228th AAS

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Meeting Abstracts

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100 – Welcome Address by AAS President Meg Urry

101 – Kavli Foundation Lecture: Observation of Gravitational Waves, Gabriela Gonzalez (LIGO)

101.01 – Observation of Gravitational Waves

On September 14 2015, the two LIGO gravitational wave detectors in Hanford, Washington and Livingston, Louisiana registered a nearly simultaneous signal with time-frequency properties consistent with gravitational-wave emission by the merger of two massive compact objects. Further analysis of the signals by the LIGO Scientific Collaboration and Virgo Collaboration revealed that the gravitational waves detected by LIGO came from the merger of a binary black hole (BBH) system approximately 420 Mpc distant (z=0.09) with constituent masses of 36 and 29 M_sun.
I will describe the details of the observation, the status of ground-based interferometric detectors, and prospects for future observations in the new era of gravitational wave astronomy.

Author(s): Gabriela Gonzalez[1]
Institution(s): *1. Louisiana State University*

102 – The NASA K2 Mission

This Special Session will highlight science from the K2 mission during its first two years of operation. A short "Town Hall" presentation by the project will be followed by science talks featuring community members and used to highlight the many types and breadth of K2 science. Additionally, planning for the K2 mission over the next two years of operation including soliciting community input will be discussed as well.

102.01 – The NASA K2 Mission: Exploring Planets, Stars, and Beyond

The NASA Kepler mission launched in 2009 and observed a single region of the Galaxy for four years. During its lifetime, Kepler discovered thousands of transiting extrasolar planets and also revolutionized the field of stellar astrophysics thanks to its ability to produce extremely high precision measurements of the brightness of stars. After a second reaction wheel failed on the Kepler spacecraft in 2013, the NASA K2 mission was born. K2 has been observing a variety of astrophysical targets in different fields along the ecliptic in ~80 day campaigns since early 2014. While K2 has no single mission goal, the science produced from the K2 mission relates to time variable observations of Solar System objects, extrasolar planets, star clusters, supernovae, and more. With about two years of scientific observations completed, K2 has already extended the legacy of the Kepler mission by making a number of its own exciting discoveries. In the field of exoplanets, K2 has discovered Earth-size planets orbiting in the habitable zone of nearby cool M dwarf stars, in addition to other small planets around bright stars that are amenable to detailed atmospheric characterization with NASA's James Webb Space Telescope (JWST). K2 has also revealed different classes of variability in young stars and is providing insight into the progenitors of Type Ia supernovae. Closer to home, K2 is observing planets and asteroids in our own solar system, providing light curves that are unrivaled in their precision and time-baseline. Finally, K2 is conducting a gravitational microlensing experiment by observing stars located in the Galactic bulge, which is a critical testbed for the microlensing survey to be performed with NASA's Wide-Field Infrared Survey Telescope (WFIRST). With approximately two more years of observations expected from K2, many more exciting discoveries are anticipated. In this presentation, I will provide an overview of the K2 mission, review the current state of operations, and discuss anticipated results from the next two years of the mission.

Author(s): Knicole D. Colón[1], Thomas Barclay[1], Geert Barentsen[1], Steve B. Howell[1]
Institution(s): *1. NASA Ames Research Center*

102.02 – K2 Extra-Galactic and Supernova Studies and C17

I will give an overview of the Kepler Extra-Galactic survey - a program using Kepler to search for supernovae, active galactic nuclei, and other transients in galaxies. To date we have found 17 supernova, and with 3 more years (through 2018) planned, including the forward-facing C17, we hope to discover 20 - 30 more SN. The 30-minute cadence of Kepler has reveales subtle features in the light-curves of these supernova not detectable with any other survey, including, shock break-out in a large number of SN, improving our understanding of supernova progenitors. We can also search in nearby galaxies for very fast and faint transients, filling in a previously unaccessible parameter space. Lastly, the precision data of any discovered type Ia supernova combined with ground based data can dramatically improve our use of type Ia for determining distances and measuring the properties of dark energy.

Author(s): Bradley E. Tucker[1], Peter M. Garnavich5, Armin Rest[2], Edward J. Shaya4, Daniel Kasen3
Institution(s): *1. Australian National University, 2. STScI, 3. UC Berkeley, 4. University of Maryland, 5. University of Notre Dame*
Contributing team(s): The Kepler Extra-Galactic Survey

102.03 – K2 Microlensing and Campaign 9

Campaign 9 of K2 will observe a contiguous 3.7 deg^2 region of the Galactic bulge in order to search for microlensing events and measure microlens parallaxes. It will also perform targeted follow-up of approximately 50 microlensing events spread throughout the Kepler focal plane. Parallax measurements are a critical ingredient for measurements of both the lens mass and distance, which contribute to our understanding of the formation of cold exoplanets, and the formation of planets as a function of Galactic environment. Additionally, as the first un-targeted, space-based microlensing survey, K2C9 offers us the first chance to measure the masses and kinematics of a large population of free-floating planet candidates, whose large abundance has been a puzzle since their discovery.

I will review the scientific goals of the K2C9 survey, which will be well underway, and report on the ongoing activity of the K2 Campaign 9 Microlensing Science Team and the wider microlensing community, with a focus on the progress that has been made towards analyzing K2 data in crowded fields.

Author(s): Matthew Penny[1]
Institution(s): *1. Ohio State University*

102.04 – DAVE: Discovery and Vetting of K2 Exoplanets

NASA's K2 mission is capable of finding planets as small as the Earth around bright, nearby stars. These targets are well-suited for JWST follow-up to study their density and atmospheric composition. Such observations will yield a better understanding of the difference between rocky and gaseous planets, particularly how composition varies as a function of radius. K2 observes over 10,000 stars every 90 days, which coupled with significant systematics due to spacecraft pointing jitter, presents a challenge in rapidly detecting high-quality planet candidates. In this talk, we present results from our Discovery and Vetting of K2 Exoplanets (DAVE) team. DAVE focuses on applying robotic vetting techniques, formulated as part of the prime Kepler mission, to possible K2 planets detected by both DAVE and other teams. We highlight these robotic vetting techniques and the types of false positives they eliminate, and present examples of well-vetted candidates. We make the DAVE pipeline, including the vetting tools, publicly available at http://github.com/barentsen /dave. This work is funded by a K2 Guest Observer Cycle 2 grant.

Author(s): Jeffrey Coughlin[2], Fergal Mullally[2], Susan Mullally[2], Knicole D. Colón[1], Geert Barentsen[1], Elisa V. Quintana[1], Christopher J. Burke[2], Thomas Barclay[1]
Institution(s): *1. NASA Ames, 2. SETI Institute*

102.05 – Spitzer to the Rescue! Improved Ephemerides Preserve K2 Planets for Future Studies With JWST

The NASA K2 mission has detected hundreds of planet candidates, including dozens of tantalizing targets for future atmospheric characterization with the James Webb Space Telescope. However, the future transit windows for the longest period planet candidates are poorly constrained because these planets transit only a few times during a 70-80 day K2 observing campaign. We are reducing the uncertainties in the transit times of these planets by conducting follow-up transit observations with the InfraRed Array Camera (IRAC) on the Spitzer Space Telescope. In addition to reducing the typical timing uncertainty by a factor of five, our Spitzer/IRAC observations allow us to place coarse limits on possible color-dependent differences in transit depth. I will discuss our target selection process and present the results of our ongoing 450-hr Spitzer program. We have already observed 26 transit opportunities of 21 planets and we have an additional three stars scheduled for observation this spring.

This work is based in part 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. Support for this work was provided by NASA through an award issued by JPL/Caltech.

Author(s): Courtney D. Dressing[1], Michael W. Werner[2], Charles A. Beichman4, Björn Benneke[1], Jessie Christiansen4, Ian Crossfield3, Varoujan Gorjian[2], Heather Knutson[1], Jessica Krick5, John H Livingston[2], Erik Petigura[1]
Institution(s): *1. California Institute of Technology, 2. JPL, 3. Lunar & Planetary Laboratory, University of Arizona, 4. NASA Exoplanet Science Institute, California Institute of Technology, 5. Spitzer Science Center, California Institute of Technology*
Contributing team(s): Spitzer/K2 Study Team

102.06 – Stellar Astrophysics with the K2 Mission

After two years of operation, NASA's K2 spacecraft has established itself as not simply a repurposed Kepler, but as a uniquely capable mission in its own right. While each field of view is observed for only ~80 days, in contrast to the 4+ years achieved by Kepler, the varied locations of the pointings along the ecliptic have made possible a wide range of new astrophysical applications. In this talk, I will discuss recent K2 results in the area of stellar astrophysics, focusing on studies of stellar activity and asteroseismology. I will also present an overview of the different data reduction pipelines available for working with K2 data.

Author(s): Derek L. Buzasi[1]
Institution(s): *1. Florida Gulf Coast University*

102.07 – K2 Survey of Ultracool Dwarfs

We report on our ongoing survey using the Kepler/K2 telescope to monitor ultracool (late-M and L) dwarfs. The survey has three goals: To detect variability due to rotation, clouds and weather, to detect white light flares from magnetic reconnection events, and to detect transits from planetary companions. We discuss the challenges of observing faint, red source with a telescope originally designed for photometry of bright, solar-type stars. We discuss case studies from our initial sample, including evidence that a nearby (7.2 pc) brown dwarf is viewed pole-on, and the measurement of the white light flare rate from a 23-million-year 61-jupiter-mass.

Author(s): John Gizis3, Rishi Paudel3, Adam J. Burgasser4, Peter K. G. Williams[1], Sarah J. Schmidt[2]
Institution(s): *1. Harvard, 2. Leibniz-Institut fur Astrophysik Potsdam (AIP), 3. Univ. Of Delaware, 4. University of California at San Diego*

102.08 – Discovery and Characterization of Eclipsing Binary Stars and Transiting Planets in Young Benchmark Clusters: The Pleiades and Hyades

Prior to K2, only one eclipsing binary in the Pleiades was known (HD 23642). We present the discovery and characterization of three additional eclipsing binaries (EBs) in this ~120 Myr old benchmark open cluster. Unlike HD 23642, all three of the new EBs are low mass ($M_{tot} < 1\ M_{\odot}$) and thus their components are still undergoing pre-main-sequence contraction at the Pleiades age. Low mass EBs are rare, especially in the pre-main-sequence phase, and thus these systems are valuable for constraining theoretical stellar evolution models. One of the three new EBs is single-lined with a K-type primary (HII 2407). The second (HCG 76) comprises two nearly equal-mass 0.3 $M_{\odot}$ stars, with masses and radii measured with precisions of better than 3% and 5%, respectively. The third (MHO 9) has an M-type primary with a secondary that is possibly quite close to the hydrogen-burning limit, but needs additional follow-up observations to better constrain its parameters. We use the precise parameters of HCG 76 to test the predictions of stellar evolution models, and to derive an independent distance to the Pleiades of 132±5 pc. Finally, we present tentative evidence for differential rotation in the primary component of the newly discovered Pleiades EB HII 2407, and we also characterize a newly discovered transiting Neptune-sized planet orbiting an M-dwarf in the Hyades.

Author(s): Keivan Stassun3, Trevor J. David[1], Kyle E. Conroy3, Lynne Hillenbrand[1], John R. Stauffer[1], Joshua Pepper[2], Luisa M. Rebull[1], Ann Marie Cody[1]
Institution(s): *1. California Institute of Technology, 2. Lehigh University, 3. Vanderbilt University*

102.09 – That's How We Roll – The NASA K2 Mission Science Planning, Products, and Performance Metrics

NASA's exoplanet Discovery mission *Kepler* was reconstituted as the *K2* mission a year after the failure of the 2nd of *Kepler*'s 4 reaction wheels in May 2013. The new spacecraft pointing method now gives typical roll motion of 1.0 pixels peak-to-peak over 6 hours at the edges of the field, two orders of magnitude greater than for *Kepler*. Despite these roll errors, the flight system and its modified data processing pipeline restores much of the photometric precision of the primary mission while viewing a wide variety of targets, thus turning adversity into diversity. We define metrics for data compression and pixel budget available in each campaign; the photometric noise on exoplanet transit and stellar activity time scales; residual correlations in corrected long cadence light curves; and the protection of test sinusoidal signals from overfitting in the systematic error removal process. We find that data compression and noise both increase linearly with radial distance from the center of the field of view, while the data compression also increases as the square root of star count. For sufficiently dense star fields, such as the Galactic Center, the data entropy so high that Huffman compression is ineffective and only requantization is used. At the FOV center, where roll motion is nearly negligible, the limiting 6 hour photometric precision for a quiet 12th magnitude star can be as low as 30 ppm, only 25% higher than that of *Kepler*. This noise performance is achieved without sacrificing signal fidelity; test sinusoids injected into the data are attenuated by less than 10% for signals with periods up 15 days. At time scales relevant to asteroseismology, light curves derived from *K2* archive calibrated pixels have high-frequency noise amplitude within 40% of that achieved by *Kepler*. These improvements follow from the data analysis efforts of *Kepler* Science Operation Center and *Kepler* Science Office, and from the operational improvements developed by Ball Aerospace and LASP, during the first 1.5 yr of *K2*. Our results through December 2015 are shown in detail in http://arxiv.org /abs/1512.06162; in this talk, we will emphasize what we have learned in the last 6 month.

Author(s): Jeffrey E. Van Cleve3, Steve B. Howell[2], Jeffrey C. Smith3, Bruce Clarke3, Susan E. Thompson3, Steve Bryson[2], Mikkel N. Lund4, Rasmus Handberg[1], William J Chaplin4
Institution(s): *1. Aarhus University, 2. NASA Ames, 3. SETI Institute, 4. University of Birmingham*
Contributing team(s): Kepler Science Office, Kepler Science Operations Center, Ball Aerospace, U. Colorado LASP

103 – Galaxies Big and Small

103.01 – Surveying for Dwarf Galaxies Within Void FN8

The dwarf galaxy population in low density volumes, or voids, is a test of galaxy formation models and how they treat dark matter; some models say dwarf galaxies cannot be in void centers while others say they can. Since it appears many dwarf galaxies are H-alpha emitters, a well-designed deep survey through a nearby void center will either find nothing, and thus constrain the population there to be at some percentage below the mean, or it will find H-alpha emitters and significantly challenge several otherwise successful theories. Either result is a significant step in better understanding galaxy formation and large-scale structure. In 2013, a redshifted H-alpha imaging survey was begun for dwarf galaxies with $-14.0 \leq M_r \leq -12.0$ in the heart and back of the void FN8. Our first results have been surprising, furnishing significantly more candidate objects than anticipated. Through the Gemini Fast Turnaround Program, seven spectrum have been obtained, with one spectrum being a strong candidate for habitation within the center of the void.

Author(s): Stephen R. McNeil[1]
Institution(s): *1. Brigham Young University - Idaho*

103.02 – Dark Times for the Fluffiest Galaxies

Ultra-diffuse galaxies (UDGs) were recently recognized as an abundant class of low-surface brightness galaxies with unusually large sizes -- found both in galaxy clusters and in the field. The nature and origins of these galaxies are unclear, with one intriguing possibility that some of them are "failed Milky Ways" with massive halos but a paucity of stars. I will present observations of stars and globular clusters in UDGs that constrain their stellar populations and masses -- including evidence for being ultra-rich in dark matter. I will also show results from simulations of UDG formation through ram-pressure stripping of gas-rich disk galaxies.

Author(s): Aaron J. Romanowsky[3], Michael A. Beasley[2], Andreas Burkert[4], Roberto G Abraham[7], Jean P. Brodie[5], Aaron Deich[3], Ignacio Martin-navarro[5], David Martinez-Delgado[9], Vincenzo Pota[1], Nicole Rider[5], Michael Sandoval[6], Vakini Santhanakrishnan[3], Maria Stone[3], Pieter G. Van Dokkum[8]
Institution(s): *1. INAF—Osservatorio Astronomico di Capodimonte, 2. Instituto de Astrofisica de Canarias, 3. San Jose State University, 4. University Observatory Munich, 5. University of California Observatories, 6. University of Tennessee, 7. University of Toronto, 8. Yale University, 9. Zentrum fur Astronomie der Universitat Heidelberg*

103.03D – Using Cosmic Telescopes to Study Dusty, Star-Forming Galaxies

Dusty, star-forming galaxies (DSFGs), characterized by their far-infrared (far-IR) emission, undergo the largest starbursts in the Universe, contributing to the majority of the cosmic star formation rate density at z = 1 – 4. These starbursts have important implications for galaxy evolution and feedback as these galaxies build up much of their stellar mass during this time and may experience strong stellar driven winds. For the first time the Herschel Space Observatory was able observe the full far-IR dust emission for a large population of high-redshift DSFGs. However, Herschel reaches the confusion limit quickly and only the brightest galaxies at redshifts z > 2 can be detected. With gravitational lensing, we are able to surpass the Herschel confusion limit and probe intrinsically less luminous and therefore more normal star-forming galaxies. With this goal in mind, we have conducted a large Herschel survey, the Herschel Lensing Survey, of the cores of almost 600 massive galaxy clusters, where the effects of gravitational lensing are the strongest. In this presentation I will discuss how using one of largest gravitational lenses enables the detailed study of star forming regions at high redshift by investigating a giant (D ~ 1 kpc) luminous star forming region in aDSFG at z=0.6. Next, I will discuss how using one of the brightest sources from our sample allows us to investigate the molecular gas and dust properties of a typical DSFG with a CO outflow at z~2. Finally, I will discuss ongoing work using the brightest DSFGs in our sample to detect rest-frame optical nebular emission lines, using near-infrared spectroscopy with Keck/MOSFIRE, LBT/LUCI, and Magellan/MMIRS, which reveal conditions of their ISM; specifically ionization, star formation, metallicity, AGN activity, and dust attenuation.

Author(s): Gregory Walth[1], Eiichi Egami[6], Benjamin Clément[3], Wiphu Rujopakarn[2], Tim Rawle[4], Marie Rex[6], Johan Richard[3], Miroslava Dessauges[5], Pablo Perez-Gonzalez[7], Daniel Stark[6]
Institution(s): *1. CASS, UC San Diego, 2. Chulalongkorn University, 3. CRAL, Observatoire de Lyon, 4. ESA/STScI, 5. Observatoire de Genève, 6. Steward Observatory, University of Arizona, 7. Universidad Complutense de Madrid*
Contributing team(s): Herschel Lensing Survey

103.04 – Ionized gas pressure correlates with star formation intensity in nearby starbursts

We estimate the electron density of the ionized gas and thus the thermal pressure in HII regions; and compare that to the SFR (star formation rate) surface density for a combined sample of about 40 green peas and Lyman Break Analogs at z < 0.30. The electron density of the ionized gas is measured from sulfur line ratio ([SII] 6716 / 6731). We find that the SFR surface density is correlated with the electron density and the thermal pressure in HII regions for the star-forming galaxies with SFR surface density above a certain threshold. This work shows quantitatively the correlation between SFR surface density and electron density and that between SFR surface density and the thermal pressure in HII regions for the nearby starburst galaxies. This is consistent with theoretical models of disks (e.g. Kim et al. (2011) if we assume that the thermal pressure in HII regions is comparable to the total diffuse gas pressure at the midplane of the diffuse neutral gas. It is also in agreement with the results from star-forming galaxies at z ~ 2.5. We might infer that the starburst galaxies at low-redshift (z < 0.3) share similar physical properties to the galaxies at high redshift (z ~ 2.5).

Author(s): Tianxing Jiang[1], Sangeeta Malhotra[1], Huan Yang[1]
Institution(s): *1. Arizona State University*

103.05 – Measurement of the Black Hole Mass in NGC 1332 with ALMA CO Observations

ALMA has a powerful capability to resolve gas kinematics within the gravitational radius of influence of supermassive black holes in galaxy nuclei. We are carrying out a program to obtain ALMA CO(2-1) observations of early-type galaxies hosting circumnuclear dust disks in order to measure black hole masses. Our program is based on a two-stage observing plan: we first obtain 0.3″ resolution observations to search for evidence of rapidly rotating gas within the black hole's sphere of influence, and when it is found, we then propose higher-resolution observations to map the gas kinematics in detail in order to obtain accurate black hole mass measurements. We will present Cycle 2 observations of NGC 1332 at 0.3″ resolution and new Cycle 3 observations at 0.044″ resolution. The Cycle 2 observation demonstrates that CO emission is co-spatial with the circumnuclear dust disk, exhibiting a central upturn in rotation speed reaching 500 km/s relative to the systemic velocity. Rotational broadening and beam smearing produce complex and asymmetric line profiles near the disk center. Dynamical model fits to the 0.3″ resolution data are unable to provide tight constraints on the black hole mass, but point to a central mass likely to be in the range $(4\text{-}8)\times10^8\ M_\odot$. The 0.044″-resolution Cycle 3 observations allow us to derive firmer constraints on the central mass, and we will present new model fitting results and the black hole mass measured from the Cycle 3 data.

Author(s): Aaron J. Barth[4], Benjamin Boizelle[4], Jeremiah K. Darling[5], Andrew J. Baker[2], David A. Buote[4], Luis C. Ho[1], Jonelle Walsh[3]
Institution(s): *1. KIAA, 2. Rutgers, 3. Texas A&M, 4. UC Irvine, 5. University of Colorado*

103.06 – Supermassive Black Holes, AGN Feedback, and Hot X-ray Coronae in Early Type Galaxies

We present the analysis of a sample of more than 200 nearby, early type galaxies observed with the Chandra X-ray Observatory. We exclude resolved point sources, and model the emission from both unresolved X-ray binaries and CVs and ABs to derive the residual thermal emission from the hot atmosphere around each galaxy. We compute the X-ray luminosity of the central supermassive black hole (SMBH). Using galaxy velocity dispersion (or stellar mass) as a proxy for SMBH mass, we derive the Eddington ratios for these low luminosity AGN. We present the X-ray luminosity and gas temperature of the hot coronae as a function of stellar mass (a proxy for dark matter halo mass) and central velocity dispersion to look for anomalously X-ray bright gaseous coronae and to determine the stellar (or halo) mass, below which galactic winds may be important. For hot coronae with X-ray cavities, we derive the "mechanical" power of SMBHs and compare these to their radiative luminosities.

Author(s): William R. Forman3, Michael E. Anderson[2], Eugene Churazov[2], Paul Nulsen[1], Christine Jones[1], Ralph P. Kraft[1]
Institution(s): *1. CfA, 2. MPA, 3. SAO*

103.07 – An Analytic Mathematical Model to Explain the Spiral Structure and Rotation Curve of NGC 3198

An analytical model of galactic morphology is presented. This model presents resolutions to two inter-related parameters of spiral galaxies: one being the flat velocity rotation profile and the other being the spiral morphology of such galaxies. This model is a mathematical transformation dictated by the general theory of relativity applied to rotating polar coordinate systems that conserve the metric. The model shows that the flat velocity rotation profile and spiral shape of certain galaxies are both products of the general theory. Validation of the model is presented by application to 878 rotation curves provided by Salucci, and by comparing the results of a derived distance modulus to those using Cepheid variables, water masers and Tully-Fisher calculations. The model suggests means of determining galactic linear density, mass and angular momentum. We also show that the morphology of NGC 3198 is congruent to the geodesic as observed within a rotating reference frame and that galaxies are gravitationally viscous and self bound.

Author(s): Bruce Rout[1], Cameron Rout[2]
Institution(s): *1. SFU, 2. Yale*

104 – Bridging Laboratory & Astrophysics: Dust & Ices in the mm and X-rays

Laboratory astrophysics is the Rosetta Stone that enables astronomers to understand and interpret the cosmos. This session will focus on the interplay between astrophysics with theoretical and experimental studies into the underlying dust and ice processes, which drive our Universe, focusing on connections to ALMA or Astro-H observations.

104.01 – IR Laboratory Astrophysics at Forty: Some Highlights and a Look to the Future

Space was thought to be chemically barren until about forty years ago. Astrochemistry was in its infancy, the composition of interstellar dust was largely guessed at, the presence of mixed molecular ices in dense molecular clouds was not taken seriously, and the notion of large, gas phase, carbon-rich molecules (PAHs) abundant and widespread throughout the interstellar medium (ISM) was inconceivable. The rapid development of infrared astronomy between 1970 and 1985, especially observations made by the Kuiper Airborne Observatory (KAO) and the Infrared Astronomical Satellite IRAS), which made it possible to measure mid-infrared spectra between 2.5 to 14 μm, changed all that. Since then observations made from ground-based, airborne and orbiting IR telescopes, together with radio and submm observations, have revealed that we live in a Universe that is not a hydrogen-dominated, physicist's paradise, but in a molecular Universe with complex molecules directly interwoven into its fabric. Today we recognize that molecules are an abundant and important component of astronomical objects at all stages of their evolution and that they play important roles in many processes that contribute to the structure and evolution of galaxies. Furthermore, many of these organic molecules are thought to be delivered to habitable planets such as Earth, and their composition may be related to the origin of life.

Laboratory astrophysics has been key to making this great progress; progress which has only been made possible thanks to the close collaboration of laboratory experimentalists with astronomers and theoreticians. These collaborations are essential to meet the growing interdisciplinary challenges posed by astrophysics.

This talk will touch on some of the milestones that have been reached in IR astrospectroscopy over the past four decades, focusing on the experimental work that revealed the widespread presence of interstellar PAHs and the composition of interstellar/precometary ices, and concluding with a personal view of important, key objectives in each area

Author(s): Louis John Allamandola[1]
Institution(s): *1. NASA Ames Research Center*

104.02 – Interstellar dust grain composition from high-resolution X-ray absorption edge structure

X-ray light is sufficient to excite electrons from n=1 (K-shell) and n=2 (L-shell) energy levels of neutral interstellar metals, causing a sharp increase in the absorption cross-section. Near the ionization energy, the shape of the photoelectric absorption edge depends strongly on whether the atom is isolated or bound in molecules or minerals (dust). With high resolution X-ray spectroscopy, we can directly measure the state of metals and the mineral composition of dust in the interstellar medium. In addition, the scattering contribution to the X-ray extinction cross-section can be used to gauge grain size, shape, and filling factor. In order to fully take advantage of major advances in high resolution X-ray spectroscopy, lab measurements of X-ray absorption fine structure (XAFS) from suspected interstellar minerals are required. Optical constants derived from the absorption measurements can be used with Mie scattering or anomalous diffraction theory in order to model the full extinction cross-sections from the interstellar medium. Much like quasar spectra are used to probe other intergalactic gas, absorption spectroscopy of Galactic X-ray binaries and bright stars will yield key insights to the mineralogy and evolution of dust grains in the Milky Way.

Author(s): Lia Corrales[1]
Institution(s): *1. MIT Kavli Institute*

104.03 – Terahertz Desorption Emission Spectroscopy (THz DES) – 'ALMA in the Lab'

ALMA is revolutionising our scope to identify and locate molecules that have been desorbed from ices, particularly complex organic molecules (COMS), which provide a vital link between interstellar and prebiotic chemistry. Explaining the existence of these molecules in star-forming regions relies on an empirical understanding of the chemistry that underpins their formation:

- do COMS form predominantly in the solid-phase and then desorb to the gas phase, or do only "smaller" species, radials or ions desorb and then undergo gas-phase chemical reactions to generate larger COMS?

-are the rotational state populations in COMS only attributable to equilibrium chemistry, or could their formation mechanisms and desorption processes affect the rotational state occupancy of these molecules, thereby directly tying certain species to solid-state origins?

We have developed a novel laboratory method - THz Desorption Emission Spectroscopy (THz-DES) that combines "traditional" laboratory astrophysics high-vacuum ice experiments with a sensitive high-spectral-resolution terahertz total-power heterodyne radiometer [1,2], partially mirroring the spectral range of ALMA band 7 (275– 373 GHz). Ices are grown in situ on a cold-plate, situated in a vacuum cell, then (thermally) desorbed. The sub-mm emission spectra of the resultant gas-phase molecules are detected as a function of time, temperature, or distance from the surface. Our first THz DES results will be shown for pure and binary ice systems including H_2O, N_2O and CH_3OH. They show good correlation with established methods e.g. TPD, with the advantage of exploiting the molecular spectroscopy to unravel surface dynamics, state-occupancy, and unequivocal molecular identification, as well as concurrently measuring desorption barriers and molecular yields. We will extend our technique to a broader frequency range, enabling us to detect radical and ion desorption, to differentiate between A and E populations of CH_3OH or ortho-para populations of e.g. H_2O, and discriminate between COMS formed at a surface and those resulting from gas-phase chemistry above the ice.

[1] B. Thomas, et al ; IEE Microwave & Wireless Comp Lett, (2009), 19, 101
[2] http://www.star-dundee.com

Author(s): Olivier Bruno Jacques Emile Auriacombe[1], Helen Fraser[1], Brian Ellison[2], Sergio Ioppolo[1], Simon Rea[2]
Institution(s): *1. Open University, 2. Rutherford Appleton Laboratory*

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105 – College Astronomy Education: Research, Resources, and Getting Involved

105.01 – Analyzing Tibetan Monastics Conception of Universe Through Their Drawings

Every culture and tradition has their own representation of the universe that continues to evolve through new technologies and discoveries, and as a result of cultural exchange. With the recent introduction of Western science into the Tibetan Buddhist monasteries in India, this study explores the monastics' conception of the universe prior to their formal instruction in science. Their drawings were analyzed using Tversky's three criteria for drawing analysis namely—segmentation, order, and hierarchical structure of knowledge. Among the sixty Buddhist monastics included in this study, we find that most of them draw a geocentric model of the universe with the Solar System as the dominant physical system, reflecting little influence of modern astronomical knowledge. A few monastics draw the traditional Buddhist model of the world. The implications of the monastics' representation of the universe for their assimilation of modern science is discussed.

Author(s): Tenzin Sonam[1]
Institution(s): *1. university of arizona*
Contributing team(s): Chris Impey

105.02 – Developing New Pedagogy to Teach Planet Formation to Undergraduate Non-Science Majors

A first order understanding of planet formation and the scientific concepts therein is critical in order for undergraduate students to understand our place in the Universe. Furthermore, planet formation integrates the topics of gravity, angular momentum, migration, and condensation in a "story-book" fashion where students can apply these concepts to a specific event. We collected syllabi and course topics from over 30 undergraduate general-education astrobiology courses from around the globe in order to determine the extent to which professors address planet formation. Additionally, we were looking to see if faculty had developed specific or original pedagogy to teach this topic. We find on average, instructors spend ½ of a lecture discussing planet formation or they leave it out all together. In the classes where planet formation is taught more extensively, instructors use PowerPoint slides or occasional videos to teach the topic. We aim to develop new pedagogy that will allow us to better determine learning gains and student understanding of this critical topic. If students in an astrobiology class are unable to understand how our own Solar System forms, it is significantly more challenging to make parallels (or find differences) between our home in the Universe and extrasolar planetary systems.

Author(s): Molly Simon[1], Chris David Impey[1], Sanlyn Buxner[1]
Institution(s): *1. University of Arizona*

105.03 – Conceptual frameworks in astronomy

How to evaluate students' astronomy understanding is still an open question. Even though some methods and tools to help students have already been developed, the sources of students' difficulties and misunderstanding in astronomy is still unclear. This paper presents an investigation of the development of conceptual systems in astronomy by 50 engineering students, as a result of learning a general course on astronomy. A special tool called Conceptual Frameworks in Astronomy (CFA) that was initially used in 1989, was adapted to gather data for the present research. In its new version, the tool included 23 questions, and five to six optional answers were given for each question. Each of the answers was characterized by one of the four conceptual astronomical frameworks: pre-scientific, geocentric, heliocentric and sidereal or scientific. The paper describes the development of the tool and discusses its validity and reliability. Using the CFA we were able to identify the conceptual frameworks of the students at the beginning of the course and at its end. CFA enabled us to evaluate the paradigmatic change of students following the course and also the extent of the general improvement in astronomical knowledge. It was found that the measure of the students' improvement (gain index) was g = 0.37. Approximately 45% of the students in the course improved their understanding of conceptual frameworks in astronomy and 26% deepened their understanding of the heliocentric or sidereal conceptual frameworks.

Author(s): David Pundak[1]
Institution(s): *1. Kinneret College on the Sea of Galilee*

105.04 – An Analysis of Learners in Introductory Astronomy Massive Open Online Courses

We describe learners enrolled in three iterations of introductory astronomy massive open online courses (MOOCs). These courses are offered through commercial providers and facilitated by an instructional team at the University of Arizona. We describe an ongoing study of those who enroll, engage in, and complete these courses. The course has undergone several revisions, including integrating pedagogical techniques, found to be effective for in-person courses, to increase engagement including peer review, online discussions, and the use of cohorts. In its current version, learners enroll on a continual basis and complete 11 weeks of course content; they watch videos, complete content quizzes, submit writing assignments, complete peer review of other students' work, and complete online citizen science projects. Tens of thousands of students has signed up for these courses but completion rates are much lower, around 10%. We have collected survey data from over 8,500 of these learners to assess their basic science knowledge, attitudes towards science and technology, motivations for taking the courses, and information about other ways they engage in science related activities. We present information about these learners, including their demographics, motivations, how they use the courses, and what factors lead to increased engagement and completion. Additionally, we present how survey data from these learners compare to 26 years of data we have collected from parallel group of undergraduate non-science major students enrolled in astronomy courses at the University of Arizona. Overall, we find that learners who enroll in the MOOCs have more interest in science and higher basic science knowledge that undergraduates who pay tuition for a similar course. Our work is helping us understand how to better serve learners in MOOCs and bridge more traditional courses with these types of courses.

Author(s): Sanlyn Buxner[1], Martin Formanek[1], Chris David Impey[1], Matthew Wenger[1]
Institution(s): *1. University of Arizona*

105.05 – Mind the Gaps: Wikipedia as an education model and public duty for scientists

Search for almost any scientific term on the Internet, and chances are that a Wikipedia page will be the first result. Wikipedia's content reaches more than 450 million readers around the world, at a rate of about 8,000 readers a second. That makes Wikipedia one of the most powerful platforms for the dissemination of science information in the world.

Although Wikipedia's coverage of science topics is robust, clear gaps remain — especially with subject matter that requires technical or specialized expertise. Some information is woefully out of date; and, while a minority, some scientific entries on Wikipedia are simply inaccurate. Furthermore, the underrepresentation of women, and diversity in general, remains a real issue.

The **Wikipedia Year of Science 2016** is an unprecedented targeted initiative designed to improve Wikipedia's potential for communicating science to the public. The multi-faceted effort is a program conceived by the Wiki Education Foundation, with support from the Simons Foundation and Google.

This talk will provide a brief overview of the Wikipedia Year of Science initiative, and ways AAS members can get involved — during the meeting, in the classroom, and beyond.

Author(s): Greg Boustead[1]
Institution(s): *1. Simons Foundation*
Contributing team(s): Wiki Education Foundation

106 – Small Telescope Research Communities of Practice: Pro-Am Communities of Practice

Communities of practice are natural, usually informal groups of people that work together. Experienced members teach new members the "ropes." This vital human activity has been studied in depth by social learning theorists such as Etienne Wenger, whose 1998 book, Communities of Practice: Learning, Meaning, and Identity, defined the field. As Wenger suggested in his classic book, "Learning is a matter of engagement: it depends on opportunities to contribute actively to the practices of communities that we value and that value us, to integrate their enterprises into our understanding of the world, and to make creative use of their respective repertoires." There are, in astronomy, many communities of practice. Some communities are centered on observing faint objects with large telescopes and analyzing the results. These communities, led by seasoned astronomers, include graduate students and post-docs who are learning the ropes. Other astronomical communities of practice are centered on observing brighter objects with smaller telescopes. These communities often stress professional-amateur (pro-am) cooperative research. They take advantage of the large number of smaller telescopes and observers. Examples of such pro-am communities of practice include variable star observers (ably organized by the American Association of Variable Star Observers), and a wide range of pro-am research fostered by the Society for Astronomical Sciences.

106.01 – Introduction to Small Telescope Research Communities of Practice

Communities of practice are natural, usually informal groups of people who work together. Experienced members teach new members the "ropes." Social learning theorist Etienne Wenger's book, *Communities of Practice: Learning, Meaning, and Identity,* defined the field. There are, in astronomy, many communities of practice. One set of communities uses relatively small telescopes to observe brighter objects such as eclipsing binaries, intrinsically variable stars, transiting exoplanets, tumbling asteroids, and the occultation of background stars by asteroids and the Moon. Advances in low cost but increasingly powerful instrumentation and automation have greatly increased the research capabilities of smaller telescopes. These often professional-amateur (pro-am) communities engage in research projects that require a large number of observers as exemplified by the American Association of Variable Star Observers. For high school and community college students with an interest in science, joining a student-centered, small telescope community of practice can be both educational and inspirational. An example is the now decade-long Astronomy Research Seminar offered by Cuesta College in San Luis Obispo, California. Each student team is required to plan a project, obtain observations (either locally or via a remote robotic telescope), analyze their data, write a paper, and submit it for external review and publication. Well over 100 students, composed primarily of high school juniors and seniors, have been coauthors of several dozen published papers. Being published researchers has boosted these students' educational careers with admissions to choice schools, often with scholarships. This seminar was recently expanded to serve multiple high schools with a volunteer assistant instructor at each school. The students meet regularly with their assistant instructor and also meet online with other teams and the seminar's overall community college instructor. The seminar features a textbook, self-paced learning units, and a website sponsored by the Institute for Student Astronomical Research.

Author(s): Russell M. Genet[1]
Institution(s): *1. California Polytechnic State University*

106.02 – The American Association of Variable Star Observers as a Professional-Amateur Astronomical Community of practice

The AAVSO was formed in 1911 as a group of US-based amateur observers obtaining data in support of professional astronomy projects. Now, it has evolved into an International Organization with members and observers in all continents, contributing photometry to a public database of about 22,000 variable objects. I will present main aspects of the association and how it has evolved with time to a premium resource for variable star research. I will also discuss current projects and opportunities for Professional-Amateur collaborations within the AAVSO, building a stronger international community of variable star observers!

Author(s): Stella Kafka[1]
Institution(s): *1. AAVSO*
Contributing team(s): 6173540484

106.03 – Capabilities of the Amateur-Science Community

Devoted non-professional astronomers can offer useful service to researchers by collecting data that can't be fit into funded observing programs, pursuing low-probability-of-success projects, stretching the limits of commercial technology, and mentoring the next generation of scientists. These individuals are performing photometry of stars and asteroids, astrometry of visual binary systems, and spectroscopy of variable stars. This report will illustrate some of the activities being done by the small-telescope research community-of-practice, and offer suggestions on how to take advantage of their capabilities and enthusiasm.

Author(s): Robert Buchheim[1]
Institution(s): *1. Society for Astronomical Sciences*

107 – Plenary Talk: From Space Archeology to Serving the World Today: A 20-Year Journey from the Jungles of Guatemala to a Network of Satellite Remote Sensing Facilities Around the World, Daniel Irwin (NASA)

107.01 – From Space Archeology to Serving the World Today: A 20-Year Journey from the Jungles of Guatemala to a Network of Satellite Remote Sensing Facilities Around the World

Earth observing satellites provide a 21st century capability to detect unrecorded archeological sites that are often invisible to the naked eye. This information can be used to understand issues in human settlement, environmental interaction, and the impact of climate change to past cultures. Archeologists want to know how ancient people successfully adapted to their environment and what factors may have led to their collapse or disappearance. Some cultures overextended the capacity of their landscape, causing destructive environmental effects which led to their demise. To avoid repeating mistakes of the past and adapt to challenges today, NASA and the US Agency for International Development (USAID)-- in partnership with leading regional organizations around the world--have implemented SERVIR. SERVIR is a joint development initiative to help countries use information provided by Earth observing satellites and geospatial technologies for managing climate risks and land use. SERVIR is improving awareness, increasing access to information, and supporting analysis to help people in Africa, Hindu Kush-Himalaya, Lower Mekong, and Mesoamerica manage challenges in the areas of food security, water resources, land use change, and natural disasters.

Author(s): Daniel Irwin[1]
Institution(s): *1. NASA*

109 – Relativistic Astrophysics, Gravitational Lenses & Waves, and CMB

109.01 – The Dawn of Gravitational-Wave Astrophysics

With the detection of GW150914 and its identification as the binary merger of two heavy black holes LIGO has launched the era of gravitational-wave astrophysics. I will review what this implies for our understanding of binary compact object formation and how we can use it to constrain current models.

Author(s): Vassiliki Kalogera[1]
Institution(s): *1. Northwestern Univ.*
Contributing team(s): The LIGO - Virgo Collaborations

109.02 – Gravity Spy - Integrating LIGO detector characterization, citizen science, and machine learning

On September 14th 2015, the Advanced Laser Interferometer Gravitational-wave Observatory (aLIGO) made the first direct observation of gravitational waves and opened a new field of observational astronomy. However, being the most complicated and sensitve experiment ever undertaken in gravitational physics, aLIGO is susceptible to various sources of environmental and instrumental noise that hinder the search for more gravitational waves.

Of particular concern are transient, non-Gaussian noise features known as *glitches*. Glitches can mimic true astrophysical gravitational waves, occur at a high enough frequency to be coherent between the two detectors, and generally worsen aLIGO's detection capabilities. The proper classification and charaterization of glitches is paramount in optimizing aLIGO's ability to detect gravitational waves. However, teaching computers to identify and morphologically classify these artifacts is exceedingly difficult.

