold limits for the total energy, airburst height and entry angle from these simulations which may be expected to cause significant window damage if an airburst occurs over an urban area.

11:30 AM-11:40 AM
505.03 Dehydration of Major Constituents of Carbonaceous Chondrites - Spectra and Compositional Changes
Leos Pohl, Daniel T. Britt
Physics, University of Central Florida, Orlando, Florida, United States

Abstract
Several subtypes of Carbonaceous Chondrites are rich in phyllosilicates, in particular in Serpentine group minerals, which in turn contain, within their crystal lattice, molecules of hydroxyl, or water. The proximity to the Sun during their orbital evolution might have been such that high enough temperatures were experienced by the asteroidal body and consequently loss of some or all hydroxyl could have occurred. Understanding of this process requires knowledge of the dehydration process itself, the temperature, rate, how the molecules migrate as well as what happens to the mineral itself and how its physical properties change. In the previous work, we have determined that the dehydration strongly depends on whether the Serpentine subgroup mineral is Mg or Fe rich (Antigorite or Lizardite on one hand or Cronstedtite on the other). We have determined that for Antigorite and Lizardite the dehydration starts around 600 C while for Cronstedtite, it starts around 400 C or even 350 C. Since Cronstedtite typically makes up about 25% of CMs (but it can make up over 50% of certain CMs), its low dehydration temperature makes the dehydration of Cronstedtite rich asteroids significantly more likely during their lifetime. Existing literature on Mg-rich Serpentines suggests that dehydration is followed re-crystallization of Forsterite and appearance of Silica and that further heating above 1000 C results in the formation of Enstatite. In the case of Fe rich Serpentines, there is little information on the phase transitions during heating. This work reports further experimental results on thermal processes in the Serpentine group minerals. We found that the amount of dehydrated mass is also influenced by grain size distribution. Further, in the data, we observed several phase transitions. Using X-Ray Diffraction, we determined the products after each phase transition. Also after each phase transition we determined the

reflectance spectra of the mineral and compare the spectra with the mineral before dehydration. We also did the analogous analysis with selected meteorite specimens.

11:40 AM-11:50 AM

505.04 Photometry and Spectroscopy of (469129) 2016 HO3

Dora Fohring[1], Vishnu Reddy[2], Richard Wainscoat[1], Al Conrad[3], Benjamin Sharkey[2]
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Abstract

The recently discovered Near Earth Asteroid (469129) 2016 HO3 is the closest and most stable quasi-satellite of Earth known to date. It orbits in a 1:1 mean motion resonance with Earth and has been shown to be dynamically stable for the next 300 years, with a minimum orbital intersection distance of 0.03 AU. Due to its stable orbit and proximity to Earth, it is an ideal candidate for future in situ study. Photometric and spectroscopic observations of this object aid the determination of its composition and origin; whether the asteroid is local or captured, and improve our understanding of the Earth's co-orbital population.
In May 2018 we performed visible-wavelength spectroscopy between 0.39 -- 1.1µm and photometry in V, R and I using the Echellette Spectrograph and Imager instrument on KECK II. Due to the faintness of the object, spectroscopy was performed via blind offsets on the object moving at around 30 mas/s. For the photometry, one complete 29 minute rotation was observed in each filter, with average signal-to-noise ratios of around 70, 30, and 15 in V, R, I, respectively, with a temporal resolution of 85s.
Light curves were constructed using aperture photometry on the trailed images. The light curves show brightness variations of 0.5±0.2, 0.4±0.1 and 0.2±0.2 in V, R, I respectively. These values are less than previously measured, which might be explained by a change in aspect angle of the asteroid (tumbling) or an artefact of the data reduction. Spectra were also taken and analysis is currently underway.

11:50 AM-12:00 PM

505.05 Systematic Characterization and Monitoring of Potentially Active Asteroids: The Case of Don Quixote

Michael Mommert[1], David Trilling[2], Matthew M. Knight[3], Joseph Hora[4], Nicolas Biver[5], Maria Womack[6], Kacper Wierzchos[6], David Polishook[7], Peter Veres[4], Annika Gustafsson[2], Andrew McNeill[2], Brian Skiff[1], Richard Wainscoat[8], Michael S. Kelley[3], Nicholas Moskovitz[1], Olga Harrington[6]
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Abstract

Over the previous decades, activity has been observed in about 20 Solar System small bodies that were until then known as asteroids. Activation mechanisms have been proposed for these objects, including the sublimation of volatiles, rotational instability, and recent impacts; all these mechanisms provide strong constraints on the physical properties and evolution of these objects. The identification of more active asteroids will improve our understanding of the processes triggering activity as well the nature of asteroids in general.

We present first results from our "Systematic Characterization and Monitoring of Potentially Active Asteroids" program, which obtains BVRI colors and performs V-band photometric monitoring of a sample of 103 dormant comet candidates and 10 near-Sun asteroids. The goal of this program is to find activity in and provide a spectrophotometric taxonomic classification for our targets in order to place limits on the volatile contents of these potentially active populations and improve our understanding of their evolution.

We present the case of near-Earth asteroid (3552) Don Quixote in which we discovered activity in multiple wavelength regimes. In October 2017 we observed activity using Spitzer Space Telescope observations that agrees with findings by Mommert et al. (2014, ApJ 781), suggesting continuous activity from the sublimation of CO or CO_2. While close in time optical observations did not reveal any dust activity, observations in March 2018 revealed for the first time episodic dust activity in this object (Mommert et al., 2018, CBET 4502). Follow-up observations in June 2018 with the 30m IRAM sub-millimeter telescope show a lack of emission from the CO(2-1) line and hence suggest that activity in this object is most likely triggered by the sublimation of CO_2. Our observations suggest that Don Quixote is most likely a weakly active CO_2-rich comet. The finding of faint activity in Don Quixote underscores the necessity of a systematic monitoring campaign to find activity.

This program is based upon work supported by NASA under Grant No. NNX17AG88G.

Friday, October 26, 2018
10:30 AM-12:05 PM
Ballroom C (Knoxville Convention Center)

506 Pluto System II: Composition and Geology
Chair(s): Alissa M. Earle, Leslie A. Young

10:30 AM-10:40 AM
506.01 Are multiple coloring agents present across the surface of Pluto and its large satellite Charon?
Silvia Protopapa[1], Dale Cruikshank[2], Cristina Dalle Ore[3, 2], William Grundy[4], Catherine Olkin[1], Dennis Reuter[5], Carly Howett[1], Francesca Scipioni[3], Jason Cook[6], Kelsi N. Singer[1], Ross A. Beyer[3, 2], Paul M. Schenk[7], Alan Stern[1], Harold Weaver[8], Leslie A. Young[1], Kimberly Ennico[2]
[1]Department of Space Studies, Southwest Research Institute, Boulder, Colorado, United States, [2]NASA Ames Research Center, Moffett Field, California, United States, [3]SETI Institute, Mountain View, California, United States, [4]Lowell Observatory, Flagstaff, Arizona, United States, [5]NASA Goddard Space Flight Center, Greenbelt, Maryland, United States, [6]Pinhead Institute, Telluride, Colorado, United States, [7]Lunar and Planetary Institute, Houston, Texas, United States, [8] Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, United States

Abstract
The New Horizons flyby of Pluto has revealed a complex world rich in a variety of landforms, colors, and compositions (Stern et al., 2015). The color imaging of Pluto's encounter hemisphere obtained by the Multi-spectral Visible Imaging Camera (MVIC) component of the Ralph instrument (Reuter et al., 2008) displays a latitude-dependent distribution of colors ranging from dark red to yellow (Olkin et al., 2017). Laboratory experiments suggest that Pluto's coloration may be due to the presence on the surface of tholin-like materials, which are organic compounds produced through photolysis and radiolysis of native material found on the surface and atmosphere of the dwarf planet. Tholins produced in the laboratory exhibit a wide range of colors (Materese et al., 2015; Cruikshank et al., 2016).

Pluto's largest moon Charon displays distinctly reddish tholin coloration around its north pole (Grundy et al. 2016a). Grundy et al. 2016b put forth the idea that this might be the result of gas from Pluto transiently cold-trapped and processed at Charon's winter pole.

The true contribution of the coloring agents cannot be assessed without consideration of the visible spectral domain as in Protopapa et al. (2017). This is due to the fact that the diagnostic spectral signature of tholins is a strong red slope in the visible part of the spectrum. We present a characterization of the tholin material across the surface of Pluto and its moon Charon through radiative transfer modeling of the New Horizons Ralph/LEISA (Linear Etalon Imaging Spectral Array, infrared spectrometer) and MVIC data. We compare our findings with optical constants of Pluto tholin we compute from laboratory reflectance measurements by Materese et al. (2015). The ultimate goal is understanding the variety of tholins on the surface of Pluto and Charon, and the processes responsible for their formation and distribution.

10:40 AM-10:50 AM
506.02 Evidence of local CH_4 stratification on Pluto from New Horisons LEISA data and a complete N_2 ice map.

Bernard Schmitt[1, 2], Leila Gabasova[2], Sylvain Philippe[2], Tanguy Bertrand[3], William Grundy[8], Eric Quirico[2], François Forget[3], John Stansberry[4], Briley Lewis[4], Silvia Protopapa[5], Rajani Dhingra[6], Leslie A. Young[5], Catherine B. Olkin[5], Dennis C.[7], S. A. Stern[5], Harold A. Weaver[9]
[1]IPAG, CNRS, Grenoble, France, [2]Université Grenoble Alpes, Grenoble, France, [3]LMD, Paris, France, [4]STSCI, Baltimore, Maryland, United States, [5]SWRI, Boulder, Colorado, United States, [6]University of Idaho, Moscow, Idaho, United States, [7]NASA Goddard Spaceflight Center, Greenbelt, Maryland, United States, [8]Lowell observatory, Flagstaff, Arizona, United States, [9]JHUAPL, Laurel, Maryland, United States

Abstract
The diurnal, seasonal and astronomical cycles on Pluto trigger sublimation-transport-condensation cycles of the volatile ices (N2, CH4, CO) with different amplitudes and time constants at the surface.
The qualitative distribution of the two major volatile ice phases identified on the surface of Pluto, N2-rich:CH4:CO ice and CH4-rich ice, has been mapped by Schmitt et al. (2017) and the spatial transitions between the predominant zone of these phases have been highlighted. The first quantitative composition map has been derived by Protopapa et al. (2017). A surprising observation, but not discussed in Schmitt et al. paper, was that the CH4 qualitative abundance maps obtained from different CH4 bands display relatively different spatial distributions, but with regular evolutions at a given location from the weakest to the strongest CH4 bands.
In this talk we demonstrate that these band depth changes reflect a stratification of CH4, either in the CH4 concentration in N2-rich ice and/or in the relative abundance between the N2-rich:CH4:CO and CH4-rich ices, depending on the area. For this we use in addition our 'CH4 state index' based on the spectral position of the CH4 bands and a new N2 ice distribution map including the area where the N2 ice band is too weak to be observed directly. The stratification of CH4 is shown to result from the differential sublimation between N2 and CH4 which tends to concentrate CH4 in N2 ice grains and, according to the phase diagram, produces a CH4-rich phase that accumulates on the surface. We will show that several different configurations appear to exist at the surface of Pluto according to the latitude and the altitude, and that they may be the witness of different stages in the sublimation-condensation cycles or of different timescales. The occurence, the CH4 concentration and the depth of these stratified terrains can be correlated with the nitrogen sublimation fluxes obtained by volatile transport models (Bertrand et al. 2018).