Human intuition has proven to be a useful tool in classifcation probelms such as this. Gravity Spy is an innovative, interdisciplinary project hosted by Zooniverse that combines aLIGO detector characterization, citizen science, machine learning, and social science. In this project, citizen scientists and computers will work together in a sybiotic relationship that leverages human pattern recognition and the ability of machine learning to process large amounts of data systematically: volunteers classify triggers from the aLIGO data steam that are constantly updated as aLIGO takes in new data, and these classifications are used to train machine learning algorithms which proceed to classify the bulk of aLIGO data and feed questionable glithces back to the users.

In this talk, I will discuss the workflow and initial results of the Gravity Spy project with regard to aLIGO's future observing runs and highlight the potential of such citizen science projects in promoting nascent fields such as gravitational wave astrophysics.

Author(s): Michael Zevin[1]
Institution(s): *1. Northwestern*
Contributing team(s): Gravity Spy

109.03 – Advanced LIGO low-latency searches

Advanced LIGO recently made the first detection of gravitational waves from merging binary black holes. The signal was first identified by a low-latency analysis, which identifies gravitational-wave transients within a few minutes of data collection. More generally, Advanced LIGO transients are sought with a suite of automated tools, which collectively identify events, evaluate statistical significance, estimate source position, and attempt to characterize source properties. This low-latency effort is enabling a broad multi-messenger approach to the science of compact object mergers and other transients. This talk will give an overview of the low-latency methodology and recent results.

Author(s): Jonah Kanner[1]
Institution(s): *1. California Institute of Technology*
Contributing team(s): The LIGO Scientific Collaboration, The Virgo Collaboration

109.04 – Weak Gravitatational Lensing by Illustris-1 Galaxies

We compute the weak gravitational lensing signal of isolated, central galaxies obtained from the z=0.5 timestep of the ΛCDM Illustris-1 simulation. The galaxies have stellar masses ranging from $9.5 \le \log_{10}(M_*/M_{sun}) \le 11.0$ and are located outside cluster and rich group environments. Although there is local substructure present in the form of small, luminous satellite galaxies, the central galaxies are the dominant objects within the virial radii (r_{200}), and each central galaxy is at least 5 times brighter than any other luminous galaxy within the friends-of-friends halo. We compute the weak lensing signal within projected radii $0.05 < r_p/r_{200} < 1.5$ and investigate the degree to which the weak lensing signal is anisotropic. Since CDM halos are non-spherical, the weak lensing signal is expected to be anisotropic; however, the degree of anisotropy that is observed depends upon the symmetry axes that are used to define the geometry. The anisotropy is expected to be maximized when the major axis of the projected dark matter mass distribution is used to define the geomety. In practice in the observed universe, one must necessarily use the projected distribution of the luminous mass to define the geometry. If mass and light are not well-aligned, this results in a suppression of the weak lensing anistropy. Our initial analysis shows that the ellipticity of the projected dark matter halo is uncorrelated with the ellipticity of the projected stellar mass. That is $\varepsilon_{halo} \neq f \times \varepsilon_{light}$, where f is a constant multiplicative factor. In addition, in projection on the sky, the major axis of the dark matter mass is offset from that of the stellar mass by $\sim 40^o$ on average. On scales $r_p \le 0.15\, r_{200}$, the weak lensing anisotropy obtained when using the stellar mass to define the geometry is of order 7% and agrees well with the anisotropy obtained when using the dark matter mass to define the geometry. On scales $r_p \sim r_{200}$, the anisotropy obtained when using the stellar mass to define the geometry is reduced by an order of magnitude compared to the anisotropy obtained when using the dark matter mass to define the geometry.

Author(s): Tereasa G. Brainerd[1], Patrick H. Koh[1]
Institution(s): *1. Boston Univ.*

109.05 – The Pan-STARRS, Mauna Kea, and PESSTO search for optical counterparts to aLIGO gravitational wave events

We have searched for an optical counterpart to the first gravitational wave source discovered by the Advanced LIGO experiment, GW150914, using the Pan-STARRS wide-field telescope and associated data processing to identify transient objects. Interesting candidates are then followed up using the UH88, Gemini, and PESSTO for the spectroscopic characterization. We mapped out 442 square degrees of the northern sky region of the initial LIGO map. We discovered 56 astrophysical transients over a period of 41 days from the discovery of the source. Of these, 19 were spectroscopically classied and a further 13 have host galaxy redshifts. All transients appear to be fairly normal supernovae and AGN variability and none are obviously linked with GW150914. We find one high energy type II supernova with an estimated explosion date consistent with that of GW150914, but no causal link can be inferred. We discuss our results as demonstration of the survey capability of Pan-STARRS, and the spectroscopic capabilities of PESSTO and Mauna Kea.

Author(s): Kenneth C. Chambers[1]
Institution(s): *1. Univ. of Hawaii*
Contributing team(s): Pan-STARRS Collaboration

109.06 – Probing 'Parent Universe' in Loop Quantum Cosmology with B-mode Polarization in Cosmic Microwave Background

We aim to use the observations of B-mode polarization in the Cosmic Microwave Background (CMB) to probe the 'parent universe' under the context of Loop Quantum Cosmology (LQC). In particular, we investigate the possibility for the gravitational waves (GW) such as those from the stellar binary systems in the parent universe to survive the big bounce and thus to be still observable today. Our study is based on the background dynamics with the zeroth-order holonomy correction using the Arnowitt-Deser-Misner (ADM) formalism. We propose a new framework in which transfer functions are invoked to bring the GWs in the parent universe through the big bounce, inflation, and big bang to reach today. This transparent and intuitive formalism allows us to accurately discuss the influence of the GWs from the parent universe on the B-mode polarization in the CMB today under backgrounds of different LQC parameters. These features can soon be tested by the forth-coming CMB observations and we note that the LQC backgrounds with symmetric bouncing scenarios are ruled out by the latest observational results from Planck and BICEP2/Keck experiments.

Author(s): Wen-Hsuan Lucky Chang[1], Jiun-Huei Proty Wu[1]
Institution(s): *1. National Taiwan University*

109.07 – The BICEP/Keck CMB polarization program: Status and results

The BICEP/Keck program is searching for the imprint of inflationary gravitational waves on the Cosmic Microwave Background polarization with 5000 detectors in sub 1-m aperture telescopes observing at 95, 150 and 220GHz. Combining BICEP/Keck data with Planck polarization data, we constrain the tensor to scalar ratio (r) to be less than 0.09 at 95% confidence, for the first time exceeding the strength of the constraint from CMB temperature data. In this talk we report on this result, along with the quality of polarized 220GHz observations at the South Pole and the deployment of the BICEP-3 camera.

Author(s): Bryan Steinbach[1]
Institution(s): *1. Caltech*

109.08 – Status and Future of Deep Searches for Compact Binary Mergers

Deep offline searches for gravitational waves from binary black hole, binary neutron star, and neutron star- black hole mergers were conducted during the first Advanced LIGO observing run, and recently Advanced LIGO announced the first detection of gravitational waves from a binary black hole merger. We discuss the recent results, the methodology of the high latency searches, along with improvements for the upcoming observing runs.

Author(s): Alexander` Harvey Nitz[1]
Institution(s): *1. AEI Hannover*
Contributing team(s): The LIGO Scientific Collaboration

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110 – Galaxy Clusters

110.01 – The Radial Mass Profile within the Entire Virial Region of a Fossil Cluster

We present a hydrostatic analysis of the azimuthally averaged hot intracluster medium (ICM) of the entire virial region of the relaxed fossil cluster RXJ 1159+5531. For a model consisting of ICM, stellar mass from the central galaxy (BCG), and an NFW dark matter (DM) halo, we obtain a good description of the projected radial profiles of ICM temperature and emission-measure that yield precise constraints on the total mass profile. The BCG stellar mass component is clearly detected with a K-band stellar mass-to-light ratio, M_star/L_K = 0.61 +/- 0.11 solar, consistent with stellar population synthesis models. We obtain a halo concentration, c_200 = 8.4 +/- 1.0, and virial mass, M_200 = 7.9 +/- 0.6 x 10^{13} M_sun. For its mass, the inferred concentration is larger than most relaxed halos produced in cosmological simulations with Planck parameters, consistent with RXJ 1159+5531 forming earlier than the general halo population. The detection of a plausible stellar BCG mass component distinct from the NFW DM halo in the total gravitational potential supports the suggestion by Newman et al. (2015) that 10^{14} M_sun represents the mass scale above which dissipation is unimportant in the formation of the central regions of galaxy clusters.

Author(s): David A. Buote3, Yuanyuan Su1, Fabio Gastaldello2, Fabrizio Brighenti4
Institution(s): *1. Havard-Smithsonian Center for Astrophysics, 2. INAF-IASF-Milano, 3. UC, Irvine, 4. Universita di Bologna*

110.02 – Big Bangs in Galaxy Clusters: Using X-ray Temperature Maps to Trace Merger Histories in Clusters with Radio Halos/Relics

Galaxy clusters are assembled through large and small mergers which are the most energetic events ("bangs") since the Big Bang. Cluster mergers "stir" the intracluster medium (ICM) creating shocks and turbulence which are illuminated by ~Mpc-sized radio features called relics and halos. These shocks heat the ICM and are detected in x-rays via thermal emission. Disturbed morphologies in x-ray surface brightness and temperatures are direct evidence for cluster mergers. In the radio, relics (in the outskirts of the clusters) and halos (located near the cluster core) are also clear signposts of recent mergers. Our recent ENZO cosmological simulations suggest that around a merger event, radio emission peaks very sharply (and briefly) while the x-ray emission rises and decays slowly. Hence, a sample of galaxy clusters that shows both luminous x-ray emission and radio relics/halos are good candidates for very recent mergers. We are in the early stages of analyzing a unique sample of 48 galaxy clusters with (i) known radio relics and/or halos and (ii) significant archival x-ray observations (>50 ksec) from Chandra and/or XMM. We have developed a new x-ray data analysis pipeline, implemented on parallel processor supercomputers, to create x-ray surface brightness, high fidelity temperature, and pressure maps of these clusters in order to study merging activity. The temperature maps are made using three different map-making techniques: Weighted Voronoi Tessellation, Adaptive Circular Binning, and Contour Binning. In this talk, we will show preliminary results for several clusters, including Abell 2744 and the Bullet cluster. This work is supported by NASA ADAP grant NNX15AE17G.

Author(s): Jack O. Burns[1], Abhirup Datta[1], Eric J. Hallman[1]
Institution(s): *1. Univ. of Colorado at Boulder*

110.03 – No Shock Across Part of a Radio Relic?

Radio relics are Mpc-scale, steep-spectrum synchrotron sources in the periphery of merging galaxy clusters, which are produced by particle acceleration at low-Mach number (M<3) shock waves. As expected, signatures of shocks have been found across the full length of all the relics studied to date. However, archival Chandra and XMM observations have revealed a possible exception in the merging galaxy cluster ZwCl 2341.1+0000. The cluster, at z=0.27, hosts two radio relics and a central, faint, filamentary radio structure. In the archival X-ray data, the density discontinuity near the SE relic appears to span an arc shorter than the arc spanned by the relic. This startling result is in apparent contradiction with our current understanding of the origin of radio relics.

We present results from recently-completed deep Chandra and VLA observations of the cluster. These observations reveal several merging subclusters, and allow a detailed study of the connection between the radio relics and the shocks in ZwCl 2341.1+0000. We discuss the complex merger scenario that triggered the shock waves, and the implications that the physical properties of the shocks have on our understanding of particle acceleration in merging clusters.

Author(s): Georgiana Ogrean3, Reinout J. Van Weeren2, Marcus Brüggen4, Aurora Simionescu1, Christine Jones2, Annalisa Bonafede4, William R. Forman2, Ralph P. Kraft2
Institution(s): *1. Japan Aerospace Exploration Agency, 2. Smithsonian Astrophysical Observatory, 3. Stanford University, 4. University of Hamburg*

110.04 – Comparing Cool Cores in the Planck SZ Selected Samples of Clusters of Galaxies with Cool Cores in X-ray Selected Cluster Samples

The Planck mission provided a representative sample of clusters of galaxies over the entire sky. With completed Chandra observations of 165 Planck ESZ and cosmology sample clusters at z<0.35, we can now characterize each cluster in terms of its X-ray luminosity, gas temperature, gas mass, total mass, gas entropy, gas central cooling time, presence of active AGN, gas cavities, radio emission, and cluster morphology. In this presentation we compare the percentages of cool core and non-cool core clusters in the Planck-selected clusters with the percentages in X-ray selected cluster samples. We find a significantly smaller percentage of cool core clusters in the Planck sample than in X-ray selected cluster samples. We will discuss the primary reasons for this smaller percentage of cool-core clusters in the Planck-selected cluster sample than in X-ray-selected samples.

Author(s): Christine Jones[2], Felipe A Santos[2], William R. Forman[2], Ralph P. Kraft[2], Lorenzo Lovisari[2], Monique Arnaud[1], Pasquale Mazzotta[6], Reinout J. Van Weeren[2], Eugene Churazov4, Chiara Ferrari5, Stefano Borgani3
Institution(s): *1. CEA, Saclay, 2. Harvard-Smithsonian, CfA, 3. INAF, 4. MPA , 5. Observatoire de La Cote d'Azure, 6. University of Rome*
Contributing team(s): Chandra-Planck Collaboration

110.05 – Galactic Conformity from z=0.2-1.0 with PRIMUS

We test for galactic conformity from z=0.2-1.0 to a projected distance of 5 Mpc using spectroscopic redshifts from the PRism MUlti-object Survey (PRIMUS). Our sample consists of ~60,000 galaxies in five separate fields covering a total of ~5.5 square degrees, which allows us to account for cosmic variance. Dividing our sample into star-forming and quiescent galaxies using a cut in specific star formation rate, we identify star-forming and quiescent “isolated primary” galaxies. We match the redshift and stellar mass distributions of these samples, to control for correlations between quiescent fraction and redshift and stellar mass. We detect a significant conformity signal (>3 sigma) of ~5% on scales of 0-1 Mpc and a 2.5-sigma signal of ~1% on scales of 1-3 Mpc. We also test for redshift and stellar mass dependence of the conformity signal within our sample.

Author(s): Angela Berti[1], Alison L. Coil[1]
Institution(s): *1. University of California, San Diego*

110.06 – JVLA Observations of Cosmic Rays in the Galaxy Cluster ZwCl2341.1+0000

We present new Karl G. Jansky Very Large Array (JVLA) observations of the merging galaxy cluster ZwCl2341.1+0000 located at z=0.27. This cluster is known to contain two diffuse radio sources, the largest being about 1 Mpc in size, located on opposite sides of the cluster center. The sources are separated by about 2 Mpc. In addition, the presence of fainter emission located between the two diffuse sources has been suggested. Diffuse Mpc-size radio sources in clusters are classified as radio *halos* and *relics*. Their existence implies the presence of cosmic rays and magnetic fields in the intracluster medium. The question is by which mechanism these cosmic rays are accelerated. For relics, there is increasing evidence that they trace particles (re)accelerated at large-scale shocks. However, the physics of the acceleration mechanism is not yet fully understood. Radio halos are centrally located in clusters. For halos, it has been suggested that the cosmic rays are re-accelerated by magneto-hydrodynamical turbulence. We use our JVLA observations of ZwCl2341.1+0000 to (1) search for the presence of additional large-scale emission in the cluster and (2) measure the spectral and polarization properties of the diffuse emission to determine its origin.

Author(s): Reinout J. Van Weeren[2], Georgiana Ogrean3, Christine Jones[2], William R. Forman[2], Annalisa Bonafede[1], Marcus Brüggen[1], Ralph P. Kraft[2]
Institution(s): *1. Hamburger Sternwarte, 2. Harvard-Smithsonian Center for Astrophysics, 3. Stanford University*

111 – Bridging Laboratory & Astrophysics: Molecules in the mm I

Laboratory astrophysics is the Rosetta Stone that enables astronomers to understand and interpret the cosmos. This session will focus on the interplay between astrophysics with theoretical and experimental studies into the underlying molecular processes, which drive our Universe, with special attention to connections with ALMA observations.

111.01 – Chemical probes in protoplanetary disks

Protoplanetary disks provide the material for new planetary systems. Moreover, the location and composition of nascent planets will depend on the chemical and physical structure of disks. The radiation field and gas temperature, as well as the chemical structure and composition in disks can be probed by the emission and spatial distribution of molecules.

I will present ALMA observations of different molecular lines in protoplanetary disks and discuss chemical probes frequently used in the ISM and in our Solar system that, thanks the spectacular capabilities of ALMA, can now be applied to protoplanetary disks. First, the CN/HCN ratio, which is a good tracer of radiation field, because CN is a major product of HCN photodissociation. Second, Nitrogen isotopic ratios, which are widely used to trace the origin of molecules in our Solar system, can also be used to trace the thermal structure in disks, since ^{15}N fractionation should depend sensitively on the formation temperature. Finally, the H_2CO ortho-to-para ratio has great potential to constrain its formation pathway, because different values are expected if it forms in the gas or on grain surfaces.

Thanks to ALMA we now have the sensitivity and angular resolution to detect and spatially resolve the emission of many new species in disks. However, in order to fully benefit from these observations, great progresses must also be made on the theoretical and experimental sides. This includes the need for spectroscopic constants, collisional rates, photodissociation rates, formation/destruction rates, and a better understanding on the interplay between the gas-phase and solid-phase chemistry.

Author(s): Viviana Guzman[1], Karin I. Oberg[1], Ryan A. Loomis[1], Chunhua Qi[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*

111.02 – Astrochemical diagnostics of star and planet formation

Stars like our Sun and planets like our Earth form out of diffuse interstellar material, which first accumulates to form molecular clouds and then it fragments into cold (~10 K) and dense (~105 H_2 molecules per cc) cloud cores, the cradle of future stellar systems. The physical structure and chemical composition of these dense cores set the stage for the next steps: gravitational contraction and the formation of protostars and protoplanetary disks. Molecules are unique tracers of the dynamical evolution of interstellar clouds and astrochemistry is needed to guide and interpret our observations. In this talk I will review work done on the early stages of star and planet formation, underlying how astrochemical diagnostics have helped us to shed light on chemical and physical processes important to constraints theories and to find connections with our Solar System. ALMA results will be highlighted.

Author(s): Paola Caselli[1]
Institution(s): *1. Max-Planck-Institute for Extraterrestrial Physics*

111.03 – New measurements of the sticking coefficient and binding energy of molecules on non-porous amorphous solid water in the submonolayer regime

Sticking and adsorption of molecules on dust grains are two important processes in gas-grain interactions. We accurately measured both the sticking coefficient and the binding energy of several key molecules on the surface of amorphous solid water as a function of coverage.

A time-resolved scattering technique was used to measure sticking coefficient of H_2, D_2, N_2, O_2, CO, CH_4, and CO_2 on non-porous amorphous solid water (np-ASW) in the low coverage limit over a wide range of surface temperatures. We found that the time-resolved scattering technique is advantageous over the conventional King-Wells method that underestimates the sticking coefficient. Based on the measured values we suggest a useful general formula of the sticking coefficient as a function of grain temperature and molecule-surface binding energy.

We measured the binding energy of N_2, CO, O_2, CH_4, and CO_2 on np-ASW, and of N_2 and CO on porous amorphous solid water (p-ASW). We were able to measure binding energies down to a fraction of 1% of a layer, thus making these measurements more appropriate for astrochemistry than the existing values. We found that CO_2 forms clusters on np-ASW surface even at very low coverage; this may help in explaining the segregation of CO_2 in ices. The binding energies of N_2, CO, O_2, and CH_4 on np-ASW decrease with coverage in the submonolayer regime. Their values in the low coverage limit are much higher than what is commonly used in gas-grain models. An empirical formula was used to describe the coverage dependence of the binding energies. We used the newly determined binding energy distributions in a simulation of gas-grain chemistry for cold dense clouds and hot core models. We found that owing to the higher value of desorption energy in the sub-monlayer regime a fraction of all these ices stays much longer and to higher temperature on the grain surface compared to the case using single value energies as currently done in astrochemical models.

This work was supported in part by a grant to GV from NSF --- Astronomy & Astrophysics Division (#1311958)

Author(s): Jiao He[2], Kinsuk Acharyya[1], S M Emtiaz[2], Gianfranco Vidali[2]
Institution(s): *1. Physical Research Laboratory, 2. Syracuse University*

111.04 – PAH Clusters and the Interstellar Infrared Emission Bands

Polycyclic aromatic hydrocarbons (or PAHs) are the leading candidate for the emitters of the interstellar aromatic infrared emission bands. Some aspects of these emission bands indicate a contribution from PAH clusters. To better assess this contribution, we measured infrared absorption spectra of a series of homogeneous and heterogeneous PAH clusters using matrix isolation spectroscopy in solid argon and we performed theoretical calculations. The spectral shifts observed in the absorption spectra as a function of the PAH concentration can be related to preferred cluster structures forming in the argon matrix. Based upon our results, we predict that the large PAHs present in the interstellar medium are likely to have clusters with redshifted absorption bands in the C–H out-of-plane bending region. These clusters could contribute to a well-known red-shading observed in the profile of the interstellar 11.2 micron emission band.

Author(s): Alessandra Ricca[1], Joseph Roser[1]
Institution(s): *1. SETI Institute*

112 – Astronomy Education for All: The 2017 Eclipse, Accessibility and NASA

112.01 – Public Education Plans for the 2017 August 21 Total Solar Eclipse

A total solar eclipse will cross the continental United States on 2017 August 21, the first such in 99 years and the first whose path of totality on land is entirely in the United States since 1776. People in the rest of the United States–as well as in Canada, Central America, and northern South America–will have a partial solar eclipse. Totality will range up to about 70 km in diameter, and will be visible from a path that extends from Oregon to South Carolina. Cloudiness statistics based on decades on satellite infrared imaging are more favorable for western sites. The sun's diameter will be 80% covered in Miami (south of totality) and New York (north of totality), and 70% covered in Los Angeles (south of totality). For the Working Group on Solar Eclipses of the International Astronomical Union, I maintain a website at http://eclipses.info that provides links to a wide variety of eclipse-related material and to useful websites run by others.
Prior to this total eclipse, annular eclipses will cross Africa (from Gabon to Tanzania and Madagascar) and Isle de la Réunion on 2016 September 1, and Chile and Argentina on 2017 February 26, at which time we plan an eclipse workshop in Esquel, Argentina.

For the forthcoming 2017 eclipse, we acknowledge grants to JMP and Williams College from the Solar Terrestrial Program of the Atmospheric and Geospace Sciences Division of the National Science Foundation and from the Committee for Research and Exploration of the National Geographic Society.

Author(s): Jay M. Pasachoff[1]
Institution(s): *1. Williams College*

112.02 – The AAS Working Group on Accessibility and Disability (WGAD)

The Working Group on Accessibility and Disability (WGAD) was formed by the Council of the American Astronomical Society in late 2015 in order to monitor and addresses issues of inclusivity in the astronomical community related to disability. WGAD promotes of the principles of universal accessibility and disability justice in both professional astronomy and astronomy education. The short term goals of WGAD for the next two years include producing a set of guidelines for a wide range of activities including supporting improved access to journals, data, and conferences. We will provide information and training regarding universal design as a guiding principle. The longer term goals of WGAD include integrating universal design as primary design strategy across the board in our many aspects of daily work life.

Author(s): Jacqueline A. Monkiewicz[1], J. Shanahan4, Nicholas Arnold Murphy3, Lauren Gilbert[2]
Institution(s): *1. Arizona State University, 2. California Institute of Technology, 3. Harvard-Smithsonian Center for Astrophysics, 4. Wesleyan University*

112.03 – Accessibility & Inclusivity in the Astronomical Community

Nearly one in five Americans have a disability. However, in a 2013 survey, fewer than 2% of AAS members identified as having a disability. Persons with disabilities are dramatically underrepresented in STEM fields and astronomy in particular. Though the Americans with Disabilities Act has been law for 25 years, few astronomy departments have implemented full universal design and structures for accessibility for students. Our field which often sees itself as pushing the limits can offer an environment for enhanced stigmatization and discrimination based on disability. Indeed, many current structures place undue burden to those who are excluded. Instead, we aspire to a way of working together that does not require disclosure of disability, and where diverse needs are being met with each of our interactions and activities. A mindset of diverse access makes the experience of learning, working, and collaborating stronger for all.

Author(s): Lauren Gilbert[2], J. Shanahan5, Jacqueline A. Monkiewicz[1], Jacob Noel-Storr4, Nicholas Arnold Murphy3
Institution(s): *1. Arizona State University, 2. Caltech, 3. Harvard-Smithsonian Center for Astrophysics, 4. Rochester Institute of Technology, 5. Wesleyan*

112.04 – NASA's Universe of Learning: Engaging Learners in Discovery

NASA's Universe of Learning is one of 27 competitively awarded education programs selected by NASA's Science Mission Directorate (SMD) to enable scientists and engineers to more effectively engage with learners of all ages. The NASA's Universe of Learning program is created through a partnership between the Space Telescope Science Institute, Chandra X-ray Center, IPAC at Caltech, Jet Propulsion Laboratory Exoplanet Exploration Program, and Sonoma State University. The program will connect the scientists, engineers, science, technology and adventure of NASA Astrophysics with audience needs, proven infrastructure, and a network of over 500 partners to advance the objectives of SMD's newly restructured education program. The multi-institutional team will develop and deliver a unified, consolidated suite of education products, programs, and professional development offerings that spans the full spectrum of NASA Astrophysics, including the Cosmic Origins, Physics of the Cosmos, and Exoplanet Exploration themes. Program elements include enabling educational use of Astrophysics mission data and offering participatory experiences; creating multimedia and immersive experiences; designing exhibits and community programs; providing professional development for pre-service educators, undergraduate instructors, and informal educators; and, producing resources for special needs and underserved/underrepresented audiences. This presentation will provide an overview of the program and process for mapping discoveries to products and programs for informal, lifelong, and self-directed learning environments.

Author(s): Denise A. Smith5, Kathleen Lestition1, Gordon K. Squires2, W. M Greene3, Lynn R. Cominsky4, Bonnie Eisenhamer5
Institution(s): *1. CXC/SAO, 2. IPAC at Caltech, 3. JPL, 4. Sonoma State Univ., 5. STScI*
Contributing team(s): NASA's Universe of Learning Team

112.05 – Creating NASA-based Education Products for the Undergraduate Classroom: A Retrospective

From 2009-15, NASA's Science Mission Directorate (SMD) coordinated the work of its mission- and program-embedded education and public outreach (E/PO) efforts through four forums representing its four science divisions. One of the priorities established by the Science Education and Public Outreach Forum (SEPOF) for the Astrophysics Division was to coordinate the NASA astrophysics community of missions in creating higher education resources useful to instructors in teaching largely non-science-major undergraduates, based on assessed needs. The presentation will focus primarily on two resources developed for this purpose: 1) the "Astro 101 Slide Sets" (short PowerPoints presenting NASA mission discoveries not yet available in textbooks, for use by instructors to incorporate current science and new discoveries into their classroom work), and 2) the Astronomy Resource Guides (extensive and timely listings of resources on cosmology and exoplanets, for use by instructors to incorporate into their lessons on these "hot topics"). The needs assessment and development processes will be outlined, as well as evaluation results presented based on user surveys, with thoughts on insights for NASA SMD's new approach to education beginning in 2016.

Author(s): Jim Manning4, Bonnie Meinke5, Gregory R. Schultz1, Andrew Fraknoi2, Denise A. Smith5, Luciana Bianchi3
Institution(s): *1. Astronomical Society of the Pacific, 2. Foothill College, 3. Johns Hopkins University, 4. NASA Astrophysics Science Education and Public Outreach Forum, 5. Space Telescope Science Institute*
Contributing team(s): The NASA SMD astrophysics E/PO community

112.06 – A Bridge to the Stars: An Innovative Pipeline to Improve STEM Diversity

Improving diversity in the STEM workforce is a top priority for both the NSF and NASA. Increasing participation from underrepresented groups in the physical sciences like astronomy remains an even more serious challenge with little progress made despite federal mandates. Focusing resources on a small number of academically high-performing individuals is not enough and reinforces the idea that STEM is exclusive. To make real progress requires (1) identifying a larger pool of inner-city secondary students who may not have been exposed to many STEM opportunities nor have the highest grades, yet, may have both the ability and desire to succeed in STEM if inspired; (2) providing these students with high impact exposure to science through an extended and engaging interaction with a professional scientist that fosters student success; and (3) establishing long-term partnerships with community teachers and administrators to facilitate a critical bridge between high school and college. My bridge pipeline provides a role model. The extended engagement is enrollment in a 1-semester, learner-centered 'Astro100' course with an award-winning professor. Using NASA Space Grant funding, 31 scholarships have been awarded over 6 semesters. All Scholars meet underrepresented/underprivileged criteria based on race, sex or income; key demographics: 2/3 AA+HA, 2/3 female. To promote student success, the program includes mentoring interns drawn from top students in previous Astro100 courses; 50% are female. The Scholars gained university credit with an 81% overall average grade, 97% with a passing grade. Longitudinal tracking of college enrollment into STEM is underway.

Author(s): Daniel H. McIntosh1
Institution(s): *1. University of Missouri-Kansas City*

113 – Small Telescope Research Communities of Practice: Student-Centered Communities of Practice

For students who would like to become scientists, joining a community of practice early in their educational career is beneficial. A number colleges and universities offer well-developed undergraduate astronomical research programs. There are also a number of summer research programs for undergraduate astronomy students, such as the NSF-sponsored Research Experience for Undergraduates (REU). High school students are also participating in organized, student-centered astronomical research programs. A good example is the now decade-long Astronomy Research Seminar offered by Cuesta College in San Luis Obispo, California. Well over 100 students, composed primarily of high school juniors and seniors, have been coauthors of several dozen published papers. Being published researchers has frequently boosted these students' educational careers with admissions to choice schools, often with scholarships. This seminar was recently expanded to serve multiple schools with a volunteer assistant instructor at each school. The students meet regularly with their assistant instructor and also meet online with other teams and the seminar's overall instructor. This seminar features a textbook, self-paced learning units, and a website sponsored by the Institute for Student Astronomical Research. Each team is required to plan a project, obtain observations (either locally or via a remote robotic telescope), analyze their data, write a paper, submit it for external review and publication, and present their results.

113.01 – Merits of Undergraduate and High School Research

When it comes to sports, everyone gets it; you have to play to really understand, experience, and learn what the game is all about. It would be ludicrous to teach basketball by practicing basketball fundamentals in the gym (layups, free throws, jump shots, dribbling, defense), reading about and attending professional basketball games, but never playing in a game. As important as classes and teaching laboratories may be in science education, there is simply no substitute for active engagement in scientific research to show students what science is all about and, perhaps even more importantly, to inspire and motivate them to become scientists or at least appreciate science. It is a widely held misconception that a student cannot really do meaningful, publishable scientific research until he/she is in graduate school. In actual fact, college undergraduates and even high school students can make original and significant scientific research contributions. Astronomical research, in particular, is very well suited to engage the beginning high school or college undergraduate researcher. The night sky's inherent accessibility and also its inherent grandeur are natural draws for the curious student's mind. And much can be learned and discovered using small telescopes. In sports, joining a team is a key aspect of the sports experience. Similarly in science, joining a research team and thereby entering a "community of scientific practice" is fundamental and transformational. As important as working with equipment and acquiring data happen to be in scientific research, this is only the beginning of the research process. Student researchers of all ages—particularly high school students and college undergraduates—have much to gain by giving presentations on their research, writing up their results for publication, and going through the peer review process. But this only works if the student researchers are imbedded within the community of practice.

Author(s): John Kenney[1]
Institution(s): *1. Concordia University*

113.02 – Double Star Research: A Student-Centered Community of Practice

Project and team-based pedagogies are increasingly augmenting lecture-style science classrooms. Occasionally, university professors will invite students to tangentially partcipate in their research. Since 2006, Dr. Russ Genet has led an astronomy research seminar for community college and high school students that allows participants to work closely with a melange of professional and advanced amatuer researchers. The vast majority of topics have centered on measuring the position angles and searations of double stars which can be readily published in the Journal of Double Star Observations. In the intervening years, a collaborative community of practice (Wenger, 1998) formed with the students as lead researchers on their projects with the guidance of experienced astronomers and educators. The students who join the research seminar are often well prepared for further STEM education in college and career. Today, the research seminar involves multile schools in multiple states with a volunteer educator acting as an assistant instructor at each location. These assistant instructors interface with remote observatories, ensure progress is made, and recruit students. The key deliverables from each student team include a published research paper and a public presentation online or in-person. Citing a published paper on scholarship and college applications gives students' educational carreers a boost. Recently the Journal of Double Star Observations published its first special issue of exlusively student-centered research.

Author(s): Jolyon Johnson[1]
Institution(s): *1. Institute for Student Astronomical Research*

113.03 – High School Astronomical Research at the Army and Navy Academy

Establishment of a high school astronomy and research program is a difficult task to accomplish in an environment of state mandated high school educational curricula and the task saturation for many teachers today created by their class room and administrative requirements. This environment is most challenging for public schools. The astronomy program we will describe seems to be better suited at least at the present time for private or specialized schools. We will outline how a broad astronomy program was developed over two years at the Army and Navy Academy (ANA), a private boarding school in Carlsbad, California. Starting with no astronomy program in 2013, the Academy now has an astronomy club, a University of California a-g certified two semester high school course, and a college accredited astronomy research seminar with over 20 published high school authors.
At ANA the development followed this path: finding a strong proponent at the school who can make actionable decisions; building interest and perceived value to other staff and faculty members; establishing an astronomy club to generate student interest and future student leaders; and designing the a-g certified high school course including the course length, structure and balance of teaching elements. Building on these foundations, the college level astronomy research seminar was then added to provide an avenue for inspired students to undertake actual research and publication of their work in scientific journals in their free time for college credit.
Creating a sustainable program with supporting infrastructure comes next. Success with the three foundation steps builds confidence in the program with faculty and staff. Published, tangible successes highlight the value and enable advanced placement and scholarship opportunities for graduates. These successes build enthusiasm. The further keys to sustainability include addressing course credit, instructor compensation and rewards, and integration into the school counseling and curricula. Active assistance from amateur astronomers and parental engagement are critical to sustainability, growth, and outreach. Possibly most important is the continuing leadership of strong advocates at the school.

Author(s): Pat Boyce[1], Grady Boyce[1]
Institution(s): *1. Boyce Research Initiative and Education Foundation*

114 – Plenary Talk: The Brightest Pulses in the Universe, Maura McLaughlin (WVU)

114.01 – The Brightest Pulses in the Universe

Over the past decade, the transient radio sky has been probed with unprecedented depth and time resolution. This has resulted in the recognition of a new class of short-duration radio transients called Fast Radio Bursts (FRBs). FRBs have pulse widths of 1-20 milliseconds and dispersion measures much higher than predicted from Galactic electron density models, indicating a likely extragalactic origin. Many models have been put forward for the origin of FRBs. Some of these models involve cataclysmic events such as a neutron star merger and others energetic but repeatable emission such as giant pulses from an extragalactic radio pulsar. Over the past year, several discoveries have provided tantalizing evidence for the origin of these bursts. These include measurements of scintillation and polarization, a possible detection of an associated host galaxy, and the first detection of repeated bursts from an FRB. At the same time, interferometric surveys are soon expected to result in the first detections of highly localized FRBs, which may lead to definitive associations with known sources. In this talk, I will review the history of FRB detection and the properties of the roughly 20 known FRBs. I will then review the evidence for the extragalactic origin of these bursts, and discuss possible sources. Finally, I will look to the future of this emerging field, describe the capabilities of upcoming surveys and instruments, and how FRBs could be used as astrophysical and cosmological probes.

Author(s): Maura McLaughlin[1]
Institution(s): *1. West Virginia University*

115 – Plenary Talk: The Galaxy Zoo, Kevin Schawinski (ETH Zurich)

115.01 – The Galazy Zoo

When the Galaxy Zoo website calling for citizen scientists around the world to help classify galaxies from the Sloan Digital Sky Survey was launched, it brought down the servers hosting the images. The Galaxy Zoo tapped into the incredible desire of the public to get involved in and contribute to scientific research. With the he help of over a quarter million citizen scientists, we were able to map out the evolution of galaxy populations from star formation to quiescence and how this "quenching" is related to changes in morphology. Citizen scientists also discovered unusual objects in public data, such as "Hanny's Voorwerp", a quasar light echo which can constrain black hole accretion on timescales of 10-100 kyr. Finally, the work of citizen scientists taking part in Galaxy Zoo points to a future where machine learning and humans both contribute to systems capable of analyzing extremely large data sets.

Author(s): Kevin Schawinski[1]
Institution(s): *1. ETH Zurich*

116 – Laboratory Astrophysics Poster Session

116.01 – Absolute X-ray emission cross section measurements of Fe K transitions

We have measured the absolute X-ray emission cross sections of K-shell transitions in highly charged L- and K-shell Fe ions using the LLNL EBIT-I electron beam ion trap and the NASA GSFC EBIT Calorimeter Spectrometer (ECS). The cross sections are determined by using the ECS to simultaneously record the spectrum of the bound-bound K-shell transitions and the emission from radiative recombination from trapped Fe ions. The measured spectrum is then brought to an absolute scale by normalizing the measured flux in the radiative recombination features to their theoretical cross sections, which are well known. Once the spectrum is brought to an absolute scale, the cross sections of the K-shell transitions are determined. These measurements are made possible by the ECS, which consists of a 32 channel array, with 14 channels optimized for detecting high energy photons ($h\nu > 10$ keV) and 18 channels optimized for detecting low energy photons (hν < 10 keV). The ECS has a large collection area, relatively high energy resolution, and a large bandpass; all properties necessary for this measurement technique to be successful. These data will be used to benchmark cross sections in the atomic reference data bases underlying the plasma modeling codes used to analyze astrophysical spectra, especially those measured by the Soft X-ray Spectrometer calorimeter instrument recently launched on the Hitomi X-ray Observatory.

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Author(s): Natalie Hell[2], Gregory V. Brown[2], Peter Beiersdorfer[2], Kevin R Boyce[4], Victoria Grinberg[3], Richard L. Kelley[4], Caroline Kilbourne[4], Maurice A. Leutenegger[4], Frederick Scott Porter[4], Jörn Wilms[1]
Institution(s): *1. Dr. Remeis-Sternwarte / ECAP / Universität Erlangen-Nürnberg, 2. LLNL, 3. MIT, 4. NASA's GSFC*

116.02 – Recommended Thermal Rate Coefficients for the C + H_3^+ Reaction and Some Astrochemical Implications

We have incorporated our experimentally derived thermal rate coefficients for C + H_3^+ forming CH^+ and CH_2^+ into a commonly used astrochemical model. We find that the Arrhenius-Kooij equation typically used in chemical models does not accurately fit our data and use instead a more versatile fitting formula. At a temperature of 10 K and a density of 10^4 cm^{-3}, we find no significant differences in the predicted abundances, but at higher temperatures of 50, 100, and 300 K we find up to factor of 2 changes. Additionally, we find that the relatively small error on our measurements (~15%) significantly reduces the uncertainties on the predicted abundances compared to those obtained using the currently implemented Langevin rate coefficient with its estimated factor of 2 uncertainty.

Author(s): Shreyas Vissapragada[2], Cam Buzard[1], Kenneth A. Miller[2], Aodh O'Connor[2], Nathalie De Ruette[2], Xavier Urbain[3], **Daniel Wolf Savin[2]**
Institution(s): *1. Barnard College, 2. Columbia Astrophysics Lab., 3. Université catholique de Louvain*

116.03 – Photodissociation of CS and SiO^+ from Excited Rovibrational Levels

Photodissociation due to ultraviolet (UV) photons is a dominant molecular destruction process in a variety of UV-irradiated interstellar (IS) environments. While most astrochemical models adopt photodissociation rates computed from cross sections out of the molecule's ground rovibrational level ($v=0,J=0$), they also assume a standard local IS radiation field and opacity due to standard IS dust. However, none of these conditions are satisfied in a host of environments including photodissociation regions, protoplanetary disks, and outflows from AGB stars. To allow for the calculation of reliable photodissociation rates, we compute cross sections from all bound v,J levels of the ground electronic state for two example molecules, CS and SiO^+. The cross sections are computed for a large number of excited electronic states using a two-state fully quantum perturbation approach. New ab initio potential energies and transition dipole moment functions, used in the photodissociation calculations, were obtained at the MRCI+Q level of theory using the quantum chemistry package MOLPRO. Applications of the v,J-state-resolved cross sections will be presented as well as LTE photodissociation cross sections which assume a Boltzmann distribution of initial v,J levels.

This work is supported at UGA by NASA grant NNX15AI61G.

Author(s): Ryan Pattillo[4], Phillip C. Stancil[4], Brendan McLaughlin[3], Jim McCann[3], Robert C. Forrey[2], James Babb[1]
Institution(s): *1. Harvard-Smithsonian CfA, 2. Pennsylvania State University, 3. Queen's University Belfast, 4. University of Georgia*

116.04 – Ro-vibrational analysis of SiO in Warm Molecular Environments

SiO emission lines are important probes of chemical processes in diverse astrophysical environments, commonly observed in shocks associated with the outflows of young stellar objects, both low- and high-mass, and in the envelopes of evolved stars. To model SiO emission for non-LTE conditions requires collisional rate coefficients due to H_2, H, and He impact, with the first of these currently unavailable. Unknown collisional rate coefficients are often estimated from known systems. For the case of SiO-H_2, rate coefficients have previously been adapted from a different collider, He, based on a reduced-mass scaling approach. Recently it has been suggested that scaling via the interaction potential well depth and the reduced masses of the collisional systems may be more reliable. Using the non-LTE spectral modeling package Radex, we construct diagnostic plots of SiO line ratios using SiO-H_2 collisional rate coefficients based on (i) reduced-mass scaling from the LAMDA database, (ii) potential well-depth scaling, (iii) a more comprehensive input with multiple colliders (H_2, He and H) , and (iv) vibrational SiO transition. We also investigate the effects of the SiO data with Cloudy in PDR and VY CMa models, exploring the chemistry of SiO in such environments.