10:50 AM-11:00 AM
506.03 Laboratory study of ammonia indices of refraction with water ice
Joseph Roser[1, 2], Cristina M. Dalle Ore[1], Dale Cruikshank[2], Alessandra Ricca[1, 2]
[1]SETI Institute, Mountain View, California, United States, [2]NASA-Ames Research Center, Moffett Field, California, United States

Abstract
A prominent, ammonia-linked absorption band at 2.2 μm was observed by *New Horizons* in the spectrum of Pluto's moons Charon, Hydra, and Nix. This absorption band or its suspected presence was also reported on a number of TNOs. Detectable ammonia on these bodies is surprising since radiation is expected to destroy this molecule on relatively short timescales. This might indicate that some kind of resurfacing process is replenishing the surface ammonia even on bodies such as Hydra and Nix that are too small to support cryovolcanism. At present, analysis of the 2.2 μm band has been hampered by a lack of complex index of refraction data on ammonia and its associated hydrates. Here we report on a combined project of laboratory experimental measurements and theoretical quantum chemistry to determine the complex indices of refraction of amorphous ammonia, cubic crystalline ammonia, and

ammonia hydrates for improved modeling of the 2.2 μm band in outer Solar System environments. This data should prove to be especially useful if ammonia or ammoniated species are also discovered on the *New Horizons* close encounter target (486958) 2014 MU_{69} in 2019.

11:00 AM-11:10 AM

506.04 Cryovolcanic Constructs on Pluto

Kelsi N. Singer[1], Paul M. Schenk[2], William B. McKinnon[3], Ross A. Beyer[4], Bernard Schmitt[7], Oliver L. White[4], Jeffrey M. Moore[5], William Grundy[6], John Spencer[1], S. A. Stern[1], Tod R. Lauer[8], Catherine B. Olkin[1], Harold A. Weaver[9], Leslie A. Young[1], Kimberly Ennico[5]

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Abstract

Pluto's surface has experienced considerable endogenic and exogenic resurfacing [1]. The terrains on Pluto represent a variety of ages, from seemingly ancient to surprisingly young. Some of the very young terrains are the result of the volatile ices on Pluto's surface (e.g., the convecting nitrogen-ice-rich plains of Sputnik Planitia). But Pluto also has several examples of more recent activity (terrains with few-to-no superimposed craters), that appear to be primarily made out of non-volatile water ice.

The most prominent examples of potential cryovolcanism are two enormous topographic constructs with wide, deep central depressions [2]. The informally named Wright Mons stands ~4 km high and the main mound spans ~150 km. The informally named Piccard Mons is ~7 km high and 225 km wide. The central depressions are dissimilar from a typical terrestrial shield volcano in that they are much wider (e.g., the Wright Mons central depression is ~40-45 km wide, taking up ~1/3rd of the total feature width) and deeper (the floors extend down to or below the level of the surrounding terrain). The central depression of Wright does not exhibit wall terraces that are typical indicators of collapse in terrestrial volcanoes. Instead, the central depression walls and floor have a large-scale hummocky texture similar to that the exterior of Wright, with individual hummocks on average ~8-10 km across. A few terrains around Wright may be older, more fractured or cratered, examples of the terrain on the flanks. Thus there is some evidence for multiple episodes of terrain emplacement, but distinct flow fronts are not obvious.

Each potential example of cryovolcanism found in the outer solar system is unique, and Pluto's features expand the information we have to understand this enigmatic process. We will present image, topographic, and composition data for Wright and Piccard along with geologic mapping results. We will discuss potential formation mechanisms in light of available empirical and model constraints.

[1] Moore, J.M. et al. (2016) Science 351, 1284-1293. doi:10.1126/science.aad7055

[2] Singer, K.N. et al. (2016) Planetary Mappers Meeting 1920, #7017, http://adsabs.harvard.edu/abs/2016LPICo1920.7017S.

1:10 AM-11:20 AM

506.05 Recent cryovolcanism on Pluto

Dale Cruikshank[1], Orkan M. Umurhan[1], Jeffrey M. Moore[1], William Grundy[2], William B. McKinnon[10], Cristina M. DalleOre[1, 5], Bernard Schmitt[6], Ross A. Beyer[1], Kirby D. Runyon[4], Francis Nimmo[9], Alan D. Howard[11], S. Alan Stern[3], James T. Keane[7], Richard Cartwright[5, 1], Oliver L. White[1], John Spencer[3], Richard P. Binzel[8], Catherine B. Olkin[3], Harold A. Weaver[4], Leslie A. Young[3], Kimberly Ennico[1], Carey M. Lisse[4]

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Abstract

The Virgil Fossae region on Pluto exhibits three spatially coincident properties that are suggestive of recent cryovolcanic activity over an area approximately 300 by 200 km. Situated in the fossae channels and in the surrounding terrain are exposures of H_2O ice in which there is entrained opaque red-colored matter of unknown composition. The H_2O ice is also seen to carry spectral signatures at 1.65 and 2.2 μm of NH_3 in some form, possibly as a hydrate, an ammoniated salt, or some other compound. High-resolution images from the New Horizons spacecraft provide a base map upon which a map of H_2O ice obtained at lower spatial resolution with the New Horizons LEISA mapping spectrometer is superimposed. Analysis of the LEISA map demonstrates that in areas where there is a minimal amount of CH_4 ice, the exposed H_2O ice exhibits the maximum NH_3 signature, localized in one end of the main channel of the fossae complex. The NH_3-H_2O is distributed in patterns suggesting flow of cryolava along the fossa floor and ejection of cryoclastics in ballistic trajectories well beyond the fossa channels. Muted topography (craters and fossae) may represent mantling by cryoclastic deposits that also bear the NH_3 signature in H_2O ice and the red color. We present a model of the flow of a cryogenic magma emerging from sources in Virgil Fossa indicating that the extent of the flow can be several km. The appearance of the frozen magma over the full length (>200 km) of the main channel in the Virgil Fossae complex and extending through the north rim of Elliot crater and varying in elevation over a range of ~2km, suggests that it emerged from multiple sources, probably along the length of the strike direction of the normal fault(s) defining the graben. The source or sources of the ammoniated H_2O are one or more subsurface reservoirs that may or may not connect to the putative global ocean postulated for Pluto's interior. In a separate study in which we take the red-colored matter to be a complex organic tholin, we show that the chemistry in such a mixture is likely to produce amino acids and many nucleobases, including the five used in terrestrial biological systems (Cruikshank et al., submitted).

11:20 AM-11:30 AM

506.06 Prebiotic Chemistry of Pluto

Yvonne Pendleton[1], Dale P. Cruikshank[1], Christopher K. Materese[2], Penelope J. Boston[1], Ross A. Beyer[1], Veronica J. Bray[6], Cristina M. DalleOre[1], Kimberly Ennico[1], William Grundy[3], James T. Keane[9], Carey M. Lisse[5], Catherine B. Olkin[4], Kirby D. Runyon[5], Bernard Schmitt[8], Francesca Scipioni[1], S. A. Stern[4], Michael E. Summers[7], Harold A. Weaver[5], Leslie A. Young[4]

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Abstract
The variety of surface colors on Pluto results from the synthesis of complex organics in the atmosphere and on the surface. There is new evidence that tholins and other organics from a subsurface aquifer were carried to the surface by ammoniated liquid water to form deposits of unique color and chemical properties. Pluto's Virgil Fossae exhibits an exposure of H2O-NH3 ice and a uniquely red color that may contain tholins produced in such a subsurface environment. Geological evidence in images from the NASA New Horizons spacecraft supports the view that ammoniated water carrying a uniquely colored red tholin-like material emanated from one or more sources from a part of Virgil Fossae. Emission from these sources appears to have progressed along parts of the fossae before freezing upon contact with the vacuum and cold solid surface. In addition, material may have traveled on ballistic trajectories for >100 km. Pluto's organic tholins and ices, when viewed in the context of laboratory syntheses of complex molecules of prebiological importance, lead to a deeper understanding of the plausible chemistry that may be occurring on icy bodies in the outer Solar System. Compounds such as nucleobases, including those of biological significance, may have formed on the surface from UV irradiation of nitrogen-rich tholins ejected with warm subsurface water in cryovolcanic events. Alternatively, these complex molecules may have formed in subsurface fluid that emerged in and around Virgil Fossae. Laboratory irradiation of ice mixtures reflecting Pluto's composition have produced strongly colored complex organics including possible aromatic molecules. Recent experiments with pyrimidine and purines frozen in H2O-NH3 ice resulted in the formation of numerous nucleobases, including the biologically relevant guanine, cytosine, adenine, uracil, and thymine (Materese et al. 2017 Astrobiology 17, 761). It is also possible that some of the oldest organics on Pluto derive from the material inherited prior to the formation of the planet. Thus, geological processes recently revealing buried tholins on Pluto may be unveiling organics of either early Solar System legacy or interior processes within Pluto.

11:30 AM-11:40 AM
506.07 Long-term Evolution of Sputnik Planitia: Cryo-clastic Eruptions and their Implications
John Stansberry[1], Leslie Young[2], Jonathan Lunine[3], Laurence Trafton[4], Will Grundy[5], John R. Spencer[2], William B. McKinnon[6], Francis Nimmo[7], Paul Schenk[8], Jeffrey M. Moore[9], James T. Keane[10], Kimberly Ennico[9], Catherine Olkin[2], S. Alan Stern[2], Harold Weaver[11]
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Abstract
The Sputnik Planitia (SP) impact basin [1] on Pluto is currently the location of an extensive deposit of volatile ices of N_2, CO and CH_4 [2]. Those ices are undergoing solid-state convection as evidenced by the organization of surface features into cellular structures tens of kilometers across [3, 4]. SP is a positive mass anomaly that migrated to its current position after a process of and sub-basin crustal thinning and volatile infilling [1, 5]. This scenario neglects the potentially important effects of endogenic heat flow, especially as might be enhanced due buried heat from the impact. Such upward heat flow would delay infilling of SP with volatile ices, and could result in interspersed episodes of infilling and removal of volatile material.

The volatile ices would form an insulating layer, and the basal temperature (and corresponding vapor pressure of the N_2 ice) would increase as the layer depth increased. For a heat-flow enhancement of just 5x over present-day endogenic heat flow, the vapor pressure of N2 will exceed the overburden stress at depths less than 1km. Such overpressure at the base of a nascent SP volatile-ice layer would lead to geyser-like activity and depletion of the volatiles.

Later, thicker ice layers could perhaps effectively confine the N2 vapor. Truly violent releases of material could result, yielding episodic increases in atmospheric bulk, and transport of liquid and solid material entrained in the gas flow (what might be termed a "cryo-clastic" eruption mechanism). Such eruptions would be significantly supersonic and have significant horizontal velocity components. As a result, the flows could travel ballistically over distances comparable to Pluto's radius before falling back to the surface. Geomorphic signatures should result, although examples of the resulting landforms may not exist on the other explored bodies of the solar system. One Plutonian landform that might have been formed via this mechanism is the bladed terrain of Tartarus Dorsa.

References [1] Nimmo et al., Nature v540 (2016). [2] Grundy et al., Science v351 (2016). [3] Stern et al., Science v350 (2015). [4] McKinnon et al., Nature v534 (2016). [5] Keane et al., Nature v540 (2016).