Author(s): Ziwei Zhang[1], Renata Cumbee[1], Kyle M. Walker[1], Phillip C. Stancil[1], Gary J. Ferland[2]
Institution(s): *1. The University of Georgia, 2. University of Kentucky*

116.05 – Recent Progresses in Laboratory Astrophysics with Ames' COSmIC Facility

We present and discuss the characteristics and the capabilities of the laboratory facility, COSmIC, that was developed at NASA Ames to generate, process and analyze interstellar, circumstellar and planetary analogs in the laboratory [1]. COSmIC stands for "Cosmic Simulation Chamber" and is dedicated to the study of neutral and ionized molecules and nano particles under the low temperature and high vacuum conditions that are required to simulate space environments. COSmIC integrates a variety of state-of-the-art instruments that allow forming, processing and monitoring simulated space conditions for planetary, circumstellar and interstellar materials in the laboratory. COSmIC is composed of a Pulsed Discharge Nozzle (PDN) expansion that generates a plasma in free supersonic jet expansion coupled to two high-sensitivity, complementary in situ diagnostics: a Cavity Ring Down Spectroscopy (CRDS) and laser induced fluorescence (LIF) systems for photonic detection and a Reflectron Time-Of-Flight Mass Spectrometer (ReTOF-MS) for mass detection [2].
Recent laboratory results that were obtained using COSmIC will be presented, in particular the progress that has been achieved in the domain of the diffuse interstellar bands (DIBs) [3] and in monitoring, in the laboratory, the formation of dust grains and aerosols from their gas-phase molecular precursors in environments as varied as stellar/circumstellar outflows [4] and planetary atmospheres [5]. Plans for future, next generation, laboratory experiments on cosmic molecules and grains in the growing field of laboratory astrophysics will also be addressed as well as the implications of the current studies for astronomy.

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[5] Sciamma-O'Brien E., Ricketts C., and Salama F. Icarus, 243, 325 (2014)

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Author(s): Farid Salama[1], Cesar Contreras[1], Ella Sciamma-O'Brien[1], Salma Bejaoui[1]
Institution(s): *1. NASA Ames Research Center*

116.06 – Computational Modeling of Laboratory X-ray Emission due to Low-Energy Collisions of H-like and He-like ions with H_2

Charge exchange between highly-charged ions and neutral molecules occurs when the solar wind, or other astrophysical plasmas, collide with cool gas. This process emits observable X-rays with specific line intensities. Recent CX experiments at Lawrence Livermore National Laboratory measured the X-ray hardness ratios of low-energy collisions between hydrogen- and helium-like ions with H_2 (Leutenegger et al. 2010). Using our recently developed X-ray modeling package, Kronos_v2 (Mullen et al. 2016), which utilizes multi-channel Landau-Zener charge exchange cross sections, we have computed theoretical hydrogen-like hardness ratios to aid in interpretation of the experimental data. While the computed hardness ratios are somewhat smaller than the experiment, it shows better agreement than earlier classical trajectory predictions. We are also in the process of building Kronos_v3; further enhancing the comprehensive charge exchange database to include helium-like and multielectron ions to allow for comparison with experiments and for models of hot astrophysical environments such as supernova remnants, star-forming galaxies, and galaxy clusters.
Leutenegger, M. et al. 2010, Phys. Rev. Lett., 105, 063201
Mullen, P. D. et al., 2016, ApJS, in press

Author(s): Ansley Miller[2], Patrick Dean Mullen[2], Renata Cumbee[2], Phillip C. Stancil[2], Maurice A. Leutenegger[1]
Institution(s): *1. NASA/GSFC, 2. University of Georgia*

116.07 – Development of a Temperature Diagnostic Based on the Emission Lines of Fluorine-Like Ions

We used the Flexible Atomic Code to calculate theoretical intensities of extreme ultraviolet emission lines of fluorine-like Al IV, Si VI, and S VIII at electron temperatures T_e from 1 eV to well above 100 eV, and found that the intensity ratio of the 3-->2 and 2-->2 transitions is temperature sensitive. We tested these calculations by measuring the relevant Al IV emission in the 115-320 Å spectral region on the Lithium Tokamak Experiment at the Princeton Plasma Physics Laboratory. Spectra were taken with the Long Wavelength Extreme Ultraviolet Spectrometer, LoWEUS, which has a resolution of ~0.3 Å. We identified emission from neon-like Al V as well as fluorine-like Al IV. Our data include emission from Li II and Li III, and O IV-VI, which we used for wavelength calibration. We used the oxygen line intensities from CHIANTI to calculate the intensity response function for the region we studied. The measurements confirm that the ratio of the intensity of the 3-->2 feature at 133 Å to a pair of 2-->2 lines at 278 Å and 281 Å can be used to derive temperature estimates for the emitting region of the plasma. Our measurements indicate a temperature T_e of ~16 ± 2 eV from the 133/278 Å line pair and ~17.5 ±2 eV from the 133/281 Å line pair, which is close to the temperature of maximum abundance of fluorine-like Al.

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Author(s): Jaan K. Lepson3, Peter Beiersdorfer[1], Robert Kaita[2], Richard Majeski[2], Dennis Boyle[2]
Institution(s): *1. Lawrence Livermore National Laboratory, 2. Princeton Plasma Physics Laboratory, 3. University of California, Berkeley*

116.08 – Lifetimes and Oscillator Strengths for Ultraviolet Transitions Involving $6s^2 6d\ ^2D$ and $6s6p3\ ^2D$ Levels in Pb II

We conducted beam-foil measurements on levels producing Pb II lines at 1203.6 and 1433.9 Å. These were supplemented by archival data from the *Hubble Space Telescope* (*HST*) covering the Pb II transitions. The oscillator strengths derived from our experimental lifetimes are generally consistent with recent large-scale theoretical results, as well as our own relativistic calculations. Our analysis of the *HST* spectra confirms the relative strengths of the two lines. However, the oscillator strength obtained for the line at 1433 Å is significantly smaller than earlier theoretical values used to derive the interstellar lead abundance, leading to an increase of 0.43 dex in this quantity. We will present our results for Pb II and compare them with others from the literature.

Author(s): Steven Robert Federman[2], Negar Heidarian[2], Richard Irving[2], Adam M. Ritchey3, David Ellis[2], Song Cheng[2], Larry Curtis[2], Walter Furman[1]
Institution(s): *1. Reed College, 2. Univ. of Toledo, 3. Univ. of Washington*

116.08 – The Infrared Spectra and Absorption Intensities of Amorphous Ices

Our research group is carrying out new IR measurements of icy solids relevant to the outer solar system and to the interstellar medium, with an emphasis on amorphous and crystalline ices below ~ 120 K. Our goal is to update and add to the relatively meager literature on this subject and to provide electronic versions of state-of-the-art data, since the abundances of such molecules cannot be deduced without accurate reference spectra and IR band strengths. In the past year, we have focused on three of the simplest and most abundant components of interstellar and solar-system ices: methane (CH_4), carbon dioxide (CO_2), and methanol (CH_3OH). Infrared spectra from ~ 4500 to 500 cm^{-1} have been measured for each of these molecules in μm-thick films at temperatures from 10 to 120 K. All known amorphous and crystalline phases have been reproduced and, for some, presented for the first time. We also report measurements of the index of refraction at 670 nm and the mass densities for each ice phase. Comparisons are made to earlier work where possible. Electronic versions of our new results are available at http://science.gsfc.nasa.gov/691/cosmicice/ constants.html.

Author(s): Perry A. Gerakines[1], Reggie L. Hudson[1], Mark Loeffler[1]
Institution(s): *1. NASA GSFC*

116.09 – Close-coupling calculations of fine-structure excitation of Ne II due to H and electron collisions

Fine-structure transitions within the ground term of ions and neutral atoms dominate the cooling in a variety of molecular regions and also provide important density and temperature diagnostics. While fine-structure rates due to electron collisions have been studied for many systems, data are generally sparse for elements larger than oxygen, at low temperatures, and for collisions due to heavy particles. We provide rate coefficients for H collisions for the first time. The calculations were performed using the quantum molecular-orbital close-coupling approach and the elastic approximation. The heavy-particle collisions use new potential energies for the lowest-lying NeH^+ states computed with the MRDCI method. The focus of the electron-impact calculations is to provide fine-structure excitation rate coefficients down to 10 K. We compare with previous calculations at higher temperatures (Griffin et al. 2001), and use a range of calculations to provide an estimate of the uncertainty on our recommended rate coefficients. A brief discussion of astrophysical applications is also provided.

Griffin, D.C., et al., 2001, J. Phys. B, 34, 4401

This work partially supported by NASA grant No. NNX15AE47G.

Author(s): Phillip C. Stancil4, Renata Cumbee4, Qianxia Wang[1], Stuart Loch[1], Michael Pindzola[1], David R. Schultz5, Robert Buenker3, Brendan McLaughlin[2], Connor Ballance[2]
Institution(s): *1. Auburn University, 2. Queens University Belfast, 3. UNC, 4. Univ. of Georgia, 5. University of North Texas*

116.10 – The Impact of Hot Electrons on X-ray Spectra: e-e Bremsstrahlung and κ Distributions

Shocks, turbulence, and winds all influence the electron velocity distribution in hot plasmas, exciting lower-energy electrons and generating a high-energy (typically power-law) tail. Sufficiently energetic electrons will emit via an electron-electron (e-e) bremsstrahlung, a process not previously included in the AtomDB. We have added this process and calculate the impact e-e bremsstrahlung has on the spectra from the post-shock regions of an accreting magnetic cataclysmic variable (CV). We find the contribution of e-e bremsstrahlung to the total spectra exceeds 10% at ~100 keV, with the total emissivity in the post-shock accretion stream differing by more than 10\% at energies above 60 keV. More generally a Maxwellian with a power law tail, typically termed a κ distribution, can have significant effects on the line and continuum X-rays emitted. In addition to the e-e bremsstrahlung term, there will be effects due to the impact of the electrons on the charge state distribution and the collisional excitation rates. We use the ``Maxwellian decomposition'' approach as described in Hahn & Savin (2015) to generate the rate coefficients for a κ distributions based on the recently-released AtomDB v3.0 atomic database. These values are compared to exact calculations done for selected recombination and bremsstrahlung rates, and are also compared to results from the CHIANTI KAPPA package.

Author(s): Randall K. Smith3, Xiaohong Cui1, Adam Foster3, Takayuki Yuasa2
Institution(s): *1. Academy of Sciences, 2. RIKEN, 3. Smithsonian Astrophysical Observatory*

116.11 – Laboratory Rotational Spectroscopy of the Interstellar Diatomic Hydride Ion SH^+ ($X\,^3\Sigma^-$)

Diatomic hydride are among the most common molecular species in the interstellar medium (ISM). The low molecular mass and thus moments of inertia cause their rotational spectra to lie principally in the submillimeter and far-infrared regions. Diatomic hydrides, both neutral (MH) and ionic (MH^+) forms, are also basic building blocks of interstellar chemistry. In ionic form, they may be the “hidden” carriers of refractory elements in dense gas. They are therefore extremely good targets for space-borne and airborne platforms such as Herschel, SOFIA, and SAFIR. However, in order to detect these species in the ISM, their rotational spectra must first be measured in the laboratory. To date, there is very little high resolution data available for many hydride species, in particular the ionic form. Using submillimeter/THz direct absorption methods in the Ziurys laboratory, spectra of the interstellar diatomic hydride SH^+ ($X\,^3\Sigma^-$) have been recorded. Recent work has concerned measurement of all three fine structure components of the fundamental rotational transition $N = 1 \leftarrow 0$ in the range 345 - 683 GHz. SH^+ was generated from H_2S and argon in an AC discharge. The data have been analyzed, and spectroscopic constants for this species have been refined. SH^+ is found in Photon Dominated Regions (PDRs) and X-ray Dominated Regions (XDRs) and is thought to trace energetic processes in the ISM. These current measurements confirm recent observations of this species at submillimeter/THz wavelengths with ALMA and other ground-based telescopes.

Author(s): DeWayne Halfen1, Lucy M. Ziurys1
Institution(s): *1. Univ. of Arizona*

116.12 – Rovibrational Collisional Rates of SiO due to Molecular Hydrogen

SiO has been detected in a variety of astronomical sources and is a potential diagnostic of dust formation and destruction in star-forming regions and evolved stars. Its rovibrational level populations are perturbed by collisions with He, H and H_2 requiring a non-LTE analysis. However, the necessary collisional rate coefficients, and their temperature dependence, are largely unknown. Scattering calculations are the primary source of such rate coefficients. In this work a full-dimensional (6D) potential energy surface (PES) for the SiO-H_2 complex was computed using the high-level CCSD(T)-F12B method and fitted using an invariant polynomial approach in 6D. The first full dimensional quantum close-coupling scattering calculations of SiO in collision with H_2 on the 6D PES have been performed for the pure state-to-state rotational excitations from SiO(v=0, j=0-10). For rovibrational transitions, state-to-state and total quenching rate coefficients from several low-lying rotational levels of SiO(v=1) are studied for both para-H_2 and ortho-H_2 collisions.

Work at UGA and Emory are supported by NASA grant No. NNX12AF42G, at UNLV by NSF Grant No. PHY-1505557, and at Penn State by NSF Grant No. PHY-1503615.

Author(s): Benhui H. Yang4, Phillip C. Stancil4, Xiaohong Wang2, J. Bowman2, Peng Zhang1, Balakrishnan Naduvalath5, Robert C. Forrey3
Institution(s): *1. Duke University, 2. Emory University, 3. Penn State University, 4. Univ. of Georgia, 5. UNLV*

116.13 – Simulating Titan’s atmospheric chemistry at low temperature (200K)

We present our latest results on the Titan Haze Simulation (THS) experiment developed on the COSmIC simulation chamber at NASA Ames Research Center. In Titan’s atmosphere, a complex organic chemistry induced by UV radiation and electron bombardment occurs between N_2 and CH_4 and leads to the production of larger molecules and solid aerosols. In the THS, the chemistry is simulated by pulsed plasma in the stream of a supersonic expansion, at Titan-like temperature (150 K). The residence time of the gas in the pulsed plasma discharge is on the order of 3 μs, hence the chemistry is truncated allowing us to probe the first and intermediate steps of the chemistry by adding heavier precursors into the initial N_2-CH_4 gas mixture.
Two complementary studies of the gas phase and solid phase products have been performed in 4 different gas mixtures: N_2-CH_4, N_2-CH_4-C_2H_2, N_2-CH_4-C_6H_6 and N_2-CH_4-C_2H_2-C_6H_6 using a combination of *in situ* and *ex situ* diagnostics. The mass spectrometry analysis of the gas phase was the first to demonstrate that the THS is a unique tool to monitor the different steps of the N_2-CH_4 chemistry (Sciamma-O’Brien et al. 2014). The results of the solid phase study are consistent with the chemical growth evolution observed in the gas phase. Grains and aggregates that form in the gas phase were jet deposited on various substrates then collected for *ex situ* analysis. Scanning Electron Microscopy images have shown that more complex mixtures produce larger aggregates (100-500 nm in N_2-CH_4, up to 5 μm in N_2-CH_4-C_2H_2-C_6H_6). Moreover, the morphology of the grains seems to depend on the precursors, which could have a large impact for Titan’s models. We will present the latest results of the X-ray Absorption Near Edge Structure measurements, that show the different functional groups present in our samples and give the C/N ratio; as well as the Direct Analysis in Real Time Mass Spectrometry coupled with Collision Induced Dissociation analyses that have been performed on all four mixtures and give insight on the specific chemical pathways associated with the presence of acetylene and benzene.
Reference: Sciamma-O’Brien et al., 2014, *Icarus* 243, 325.
Acknowledgements: The authors acknowledge the support of NASA SMD.

Author(s): Ella Sciamma-O'Brien1, Kathleen T. Upton2, Jesse L. Beauchamp2, Farid Salama1
Institution(s): *1. NASA Ames Research Center, 2. Noyes Laboratory of Chemical Physics and the Beckman Institute*

116.14 – Laser Induced Emission Spectroscopy of Cold and Isolated Neutral PAHs and PANH: Implications for the red rectangle emission

Blue luminescence (BL) in the emission spectra of the red rectangle centered on the bright star HD44179 is recently reported by Vijh et al [1]. This results is consistent with the broad band polarization measurements obtained in 1980 by Schmidt et al. Both experimental and theoretical studies support that BL emission could be attributed the luminescence of Polycyclic Aromatic Hydrocarbon (PAH) excited with ultraviolet light from the center of the star [4 and reference therein]. The abundance on N to C in the interstellar medium suggest also that nitrogen substituted PAH (PANH) are likely abundant in the interstellar medium [3]. They exhibit similar features as PAHs and could contribute to the unidentified spectral bands. Comparing the BL to laboratory spectra obtained on similar environment is crucial for the identification of interstellar molecules. We present in this works the absorption and the laser induced emission spectra of several isolated and cold PAHs and PANHs. Laser induced emission was performed first to PAHs and PANHs isolated in Argon matrix at 10 K. Then, measurements are performed with the supersonic jet technique of the COSmIC laboratory facility at NASA Ames. We focus, here, on the emission spectra (fluorescence and (or) phosphorescence) of these molecules and we discuss their contributions to the blue luminescence emission in the Red Rectangle nebula.

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[2] Schmidt, G. D., Cohen, M. & Margon, B., ApJ, 239L.133S (1980)
[3] Spitzer, L., Physical Processes in the Interstellar Medium (New York Wiley-Interscience) (1978)
[4] Salama, F., Galazutdinov, G. A., Kre lowski, J., Allamandola, L. J., & Musaev, F. A. ApJ, 526,(1999)

Author(s): Salma Bejaoui[1], Farid Salama[1], Ella Sciamma O'Brien [1]
Institution(s): *1. NASA Ames Research center*

116.15 – Prebiotic Organic Matter from the Center of the Galaxy

The origins of life on Earth must have begun with simple organic compounds. A plausible source of such prebiotic molecules was the interstellar medium (ISM). Of the over 160 molecules that have been identified in interstellar gas, about half have been discovered in one source, Sagittarius B2(N), located in the Galactic Center. This giant molecular cloud is also home to many large organic species observed in the ISM. How complex these species can become is unknown. In order to accurately establish an inventory of potentially, prebiotic organic molecules, we completed a continuous spectral-line survey of Sgr B2(N) at the confusion limit using the Arizona Radio Observatory facilities: the Kitt Peak 12 m and the Submillimeter Telescope. The survey covers the 1, 2, and 3 mm atmospheric windows in the range 68 - 280 GHz, and about 15,000 individual spectral lines have been observed. Seventy-four molecules have been identified in the data, including several potential prebiotic species, such as glycolaldehyde, acetamide, and methyl isocyanate. These molecules are relatively abundant in Sgr B2(N), with fractional abundances of $f \sim 10^{-10}$ - 10^{-12} relative to H_2. Current results of this survey will be presented, along with its implications for interstellar organic chemistry and prebiotic synthesis. A comparison with organics found in comets and meteorites will also be discussed.

Author(s): DeWayne Halfen[1], Lucy M. Ziurys[1]
Institution(s): *1. Univ. of Arizona*

116.16 – Measurement of the 1s2l3l’ Dielectronic Recombination Emission Line in Li-Like Ar and Its Contribution to the Faint X-Ray Feature Found in the Stacked Spectrum of Galaxy Clusters

Driven by the recent detection of an unidentified emission line previously reported at 3.55-3.57 keV in a stacked spectrum of galaxy clusters, we investigated the resonant DR process in Li-like Ar as a possible source of, or contributor to, the emission line. The Li-like transition $1s^2 2l$-1s2l3l’ was suggested to produce a 3.62 keV photon [1] near the unidentified line at 3.57 keV and was the primary focus of our investigation. Apart from the mentioned transitions, we have found other features that can be possible contributors to the emission in this region. The Electron Beam Ion Trap at NIST was used to produce and trap the highly-charged ions of argon. The energy of the quasi-monoenergetic electron beam was incremented in steps of 15 eV to scan over all of the Li-like Ar DR resonances. A Johann-type crystal spectrometer and a solid-state germanium detector were used to take x-ray measurements perpendicular to the electron beam. The DR cross sections were measured and normalized to the well-known photoionization cross sections using radiative recombination peaks in the measured spectra. Corrections for different instrument and method related effects such as charge state balance, electron beam space charge, and charge exchange have been considered. Our high-resolution crystal spectra allowed the experimental separation of features that are less than 2 eV apart. We have used a collisional radiative model NOMAD [2] aided by atomic data calculations by FAC [3] to interpret our observations and account for the corrections and uncertainties. Experimental results were compared to the AtomDB theoretical emission lines used to fit the galaxy cluster spectra containing the unidentified 3.57 keV line. These data points can be added benchmarks in the database and used to accurately interpret spectra from current x-ray satellites, including Hitomi, Chandra, and XMM-Newton x-ray observatories.
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[2] Ralchenko Yu. et al., 2014, JQSRT, 71, 609
[3] Gu M. F., 2008, Can. J. Phys. 86, 675

Author(s): Amy Christina Gall[1], Roshani Silwal[1], Joan Dreiling[2], Alexander Borovik[2], Marco Ajello[1], John Gillaspy[3], Ethan Kilgore[1], Yuri Ralchenko[2], Endre Takacs[1]
Institution(s): *1. Clemson University, 2. National Institute of Standards and Technology, 3. National Science Foundation*

116.17 – A New Laboratory For Terahertz Characterization Of Cosmic Analog Dusts

Most studies conducted with observatories such as ALMA, SOFIA, PLANCK, and Herschel will benefit from knowledge of (1) the predominant cosmic dust species in various environments and (2) the mm/sub-mm optical properties of cosmic dusts, including the temperature dependent-emissivity and spectral index. We have undertaken two efforts to enable the laboratory study of cosmic analogs dusts in the frequency range 60-2000 GHz. They are: (1) the construction of a novel compact Fourier Transform Spectrometer (FTS) design coupled to a dry 4-K cryostat which houses a cooled sample exchanger (filter wheel) and a bolometer. (2) The production of Mg- and Fe-rich silicate dusts using sol-gel methods; various tests to determine their physical and chemical properties; embedding of samples in LDPE pellets for insertion into the novel FTS. This presentation will focus on the current status of the apparatus and data from its first few months of use.

Author(s): Thushara Perera[1], Lunjun Liu[1], Fiona Breyer[1], Ryan Schonert[1], Kyle O'Shea[1], Rebecca Roesner[1]
Institution(s): *1. Illinois Wesleyan University*

117 – The NASA K2 Mission Poster Session

117.01 – Discovery of a Long-Period Eclipsing Binary in M67

We announce the detection of an eclipsing binary (WOCS 12009 / Sanders 1247) near the turnoff of the heavily-studied old open cluster M67 using K2 Campaign 5 data. The object was previously known to be a double-lined spectroscopic binary, and the orbit period (69.75 d) agrees with the photometric period. We present a preliminary analysis of the K2 photometry, multi-band ground-based photometry of the eclipses, and extensive radial velocity observations of the two stars. Precise measurements of the pair will begin to provide mass and radius scales for cluster stars, and will constrain the age of this iconic open cluster.

We gratefully acknowledge support from NASA through grant NNX15AW24A to R.D.M.

Author(s): Eric L. Sandquist[3], David W. Latham[1], Robert D. Mathieu[4], Andrew Vanderburg[1], Timothy M. Brown[2]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. Las Cumbres Global Telescope Network, Inc., 3. San Diego State Univ., 4. Univ. of Wisconsin*
Contributing team(s): The M67 K2 Team

117.02 – Twinkle Twinkle Little Star - Speckle Imaging for Exoplanet Characterization

The NASA K2 mission is finding many high-value exoplanets and world-wide follow-up is ensuing. The NASA TESS mission will soon be launched, requiring additional ground-based observations as well. As a part of the NASA-NSF
NN-EXPLORE program to enable exoplanet research, our group is building two new speckle interferometry cameras for the Kitt Peak WIYN 3.5-m telescope and the Gemini-N 8-m telescope. Modeled after the successful DSSI visitor instrument that has been used at these telescopes for many years, speckle observations provide the highest resolution images available today from any ground- or

space-based single telescope. They are the premier method through which small, rocky exoplanets can be validated. Available for public use in early 2017, WIYNSPKL and GEMSPKL will obtain simultaneous images in two filters with fast EMCCD readout, "speckle" and “wide-field” imaging modes, and user support for proposal writing, observing, and data reduction. We describe the new cameras, their design, and their benefits for exoplanet follow-up, characterization, and validation. Funding for this project comes from the NASA Exoplanet Exploration Program and NASA HQ.

Author(s): Steve B. Howell[1], Nic Scott[1], Elliott Horch[2]
Institution(s): *1. NASA ARC, 2. Southern Connecticut State University*

117.03 – Validation and Characterization of K2 Exoplanet Candidates with NIR Transit Photometry from the 4m Mayall and 3.5m WIYN Telescopes

We present new ground-based near-infrared (NIR) transit photometry of exoplanet candidates recently discovered by the NASA K2 mission. These observations support the confirmation and characterization of these newly discovered transiting exoplanets, many which are in the super-Earth to mini-Neptune size regime and orbit cool, nearby stars. We specifically used NEWFIRM on the 4m Mayall telescope and WHIRC on the 3.5m WIYN telescope, both located at Kitt Peak National Observatory, to observe several K2 exoplanet candidates in transit. To our knowledge, these facilities have not been tested for such high-precision differential transit photometry before. Follow-up transit photometry with the high spatial resolution NIR cameras installed on the Mayall and WIYN telescopes allows us to confirm the transit host, which is critical given the large pixel scale of the Kepler spacecraft. NIR transit photometry in particular allows us to verify that the transit is achromatic, after comparing the NIR transit depth to the transit depth measured in the optical from K2. Finding a different depth in different bandpasses indicates that the candidate is instead an eclipsing binary false positive. Furthermore, NIR transit photometry provides robust constraints on the measured planet radius, since stellar limb darkening is minimized in the NIR. Finally, the high-precision and high-cadence photometry we achieve allows us to refine the transit ephemeris, which is crucial for future follow-up efforts with other facilities like NASA's James Webb Space Telescope. The capabilities of these ground-based facilities therefore approach those of space telescopes, since we are able use these ground-based observatories to refine transit parameters and constrain properties for the exoplanets that K2 is discovering, all the way down to super-Earth-size planets.

Author(s): Knicole D. Colón[1], Thomas Barclay[1]
Institution(s): *1. NASA Ames Research Center*

117.04 – A Comprehensive Stellar Astrophysical Study of the Old Open Cluster M67 with Kepler

M67 is among the best studied of all star clusters. Being at an age and metallicity very near solar, at an accessible distance of 850 pc with low reddening, and rich in content (over 1000 members including main-sequence dwarfs, a well populated subgiant branch and red giant branch, white dwarfs, blue stragglers, sub-subgiants, X-ray sources and CVs), M67 is a cornerstone of stellar astrophysics.

The K2 mission (Campaign 5) has obtained long-cadence observations for 2373 stars, both within an optimized central superaperture and as specified targets outside the superaperture. 1,432 of these stars are likely cluster members based on kinematic and photometric criteria.

We have extracted light curves and corrected for K2 roll systematics, producing light curves with noise characteristics qualitatively similar to Kepler light curves of stars of similar magnitudes. The data quality is slightly poorer than for field stars observed by K2 due to crowding near the cluster core, but the data are of sufficient quality to detect seismic oscillations, binary star eclipses, flares, and candidate transit events. We are in the process of uploading light curves and various diagnostic files to MAST; light curves and supporting data will also be made available on ExoFOP.

Importantly, several investigators within the M67 K2 team are independently doing light curve extractions and analyses for confirmation of science results. We also are adding extensive ground-based supporting data, including APOGEE near-infrared spectra, TRES and WIYN optical spectra, LCOGT photometry, and more.

Our science goals encompass asteroseismology and stellar evolution, alternative stellar evolution pathways in binary stars, stellar rotation and angular momentum evolution, stellar activity, eclipsing binaries and beaming, and exoplanets. We will present early science results as available by the time of the meeting, and certainly including asteroseismology, blue stragglers and sub-subgiants, and newly discovered eclipsing binaries.

This work is supported by NASA grant NNX15AW24A to the University of Wisconsin – Madison.

Author(s): Robert D. Mathieu[2], Andrew Vanderburg[1]
Institution(s): *1. Harvard University, 2. Univ. of Wisconsin*
Contributing team(s): K2 M67 Team

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118 – Evolution of Galaxies and Galaxy Clusters Poster Session

118.01 – "Sausage" and "Toothbrush" in the Sky

Radio-relic clusters are a subclass of merging clusters that exhibit elongated diffuse radio emissions at the periphery of the systems. A number of observational and theoretical studies support the premise that the relics trace the locations of shock fronts induced by cluster mergers. Detailed analysis of the radio relic data enables us to put independent constraints on the key parameters necessary in our reconstruction of the merging scenario, including the direction of the merger, the projection angle between the merger axis and the plane of the sky, the shock velocity, and the time since the impact. Because of the limited observational time window set by both development and deterioration of mature shocks, only a few tens of radio relic clusters are known to date. In this poster, we present a detailed study of the two radio-relic clusters CIZA J2242.8+5301 and RX J0603.3+4214, whose peculiar radio-relic morphologies give them the nicknames "Sausage" and "Toothbrush", respectively. Both clusters possess remarkably large (~2 Mpc) radio relics stretched perpendicular to the hypothesized merger axes. After briefly reviewing previous studies, we highlight our recent weak-lensing analysis of these two interesting systems. We find that the "Sausage" cluster's dark matter is elongated along the merger axis and composed of two massive systems, each weighing ~10^{15} solar masses. On the other hand, the dark matter of the "Toothbrush" cluster is distributed complicatedly and resolved into at least four subclusters with relatively modest masses. Our weak-lensing studies help us to constrain the merger scenarios and enable detailed follow-up numerical studies in the future.

Author(s): Myungkook J. Jee4, William Dawson[2], Reinout J. Van Weeren[1], David M. Wittman3
Institution(s): *1. Harvard Smithsonian Center for Astrophysics, 2. Lawrence Livermore National Laboratory, 3. UC Davis, 4. Yonsei University*
Contributing team(s): Merging Cluster Collaborations

118.02 – Spectrophotometric Redshifts in the Faint Infrared Grism Survey

We have combined HST grism spectroscopy and deep broadband imaging to measure spectro-photometric redshifts (SPZs) of faint galaxies. Using a technique pioneered by Ryan et al. 2007, one can combine spectra and photometry to yield an SPZ that is more accurate than pure photometric redshifts, and can probe more deeply than ground-based spectroscopic redshifts. By taking mid-resolution spectra from the HST Faint Infrared Grism Survey (FIGS), SPZs can be found for measurements potentially down to 27th magnitude (the typical brightness of a dwarf galaxy at redshift ~1.5). A galaxy’s redshift is vital for understanding its place in the growth and evolution of the universe. The measurement of high-accuracy SPZs for FIGS sources will improve the faint-end and high-redshift portions of the luminosity function, and make possible a robust analysis of the FIGS fields for signs of Large Scale Structure (LSS). The improved redshift and distance measurements allowed for the identification of a structure at z=0.83 in one of the FIGS fields.

Author(s): John Pharo[1], Sangeeta Malhotra[1], James E. Rhoads[1]
Institution(s): *1. Arizona State University*

118.03 – The CO-H_2 Conversion Factor in Star-Forming Galaxies at z<1.5

Using data drawn from the Plateau de Bure High-z Blue Sequence Survey (PHIBSS) and the CO Legacy Database for GASS (COLD GASS), we study the correlation between the CO-H_2 conversion factor (α_{CO}) and integrated galaxy properties, such as gas-phase metallicity and total mass surface density, for a sample of ~200 star-forming galaxies at z < 1.5. Consistent with existing observations, we find a weak anti-correlation between α_{CO} and metallicity, such that the most metal-poor galaxies exhibit an α_{CO} in excess of that observed in the Milky Way disk. Contrary to theoretical predictions, however, we find no significant correlation between α_{CO} and total mass surface density at z ~ 0 or z ~ 1; our results indicate that molecular gas primarily exists in the form of Milky Way-like GMCs in typical star-forming galaxies at z < 1.5, independent of the galaxy's mass surface density. For massive galaxies on the star-forming "main sequence" at z ~ 1, we find a factor of 4 difference in the molecular depletion timescales inferred using the predicted CO-H_2 conversion factor versus those inferred using a Milky Way-like α_{CO}. This analysis underscores the importance of the CO-H_2 conversion factor in interpreting CO observations, both locally and especially at high redshift during the peak of cosmic star formation.

Author(s): Timothy Carleton[1], Mike Cooper[2]
Institution(s): *1. UC Irvine, 2. UC Irvine*
Contributing team(s): the PHIBSS team

118.04 – Exploring the environmental impacts on star-forming galaxies at z~3.8

We investigate how galaxy formation proceeded in field and protocluster environment at high redshift. Our protocluster sample consists of a large number of spectroscopically confirmed galaxies residing in PC 217.96+32.3 at z=3.78, one of the most massive protoclusters discovered to date with the present-day mass comparable to that of Coma cluster. Our control sample includes similarly selected sources not associated with the protocluster at the same redshift range . Taking advantage of the deep imaging data taken of this structure, we measure the stellar population parameters — star formation rates, stellar mass, age, and dust reddening — and carry out a detailed comparison of the two samples. We conclude that PC 217.96+32.3 harbors an excess number of both massive galaxies and high-SFR galaxies relative to the field. Protocluster galaxies obey the same SFR-M* correlation as the field galaxies, but their distribution on the SFR-M* plane is skewed towards more massive and higher SFR regions . Comparison of our results with the current theoretical expectation is also presented.

Author(s): Ke Shi[1], Kyoung-Soo Lee[1]
Institution(s): *1. Purdue University*

118.05 – Results from Stacking Grism Spectra of Galaxies at 0.6 < z < 1.2 in the Probing Evolution And Reionization Survey (PEARS)

We present results from median stacking of low-resolution grism spectra for ~1700 galaxies at 0.6 < z < 1.2. The data are from the Probing Evolution And Reionization Survey (PEARS) which is a 200 orbit HST ACS G800L grism survey in GOODS-N and GOODS-S. The visible and near-IR coverage of the grism, 6000A to 9500A, provides rest-frame visible wavelength coverage from ~3000A to ~6000A for the redshift range of our sample. We median stack galaxies of similar rest-frame u-r color and stellar mass by selecting them based on their location in our u-r color vs stellar mass diagram. The grism spectra are stacked in bins of 0.3 in u-r color and 0.5 dex in stellar mass over a range of 0.0 < u-r < 3.0 and 7.0 < log(M) [M_sol] < 11.5 with an average of ~30 galaxies per bin. We find that blue cloud galaxies typically show bluer continua, Balmer breaks and also show H-beta and [OIII] emission lines that are blended together due to the low-resolution of the grism. Red sequence galaxies typically show strong 4000A breaks and redder continua and, at lower significance, also the G-band and Mgb absorption features characteristic of late type stars. We also observe that green valley galaxies, which form ~6% of the total sample, typically show weaker 4000A breaks and relatively flatter continua at wavelengths redder than 4000A.

Author(s): Bhavin Joshi[1], Sangeeta Malhotra[1], Rogier A. Windhorst[1]
Institution(s): *1. Arizona State University*
Contributing team(s): PEARS team, FIGS team

118.06 – Measuring the Dust Stripping of Galaxies by the Hot Intracluster Gas in the Virgo Cluster

Ram pressure stripping, the removal of gas from galaxies interacting with the hot intracluster medium, has been proposed as a mechanism for quenching star formation in cluster galaxies. While much effort has been made to identify gas stripped from the interstellar medium (ISM) of cluster galaxies, the ISM also includes dust, another potential tracer of stripping. Previous studies using radio and infra-red wavelengths have suggested gas and dust stripping in several cluster galaxies. In our study, we try a different approach: searching for optical extinction and reddening of background galaxies by dust stripped from foreground cluster members. As the first step, using data from the Sloan Digital Sky Survey Data Release 12 (SDSS DR12) and the VLA Imaging of Virgo in Atomic gas (VIVA) HI survey, we map the magnitudes and colors of galaxies behind Virgo cluster galaxies whose HI morphologies are disrupted. We discuss how efficiently dust stripping can be measured with this method and the connection to gas stripping.

Author(s): Hye-Ran Lee[3], Ann I Zabludoff[2], Joon Hyeop Lee[1], K. Decker French[2], Byeong-Gon Park[1]
Institution(s): *1. Korea Astronomy and Space Science Institute, 2. University of Arizona, 3. University of Science and Technology*

118.07 – Still Red and Dead? Measuring feedback and star-formation in clusters at z > 1

Optical and infrared (IR) surveys have discovered that galaxy clusters at z < 1 are “red and dead”, characterized by relatively low and inefficient star formation. While most studies of color and luminosity evolution function find that stars in red, early-type cluster galaxies formed at z > 2 and underwent passive evolution thereafter without dominant star formation, some samples indicate that an era of star formation and AGN activity is seen in cluster galaxies at z > 1. Only recently have large samples of z > 1 clusters been identified, mostly through IR and Sunyaev-Zel’dovich (SZ) surveys, which indicate an increase in SFR in clusters at high redshifts and incomplete quenching. Moreover, a robust cluster sample in-hand allows us to understand how galaxy clusters become “red and dead”, and the role of astrophysical feedback in this process. The South Pole Telescope (SPT) collaboration has produced mass-limited redshift-independent catalog of 516 clusters from 0.0 < z < 1.7, by observing 2500 sq. degrees of the sky in the mm-band, detecting them using the SZ effect. This catalog contains an estimated 37 massive clusters with z > 1.0, with three newly found systems having a z_{phot} > 1.5. In this work, we focus on a sub-sample of SPT-SZ selected clusters at z > 1.2 with multi-wavelength observations in X-ray (Chandra), infrared (Herschel, Spitzer), optical (Magellan - imaging and spectroscopy), and mm-wavelength (SPT) bands. These observations enable constraints on cluster stellar, baryonic, and total mass, in addition to a host of other information, including the star-formation rate, level of AGN activity, cluster dynamical state, and signatures of astrophysical feedback in the intra-cluster gas. We will describe the overall observing program, early results, and future directions.

Author(s): Gourav Khullar[2], Michael McDonald[1], Lindsey Bleem[2], Bradford Benson[2], Michael Gladders[2]
Institution(s): *1. Massachusetts Institute of Technology, 2. The University of Chicago*
Contributing team(s): The South Pole Telescope (SPT) Collaboration

118.08 – A Spectacular Bow Shock in the 11 keV Galaxy Cluster Around 3C 438

We present results of deep 153 ks Chandra observations of the hot, 11 keV, galaxy cluster associated with the radio galaxy 3C 438. By mapping the morphology of the hot gas and analyzing its surface brightness and temperature distribution, we argue that the cluster is undergoing a major merger between two massive sub-clusters. To the southeast of 3C 438, we detect two jumps in surface brightness, at 90” (400 kpc) and at 180” (800 kpc). The inner jump corresponds to an increase in density by a factor of two, while the outer jump implies a decrease in density by a factor of almost four. Combining these density jumps with the temperature distribution within the cluster, we establish that the pressure of the hot gas is continuous at the inner jump, while there is a significant pressure increase at the outer jump. From the magnitude of the outer pressure jump, we determine that one sub-cluster is moving with a relative velocity of approximately 2300 km/s with respect to the intracluster medium of the second sub-cluster, creating a bow shock. Based on these findings, we conclude that the discontinuity is likely the result of an ongoing major merger between two massive sub-clusters.

Author(s): Deanna Lily Emery[1], Akos Bogdan[2], Ralph P. Kraft[2], William R. Forman[2], Christine Jones[2], Felipe A Santos[2]
Institution(s): *1. Harvard University, 2. Harvard-Smithsonian Center for Astrophysics*

118.09 – Attribution of halo merger mass ratio and star formation rate density

We have used codes for implementing the merger tree algorithm by Cole et al. (2007) and Parkinson et al. (2008) and derived the halo merger mass ratio of protocluster of galaxies across the cosmic time. The authors compare the observed and simulated star formation rates reported by the various groups and derive the star formation rate densities at different red-shifts. This study implies that an investigation of different mass variables should be incorporated into the analysis in order to accurately estimate cumulative star formation rates of galaxies and star formation rate densities as a function of red-shifts.

Author(s): Sungeun Kim[1], Jeong-woon Jo[1], Jihe Hwang[1], Soyoung Youn[1], Boha Park[1]
Institution(s): *1. Department of Physics and Astronomy, Sejong University*

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119 – The Sun and the Solar System Poster Session

119.01 – The Pioneer Anomaly as a Coulomb Attraction

The anomalous acceleration of the Pioneer 10 and Pioneer 11 spacecraft can be explained as a Coulomb attraction between the positively-charged Solar System (due to cosmic rays) and the negatively-charged spacecraft (due to alpha-particle emission from the radioisotope thermoelectric generators).