11:40 AM-11:50 AM
506.08 The Nature and Origin of Charon's Smooth Plains
Ross A. Beyer[1], John Spencer[2], William B. McKinnon[3], Francis Nimmo[4], Chloe Beddingfield[1], William Grundy[5], Kimberly Ennico[6], James T. Keane[7], Jeffrey M. Moore[6], Catherine B. Olkin[2], Stuart Robbins[2], Kirby D. Runyon[8], Paul M. Schenk[9], Kelsi N. Singer[2], S. Alan Stern[2], Harold A. Weaver[8], Leslie A. Young[2]
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Abstract
Charon displays extensive plains that cover the equatorial area and south to the terminator on the sub-Pluto hemisphere observed by New Horizons. We hypothesize that these plains are a result of Charon's global extension and early subsurface ocean yielding a large cryoflow composed of mantle material that completely resurfaced this area leaving the plains and other features we that we observe today.

The resurfacing of the plains is not the result of a singular eruptive or effusive center from which cryoflows spread out across the more than 400,000 square kilometers of Vulcan Planitia. We hypothesize that the resurfacing was the result of ammonia-rich cryo-material from the last stages of ocean freezing either buoyantly rising and flowing out on to the pre-Vulcan lowlands, or as a result of more severe disruption that resulted in crustal blocks foundering, and the buoyant, viscous cryo-material under those blocks rising up and spreading out. Under these hypotheses, there would be no singular effusive center, but the sources of the plains material would be in many places across the region, and as the material flowed across the pre-Vulcan lowlands or enveloped the foundering blocks, it would create an extensive plains unit.

Geological observations, modeling of possible flow rheology, and an analysis of rille orientations support the conclusion that the extensive plains on Charon are a vast cryoflow emplaced unit, similar to those seen on Ariel and Miranda and possibly other icy worlds in the solar system. Charon fits into the panoply of icy satellites which display evidence for the movement of cryoflows and resurfacing.

11:50 AM-12:05 PM

506.09D Young Surface of Pluto's Sputnik Planitia Caused by Viscous Relaxation

Qiang Wei[1, 2], Yongyun Hu[2], Yonggang Liu[2]
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Abstract
One of the most prominent features of Pluto observed by the New Horizon mission is the absence of craters on Sputnik Planitia (SP) (Moore et al. 2016; Stern et al. 2015a). Although vigorous thermal convection could renew SP surface at a timescale of ~500,000 years (McKinnon et al. 2016; Trowbridge et al. 2016), ournumerical simulations demonstrate that craters can be removed much faster by rapid viscous relaxation of nitrogen (N_2) ice within 1000 terrestrial years if the N_2-ice thickness is a few kilometers. Moreover, it is found that for the relatively thin N_2 ice on SP (Grundy et al. 2016), the shortest relaxation timescale of a crater corresponds to the crater diameter of about 10 km, while the timescale increases nonlinearly with both increasing and decreasing crater diameters. This is different from the situation for most other icy moons in the solar system, where the relaxation timescale of craters increases with decreasing diameters because of their thick ice layers. Grain size and compositional difference could result in a dichotomy of relaxation behavior between pits and craters.

Friday, October 26, 2018
01:30 PM-03:30 PM
Ballroom A (Knoxville Convention Center)

507 Giant Planet Atmospheres II
Chair(s): Laura Mayorga, Michael L. Wong

01:30 PM-01:40 PM
507.01 Contrasting Temperature Conditions at the Poles of Jupiter and Saturn
Leigh Fletcher[1], Arrate Antuñano[1], Henrik Melin[1], Padraig T. Donnelly[1], Glenn Orton[2], James Sinclair[2], John Rogers[3], Gerald Eichstädt[4], Candice Hansen[5], Thomas W. Momary[2], T. M. Sato[8], Yasumasa Kasaba[6], Takuya Fujiyoshi[7]
[1]Physics and Astronomy, University of Leicester, Leicester, Leicestershire, United Kingdom, [2]Jet Propulsion Laboratory, Pasadena, California, United States, [3]British Astronomical Association, London, United Kingdom, [4]Independent, Stuttgart, Germany, [5]Planetary Science Institute, Tucson, Arizona, United States, [6]Tohoku University, Sendai, Miyagi, Japan, [7]Subaru Telescope, Hilo, Japan, [8]Institute of Space and Astronautical Science, Japan Aerospace and Exploration Agency, Sagamihara, Kanagawa, Japan

Abstract
Seasonal influences on the thermal structure of gas-giant atmospheres can be explored via comparison of the polar environments of Jupiter and Saturn. Saturn exhibits a seasonal stratospheric vortex of enhanced temperatures and hydrocarbon abundances in a region spanning ~15° from the summertime pole (Fletcher et al., doi:10.1016/j.icarus.2014.11.022). Long-term monitoring of Saturn's thermal field by the Cassini Composite Infrared Spectrometer (CIRS) constrained the development of this vortex during northern spring (2014-2017), which can be explained via a combination of radiative warming on seasonal polar aerosols and adiabatic heating from atmospheric subsidence. Jupiter's polar atmosphere was investigated via a campaign of mid-infrared (5-20 µm) imaging from ESO's Very Large Telescope VISIR and the Subaru Telescope's COMICS instruments to support NASA's Juno mission. Unlike Saturn, Jupiter exhibits cold polar vortices with wave-perturbed boundaries in the troposphere and stratosphere (the boundary is more distinct at the north pole than the south), coinciding with the transition from organised belt/zone structures at low latitudes to the more chaotic polar environment revealed by Juno. Cooler polar conditions would typically be associated with upwelling or enhanced radiative cooling (from hydrocarbons or aerosols). Emission associated with stratospheric heating by Jupiter's south polar aurora was strong and well-resolved at 7.8 and 10-12 µm, whereas negligible heating could be seen in the north in May 2018, supporting the independent evolution of temperatures associated with these polar aurora (Sinclair et al., doi: 10.1002/2017GL073529). VISIR images at 5 µm (Fletcher et al., doi: 10.3847/1538-3881/aace02), sensing emission from the mid troposphere, reveal structures up to ±80°latitude in both hemispheres that can be compared to JunoCam observations, and are dominated by diffuse patches of emission associated with folded filamentary regions (FFRs) and bright cloud-free rings surrounding dark, cloudy vortices. Jupiter's circumpolar cyclones poleward of ±80° (Adriani et al., doi:10.1038/nature25491) could not be resolved from the ground, but longitudinal wave patterns will be discussed.

01:40 PM-01:50 PM
507.02 Dynamical Regimes of Giant Planet Polar Vortices from Shallow Water Modeling
Shawn Brueshaber[1], Kunio Sayanagi[2], Timothy Dowling[3]

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Abstract
We present the results of a shallow-water numerical model that reveals a mechanism governing the polar atmospheric dynamics of Jupiter, Saturn, Uranus and Neptune. Our target of interest includes Jupiter's tightly packed cyclones surrounding a central cyclone, discovered by the Juno spacecraft. Cassini finds a single, intense, compact polar cyclone centered on each pole of Saturn, and Voyager data and ground-based observations suggesting Uranus and Neptune have dominant, single polar cyclones too. These discoveries raise questions about the mechanism that differentiates these polar atmospheric dynamics regimes. To help determine what physical mechanisms control these differences, we use the Explicit Planetary Isentropic Coordinate (EPIC) model to carry out forced-turbulence shallow-water simulations in a gamma-plane configuration. The model is forced by small-scale stochastic mass pulses that parametrically represent cumulus storms. The effects of three parameters, the planetary Burger number, $Bu = (L_d/a)^2$ (L_d is the Rossby deformation radius, a is the planetary radius), input storm strength, s, and proportion of cyclonic and anticyclonic storms injected into the domain, α, are systematically investigated. Bu emerges to be the most important, able to distinguish between four distinct dynamical regimes, which from large to small Bu matches observations of Jupiter, Saturn, and the Ice-Giants, and a transitional regime between Jupiter and Saturn-like regimes. The boundaries of these regimes are found to be only slightly modulated by the values of s and α. By applying this correlation with respect to Bu in reverse, an observation of a particular polar regime could in principle used to constrain L_d.
We find:
1. Differences observed between the polar vortex configurations of Jupiter, Saturn, and Uranus/Neptune are successfully explained by our numerical simulations.
2. A key controlling parameter is the planetary Burger number, the square of the ratio of Rossby deformation length to planetary radius.
3. The polar configurations are only weakly affected by the strength and sign of small storms used to force the turbulence.

01:50 PM-02:00 PM

507.03 Visualization and Statistical Analyses of Jovian Atmosphere

Padma Yanamandra-Fisher[1], Eric Sussenbach[3], Andrew Casely[4], Glenn Orton[2]
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Abstract
Jupiter exhibits dramatic and dynamic changes at all levels of its atmosphere, as probed at various wavelengths – from high-altitude stratosphere down through the visible cloud tops and to the deeper atmosphere. Earlier case studies of Principal Component Analysis (PCA) performed on Jupiter and Saturn illustrated the viability of this approach (Quan et al; BAAS, 38, 2006; Otto, Yanamandra-Fisher and Simon-Miller, BAAS, 41, 2009). Yanamandra-Fisher et al. (2010) analyzed the passages of Jupiter's vortices GRS and Oval BA at three different epochs with PCA . Spectral decomposition of the geometrically-registered data identified several physical changes on the planet: variation of global cloudiness increased during the interaction; the albedo of discrete clouds at different altitudes vary and there appear to be either enhancement or depletion of ammonia vertically in the atmosphere, especially

after the color change in Oval BA in 2005. Analyses of the post-color change interactions of GRS and Oval BA in 2006 and 2008 indicated changes in thermal and albedo fields, with enhancement of ammonia in the perturbed region (Otto, Yanamandra-Fisher and Simon-Miller, BAAS, 2009; Fletcher et al., Icarus, 208, Issue 1). Our current work incorporates geospatial mapping (commonly used for terrestrial applications) with the application of PCA to Jovian atmospheric data. The data used in our study includes a combination of professional and amateur observations in the spectral range of 0.5 – 24.0 microns, from 2015 -present. Specifically, we use ArcGIS re-projection of multispectral 2D maps of Jupiter and PCA to visualize the changes. Our preliminary results indicate that a psuedo-3D visualization of the atmosphere is possible and therefore, can be used qualitatively to understand the evolution of interactions of various structures on the planet (such as the recent GRS-STropical Disturbance). The combination of these approaches to legacy and large data sets will make tractable the study of various problems such as seasonal variations of non-auroral neutral atmosphere; taxonomy of hot spots, their variability and correlation with visible cloud field; and temporal evolution of discrete features and interactions between them.

02:00 PM-02:10 PM

507.04 Atmospheric Dynamics in the Aftermath of Saturn’s Great Storm

Jacob L. Gunnarson[1], Kunio Sayanagi[1], John J. Blalock[1], Justin Garland[1], Andrew Ingersoll[2], Ulyana Dyudina[2], Tricia Ewald[2]

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Abstract

Using imagery from Cassini ISS and VIMS, we present an analysis of the evolution of Saturn’s northern mid-latitudes after the great storm of 2010-2011. This intense, planet-encircling storm disrupted existing features such as the “String of Pearls,” and gave rise to new dynamical features. The storm produced several “ribbon” waves in the 42°N jet, which are visible as undulations in the cloud bands. In addition to a pre-existing ribbon wave at the northern flank of the jet, the storm caused ribbon waves to form on the southern flank and peak of the jet. We measured the wavelength and dispersion of the ribbons and have identified them as barotropic Rossby waves with a smaller baroclinic component. Our dispersion analysis yielded a Rossby deformation radius of 887±197 km and a potential vorticity gradient ten times the planetary vorticity gradient. The storm also spawned a large anticyclonic vortex, which was still present at the end of Cassini’s mission. This oval-shaped anticyclone exhibited dramatic changes in aspect ratio and orientation reminiscent of Kida vortex oscillation. Additionally, we present the morphological evolution of the storm region from 2010 to 2017. Our work has been supported by NASA CDAP NNX15AD33G, NASA PATM NNX14AK07G, NSF AAG 1212216, and NASA NESSF NNX15AQ70H.