Author(s): Steven Morris[1]
Institution(s): *1. Los Angeles Harbor College*

119.02 – Continuing Improvement in the Planetary Ephemeris with VLBA Observations of Cassini

During the past decade a continuing series of measurements of the barycentric position of the Saturn system in the inertial International Celestial Reference Frame (ICRF) has led to a significant improvement in our knowledge of Saturn's orbit. This in turn has improved the current accuracy and time range of the solar system ephemeris produced and maintained by the Jet Propulsion Laboratory. Our observing technique involves high-precision astrometry of the radio signal from Cassini with the NRAO Very Long Baseline Array, combined with solutions for the orbital motion of Cassini about the Saturn barycenter from Doppler tracking by the Deep Space Network. Our VLBA astrometry is done in a phase-referencing mode, providing nrad-level relative positions between Cassini and angularly nearby extragalactic radio sources. The positions of those reference radio sources are tied to the ICRF through dedicated VLBI observations by several groups around the world. We will present recent results from our astrometric observations of Cassini through early 2016. This program will continue until the end of the Cassini mission in 2017, although future improvement in Saturn's orbit will be more incremental because we have already covered more that a quarter of Saturn's orbital period. The Juno mission to Jupiter, which will orbit Jupiter for about 1.5 years starting in July 2016, will provide an excellent opportunity for us to apply the same VLBA astrometry technique to improve the orbit of Jupiter by a factor of several.

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. This work made use of the Swinburne University of Technology software correlator, developed as part of the Australian Major National Research Facilities Program and operated under license. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Funding from the NASA Planetary Astrometry program is gratefully acknowledged.

Author(s): Dayton L. Jones3, William M. Folkner[1], Robert A. Jacobson[1], Christopher S. Jacobs[1], Jonathan D. Romney[2], Vivek Dhawan[2], Edward B. Fomalont[2]
Institution(s): *1. JPL/Caltech, 2. National Radio Astronomy Observatory, 3. Space Science Institute*

119.03 – SOHO/UVCS spectroscopic observations of coronal oscillations

We analyzed the temporal evolution of the intensities and Doppler shifts of two sets of high-cadence sit-and-stare observations acquired with the Ultraviolet Coronagraph Spectrometer (UVCS) on board the Solar and Heliospheric Observatory (SOHO) satellite to detect the possible signature of wave and oscillatory motions in the solar corona. The first set of data consisted of H I Lyα observations collected on 1997 December 14 at 1.43 R_S above the eastern limb of the Sun. Spectral analysis of the data revealed clear Doppler-shift oscillations with period P = 14.3 min over a portion of the UVCS slit. The origin of these oscillations is attributable to the excitation of propagating fast-mode magnetoacoustic kink waves along a narrow, jet-like ejection observed higher up in the white-light corona. The second set of data consisted of O VI 1032 Å observations collected on 1996 December 19 at 1.38 R_S above the north polar coronal hole. In this case, clear intensity oscillations (P = 19.5 min) and Doppler-shift oscillations (P = 7.2 min) over two different portions of the UVCS slit were detected. The origin of these oscillations is attributable to the excitation of slow-mode magnetoacoustic waves propagating along polar plumes that may partially account for heating of the plasma in the corona.

Author(s): Salvatore Mancuso3, John C. Raymond[2], Sara Rubinetti[1], Carla Taricco[1]
Institution(s): *1. Dipartimento di Fisica, Università di Torino, 2. Harvard-Smithsonian Center for Astrophysics, 3. INAF - Astrophysical Observatory of Torino*

119.04 – American Solar Eclipses 2017 & 2024

This research focuses on harnessing the statistical capacity of many available concurrent observers to advance scientific knowledge. By analogy to some Galilean measurement-experiments in which he used minimal instrumentation, this researcher will address the question: How might an individual observer, with a suitably chosen common metric and with widely available, reasonably affordable equipment, contribute to new knowledge from observing the solar eclipse of 2017? Each observer would report data to an institutional sponsor who would analyze these data statistically toward new knowledge about some question currently unsettled in astronomy or in the target field connected with the question which the chosen metric is targeted to address. A subordinate question will be discussed: As a tradeoff between "best question to answer" and "easiest question for observers' data to answer", is there an event property and related target question that, with high potential utility and low cost, would be measurable by an observer positioned in the path of totality with minimal or inexpensive equipment and training? (And that, as a statistical sample point, might contribute to new knowledge?) In dialog with the audience, the presenter will suggest some measurables; e.g., solar flares, ground shadow bands, atmospheric metrics, coronal structure, etc., correlated or not with certain other dependent variables. The independent variable would be time in the intervention interval from eclipse contacts 1 -- 4. By the aforementioned analogy, the presenter will review as examples some measurement-experiments conducted or suggested by Galileo; e.g., pendulum laws, Jovian satellite eclipse times, geokinesis as later seen in Bessel's parallactic measurement, and Michelson's measurement of light speed. Because criteria of metrics-determination would naturally include existence of a data-collection-analysis method, this presentation requires dialogue with a critical mass of audience members who would participate in the consideration of the research objective and of candidate institutional sponsors as a function of candidate target questions.

Author(s): Albert DiCanzio[1]
Institution(s): *1. ADASI*

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120 – Instrumentation: Ground Based or Airborne Poster Session

120.01 – The Astrometric Calibration of the Gemini Planet Imager

The Gemini Planet Imager (GPI), housed on the 8-meter Gemini South telescope in Chile, is an instrument designed to detect Jupiter-like extrasolar planets by direct imaging. It relies on adaptive optics to correct the effects of atmospheric turbulence, along with an advanced coronagraph and calibration system. One of the scientific goals of GPI is to measure the orbital properties of the planets it discovers. Because these orbits have long periods, precise measurements of the relative position between the star and the planet (relative astrometry) are required. In this poster, I will present the astrometric calibration of GPI. We constrain the plate scale and orientation of the camera by observing different binary star systems with both GPI and another well-calibrated instrument, NIRC2, at the Keck telescope in Hawaii. We measure their separations with both instruments and use that information to calibrate the plate scale. By taking these calibration measurements over the course of one year, we have measured the plate scale to 0.05% and shown that it is stable across multiple epochs. I will also discuss our effort to correct for optical distortion using pinhole masks in the laboratory.

Author(s): Debby Tran[1], Quinn Konopacky[1]
Institution(s): *1. University of California, San Diego*
Contributing team(s): GPIES Collaboration

120.02 – The New ALMA Prototype 12 M Telescope of the Arizona Radio Observatory

The Arizona Radio Observatory (ARO) recently acquired the European 12 m prototype antenna of the Atacama Large Millimeter Array (ALMA) project from the European Southern Observatory (ESO). The antenna was located at the Very Large Array (VLA) site near Socorro, New Mexico. In November 2013, the 97 ton antenna was transported to Kitt Peak, Arizona in two major parts: the 40 ft. reflector and the base/receiver cabin. The antenna, which replaced the former NRAO 12 m telescope, was reassembled in the dome at Kitt Peak. Recommissioning began in January 2014, and scientific observations commenced in early 2015. The instrument is now fully operational with a measured surface accuracy of 53 microns, rms, and a pointing accuracy of 2 arc seconds. Further antenna improvements are in progress. The new 12 m currently supports a dual polarization, 3 mm receiver (84-116 GHz) with ALMA Band 3 sideband-separating mixers. A multiband receiver also covering the 4 mm (67 – 90 GHz), 2 mm (130-180 GHz) and 1 mm (210-280 GHz) regions with dual polarization, sideband-separating mixers is currently under construction. A new digital backend, the ARO Wideband Spectrometer (AROWS: 4 x 4 GHz total bandwidth), is also in the development stage.

Author(s): Lucy M. Ziurys[1], Thomas W. Folkers[1], Nicholas J. Emerson[1], Robert Freund[1], Eugene F. Lauria[1], David Forbes[1], George P. Reiland[1], Martin McColl[1]
Institution(s): *1. Univ. of Arizona*

120.03 – A near-infrared SETI experiment: A multi-time resolution data analysis

We present new post-processing routines which are used to detect very fast optical and near-infrared pulsed signals using the latest NIROSETI (Near-Infrared Optical Search for Extraterrestrial Intelligence) instrument. NIROSETI was commissioned in 2015 at Lick Observatory and searches for near-infrared (0.95 to 1.65μ) nanosecond pulsed laser signals transmitted by distant civilizations. Traditional optical SETI searches rely on analysis of coincidences that occur between multiple detectors at a fixed time resolution. We present a multi-time resolution data analysis that extends our search from the 1ns to 1ms range. This new feature greatly improves the versatility of the instrument and its search parameters for near-infrared SETI. We aim to use these algorithms to assist us in our search for signals that have varying duty cycles and pulse widths. We tested the fidelity and robustness of our algorithms using both synthetic embedded pulsed signals, as well as data from a near-infrared pulsed laser installed on the instrument. Applications of NIROSETI are widespread in time domain astrophysics, especially for high time resolution transients, and astronomical objects that emit short-duration high-energy pulses such as pulsars.

Author(s): Melisa Tallis[4], Jerome Maire[1], Shelley Wright[4], Frank D. Drake[2], Andres Duenas[4], Geoffrey W. Marcy[5], Remington P. S. Stone[6], Richard R. Treffers[3], Dan Werthimer[5]
Institution(s): *1. Dunlap Institute for Astronomy and Astrophysics, Univ. of Toronto , 2. SETI Institute, 3. Starman Systems, 4. UC San Diego, 5. Univ. of California, Berkeley, 6. University of California Santa Cruz UCO/Lick Observatory*
Contributing team(s): NIROSETI

120.04 – A near-Infrared SETI Experiment: Alignment and Astrometric precision

Beginning in March 2015, a Near-InfraRed Optical SETI (NIROSETI) instrument aiming to search for fast nanosecond laser pulses, has been commissioned on the Nickel 1m-telescope at Lick Observatory. The NIROSETI instrument makes use of an optical guide camera, SONY ICX694 CCD from PointGrey, to align our selected sources into two 200μm near-infrared Avalanche Photo Diodes (APD) with a field-of-view of 2.5"x2.5" each. These APD detectors operate at very fast bandwidths and are able to detect pulse widths extending down into the nanosecond range. Aligning sources onto these relatively small detectors requires characterizing the guide camera plate scale, static optical distortion solution, and relative orientation with respect to the APD detectors. We determined the guide camera plate scale as 55.9+- 2.7 milli-arcseconds/pixel and magnitude limit of 18.15mag (+1.07/-0.58) in V-band. We will present the full distortion solution of the guide camera, orientation, and our alignment method between the camera and the two APDs, and will discuss target selection within the NIROSETI observational campaign, including coordination with Breakthrough Listen.

Author(s): Andres Duenas[6], Jerome Maire[1], Shelley Wright[6], Frank D. Drake[3], Geoffrey W. Marcy[5], Andrew Siemion[5], Remington P. S. Stone[2], Melisa Tallis[6], Richard R. Treffers[4], Dan Werthimer[5]
Institution(s): *1. Dunlap Institute for Astronomy and Astrophysics, 2. Lick Observatory, University of California, Santa Cruz , 3. SETI Institute , 4. Starman System, LLC, 5. University of California, Berkeley, 6. University of California, San Diego*

120.05 – The SMARTS Observatory: CHIRON Spectrometer & Data Products, Accessible to All

The SMARTS observatory announces opportunities for new and returning members and proposers to use the SMARTS 1.5m telescope and CHIRON fiber echelle spectrometer at CTIO in Chile to carry out their science programs in 2017A. SMARTS Queues for You! Our Yale University-based team schedules all CHIRON requests, allowing unprecedented flexibility in observing strategy. Users submit requests easily and at their convenience on our CHIRON Scheduling Site; raw and processed data as well as calibrations are retrieved in the very same place. CHIRON is ideal for target monitoring, space mission follow-up, and simultaneous observing campaigns with space-based as well as other southern, ground-based instruments. With dedicated assistance from both the SMARTS and CTIO teams, we are able to accept Target of Opportunity requests for same-night observation as well as provide processed data quickly and efficiently. Mounted on the 1.5m telescope since 2011B, CHIRON is a highly stable, cross-dispersed echelle spectrometer fed by fiber. Its spectral resolution ranges from 25K in fiber mode to 120K with narrow slit mask. Spectral range is fixed, 410 – 870nm.
SMARTS has been producing excellent science for 13 years, and we aim to maintain and operate CHIRON into the future. We invite everyone: institutions, faculty, research scientists, students and staff, to take a look at what we have to offer; take a look at what has already been accomplished with this specialized instrument, and consider what can be accomplished now and moving forward once you've joined the SMARTieS!
In this poster, we show exciting science results from CHIRON users as well as statistics on productivity. We describe the capabilities of SMARTS+CHIRON, as well as our expected availability within the 2017A semester. We highlight a recent user-driven effort to enhance data reduction products for those using the instrument for purposes beyond the intentions of the original reduction code. Historically intended for precise radial velocity measurements, users are fine-tuning the CHIRON reduction process for their interests; we plan to share these advancements with the entire community of past and present users.

Author(s): Emily MacPherson[2], Victoria Misenti[2], Todd J. Henry[1]
Institution(s): *1. Georgia State University, 2. Yale University*

120.06 – Characterization of Optical Components for the Cosmology Large Angular Scale Surveyor (CLASS)

Inflation theory posits a rapid expansion at the beginning of the universe that explains the homogeneity, isotropy and flatness of our universe. The theory postulates perturbations to space-time with both scalar and tensor components, the latter of which would give rise to a "B-mode" polarization in the Cosmic Microwave Background (CMB). The Cosmology Large Angular Scale Surveyor (CLASS), with its broadband frequency coverage and rapid front-end modulation, has the unique ability to map the entire B-mode angular power spectrum where there the inflationary signal is expected to dominate. In this poster, I give an overview of CLASS and present work on the characterization of CLASS optical components, including infrared filters, using a custom Fourier Transform Interferometer.

Author(s): Zhuo Zhang[1], Thomas Essinger-Hileman[1], Zhilei Xu[1], Tobias Marriage[1]
Institution(s): *1. Johns Hopkins University*

120.07 – Modular Orbital Demonstration of an Evolvable Space Telescope

The key driver for a telescope's sensitivityis directly related to the size of t he mirror area that collects light from the objects being observed.The "Search for Life" via imaging of exoplanets is a mission that requires extremely stable telescopes with apertures in the 10 m to 20 m range. The HDST envisioned for this mission would have an aperture >10 m, which is a larger payload than can be delivered to space using a single launch vehicle. Building and assembling the mirror segments enabling large telescopes will likely require multiple launches and assembly in space. The Optical Telescope Assembly for HDST is a primary mission cost driver. Enabling affordable solutions for this next generation of large aperture space-based telescope are needed.This reports on the concept for the MODEST, which demonstrates on-orbit robotic and/or astronaut assembly of a precision optical telescope in space. It will facilitate demonstration of active correction of phase and mirror shape. MODEST is proposed to be delivered to the ISS using standard Express Logistics Carriers and can mounted to one of a variety of ISS pallets. Post-assembly value includes space, ground, and environmental studies, a testbed for new instruments, and a tool for student's exploration of space. This demonstration program for next generation mirror technology provides significant risk reduction and demonstrates the technology in a six-mirror phased telescope. Key features of the demonstration include the use of an active primary optical surface with wavefront feedback control that allows on-orbit optimization and demonstration of precise surface control to meet optical system wavefront and stability requirements.
MODEST will also be used to evaluate advances in lightweight mirror and metering structure materials such as SiC or Ceramic Matrix Composite that have excellent mechanical and thermal properties, e.g. high stiffness, high thermal conductivity, and low thermal expansion. It has been demonstrated that mirrors built from these materials can be rapidly replicated in a highly cost effective manner, making these materials excellent candidates for a low cost, high performance OTA.

Author(s): Brian Baldauf[1]
Institution(s): *1. Northrop Grumman Corporation*

120.08 – Recent progress in the simulation and synthesis of Wide Field Imaging Interferometry Testbed (WIIT) data

The Wide-field Imaging Interferometry Testbed (WIIT) is a double Fourier interferometer (DF) operating at optical wavelengths, and provides data that are highly representative of those from a space-based far-infrared interferometer like the Space Infrared Interferometric Telescope (SPIRIT). Developed at NASA's Goddard Space Flight Center, this testbed produces high-quality interferometric data and is capable of observing spatially and spectrally complex hyperspectral test scenes, from geometrically simple to astronomically representative test scenes.
Here we present the simulation of recent WIIT measurements using the Far-infrared Interferometer Instrument Simulator (FIInS). This simulation enables us to compare a synthesized spatial-spectral data cube based on FIInS-generated DF data with the input hyperspectral test scene. FIInS has been modified to perform the calculations at optical wavelengths and to include an extended field of view due to the presence of a detector array. The results from FIInS are compared with the results obtained from recent measurements with WIIT. For this current study, the test scene under consideration spatially consists of four reference point sources intended for spectral and spatial calibration, and six science sources, comprised of binary systems. Each binary pair member has a unique spectrum. Our results demonstrate that FIInS accurately describes the performance of a real double Fourier interferometer, and that the expected hyperspectral data cube can be reconstructed from synthetic or real interferometric data.

Author(s): Roser Juanola-Parramon[1], David Leisawitz[1], Matthew R Bolcar[1], Alexander Iacchetta[2], Stephen F Maher[1], Stephen Rinehart[1]
Institution(s): *1. NASA Goddard Space Flight Center, 2. University of Rochester*

120.09 – Manastash Ridge Observatory Autoguider Upgrade

The Astronomy Undergraduate Engineering Group (AUEG) at the University of Washington has designed and manufactured a novel autoguider system for the 0.8-meter telescope at the Manastash Ridge Observatory in Ellensburg, Washington. The system uses a pickoff mirror placed in the unused optical path, directing the outer field to the guide camera via a system of axi-symmetrically rotating relay mirrors (periscope). This allows the guider to sample nearly 7 times the area that would be possible with the same fixed detector. This system adds closed loop optical feedback to the tracking capabilities of the telescope. When tuned the telescope will be capable of acheiving 0.5 arcsecond tracking or better. Dynamic focusing of the primary optical path will also be an included feature of this system. This unique guider will be a much needed upgrade to the telescope allowing for increased scientific capability.

Author(s): Jason Lozo[1], Joseph Huehnerhoff[1], John Armstrong[1], Adrian Davila[1], Courtney Johnson[1], Alex McMaster[1], Kyle Olinger[1]
Institution(s): *1. University of Washington*

121 – Observatory Site Protection and Light Pollution Poster Session

121.01 – Artificial Lighting Protection of Mauna Kea Observatories: An Experiment to Replace LPS Street Lighting With LEDs in Waikoloa Village, HI

Segments of the astronomical community have long lobbied in support of the use of Low Pressure Sodium (LPS) street lights as a method of minimizing impacts of sky glow on neighboring observatories. There has been vociferous objection to the replacement of LPS by Light Emitting Diode (LED) street lights. Such replacement is being precipitated by advances in lighting technologies, high economic efficiencies of LEDs, and plummeting interest in manufacturing LPS fixtures. Waikoloa Village, HI, located on the western slopes of Mauna Kea, home to major northern hemisphere observatories, has for many years been almost exclusively illuminated by LPS lighting. During the winter of 2015-2016 the County of Hawai'i Department of Public Works, Traffic Division replaced the approximately 550 LPS street lights in the community with Filtered LED (FLED) fixtures on a one-for-one basis. About 100 other LPS lights on private properties in the community were similarly replaced by the lighting manufacturer. This retrofit offered an excellent opportunity to make measurements of lighting parameters in the community before and after the retrofit process. Measurements were made using satellite, airborne, and ground based observations, and included photometric, photographic, and spectroscopic measurements. Data analyzed included integrated brightness of the community, zenith angle function brightness distributions, and spectral energy distributions. We present the results of these observations and discuss their implications for future protection of astronomical observatory sites.

Author(s): Eric R. Craine[1], Brian L. Craine[2]
Institution(s): *1. STEM Laboratory, Inc., 2. Western Res. Co. Inc.*

121.02 – An Approach to Objectively Defining and Ranking Dark Night Communities

There has long been an interest in protecting dark skies around astronomical observatory sites, a task that has become more urgent with the rapid growth of communities surrounding many of these locations. "Dark sky communities" have been discussed in the context of stimulating interest in mediating effects of artificial light at night, and efforts have been made in some areas to attempt to legislate less intrusive lights. Arguably, the latter has been largely unsuccessful, and the former represents a very small percentage of the extant dark night areas. In nearly all instances, the trend is for community contributions to the overall light at night output to increase with time. A complementary, if not alternative, approach is to recognize that all communities are "dark night communities" until they are not. This implies, of course, an understanding of quantitative levels of light output and distributions, and some agreement on thresholds beyond which a community ceases to satisfy definition as a Dark Night Community. Three parameters of primary interest in this regard are 1) integrated community brightness as seen from the zenith, 2) zenith angle brightness distribution, and 3) spectral energy distribution. The first we have addressed using Suomi VIIRS satellite data, which we discuss in this presentation. These data can be further parsed by comparing with demographic databases of interest, such as population and area. In this presentation we discuss the metrics involved, a formula for weighting the metrics to generate a comparative score, and the implications of each for the evaluation of energy waste in hundreds of communities that have now been ranked.

Author(s): Roger B. Culver[1], Brian L. Craine3, Eric R. Craine[2]
Institution(s): *1. Colorado State Univ., 2. STEM Laboratory, Inc., 3. Western Research Company, Inc.*
Contributing team(s): 5203254505

121.03 – High Cadence Photometry of the Tumbling Hitomi X-ray Satellite

Hitomi was a Japanese X-ray astronomy satellite launched February 17, 2016. The space observatory was designed to perform imaging and spectroscopy in the hard X-ray band above 10 keV. It was hoped these measurements could provide insight into the evolution of galaxy clusters and the large-scale structure of the universe. On March 26, 2016, contact was lost with Hitomi. That same day, the United States Joint Space Operations Center (JSpOC) reported the breakup of the satellite into a total of 6 pieces. When clear weather was available beginning March 31, 2016, the satellite and several of its debris pieces were optically tracked and observed from Daytona Beach, Florida using the OSCOM system---designed for observation of small satellites and debris using commercial-of-the-shelf (COTS) equipment. The brightness of the main piece, peaking between magnitude 2 and 3 in the SDSS r' band, allowed photometric measurements to be made at over 100 Hz for several passes of the satellite and its debris over several nights. These high cadence measurements show a clear and consistent flash pattern with a primary period of 2.66 seconds. We present reduced photometric observations and discuss how high cadence data can be used to understand the cause of failure for future satellite missions or for shape modeling of debris and near-Earth asteroids.

Author(s): Forrest Gasdia[1], Sergei Bilardi[1], Aroh Barjatya[1]
Institution(s): *1. Embry-Riddle Aeronautical University*

200 – LAD Plenary Talk: X-ray Spectra and Photoionized Plasmas, Tim Kallman (NASA GSFC)

200.01 – X-ray Spectra and Photoionized Plasmas

Much of the emission from accreting compact objects (black holes and neutron stars) is in the X-ray band. Key diagnostic information about kinematics, gravitational potential, element abundances, and total energy output is contained in the emission and absorption features imprinted by reprocessing in gas which surrounds the accreting source. Observations of these features are a key goal of recent X-ray spectroscopy instruments. In this talk I will review the dominant physical processes in such plasmas, the likely spectral diagnostics, the science questions to be addressed, and examples from recent observations.

Author(s): Timothy R. Kallman[1]
Institution(s): *1. NASA's GSFC*

201 – Extrasolar Planets: Atmospheres

201.01 – Raman scattering by H_2 and N_2 in the atmospheres of exoplanets

Rayleigh scattering is an important source of opacity in the atmospheres of exoplanets at short optical and near-UV wavelengths. Raman scattering is an inelastic process related to Rayleigh scattering, but with a weaker cross section. We analyze the signatures of Raman scattering imprinted in the reflected light and the geometric albedo of exoplanets. Raman scattering causes filling-in of absorption lines in the incident spectrum, thus producing sharp enhancements in the geometric albedo. It also shifts the wavelengths of spectral features in the reflected light causing the Raman ghost lines. Observing the albedo enhancements could be used to measure the column density of the scattering molecule and provide constrains on the presence of clouds and hazes in the atmosphere. Observing the Raman ghost lines could be used to spectroscopically identify the main scatterer in the atmosphere -- molecules like H_2 or N_2 which do not show prominent spectral signatures in the optical wavelength range. If detected, ghost lines could also provide information about the temperature of the atmosphere. Here we present how these signatures of Raman scattering in hydrogen- and nitrogen-dominated atmospheres can be used as probes of atmospheric pressure, temperature and composition. We analyze the feasibility of detecting these features in the albedo spectra of nearby exoplanets with the existing and future observational facilities.

Author(s): Antonija Oklopcic[1], Christopher M. Hirata[2], Kevin Heng3
Institution(s): *1. California Institute of Technology, 2. Ohio State University, 3. University of Bern*

201.03 – The Surface of a Limestone-Rich World?

We present spectroscopic observations of the dust- and gas-enshrouded, polluted white dwarf star SDSSJ104341.53+085558.2 (hereafter SDSSJ1043). Hubble Space Telescope Cosmic Origins Spectrograph far-ultraviolet spectra combined with deep Keck HIRES optical spectroscopy reveal the elements C, O, Mg, Al, Si, P, S, Ca, Fe, and Ni and enable useful limits for Sc, Ti, V, Cr, and Mn in the photosphere of SDSSJ1043. From this suite of elements we determine that the parent body being accreted by SDSSJ1043 is dry, rocky, and iron-poor. Synthesizing all available heavily-polluted white dwarf measurements, we find a trend in the Fe/Mg vs Fe/Si abundance ratio-space suggestive of whether accreted material originates from the inner or outer regions of a rocky body; we use this trend to identify the material being accreted by SDSSJ1043 as likely to have come from the outermost layers of a differentiated object. Enhanced levels of Ca and C in this object can be explained by the presence of significant amounts of calcium-carbonate and, if definitive, could be suggestive of a world with a crust rich in limestone.

Author(s): Carl Melis[1], Patrick Dufour[2]
Institution(s): *1. UC San Diego, 2. Université de Montréal*

201.04 – EPIC211351816.01: A test of giant planet inflation scenarios

Giant planets with high equilibrium temperatures have been observed with radii larger than pure gravitational contraction models of formation would allow. Although these anomalously inflated planets have been known about for over a decade, it is unclear whether their inflation is caused by energy deposition from the host star, or inhibited cooling of the planet. These processes can be distinguished if the planet orbits at a period such that it becomes highly irradiated only when the star evolves onto the red giant branch. We report the discovery of EPIC211351816.01, a 1.4 Rjup planet orbiting a low-luminosity red giant star with a period of 8.4 days. Stellar and planetary parameters were obtained with medium and high-resolution spectra, and transit and asteroseismic analysis of the K2 lightcurve. Radial velocity measurements confirm the planetary nature of this object. Preliminary estimates of this planet's radius suggest planets become inflated directly from incident stellar radiation rather than by delayed loss of heat from formation. Further studies of planets around red giant branch stars will confirm or contradict this inflation hypothesis, and may reveal a new class of re-inflated planets.

Author(s): Samuel Kai Grunblatt[1], Eric Gaidos[1], Daniel Huber[2], Andrew Howard[1]
Institution(s): *1. University of Hawaii, 2. University of Sydney*

201.05 – K2 Warm Jupiters with the LCOGT TECH collaboration

Many transiting gas giant planets on short orbital periods (so called hot Jupiters) have larger radii than theoretically expected. Although several explanations have been proposed, none have completely solved this puzzle. As the number of known transiting planets grew a correlation was identified between gas giant radius and the stellar incident flux. Still, it is not clear whether this correlation is causation. Several questions remain and answering them will characterize in more detail this observed correlation and in turn the process responsible for the inflated radii, such as: Is the lack of inflated warm Jupiters a robust feature? What is the incident flux below which there are no inflated gas giants? How low in incident flux does this correlation stretch? These questions arise since there are only a small number of transiting gas giants with low incident flux, below about 10^8 erg/s/cm^2, corresponding to orbital periods of about 10 days and longer for a Sun-like host star. Discovering and confirming more transiting warm Jupiters is the goal of this project, undertaken by the LCOGT Transiting Exoplanet CHaracterization (TECH) team. We are using K2 as our main source of transiting warm Jupiter candidates, with a few candidates discovered in each K2 campaign. LCOGT telescopes are being used for obtaining additional ground-based transit light curves, which are critical for confirming and refining the K2 transit ephemeris as outliers during ingress or egress of the few transit events observed by K2 can bias the measured ephemeris. Further ground-based follow-up data, including spectroscopy, radial velocities, and high angular resolution imaging, are obtained by facilities directly accessible by LCOGT TECH team members. In addition, once LCOGT's Network of Robotic Echelle Spectrographs (NRES) are deployed in the near future they will allow obtaining spectroscopy and radial velocities with LCOGT facilities. On top of studying the inflated hot Jupiter conundrum, confirming a sample of warm Jupiters transiting bright stars will support extending atmospheric characterization and spin-orbit alignment studies beyond the hot Jupiter planet class.

Author(s): Avi Shporer[2], Daniel Bayliss5, William D. Cochran[8], Knicole D. Colón4, Diana Dragomir7, Enric Palle[1], Stephen Potter[6], Robert Siverd3
Institution(s): *1. Instituto de Astrofisica de Canarias, 2. JPL, 3. Las Cumbres Observatory Global Telescope, 4. NASA Ames Research Center, 5. Observatoire Astronomique de l'Université de Genève, 6. South African Astronomical Observatory, 7. University of Chicago, 8. University of Texas at Austin*
Contributing team(s): The LCOGT TECH collaboration

201.06 – Core Deuterium Fusion and Radius Inflation in Hot Jupiters

Several laboratory-based studies have shown that the Deuterium fusion cross-section is enhanced in a solid deuterated target as compared to a gas target, attributable to enhanced mobility of deuterons in a metal lattice. As an application, we propose that, for core temperatures and compositions characterizing hot Jupiters, screened Deuterium fusion can occur deep in the interior, and show that the amount of radius inflation from this effect can be important if there is sufficient rock-ice in the core. The mechanism of screened Deuterium fusion, operating in the above temperature range, is generally consistent with the trend in radius anomaly with planetary equilibrium temperature. We also explore the trend with planetary mass using a simple analytic model.

Author(s): Prashanth Jaikumar[1]
Institution(s): *1. CSU Long beach*
Contributing team(s): Rachid Ouyed

201.07 – The Most Suitable Habitats in the Galaxy

Astrophysical environments constrain life on the surface of planets. The classical habitable zone characterized by stellar luminosity and temperature may be defined both for single stars and planets in binary star systems. However, in many cases, habitability is strongly affected by stellar UV radiation, winds, and catastrophic events such as nearby supernovae, GRBs, and AGN. Planets with sufficiently thick atmospheres and strong magnetic fields provide protection against radiation from the host star(s) and some nearby radiation events. Atmospheric ozone provides significant UV shield if present. Single star and binary winds provide additional protection for habitable zone planets from galactic cosmic-rays. In certain cases, binary star winds have increased protection over single stars, by providing a longer path-length against particle fluxes, since these binaries produce a higher wind flux and thus a larger "heliosphere" than a single star of comparable mass. Metallicity also plays an important role, with improvements in habitability increasing with stellar metallicity. It is proposed that circumbinary planets, Earth-like and super-Earths, with thick atmospheres, including ozone, high metallicity, and strong magnetic fields are the most suitable habitats in the Galaxy.

Author(s): Paul A. Mason[1]
Institution(s): *1. New Mexico State University*
Contributing team(s): 5756406268

202 – Evolution of Galaxies

202.01 – The Information Content of Stellar Halos: Accretion Histories and Stellar Population Gradients in Quiescent Illustris Galaxies

Long dynamical timescales in the outskirts of galaxies are thought to preserve the information content of their accretion histories, in the form of stellar population gradients. We present a detailed analysis of the stellar halo properties of a statistically representative sample of quiescent galaxies from the Illustris simulation, and show that stellar population gradients at large radii can indeed be used to infer galactic accretion histories. We measure metallicity, age, and surface-brightness profiles in the halos of Illustris galaxies ranging from 10^{10} to 10^{12} solar masses. We find that the ex-situ mass fraction – the fraction of stars that were accreted from smaller bodies – at large radius is correlated with the gradients of both metallicity and surface-brightness between 2-10 effective radii. There is a tight relation between the two gradients, suggesting that the information content of hierarchical accretion is predominantly the same between the two. The residuals from this mean relation are correlated with the mean (mass-weighted) merger mass ratio, which implies that major and minor mergers leave slightly different signatures in the stellar populations of stellar halos.

Author(s): Benjamin A. Cook[1], Charlie Conroy[1], Annalisa Pillepich[1], Vicente Rodriguez-Gomez[1], Lars Hernquist[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*

202.02 – Distant Low-mass Galaxies as an Incisive Tool to Explore Galaxy Formation and Evolution

Distant low-mass galaxies, with stellar mass below 10^9.5 solar mass, are key to our understanding of galaxy formation. They are the building blocks or progenitors of massive galaxies, e.g., our Milky Way. They are also the most sensitive probes of the feedback mechanisms that regulate the star formation, due to their shallow gravitational potential wells. Our knowledge of distant low-mass galaxies is, however, very limited because of the difficulty of observing them as well as modeling them. I will present my work on using deep multi-wavelength photometric and spectroscopic surveys to study three aspects of low-mass galaxies when the universe was about 7-billion-year old ($0.5 \leq z \leq 1$): star formation history, gas-phase metallicity, and morphology. I will discuss how to use them to understand the physical mechanisms that control the mass--energy--chemical cycles in galaxies. The three aspects also shed light on the relation between galaxies and their dark matter halos.

Author(s): Yicheng Guo3, David C. Koo3, Sandra M. Faber3, Marc Rafelski[1], Jonathan R. Trump[2]
Institution(s): *1. IPAC/Caltech, 2. Penn State, 3. UCO/Lick Observatory*

202.03 – The Nature of Hβ+[OIII] and [OII] emitters to *z* ~ 5 with HiZELS: stellar mass functions and the evolution of EWs

I will present our recent-study of the properties of ~ 7000 narrow-band selected galaxies with strong Hβ+[OIII] and [OII] nebular emission lines from the High-*z* Emission Line Survey (HiZELS) between *z* ~ 0.8 – 5.0. Our sample covers a wide range in stellar mass
(*M*_stellar ~ 10^7.5–10^12.0 M⊙), rest-frame equivalent widths (EW_rest~ 10–10^5 A), and line luminosities (*L*_line ~ 10^40.5–10^43.2 erg s–1) allowing us to study the properties of typical active/star-forming galaxies. I will present our measurements of the Hβ+[OIII]-selected and [OII]-selected stellar mass functions and densities out to *z* ~ 3.5 where we find that for the Hβ+[OIII]-selected stellar mass functions both M* and φ* increases with cosmic time, which may be due to the [OIII] selection including an increasing fraction of AGN at lower redshifts. The [OII]-selected stellar mass functions show a constant *M** ≈ 10^11.6 M⊙ and a strong, increasing evolution with cosmic time in φ* in line with Hα studies. I will also present our measurements in the evolution of the rest-frame equivalent widths for both emission-lines up to *z* ~ 5. This is the first time that the EW_rest evolution has been directly measured for Hβ+[OIII] and [OII] emitters up to these redshifts (*z* > 1). We find evidence for a slower evolution for *z* > 2 in the H β+[OIII] EW_rest and a decreasing trend for *z* > 3 in the [OII] EW_rest evolution, which would imply low [OII] EW at the highest redshifts and higher [OIII]/[OII] line ratios. This suggests that the ionization parameter at higher redshift is significantly higher than the local Universe, although other factors such as changes in metallicities and abundances over cosmic time can influence the [OIII]/[OII] evolution. Our results set the stage for future near-IR space-based narrow-band and spectroscopic surveys to test our extrapolated predictions and also produce *z* > 5 measurements to constrain the high-*z* end of the EW_rest and [OIII]/[OII] evolution.

Author(s): Ali Ahmad Khostovan[2], David Sobral[1], Bahram Mobasher[2]
Institution(s): *1. Lancaster University, 2. University of California, Riverside*

202.04 – The MOSDEF Survey: The Strong Agreement Between Hα and UV-To-FIR Star Formation Rates for z ~ 2 Star-Forming Galaxies

We present the first direct comparison between Balmer line and panchromatic SED-based star-formation rates (SFRs) for z ~ 2 galaxies. While dust-corrected SFRs(Hα,Hβ) using Balmer decrements are commonly used at low redshift, it has been argued that Balmer lines may miss optically thick star-forming regions at high redshifts. In order to investigate this possible bias, we compare the SFRs(Hα,Hβ) with independently measured UV-to-far-IR SFRs for star-forming galaxies at z ~ 2. For this comparison we use a sample of galaxies selected from the unique spectroscopic dataset of the MOSFIRE Deep Evolution Field (MOSDEF) survey. The MOSDEF survey is a multi-year project that uses the near-IR MOSFIRE spectrograph on the 10-m Keck I telescope to characterize the gaseous and stellar contents of ~ 1500 rest-frame optically selected galaxies at $1.37 \leq z \leq 3.80$. In addition to the rest-frame optical spectra, we use data from Spitzer/MIPS 24 μm, Herschel/PACS 100 and 160 μm, and Herschel/SPIRE 250, 350, and 500 μm to measure mid- and far-IR fluxes. We fit the UV-to-far-IR SEDs with the state-of-the-art flexible stellar population synthesis (FSPS) models, which utilize energy balance to fit the stellar and dust emission simultaneously. Comparing the SFR(Hα,Hβ) with the robust UV-to-far-IR SED inferrred SFRs, show us how accurately Balmer decrements predict the obscuration of the nebular lines in order to robustly calculate SFRs for star-forming galaxies at high redshift. Furthermore, we use our data to assess SFR indicators based on modeling the UV-to-mid-IR SEDs or by adding SFR(UV) and SFR(IR), for which the latter is based on the empirical conversions from mid-IR to total IR luminosity. This study shed light on the validity of various SFR indicators, specifically the nebular emission lines, for galaxies at z ~ 2.

Author(s): Irene Shivaei[2], Naveen Reddy[2], Mariska T Kriek[1], Alice E. Shapley3, Bahram Mobasher[2], Alison L. Coil4, Brian D. Siana[2], Ryan Sanders3, Sedona Price[1], William R. Freeman[2], Mojegan Azadi4
Institution(s): *1. UC Berkeley, 2. UC Riverside, 3. UCLA, 4. UCSD*

202.05 – The MOSDEF Survey: Outflows from AGN at z~2.3

The MOSFIRE Deep Evolution Field (MOSDEF) survey, which is being undertaken with the new MOSFIRE spectrograph on the Keck I telescope, will obtain rest-frame optical spectra of ~1500 galaxies and AGN at 1.4 < z < 3.8. We analyze the spectra of 67 X-ray, IR, and/or optical AGN at z~2.3 in data from the first two years of the MOSDEF survey. We measure the H$_\beta$, [O III], H$_\alpha$ and [N II] emission line profiles to identify and characterize potential outflows from the AGN. We present measurements of the kinematics, physical extent, and emission line ratios of the outflows and quantify the high incidence of outflows in these AGN at z~2.3.

Author(s): Gene Leung[1], Alison L. Coil[1]
Institution(s): *1. UC San Diego*
Contributing team(s): MOSDEF Team

202.06 – Lyman continuum galaxies: Observed

Lyman continuum flux measurements at z ~ 3-4 and mechanisms behind the escape

Measuring the surviving Lyman continuum (LyC) flux and inferred ionizing photon escape fraction (f_esc) of Lyman break galaxies has proved challenging, in part due to the historical selection criteria based on a Lyman continuum break. A few galaxies, largely serendipitous, have been detected with measurable LyC flux but have colors inconsistent with Lyman break galaxy expectations for their specific redshifts. I will discuss our physically motivated technique that provides an accurate measure of the average f_esc for the z ~ 3 Lyman break galaxy population that has also identified a population of galaxies, termed Lyman continuum galaxies (LCGs) with high expected levels of surviving LyC flux. I will present the results of our program that uses 30-band photometry, HST imaging, and deep medium-band IR imaging from the ZFOURGE survey to select z ~ 3-4 LCGs. We obtained very deep Keck spectroscopy that has confirmed the LCG population and has directly measured the predicted level of LyC flux. In addition, our program has obtained deep Keck infrared spectroscopy to calibrate restframe optical nebular emission-line models used to predict the LyC escape fraction, with the aim to measure the f_esc of galaxies at the Epoch of Reionization where direct LyC flux detection is not possible.

Author(s): Jeff Cooke[1], Emma Ryan-Weber[1], Thibault Garel[2], C. Gonzalo Diaz[1]
Institution(s): *1. Swinburne University, 2. University of Lyon*

202.07 – What Powers Diffuse Lyα Emission around High-Redshift Galaxies?

We report the detection of diffuse Lyα emission, or Lyman-α halos (LAHs), around high-redshift star-forming galaxies. Our samples consist of ~1400 galaxies at z~2.66 and z~3.78 within the total area of 2.0 deg^2 where several massive protoclusters are known to reside. Taking advantage of the wide range of galaxy parameters spanned by our samples, we investigate how the LAH characteristics depend on UV and Lyα properties and local environmental galaxy density. We find that the median size of the LAHs depends strongly on UV continuum luminosities (and thus UV star formation rates), while it does not correlate with Lyα equivalent widths and galaxy overdensity. The galaxies in our sample – the majority are continuum-faint Lyα line emitters (LAEs) – have the median LAH size of 5-6 kpc with 40-50% of the Lyα emission originating from the diffuse Lyα halo. However, the most UV-luminous galaxies show more extended halos (6-9 kpc). Most of the discrepancies found among the existing studies may be reconciled if the LAH size is primarily driven by the UV luminosity of the host galaxy, while other parameters themselves weakly correlate with UV luminosities but with large scatter. Based on the considerations of the observed trends and detailed comparisons of the measured Lyα radial profile with theoretical predictions, we conclude that diffuse Lyα emission is largely powered by central star formation while the contribution from gravitational cooling and faint satellites is at best secondary.

Author(s): Rui Xue[1], Kyoung-Soo Lee[1]
Institution(s): *1. Purdue University*

202.08 – Origin of Non-axisymmetric Features of dEs in the Virgo Cluster

A fraction of early-type dwarf galaxies in the Virgo cluster have a disk component and even possess disk features such as bar, lens, and spiral arms. Using N-body simulations, we propose formation scenarios of these non-axisymmetric features in the disky dwarf galaxies. By adopting VCC 856 as our progenitor, a bulgeless dwarf disk galaxy with embedded faint spiral arms, we construct 11 initial conditions with slight dynamical variations based on observational error range. After 10 Gyrs of evolution in isolation, our standard model slowly forms a bar at ~3 Gyr and then undergoes buckling instability that temporarily weakens the bar, although the bar strength continues to grow afterward. Nine of our isolated models are also unstable to bar formation and undergo buckling instability. This suggests that the disky dwarf galaxies are intrinsically unstable to form bars, accounting for a population of barred dwarf galaxies in the outskirts of the Virgo cluster. We also find that both the concentration of dark matter halo and the degree of random motions within stellar disk affect the vigor of buckling instability. To understand the origin of the faint grand-design spiral arms, we additionally construct 6 sets of tidal models by differing pericenter distances. We reveal that its formation mechanism is rather more complicated: the faint spiral arms consistent with the observations could develop on marginally unstable disk by relatively weak tidal force. We discuss our results in light of dynamical evolution of disky dwarf galaxies including mergers.

Author(s): SungWon Kwak[2], Woong-Tae Kim[2], Soo-Chang Rey[1], Suk Kim[1]
Institution(s): *1. Chungnam National University, 2. Seoul National University*

202.09 – FIRE simulations: galactic outflows and their consequences

We study gaseous outflows and their consequences in high-resolution galaxy formation simulations with explicit stellar feedback from the Feedback in Realistic Environments project. Collective, galaxy scale, effect of stellar feedback results in episodic ejections of large amount of gas and heavy elements into the circum-galactic medium. Gas ejection episodes follow strong bursts of star formation. Properties of galactic star formation and ejection episodes depend on galaxy mass and redshift and, together with gas infall and recycling, shape the evolution of the circum-galactic medium and galaxies. As a consequence, our simulated galaxies have masses, star formation histories and heavy element content in good agreement with the observed population of galaxies.

Author(s): Dusan Keres[1]
Institution(s): *1. University of California San Diego*
Contributing team(s): FIRE team

203 – Bridging Laboratory & Astrophysics: Molecules in the mm II

Laboratory astrophysics is the Rosetta Stone that enables astronomers to understand and interpret the cosmos. This session will focus on the interplay between astrophysics with theoretical and experimental studies into the underlying molecular processes, which drive our Universe, with special attention to connections with ALMA observations.

203.01 – On the importance of having accurate data for astrophysical modelling

The Herschel telescope and the ALMA and NOEMA interferometers have opened new windows of observation for wavelengths ranging from far infrared to sub-millimeter with spatial and spectral resolutions previously unmatched. To make the most of these observations, an accurate knowledge of the physical and chemical processes occurring in the interstellar and circumstellar media is essential.
In this presentation, I will discuss what are the current needs of astrophysics in terms of molecular data and I will show that accurate molecular data are crucial for the proper determination of the physical conditions in molecular clouds.
First, I will focus on collisional excitation studies that are needed for molecular lines modelling beyond the Local Thermodynamic Equilibrium (LTE) approach. In particular, I will show how new collisional data for the HCN and HNC isomers, two tracers of star forming conditions, have allowed solving the problem of their respective abundance in cold molecular clouds. I will also present the last collisional data that have been computed in order to analyse new highly resolved observations provided by the ALMA interferometer.
Then, I will present the calculation of accurate rate constants for the $F+H_2 \rightarrow HF+H$ and $Cl+H_2 \leftrightarrow HCl+H$ reactions, which have allowed a more accurate determination of the physical conditions in diffuse molecular clouds. I will also present the recent work on the ortho-para-H_2 conversion due to hydrogen exchange that allow more accurate determination of the ortho-to-para-H_2 ratio in the universe and that imply a significant revision of the cooling mechanism in astrophysical media.

Author(s): Francois Lique[1]
Institution(s): *1. University Le Havre*

203.02 – Millimeter and Sub-millimeter High Resolution Spectroscopy: New Frontiers with ALMA

It is becoming increasingly clear that new laboratory data will be critical for the next decade of observations with the Atacama Large Millimeter Array (ALMA). The high spatial resolution offered by ALMA will probe new regions of molecular complexity, including the inner envelopes of evolved stars, regions dominated by UV radiation, and the densest cores of molecular clouds. New molecular lines will be discovered in the wide wavelength range covered by the ALMA bands, and high resolution, gas-phase spectroscopy are needed to provide crucial “rest frequencies.” In particular, highly accurate methods that measure millimeter and sub-millimeter rotational transitions, such as direct absorption and Fourier transform mm-wave techniques, are important, especially when coupled to exotic molecular production schemes. Recent ALMA studies of SH+ and larger organic species have already demonstrated the need for laboratory measurements. New laboratory work will likely be required for circumstellar refractory molecules, radicals and ions generated near photon-dominated regions (PDRs), and large, organic-type species. This talk will give an overview of current contributions of laboratory spectroscopy to ALMA observations, summarize relevant spectroscopic techniques, and provide input into future prospects and directions.

Author(s): Lucy M. Ziurys[1]
Institution(s): *1. Univ. of Arizona*

203.03 – The Role of Low-Energy Electrons in Astrochemistry: A Tale of Two Molecules

In the interstellar medium, UV photolysis of ice mantles encasing dust grains is thought to be the mechanism that drives the synthesis of “complex” molecules. The source of this reaction-initiating UV light is assumed to be local because externally-sourced UV radiation cannot pass through the ice-containing dark, dense molecular clouds. Externally sourced cosmic rays ($E_{max} \sim 10^{20}$ eV), in addition to producing UV light within these clouds, also produce large numbers of low-energy (≤ 20 eV) secondary electrons. The goal of our studies is to understand the low-energy electron-induced processes that occur when high-energy cosmic rays interact with interstellar ices. Using electron stimulated desorption (ESD), post-irradiation temperature-programmed desorption (TPD), and infrared reflection absorption spectroscopy (IRAS), we have investigated the radiolysis initiated by electrons in condensed methanol and ammonia at ~ 90 K under ultrahigh vacuum (1×10^{-9} Torr) conditions. We have identified fifteen low-energy (≤ 20 eV) electron-induced methanol radiolysis products, many of which have been previously identified as being formed by methanol UV photolysis in the interstellar medium. We have also found evidence for the electron-induced formation from ammonia of hydrazine (N_2H_4), diazene (N_2H_2), cyclotriazane/triazene (N_3H_3) and triazane (N_3H_5). We have investigated the reaction yields’ dependence on film thickness, irradiation time, incident current, electron energy, and metal substrate. These results provide a basis from which we can begin to understand the mechanisms by which methanol and ammonia can form more complex species in cosmic ices. Studies such as ours may ultimately help us better understand the initial stages of the genesis of life.

Author(s): Chris Arumainayagam[1], Jyoti Cambell[1]
Institution(s): *1. Wellesley College*
Contributing team(s): Leon Sanche, Michael Boyer, and Petra Swiderek.

203.04 – Life's First Handshake - Discovery of the Interstellar Chiral Molecule Propylene Oxide

Life on Earth relies on chiral molecules, that is, species not superimposable on their mirror images. This manifests itself in the selection of a single molecular handedness, or homochirality, across the biosphere, and is perhaps most readily apparent in the large enhancement in biological activity of particular amino acid and sugar enantiomers. Yet, the ancestral origin of biological homochirality remains a mystery. The non-racemic ratios in some organics isolated from primitive meteorites hint at a primordial chiral seed, but even these samples have experienced substantial processing during planetary assembly, obscuring their complete histories. To determine the underlying origin of any enantiomeric excess, it is critical to understand the molecular gas from which these molecules originated. Here, we present the first extra-solar, astronomical detection of a chiral molecule, propylene oxide (CH_3CHCH_2O), in absorption toward the Galactic Center. We discuss the implications of the detection on observational searches to determine a primordial chiral excess, as well as the state of laboratory efforts in these areas.

Author(s): Brett A. McGuire3, P. Brandon Carroll[1], Ryan A. Loomis[2], Ian A Finneran[1], Philip R. Jewell3, Anthony J. Remijan3, Geoffrey A. Blake[1]
Institution(s): *1. California Institute of Technology, 2. Harvard-Smithsonian Center for Astrophysics, 3. National Radio Astronomy Observatory*

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204 – The Limits of Scientific Cosmology: Setting the Stage

The goals of the first session are to lay out what most astronomers would agree is established about cosmology beyond reasonable doubt albeit with some "grey" areas, to present the case that much of what is being proposed lies beyond traditional norms for scientific inquiry and should be treated with caution and a contrary view that modern cosmology and related fields require us to go beyond these norms and develop new methodologies It is planned to conclude with a roundtable comprising the three speakers fielding questions.

204.01 – Accepted Facts in Observational Cosmology

I will review the observational evidence, both historical and modern, for the current "Standard Cosmological Model".

Author(s): Wendy L. Freedman[1]
Institution(s): *1. University of Chicago*

204.02 – The Limits of Scientific Cosmology: How Far Can We Go?

I will discuss the limits of scientific cosmology. I will give examples of scientific challenges in cosmology that may never be explored in our lifetimes, and perhaps only via idealized experiments that may not be practically feasible, given our present understanding. I will contrast this approach with challenges raised by theories whose evaluation raises more subtle issues, often appealing for Bayesian considerations to bolster non-empirical verification.

Author(s): Joseph I Silk[1]
Institution(s): *1. Institute of Astrophysics*

204.03 – Normal Science in a Multiverse

A number of theories in contemporary physics and cosmology place an emphasis on features that are hard, and arguably impossible, to test. These include the cosmological multiverse as well as some approaches to quantum gravity. Worries have been raised that these models attempt to sidestep the purportedly crucial principle of falsifiability. Proponents of these theories sometimes suggest that we are seeing a new approach to science, while opponents fear that we are abandoning science altogether. I will argue that in fact these theories are straightforwardly scientific and can be evaluated in absolutely conventional ways, based on empiricism, abduction (inference to the best explanation), and Bayesian reasoning. The integrity of science remains intact.

Author(s): Sean Carroll[1]
Institution(s): *1. Caltech*

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205 – Small Telescope Research Communities of Practice: Research Areas

Suitable for Small Telescopes

Advances in low cost but increasingly powerful instrumentation, computers, and software have greatly increased the capabilities of smaller telescopes. Close visual binary star astronomy provides a good example of how such advances have allowed observers, at very low cost, to obtain outstanding results. Visual double stars with separations below the seeing limit typically require speckle interferometry observations with high-speed, low-noise, electron-multiplying emCCD cameras costing well over $10,000. Recently, however, low-noise CMOS cameras (such as the ZWO ASI290MM) have become available which cost under $1000 and perform nearly as well. There are many other areas that are well suited to smaller telescope research, including time series photometry of eclipsing binaries, variable stars, exoplanet transits, and asteroids, not to mention asteroid and lunar occultations, as well as stellar polarimetry. Low resolution spectroscopy on smaller telescopes works well for both stellar spectral classification and following variable stars. These many research areas have not only benefited from camera and computer advances, but increasingly from the automation of smaller telescopes and observatories.

205.01 – Advances in Small-Telescope Speckle Interferometry

The current revolution in CMOS camera technology has enabled a new generation of small telescope systems targeted at the measurement of close binary systems using the techniques of speckle interferometry and bispectrum analysis. These inexpensive, ultra-sensitive, high resolution cameras are now outperforming CCD technology, and come at a truly affordable price. In addition, dedicated, user-friendly speckle interferometry reduction software has been developed for the amateur, making it easy to perform the otherwise complicated data processing tasks. This talk will address these recent advances in hardware and software, and describe some of the results of the informal amateur-professional collaboration that has formed around them.

Author(s): David J. Rowe[1]
Institution(s): *1. PlaneWave Instruments*

205.02 – A Low Cost Grism Spectrometer for Small Telescopes

We have designed and built a low cost (appx. $500) low resolution (R ~ 300) grating-prism (grism) spectrometer for the University of Iowa's robotic observatory. Grism spectrometers differ from simple transmission grating systems by partially compensating for the curved focal plane using a wedge prism. The spectrometer has five optical elements, and was designed using a ray tracing program. The collimating and focusing optics are easily modified for other telescope optics. The optics are mounted in an enclosure made with a 3-d printer. The spectrometer was installed in a modified (extended) filter wheel and has been in routine operation since January 2016. I will show sample spectra using this system and discuss spectral calibration, and optical design considerations for other telescopes. I will also discuss how low-resolution spectrometers can be used in undergraduate teaching laboratories.

Author(s): Dominic Ludovici[1]
Institution(s): *1. University of Iowa*

205.03 – Second-to-Last Thoughts

You can't really prepare an abstract of a concluding-remarks talk, but having spent 19 years, 8 months as a full time student (Sept. 1948, Toluca Lake Grammar School kindergarten to April 1968 Caltech Ph.D.), most of the ensuing 48 years as a teacher, and about 51 years as some sort of astronomer, I find myself woefully ignorant of astronomy education and therefore well prepared to bring a fresh and vacant mind to the ideas presented by our colleagues here. Several thoughts, however, intrude. First, as Cecilia Payne Gaposchkin said, "a woman should do astronomy only if nothing else will satisfy her, for nothing else is what she will get." Make that "person" and "science" and it still carries much truth. Second, it is better to be a professional astronomer and an amateur alto than the converse. And third, it is better to be a professional dentist and an amateur astronomer than the converse. This, I think, leaves room for all of us to work in areas that we find attractive and that we turn out to be reasonably good at. The latter is at least as important as the former. There is a great deal of pleasure to be found as a second-rate singer or artist, but not, I hope, as a lousy astronomer or teacher.

Author(s): Virginia L. Trimble[1]
Institution(s): *1. UC, Irvine*

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206 – Plenary Talk: APOGEE: The New View of the Milky Way -- Large Scale Galactic Structure, Jo Bovy (University of Toronto)

206.01 – APOGEE: The New View of the Milky Way -- Large Scale Galactic Structure

Observations of the structure and dynamics of different stellar populations in the Milky Way's disk provide a unique perspective on galactic growth, evolution, and dynamics over cosmic time. The Apache Point Observatory Galactic Evolution Experiment (APOGEE) has over the past five years collected almost 1 million high-resolution (R~22,500), high quality (S/N > 100) spectra in the near-infrared H-band (1.51-1.68 μm) for about 250,000 stars covering all stellar populations of the Milky Way. I will take the audience on a tour of the exciting results from APOGEE and show how its novel, global view of the Milky Way is reshaping our understanding of how galactic disks form and evolve.

Author(s): Jo Bovy[1]
Institution(s): *1. University of Toronto*

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208 – Classification and Properties of Variables, Binaries and White Dwarfs and Stellar Evolution

208.01D – Ensemble Supervised and Unsupervised Learning with Kepler Variable Stars

Variable star analysis and classification is an important task in the understanding of stellar features and processes. While historically classifications have been done manually by highly skilled experts, the recent and rapid expansion in the quantity and quality of data has demanded new techniques, most notably automatic classification through supervised machine learning. I present a study on variable stars in the Kepler field using these techniques, and the novel work of unsupervised learning. I use new methods of characterization and multiple independent classifiers to produce an ensemble classifier that equals or matches existing classification abilities. I also explore the possibilities of unsupervised learning in making novel feature discovery in stars.

Author(s): Gideon Bass[1]
Institution(s): *1. George Mason University*
Contributing team(s): Kirk Borne

208.02 – Classification of compact binaries: an X-ray analog to the HR diagram

X-ray binary systems (XRBs), when examined in an appropriate coordinate system derived from X-ray spectral and intensity information, appear to cluster based on their compact object type. We introduce such a coordinate system, in which two coordinates are hardness ratios and the third is a broadband X-ray intensity. In Gopalan, Vrtilek, & Bornn (2015) we developed a Bayesian statistical model that estimates the probability that an XRB contains a black hole, non-pulsing neutron star, or pulsing neutron star, depending on its location in our coordinate space. In particular, we utilized a latent variable model in which the latent variables follow a Gaussian process prior distribution. Here we expand our work to incorporate systems where the compact object is a white dwarf: cataclysmic variables (CVs). The fact that the CVs also fall into a location spatially distinct from the other XRB types supports the use of X-ray color-color-intensity diagrams as 3-dimensional analogs to the Hertzsprung-Russell diagram for normal stars.

Author(s): Saeqa Dil Vrtilek[2], John C. Raymond[2], Giri Gopalan[2], Bram Seth Boroson[1], Luke Bornn[2]
Institution(s): *1. Clayton State University, 2. Harvard-Smithsonian, CfA*

208.03 – Rapid and Bright Stellar-mass Binary Black Hole Mergers in Active Galactic Nuclei

Galactic nuclei are expected to harbor the densest population of stellar-mass black holes, accounting for as much as ~ 2% of the mass of the nuclear stellar cluster. A significant fraction (~ 30%) of these black holes can reside in binaries. We discuss the fate of the black hole binaries in active galactic nuclei, which get trapped in the inner region of the accretion disk around the central supermassive black hole. Binary black holes can migrate into and then rapidly merge within the disk. The binaries also accrete a significant amount of gas from the disk, potentially leading to detectable X-ray or gamma-ray emission.

Author(s): Imre Bartos[1]
Institution(s): *1. Columbia University*

208.04 – Modeling the Variable Polarization of Epsilon Aurigae

The nature of the edge-on eclipsing binary Epsilon Aurigae remains perplexing, despite notable progress since the recent 2009-2011 eclipse. The binary involves an early F supergiant with a still unknown companion enshrouded in a disk. Although the eclipse geometry produces a significant broad band polarization signature, semiregular pulsations of the F supergiant are also a source of variable polarization, with an amplitude that is commensurate with the effect of the eclipse. This fact makes use of the polarization for studying the disk of the companion far more challenging. In an effort to better understand the pulsation nature of the supergiant, we explore a simple model for the stellar contribution to the polarization signal. The model does reasonably well in characterizing the gross properties of the time-variable polarization.

Author(s): Richard Ignace[1], Gary D. Henson[1], William Asbury[1]
Institution(s): *1. East Tennessee State Univ.*

208.05D – A Search for Planets and Brown Dwarfs around Post Main Sequence Stars

The most promising current theory for the origin of subdwarf B (sdB) stars is that they were formed during binary star evolution. This project was conducted to test this hypothesis by searching for companions around six sdB pulsators using the Observed-minus-Calculated (O-C) method. A star's position in space will wobble due to the gravitational forces of any companion. If it is emitting a periodic signal, the orbital motion of the star around the system's center of mass causes periodic changes in the light pulse arrival times. O-C diagrams for six sdB pulsators were constructed from several years' observations, providing useful limits on suspected companions' minimum masses and semimajor axes. The results were constrained by "period vs. amplitude" and "mass vs. semimajor axis" models to quantify companion masses and semimajor axes that are consistent with the observational data, if any.
Two of our targets, V391 Peg and HS0702+6043, are noted in previous publications to have substellar companions. These were used to validate the method used in this research. The results of this study yielded the same masses and semimajor axes for these two stars as the published values, within the uncertainties. Another of the targets, EC20117-4014, is noted in the literature as a binary system containing an sdB and F5V star, however the orbital period and separation were unknown. The new data obtained in this study contain the signal of a companion candidate with a period of 158.01 *days*. Several possible mass and semimajor axis combinations for the companion are consistent with the observations. One of the other targets in this study displayed preliminary evidence for a companion that will require further observation. Though still a small sample, these results suggest that planets often survive the post-main-sequence evolution of their parent stars.

Author(s): Tomomi Otani[2], Terry D. Oswalt[1]
Institution(s): *1. Embry Riddle Aeronautical University, 2. Florida Institute of Technology*

208.06 – Mass Determination of the Nearby White Dwarf Stein 2051B through Astrometric Microlensing using HST

The nearby white dwarf (WD) Stein 2051B is one of the coolest and oldest known WDs. It passed very close to a 19.5-mag background star in 2014 March, with an impact parameter of only ~0.1 arcsec. This afforded us the opportunity to measure the mass of this WD through the deflection of the position of the background star -- the first application of this method to measure a stellar mass. We obtained HST/WFC3 images of the field at 7 epochs during the close passage to measure the deflection of the faint star. Since the background star is fainter than the WD by a factor of 400, it was a challenge to measure the astrometric deflection, but the deflection has been clearly measured. The gravitational deflection angle depends only on the distances and relative positions of the stars, and on the mass of the WD. Since the parallax distance and the positions of the WD could be determined precisely from the HST observations, the astrometric measurement offers a unique and direct method to measure the mass of the WD. One key astrophysical prediction for WDs is the existence of a mass-radius relation, which depends primarily on the core composition of the WD. Since the radius of Stein 2051B is known (from its distance, luminosity, and effective temperature), our mass measurement provides an important addition to the very small number of WDs with well-determined radii and masses.

Author(s): Kailash C. Sahu[1], Jay Anderson[1], Stefano Casertano[1], Howard E. Bond[1], Edmund P. Nelan[1], Annalisa Calamida[1], Noe Kains[1]
Institution(s): *1. STScI*

208.07 – Interesting Cataclysmic Variables Observed with K2

The K2 long continuous coverage (75 days) of various fields around the ecliptic has provided novel light curves of a variety of cataclysmic variables, many of which are too faint for previous detailed studies. The data through K2-6 has produced light curves for 38 systems, many of which have multiple dwarf nova outbursts. The coverage allows visibility of pre-cursors, inter-outburst behavior as well as orbital features such as eclipses and hot spots. Some of the most intriguing features are presented.

Author(s): Paula Szkody[1], Peter M. Garnavich[2], Mark Kennedy[2], Zhibin Dai3
Institution(s): *1. Univ. of Washington, 2. University of Notre Dame, 3. Yunnan Observatories*

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209 – The Milky Way and Dwarf Galaxies

209.01 – Metallicity Distribution Functions of Dwarf Galaxies: A Probe of Star Formation History and Baryonic Physics

We examine the metallicity distribution functions (MDFs) of simulated, isolated dwarf galaxies (M$_{star}$ = 4 $\times$ 10^{4} - 3 $\times$ 10^{8} M$_{\odot}$) from the Feedback in Realistic Environments (FIRE) project to quantify the impact of star formation history (SFH) and baryonic physics. These high-resolution cosmological simulations include realistic treatments of stellar evolution and complex gas dynamics and do not require the usual approximations (e.g., instantaneous recycling and instantaneous mixing) of analytic chemical evolution models. The evolution of the MDF with redshift informs which processes drive the dominant contributions to the distribution at z = 0, thus enabling a reconstruction of the SFH and gas loss/accretion history. We then compare the theoretical MDFs to the observed MDFs of Local Group dwarf galaxies to infer plausible SFHs for each matched galaxy.

Author(s): Ivanna Escala[1], Evan N Kirby[1], Andrew R. Wetzel[1], Philip F. Hopkins[1]
Institution(s): *1. California Institute of Technology*

209.02D – Testing the Caustic Ring Dark Matter Halo Model Against Observations in the Milky Way

One prediction of axion dark matter models is they can form Bose-Einstein condensates and rigid caustic rings as a halo collapses in the non-linear regime. In this thesis, we undertake the first study of a caustic ring model for the Milky Way halo (Duffy & Sikivie 2008), paying particular attention to observational consequences. We first present the formalism for calculating the gravitational acceleration of a caustic ring halo. The caustic ring dark matter theory reproduces a roughly logarithmic halo, with large perturbations near the rings. We show that this halo can reasonably match the known Galactic rotation curve. We are not able to confirm or rule out an association between the positions of the caustic rings and oscillations in the observed rotation curve, due to insufficient rotation curve data. We explore the effects of dark matter caustic rings on dwarf galaxy tidal disruption with N-body simulations. Simulations of the Sagittarius (Sgr) dwarf galaxy in a caustic ring halo potential, with disk and bulge parameters that are tuned to match the Galactic rotation curve, match observations of the Sgr trailing tidal tails as far as 90 kpc from the Galactic center. Like the Navarro-Frenk-White (NFW) halo, they are, however, unable to match the leading tidal tail. None of the caustic, NFW, or triaxial logarithmic halos are able to simultaneously match observations of the leading and trailing arms of the Sagittarius stream. We further show that simulations of dwarf galaxies that move through caustic rings are qualitatively similar to those moving in a logarithmic halo.
This research was funded by NSF grant AST 10-09670, the NASA-NY Space Grant, and the American Fellowship from AAUW.

Author(s): Julie Dumas[2], Heidi Jo Newberg[1], Bethany Niedzielski[1], Adam Susser[1], Jeffery M. Thompson[1], Jake Weiss[1], Kim M Lewis[1]
Institution(s): *1. Rensselaer Polytechnic Institute, 2. Vanderbilt University*

209.03 – A Numerical Study of Feathering Instability

The stability of a spiral shock of self-gravitating, magnetized interstellar medium is studied by performing two-dimensional numerical simulations of a local patch of tight-winding spiral arm. As previously suggested by the linear studies, two types of instabilities are identified, namely, wiggle instability and feathering instability. The former instability occurs in the hydrodynamics limit and results in short wavelength perturbations. On the other hand, the feathering instability requires both self-gravitating and magnetic fields and results in wider structures.

Author(s): Wing-Kit Lee[1], Hsiang-Hsu Wang[1]
Institution(s): *1. Academia Sinica Institute of Astronomy and Astrophysics*

209.04D – Sweating the small stuff: simulating dwarf galaxies, ultra-faint dwarf galaxies, and their own tiny satellites

The high dark matter content and the shallow potential wells of low mass galaxies (10^3 Msun < Mstar < 10^9.5 Msun) make them excellent testbeds for differing theories of galaxy formation. Additionally, the recent up-tick in the number and detail of Local Group dwarf galaxy observations provides a rich dataset for comparison to simulations that attempt to answer important questions in near field cosmology: why are there so few observed dwarfs compared to the number predicted by simulations? What shuts down star formation in ultra-faint galaxies? Why do dwarfs have inverted age gradients and what does it take to convert a dwarf irregular (dIrrs) into a dwarf spheroidal (dSph) galaxy?
We to attempt to answer these questions by running ultra-high resolution cosmological FIRE simulations of isolated dwarf galaxies. We predict that many ultra-faint dwarfs should exist as satellites of more massive isolated Local Group dwarfs. The ultra-faints (Mstar < 10^4 Msun) formed in these simulations have uniformly ancient stellar populations (> 10 Gyr), having had their star formation shut down by reionization. Additionally, we show that the kinematics and ellipticities of isolated simulated dwarf centrals are consistent with observed dSphs satellites without the need for harassment from a massive host. We further show that most (but not all) observed *isolated* dIrrs in the Local Volume also have dispersion-supported stellar populations, contradicting the previous view that these objects are rotating. Finally, we investigate the stellar age gradients in dwarfs — showing that early mergers and strong feedback can create an inverted gradient, with the older stars occupying larger galactocentric radii.
These results offer an interesting direction in testing models that attempt to solve dark matter problems via explosive feedback episodes. Can the same models that create large cores in simulated dwarfs preserve the mild stellar rotation that is seen in a minority of isolated dIrrs? Can the bursty star formation that created a dark matter core also match observed stellar gradients in low mass galaxies? Comparisons between our simulations and observed dwarfs should provide an important benchmark for this question going forward.

Author(s): Coral Rose Wheeler[1]
Institution(s): *1. University of California, Irvine*

209.05 – Missing metals and baryons in galaxies: Clues from our Milky Way

It is well-known that most galaxies are missing most of their baryonic mass. Perhaps more surprisingly, they also seem to be missing most of their metals. Our Milky Way galaxy, like other nearby galaxies, is missing most of its baryons. Cosmological simulations of galaxy formation suggest that the missing baryonic mass should reside in the circum-galactic medium (CGM), in a warm-hot gas phase at temperatures between one million and 10 million K. Although theoretical models predict the existence of the warm-hot gas in the CGM, detecting and characterizing the diffuse CGM has been difficult. At the expected temperatures the baryons are in the form of highly ionized plasma, observable in soft X-rays. A combination of absorption and emission studies at soft X-ray energies is required to fully characterize this warm-hot CGM. Recently, combining the Chandra observations of OVII and OVIII absorption lines and XMM-Newton and Suzaku measurements of the Galactic halo emission measure, we found that there is a huge reservoir of ionized gas around the Milky Way, with the mass of over 2 billion solar masses and the radius of over 100 kpc.

I will present Chandra, XMM-Newton and Suzaku observations probing our Milky Way halo in absorption and emission. Our results show that the Milky Way halo contains a huge reservoir of warm-hot gas that may account for a large fraction of missing baryons and metals. I'll review current status of this field, discuss implications of our results to models of galaxy formation and evolution and outline paths for future progress.

Author(s): Anjali Gupta[1], Smita Mathur[2]
Institution(s): *1. CSCC, 2. Ohio State University*

209.06 – Character and properties of near-infrared excess sources in the Galactic centre

Near-infrared observations reveal a large number of young stars in the innermost parsec of the Galactic centre, with estimated ages of a few million years. Recently, a group of near-infrared excess sources located in the S-cluster has been studied and the basic characteristics of their continuum and spectra have been determined. One of the objects, Dusty S-cluster object (DSO/G2), has recently passed the pericentre at approx. 2000 Schwarzschild radii and remained compact, which implies that at least in this case it is a dust-enshrouded star, plausibly even younger than numerous massive OB stars in the region. The occurrence of such a young object supports the theory of continuing star-formation in the Galactic centre.
We will report on our analysis of how these objects - plausibly pre-main-sequence stars - that are apparently still embedded in dusty envelopes could have formed in the innermost parts of the dense nuclear star cluster. In particular, we study under which conditions infalling molecular gas can reach sufficient densities to

collapse, fragment and form stars. Furthermore, we analyze the typical timescales that determine the stability of circumstellar envelopes and disks that give rise to the near-infrared excess of these young objects. The stability and optical depth of the envelopes determine the spectral energy distribution, for which we give predictions. In the analysis, we employ dynamical modelling (analytical and numerical) and 3D Monte Carlo radiative transfer modelling.

Author(s): Michal Zajacek[2], Andreas Eckart[2], Monika Valencia-S.[2], Florian Peissker[2], Vladimir Karas[1]
Institution(s): *1. Astronomical Institute of the Academy of Sciences of the Czech Republic, 2. Universität zu Köln*

209.07 – The Secret Lives of Cepheids: The prototype Classical Cepheid δ Cephei is a Pulsed Variable X-ray and FUV Source - Implications for achieving a high precision Hubble Constant (Ho)

As part of our "Secret Lives of Cepheids" program, we report that the prototype Classical Cepheid – δ Cep is an X-ray source with pulsation-modulated X-ray & FUV emissions. Recent Chandra X-ray observations, when combined with our previous *Chandra* & *XMM-Newton* data, confirm a periodic sharp ~ 5 fold increase in X-ray flux at ~ 0.5φ. The X-ray emission phases with the star's pulsation P = 5.366-d, confirms that the X-ray emissions arise from the Cepheid itself and not from a companion. The X-ray variation is "spike-like" with an Lx (max) ~ 2.1 $x10^{29}$ erg/s, with plasma temperatures of ~ 2 - 6 MK. The *HST-COS FUV* fluxes increase ~10-20 times and reach maximum strengths during ~0.88-0.97φ - prior to maximum brightness. The FUV emissions arise from ionized plasmas with T ~10 - 300 $x10^3$ K. The FUV emission lines show turbulent broadening near the maximum fluxes. The FUV emissions are best explained by pulsation-induced collisional shocks originating from the star's pulsating atmosphere. However, the X-ray emissions occur 0.5 - 0.6 φ (~3 days) later than the FUV emission line maxima. Thus, it appears that the X-ray emissions arise further out from the star. We suggests that to produce the observed high temperature X-ray emitting plasmas, that the X-rays most likely arise from pulsation-shock induced turbulent-magnetic heated plasmas. If this behavior is extended to other Cepheids, the presence of pulsation induced X-ray and FUV emissions could play major roles in the dynamics and heating of Cepheid atmospheres and could have consequences affecting the Cepheid Period-Luminosity (P-L) law.
For example, the additional energy and shock-heating could produce enhanced mass loss leading to the formation of circumstellar shells. For example, the presence of circumstellar matter could bias the *P-L* relation if not accounted for. Similar X-ray - UV behavior is indicated by at least one other Cepheid, β Doradus.
This research is supported from grants from NASA for the HST, Chandra and XMM-Newton observations.

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Author(s): Edward F. Guinan[4], Scott G. Engle[4], Hilding Neilson[3], Graham M Harper[2], Nancy Remage Evans[1]
Institution(s): *1. SAO, 2. University of Colorado, 3. University of Toronto, 4. Villanova Univ.*

210 – Bridging Laboratory & Astrophysics: Planetary Physics in the mm and X-rays

Laboratory astrophysics is the Rosetta Stone that enables astronomers to understand and interpret the cosmos. This session will focus on the interplay between astrophysics with theoretical and experimental studies into the underlying planetary science processes, which drive our Universe, with special attention to observations done with ALMA and Astro-H.

210.01 – Remote detection and mapping of organic molecules in Titan's atmosphere using ALMA

Titan is the largest moon of Saturn, with a thick (1.45 bar) atmosphere composed primarily of molecular nitrogen and methane. Atmospheric photochemistry results in the production of a wide range of complex organic molecules, including hydrocarbons, nitriles, aromatics and species of possible pre-biotic relevance. Studies of Titan's atmospheric chemistry thus provide a unique opportunity to explore the origin and evolution of complex organic matter in a primitive (terrestrial) planetary atmosphere.
Underpinned by laboratory measurements, remote and in-situ observations of hydrocarbons, nitriles and oxygen-bearing species provide important new insights in this regard. The Atacama Large Millimeter/submillimeter Array (ALMA) is a powerful new facility, well suited to the study of molecular emission from Titan's upper and middle-atmosphere. This presentation will focus on results from our ongoing studies of Titan using ALMA during the period 2012-2014, including detection and mapping of rotational emission lines from molecules including HNC, CO, HC3N, CH3CN, C2H3CN and C2H5CN, as well minor isotopologues. Possible chemical formation pathways for these species will be discussed, and the the scope for improved understanding of non-aqueous organic chemistry through laboratory experiments and atmospheric/liquid-phase simulations under Titan-like conditions will be examined.

Author(s): Martin Cordiner[2], Conor A. Nixon[2], Steven B. Charnley[2], Maureen Palmer[2], Michael J. Mumma[2], Edward Molter[2], Nicholas Teanby4, Patrick GJ Irwin5, Zbigniew Kisiel3, Joseph Serigano[1]
Institution(s): *1. John's Hopkins University, 2. NASA Goddard Space Flight Center, 3. Polish Academy of Sciences, 4. University of Bristol, 5. University of Oxford*

210.02 – Snow Lines in Gas Rich Protoplanetary Disks and the Delivery of Volatiles to Planetary Surfaces

Compared to the Sun and to the gas+dust composition of the interstellar medium from which the solar system formed, the Carbon and Nitrogen content of the bulk silicate Earth (mantle+hydrosphere+atmosphere) is reduced by several orders of magnitude, relative to Silicon. Evidence from primitive bodies as a function of distance from the Sun suggests that at least part of this depletion must occur early in the process of planetesimal assembly. With combined infrared and (sub)mm observations such as those enabled by ground-based 8-10m class telescopes (and in future the James Webb Space Telescope) and the Atacama Large Millimeter Array (ALMA), we can now examine the principal volatile reservoirs of gas rich disks as a function position within the disk and evolutionary state. Key to these studies is the concept of condensation fronts, or 'snow lines,' in disks - locations at which key volatiles such as water, carbon monoxide, or nitrogen first condense from the gas. This talk will review the observational characterization of snow lines in protoplanetary disks, especially recent ALMA observations, and highlight the laboratory astrophysics studies and theoretical investigations that are needed to tie the observational results to the delivery of volatiles to planetary surfaces in the habitable zones around Sun-like stars.

Author(s): Geoffrey A. Blake[1]
Institution(s): *1. Caltech*

210.03 – Theoretical and Experimental Approaches to Understanding the Anomalous Distribution of Oxygen Isotopes in the Solar System

Decades of careful laboratory analysis of primitive meteorites have revealed an intriguing and unexplained pattern in the distribution of oxygen isotopes in the solar system. With the recent analysis of solar wind oxygen by NASA's Genesis mission, it appears that the Sun has a distinct oxygen isotopic composition from the terrestrial planets, asteroids, and comets. These differences cannot be explained by mass-dependent diffusion and require a physical-chemical mechanism or mechanisms that separate oxygen isotopes in a non-mass dependent manner.

Several hypothesis have been proposed to explain the anomalous distribution. Photochemical self-shielding of CO may explain the anomalous distribution, however, this mechanism has key weaknesses including the requirement of a very fine tuned timescale to explain the isotopic differences between the Sun and bulk of the terrestrial planets. Recently, attention has been directed at understanding specific chemical reactions that occur on interstellar dust grains due to their similarities with non-equilibrium photochemical reactions believed to be responsible for the mass-independent isotopic fractionation patterns observed in Earth's atmosphere. A specific focus has been directed towards understanding the formation of H_2O because some of its precursor (HO_2, and O_3) are well-known to acquire mass-independent isotopic signatures when formed in the gas-phase.

In this presentation, I describe a series of laboratory astrophysical experiments whose goal is to understand the distribution of oxygen isotopes in the solar system and perhaps, by extension, the distribution in other planetary systems. Preliminary results for the isotopic composition of O_3 formed at 5K will be presented as well as the first, to our knowledge, measurements of the isotopic composition of H_2O ($^{18}O/^{16}O$, $^{17}O/^{16}O$, D/H) formed at 32K. We find that H_2O formed in the astrophysical conditions we simulated acquired an anomalous isotopic composition with a triple-oxygen isotope plot slope ($\Delta\delta^{17}O/\Delta\delta^{18}O$) similar to the Carbonaceous Chondrite and Anhydrous Mineral line that characterizes the distribution of oxygen isotopes in the solar system.

Author(s): Gerardo Dominguez[1], Elizabeth Christensen[1], Charisa Boyer[1], Manesseh Park[1], Ezra Benitez[1], Morgan Nunn[2], Mark H. Thiemens[2], Terri Jackson[2]
Institution(s): *1. California State University, San Marcos, 2. University of California, San Diego*

210.04 – Cometary Solar Wind Charge Exchange Line Ratios: Source of X-rays in Comet C/2000 WM1 (linear)

Cometary solar wind charge exchange (C-SWCX) occurs when highly charged projectile ions present in solar wind capture an electron from a target neutral species present in the cometary atmosphere. The availability of atomic and molecular data necessary for the X-ray emission modeling due to C-SWCX is limited; therefore, we apply multi-channel Landau-Zener (MCLZ) theory (Mullen et al. 2016) to generate cross section data and theoretical X-ray line ratios for a variety of bare and non-bare ion single electron capture (SEC) collisions. Namely, we consider collisions between the solar wind constituent H-like and He-like ions of C, N, O, Ne, Na, Al, and Si and the cometary neutrals H, H_2O, CO, CO_2, OH, and O. To exemplify the application of this data, we model the X-ray emission of comet C/2000 WM1 (linear) using the charge exchange package in SPEX (Gu et al. 2015) and find excellent agreement with observations made with the XMM-RGS detector. Our analyses show that the X-ray intensity is dominated by C-SWCX with H.

Work at UGA was partially funded by NASA grant NNX13AF31G.

References:
Gu et al. 2016, A&A, *accepted 22 January 2016*
Mullen et al. 2016, ApJS, *in press*

Author(s): Patrick Dean Mullen[2], Renata Cumbee[2], David Lyons[2], Liyi Gu[1], Jelle S. Kaastra[1], Robin L. Shelton[2], Phillip C. Stancil[2]
Institution(s): *1. SRON Netherlands Institute for Space Research, 2. University of Georgia*

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211 – The Limits of Scientific Cosmology: Historical and Cosmological Context

The goals of the second session are to present a context form the discussion. In particular we wish to examine if the questions of today have strong historical roots and if they crop up in other scientific disciplines. The first talk will be historical, the second philosophical and the third will make the case that in astronomy we have often proceeded from the eponymous to the ensemble and it is reasonable to entertain this possibility for the observable universe. We will conclude with another round table.

211.01 – The history of changing boundaries in cosmology

Cosmology has always been self-consciously on the edge of science. Traditionally, the danger of unhinged speculation has meant that cosmologists, more than most scientists, felt a need to explicitly defend their work as properly scientific. For the last two centuries or so, each generation of astronomers has claimed that they were the first to be able to understand the early universe. A historical perspective on the changing standards of what has counted as scientific cosmology can help flag persistent sticking points, and perhaps suggest some past successful strategies for widening what counts as "scientific."