02:10 PM-02:20 PM

507.05 The Nature of South Polar Cloud Shadows and Anti-Shadows on Saturn

Lawrence Sromovsky, Patrick Fry

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Abstract

Dyudina et al. (2009, Icarus 202, 340-248) interpreted cloud shadows in Saturn's south polar region as being cast by concentric cloud walls extending 20-70 km above the poleward clouds, analogous to the

physically and optically thick eye walls of a hurricane. However, our radiation transfer modeling of clouds in this region does not support this interpretation. Using models with four cloud layers, we find that all layers are present both outside and inside the putative wall locations, that at least the upper three layers are not very optically thick, that their effective pressures do not change very much compared to what would be required to match the vertical changes inferred from shadow length, and optical depth and particle size changes are also modest. The layers include a stratospheric haze with an effective pressure near 25 mbar, a putative diphosphine layer near 250 mbar, an ammonia layer near 700-800 mbar, and finally an NH_4SH cloud top near 3-4 bars. The most plausible scenario seems to be that the outer shadows near 88° S are cast by a sudden decrease in optical depth of the putative diphosphine layer, and that the inner shadows near 89.1° S are cast by a sudden drop in the optical depth of the ammonia layer. In each case, the shadow is cast on the next layer down, primarily by changes in the layer above it. At 2 microns the optical depths of these layer are rather small, only a few tenths for the putative diphosphine haze, and about 1 for the NH_3 haze. At 752 nm, a wavelength at which shadows are observed, these optical depths are several times larger and sufficient to create significant shadows. Another feature of the shadow boundary is that when the sun azimuth is opposite to the original shadow-causing direction, there is a brightness increase exterior to the shadow region (anti-poleward) as expected if the shadow casting layer is now seeing extra illumination from below by light passing underneath the upper layer, an example of a less reflecting interior region casting an "anti-shadow" of extra sunlight underneath the more reflective outer region in the same layer.

This research was supported by NASA CDAPS Grant NNX15AL10G and
CDAP Grant 80NSSC18K0966.

02:20 PM-02:30 PM

507.06 Modeling the Middle Atmosphere of Jupiter: A 3D GCM of the Stratosphere Incorporating Eddy Forcing and Hydrocarbon Transport

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Abstract
Jupiter continually shows evidence of a fascinating dynamic upper atmosphere, supported by a multitude of observations showing eastward and westward stratospheric jets, meridional circulation of hydrocarbons, and upwardly propagating waves/eddies from the troposphere. Thus far GCMs (global circulation models) have had some success in recreating temperature distributions, yet many fundamental questions remain unanswered about forcing in the stratosphere and upper troposphere. We wish to fully examine the extent that circulation is controlled by radiative forcing (heating from solar insolation and infrared cooling from hydrogen and hydrocarbons) and conversely by forcing from below due to waves propagating from the underlying troposphere. Understanding middle atmosphere circulation is also important for explaining meridional transport of hydrocarbons, which have been observed by Voyager, Cassini, and possibly by Juno. There is a marked difference in the enhancement of C_2H_2 at low latitudes versus the enhancement of C_2H_6 at high latitudes, leaving unanswered questions about how hydrocarbon spatial variation is controlled by chemistry and dynamics in the stratosphere. These distributions have not been fundamentally explained by previous GCMs.
Here we present the latest results of a 3D GCM of Jupiter's atmosphere with a correlated-k radiative transfer scheme, the first such model incorporating tracers with atmospheric chemistry. We analyze the impact of radiative heating and cooling, along with eddy forcing, on the stratospheric temperature

distribution and dynamical features. Finally, we discuss the effects of stratospheric circulation on meridional hydrocarbon transport on Jupiter, and compare with observations.

02:30 PM-02:40 PM

507.07 First Measurements of Methyl Radical (CH_3) in Jupiter's atmosphere using TEXES/IRTF and EXES/SOFIA

Thierry Fouchet[1, 2], Thomas Greathouse[3], Bruno Bézard[1], Matt Richter[4], Julianne Moses[5]
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Abstract
We observed Jupiter with the TEXES instrument mounted on the IRTF telescope and the EXES instrument on board the SOFIA observatory in the range of methyl ν_2 band at 16.5 µm. Both observations independently led to the detection of one or several lines of the methyl band. These observations, compared with synthetic spectra generated for several methyl vertical profiles, allows us to test photochemical models. Indeed, methyl recombination is the highly dominant pathway for the production of the most abundant photochemical product in Jupiter's atmosphere, ethane. Hence, this first measurement of methyl provides strong constraints on photochemical productions of heavy hydrocarbons in Jupiter's atmosphere.

02:40 PM-02:50 PM

507.08 Revealing Jupiter's low-latitude ionosphere with ground-based observations, past and present

James O'Donoghue[1], Tom Stallard[3], Luke Moore[2], John E. Connerney[1]
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Abstract
Jupiter's auroral regions are powerful and bright, lending themselves more readily to sharing the secrets of the Jovian ionosphere in which they occur. However, as we will show, the relatively under-studied non-auroral ionosphere of Jupiter is at least as intriguing a region to study. In ground-based global maps of Jupiter's ionosphere and using narrow-band images taken in 1995-2000, we report on the detection that H_3^+ emissions are diminished in a sinusoidal like pattern across the entire planet. The ribbon is found to run almost exactly co-aligned with Jupiter's magnetic dip equator - a region where Jupiter's magnetic field runs parallel to the surface. While this coincidence provides a important clues as to the mechanics at play, it remains unknown why H_3^+ emissions are found to be weaker along it. What we do know is that H_3^+ emissions only become weaker for two reasons: either a reduced H_3^+density or a reduced H_3^+ temperature, or some combination of both. If the reason for the diminished emissions is a lower density, this suggests a reduction in the ionization rate; alternatively, if the cause is related to low temperatures, this could mean that Jupiter's low-latitude ionospheric heating source (which is also unknown) is being interrupted for some reason. We endeavor in this report to reveal what combination of temperature and density diminution is occurring using spectroscopic observations taken with the Keck telescope in 2016. These Keck observations will show new partially-global maps of H_3^+ temperatures and densities of Jupiter for the first time at high spatial resolution (5-10 degree longitude/latitude), which will hopefully provide more clues as to how the ribbon is formed.

02:50 PM-03:00 PM

507.09 The Composition and Thermal Structure of Saturn’s Upper Atmosphere from Cassini/INMS Measurements

Joseph Serigano[1], Sarah M. Horst[1], Roger Yelle[2], Tommi Koskinen[2], Chao He[1], Mark Perry[3], Thomas Cravens[4], Rebecca Perryman[5], J. H. Waite[5]

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Abstract

In September 2017, the Cassini spacecraft entered Saturn’s atmosphere, providing new insights into the composition and structure of the planet’s upper atmosphere. Prior to atmospheric entry, Cassini executed a series of 22 highly inclined orbits through the previously unexplored region between Saturn and its rings, yielding the first ever direct sampling of Saturn’s atmosphere. Data returned from the Ion and Neutral Mass Spectrometer (INMS) aboard Cassini have already revealed surprising results, including an unexpected external contribution of molecules into Saturn’s upper atmosphere and the presence of complex hydrocarbons in Saturn’s atmosphere.

We present here the first results of the composition and thermal structure of Saturn’s upper atmosphere from INMS measurements during Cassini’s final orbits and atmospheric entry, including the distribution of H_2, He, and CH_4 in Saturn’s equatorial thermosphere (Yelle et al. 2018). Measurements of the H_2 density in this region indicate temperatures ranging from 340 to 370 K. CH_4 is observed to not be in diffusive equilibrium above Saturn’s homopause, indicating the presence of an external source for this molecule. The downward external flux of this molecule, most likely coming from the ring system, is ~10^{13} $m^{-2}s^{-1}$. The upper atmospheric density and the relative abundances of Saturn’s major constituents will be presented. The unexpected complexities of Saturn’s mass spectrum at higher masses will also be discussed.

03:00 PM-03:10 PM

507.10 Monitoring Saturn's Upper Atmosphere Density Variations and Determination of the Saturnian He Mixing Ratio Using Helium 584 Å Airglow

Chris Parkinson[1], Tommi Koskinen[2], Larry Esposito[3]

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Abstract

The atmosphere of Saturn is mainly composed of H_2 and neutral atomic helium. The study of He 584 Å brightnesses is interesting as the EUV (Extreme UltraViolet) planetary airglow have the potential to yield useful information about mixing and other important parameters in its thermosphere. Resonance scattering of sunlight by He atoms is the principal source of the planetary emission of He 585 Å. The helium is embedded in an absorbing atmosphere of H_2 and since it is heavier than the background atmosphere, it’s concentration falls off rapidly above the homopause. The scattering region (i.e. where the absorption optical depth in H_2 is less than 1) generally lies well above the homopause. As the eddy diffusion coefficient, K_z, increases in the middle atmosphere, more helium is mixed into the scattering region and thus the reflected intensity increases.

Specifically, He emissions come from above the homopause where optical depth τ=1 in H_2 and therefore

the interpretation depends mainly on two parameters: He mixing ratio of the lower atmosphere and eddy mixing profile, K_z. The occultations of Koskinen et al. (2015) give K_z and temperature, T(z) with an accuracy that has never been possible before and the combination of these occultations and airglow analyses can therefore can provide estimates of the mixing ratio in the lower atmosphere.

Using Cassini UVIS data and powerful modeling and analysis techniques, we can address longstanding questions regarding the He mixing ratio in Saturn's atmosphere and upper atmosphere density variations using the observed He 584 Å airglow. We discuss results of work to determine the Saturnian mixing ratio of He and constrain dynamics in the upper atmosphere of Saturn with particular attention to the Grand Finale end of mission analyses.

03:10 PM-03:20 PM

507.11 Constrains on the 12C/13C and 14N/15N Isotopic Ratio in Neptune's Atmosphere from ALMA Observations of HCN and its Isotops

Raphael Moreno[1], Emmanuel Lellouch[1], thibault cavalie[1], Arielle Moullet[2]
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Abstract

We report the detection of H13CN, HCN and upper limits of HC15N in Neptune's atmosphere with our ALMA observations. These measurements will allow us to constrain the 12C/13C and 14N/15N Isotopic ratio in Neptune's stratosphere.

Our observations -performed on April 30, 2016- used the ALMA interferometer to search in Neptune's atmosphere for HCN(4-3), H13CN(4-3) and HC15N(4-3) rotational lines at 354.505, 345.339, and 344.200 GHz, respectively. These measurements were obtained using about 41 antenna of the 12m array, despite the angular resolution of ~0.6'' and Neptune's angular surface diameter was 2.24'', only disk-averaged measurements allowed to detect with sufficient signal-to-noise ratio the H13CN line, while only upper limits of HC15N were obtained.

We will present the analysis of these observations, which will include i) the vertical profile of HCN, ii) the isotopic ratio of 12C/13C and 14N/15N and finally discuss the origin of HCN in Neptune's stratosphere.