Author(s): Matthew Stanley[1]
Institution(s): *1. New York University*

211.02 – Non-Empirical Confirmation

In fundamental physics today, some theories are taken to be probably viable despite a lack of strong (or any) empirical confirmation. This situation suggests, I argue, an extension of the concept of theory confirmation that allows for confirmation by observations that are not predicted by the theory in question. "Non-empirical confirmation", as I call the latter form of confirmation, plays a more conspicuous role today than in earlier periods of physics. It has always constituted a significant albeit implicit element of the assessment of physical theory, however, that has not been adequately accounted for in canonical reconstructions of the scientific method. The talk discusses the core argumentative structure of non-empirical confirmation, analyses the concept's reliance on the empirical testability of the theories in question and addresses some worries that have been raised in its regard.

Author(s): Richard Dawid[1]
Institution(s): *1. University of Stockholm*

211.03 – From One to Many

For most of our early ancestors, the earth was the universe, with a blue bowl over it, good things above and evil things below, and exoplanets would have been multiverses. The steps beyond that included (1) many planets orbiting the sun, (2) the stars are suns, (3) most probably with their own planets, (4) the solar system is not central to the Milky Way, (5) other galaxies exist, and (6) many groups, clusters and superclusters (on a cosmic web). Famous names associated with these steps include Copernicus, Digges, Galileo, Newton, Shapley, Hubble, Sandage, and Peebles (plus many other less famous contributors). At every stage there have been mavens who said "one" and supermavens who have said "many". So far, the latter have always won. I see no reason why this should not continue to be the case onward to one or more of the concepts now subsumed under the name multiverse. If we cannot think of a way to falsify the concepts, does this mean that they are not science? Or does it just mean that we have not yet thought of the right observations, in the way the lagging 17^{th} century geocentrists did not anticipate Bradley's aberration of starlight and Kapteyn did not have the chance to incorporate Shapley's globular clusters in his universe? Some of the images shown will be more realistic than others.

Author(s): Virginia L. Trimble[1]
Institution(s): *1. UC, Irvine*

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212 – Plenary Talk: The Ocean World Enceladus, Linda Spilker (JPL)

212.01 – The Ocean World Enceladus

Does life exist elsewhere in our solar system? This key question has been a major motivator for our exploration beyond Earth. Life as we know it requires liquid water, organic chemistry and energy. As Cassini discoveries have shown, all of these key ingredients appear to exist on Saturn's tiny moon Enceladus, making it a possible habitat for life.
NASA's Cassini spacecraft arrived at Saturn in July 2004 and began making incredible findings in the Saturn system. Some of the most striking discoveries involved Enceladus. Only 300 miles in diameter, a huge plume of water ice and water vapor is erupting from a liquid

water reservoir under Enceladus' south pole. Jets and curtains of icy material shoot skyward from a series of four linear fractures nicknamed "tiger stripes". Over the course of the next decade, Cassini repeatedly flew close to Enceladus and directly sampled its icy plume seven times. Cassini's sensitive instruments discovered complex organic molecules, salts and silicates in the plume indicating that the water is in contact with a rocky core. We now know that the liquid reservoir underneath Enceladus' icy crust is not a regional sea but a global, subsurface ocean. The ocean is salty, much like our own seas. Excess heat originates from the narrow tiger stripes and tiny silica nanograins in the plume provide evidence for hydrothermal activity on Enceladus' seafloor. Similar hydrothermal systems on Earth support rich communities of life that contain organisms as large as tubeworms and crabs.
With each discovery, Enceladus becomes an increasingly enticing astrobiology target. Could life exist in Enceladus' ocean? A future mission may answer this question. Cassini was never meant to be a sea-faring mission, and while its instruments have helped answer important questions about the habitability of Enceladus, the question of whether life exists will require a more specialized set of instruments and a targeted mission. Enceladus' lofting of free samples into space makes it a compelling destination.
This research was performed at the Jet Propulsion Laboratory, California Institute of Technology (Caltech), under contract with NASA. Copyright 2016 Caltech. Government sponsorship is acknowledged.

Author(s): Linda J. Spilker[1], Morgan Cable[1]
Institution(s): *1. JPL*

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213 – Plenary Talk: MAVEN Observations of Atmospheric Loss at Mars, Shannon Curry (UC Berkeley)

213.01 – MAVEN Observations of Atmospheric Loss at Mars

The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission has been making observations of the Martian upper atmosphere and its escape to space since November 2014. The subject of atmospheric loss at terrestrial planets is a subject of intense interest not only because of the implications for past and present water reservoirs, but also for its impacts on the habitability of a planet. Atmospheric escape may have been especially effective at Mars, relative to Earth or Venus, due to its smaller size as well as the lack of a global dynamo magnetic field. Not only is the atmosphere less gravitationally bound, but also the lack of global magnetic field allows the impinging solar wind to interact directly with the Martian atmosphere. When the upper atmosphere is exposed to the solar wind, planetary neutrals can be ionized and 'picked up' by the solar wind and swept away.Both neutral and ion escape have played significant roles the long term climate change of Mars, and the MAVEN mission was designed to directly measure both escaping planetary neutrals and ions with high energy, mass, and time resolution. We will present 1.5 years of observations of atmospheric loss at Mars over a variety of solar and solar wind conditions, including extreme space weather events. We will report the average ion escape rate and the spatial distribution of escaping ions as measured by MAVEN and place them in context both with previous measurements of ion loss by other spacecraft (e.g. Phobos 2 and Mars Express) and with estimates of neutral escape rates by MAVEN. We will then report on the measured variability in ion escape rates with different drivers (e.g. solar EUV, solar wind pressure, etc.) and the implications for the total ion escape from Mars over time. Additionally, we will also discuss the implications for atmospheric escape at exoplanets, particularly weakly magnetized planetary bodies orbiting M-dwarfs, and the dominant escape mechanisms that may drive atmospheric erosion in other stellar systems.

Author(s): Shannon Curry5, Janet Luhmann5, Bruce M. Jakosky7, David Brain7, Francis LeBlanc[1], Ronan Modolo[1], Jasper S Halekas[8], Nicholas M. Schneider7, Justin Deighan7, James McFadden5, Jared R. Espley3, David L. Mitchell5, J. E. P. Connerney3, Yaxue Dong7, Chuanfei Dong4, Yingjuan Ma[6], Ofer Cohen9, Markus Fränz[2], Mats Holmström[2], Robin Ramstad[2], Takuya Hara5, Robert J. Lillis5
Institution(s): *1. LATMOS-IPSL/CNRS, 2. Max-Planck-Institute, 3. NASA GSFC, 4. Princeton University, 5. Space Sciences Laboratory, 6. UCLA, 7. University of Colorado, 8. University of Iowa, 9. University of Massachusetts*

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214 – Astronomy Education: In and Out of the Classroom, for All Ages, and Around the Globe Poster Session

214.01 – Measuring Visual Double Stars with Robotic Telescopes

The Astronomy Research Seminars introduce students to scientific research by carrying out the entire process: planning a scientific research project, writing a research proposal, gathering and analyzing observational data, drawing conclusions, and presenting the research results in a published paper and presentation.

In 2015 Cuesta College and Russell Genet sponsored a new hybrid format for the seminar enabling distance learning. Boyce Research Initiatives and Education Foundation (BRIEF) conducted the course at The Army and Navy Academy (ANA) in Carlsbad, California, in the spring and fall of 2015.

The course objective is to complete the research and publish the paper within one semester. Our program schedule called for observations to be performed within a two week period. Measurement of visual binary stars was chosen because sufficient observations could be made in just two evenings of good weather. We quickly learned that our location by the ocean did not provide reliable weather to use local telescopes.

The iTelescope network of robotic telescopes located in Australia, Spain and the U.S. solved the problem. Reservations for these systems are booked online and include date, time, exposure and filters. The high quality telescopes range from 4" to 27" in size with excellent cameras. By watching the weather forecasts for the sites, we were able to schedule our observations within the two week time frame required.

Timely and reliable data reduction was the next hurdle. The students were using widely varying equipment (PCs, MACs, tablets, smart phones) with incompatible software. After wasting time trying to be computer technicians, we settled a on standard set of software relying on Mirametrics' Mira Pro x64. We installed the software on an old laptop, downloaded the iTelescope data files, gave the students remote access using GoToMyPC.

These efficiencies enabled us to meet the demanding one semester schedule and assure a better learning experience. We have been able to produce four published research papers on seven visual double star systems and have our data added to the Washington Double Star Catalog. A school can adopt these techniques to do visual double star research with a minimal investment.

Author(s): Pat Boyce[1], Grady Boyce[1], Russell M. Genet[2]
Institution(s): *1. Boyce Research Initiative and Education Foundation, 2. Institute for Student Astronomical Research*
Contributing team(s): Faisal Al-Zaben, Dewei Li, Yongyao Li, Aren Dennis, Zhixin Cao, Junyao Li, Steven Qu, Jeff Li, Michael Fene, Allen Priest, Stephen Priest, Rex Qiu, , and, Bill Riley

214.02 – High School and Community College Astronomy Research Seminar

For the past decade, Cuesta College has held an Astronomy Research Seminar. Teams of high school and community college students, with guidance from instructors and advanced amateur astronomers, have made astronomical observations, reduced their data, and submitted their research results to appropriate journals. A variety of projects, using modest-aperture telescopes equipped with low-cost instruments, are within reach of motivated students. These include double star astrometry, variable star photometry, and exoplanet transit timing. Advanced scientific knowledge and mastery of sophisticated experimental skills are not required when the students are immersed within a supportive community of practice. The seminar features self-paced, online learning units, an online textbook (the *Small Telescope Astronomical Research Handbook),* and a supportive website sponsored by the Institute for Student Astronomical Research (www.In4StAR.org). There are no prerequisites for the seminar. This encourages everyone—including underrepresented minorities and persons with disabilities—to participate. Each participant contributes as their time, talents, and experience dictates, thus replicating the modern, professional research team. Our spring 2015 seminar was the largest yet. Volunteer assistant instructors provided local in-person leadership, while the entire seminar met online for PowerPoint presentations on proposed projects and final research results. Some 37 students from eight schools finished the seminar as coauthors of 19 papers published in the January 2016 volume of the *Journal of Double Star Observations.* Robotic telescopes devoted to student research are coming online at both Concordia University and the Boyce Astronomical Robotic Observatory, as is a central online sever that will provide students with uniform, cost-free reduction and analysis software. The seminar has motivated many of its graduates to pursue careers in science, engineering, and medicine, often with scholarships. We are planning on expanding the seminar to other high schools and community colleges within California and across the nation.

Author(s): Russell M. Genet[3], Pat Boyce[1], Robert Buchheim[8], Dwight Collins[4], Rachel Freed[7], Richard Harshaw[2], Jolyon Johnson[9], John Kenney[5], Vera Wallen[6]
Institution(s): *1. Boyce Research Initiatives and Educational Foundation, 2. Brilliant Sky Observatory, 3. California Polytechnic State University, 4. Collins Educational Foundation, 5. Concordia University, 6. Cuesta College, 7. Freed Educational Associates, 8. Society for Astronomical Sciences, 9. University of Washington*

214.03 – Hunting for Exoplanets at Florida Gulf Coast University

Honors Program participants at Florida Gulf Coast University must complete two of four required "Honors Experiences". One student option is a research experience, and we have developed a "Planet Hunters" course to provide an astronomical research track. In the course, students spend the first semester learning astronomical background and exoplanet detection techniques, while the second semester is devoted to planet searches in Kepler and K2 data, using student-oriented software tools developed specifically for the task. In this poster, we present the tools, data sets, and results obtained by students participating in the first year of the course, along with lessons learned for future implementation.

Author(s): Derek L. Buzasi[1], Andy Lezcano[1], Stephanie Fine[1], Cassandra Humes[1], Alex King[1], Keval Patel[1], Dakota Rivers[1], Kelsey Sinclair[1], Enzo Stacey[1], Leyla Vural[1], Jenna Zimmer[1]
Institution(s): *1. Florida Gulf Coast University*

214.04 – The Planetary Project

This poster presentation presents the Planetary Project, a multi-week simulated research experience for college non-science majors. Students work in research teams of three to investigate the properties of a fictitious planetary system (the “Planetary System”) created each semester by the instructor. The students write team and individual papers in which they use the available data to draw conclusions about planets, other objects or general properties of the Planetary System and in which they compare, contrast and explain the similarities between the objects in the Planetary System and comparable objects in the Solar System.

Data about the orbital and physical properties of the planets in the Planetary System are released at the start of the project. Each week the teams request data from a changing pool of available data. For example, in week one pictures of the planets are available. Each team picks one planet and the data (pictures) on that planet are released only to that team. Different data are available in subsequent weeks. Occasionally a news release to all groups reports an unusual occurrence - *e.g.* the appearance of a comet.

Each student acts as principal author for one of the group paper which must contain a description of the week’s data, conclusions derived from that data about the Planetary System and a comparison with the Solar System. Each students writes a final, individual paper on a topic of their choice dealing with the Planetary System in which they follow the same data, conclusion, comparison format.

Students “publish” their papers on a class-only restricted website and present their discoveries in class talks. Data are released to all on the website as the related papers are “published.” Additional papers commenting on the published work and released data are encouraged.

The successes and problems of the method are presented.

Author(s): Louis P. Pataki[1]
Institution(s): *1. New York University*

214.05 – The Quantitative Reasoning for College Science (QuaRCS) Assessment in non-Astro 101 Courses

The innumeracy of American students and adults is a much lamented educational problem. The quantitative reasoning skills of college students may be particularly addressed and improved in "general education" science courses like Astro 101. Demonstrating improvement requires a standardized instrument. Among the non-proprietary instruments the Quantitative Literacy and Reasoning Assessment[1] (QRLA) and the Quantitative Reasoning for College Science (QuaRCS) Assessment[2] stand out.

Follette et al. developed the QuaRCS in the context of Astro 101 at University of Arizona. We report on QuaRCS results in different contexts: pre-med physics and pre-nursing microbiology at a liberal arts college. We report on the mismatch between students' contemporaneous report of a question's difficulty and the actual probability of success. We report correlations between QuaRCS and other assessments of overall student performance in the class. We report differences in attitude towards mathematics in these two different but health-related student populations .

[1] QLRA, Gaze et al., 2014, DOI: http://dx.doi.org/10.5038 /1936-4660.7.2.4

[2] QuaRCS, Follette, et al., 2015, DOI: http://dx.doi.org/10.5038 /1936-4660.8.2.2

Author(s): Thomas W. Kirkman[2], Ellen Jensen[1]
Institution(s): *1. College of Saint Benedict, 2. St. Johns Univ.*

214.06 – InsightSTEM Campus Ambassadors: A Global Student Network to Promote Exploration in STEM Education

InsightSTEM has the mission to democratize STEM knowledge worldwide. Here, we present our InsightSTEM Campus Ambassadors program, and our growing global network of students worldwide. Our Campus Ambassadors are committed to advancing their careers in STEM fields, and in promoting exploration in STEM education -- while developing education and outreach skills that they can use during their student years, and moving forwards in their careers. We discuss the challenges of operating a remote student network worldwide, including addressing the needs of students in many different settings, on every continent. We illustrate how we can capture the passions of STEM students in allowing others to explore STEM knowledge. We explain how we deliver "profession development" for our cadre students, and leave them with education and outreach skills that move beyond "showing up and giving a PowerPoint presentation" to developing strategies to really engage multiple audiences in the exploration of STEM knowledge.

Author(s): Jacob Noel-Storr[1]
Institution(s): *1. InsightSTEM*
Contributing team(s): InsightSTEM Campus Ambassadors

214.07 – An Undergraduate Summer Research Program Through A University-Community College Partnership: Design and Results

We present a model for an undergraduate summer research program in astronomy targeted at 2-year and 4-year students and the short-term success of student participants. California State University San Bernardino (CSUSB) is Hispanic Serving Institution (HSI) serving 16,000 students, with no dominant ethnic or racial majority. Most (80%) CSUSB students are first-generation college students, and many of the students – both minority and "majority" – are *economically disadvantaged and cannot afford to take on research projects without compensation*. Approximately 60 percent of our students transfer from two year colleges, and all of the local community colleges are also officially designated as minority serving institutions. Mt. San Antonio College (Mt. SAC) is the largest single-campus community college in the state of California. It serves a student population of approximately 60,000 students (~35,000 full-time equivalent), also with no dominant ethnic or racial majority. Mt. SAC is currently 5th in the state in transfer ranking into the CSU system.

In an effort to involve students in research as early as possible, we selected 2 students from each campus to participate in a summer research program. This program taught students observational techniques, data reduction and analysis skills, and then allowed them to work on more complex faculty astronomical research projects. These students were not selected based on their grades, or specific courses completed, simply based on their essays expressing their interests in astronomy. Students were only required to have already completed at least 1 physics or astronomy class and typically would be classified as freshman or sophomores. This program ran for 2 summers, before funding ran out. By the end of each summer, students were able to run the state-of-the-art campus observatory, and many chose to continue working on their research projects into the school year. To date, 3 students were selected for further summer research programs at SETI, CIERA, UC-Irvine, and NASA centers JPL and Armstrong. An additional 3 students have obtained employment directly or indirectly related to the skills they developed in the program and 2 of the Mt. SAC students have transferred to 4-year institutions.

Author(s): Carol E. Hood[1], Michael Hood[2], Laura Woodney[1]
Institution(s): *1. California State University, San Bernadino, 2. Mt. San Antonio College*

214.08 – The Cal-Bridge Program: Increasing the Gender and Ethnic Diversity of Astrophysics Students in Southern California

The mission of the Cal-Bridge program is to increase the number of underrepresented minority and women students completing a bachelor's degree and entering a PhD program in astronomy, physics, or closely-related fields. The program has created a network of faculty at diverse higher education institutions, including 5 University of California (UC) campuses, 9 California State Universities (CSUs), and 10 community colleges in southern California, dedicated to this goal. Students selected for the program are know as "Cal-Bridge Scholars" and they are given a wide variety of support: (1) scholarships in their junior/senior years at CSU and their first year of graduate school at a UC, (2) intensive mentoring by a pair of CSU and UC faculty members, (3) tutoring, when needed, (4) professional development workshops, (5) exposure to research opportunities at various universities, and (6) membership in a growing cohort of like-minded students. We report on the structure of our program, lessons learned with our current 12 Cal-Bridge scholars, and the results of our first two years of operation. Funding for this program is provided by NSF-SSTEM Grant #1356133.

Author(s): Tammy A. Smecker-Hane[2], Alexander L. Rudolph[1]
Institution(s): *1. California State Polytechnic University, 2. UC, Irvine*

214.09 – The Cincinnati Observatory as a Research Instrument for Undergraduate Research

The Cincinnati Observatory, founded in 1842, was the first public observatory in the Western Hemisphere. The history of Cincinnati is closely intertwined with the history of the Observatory, and with the history of science in the United States. Previous directors of the Observatory helped to create the National Weather Service, the Minor Planet Center, and the first astronomical journal in the U.S. The Cincinnati Observatory was internationally known in the late 19th century, with Jules Verne mentioning the Cincinnati Observatory in two of his books, and the Observatory now stands as a National Historic Landmark.

No longer a research instrument, the Observatory is now a tool for promoting astronomy education to the general public. However, with the 11" and 16" refracting telescopes, the Observatory telescopes are very capable of collecting data to fuel undergraduate research projects. In this poster, we will discuss the history of the Observatory, types of student research projects capable with the Cincinnati Observatory, future plans, and preliminary results. The overall goal of this project is to produce a steady supply of undergraduate students collecting, analyzing, and interpreting data, and thereby introduce them to the techniques and methodology of an astronomer at an early stage of their academic career.

Author(s): Nicholas Abel3, Dean Regas[1], Davin C. Flateau[2], Cliff Larrabee3
Institution(s): *1. Cincinnati Observatory, 2. unaffiliated, 3. University of Cincinnati, Clermont Campus*
Contributing team(s): 5134605960

214.11 – A New Way to See Inside Black Holes

Black holes exert great fascination on the public, and are also widely misunderstood in many ways. Some of these misunderstandings result from the coordinate systems that are usually used to illustrate the internal structure of black holes. Any choice of coordinates necessarily produces a distorted view, just as the choice of projection distorts a map of the Earth. The truest way to depict the properties of a black hole is through quantities that are *coordinate-invariant*. We have computed and plotted the independent curvature invariants of rotating, charged black holes for the first time, revealing a deep interior "landscape" that is much more beautiful and complex than usually thought. The resulting images are useful for public outreach, especially in the centennial year of Einstein's theory of General Relativity.

Author(s): Kielan Wilcomb[2], James Overduin[2], Richard Conn Henry[1]
Institution(s): *1. Johns Hopkins University, 2. Towson University*

214.12 – When Will It Be ...?: U.S. Naval Observatory Calendar Computers

Sensitivity to religious calendars is increasingly expected when planning activities. Consequently, the U.S. Naval Observatory (USNO) has redesigned its on-line calendar resources to allow the computation of select religious dates for specific years via an application programming interface (API). This flexible interface returns dates in JavaScript Object Notation (JSON) that can be incorporated into third-party websites or applications. Currently, the services compute Christian, Islamic, and Jewish events.
The "Dates of Ash Wednesday and Easter" service (http://aa.usno.navy.mil/data/docs/easter.php) returns the dates of these two events for years after 1582 C.E. (1582 A.D.) The method of the western Christian churches is used to determined when Easter, a moveable feast, occurs.
The "Dates of Islamic New Year and Ramadan" service (http://aa.usno.navy.mil/data/docs/islamic.php) returns the approximate Gregorian dates of these two events for years after 1582 C.E. (990 A.H.) and Julian dates are computed for the years 622–1582 C.E. (1–990 A.H.). The appropriate year in the Islamic calendar (anno Hegira) is also provided. Each event begins at 6 P.M. or sunset on the preceding day. These events are computed using a tabular calendar for planning purposes; in practice, the actual event is determined by observation of the appropriate new Moon.

The “First Day of Passover” service (http://aa.usno.navy.mil /data/docs/passover.php) returns the Gregorian date corresponding to Nisan 15 for years after 1582 C.E. (5342 A.M.) and Julian dates are computed for the years 360–1582 C.E. (4120–5342 A.M.). The appropriate year in the Jewish calendar (anno Mundi) is also provided. Passover begins at 6 P.M. or sunset on the preceding day. On-line documentation for using the API-enabled calendar computers, including sample calls, is available (http://aa.usno.navy.mil/data/docs/api.php). The same web page also describes how to reach the Complete Sun and Moon Data for One Day, Phases of the Moon, Solar Eclipse Computer, Day and Night Across the Earth, and Apparent Disk of a Solar System Object services using API calls.
An “Introduction to Calendars” (http://aa.usno.navy.mil/faq/docs /calendars.php) provides an overview of the topic and links to additional resources.

Author(s): Jennifer L. Bartlett[1], Malynda Chizek Frouard[1], Michael V. Lesniak[1]
Institution(s): *1. US Naval Observatory*

214.13 – AAS Oral History Project

Now in its fourth year, the AAS Oral History Project has interviewed over 80 astronomers from all over the world. Led by the AAS Historical Astronomy Division (HAD) and partially funded by the American Institute of Physics Niels Bohr Library and ongoing support from the AAS, volunteers have collected oral histories from astronomers at professional meetings starting in 2015, including AAS, DPS, and the IAU general assembly. Each interview lasts one and a half to two hours and focuses on interviewees’ personal and professional lives. Questions include those about one’s family, childhood, strong influences on one’s scientific career, career path, successes and challenges, perspectives on how astronomy is changing as a field, and advice to the next generation. Each interview is audio recorded and transcribed, the content of which is checked with each interviewee. Once complete, interview transcripts are posted online as part of a larger oral history library at https://www.aip.org/history-programs/niels-bohr-library/oral-histories. Future analysis will reveal a rich story of astronomers and will help the community address issues of diversity, controversies, and the changing landscape of science. We are still recruiting individuals to be interviewed from all stages of career from undergraduate students to retired and emeritus astronomers. Contact Jarita Holbrook to schedule an interview or to find out more information about the project (astroholbrook@gmail.com). Also, contact Jarita Holbrook if you would like to become an interviewer for the project.

Author(s): Sanlyn Buxner[1], Jarita Holbrook[2]
Institution(s): *1. University of Arizona, 2. University of the Western Cape*
Contributing team(s): AAS Oral History Team

214.15 – Physics in our Universe

The recent detection of gravitational waves from the merger of two massive black holes means that we must now take Newton's approach to the Universe even more seriously than we have taken it since *Principia*: General Relativity has now been tested, as never before, and GR has passed with flying colors! In my poster I try to summarize all of fundamental physics taken together --- gravitation, dark energy, and particles. But the whole job is not yet done: mass + energy remains as a final frontier. It may be that the topology of 4-space is the answer: how I wish I were a mathematical topologist of great ability!

Author(s): Richard Conn Henry[1]
Institution(s): *1. Johns Hopkins Univ.*

214.16 – Bringing authentic service learning to the classroom: benefits and lessons learned

Project-based learning, which has gained significant attention within K-12 education, provides rich hands-on experiences for students. Bringing an element of service to the projects allow students to engage in a local or global community, providing an abundance of benefits to the students’ learning. For example, service projects build confidence, increase motivation, and exercise problem-solving and communication skills in addition to developing a deep understanding of content. I will present lessons I have learned through four years of providing service learning opportunities in my classroom. I share ideas for astronomy projects, tips for connecting and listening to a community, and helpful guidelines to hold students accountable in order to ensure a productive and educational project.

Author(s): Leslie C. Chamberlain[1]
Institution(s): *1. The Harpeth Hall School*

214.17 – Astronomical Data in Undergraduate courses

We present status and plans for our ongoing efforts to develop data analysis and problem-solving skills through Undergraduate Astronomy instruction. While our initiatives were developed with UM-Dearborn’s student body primarily in mind, they should be applicable for a wide range of institution and of student demographics. We focus here on two strands of our effort.

Firstly, students in our Introductory Astronomy (ASTR 130) general-education course now perform several “Data Investigations”, in which they interrogate the Hubble Legacy Archive to illustrate important course concepts. This was motivated in part by the realization that typical public data archives now include tools to interrogate the observations that are sufficiently accessible that introductory astronomy students can use them to perform real science, albeit mostly at a descriptive level. We are continuing to refine these investigations, and, most importantly, to critically assess their effectiveness in terms of the student learning outcomes we wish to achieve. This work is supported by grant HST-EO-13758, provided by NASA through a grant from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555.

Secondly, at the advanced-undergraduate level, students taking courses in our Astronomy minor are encouraged to gain early experience in techniques of astronomical observation and analysis that are used by professionals. We present two example projects from the Fall 2015 iteration of our upper-division course ASTR330 (The Cosmic Distance Ladder), one involving Solar System measurements, the second producing calibrated aperture photometry. For both projects students conducted, analysed, and interpreted observations using our 0.4m campus telescope, and used many of the same analysis tools as professional astronomers. This work is supported partly from a Research Initiation and Seed grant from the University of Michigan-Dearborn.

Author(s): William I. Clarkson[1], Carrie Swift[1], Kelli Hughes[1], Christopher J. F. Burke[1], Colin C Burgess[1], Aunna V Elrod[1], Brittany Howard[1], Lucas Stahl[1], David Matzke[1], Donald J. Bord[1]
Institution(s): *1. University of Michigan-Dearborn*

214.18 – CosmoQuest – Scientist Engagement with the Public and Schools via a Virtual Research Facility

CosmoQuest is a virtual research facility where science data can be analyzed by teams of interested citizen scientists from across the world. Scientists can apply to have their data analyzed through crowdsourcing in our online observatory, which generates validated and publishable results (Robbins et al 2014). Scientists have the opportunity to provide connections to teachers in classrooms so that students can analyze original data and understand the process that astronomers go through from image to result. Scientists can also teach online classes for different audiences including formal classroom teachers, informal educators, and lifelong learners to further the broader impacts of their work and increase engagement in their scientific endeavors. We provide training, through online and in-person workshops, on how to incorporate your datasets into the observatory and how to deliver online classes through our CosmoAcademy. This work is funded in part by NASA Cooperative Agreement Notice number NNX16AC68A. For more information, visit http://cosmoquest.org/.

Author(s): Jacob Noel-Storr[1], Sanlyn Buxner[2], Pamela L. Gay[3], Jennifer A. Grier[2], Cory Lehan[3]
Institution(s): *1. InsightSTEM, 2. Planetary Science Institute, 3. Southern Illinois University - Edwardsville*
Contributing team(s): The CosmoQuest Team

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215 – Galaxies Poster Session

215.01 – The Mysterious Galactic Center Radio Source N3

Here we report on new, multi-wavelength radio observations of the mysterious point source "N3" that appears to be located in the vicinity of the Galactic Center. VLA observations between 2 and 50 GHz reveal that N3 is a compact and bright non-thermal source (56 mJy at 10 GHz) which is superimposed upon the non-thermal radio filaments (NTFs) of the Radio Arc. Our highest frequency observations place a strict upper limit of 65x28 milli-arcseconds on the size of this source. We compare our observations to those of Yusef-Zadeh (1987) and Lang (1997) and conclude that N3 is variable over long time scales. Additionally, we present the detection of a compact molecular cloud located adjacent to N3 in projection. CH_3CN, CH_3OH, CS, HC_3N, HNCO, SiO, SO, and NH_3 are detected in the cloud and most transitions have FWHM line widths of ~20 km s^{-1}. The rotational temperature determined from the metastable NH_3 transitions ranges from 79 K to 183 K depending on the transitions used and the location in the cloud. We present evidence that this molecular cloud is interacting with N3. After exploring the relationship between the NTFs, molecular cloud, and N3, we conclude that N3 likely lies within the Galactic Center. While we are able to rule out many possible physical counterparts, including an active star, HII region, young supernova, AGN, and microquasar, further observations will be required to determine the true nature of this mysterious source.

Author(s): Dominic Ludovici[4], Cornelia C. Lang[4], Mark Morris[3], Robert Lucien Mutel[4], Elisabeth A.C. Mills[1], James E Toomey[2], Juergen Ott[1]
Institution(s): *1. National Radio Astronomy Observatory, 2. United States Coast Guard Academy, 3. University of California, 4. University of Iowa*

215.02 – Dynamical Simulations of Molecular Clouds in the Galactic Center

The formation of the central massive cluster of young stars orbiting the Galactic black hole, Sgr A*, has been modeled by several groups by invoking an almost radially infalling molecular cloud that interacts with the black hole and creates a dense, gaseous disk in which stars can then form. However, the dynamical origin of such a cloud remains an open question. We present simulations of the central 30-100 pc of the Milky Way, starting from a population of molecular clouds located in a disk with scale height of ~30 pc, using the N-body/smoothed-particle hydrodynamics code, Gadget2. We followed the dynamical evolution of clouds in a galactic potential that includes a bar to explore whether cloud collisions or a succession of cloud scatterings can remove sufficient angular momentum from a massive cloud to endow it with a predominantly radial orbit. Initial results illustrate the importance of tidal shear; while dense cloud cores remain identifiable for extended periods of time, much of the molecular mass ends up in tidal streams, so cannot be deflected onto low angular momentum orbits by their mutual interactions. At the completion of our ongoing computations, we will report on whether the cloud cores can undergo sufficient scattering to achieve low-angular-momentum orbits.

Author(s): Jesus Salas[1], Mark Morris[1]
Institution(s): *1. University of California - Los Angeles*

215.04 – Studying the Gravitational Dark Matter Wake of M33

Recent proper motions of M31 by Sohn et al. 2012 indicate that the Milky Way and Andromeda will coalesce in ~5.9 Gyr. We investigate the effects of dynamical friction exerted on M31's satellite galaxy M33 in the near future and throughout the impending Milky Way-Andromeda-M33 merger. We use the merger simulation presented in van der Marel, Besla, et al. (2012) with approximately 10^6 dark matter particles in order to analyze the density and morphology of the induced gravitational wake as M33 orbits within the dark matter halo of Andromeda and ultimately within the halo of the Andromeda-Milky Way merger remnant. We explore the mass, density and time evolution of the induced wake and its future consequences to M33's orbit and Andromeda's galactic disk.

Author(s): William Yingling[1], Gurtina Besla[1]
Institution(s): *1. University of Arizona*

215.05 – Exploring Bias and Uncertainty in Gaussian Mixture Models of Young, Massive Star Clusters

Mixture models are important for studies of star clusters observed against a foreground or background field population. By directly estimating both the distribution parameters of the components and the component fractions (and thus the formal membership probabilities), the populations of interest can be fit directly without recourse to binning. Gaussian Mixtures are a highly popular choice when modeling star clusters, and their determination using the Expectation Maximization algorithm, or its extension to cases with strongly varying measurement uncertainty (e.g. Bovy et al.'s Extreme Deconvolution) now appears in some statistics textbooks.
Here we describe our Monte Carlo study to estimate the effect of the choice of instrumental setup, particularly different field of views, on parameter recovery for simulated star clusters under a variety of situations. We simulate observations of a Young, Massive Cluster like those near the Galactic Center, focusing mainly on scenarios where the same cluster is observed from ground and from space. We characterize the bias and uncertainty that might be introduced when using this fairly recent yet increasingly popular technique across heterogenous instrumental setups.

Author(s): Aunna Elrod[1], William I. Clarkson[1]
Institution(s): *1. University of Michigan - Dearborn*

215.06 – An HI Survey of Extremely Isolated Early-Type Galaxies

We present the results of an HI survey of extremely isolated early-type galaxies (IEGs) using the NRAO Green Bank Telescope (GBT). The systems studied here, drawn from Marcum et al. (2004) and Fuse et al. (2012), were selected for their isolation from companions ($M_V < -16.5$) within a distance of at least 2.5 Mpc. Previous optical imaging/spectroscopy investigations of these galaxies found a higher percentage of the sample exhibiting recent or ongoing star formation, relative to their counterparts in higher density environments. The HI masses and kinematics derived from the presented data provide a characterization of the IEGs' gas reservoirs, which may be fueling their star formation. Initial findings from the HI survey, the first comprehensive assessment of neutral gas content within and around such systems, indicate at least 50% of the observed isolated early-type galaxies have detectable HI gas. We also find that a linear relationship between B–V and $\log(M_{HI}/L_B)$ provides a method for predicting H I mass in non-cluster early-type galaxies.

Author(s): Trisha L. Ashley[1], Pamela M. Marcum[2], Michael N. Fanelli[2]
Institution(s): *1. Bay Area Environmental Research Institute and NASA Ames, 2. NASA Ames*

215.07 – Hα Emitting Galaxies in the Deep And Wide Narrowband Survey

We present new measurements of the Hα luminosity function (LF) and star formation rate (SFR) volume density for galaxies at z~0.62. Our results are part of the Deep And Wide Narrowband Survey (DAWN), a unique infrared imaging program with large areal coverage (~1.1 deg^2 over 5 fields) and sensitivity (9.9×10^{-18} $erg/cm^2/s$ at 5σ). The present sample, based on a single DAWN field, contains 85 Hα emission-line candidates at z~0.62, 25% of which have spectroscopic confirmations. These candidates have been selected through comparison of narrow and broad-band images and through matching with existing catalogs in the COSMOS field. The dust-corrected LF is well described by a Schechter function. We calculate a SFR density of $\rho_{SFR} = 10^{(-1.15\pm0.07)}$ $M_\odot$ / yr/ Mpc3. We compare our results to already existing surveys at similar redshifts and find that our faint slope of the LF is flatter than that of most other surveys and that our SFR density is higher than that reported from similar surveys at z<2.

Author(s): Alicia Gonzalez[1], Sangeeta Malhotra[1], James E. Rhoads[1]
Institution(s): *1. Arizona State University*
Contributing team(s): DAWN collaboration

215.08 – Comparing sizes of Lyα and UV emission of Green Pea galaxies

We studied the spatial profiles of Lyα and UV emission from 16 Green Pea galaxies with Cosmic Origins Spectrograph (COS) data from the Hubble Space Telescope (HST). Green Pea galaxies are nearby analogs of high-z Lyα emitting galaxies. We extract the spatial profiles of Lyα emission from the 2D COS spectra of Green Peas. The Lyα emission shows more extended spatial profiles than the UV emissions in most galaxies in our sample. The intrinsic Lyα sizes (measured as the Full Width Half Maximum of intrinsic Lyα spatial profile) are about 2 to 5 times of the UV sizes (measured as the FWHM of UV image) in most cases. The Lyα emissions show large offsets from the UV emissions in three galaxies and double-horned spatial profile in one galaxy. We compare the spatial profiles of Lyα photons at different velocities and find a relation between Lyα velocity profile and spatial profile. These results suggest that most Lyα photons escape out of a galaxy through many resonant scatterings in the HI gas with low column density, instead of directly escaping through ionized holes in the interstellar medium.

Author(s): Huan Yang[1], Sangeeta Malhotra[1], James E. Rhoads[1], Tianxing Jiang[1], JunXian Wang[2]
Institution(s): *1. Arizona State University, 2. USTC*

215.09 – How do optically-similar quasars look elsewhere?

As too many spectroscopic and physical parameters complicates the study of quasars, reducing the number of parameters can help to isolate many problems in general. Using spectral principal component analysis, we selected from SDSS a pilot sample of quasars with virtually identical spectral features in H-beta region. We found that they also show very similar spectral features outside the H-beta region in the optical band. We also explore their properties in other available wavelength bands and plan to study the accretion, ionization, and possibly geometry of quasars using this controlled sample.

Author(s): Zhaohui Shang[1], Bin Ma[1], Michael S. Brotherton[2]
Institution(s): *1. National Astronomical Observatories, CAS, 2. University of Wyoming*

215.10 – The Impact of Baryonic Physics on the Structure of Dark Matter Halos: the View from the FIRE Cosmological Simulations

We study the distribution of cold dark matter (CDM) in cosmological simulations from the FIRE (Feedback In Realistic Environments) project, which incorporates explicit stellar feedback in the multi-phase ISM, with energetics from stellar population models. We find that stellar feedback, without ``fine-tuned" parameters, greatly alleviates small-scale problems in CDM. Feedback causes bursts of star formation and outflows, altering the DM distribution. As a result, the inner slope of the DM halo profile (α) shows a strong mass dependence: profiles are shallow at $M_h \sim 10^{10}$-10^{11} $M_\odot$ and steepen at higher/lower masses. The resulting core sizes and slopes are consistent with observations. Because the star formation efficiency, M_s/M_h is strongly halo mass dependent, a rapid change in α occurs around $M_h \sim 10^{10} M_\odot$, ($M_s \sim 10^6$-$10^7 M_\odot$) as sufficient feedback energy becomes available to perturb the DM. Large cores are not established during the period of rapid growth of halos because of ongoing DM mass accumulation. Instead, cores require several bursts of star formation after the rapid buildup has completed. Stellar feedback dramatically reduces circular velocities in the inner kpc of massive dwarfs; this could be sufficient to explain the ``Too Big To Fail" problem without invoking non-standard DM. Finally, feedback and baryonic contraction in Milky Way-mass halos produce DM profiles slightly shallower than the Navarro-Frenk-White profile, consistent with the normalization of the observed Tully-Fisher relation.

Author(s): Tsang Keung Chan[5], Dusan Keres[5], Jose Oñorbe[2], Philip F. Hopkins[1], Alexander Muratov[5], Claude-Andre Faucher-Giguere[3], Eliot Quataert[4]
Institution(s): *1. California Institute of Technology, 2. Max-Planck-Institut fuer Astronomie, 3. Northwestern University, 4. University of California Berkeley, 5. University of California San Diego*

215.11 – Stellar Population Maps of High-Redshift Galaxies

A comprehensive study of resolved galaxy structure can shed light on the formation and evolution of galactic properties, such as the distribution of stars and interstellar dust that obscures starlight. This requires high-resolution, multi-waveband photometry and spectroscopy to completely characterize the galaxies. Previous studies lacked key spectroscopic information, were comprised of small samples, or focused on the local universe. We use HST ACS/WFC3 high-resolution, multi-waveband imaging from the CANDELS project in parallel with moderate-resolution Keck I MOSFIRE spectra from the MOSFIRE Deep Evolution Field (MOSDEF) survey to produce resolved stellar population and dust maps of ~500 galaxies at redshifts $1.4 < z < 2.6$—covering the key epoch when galaxies accreted most of their mass. For data preparation and analysis we develop an automated Python program to process our large, comprehensive dataset. From the multi-waveband imaging and spectroscopic redshifts, we model the spectral energy distribution for every resolution element within each galaxy and compare these results to the spectroscopically measured global properties. From our stellar population and dust maps we identify resolved structures within these galaxies. We also investigate if spectroscopically measured galaxy properties are biased when compared with that of localized sub-galactic structures.

Author(s): Tara Fetherolf[1], Naveen Reddy[1]
Institution(s): *1. University of California Riverside*
Contributing team(s): MOSDEF

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216 – Instrumentation: Space Missions Poster Session

216.01 – A suborbital experiment to study Circumgalactic Lines in Ultraviolet Emission (CLUE)

We present the design and expected performance of CLUE, a new suborbital mission designed to image OVI emission from the circumgalactic medium of nearby galaxies. CLUE will act as a scientific pathfinder for future far ultraviolet emission missions. It will establish, on three nearby galaxies, the brightness, extent, and morphology of the OVI emission from the circumgalactic medium. These results will be essential in planning and evaluating any future FUV emission mission.

The experiment will demonstrate an instrument design, called the monochromatic imager, which provides an all-reflective solution to the "narrow band imaging problem". Narrowband imaging is a staple astronomical technique. It allows observers to map the spatial distribution of ionic, atomic, and molecular features, and to determine the temperature, density, etc. of the emitting gas. Unfortunately, this technique cannot be applied in the far-ultraviolet band where transmissive materials are unavailable and ionic features are closely spaced, requiring a quickly varying spectral response.