03:20 PM-03:30 PM

507.12 Constraining Opacity Sources on Neptune with ALMA

Joshua Tollefson[1], Imke de Pater[1], Statia Luszcz-Cook[2, 3]
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Abstract

Spatially resolved millimeter maps of Neptune reveal brightness temperature variations in the troposphere. These differences are mainly due to latitudinal variations in opacity, but previous maps were unable to resolve the source of this opacity. ALMA provides the high spatial resolution, sensitivity, and wavelength coverage needed to better constrain the abundances of these opacity sources, such as H2S, CH4, and ortho/para H2, across the disk. We present ALMA millimeter maps taken in Bands 3 (95-109 GHz), 4 (136-150 GHz), and 6 (224-242 GHz). We find brightness enhancements of 2-4K at Neptune's

south pole and depletions of 2-4K at the mid-latitudes compared to a ‘nominal’ uniform global model for Neptune’s troposphere taken from Luszcz-Cook et al. (2013). We place constraints on the abundances of H2S and CH4 as a function of latitude using radiative transfer models. Further, we relate these brightness variations to global circulation patterns. Low abundances of microwave absorbers mean decreased opacity, allowing deeper, warmer layers to be probed. Thus, radio brightness enhancements are consistent with subsiding dry air (south pole), while brightness decreases are consistent with uplifted wet air (mid-latitudes).

Friday, October 26, 2018
01:30 PM-03:30 PM
Ballroom B (Knoxville Convention Center)

508 Asteroid Physical Characteristics: NEOs II
Chair(s): Josef Hanus, Stephen Lowry

01:30 PM-01:40 PM
508.01 The Mission Accessible Near-Earth Objects Survey (MANOS): First Results from the Visible Spectroscopic Survey
Maxime Devogele[1], Nicholas Moskovitz[1], Cristina Thomas[2], Audrey Thirouin[1], Michael Mommert[1], David Polishook[3], Brian Skiff[1], Mitchell Magnuson[2], Annika Gustafsson[2]
[1]Lowell observatory, Flagstaff, Arizona, United States, [2]Northern Arizona University, Flagstaff, Arizona, United States, [3]Weizmann Institute of Science, Rehovot, Israel

Abstract
The Mission Accessible Near-Earth Objects Survey (MANOS) started in August 2013 and is a multi-year survey supported by the National Optical Astronomy Observatory (NOAO) and Lowell Observatory, and funded by the NASA NEOO (Near-Earth Object Observations) program. It aims at characterizing sub-km, low delta-v (typically <7 km/s), Near-Earth Objects (NEOs) by collecting astrometry, lightcurve photometry, and reflectance spectra.
The physical properties of NEOs are known to be size dependent. However, some open questions remain such as whether these objects are rubble piles or monolithic bodies, or whether they are covered by regolith. A compositional discrepancy between large NEOs (>1km) and meteorite collection is also observed (Stuart et al., 2004; Vernazza et al., 2008). Laboratory measurements have also shown that grain size can cause variation in spectral slope or absorption band depth (Cooper et al., 1999;Cloutis et al., 2013). The smallest NEOs can have rotation periods under 1 minute (Thirouin et al., 2016), while asteroids larger than 150m do not rotate faster than 2.2 hours. This supports the hypothesis of small asteroids being monolithic and structurally different than larger ones.
We report here the first results from MANOS on the visible spectroscopic properties. We have analysed roughly 300 asteroids with a mean size around 80 meters (H ~ 25), and with some targets as small as few meters (H=30). This represents one of the largest comprehensive spectroscopic datasets for NEOs < 100 meters. We will discuss the compositional properties of this sample relative to other NEOs (km and sub-km) (Perna et al., 2018; Thomas et al., 2011, and DeMeo et al., 2008), and to Main Belt asteroids (Bus et al., 2002 and DeMeo et al., 2009) and compare them with the meteorite population.
All spectroscopic data have been reduced using a new python based pipeline for asteroid spectroscopic reduction developed to be easily portable to any visible spectrograph. The use of the same pipeline for all data obtained by this survey allows us to obtain a consistent data set of spectral properties of small NEOs.
This work is supported by the NASA NEOO program, grant number NNX17AH06G.

01:40 PM-01:50 PM
508.02 OH/H_2O on Near-Earth Asteroids
Lauren McGraw[1], Joshua Emery[1], Cristina Thomas[2], Andrew Rivkin[3], Nate Wigton[4]
[1]Earth and Planetary Science, University of Tennessee , Knoxville, Tennessee, United States, [2]Northern Arizona University, Flagstaff, Arizona, United States, [3]JHU/APL, Laurel, Maryland, United States, [4]Oak Ridge National Laboratory, Oak Ridge, Tennessee, United States

Abstract
Near-Earth Asteroids (NEAs) are excellent laboratories for processes that affect the surfaces of airless bodies. Most NEAs are not expected to contain OH/H_2O on their surfaces because they formed in the anhydrous regions of the Solar System and their surface temperatures are high enough to remove these volatiles. However, a 3-µm feature typically indicative of OH/H_2O has been identified on other seemingly dry bodies in the inner Solar System, such as the Moon and Vesta. Possible sources for OH/H_2O on these bodies include carbonaceous chondrite impacts or interactions with protons implanted by solar wind. Characterizing the shape of the 3-µm absorption feature can yield information on the nature and source of the OH/H_2O on the surface. NEAs should be subjected to the same processes as other "dry" bodies in the inner solar system, therefore they are hypothesized to also exhibit a 3-µm feature.

We observed NEAs using SpeX on NASA's Infrared Telescope Facility on Mauna Kea, Hawaii. Spectra were collected using both prism (0.7-2.52 µm) and LXD_short (1.67-4.2 µm) modes in order to accurately characterize asteroid spectral type and the 3-µm region. We have made 29 observations of 21 NEAs as part of this ongoing project. Of those, at least 3 NEAs exhibit an absorption feature in the 3-µm region: (433) Eros, (1036) Ganymed, and (3122) Florence. All three have been observed multiple times and by multiple observers (e.g., Rivkin et al. [2018]. *Icarus* 304, 74-82). Data for 8 objects have not yet been reduced (preliminary results for 3200 Phaethon suggest it does not exhibit an absorption feature in the 3-µm range) and the rest either do not exhibit a 3-µm spectral feature or have too low of S/N to definitively detect one.

Band depth and shape analyses of Eros and Ganymed suggest the 3-µm feature is due to the presence of OH that was delivered via solar wind proton bombardment. Similar studies on Florence and the 8 unprocessed NEAs will determine the source and composition of the material, if present. Further study of these objects will shed more light on the origin of OH/H_2O on the surfaces of "dry" NEAs, which in turn increases our understanding of volatiles in near-Earth space.

01:50 PM-02:00 PM
508.03 First multi-band results from the rapid-response spectrophotometric characterization of Near-Earth objects using RATIR
Samuel Navarro-Meza[1, 2], Michael Mommert[3, 1], David Trilling[1], Nathaniel Butler[4], Mauricio Reyes-Ruiz[2], Barbara Pichardo[2]
[1]Northern Arizona University, Flagstaff, Arizona, United States, [2]Universidad Nacional Autónoma de México, Flagstaff, Arizona, United States, [3]Lowell Observatory, Flagstaff, Arizona, United States, [4]Arizona State University, Tempe, Arizona, United States

Abstract
We are carrying out a program to obtain rapid-response spectrophotometric characterization of newly discovered Near Earth Objects. Here we present a detailed analysis of the taxonomic distribution of about 100 small (tens to hundreds of meters in diameter) NEOs observed with the RATIR instrument on the 1.5-m telescope on San Pedro Martir, Mexico. The observations are made in queue mode using r, i, Y, Z, J, H bands, and the data processing is carried out autonomously. Using machine learning techniques and synthetic colors derived from measured asteroid spectra, we derive probabilistic taxonomic classifications for our targets. This work is part of a collaboration in which we will characterize hundreds of NEOs that are generally too faint for other characterization techniques (down to V~21). This work is supported by funding from NASA's Solar System Observations program.

02:00 PM-02:10 PM

508.04 Predicting Space Weathering Effects on Primitive Asteroids (101955) Bennu and (162173) Ryugu

Humberto Campins[1], Noemi Pinilla-Alonso[1], Julia de Leon[2], David Morate[3]
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Abstract

Two sample-return missions, OSIRIS-REx and Hayabusa 2, have just arrived at primitive near-Earth asteroids (NEAs) (101955) Bennu and (162173) Ryugu, and it is of interest to predict the effects of space weathering on their surfaces. Most spacecraft-accessible NEAs originate in the inner asteroid belt, and these two sample-return targets most likely originated in the Polana asteroid family (e.g., Campins et al. 2018 and references therein). Spectroscopic studies of primitive inner-belt families offer a preview of the properties expected in the NEAs they produce. So far, primitive asteroids in the inner-belt fall into at least two spectral groups. The first group includes the Polana, Eulalia and Clarissa families, which show considerable spectral homogeneity and no 0.7-μm hydration feature. In contrast, the Erigone and Sulamitis families are spectrally diverse and most of their members show clear 0.7-μm hydration features (e.g., Pinilla-Alonso et al. 2017; Morate et al. 2018). The Clarissa family is considerable younger than the Polana family, at less than 100 million years versus approximately 2000 million years, respectively (Nesvorný et al. 2015), and there are subtle yet significant spectral differences between these two families. These differences are consistent with the space weathering trend suggested by Lantz et al. (2015, 2017 and 2018). This agreement between observations of inner-belt families and laboratory simulations of space weathering has testable implications for Bennu and Ryugu: older terrains would be expected to be bluer than younger surfaces (Campins et al. 2018; de León et al. 2018).

02:10 PM-02:20 PM

508.05 The Thermal Response of Asteroid Surfaces: Results from ESO Large Programme

Stephen Lowry[1], Agata Rozek[1], Benjamin Rozitis[2], Tarik Zegmott[1], Simon Green[2], Colin Snodgrass[2], Alan Fitzsimmons[3], Paul Weissman[4], Eloise Brown[5]
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Abstract

The (YORP) effect [1] is a torque due to incident solar radiation and the subsequent recoil effect from the anisotropic emission of thermal photons on small bodies in the Solar System. The YORP effect can: change rotation rates and spin-axis orientations over relatively short time-scales; modify orbits (semi-major axis drift from the related Yarkovsky effect depends on the obliquity) and thus plays a key role in replenishment of the near-Earth asteroid (NEA) population; cause regolith mobility and resurfacing as spin rates increase, form binary asteroids through equatorial mass loss and re-aggregation and cause catastrophic disruption. When we began our systematic monitoring programme in 2010, the YORP effect had only been detected for three asteroids [3-5] with a marginal detection following in 2012 [6]. That has now increased to six [7-8]. All detections so far are in the spin-up sense, and theoretical studies are making progress in explaining this observation [9]. However, a much larger statistical sample is required to robustly test this theory. We are conducting an observational programme of a sample of NEAs to detect YORP- induced rotational accelerations. For this we use optical photometry from a range of small to medium size telescopes. This is supplemented by thermal-IR observations and thermophysical modelling

to ascertain expected YORP strengths for comparison with observations. For selected objects, we use radar data to determine shape models. We will present our latest results and progress on YORP detections/upper limits for a subset of NEAs from our programme, which include: (1917) Cuyo, (8567) 1996 HW1, (85990) 1999 JV6, (6053) 1993 BW3, and (29075) 1950 DA.

[1] Rubincam (2000). *Icarus 148,* 2. [2] Lowry et al. (2007). *Science 316*, 272. [3] Taylor et al. (2007). *Science 316*, 274. [4] Kaasalainen et al. (2007). *Nature 446*, 420. [5] Durech et al. (2008). *A&A 489,* L25. [6] Durech et al (2012). *A&A 547*, A10. [7] Lowry et al. (2014). *A&A 562*, A48. [8] Durech et al. (2018), *A&A* 609, A86. [9] Golubov, et al. (2014). *ApJ* 794, 22.

02:20 PM-02:30 PM
508.06 Goldstone/Green Bank Radar Imaging of Near-Earth Asteroid 2012 TC4
Lance Benner[1], Marina Brozovic[1], Shantanu Naidu[1], Michael W. Busch[2], Jon Giorgini[1], Martin A. Slade[1], Joseph S. Jao[1], Clement G. Lee[1], Lawrence G. Snedeker[1], Marc A. Silva[1], Frank G. Ghigo[3]
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Abstract
Near-Earth asteroid 2012 TC4 approached within 0.00035 au (7 Earth radii of Earth's surface) on 2017 October 12. This was one of the closest near-Earth asteroid encounters known in advance and it provided an outstanding opportunity to investigate the physical properties of this object. Here we report radar observations obtained between 2017 Oct. 9-14 with the 70 m DSS-14 (8560 MHz, 3.5 cm) and 34 m DSS-13 (7190 MHz, 4.2 cm) antennas at the Goldstone Deep Space Communications Complex and with the 100 m Green Bank Telescope. 2012 TC4 has an absolute magnitude of 26.7, suggesting a diameter within a factor of two of 15 meters. Despite its diminutive size, the flyby was so close that we expected extremely strong radar signal-to-noise ratios. The highest resolution images were obtained on Oct. 12 using transmissions at DSS-13 and reception at Green Bank, and achieved a range resolution of 1.875 m/pixel that is the finest ever obtained at Goldsone and Green Bank for any near-Earth asteroid. The images reveal an elongated, angular, asymmetric, and rapidly rotating object and place lower bounds on its intermediate and long axes of about 6 x 12 meters. Combined with an effective diameter of 7-10 meters, the implication is that 2012 TC4 is an optically-bright object. The rotation evident in the images is consistent with the 12 minute period that is prominent in the lightcurves obtained by W. B. Ryan (pers. comm.). The ratio of same-sense circular (SC) to opposite-sense circular (OC) polarization, SC/OC, is about 0.55, which probably indicates that this object has an unusually rough near-surface at decimeter spatial scales. Circular polarization ratios have been obtained for hundreds of near Earth asteroids, and the ratio for 2012 TC4 overlaps the upper end of values reported for C- and SQ-class near-Earth asteroids and the lower end for E- and V-class objects. The radar images are suitable for estimation of the 3D shape and spin state. When combined with the area/mass ratio estimated independently from orbit fitting (D. Farnocchia, pers. comm.), the physical model will be used to obtain the mass and the bulk density, information that is generally not available for solar system objects in this size regime.

02:30 PM-02:40 PM
508.07 Radar and Optical Observations of Equal-Mass Binary Near-Earth Asteroid 2017 YE5
Patrick A. Taylor[1], Marina Brozovic[2], Joseph S. Jao[2], Shantanu Naidu[2], Lance Benner[2], Flaviane C. Venditti[3], Sean E. Marshall[3], Anne Virkki[3], Amber Bonsall[4], Frank G. Ghigo[4], Brian D. Warner[5], Julian Oey[6], Filipe Monteiro[7], Petr Pravec[8], Riley McGlasson[9], Brynn Presler-Marshall[10], Luisa F. Zambrano-Marin[3], Edgard G. Rivera-Valentin[1], Betzaida Aponte-Hernandez[1], Jon Giorgini[2], Alan W. Harris[5]

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Abstract
Radar observations with the 70-m Goldstone, 305-m Arecibo, and 100-m Green Bank radio telescopes between 2018 June 21 and 26 find that near-Earth asteroid 2017 YE5 is, in fact, two asteroids of similar size in mutual orbit about each other. 2017 YE5 is only the fourth equal-mass binary asteroid system identified among the near-Earth asteroid population, following (69230) Hermes (Margot et al., 2003; IAUC 8227), 1994 CJ1 (Taylor et al., 2014; DPS 46, #409.03), and (190166) 2005 UP156 (Taylor et al., 2017; DPS 49, #204.02). Equal-mass binaries make up less than 1% of radar-observed near-Earth objects larger than 200 meters in diameter compared to roughly 15% for bilobate (peanut-shaped) asteroids and roughly 15% for binaries with more disparate sizes. Both components in the 2017 YE5 system are approximately 900 m in diameter, implying a very dark optical albedo of less than 3% for an absolute magnitude of 19.2. When combined with their relatively close approach to Earth, within about 16 lunar distances (6 million km), the radar images of 2017 YE5, with resolution as fine as 7.5 m per pixel, are the best yet of an equal-mass binary system. The radar images suggest the components have somewhat different shapes and possibly different radar-scattering properties. Variation in the radar images from day to day suggests the system was initially viewed far from edge on and that the mutual orbit has a separation of about four component radii and a period of roughly one day. Analysis of optical lightcurves, including possible mutual events, collected between late June and late July from the Center for Solar System Studies (CS3; United States), Observatorio Astronomico do Sertao de Itaparica (OASI; Brazil), and Blue Mountains Observatory (BMO; Australia) is ongoing. Constraints on the spin states, shapes, scattering properties, and mutual orbit will be presented and placed into context with the other three known, equal-mass, near-Earth binary systems.

02:40 PM-02:50 PM

508.08 Goldstone and Lightcurve Observations of Radar-bright Binary Near-Earth Asteroid 2018 EB

Marina Brozovic[1], Lance Benner[1], Shantanu Naidu[1], Jon Giorgini[1], Brian D. Warner[2], Joseph S. Jao[1], Lawrence G. Snedeker[3], Michael W. Busch[4], Clement G. Lee[1], Martin A. Slade[1], Kenneth J. Lawrence[1]
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Abstract
We report Goldstone radar and optical lightcurve observations of near-Earth asteroid (NEA) 2018 EB obtained in April 2018 during this asteroid's approach within 0.027 au. The radar observations occurred during one track on April 7; lightcurves were obtained on April 8 and 9 at CS3. The radar data reveal echoes from two objects whose positions change with time and establish that 2018 EB is a binary system. The size of the primary is consistent with the diameter of ~240 m estimated from NEOWISE data by J. Masiero (pers. comm.). The diameter of the moon is a few tens of meters in size and is among the smallest satellites discovered around any binary NEAs.
The observations yielded delay-Doppler images achieving range resolutions as fine as 18.75 m/pixel that

coarsely resolved the primary. The satellite is visible as a clump of bright pixels located several hundred meters up-range from the primary. The images do not span enough time to estimate the orbital period of the satellite. The lightcurves collected by one of us (B. D. Warner) indicate that 2018 EB is a very rapid rotator with a period of ~1.2 h that is much more rapid for an object of its size than the "spin barrier" of ~2.2 h observed for thousands of other asteroids (Pravec and Harris, 2000; Warner et al., 2009). Among asteroids with companions, the rotation period of 2018 EB is the fastest by about a factor of two. We estimated a radar cross section of 0.026 ± 0.08 km^2, that, assuming a diameter of 0.24 km obtained from NEOWISE, gives a very bright radar albedo of ~0.56. 2018 EB is at the high end of the observed radar albedo values for near-Earth and main-belt asteroids, and hints at a metallic composition. 2018 EB makes another close approach to Earth in early October 2018, and we plan to conduct extensive new radar, optical, and spectroscopic observations to investigate its radar properties, rotation period, composition, orbital parameters, and estimate its mass and density.

02:50 PM-03:00 PM

508.09 Rotationally induced structural failure of irregularly shaped rubble pile asteroids

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Abstract

Studies have shown that asteroids are rubble piles with irregular shapes. While the irregular shapes of large asteroids may be attributed to collisional events, those of small asteroids may result from not only impact events but also rotationally induced deformation processes, a long-term consequence of small torques, for example, caused by solar radiation pressure. A better understanding of shape deformation induced by such small torques allows us to give constraints on the evolution process of an asteroid and its structure. However, no quantitative study has been reported to provide the relationship between an asteroid's shape and its failure mode due to its fast rotation. Here, we use a finite element model (FEM) technique to analyze the failure modes and conditions of 24 asteroids with diameters less than 30 - 40 km, which were observed at high resolution by ground radar or asteroid exploration missions. Assuming that the material distribution is uniform, we investigate how these asteroids fail structurally at different spin rates. Our FEM simulations describe the detailed deformation mode of each irregularly shaped asteroid at fast spin. The failed regions depend on the original shape. Spheroidal objects structurally fail from the interior, while elongated objects experience structural failure on planes perpendicular to the minimum moment of inertia axes in the middle of their structure. Contact binary objects have structural failure across their most sensitive cross sections. We further investigate if our FEM analysis is consistent with earlier works that theoretically explored a uniformly rotating triaxial ellipsoid. The results show that while the failure mode may be controlled by global shape features, small variations in shape may significantly change the failure condition of an asteroid. Our work suggests that it is critical to take into account the actual shapes of asteroids to explore their failure modes in detail.

03:00 PM-03:10 PM

508.10 Asteroid 3200 (Phaethon): Simultaneous Visible and Near-Infrared Observations

Annika Gustafsson[1], Nicholas Moskovitz[2], Matthew M. Knight[3], Michael S. Kelley[3], David G. Schleicher[2], Henry Roe[4], Thomas A. Bida[2], Edward W. Dunham[2]

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Abstract

The Near-Infrared High Throughput Spectrograph (NIHTS) is a low resolution spectrograph that operates from 0.86-2.4 microns on Lowell Observatory's 4.3-m Discovery Channel Telescope (DCT) in Happy Jack, AZ. Using a dichroic mirror which transmits visible wavelengths and reflects the near-infrared, we have the opportunity to operate the Large Monolithic Imager, an independent visible wavelength CCD, simultaneously with NIHTS. In combination with the premier non-sidereal tracking capabilities of the DCT, NIHTS is an extremely efficient instrument and is expected to make significant contributions to several areas of astronomy.

We present an overview of the first NIHTS spectroscopic results which also employed simultaneous optical LMI imaging of asteroid 3200 (Phaethon). The unique active asteroid Phaethon, dynamically related to the parent body of the Geminid meteor shower (Whipple 1983), made a close approach to Earth in December 2017. The target passed within 0.07 AU and provided a rare opportunity to search for rotationally resolved compositional differences across the surface of the ~5 km body.

Phaethon is a B-type NEO (Bus and Binzel 2002), dynamically linked to Main-belt asteroid Pallas (2) (deLeon et al. 2010). Phaethon's dayside temperatures are ~1000 K from solar radiation heating near perihelion at 0.14 AU (Jewitt 2010). As a result, the activity on the surface is unlikely a result of near-surface ice sublimation, but instead, a combination of thermal fracture, dehydration cracking, radiation pressure sweeping, and electrostatic effects (Jewitt 2010). Due to the mass loss that the object has undergone, it is hypothesized that the surface would show evidence of the effects of solar radiation through spectral reddening.

We observed Phaethon before and after closest approach between December 14, 2017 and December 18, 2017 obtaining both near-infrared spectra with NIHTS and visible lightcurves with LMI in SDSS r' and a narrow-band Blue Continuum comet filter (4420-4500 Å) centered at 4453 Å. We report our time-resolved spectroscopic findings of this unique object.

This work is supported in part by the NASA NEOO program, grant number NNX17AH06G.