The monochromatic imager uses a conventional telescope with a grating monochromator to select the wavelength of interest. After passing through the monochromator an image of the target (now monochromatic) is focused on the detector. Unlike a push broom imaging system, CLUE produces a full image in a single emission line. CLUE is able to efficiently devote its observing time and detector area to collecting photons of interest while NOT devoting time and collecting area to recording uninteresting spectral regions.

Author(s): Timothy Cook[1], Bart P. Wakker[2], Susanna Finn[1], Jason F Martel[1]
Institution(s): *1. UMass Lowell, 2. University of Wisconsin*

216.02 – Fourteen Years of the Hubble Space Telescope's Advanced Camera for Surveys : Calibration Update

The Advanced Camera for Surveys (ACS) has been a workhorse HST imager for over fourteen years, subsequent to its Servicing Mission 3B installation in 2002. The once defunct ACS Wide Field Channel (WFC) has now been operating considerably longer (>7yrs) since its Servicing Mission 4 repair than it had originally operated (<5yrs) prior to its 2007 failure. Despite the accumulating radiation damage to the WFC CCDs during their long stay in low Earth orbit, ACS continues to be heavily exploited by the HST community as both a prime and a parallel detector. Conspicuous recent examples include the HST Multi-cycle Treasury programs, and the ongoing HST Frontier Fields (HFF) program.

We review recent developments in ACS calibration that enable the continued high performance of this instrument, including both the Wide Field Channel (WFC) and the Solar Blind Channel (WFC). Highlights include: 1) redefined WFC subarray modes to allow for more consistent high-fidelity calibration; 2) LED post-flashing the WFC darks to compensate for worsening WFC charge-transfer efficiency (CTE); 3) long term hot- and warm-pixel WFC stability analyses; and 4) refined characterization of the extended SBC point spread function and long-term SBC flatfield stability.

Author(s): Norman A. Grogin[1]
Institution(s): *1. Space Telescope Science Institute*
Contributing team(s): HST Advanced Camera for Surveys Instrument Team

216.03 – HST/WFC3: Evolution of the UVIS Channel's Charge Transfer Efficiency

The Wide Field Camera 3 (WFC3) on the Hubble Space Telescope (HST) contains both an IR and a UVIS channel. After more than six years on orbit, the UVIS channel performance remains stable; however, on-orbit radiation damage has caused the charge transfer efficiency (CTE) of UVIS's two CCDs to degrade. This degradation is seen as vertical charge 'bleeding' from sources during readout and its effect evolves as the CCDs age. The WFC3 team has developed software to perform corrections that push the charge back to the sources, although it cannot recover faint sources that have been bled out entirely. Observers can mitigate this effect in various ways such as by placing sources near the amplifiers, observing bright targets, and by increasing the total background to at least 12 electrons, either by using a broader filter, lengthening exposure time, or post-flashing. We present results from six years of calibration data to re-evaluate the best level of total background for mitigating CTE loss and to re-verify that the pixel-based CTE correction software is performing optimally over various background levels. In addition, we alert observers that CTE-corrected products are now available for retrieval from MAST as part of the CALWF3 v3.3 pipeline upgrade.

Author(s): Catherine Gosmeyer[1], Sylvia M. Baggett[1], Jay Anderson[1]
Institution(s): *1. Space Telescope Science Institute*
Contributing team(s): WFC3 Team

216.04 – HST/WFC3: Improvements to the UVIS Dark Calibration

The Hubble Space Telescope (HST) Wide Field Camera 3 (WFC3) UVIS detector, comprised of two e2v CCDs, exhibits an inherent dark current (in the absence of any illumination) presently measured at ~7 e-/hr and increasing at ~1 e-/hr/yr. Additionally, detector degradation due to on-orbit radiation damage generates a continuously increasing though small population of hot pixels (dark current exceeding 54 e-/hr, currently ~4% of each chip). We present the results of the WFC3/UVIS dark calibration, which provides calibration files used as a correction for these detector characteristics. We also discuss the impacts that Charge Transfer Efficiency (CTE) losses and detector post-flashing have on the hot pixel population, as well as various improvements to the calibration procedure that were introduced in the CALWF3 v3.3 pipeline.

Author(s): Matthew Bourque[1], Sylvia M. Baggett[1]
Institution(s): *1. Space Telescope Science Institute*
Contributing team(s): WFC3 Team

216.05 – WFC3: Status, Calibrations and Advice for the CY24 Observers

The Wide Field Camera 3 is UV, Visible and near Infrared Camera on boar of the Hubble Space Telescope. We report on the current status of the instrument and on the recent significant improvements in the photometric, flat fields, dark current, and CTE calibrations for the UVIS channel. As a result of this effort we obtained the new independent solutions for the two CCD detectors, and have improved the zero points and color terms in the near-UV and visual wavelengths. We report on the improved astrometric solutions and PSF calibrations. We also highlight new observing strategies recently developed to allow efficient observations of very wide fields of view. Finally new tools for the planning and extraction of slittles spectroscopic observations of crowded fields are presented.

Author(s): Elena Sabbi[1]
Institution(s): *1. STScI*
Contributing team(s): WFC3 Team

216.06 – HST Frontier Fields: WFC3/IR data processing, persistence, time-variable background

The Hubble Space Telescope Frontier Fields (HFF) pipeline and WFC3 teams discuss the specialized procedures for processing IR data for the Frontier Fields program. Frontier Fields is a Director's Discretionary program that uses ultra-deep imaging to observe lensing galaxy clusters in an effort to search for the most distant observable galaxy. The program uses both the Advanced Camera for Surveys (ACS) and Wide-Field Camera 3 (WFC3/IR) observing the prime and parallel areas of each field simultaneously. The WFC3/IR data are processed through a pipeline which performs calibrations not included in the standard CalWF3 software including persistence correction, Time-Variable-Background (TVB) correction, and scripts used to create satellite trail masks. Here the HFF pipeline team present the individual methods that perform the corrections and showcase the results of these corrections on sample data of Abell 370, Abell S1063 and others.

Author(s): Harish G. Khandrika[1], Anton M. Koekemoer[1], Jennifer M. Lotz[1], Jennifer Mack[1], Massimo Robberto[1], Bryan Hilbert[1], Elena Sabbi[1]
Institution(s): *1. Space Telescope Science Institute*
Contributing team(s): Hubble Frontier Fields Pipeline Team, WFC3 Team

216.07 – ACS/WFC Pixel Stability – Bringing the Pixels Back to the Science

Electrical current that has been trapped within the lattice structure of a Charged Coupled Device (CCD) can be present through multiple exposures, which will have an adverse effect on its science performance. The traditional way to correct for this extra charge is to take an image with the camera shutter closed periodically throughout the lifetime of the instrument. These images, generally referred to as dark images, allow for the characterization of the extra charge that is trapped within the CCD at the time of observation. This extra current can then be subtracted out of science images to correct for the extra charge that was there at this time. Pixels that have a charge above a certain threshold of current are marked as “hot” and flagged in the data quality array. However, these pixels may not be "bad" in the traditional sense that they cannot be reliably dark-subtracted. If these pixels are shown to be stable over an anneal period, the charge can be properly subtracted and the extra noise from this dark current can be taken into account. We present the results of a pixel history study that analyzes every pixel of ACS/WFC individually and allows pixels that were marked as bad to be brought back into the science image.

Author(s): David Borncamp[1], Norman A. Grogin[1], Matthew Bourque[1], Sara Ogaz[1]
Institution(s): *1. Space Telescope Science Institute*

216.09 – NIRSpec Pre-Imaging

Most future observations that will propose to obtain NIRSpec spectroscopy (such as all MSA observations, as well as crowded-field observations using the IFU and FS) will requiere high spatial resolution images of the science field previous to performing the spectroscopy. This is due to the fact that the standard NIRSpec target acquisition (TA) procedure needs to acquiere reference stars with a position RMS of less than 20mas. NIRSpec TA uses 8-20 reference stars with accurate astromerty (<5mas), calculates centroids of the individual stars on the detector, transforms their pixel coordinate positions into positions on the sky, and iterates on the telescope pointing and slew until the position RMS of the reference stars is less than 20mas.

For some planned observations, very high spatial resolution HST images (either ACS/WFC or WFC3/UVIS/IR) might be already available and, in other cases, NIRCam observations will be performed.

In this study we describe in detail the proposed method to generate a high resolution mosaic of the NIRSpec field of view for any given observation. We show several examples of a variety of science cases. We also describe the creation of catalogs of sources.
These two data products will be crucial for the success of any NIRSpec observation.

Author(s): Leonardo Ubeda[1], Tracy L. Beck[1]
Institution(s): *1. Space Telescope Science Institute*

216.10 – The SPHEREx All-Sky Spectroscopic Survey

SPHEREx is a mission to conduct an optical-near-IR survey of the entire sky with a spectrum at every pixel location. It was selected by NASA for a Phase A study in its Small Explorer Program; if selected, development would begin in 2016, and the observatory would start a 2-year prime mission in 2020. An all-sky spectroscopic survey can be used to tackle a wide range of science questions. The SPHEREx science team is focusing on three: (1) Probing the physics of inflation through measuring non-Gaussianity from the study of large-scale structure; (2) Studying the origin of water and biogenic molecules in a wide range of physical and chemical environments via ice absorption spectra; (3) Charting the history of star formation in the universe through intensity mapping of the large-scale spatial power.

The instrument is a small wide-field telescope operating in the range of 0.75 - 4.8 µm at a spectral resolution of 41.5 in the optical and 150 at the long-wavelength end. It observes in a sun-sync low-earth orbit, covering the sky like WISE and COBE. SPHEREx is a simple instrument that requires no new technology. The Phase A design has substantial technical and resource margins and can be built with low risk. It is a partnership between Caltech and JPL, with Ball Aerospace and the Korea Astronomy and Space Science Institute as major partners.

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Author(s): Stephen C. Unwin[1]
Institution(s): *1. JPL*
Contributing team(s): SPHEREx Science Team, SPHEREx Project Team

216.11 – Current Calibration Efforts and Performance of the HST Space Telescope Imaging Spectrograph: Echelle Flux Calibration, the BAR5 Occulter, and Lamp Lifetimes

The variety of operating modes of the Space Telescope Imaging Spectrograph (STIS) on the Hubble Space Telescope (HST) continues to allow STIS users to obtain unique, high quality observations and cutting-edge results 19 years after its installation on HST. STIS is currently the only instrument available to the astronomy community that allows high spectral and spatial resolution spectroscopy in the FUV and NUV, including echelle modes. STIS also supports solar-blind imaging in the FUV. In the optical, STIS provides long-slit, first-order spectra that take advantage of HST's superb spatial resolution, as well as several unique unfiltered coronagraphic modes, which continue to benefit the exoplanet and debris-disk communities. The STIS instrument team monitors the instrument's health and performance over time to characterize the effects of radiation damage and continued use of the detectors and optical elements. Additionally, the STIS team continues to improve the quality of data products for the user community. We present updates on efforts to improve the echelle flux calibration of overlapping spectral orders due to changes in the grating blaze function since HST Servicing Mission 4, and efforts to push the contrast limit and smallest inner working angle attainable with the coronagraphic BAR5 occulter. We also provide updates on the performance of the STIS calibration lamps, including work to maintain the accuracy of the wavelength calibration for all modes.

Author(s): TalaWanda R. Monroe[1], Alessandra Aloisi[1], John H. Debes[1], Robert I. Jedrzejewski[1], Sean A. Lockwood[1], Molly S. Peeples[1], Charles R. Proffitt[1], Allyssa Riley[1], Nolan R. Walborn[1]
Institution(s): *1. Space Telescope Science Institute*

216.12 – Updated Status and Performance for the Cosmic Origins Spectrograph

The Cosmic Origins Spectrograph (COS) was installed on the Hubble Space Telescope (HST) in May 2009. COS is designed to perform high-sensitivity medium- and low-resolution spectroscopy of astronomical objects in the far-ultraviolet (FUV) and near-ultraviolet (NUV) wavelength regimes. We present updates on the time-dependent sensitivities of both the NUV and FUV detectors. Additionally, we discuss the appearance and mitigation of transient, isolated regions of increased count rates on the COS FUV detector called "hot spots". We also present updates to the COS calibration pipeline, CalCOS, that provide improvements to COS data products.

Author(s): Joanna M. Taylor[1], Gisella De Rosa[1], John H. Debes[1], Justin Ely[1], Mees B. Fix[1], Andrew Fox[1], Robert I. Jedrzejewski[1], Sean A. Lockwood[1], TalaWanda R. Monroe[1], Cristina M. Oliveira[1], Molly S. Peeples[1], Steven V. Penton[1], Rachel Plesha[1], Charles R. Proffitt[1], Julia Roman-Duval[1], David J. Sahnow[1], Paule Sonnentrucker[1], Nolan R. Walborn[1], James White[1]
Institution(s): *1. Space Telescope Science Institute*

216.13 – Improvements to the Wavelength Calibration of the HST/COS FUV Detector

The Cosmic Origins Spectrograph (COS) was installed on the Hubble Space Telescope in 2009 during Servicing Mission 4. Since then, the teams at the Space Telescope Science Institute have striven to provide the highest quality scientific products to the community. One of the latest improvements to COS/FUV data is an updated wavelength solution. We improved wavelength dispersion solutions from the current accuracy of ~15 km/s for medium-resolution data obtained at Lifetime Position 1 (i.e. before July 2012). Here we present the methodology and results behind the improvements of the wavelength dispersion solutions. We also discuss ongoing efforts to improve the wavelength dispersion solutions for other lifetime positions as well as updates to the geometric distortion and walk corrections.

Author(s): Rachel Plesha[1], Thomas B. Ake[1], Justin Ely[1], Sean A. Lockwood[1], Cristina M. Oliveira[1], Steven V. Penton[1], Charles R. Proffitt[1], Julia Roman-Duval[1], David J. Sahnow[1], Paule Sonnentrucker[1]
Institution(s): *1. Space Telescope Science Institute*

216.14 – Hubble Space Telescope (HST) Fine

Guidance Sensor Performance Analysis with Respect to Guide Stars

The Fine Guidance Sensors (FGS) onboard HST include one of Hubble's first-generation instruments still in operation today. After several servicing missions and even some refurbishment to the FGSs, the interferometers, although aged, perform at a level exceeding expectations. Since launch in April 1990, FGS3 has performed within operational standards while FGS1 & 2 underwent replacements or refurbishments during SM2, SM3A and SM4. Up until 1999 FGS3 was used for astrometry science when FGS1R took over that role. Currently FGS1R is the only FGS used as a primary science instrument. While very few observing programs request the FGS as their prime instrument nearly all GO observations executed onboard HST use the interferometers to lock onto guide stars. Most observations execute successfully onboard HST while 1.93% of all orbits executed onboard HST have an issue that requires repeating the observations. Of all failed visits, roughly 65% are due to a variation of suboptimal guide star options that test the boundaries of FGS capabilities. In this poster we present the limitations of the FGS interferometers regarding guide stars, their surprising capabilities, and suggest specific guidelines to astronomers who are faced with "shared risk" opportunities for their observations. We hope to share this knowledge with the HST community to improve guide star execution onboard Hubble and to make comparisons to the future James Webb Space Telescope FGS instrument, where astronomers will take part in guide star selection.

Author(s): Amber Armstrong[1], Denise Taylor[1], Merle Reinhart[1]
Institution(s): *1. Space Telescope Science Institute*

216.15 – HST/WFC3: IR Channel Photometric Performance and Stability

The Hubble Space Telescope (HST) Wide Field Camera 3 (WFC3) contains two channels: UVIS and IR. The IR channel makes use of a HgCdTe detector produced by Teledyne. By periodically observing a set of bright white dwarf stars we are able to monitor the photometric performance of the IR detector over the last seven years. We present the results of the photometric measurements over time. In addition we discuss the effects of detector behavior not accounted for by the typical calibration (performed by CALWF3) such as the high order nonlinear response of detector pixels, persistence of previous exposures, and contamination of the channel. The findings of this investigation will have a direct impact on the flux calibration of the channel (and the resulting zeropoints).

Author(s): Varun Bajaj[1], Susana E. Deustua[1], Catherine Gosmeyer[1], Peter R. McCullough[1]
Institution(s): *1. Space Telescope Science Institute*
Contributing team(s): WFC3 Team

216.16 – ACS/SBC Internal Lamp P-flat Monitoring

We report on a Cycle 23 calibration program to monitor the status of the SBC P-flat. We find random pixel to pixel changes to be small, with only ~2% of pixels having changed by more than 3σ. There are coherent changes that we measure to be above the poisson errors, in some regions as high as 4% peak to peak. We therefore recommend that the ACS team obtain new observations in order to create a new P-flat. We also measured the degradation of the deuterium lamp used to create internal flats. The brightness of the lamp is currently ~65% of its initial level, the degradation being dependent on lifetime usage.

Author(s): Roberto J. Avila[1], Marco Chiaberge[1], Ralph Bohlin[1]
Institution(s): *1. Space Telescope Science Institute*

216.17 – New Sky Flats for HST's ACS/WFC

We have begun experiments to make new sky flat files for HST's ACS/WFC. Sky flats can be especially useful for deep imaging in such as programs as deep, extragalactic survey programs because they can help to better deal with noise at low levels. Although we also hope to make similar sky flats for some other popular filters including F606W and F814W, we are beginning this experiment with the F435W filter on the ACS/WFC since it is a popular filter in use in many deep extragalactic surveys, and since the bluer filters such as F435W generally have lower throughput and images in that filter are typically noisier than others at some longer mid-optical wavelengths. Initially, although sources will be masked in these images, etc. we are endeavoring to use just post-SM4 F435W images of duration equal to or greater than 800 seconds and which are free of bright stars in order to try and avoid scattered light and sky background color issues as much as possible, although the sky in different images taken at different times and in different directions will likely have some different background levels and color terms in any event. However, our hope is that the final sky flats will be of sufficient S/N to be good calibrators for deep survey programs.

Author(s): Ray A. Lucas[1], Norman A. Grogin[1]
Institution(s): *1. STScI*

216.18 – Development of megapixel HgCdTe detector arrays with 15 micron cutoff

I. History
HgCdTe is a versatile II-VI semiconductor with a direct-bandgap tunable via the Hg:Cd ratio. Hg:Cd ratio = 53:47 (2.5 micron cutoff) was used on the NICMOS instrument on HST and the 2MASS. Increasing Hg:Cd ratio to 70:30 leads to a 5.4 micron cutoff, utilized in NEOWISE and many JWST instruments. Bailey, Wu et al. (1998) motivated extending this technology to 10 microns and beyond. Bacon, McMurtry et al. (2003, 2004) indicated significant progress toward this longwave (LW) goal.
Warm-Spitzer has pioneered passive cooling to below 30 K in space, enabling the JWST mission.
II. Current
NASA's proposed NEOcam mission selected HgCdTe with a 10.6 micron cutoff because it promises natural Zodiacal background limited sensitivity with modest cooling (40 K). Teledyne Imaging Systems (TIS) is producing megapixel arrays with excellent performance (McMurtry, Lee, Dorn et al. (2013)) for this mission.
III. Future
Modest cooling requirements (circa 30 K) coupled with megapixel arrays and LW sensitivity in the thermal IR make HgCdTe attractive for many infrared instruments. For instance, the spectral signature of a terrestrial planet orbiting in the habitable zone of a nearby star will be the deep and wide absorption by CO_2 centered at 15 microns (Seager and Deming, 2010). LW instruments can enhance Solar System missions, such as exploration of the Enceladus geysers (Spencer, Buratti et al. 2006). Passive cooling will be adequate for these missions. Modern ground-based observatories will benefit from infrared capability out to the N band (7.5-13.6 microns). The required detector temperatures (30-40 K) are easily achievable using commercially available mechanical cryo-coolers (refrigerators).
IV. Progress to date
TIS is developing megapixel HgCdTe arrays sensitive out to 15 microns under the direction of the University of Rochester. As a first step, we have produced arrays with a 13 micron cutoff. The initial measurements indicate very promising performance. We will present the measurements of dark current, noise, and quantum efficiency for these devices and discuss our plans to reach our 15 micron target wavelength.

Author(s): William J. Forrest[1], Craig W. McMurtry[1], Meghan L Dorn[1], Judith Pipher[1], Mario S. Cabrera[1]
Institution(s): *1. Univ. of Rochester*

216.19 – Relative Throughput of the Near-IR Science Instruments of the James Webb Space Telescope as Measured in the Ground Testing of the Integrated Science Instrument Module

Data were obtained for the purpose of measuring the relative throughput of the Near-IR Science Instruments (SIs) of the James Webb Space Telescope (JWST) as part of the second and third cryogenic-vacuum tests (CV2/CV3) of the Integrated Science Instrument Module (ISIM) conducted at the Goddard Space Flight Center (GSFC) in 2014 and 2015/2016, at the beginning and end of the environmental test program, respectively. In this work we focus on data obtained as part of the Initial Optical Baseline and as part of the Final Performance test -- two epochs that roughly bracket the CV3 test.

The purpose of the test is to trend relative throughput to monitor for any potential changes from gross problems such as contamination or degradation of an optical element. Point source data were taken at a variety of wavelengths for NIRCam Module A and Module B, NIRSpec, NIRISS, Guider 1 and Guider 2 using the Laser Diode (LD) 1.06 micron, LD 1.55 micron, 2.1 micron LED and 3.5 micron LED, as well as for NIRCam Mod A and B and NIRISS using a tungsten source and the F277W, and F480M filters. Spectra were taken using the G140M, G235M, and G395M gratings for NIRSpec, the GRISMR grism for NIRCam Mod A and B and the GR150C grism for NIRISS. The results of these measurements will be compared to what would be expected given the efficiency of each of the optical elements in each SI.

Although these data were taken as a check against gross problems, they can also be used to provide the first relative throughput estimate for each SI through the various filters/source wavelengths measured in their flight-like configurations.

The data, the reduction steps and the resulting cross calibration are presented.

Author(s): Eliot Malumuth[8], Stephan Birkmann[2], Douglas M. Kelly[6], Randy A. Kimble[4], Don Lindler[5], Andre Martel[7], Raymond George Ohl[4], Marcia J. Rieke[6], Neil Rowlands[3], Maurice Te Plate[1]
Institution(s): *1. European Space Agency, 2. European Space Agency/STScI, 3. Honeywell Aerospace, 4. NASA's GSFC, 5. Sigma Space Corporation/NASA's GSFC, 6. Steward Observatory, University of Arizona, 7. STScI/NRC Herzberg, 8. Wyle STE/NASA's GSFC*

216.20 – An Update on Simulating Imaging, Spectroscopic, and Coronagraphic PSFs for JWST (and WFIRST too!)

Simulated point spread functions (PSFs) are an essential tool in preparing for future space telescopes, supporting pre-launch science simulations, observation planning, and analysis software development. The open-source Python package WebbPSF provides simulated PSFs for all of JWST's instruments and observing modes. We present the latest updates to WebbPSF based on both updated models of
the assembled telescope optics and recent cryo-test data for the science instruments. Outputs from this latest version of WebbPSF will support the JWST Exposure Time Calculator and the first calls for proposals in the year ahead, among many other uses by the community. Furthermore, the same toolkit also now provides support for simulating PSFs for both the WFI and CGI instruments planned for WFIRST.

Author(s): Marshall D. Perrin[1], Joseph D. Long[1], Neil T Zimmerman[1], Kyle Van Gorkom[1]
Institution(s): *1. STScI*

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217 – Extremely Cool Stars: Surveys and Individual Stars Poster Session

217.01 – Using Clustering Algorithms to Identify Brown Dwarf Characteristics

Brown dwarfs are stars that are not massive enough to sustain core hydrogen fusion, and thus fade and cool over time. The molecular composition of brown dwarf atmospheres can be determined by observing absorption features in their infrared spectrum, which can be quantified using spectral indices. Comparing these indices to one another, we can determine what kind of brown dwarf it is, and if it is young or metal-poor. We explored a new method for identifying these subgroups through the expectation-maximization machine learning clustering algorithm, which provides a quantitative and statistical way of identifying index pairs which separate rare populations. We specifically quantified two statistics, completeness and concentration, to identify the best index pairs. Starting with a training set, we defined selection regions for young, metal-poor and binary brown dwarfs, and tested these on a large sample of L dwarfs. We present the results of this analysis, and demonstrate that new objects in these classes can be found through these methods.

Author(s): Caleb Choban[1]
Institution(s): *1. UC San Diego*

217.02 – SPLAT: Using Spectral Indices to Identify and Characterize Ultracool Stars, Brown Dwarfs and Exoplanets in Deep Surveys and as Companions to Nearby Stars

The majority of ultracool dwarf stars and brown dwarfs currently known were identified in wide-field red optical and infrared surveys, enabling measures of the local, typically isolated, population in a relatively shallow (<100 pc radius) volume. Constraining the properties of the wider Galactic population (scale height, radial distribution, Population II sources), and close brown dwarf and exoplanet companions to nearby stars, requires specialized instrumentation, such as high-contrast, coronagraphic spectrometers (e.g., Gemini/GPI, VLT/Sphere, Project 1640); and deep spectral surveys (e.g., HST/WFC3 parallel fields, Euclid). We present a set of quantitative methodologies to identify and robustly characterize sources for these specific populations, based on templates and tools developed as part of the SpeX Prism Library Analysis Toolkit. In particular, we define and characterize specifically-tuned sets spectral indices that optimize selection of cool dwarfs and distinguish rare populations (subdwarfs, young planetary-mass objects) based on low-resolution, limited-wavelength-coverage spectral data; and present a template-matching classification method for these instruments. We apply these techniques to HST/WFC3 parallel fields data in the WISPS and HST-3D programs, where our spectral index set allows high completeness and low contamination for searches of late M, L and T dwarfs to distances out to ~3 kpc.
The material presented here is based on work supported by the National Aeronautics and Space Administration under Grant No. NNX15AI75G.

Author(s): Christian Aganze[3], Adam J. Burgasser[4], Eduardo Martin[2], Quinn Konopacky[4], Daniel C. Masters[1]
Institution(s): *1. Caltech/IPAC, 2. Centro de Astrobiologia, 3. Morehouse College, 4. UC San Diego*

217.03 – Knowing Our Neighbors: Six Young, Nearby Systems

Obtaining a well-understood, volume-limited (and ultimately volume-complete) sample of nearby stars is necessary for determining a host of astrophysical quantities, including the stellar luminosity and mass functions, the stellar velocity distribution, and the stellar multiplicity fraction. Furthermore, such a sample provides insight into the local star formation history. Towards that end, the Research Consortium on Nearby Stars (RECONS) measures trigonometric parallaxes to establish which systems truly lie within the 25-pc radius of the Solar Neighborhood. Recent measurements with the CTIO/SMARTS 0.9-m telescope establish six new systems as members of the Solar Neighborhood and also potential members of young moving groups based on (a) CTIOPI astrometry and (b) radial velocities from the literature, where available:

● G 75-35 at a distance of 11.8±0.2 pc and G 161-71 at 13.5±0.3 pc are possible members of the Argus Association;

● LP 888-18 at a distance of 12.5±0.2 pc is a member of the AB Doradus Moving Group, while LP 834-32 at 17.3±0.6 pc and LP 870-65 at 18.2±0.5 pc are possible group members;

● LHS 6167AB at a distance of 9.68±0.09 pc is a possible member of the Hercules-Lyra Moving Group.

To characterize these systems further, RECONS obtained VRI photometry for each, which range from 12.44–18.81 mag. in V. LP 834-32, LHS 6167AB, and G 161-71 demonstrated significant long-term variability in V-band; the first two appear to have flared in 2011 and 2012, respectively. Furthermore, CTIOPI 1.5-m spectroscopy identifies these systems as M3.5–M8.0 dwarfs. G 161-71 displayed strong H_{α} emission but weak sodium and potassium features.

The Solar Neighborhood contains both young and old stars that can be observed more easily than their more distant counterparts, which allows their characteristics to be studied in greater detail.

NSF grants AST 05-07711 and AST 09-08402, NASA-SIM, Georgia State University, the University of Virginia, Hampden-Sydney College, and the Levinson Fund of the Peninsula Community Foundation supported this research. CTIOPI was an NOAO Survey Program and continues as part of the SMARTS Consortium. We thank the SMARTS Consortium and the CTIO staff, who enable the small telescope operations at CTIO.

Author(s): Jennifer L. Bartlett5, John C. Lurie[6], Philip A. Ianna3, Adric R. Riedel[1], Jennifer G. Winters[2], Charlie T. Finch5, Wei-Chun Jao[2], John P Subasavage4, Todd J. Henry3
Institution(s): *1. California Institute of Technology, 2. Georgia State University, 3. RECONS Institute, 4. U.S. Naval Observatory, 5. U.S. Naval Observatory, 6. University of Washington*

217.04 – A Systematic Search for Low-mass Field Stars with Large Infrared Excesses

We present a systematic search for low-mass field stars exhibiting extreme infrared (IR) excesses. One potential cause of the IR excess is the collision of terrestrial worlds. Our input stars are from the Motion Verified Red Stars (MoVeRS) catalog. Candidate stars are then selected based on large deviations (3σ) between their measured *Wide-field Infrared Survey Explorer* (*WISE*) 12 μm flux and their expected flux (as estimated from stellar models). We investigate the stellar mass and time dependence for stars showing extreme IR excesses, using photometric colors from the Sloan Digital Sky Survey (SDSS) and Galactic height as proxies for mass and time, respectively. Using a Galactic kinematic model, we estimate the completeness for our sample as a function of line-of-sight through the Galaxy, estimating the number of low-mass stars that should exhibit extreme IR excesses within a local volume. The potential for planetary collisions to occur over a large range of stellar masses and ages has serious implications for the habitability of planetary systems around low-mass stars.

Author(s): Christopher Theissen[1], Andrew A. West[1]
Institution(s): *1. Boston University*

217.05 – Potential Brown Dwarf-Planet System in the ~40 Myr Argus Association

Low-temperature L and T dwarfs in young moving groups are excellent proxies of giant exoplanet atmospheres, and allow us to probe the very lowest limits of the substellar initial mass function. We present a detailed spectral analysis of an L9 dwarf candidate member of the Argus young moving group, whose peculiar and unusually red spectrum suggests the presence of an unresolved, even lower temperature companion. Using the spectral binary technique, we are able to reproduce the shape of this peculiar spectrum, and using evolutionary models we infer that the component masses straddle the deuterium burning minimum mass limit, making this a candidate brown dwarf/giant planet system. This system is unique in that its secondary is one of only a few examples of a young T dwarf, and the discovery of this system implies that the spectral binary technique can probe companions down to planetary masses. High-resolution imaging and spectroscopy are still needed to confirm the multiplicity of this source.

Author(s): Daniella Bardalez Gagliuffi[2], Jonathan Gagne[1], Jackie Faherty[1], Adam J. Burgasser[2]
Institution(s): *1. Carnegie Institution of Washington, Department of Terrestrial Magnetism, 2. University of California, San Diego*

217.06 – Millimeter-Wave Observations of Circumstellar $^{14}N/^{15}N$ and $^{12}C/^{13}C$ Ratios: New Insights into J-Type Stars

Measurements of $^{14}N/^{15}N$ and $^{12}C/^{13}C$ isotopic ratios have been conducted towards circumstellar envelopes of a sample of evolved stars using the J = 3→2 rotational transitions of the isotopologues of HCN, observed with the Submillimeter Telescope (SMT) of the Arizona Radio Observatory (ARO). Towards the J-type stars Y CVn and RY Dra, where $^{12}C/^{13}C$ ~ 3, the $^{14}N/^{15}N$ ratios were found to be 120-180 and 225, respectively. The $^{14}N/^{15}N$ ratio is thus anomalously low relative to interstellar values and a factor ~100 lower than equilibrium values predicted from the CNO cycle. Combining these results with previous chemical and isotopic prior observations of these stars, we conclude that two anomalous behaviors are likely to have occurred in Y CVn and RY Dra. First, the stellar envelope failed to participate in the normal mixing seen in low mass red giants, in which C and then O are substantially converted to N. Secondly, both the carbon enrichment and anomalous isotopic composition of both ^{13}C and ^{15}N could have been caused by a plume of hot gas, hydrogen poor but enriched in ^{12}C, from a helium flash mixing into the envelope.

Author(s): Gilles Adande[1], Lucy M. Ziurys[2], Neville Woolf[2]
Institution(s): *1. NASA, 2. University of Arizona*

217.07 – Insights from the rotational braking of solar twins: is the Sun a regular rotator?

Although the Sun is widely used as a reference star in astrophysics, it is still unclear how regular it is when compared to other similar stars in regards to some of its physical properties, such as its rotation. We analyze the rotational velocities (limited by the unknown rotation axis inclination angle) of an unprecedented sample of solar twins in order to study how common the Sun is in its rotation. We use high-resolution (R = 115000) spectra obtained with the HARPS spectrograph and ESO's 3.6 m telescope at La Silla Observatory. The projected rotational velocities for 71 solar twins are estimated through line profile fitting using synthetic spectra. We take into account the macroturbulence velocities in a separate analysis, for they are known to be difficult to disentangle from rotation. Our sample of solar twins include some spectroscopic binaries with enhanced rotational velocities, and we do not find any non-spectroscopic binaries with unusually high rotation velocities. The Sun does not have a peculiar rotation, but the solar twins exhibit rotational velocities that depart from the tried and tested Skumanich's law. We conclude that the Sun is a regular rotator when compared to solar twins with a similar age, and obtain a rotational braking law that better describes the stars in our sample when compared to previous, often-used scalings.

Author(s): Leonardo Augusto Dos Santos[1], Jorge Melendez[1]
Institution(s): *1. Universidade de São Paulo*

217.08 – Completing the census of young stars near the Sun with the FunnelWeb spectroscopic survey

From late 2016, the Australian FunnelWeb survey will obtain medium-resolution (R~2000) spectra covering the full optical range for 2 million of the brightest stars (I<12) in the southern sky. It will do so using an upgraded UK Schmidt Telescope at Siding Spring Observatory, equipped with a revolutionary, parallelizable optical fibre positioner ("Starbugs") and spectrograph. The ability to reconfigure a multi-fibre plate in less than 5 minutes allows FunnelWeb to observe more stars per night than any other competing multi-fibre spectrograph and enables a range of previously inefficient bright star science not attempted since the completion of the HD catalogues in the 1940s. Among its key science aims, FunnelWeb will obtain spectra for thousands of young and adolescent (<1 Gyr) stars near the Sun (<200 pc) across a wide range of spectral types. These spectra will include well-studied youth and activity indicators such as H-alpha, Li I 6708A, Ca II H&K, as well as surface gravity diagnostics (e.g. Na I, K I). In addition, FunnelWeb will obtain stellar parameters (Teff, logg, vsini), abundances (Fe/H, alpha/Fe) and radial velocities to 1-2 km/s for every star in the survey. When combined with high precision parallaxes and proper motions from the Gaia mission expected from 2017, this dataset will provide a near-complete census of adolescent stars in the solar neighbourhood. It will help reveal the typical formation environments of young solar-type stars, how such stars move from their stellar nurseries to their adult lives in the field, and identifying thousands of high-priority targets for follow-up direct imaging (GPI,

SPHERE), transit (including TESS) and radial velocity exoplanet studies. In this poster contribution we introduce the FunnelWeb survey, its science goals and input catalogue, as well as provide an update on the status of the fibre positioner and spectrograph commissioning at Siding Spring.

Author(s): Warrick Lawson3, Simon Murphy3, Christopher G. Tinney2, Michael Ireland1, Michael S Bessell1
Institution(s): *1. ANU, 2. UNSW, 3. UNSW Canberra*

217.09 – A New Mass Criterium for Electron Capture Supernovae

Electron capture supernovae (ECSN) are thought to populate the mass range between massive white dwarf progenitors and core collapse supernovae. It is generally believed that the initial stellar mass range for ECSN from single stars is about 0.5-1.0 $M_\odot$ wide and centered around a value of 8.5 or 9 $M_\odot$, depending on the specifics of the physics of convection and mass loss one applies. Since mass loss in a binary system is able to delay or cancel the second dredge-up, it is also believed that the initial mass range for ECSN in binary systems is wider than in single stars, but an initial mass range has not been defined yet.
The last phase of stars in this particular mass range, however, is challenging to compute, either due to recurring Helium shell flashes, or due to convectively bound flames in the degenerate interior of the star. It would be helpful, nevertheless, to know before we enter these computationally intensive phases whether a star will explode as an ECSN or not. The mass of the helium core after helium core burning is one such criterium (Nomoto, 1984), which predicts that ECSN will occur if the helium core mass is between 2.0 $M_\odot$ and 2.5 $M_\odot$. However, since helium cores can be subject to erosion due to mass loss — even during helium core burning, this criterium will not yield accurate predictions for stars in binary systems.
We present a dense grid of stellar evolution models that allow us to put constraints on the final fate of their cores, based on a combination of Carbon/Oxygen core mass, the mass of the surrounding Helium layer and C/O abundance. We find that CO cores with masses between 1.365 and 1.420 $M_\odot$ at the end of Carbon burning will result in ECSN, with some minor adjustments of these ranges due to the mass of the Helium layer and the C/O ratio. While detailed models of stars within the ECSN mass range remain necessary to understand the details of pre-ECSN evolution, our research refines the Helium core criterion and provides a useful way to determine the final fate of stars in this complicated mass range early on.

Author(s): Arend Poelarends1
Institution(s): *1. Wheaton College*

217.10 – Contamination in Kepler samples of stellar rotation

We report preliminary results of a survey that identifies contamination among Kepler stars with measured rotational periods. These periods are derived from photometric modulation attributed to star spots. We detect contamination through composite spectral energy distributions, photometric modulation of nearby stars blended in the Kepler PSF, and from radial velocity variations that uncover tidally synchronized binaries. In this poster, we concentrate on our radial velocity survey, and show that the contamination rate among rapid (P < 10d) rotators is low.

Author(s): Rachel Cannata1, Donald M. Terndrup1
Institution(s): *1. The Ohio State University*

217.11 – Spectral Characterization of A Resolved M dwarf-M dwarf Binary

We report characterization of the resolved binary M dwarf SDSS J155526.53+095409.5AB through spectroscopic and imaging analysis. Classification of resolved near-infrared spectra with IRTF/SpeX and tools in the SpeX Prism Library Analysis Toolkit (SPLAT) indicate component types of M3.5 and M8, separated by about 4''. We match the data to atmosphere models using an Monte Carlo Markov Chain routine to determine preliminary physical properties for each component (temperature, surface gravity and metallicity), and obtain estimates for the distance (106±11 pc) and projected separation (419±45 AU).

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Author(s): Tomoki Tamiya2, Adam J. Burgasser2, Christian Aganze1, Gretel Mercado2, Adrian Suarez2
Institution(s): *1. Morehouse College, 2. University of California, San Diego*

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218 – Variable Stars, Binary and Multiple Stellar Systems, and White Dwarfs Poster Session

218.01 – Variable Star Discovery with Ultra-Low Cost Equipment

We present preliminary results of a variable star search using commercial DSLR equipment. The camera in use images the sky at DEC=+44 every ten minutes, day and night. A wide variety of open-source tools, from photo editors to specialty programs like the astrometry.net suite, are used to process the images and identify variable stars.

Author(s): Nathaniel Paust1, Danielle Wilson1
Institution(s): *1. Whitman College*

218.02 – Three Red Variable Stars in SDSS Stripe 82

We examined light curves of stars with g-r values greater than 0.6 in the LSST project's re-reduction of the SDSS Stripe 82 photometric data. A few stars have interesting light curves in which we chose for spectroscopic follow-up with DIS on the Apache Point 3.5-m telescope. In this poster we will report our findings on three of the most interesting red variable stars. One of the stars (GI Cet) has a period of 219.86 days, as determined from the Stripe 82 light curve. Spectra of GI Ceti taken at 3 epochs will be discussed. A second variable, TY Aqr, does not have a period. We will present the light curve and spectra taken in 2013 and 2014. The third variable is very red and a-periodic. The spectrum obtained in 2013 is that of a carbon star.

Author(s): Kyle Olinger1, Julie H. Lutz1
Institution(s): *1. University of Washington*

218.03 – An Analysis of the High Amplitude delta Scuti Star V2455 Cygni

The high amplitude delta Scuti (HADS) V2455 Cyg was first noted as a variable star by Wils et al. (2003). They reported a period of 0.0942075 days, with a V amplitude of about 0.44. It has also been suggested that this might be an SX Phe type variable. Since the original discovery paper this star has only received a limited amount of attention. We have collected both spectroscopic and photometric data on this target for the last 10 years. We will present an analysis of the period of V2455 Cyg which suggests a very small companion star. We also examine the temperature and radial velocity over complete pulsation cycles.

Author(s): Eric G. Hintz1, Michael D. Joner1, Maureen Hintz1, Marissa Mannard1
Institution(s): *1. Brigham Young Univ.*

218.04 – Variable Stars in the Field of the Hydra II Ultra-Faint Dwarf Galaxy

We searched for variable stars in Hydra II, one of the recently discovered ultra-faint dwarf satellites of the Milky Way, using gri time-series obtained with the Dark Energy Camera (DECam) at Cerro Tololo Inter-American Observatory, Chile. We discovered one RR Lyrae star in the galaxy which was used to derive a distance of 154 ± 8 kpc to this system and to re-calculate its absolute magnitude and half-light radius.

A comparison with other RR Lyrae stars in ultra-faint systems indicates similar pulsational properties among them, which are different to those found among halo field stars and those in the largest of the Milky Way satellites. We also report the discovery of 31 additional short period variables in the field of view (RR Lyrae, SX Phe, eclipsing binaries, and a likely anomalous cepheid) which are likely not related with Hydra II.