03:10 PM-03:20 PM

508.11 HST Investigation of Recent Disruption of (3200) Phaethon

Quanzhi Ye[1], Paul Wiegert[2], Man-To Hui[3]

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Abstract

Asteroid (3200) Phaethon is notable for its association with a strong annual meteor shower, the Geminids, indicative of one or more episodes of mass ejection in the past. Here we present a Hubble Space Telescope search of meter-sized fragments in the vicinity of Phaethon, carried out during Phaethon's historic approach to the Earth in mid-December of 2017. Our search was completed down to about 4 meters (assuming Phaethon-like albedo) and was expected to detect 0.035% particles ejected by Phaethon in the last several decades. The negative result of our search capped the total mass loss of Phaethon over the past few dozen orbits to be 1e12 kg at 3-sigma level, taking the best estimates of size power-law from meteor observations and spacecraft data. Our result also implies a millimeter-sized dust flux of <1e-12 $m^{-2}s^{-1}$ within 0.1~au of Phaethon, suggesting that any Phaethon-bound mission (such as the DESTINY+ mission) is unlikely to encounter dense dust clouds.

03:20 PM-03:30 PM

508.12 Physical Characterization of (3200) Phaethon: Target of the DESTINY+ Mission

Theodore Kareta[1], Vishnu Reddy[1], Carl Hergenrother[1], Dante S. Lauretta[1], Tomoko Arai[2], Driss Takir[3], Juan Sanchez[4]
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Abstract

(3200) Phaethon is a B-type near-Earth object (NEO) that is associated with the Geminids meteor shower and shows a small comet-like dust tail near perihelion. We obtained rotationally resolved spectroscopy across visible (0.4-0.74 microns) and near-infrared (0.68 – 2.55 microns) wavelengths to investigate its surface composition and albedo. Visible spectra show no absorption features throughout a full rotation as well as consistently negative (blue) slopes, with no UV-drop off at wavelengths larger of 0.4 microns. The NIR spectra show consistently blue slopes with minimal variation and no coherent trends. We detect a thermal emission longwards of 2.0 microns, and calculate visible albedos and beaming parameters using the Near-Earth Asteroid Thermal Model, retrieving an average albedo of pv = 0.068 +/- 0.009 and an average beaming parameter of n = 1.7 +/- 0.05. This albedo is lower than previously reported, but is within 1.1 standard deviations of the albedo expected using the albedo-diameter-absolute-relationship utilizing the recent radar estimate of the diameter of Phaethon (5.7 km, Taylor et al., 2018) and the lower of the two published absolute magnitudes (H 14.6, JPL Horizons). We also discuss the implications of our observations on the future mission to (3200) Phaethon, JAXA's DESTINY+. This work was funded by NASA NEOO Grant NNX17AJ19G (PI: Reddy).

Friday, October 26, 2018
01:30 PM-03:30 PM
Ballroom C (Knoxville Convention Center)

509 Centaurs/TNOs III: Dwarf Planets and Physical Characteristics
Chair(s): Csaba Kiss, Alex Parker

01:30 PM-01:40 PM
509.01 Dwarf Planets: Their Diameters, Albedos, Colors and Satellites Compared
Scott Sheppard[1], Yanga Fernandez[2], Arielle Moullet[3], Darin A. Ragozzine[4]
[1]Department of Terrestrial Magnetism, Carnegie Institution for Science, Washington, District of Columbia, United States, [2]University of Central Florida, Orlando, Florida, United States, [3]NRAO, Charlottesville, Virginia, United States, [4]Brigham Young University, Provo, Utah, United States

Abstract
The survey for objects beyond the Kuiper Belt edge of Sheppard, Trujillo and Tholen (2016) found the ninth intrinsically brightest known TNO, 2013 FY27. We determined the albedo, size, color and found a satellite for 2013 FY27. From our ALMA, Magellan and Hubble Space Telescope observations of 2013 FY27, we put this likely dwarf planet into the context of the other known dwarf planet sized Trans-Neptunian Objects. In particular, we find that 2013 FY27 might be the largest moderately red TNO known. None of the TNOs larger than about 800 km in diameter show moderately red surfaces but only ultra-red or neutral surfaces. TNOs smaller than 800 km show an abundance of moderately red surfaces. This suggests TNOs larger than about 800 km might have different surfaces than smaller TNOs. Moderately red colors might be an indication of very old or less ice rich surfaces. The TNOs larger than 800 km might have fresher surfaces through cryovolcanism, are able to hold onto more volatile ices, or they might be more fully differentiated giving different surface compositions. 2013 FY27 is interesting because its size is near the start of the transition region between the largest TNOs that have higher albedos, higher densities and extreme colors compared to the smaller TNOs.

01:40 PM-01:50 PM
509.02 The Mass, Density, and Figure of the Kuiper Belt Dwarf Planet Makemake
Alex Parker[1], Marc W. Buie[1], Will Grundy[2], Keith Noll[3], Leslie Young[1], Megan E. Schwamb[4], Csaba Kiss[5], Gábor Marton[5], Aniko I. Farkas-Takács[5]
[1]Southwest Research Institute, Boulder, Colorado, United States, [2]Lowell Observatory, Flagstaff, Arizona, United States, [3]NASA GSFC, Greenbelt, Maryland, United States, [4]Gemini Observatory, Hilo, Hawaii, United States, [5]Konkoly Observatory, Budapest, Hungary

Abstract
The recent discovery and subsequent orbital characterization of Makemake's satellite have provided a means to measure the mass of the dwarf planet for the first time. As Makemake is a fast rotator, it is expected to have a non-spherical equilibrium figure. If the orbital pole of the satellite is aligned with the spin pole of Makemake, then the spin pole is nearly orthogonal to the occultation chords presented in Ortiz et al. (2012). It is difficult to constrain the equatorial radius of a spheroid aligned in such a way; the resulting preferred volume and its uncertainty are larger than previous estimates. The preferred figure has a ratio of equatorial to polar diameters of ~1.13. Combining this new figure estimate and the mass measurement of ~3.1×10^{21} kg, we derive a relatively low density for Makemake of ~1.7 g/cc; adopting the

Brown (2013) volume estimate results in a higher density of ~2.1 g/cc. In this presentation, we will describe the existing and upcoming Hubble Space Telescope observations of the system that enable these mass and orbit plane measurements, derivation of the mass, figure, and density of Makemake, and the implications for the internal structure of Makemake. We will also describe possible upcoming opportunities to observe mutual events between Makemake and its satellite.

01:50 PM-02:00 PM

509.03 Breaking the degeneracy of Eris' pole orientation

Bryan J. Holler[1], William Grundy[2], Marc W. Buie[3], Keith Noll[4]
[1]STScI, Baltimore, Maryland, United States, [2]Lowell Observatory, Flagstaff, Arizona, United States, [3]SwRI, Boulder, Colorado, United States, [4]NASA/GSFC, Greenbelt, Maryland, United States

Abstract

The most massive trans-Neptunian object, (136199) Eris, has one known satellite, Dysnomia. By observing changes in Dysnomia's orbit projected on the sky over multiple different epochs, we were able to break the mirror degeneracy and determine the pole orientation of Eris. Images of the Eris/Dysnomia system were obtained with WFC3/HST in January and February 2018 (program 15171). These images were taken through the F606W filter and visits were scheduled to capture Dysnomia at different orbital phases. We also folded in data from ACS/HRC/HST and NIRC2/Keck programs from 2005/2006 (Brown and Schaller, 2007) and WFC3/HST program 13668 from 2015. The 2005/2006 data were considered "Epoch 1" and the 2015 and 2018 data were combined into "Epoch 2." PSF-fitting produced relative astrometry of Dysnomia with respect to Eris and was used to fit Keplerian orbits to each epoch. Comparison of the orbit fits from these different epochs enabled the determination of Eris' rotation pole orientation, assuming Dysnomia orbits in Eris' equatorial plane. We report that Eris' obliquity is 78°, the sub-solar latitude in early 2018 was 42°, and the next period of mutual events will occur in 2239, all in agreement with Orbit 1 from Brown and Schaller (2007). With this viewing geometry, approximately 30% of the visible hemisphere of Eris is in constant sunlight. Assuming a peak-to-valley amplitude of 0.10 mag (Roe et al., 2008) due entirely to albedo variations, the hemispheres representing the maximum and minimum in the light curve have a ~10% difference in albedo. Eris' high visible geometric albedo (0.96; Sicardy et al., 2011) and this small albedo difference together imply that Eris' surface lacks large-scale, low-albedo features like Cthulhu Macula on Pluto.

02:00 PM-02:10 PM

509.04 "Stay Active My Friend": 29P/S-W1, The Most Interesting Comet in the World

Gal Sarid[1], Maria Womack[2], Kacper Wierzchos[2]
[1]University of Central Florida, Florida Space Institute, Orlando, Florida, United States, [2]University of South Florida, Tampa, Florida, United States

Abstract

There is no other comet like 29P/Schwassmann-Wachmann 1. It has continuously exhibited a dust coma since its discovery almost a century ago and constantly outgasses in a near-circular orbit just beyond the orbit of Jupiter (~6 AU). Some studies showed that it probably only recently transferred to its current orbit from much further out, possibly the Kuiper Belt. It is straddling the transition region between the inner and outer solar system and may have intricate connections with Centaurs, Trojans, JFCs or even Hildas.

29P's orbital distance is beyond the region where water-ice sublimates efficiently; thus, another volatile must be the culprit. CO gas emission is routinely observed in the coma with production rates high enough

to drive the quiescent activity. It is a relatively large object (30 km) with a poorly constrained rotation period, and it outbursts several times per year. Some of the outbursts may be fueled by the amorphous-to-crystalline phase transition of water ice (100-125K), which is predicted to proceed at these equivalent blackbody temperatures. If this occurs, any trapped volatiles (e.g., CO) in the solid ice cage will be released. Thus, 29P may be one of the best examples of active small bodies fueled by this phase transition and quick super-volatile ice sublimation.
29P's unusual activity is also evident in having a semi-persistent jet-like feature in dust images and a twice-observed off-nucleus region of excess CO emission. 29P may release relatively large fragments which are responsible for its unique activity patterns. Fragments, rings and ring arcs have been reported around other Centaurs and may contribute significantly to active processes on the surface and in the coma.
We will discuss models for the CO-driven activity, due to water-ice phase transition, and its potential connection with a companion fragment that affects the activity in the sub-surface, surface and coma. We will also relate these considerations to the orbital history of 29P and the many issues related to its structure, composition, dynamics and activity. G.S., M.W. and K.W. acknowledge support from NSF AST-1615917.

02:10 PM-02:20 PM

509.05 Great Expectations: Anticipating Results from the First Encounter with a Cold Classical Kuiper Belt Object

Catherine Olkin[1], Jeffrey M. Moore[2], Alan Stern[1], Will Grundy[3], John Spencer[1], William B. McKinnon[4], Dale Cruikshank[2], G. R. Gladstone[1], Oliver L. White[2], Orkan Umurhan[2], Ross A. Beyer[2], Kelsi N. Singer[1], Paul M. Schenk[5], Harold A. Weaver[6]
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Abstract

On January 1, 2019, the New Horizons spacecraft will encounter 2014 MU69 (nicknamed Ultima Thule). Little is known about this object, but its orbit and color are consistent with the cold classical population. The flyby of New Horizons past 2014 MU69 will be the first close-up look at a cold classical Kuiper Belt object – a primordial object. Given theories of the dynamic and chaotic nature of solar system evolution, the cold classical population of the Kuiper belt has emerged as a singular candidate for a fundamentally unaltered original planetesimal population.
This flyby of 2014 MU69 is a unique opportunity to explore the disk processes and chemistry of the primordial solar nebula. As such, compositional measurements during the NH flyby are of paramount importance. So is high-resolution imaging of shape and structure, as the intermediate size of MU69 (much smaller than Pluto but much larger than a typical comet) may show signs of its accretion from much smaller bodies (layers, pebbles, lobes, etc., in the manner of 67P/C-G), or alternatively, derivation via the collisional fragmentation of a larger body if KBOs are "born big". MU69 may also be big enough to show signs of internal evolution driven by radiogenic heat from ^{26}Al decay, if it accreted early enough and fast enough. The size of MU69 (20 - 40 km) places it in a class that has the potential to harbor unusual, and in some cases, possibly active, surface geological processes: several small satellites of similar size, including Helene and Epimetheus, display what appears to be fine-grained material covering large portions of their surfaces, and the surface of Phobos displays an unusual system of parallel grooves. Invariably, these intriguing surface features are only clearly defined at imaging resolutions of at least tens of meters per pixel. The best images of MU69 are planned to have resolutions of 20 - 40 m/pixel at a phase angle range of 40 - 70°. We also plan color imaging at 200 - 500 m/pixel, and spectroscopy from 1.25 to 2.5 µm at 1 -

4 km/pixel. Additionally, we will search for satellites and rings around 2014 MU69, make disk averaged measurements of the object's brightness temperature, and search for coma using the Alice UV spectrometer.

02:20 PM-02:30 PM

509.06 Pre-encounter update on (486958) 2014MU69 and occultation results from 2017 and 2018

Marc Buie[1], Simon B. Porter[1], Anne Verbiscer[2], Rodrigo Leiva[1], Brian A. Keeney[1], Con Tsang[1], David Baratoux[3], Michael Skrutskie[2], François Colas[4], Josselin Desmars[4], S. Alan Stern[1]
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Abstract

Following success of three stellar occultations in 2017 involving the New Horizons extended mission target: (486958) 2014 MU69, we identified one more opportunity for a stellar occultation prior to encounter on 2019 Jan 1. This latest event was predicted for 2018 August 4, visible from northern South America and north-central Africa. The star was relatively bright at G=13.4, from Gaia DR2. The final prediction reached a 1σ crosstrack uncertainty of 13 km (0.4 mas). We will present results from the 2018 stellar occultation campaign involving 24 portable systems deployed by the New Horizons project. Additional contributions will be discussed, so far from Mexican and Colombian astronomers. These observations, when combined with HST astrometry are important for the navigation of New Horizons to its upcoming encounter. Furthermore, the albedo and shape are directly constrained thus providing essential input for optimizing the encounter sequence. One of the more critical things we would like to know is if the body is a single object or a close binary as is very common in the Cold Classical Kuiper Belt. The observations from 2017 will be reviewed for the constraints provided and a new occultation dataset is highly likely to either show two objects or essential rule out that option. This work and especially the latest occultation effort would not have been possible without the financial support of the New Horizons mission, NASA, CNES, imaging data from the Hubble Space Telescope, astrometric support from the Gaia mission, and logistical support from Senegal as well as assistance from the US Embassies in Dakar and Bogota.

02:30 PM-02:40 PM

509.07 New Horizons Distant Observations of Cold Classical KBOs

Simon B. Porter[1], Anne Verbiscer[2], Harold A. Weaver[4], John Spencer[1], Susan Benecchi[3], Alex Parker[1], Catherine B. Olkin[1], Joel Parker[1], S. Alan Stern[1]
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Abstract

NASA's New Horizons spacecraft will fly past the cold classical Kuiper Belt Object (KBO) 2014 MU69 "Ultima Thule" on January 1, 2019. Before and after that flyby, New Horizons is flying through the cold classical Kuiper Belt. This has enabled observations of numerous different cold classical KBOs in both 2017 and 2018. From Earth, cold classical KBOs can only be observed at solar phase angles up to 1.5 degrees, while the New Horizons observations are at phase angles up to and beyond 80 degrees. The New Horizons observations also enable satellite searches, and high-phase lightcurves that can be used to constrain shape. We will present the initial astrometry and photometry of the 2018 cold classical KBO

observations, place them in context with the 2017 cold classical observations, and show how they enable the analysis of the upcoming 2014 MU69 flyby observations.

02:40 PM-02:50 PM

509.08 Solar Phase Curves of Distant Kuiper Belt Objects Observed by New Horizons' LOng-Range Reconnaissance Imager (LORRI)

Anne Verbiscer[1], Simon Porter[3], Susan Benecchi[6], J. J. Kavelaars[5], Harold A. Weaver[2], John Spencer[3], Marc W. Buie[3], Bonnie J. Buratti[4], Catherine B. Olkin[3], Joel Parker[3], S. Alan Stern[3], Leslie A. Young[3], Andrew Cheng[2]

[1]University of Virginia, Charlottesville, Virginia, United States, [2]JHUAPL, Laurel, Maryland, United States, [3]SWRI, Boulder, Colorado, United States, [4]JPL, Pasadena, California, United States, [5]National Research Council of Canada, Victoria, British Columbia, Canada, [6]PSI, Tucson, Arizona, United States

Abstract

NASA's *New Horizons* spacecraft has observed Kuiper Belt objects (KBOs) at distances ranging from 0.1 to 70 AU and at solar phase angles far larger than those attainable from Earth. While the size of Earth's orbit limits Earth-based KBO observations to phase angles less than 2°, *New Horizons'* LOng-Range Reconnaissance Imager (LORRI) can observe distant KBOs (DKBOs) at nearly the full range of solar phase angles. By combining low-phase, Earth-based DKBO observations from sources including the Hubble Space Telescope, Subaru, and the Canada France Hawaii Telescope with data obtained at higher phase angles by *New Horizons'* LORRI, we have constructed the first DKBO solar phase curves with substantial phase angle coverage using multiple observations at phase angles ranging from 0.06° to 90°. DKBO targets successfully observed to date include dwarf planets Haumea, Makemake, Quaoar, and 2002 MS_4; cold classical KBOs 2011 HJ_{103}, 2012 HE_{85}, and 2012 HZ_{84}; and Plutino (15810) Arawn (1994 JR_1) (Porter et al. 2016, *Astrophys. J. Lett.* 828, L15). We compare the phase functions of these DKBOs with those of objects in the Pluto system and other Solar System bodies such as comets, asteroids, and icy satellites. Reflectance measurements at moderate phase angles (e.g. 30° - 90°) constrain surface characteristics such as the mean topographic slope, or roughness, while those at extreme phase angles (large and small) constrain directional scattering behavior and allow us to determine whether particles on these DKBO surfaces scatter reflected light preferentially in the forward or backward direction. For DKBOs with known geometric albedos, these measurements enable calculation of the phase integral, a photometric property that characterizes the energy balance on a DKBO surface. We find that DKBO phase integrals differ from those of other Solar System objects with similar geometric albedos. During its approach to 2014 MU_{69}, and following its close encounter on 1 January 2019, *New Horizons* will continue to exploit its capabilities as NASA's only observatory within the Kuiper Belt by acquiring many more DKBO observations at higher phase angles than those attainable from Earth.

02:50 PM-03:05 PM

509.09D Physical properties of trans-Neptunian objects and centaurs

Estela Fernández-Valenzuela[1], Jose Luis Ortiz[2], René Duffard[2], Pablo Santos-Sanz[2]

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Abstract

A systematic photometric study of four small icy bodies was performed. This work has been published in four recent peer-reviewed papers, two of them led by Dr. Fernandez-Valenzuela.

The first study focused on the TNO 2008 OG19. The light-curve of this object, with a large amplitude of

0.43 mag, is rather unusual for an object of its size (~ 600 km). There are less than 10 out of 150 TNOs for which rotational light-curves are available that show comparable characteristics. Our photometric analysis enabled the determination of the rotational period, shape and density (assuming hydrostatic equilibrium) of 2008 OG19. These are important results, in particular because the determination of densities of objects of the Solar system is generally quite challenging.
The second and third studies are based on the centaurs Chariklo and Chiron, respectively, and specifically, the discovery of ring systems around them. The variation of the magnitude and amplitude of the light-curve of these bodies as they move around the Sun was modeled, including the effect of the ring systems. The novelty of our approach consisted of accounting for changes of the viewing angle of both the object and the ring systems. From the models, size of the semi-axes of the central body and its pole orientation were obtained. Additionally, the density was also obtained under the assumption of hydrostatic equilibrium.
Finally, the last study was devoted to the analysis of Bienor. New observational data for the light-curve amplitude and absolute magnitude were obtained and fitted together with data obtained from the literature. Several scenarios, including the existence of a ring system, were proposed in order to explain the variation of the photometric results for the absolute magnitude and light curve amplitude, in a simultaneous fit of the data. The scenarios provide the pole orientation, the axes ratio and the density of the body in a well constrained range.
In summary, we demonstrate how photometric data from small bodies can be used to extract information about their rotational state, density, and the presence of rings. This methodology is of special interest to support exploration missions to small icy bodies.

03:05 PM-03:15 PM
509.10 Status and results from the Research and Education Collaborative Occultation Network (RECON)
Rodrigo Leiva[1], Marc W. Buie[1], John Keller[2]
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Abstract
Characterization for Trans-Neptunian objects is key for the understanding of the Solar System formation and its early evolution.
The cold-classical population, with highly circular, low-inclination orbits beyond the 2:3 mean-motion resonance with Neptune were likely formed in situ and have been less perturbed with respect to other TNO populations.
Stellar occultations by these TNOs are a powerfull technique to provide us with sizes and albedos, and to put constraints in formation mechanisms of the binary population.
The Research and Education Collaborative Occultation Network (RECON) is a citizen science research project involving over 50 high schools across the western United States forming a coordinated network of telescopes.
RECON is designed to measure stellar occultations by TNOs down to diameters of 100 km and detect down to contact binaries.
We will present the current status of the project, astrometry performed to keep the TNO orbit below the desired uncertainties, the level of participation of our observer network , and recent results from stellar occultation by 50000 Quaoar and Pluto.
Finally, we will present the plans for RECON next stage.

03:15 PM-03:30 PM

509.11D Uncovering Signatures of Refractory Materials on KBOs and Centaurs by Reflectance Spectroscopy

Tom Seccull[1], Wes Fraser[1], Thomas Puzia[5], Michael E. Brown[6], Alan Fitzsimmons[1], Méabh Hyland[1], Matthew Izawa[7, 8]

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Abstract

In reflectance spectra of minor planets such as Kuiper Belt Objects (KBOs) and centaurs, absorption features related to components of their surface composition reveal details of their likely formation environment and their subsequent dynamical and thermal evolution. Their NIR reflectance spectra often exhibit water ice absorption features and for some objects methanol ice has also been observed. Their optical spectra, however, have mostly consisted of only a red featureless slope. The presence of suspected absorption features in this range that might be associated with silicate and organic materials, while reported in the spectra of some KBOs, have so far eluded confirmation. We report three new results that have arisen from a study into the surface compositions of KBOs and centaurs through optical reflectance spectroscopy. First, we report the discovery that the plutino 2004 EW95 exhibits optical reflectance properties that are very similar to those of a hydrated carbonaceous asteroid, bearing features associated with ferric oxides and phyllosilicates. These surface properties indicate that this object has been heated at some point during its history, potentially pointing to its origins in the early Solar System's giant planet region. Second, we report spectroscopic comparisons of the surface of active centaur 174P/Echeclus before and after its 2016 cometary outburst along with the observation of its unusually blue dust coma. Third, we report preliminary results on the spectrum of an extreme centaur which exhibits a curious drop in reflectance towards the near-UV. This spectrally confirmed feature is similar to that observed in laboratory reflectance spectra of complex aromatic hydrocarbons. These results constitute the first spectroscopically confirmed features observed at visual wavelengths in KBO and centaur spectra, and are the first attributable to refractory materials.

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