Author(s): Anna Katherina Vivas[1], Knut A. Olsen[6], Robert D. Blum[6], David L. Nidever[4], Alistair R. Walker[1], Nicolas Martin[5], Gurtina Besla[9], Carme Gallart[3], Roeland P. Van Der Marel[7], Steven R. Majewski[11], Ricardo Munoz[8], Catherine C. Kaleida[1], Abhijit Saha[6], Blair Conn[2], Shoko Jin[10]
Institution(s): *1. Cerro Tololo Inter-American Observatory, 2. Gemini Observatory, 3. Instituto de Astrofisica de Canarias, 4. LSST, 5. Max-Planck Institut fur Astronomie, 6. NOAO, 7. Space Telescope Science Institute, 8. Universidad de Chile, 9. University of Arizona, 10. University of Groningen, 11. University of Virginia*

218.05 – Spectra from the IRS of Bright Oxygen-Rich Evolved Stars in the SMC

We have used *Spitzer*'s Infrared Spectrograph (IRS) to obtain spectra of stars in the Small Magellanic Cloud (SMC). The targets were chosen from the Point Source Catalog of the *Mid-Course Space Experiment* (*MSX*), which detected the 243 brightest infrared sources in the SMC. Our SMC sample of oxygen-rich evolved stars shows more dust than found in previous samples, and the dust tends to be dominated by silicates, with little contribution from alumina. Both results may arise from the selection bias in the *MSX* sample and our sample toward more massive stars. Additionally, several sources show peculiar spectral features such as PAHs, crystalline silicates, or both carbon-rich and silicate features. The spectrum of one source, MSX SMC 145, is a combination of an ordinary AGB star and a background galaxy at z~0.16, rather than an OH/IR star as previously suggested.

Author(s): Kathleen E. Kraemer[2], Greg Sloan[3], Peter Wood[1]
Institution(s): *1. Australian National University, 2. Boston College, 3. Cornell University*

218.06 – Constraining the Extremely Hard X-ray Excess of Eta Carinae using *XMM-Newton* and *NuSTAR*

Eta Carinae (η Car), the most luminous ($L \sim 10^{6.7} L_\odot$), evolved, supermassive star ($M \geq 100 M_\odot$) in our Galaxy, has been extensively studied over the entire range of wavelengths of the electromagnetic spectrum, and yet it remains to be intriguingly mysterious. η Car is a binary system with an orbital period of 2024 days (5.53 years). The collision of the slow (~500 km s^{-1}), dense winds from the primary star with the fast (~3000 km s^{-1}), thin winds from the companion, produces very hot plasma with temperatures of severals of millions of Kelvin via shock heating. Previously, the *INTEGRAL* and *Suzaku* observatories have suggested extremely high energy (15-100 keV) emission from η Car, which may arise from inverse Compton scattering of UV/optical photons by high-energy electrons accelerated in the wind colliding regions, or from the super hot plasma at the head-on collision. Recently, within a span of about 1.4 years (March 2014-July 2015), η Car was observed a total of 13 times with *NuSTAR*. The spectrum from the 2015 July observation, shows a hard X-ray excess above ~ 17 keV, which can be constrained with a flat power-law (Γ~0.5) or very hot bremsstrahlung (kT~10 keV) component. This hard X-ray excess is significantly above the background level below 25 keV and therefore should not be instrumental. The light curves of the narrow sections of energy bands above 10 keV do not show significant variation. We discuss the origin of this extremely hard excess component from combined analysis of the *XMM-Newton* and *NuSTAR* data.

Author(s): Neetika Sharma[7], Kenji Hamaguchi[4], Theodore R. Gull[4], Michael F. Corcoran[4], Thomas Madura[4], Christopher Michael Post Russell[4], Hiromitsu Takahashi[3], Brian Grefenstette[1], Tadayuki Yuasa[5], Anthony F. J. Moffat[9], Noel Richardson[10], Jose H Groh[2], Julian M Pittard[6], Stanley P. Owocki[8]
Institution(s): *1. California Institute of Technology , 2. Geneva University , 3. Hiroshima University, 4. NASA/GSFC, 5. RIKEN, 6. The University of Leeds, 7. UMBC, 8. University of Delaware, 9. University of Montreal, 10. University of Toredo*

218.07 – Disk Accretion of Tidally Disrupted Rocky Bodies onto White Dwarfs

About 1/3 of white dwarfs (WDs) are polluted with heavy elements (e.g., Koester et al., 2014; Zuckerman et al., 2010) that should sediment out of their atmospheres on astronomically short timescales unless replenished by accretion from a reservoir, at rates that for many WDs must exceed ~10^{10} g/s (Farihi et al., 2010). Direct accretion of planetesimals is too improbable and Poynting-Robertson drag of dust is too slow (due to the low luminosity of WDs) (Jura, 2003), so it is often assumed that WDs accrete from a disk of gas and solid particles, fed by tidal disruption of planeteismals inside the WD Roche limit (e.g. Debes et al., 2012; Rafikov, 2011a, 2011b). A few such gaseous disks have been directly observed, through emission from Ca II atoms in the disk (e.g. Manser et al., 2016; Wilson et al. 2014). Models successfully explain the accretion rates of metals onto the WD, provided the gaseous disk viscously spreads at rates consistent with a partially suppressed magnetorotational instability (Rafikov, 2011a, 2011b). However, these models currently do not explore the likely extent of the magnetorotational instability in disks by calculating the degree of ionization, or suppression by strong magnetic field.

We present a 1-D model of a gaseous WD disk accretion, to assess the extent of the magnetorotational instability in WD disks. The composition of the disk, the ionization and recombination mechanisms, and the degree of ionization of the disk are explored. Magnetic field strengths consistent with WD dipolar magnetic fields are assumed. Elsasser numbers are calculated as a function of radius in the WD disk. The rate of viscous spreading is calculated, and the model of Rafikov (2011a, 2011b) updated to compute likely accretion rates of metals onto WDs.

Author(s): Wanda Feng[1], Steven Desch[1], Neal Turner[2], Anusha Kalyaan[1]
Institution(s): *1. Arizona State University, 2. NASA Jet Propulsion Laboratory*

218.08 – SARA South Observations and Analysis of the Solar Type, Totally Eclipsing, Contact Binary, DD Indus

DD Ind (NSVS5066754) is a Solar Type (T ~ 5850K) solar type eclipsing binary. It was observed in June to September, 2013 at Cerro Tololo in remote mode with the 0.6-m SARA South reflector. Five times of minimum light were calculated from our present observations, for three primary and two secondary eclipses:

HJD Min I = 2456505.8085±0.0002, 2456533.73933±0.00003, 2456536.6378±0.0012
HJD Min II = 2456503.8132±00.0014, 2456533.5583±0.0004

In addition, two observations at minima were determined from archived All Sky Automated Survey Data:

HJD Min II = 2452872.9104, 2452883.6097.

The following quadratic ephemerides was determined from all available times of minimum light:

JD Hel Min I=2456533.7394±0.0002d + 0.3627463±0.0000002 X E +0.00000000006 ± 0.00000000002 X E^2

A BVRcIc filtered simultaneous Wilson-Devinney Program (W-D) solution reveals that the system has a mass ratio of ~0.46, and a component temperature difference of ~200 K. Two weak (Tfact ~

0.95, ~20 degree radius) cool spots were iterated on the secondary component in the WD Synthetic Light Curve Computations. They appeared in the Northern Hemisphere (colatitude 45 degrees) and near the equator (colatitude ~95 degrees), respectively.

The Roche Lobe fill-out of the binary is ~13%. The inclination is ~84.8^{0}. An eclipse duration of ~16 minutes was determined for the primary eclipse. Additional and more detailed information is given in the meeting report.

Author(s): Ronald G. Samec[1], Cody Norris[1], Walter V. Van Hamme[2], Danny R Faulkner3
Institution(s): *1. Emmanuel College, 2. Florida International University, 3. University of South Carolina, Lancaster*

218.09 – BVRI Photometric Study of the Totally Eclipsing Short Period Solar Type, Near-Contact W UMA Binary, NSVS 5066754

High precision BVR$_C$I$_C$ light curves of NSVS 5066754 were observed on May 17-20, 2014 at Dark Sky Observatory in North Carolina with the 0.81-m reflector of Appalachian State University. It is a solar type eclipsing binary (T_1~5750 K) with a period of only 0.375132 (1) d. In fact, it appeared as one of the shortest period in Shaw's list of near contact binaries. Therefore, we initially believed this to be a pre-contact WUMa Binary (PCWB's). However, the Binary Maker fits and our Wilson-Devinney solutions show that the binary could have either a semi-detached or a contact binary configuration.
Five times of minimum light were calculated, for 3 primary and 2 secondary eclipses from our present observations: In addition, observations at minima were introduced from archived All Sky Automated Survey Data along with the discovery ephemeris. The following decreasing quadratic ephemeris was determined from all available times of minimum light:
JDHelMinI=2456797.63848±0.00047d + 0.3747796± 0. 0000068 X E --0.0000000241± 0.0000000005X E^2
Our contact solution, with a sum of square residuals = 0.49, gave a mass ratio of 0.50, and a component temperature difference of ~360 K, somewhat large for a contact binary. Two substantial cool spots were determined in this solution of 37 deg and 28 deg radius with a t-factor or 0.92 and 0.78 respectively. The fill-out is very shallow, ~6%.
The semi-detached solution (mode 4: V1010 Oph configuration, meaning the system is approaching first contact) is of poorer quality with a sum of square residuals = 0.87. It has a mass ratio of 0.63, and a component temperature of ~460 K. The fill-outs are 100% and 97% for the primary and secondary components, respectively. Two spots were determined, one hot (t-factor of 1.16, 14 deg radius, colatitude 101 deg) and one cool spot (t-factor of 0.94, 48 deg radius, colatitude 90 deg). The models in both cases are total eclipsing with high inclinations in the 86-89 deg range, and a time of constant light is found in the secondary eclipse. Since the period study would indicate that the binary may be coalescing, both solutions fit that scenario. The system may have just come into contact or is approaching contact. The first model is more probable.

Author(s): Daniel B. Caton[1], Ronald G. Samec[2], Ropafadzo Nyaude[2], Danny R Faulkner3
Institution(s): *1. Appalachian State Univ., 2. Emmanuel College, 3. University of South Carolina Lancaster*

218.10 – Statistics of Triple Star Systems in the Kepler Field

A long-period tertiary companion of an eclipsing binary system can affect the binary's orbit such that the eclipse times deviate noticeably from those predicted by a simple linear ephemeris model. Thus the tertiary star may be detected even when it does not transit the binary pair. We consider 33 eclipsing binary systems whose light curves indicate consistent, significant deviations from linear ephemeris both for the primary and secondary stars (hereafter, eclipse timing variations or ETVs). In these cases, the ETVs may be caused by orbital precession due to tides or general relativity (GR). We dynamically modeled each system in detail using the ELC code to determine whether tides and GR could plausibly explain the ETVs. We will present the results of this study and examples of systems where GR and tides are sufficient as well as examples where third bodies are needed.

Author(s): Eliot Halley Vrijmoet[1], Jerome A. Orosz[1], William F. Welsh[1], Donald R Short[1], Gur Windmiller[1]
Institution(s): *1. San Diego State University*

218.11 – Detailed Modeling of Higher Order Hierarchical Kepler Star Systems

Most stars have stellar companions (i.e. they exist in double, triple, or higher order configurations). Binary star systems are those which contain two stars. These systems are valued scientifically because they allow for the measurement of fundamental stellar properties such as masses and radii. These properties in turn allow for detailed studies of stellar evolution. The Kepler space telescope has discovered roughly 2900 eclipsing binary stars in its field of view. Various studies have shown that roughly 20% of the Kepler eclipsing binaries contain companions are are most likely triple star systems. We present a preliminary survey of the orbital properties of the tertiary bodies in a sample of thirty triple systems. In addition, a small number of the triple systems show eclipse events due to the third star. We present the results of detailed modeling of two of these systems, and discuss how in some cases these triple systems allow for extremely precise measurements of the fundamental stellar parameters.

Author(s): Joanna Gore[1], Jerome A. Orosz[1]
Institution(s): *1. San Diego State University*

218.12 – Radial Velocity Solution for Kepler Eclipsing Binary Stars from SDSS APOGEE

Proper characterization of binary stars is provided by high quality spectra combined with light curves allowing for precise determination of stellar masses, radii, and effective temperatures along with binary semi-major axes and eccentricities. A program to extract radial velocities of Kepler eclipsing binaries observed by SDSS APOGEE is presented. We combine the quality light curves from the Kepler telescope with high precision radial velocity measurements from SDSS APOGEE in order to characterize the binary and stellar components. We report on the first results of this program on three eclipsing binaries, KIC 6864859, KIC 6698670, and KIC 7121885.

Author(s): Joni Marie Clark[1], Paul A. Mason[1], Meredith L. Rawls[1], Jason Jackiewicz[1]
Institution(s): *1. New Mexico State University*
Contributing team(s): SDSS NMSU FAST

218.13 – Analysis of a subdwarf B pulsator observed during Campaign 2 of K2

We present an analysis of the pulsating subdwarf B (sdB) star EPIC 203948264, observed during Campaign 2 of the extended Kepler mission. A time series analysis of the short cadence data set has revealed a rich g-mode pulsation spectrum with 17 independent pulsation periods between 0.5 and 2.8 hours. All of the pulsations fit the asymptotic period sequences for ell=1 or 2, with average period spacings of 259+/-1.4 and 149+/-0.3 s, respectively. The pulsation amplitudes range from 0.77 to the detection limit at 0.26 ppt, with amplitudes that vary over time. Radial velocity measurements give no indication for binarity in this star. We did not find rotationally induced pulsation multiplets, which indicates that the rotation period of the star is longer than about 45 days, which would make the data too short to resolve multiplets. By characterizing the various pulsation modes present in pulsating sdB stars, and by examining the time-dependence of pulsation amplitudes, we can constrain structural models of the interiors of sdB stars. This is a promising approach to enhancing our understanding of these stars.

Author(s): Laura Ketzer3, Andrzej Baran[1], Mike Reed3, John H Telting4, Peter Nemeth[2]
Institution(s): *1. Krakow Pedagogical University, 2. KU Leuven, 3. Missouri State University, 4. Nordic Optical Telescope*

218.14 – CCD Imaging of KIC 8462852

A particularly interesting star, KIC 8562852, recently became famous for its enigmatic dips in brightness. The interpretation broadcast by many popular media outlets was that the dips were caused by a megastructure built around the star by an intelligent civilization. The best scientific hypothesis relies on a natural phenomenon: the break-up of a comet orbiting the star. To further address this problem, we have measured the star for four months using BGSU's 0.5m telescope and digital CCD camera, and we present the star's brightness as a function of time. Using three very clear nights, we refined the brightness of four comparison stars which can be used by the local astronomical community to monitor the star's brightness. These newly refined magnitudes should reduce the uncertainties in our brightness measurements; this error analysis is essential in determining the significance of any brightness deviations. An observed dip in brightness would confirm the comet hypothesis by establishing a cyclical pattern, or may serve as a basis for new understanding of variable stars. An additional element to the project involves creating CCD calibration images and a well-documented procedure for future use.

Author(s): Adam Lahey[1]
Institution(s): *1. Bowling Green State University*

218.15 – Updated Ephemerides for Two Eclipsing Cataclysmic Variables: DW Ursae Majoris and DO Leonis

Cataclysmic Variables (CVs) are close binary systems containing a white dwarf primary that accretes gas from a less massive secondary star. Eclipsing CVs offer the opportunity to determine fundamental properties of the binary. Here, we present time-resolved CCD photometry of two eclipsing nova-like CVs: DW Ursae Majoris and DO Leonis. Observations were taken in Spring 2015 using San Diego State University's 40-inch telescope at Mount Laguna Observatory. In order to construct light curves, we computed differential magnitudes between the CVs and several comparison stars in their fields. All observed eclipses were at least one magnitude deep, allowing us to measure accurate mid-eclipse times and to update the orbital ephemerides for these two systems. No evidence was found for any significant period change in the two systems over the more than 25-year span for which eclipse timings are available.

Author(s): Benjamin Kuhn[1], Allen W. Shafter[1]
Institution(s): *1. San Diego State University*

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219 – Neutron Stars and Supernovae Poster Session

219.01 – Numerical Simulations of Viscous Accretion Flow around Black Holes

We present shocked viscous accretion flow onto a black hole in a two dimensional cylindrical geometry, where initial conditions were chosen from analytical solutions. The simulation code used the Lagrangian Total Variation Diminishing (LTVD) and remap routine, which enabled us to attain high accuracy in capturing shocks and to handle the angular momentum distribution correctly. The steady state shocked solution in the inviscid, as well as in the viscous regime, matched theoretical predictions well, but increasing viscosity renders the accretion shock unstable. Large amplitude shock oscillation is accompanied by intermittent, transient inner multiple shocks. Such oscillation of the inner part of disk is interpreted as the source of QPO in hard X-rays observed in microquasars; and strong shock oscillation induces strong episodic jet emission. The periodicity of jets and shock oscillation are similar. Our simulation shows that the jets for higher viscosity parameter are evidently stronger and faster than that for lower viscosity.

Author(s): Seong-Jae Lee[2], Indranil Chattopadhyay[1], Rajiv Kumar[1], Siek Hyung[2], Dongsu Ryu[3]
Institution(s): *1. ARIES, 2. Chungbuk National University, 3. UNIST*

219.02 – Particle in Cell Simulations of the Pulsar Y-Point -- Nature of the Accelerating Electric Field

Over the last decade, satellite observations have yielded a wealth of data on pulsed high-energy emission from pulsars. Several different models have been advanced to fit this data, all of which "paint" the emitting region onto a different portion of the magnetosphere.

In the last few years, particle in cell simulations of pulsar magnetospheres have reached the point where they are able to self-consistently model particle acceleration and dissipation. One of the key findings of these simulations is that the region of the current sheet in and around the Y-point provides the highest rate of dissipation of Poynting flux (Belyaev 2015a). On the basis of this physical evidence, it is quite plausible that this region should be associated with the pulsed high energy emission from pulsars.

We present high resolution PIC simulations of an axisymmetric pulsar magnetosphere, which are run using PICsar (Belyaev 2015b). These simulations focus on the particle dynamics and electric fields in and around the Y-point region. We run two types of simulations -- first, a force-free magnetosphere and second, a magnetosphere with a gap between the return current layer and the outflowing plasma in the polar wind zone. The latter setup is motivated by studies of pair production with general relativity (Philippov et al. 2015, Belyaev & Parfrey (in preparation)).

In both cases, we find that the Y-point and the current sheet in its direct vicinity act like an "electric particle filter" outwardly accelerating particles of one sign of charge while returning the other sign of charge back to the pulsar. We argue that this is a natural behavior of the plasma as it tries to adjust to a solution that is as close to force-free as possible. As a consequence, a large E dot J develops in the vicinity of the Y-point leading to dissipation of Poynting flux. Our work is relevant for explaining the plasma physical mechanisms underlying pulsed high energy emission from pulsars.

Author(s): Mikhail Belyaev[1]
Institution(s): *1. UC Berkeley*

219.03 – Pulsars at the Center of the Galaxy

Over the past few years, a number of groups using data from NASA's space-borne Fermi LAT instrument have identified excess gamma-ray flux toward the inner degree of the Galactic Center (GC), with an even larger significant excess within 0.2 degrees. At present there are two leading candidates for this excess: dark matter annihilation and a population of unresolved millisecond pulsars (MSPs). We are currently developing dedicated instrumentation to carry out a sensitive search for the pulsars in this region of the galaxy using a newly developed front end and receiver on a Deep Space Network large diameter antenna in Australia. In this presentation, we will provide an overview of the challenges encountered with pulsar searches at the GC region and a summary of previous and ongoing efforts to survey this region with radio telescopes. We will also provide preliminary results from our recent observations of the GC region at 2 and 8 GHz and will conclude with prospects for detection of perhaps hundreds of pulsars in this region with new generations of radio telescopes now under construction.

Author(s): Walid A. Majid[1], Thomas A Prince[1]
Institution(s): *1. JPL/Caltech*

219.04 – Timing the Relativistic Binary Pulsar PSR B1913+16

We present results of three decades of timing data from the relativistic binary pulsar PSR B1913+16. With kinematic corrections, the measured rate of orbital decay due to gravitational wave radiation exhibits 99.69+/-0.17% agreement with the prediction of general relativity. For the first time in this system, the Shapiro delay parameters have been determined, therefore constituting two additional tests of gravity theories. We have also measured the relativistic deformation parameter of the orbit, and marginally the derivative of the semimajor axis, both of which are biased by the presence of aberration delay. We will discuss the possibility of constraining the moment of inertia of the pulsar in this system through improved measurement of the orbital semimajor axis derivative, and the determination of the aberration delay parameters from future geodetic precession modelling.

Author(s): Yuping Huang[1], Joel M. Weisberg[1]
Institution(s): *1. Carleton College*

219.05 – Hydroxyl Emission in the Westbrook Nebula

CRL 618, also known as the Westbrook Nebula, is a carbon-rich pre-planetary nebula. Hydroxyl (OH) transitions are typically not detected in carbon-rich late-type stellar objects, however observations conducted with the 305m Arecibo Telescope in 2008 resulted in the detection of 4765 MHz OH emission in CRL 618. We present results of observations carried out a few months after the original detection that confirm the line. This is the first detection of 4765 MHz OH emission (most likely a maser) in a pre-planetary nebula. Follow up observations conducted in 2015 resulted in non-detection of the 4765 MHz OH transition. This behavior is consistent with the high level of variability of excited OH lines that have been detected toward a handful of other pre-planetary nebulae. Our work supports that excited OH masers are short-lived during the pre-planetary nebula phase. We also conducted a search for other OH transitions from 1612 MHz to 8611 MHz with the Arecibo Telescope; we report no other detections at rms levels of ~5 mJy.

This work has made use of the computational facilities donated by Frank Rodeffer to the WIU Astrophysics Research Laboratory. We also acknowledge support from M. & C. Wong RISE scholarships and a grant from the WIU College of Arts and Sciences.

Author(s): Angelica Strack[7], Esteban Araya[7], Tapasi Ghosh[3], Hector G. Arce[8], Mayra E. Lebron[6], Christopher J. Salter[3], Robert F. Minchin[3], Ylva Pihlstrom[5], Stan Kurtz[2], Peter Hofner[4], Luca Olmi[1]
Institution(s): *1. INAF, Osservatorio Astrofisico di Arcetri University of Puerto Rico at Rio Piedras, 2. Instituto de Radioastronomía y Astrofísica, 3. NAIC, Arecibo Observatory, 4. New Mexico Institute of Mining and Technology, 5. University of New Mexico, 6. University of Puerto Rico, 7. Western Illinois University, 8. Yale University*

219.06 – Resolving shocked and UV excited components of H2 emission in planetary nebulae with high-resolution near-infrared spectroscopy

Planetary nebulae (PNe) form when low and intermediate-mass stars eject their outer layers into the ISM at the end of the AGB phase. Many PNe exhibit near-infrared (NIR) emission from molecular hydrogen (H2). This NIR emission arises from radiative decay out of excited rotation-vibration (rovibrational) states. The rovibrational states can be populated by excitation to higher electronic states through absorption of a far-UV photon followed by a radiative cascade to the electronic ground state, or by collisions (e.g., in a hot gas). The two processes populate the rovibrational levels of H2 differently, so the observed emergent emission spectrum provides an effective probe of the mechanisms that excite the H2. Many PNe display line intensity ratios that are intermediate between these two processes (Otsuka et al. 2013). With the advantages of the high spectral resolution (R~40000), broad wavelength coverage (1.45-2.45 µm), and high spatial resolution of the Immersion GRating Infrared Spectrometer (IGRINS, Park et al. 2014), we are able to differentiate components in position-velocity space: we see a slowly expanding UV-excited H2 shell in the PN M 1-11 and two faster moving “bullets” of thermalized H2 that we interpret as shocked gas from a bipolar outflow. We also present observations of several other PNe that exhibit similar morphologies of thermalized and UV-excited H2 components.

Author(s): Kyle Kaplan[1], Harriet L. Dinerstein[1], Daniel Thomas Jaffe[1]
Institution(s): *1. UT Austin*

219.07 – Tracing Physical Conditions of the Circumstellar Medium in the Supernova Remnant G292.0+1.8

Recent X-ray and infrared studies of the oxygen-rich supernova remnant G292.0+1.8 have shown that it is likely interacting with the circumstellar wind from the massive progenitor star (≥20 Solar Masses). Some of this material lies in a moderately dense equatorial belt stretching across the middle of G292.0+1.8. Here we present analysis of ground based optical spectra of the equatorial belt. We use forbidden line diagnostics to probe the abundances, density and temperature in the belt, where non-radiative shocks are beginning to transition to the radiative stage. We interpret our results in conjunction with existing X-ray and infrared data to improve our understanding of how a supernova remnant interacts with the outermost part of its relic red giant wind.

Author(s): Kielan Wilcomb[2], Parviz Ghavamian[2], John Patrick Hughes[1]
Institution(s): *1. Rutgers University, 2. Towson University*

219.08 – The Early Spectral Evolution of the Classical Nova ASASSN-15th in M33

During the course of the All Sky Automated Survey for SuperNovae (ASAS-SN) a new transient source designated ASASSN-15th was identified on images of the nearby galaxy M33 obtained with the 14 cm Brutus telescope in Haleakala, Hawaii on 2015 Dec 1.4 UT at V ~ 16.5 mag. Given the location of the transient in M33 and its apparent V magnitude at discovery, the implied absolute visual magnitude was about -8.5 mag suggesting that the transient was a new classical nova outburst in M33. Optical spectroscopy obtained by us on 2015 Dec 2.3 showed broad emission lines of Balmer, Fe II, and Na I D with P Cygni-type line profiles superposed on a blue continuum. The spectrum was consistent with a Fe II-type classical nova in M33 discovered early in the outburst. Subsequent spectra obtained by us on 2015 Dec 10.9 UT showed significant evolution since our first spectrum in that the deep P Cygni-type line profiles seen earlier were now extremely shallow or had almost completely disappeared with the emission component growing in strength. Additional emission lines from O I, Si II, and possibly He I were also present. We obtained optical spectroscopy of ASASSN-15th on 17 epochs between 2015 Dec 1 and 2016 Feb 11 UT with the 2.4 m Hiltner telescope (+OSMOS) of the MDM Observatory, the 2 m fully robotic Liverpool Telescope (+SPRAT), and the 2 x 8.4 m Large Binocular Telescope (+MODS). We will present our spectroscopy and discuss the early evolution of ASASSN-15th in the context of Galactic Fe II-class novae.

Author(s): R. Mark Wagner[4], Marko Neric[1], Matt J. Darnley[5], Steven Williams[3], Sumner Starrfield[1], Charles E. Woodward[6], Jose Luis Prieto[2]
Institution(s): *1. Arizona State University, 2. Diego Portales, 3. Lancaster University, 4. LBT Observatory, 5. Liverpool John Moores University, 6. University of Minnesota*

219.11 – Dependence of Simulated Supernova Yields on the Explosion Morphology

Supernovae are the principal source of heavy elements in the universe, and their yields can vary significantly depending on the morphology of the explosion. The structure of the circumstellar medium, the rotation or magnetic fields of the progenitor, the presence of a companion, and other factors can all affect the proportions of different isotopes that are synthesized, as well as where those products are deposited. To examine in detail the effects of these different factors, we employ supercomputer simulations of supernova explosions in three dimensions using the SNSPH code, with postprocessing to predict total and spatially mapped yields for 522 isotopes. We present visualizations and comparative analysis of the yields from simulations with spherically symmetric, unipolar, and bipolar geometries for 15- and 20-solar-mass progenitors. These allow us to begin identifying the effects of the explosion morphology and improving our understanding of how these events influence the composition of matter in the universe.

Author(s): Gregory Vance[1], Patrick A. Young[1]
Institution(s): *1. Arizona State University*

219.12 – The LCOGT Supernova Key Project

We highlight results from the Las Cumbres Observatory Global Telescope (LCOGT) Supernova Key Project -- a 3 year program to obtain lightcurves and spectra of approximately 500 low-redshift SNe. LCOGT is a robotic network of elevent one and two meter telescopes spaced around the globe. We are involved in a variety of surveys, including the intermediate Palomar Transient Factory, LaSilla Quest, PESSTO, and KMTNet. Recent results include analysis of large samples of core-collaspe SNe, the largest sample of SNe Ibn, evidence of the progenitors of SNe Ia from companion shocking, and new findings about superluminious SNe.

Author(s): Dale Andrew Howell[1], Iair Arcavi[1], Griffin Hosseinzadeh[1], Curtis McCully[1], Stefano Valenti[2]
Institution(s): *1. Las Cumbres Global Telescope Network, Inc., 2. University of California, Davis*
Contributing team(s): The LCOGT Supernova Key Project

219.13 – A Study of the Type II-Plateau Supernova SN 2014cx

The type II-plateau (II-P) class of supernova is the most commonly observed type of core-collapse event, and yet the basic characteristics of this class are still being defined (e.g. Pejcha & Prieto 2015). Here we add to the growing sample of type II-P events with well-sampled data from observations of SN 2014cx. SN 2014cx was independently discovered on September 2, 2014 UT by Nakano et al. (2014; CBET 3963) and Holoien et al. (2014; ATEL 6436) in the nearby (d ~ 20.7 Mpc, Tully 1988) SBd galaxy NGC 337. It was classified as a young Type II supernova through spectra taken within a day of discovery at both optical (Nakano et al. 2014) and near-infrared (Morrell et al. 2014; ATEL 6442) wavelengths. Later (Andrews et al. 2015; ATEL 7084), it was photometrically determined to be specifically a type II-P supernova, indicating the core-collapse event of a progenitor that had a large hydrogen envelope (Pejcha & Prieto 2015). We initiated a photometric and spectropolarimetric campaign to follow SN 2014cx; over a five month period following the supernova's discovery, we obtained optical images using the 1-meter telescope at Mount Laguna Observatory as part of the MOunt LAguna SUpernova Survey (MOLASUS), and spectra as part of the SuperNova SpectroPOLarimetry project (SNSPOL). Here we present the analysis of the photometry and spectroscopy obtained as part of this campaign. We acknowledge support from NSF grants AST-1009571 and AST-1210311, under which part of this research was carried out.

Author(s): Kelsi Flatland[2], Douglas C. Leonard[2], Grant Williams[1], Paul S. Smith[3], Christopher Bilinski[3], Luis Gonzalez[2], Jennifer L. Hoffman[4], Leah N. Huk[4], Peter Milne[3], Nathan Smith[3]
Institution(s): *1. MMT Observatory, University of Arizona, 2. San Diego State University, 3. Steward Observatory, University of Arizona, 4. University of Denver*
Contributing team(s): The Supernova Spectropolarimetry Project

219.15 – Probing the Cirucmstellar Medium of Supernova Progenitors with Swift XRT

The circumstellar medium surrounding the progenitor stars of core-collapse supernovae can be studied via the X-ray emission by the shock-heated gas following the supernova. By observing this emission over several days, we are able to determine a rough radial gas density profile. We present results of this analysis for 26 core-collapse supernovae observed by the Swift X-Ray Telescope, including supernovae of various subtypes. Overall, we find the CSM density scales with radius as $n \sim r^{-1.6}$, with some variation between different subtypes. In addition, we provide updated upper limits on X-ray emission from CSM around progenitor systems of Type Ia supernovae.

Author(s): Brock Russell[1], Destiny Murillo[1]
Institution(s): *1. Whittier College*

219.16 – Swift X-Ray Telescope Observations of Superluminous Supernovae

Superluminous Supernovae (SLSNe) are a part of an emerging class of exceptionally bright supernovae with peak luminosities 10 times brighter than typical Type Ia supernovae. Similar to supernovae, SLSNe are divided into two subclasses: hydrogen poor SLSN-I and hydrogen rich SLSN-II. However, the luminosity of these events is far too high to be explained by the models for normal supernovae. New models developed to explain SLSNe predict high luminosity X-ray emission at late times. A consistent analysis of incoming SLSNe is essential in order to place constraints on the mechanisms behind these events. Here we present the results of X-ray analysis on SLSNe using a Bayesian method of statistical inference for low count rate events.

Author(s): Melanie Kae Batara Olaes[1], Robert Quimby[1]
Institution(s): *1. San Diego State University*

219.17 – Multi-Epoch Spectroscopy of Hydrogen-Poor Superluminous Supernovae

A growing sample of intrinsically rare supernovae is being uncovered by wide-field synoptic surveys, such as the Palomar Transient Factory (PTF). A fraction of these events have been labeled "superluminous supernovae" due to their peak luminosities, which can exceed normal supernovae by factors of 10 to 100. The power sources for these events and thus their connection to normal luminosity supernovae remains uncertain. Here we present results from 134 spectroscopic observations of 17 hydrogen-poor superluminous supernovae (SLSN-I) discovered by PTF. We select our targets from the full PTF sample using only spectroscopic information; we do not employ the traditional cut in absolute magnitude (e.g. M < -21) to avoid potential bias. Using our multi-epoch observations, we identify the ion species contributing to the spectroscopic features, and we perform parametric modeling to estimate photospheric velocities. Finally we discuss the physical insights into the nature of these explosions offered by this unique dataset.

Author(s): Robert Quimby[3], Annalisa De Cia[4], Avishay Gal-Yam[4], Giorgos Leloudas[4], Ragnhild Lunnan[1], Daniel A. Perley[2], Paul Vreeswijk[4], Lin Yan[1]
Institution(s): *1. Caltech, 2. Dark, 3. SDSU, 4. Weizmann*

219.18 – The Intermediate Luminosity Optical Transient SN 2010da: The Progenitor, Eruption and Aftermath of an Unusual Supergiant High-mass X-ray Binary

We present high- and medium-resolution optical spectroscopy, optical/UV imaging and archival Chandra, Hubble and Spitzer observations of the intermediate luminosity optical transient (ILOT) SN 2010da, discovered in the nearby galaxy NGC 300 (d=1.86 Mpc). SN 2010da had a peak absolute magnitude of M ~ -10.4 mag, dimmer than other recent ILOTs and supernova impostors. We detect hydrogen Balmer, Paschen and Ca II emission lines in our high-resolution spectra, which indicate a dusty and complex circumstellar environment. Based on SN 2010da's light curve and multi-epoch SEDs, we conclude that the progenitor of SN 2010da is a ~10-12 Msol yellow supergiant possibly transitioning into a blue loop phase. Since the 2010 eruption, the star has brightened by a factor of ~5 and remains highly variable in the optical. SN 2010da is a unique ILOT which seems to stem from a different physical origin than red SN 2008S-like events and luminous blue variable outbursts. Furthermore, we detect SN 2010da in archival Swift observations as an ultraluminous X-ray source. We additionally attribute He II 4686 and coronal Fe emission in addition to a steady X-ray luminosity of ~10^{37} erg/s to the presence of a compact companion.

Author(s): Victoria Villar[1], Edo Berger[1], Ryan Chornock[3], Tanmoy Laskar[5], Raffaella Margutti[2], Peter J Brown[4]
Institution(s): *1. Harvard, 2. New York University, 3. Ohio University, 4. Texas A&M University , 5. UC Berkeley*

219.19 – Neutron star population in the Galactic center region as a potential source of polarized X-ray emission

We analyse the emission properties of neutron stars that are predicted to exist in large numbers of the order of 10000 in the innermost parts of the Galactic center. A part of the population of isolated neutron stars propagates supersonically through denser ionized streams of the Minispiral (Sgr A West), forming bow shocks where particles are accelerated and are expected to produce polarized X-ray synchrotron signal. Another source of the synchrotron emission is an elongated magnetosphere and tail. We investigate whether the polarized X-ray emission from Galactic center neutron stars will be potentially detectable in the framework of future X-ray polarimeters. A special case is a detected young neutron star - magnetar SGRJ1745-2900 - that has undergone a series of outbursts with a peak X-ray luminosity of the order of 10^{35} erg s^{-1} (1-10 keV). Apart from an intrinsic X-ray emission, the X-ray emission from neutron star outbursts may be scattered by molecular clouds in the Central Molecular Zone by Thomson scattering, which is another potential source of polarized X-ray emission.

Author(s): Michal Zajacek[2], Vladimir Karas[1], Andreas Eckart[2]
Institution(s): *1. Astronomical Institute of the Academy of Sciences of the Czech Republic, 2. Universität zu Köln*

219.20 – Long-Term Photometric Monitoring of Two Redback Pulsar Systems

Redback systems consist of an eclipsing millisecond pulsar in a short period orbit (< 1 day) around a non-degenerate companion. These systems can potentially transition from their current state where they are ablating their companion to an accreting state. How such a transition can take place is poorly understood. Long-term monitoring of their optical orbital light-curves are important to answer questions about their evolution as well as to catch transitions between states. The orbital light curves can be used to infer the systems' inclination angle, necessary to measure component masses, the effects of the pulsar heating on the atmosphere of the companion, and long term trends in the light curve may give some clue to the mechanism by which they transition. In this poster we present preliminary photometric light-curves of two binary, redback pulsar systems: PSR J2215+5135 and PSR J1628-3205. These data were taken in 2015 and 2016 with the 1m telescopes of the LCOGT observatory in several standard SDSS filter bands. We will compare the resulting light-curves with previous work on these systems to refine models of the light curves and to look for any long term trends in the optical emission such has been seen in the redback system PSR J2129-0429.

Author(s): Rodrigo Alberto Torres[2], Mallory Roberts[1], Dave Russell[2]
Institution(s): *1. Eureka Scientific, 2. NYU Abu Dhabi*

219.21 – Examining the hard X-ray emission of the redback PSR J2129-0429

We present new NuStar data of the redback millisecond pulsar (MSP) system PSR J2129-0429. Redback systems are important when it comes to understanding the evolution of MSPs, in terms of pulsar recycling, as they have been observed to transition between a state of accretion, where emission is in the optical and X-ray regimes, and a state of eclipsed radio pulsation. This system is particularly interesting due to some peculiarities: it has a more massive companion as well as a stronger magnetic field than other redbacks, indicating that the system is in a fairly early stage of recycling. It's X-ray lightcurve (as obtained from XMM-Newton data) has a very hard power-law component and exhibits an efficiency of a few percent in X-ray. With the NuStar data, the spectrum can be seen to extend to ~30 keV. Additionally, it shows strong orbital variation, about 5 times greater than is typical for other systems, and is also very clearly double peaked. Hints of similar peaks have been observed in the lightcurves of other redback systems; hence, this system can help in understanding the intrabinary shock of eclipsing MSPs.

Author(s): Hind Al Noori[2], Mallory Roberts[2], Maura McLaughlin4, Jason Hessels[1], Rene Breton3
Institution(s): *1. ASTRON, 2. New York University Abu Dhabi, 3. University of Manchester, 4. West Virginia University*
Contributing team(s): 17077031498

219.22 – Black hole - neutron star merger simulations: Precessing binaries with neutrino treatment

Black hole-neutron star (BH-NS) mergers are exciting events to model, as they are a source of gravitational waves, like those discovered for the first time by Advanced LIGO earlier this year. These mergers are also the source of gamma-ray bursts and radioactively powered transients. We present here an outline of our entire research process. We first display results of general relativistic-hydrodynamic simulations using the Spectral Einstein Code (SpEC). We ran a set of BH-NS merger simulations varying three of the initial parameters of the black hole: mass, spin magnitude, and spin inclination (relative to the orbital angular momentum of the binary system). The code factors in neutrino cooling and use a temperature dependent, nuclear theory based equation of state, as opposed to simpler equations of state previously used. Though systems which treat precession and neutrino cooling have been simulated individually, the systems we analyzed are the first to take both into account. Once a disk has formed and settled down, we take data from the GR simulations and input it into the particle evolution code, which reads in the positions/velocities and further evolves the system in a Newtonian potential. We then present the fallback rate of bound particles throughout this period of evolution, the approximate density evolution, and the spatial distribution of ejecta.

Author(s): Dhruv Desai[1], Francois Foucart[1], Daniel Kasen[1]
Institution(s): *1. UC Berkeley*

219.23 – Rotating Bondi Accretion Flow

The characteristics of accretion flow onto a black hole are determined by the physical condition of gas at large radius. When the gas has no angular momentum and is polytropic, the accretion flow becomes the classic Bondi flow. The mass accretion rate in such case is an eigenvalue and uniquely determined by the density and the temperature of the surrounding gas for a given black hole mass. When the gas has angular momentum above some critical value, the angular momentum of the gas should be removed by viscosity to reach the black hole horizon. We study, within the slim disk approximation, rotating polytropic accretion flow with alpha viscosity as an an extension of the Bondi flow. The characteristics of the accretion flow are now determined by the temperature, density, and angular momentum of the gas at the outer boundary. We explore the effects of the viscosity parameter and the outer boundary radius on the physical characteristic of the flow, especially on the mass accretion rate, and compare the result with previous works of Park (2009) and Narayan & Fabian (2011).

Author(s): Myeong-Gu Park[1], Du-Hwan Han[1]
Institution(s): *1. Kyungpook National University*

219.25 – Long-term Multiwavelength Observations of Polars

Polars are cataclysmic variables with the highest magnetic field strengths (10-250 MG). Matter is accreted after being funneled by the strong magnetic field of the white dwarf. We perform a meta-study of multi-wavelength data of polars. Many polars have been observed in surveys, such as SDSS, 2MASS, ROSAT, just to name a few. Some polars have now been detected by the JVLA, part of an expanding class of radio CVs. A large subset of polars have long-term optical light curves from CRTS and AAVSO. We suggest that the long term light curves of polars display a variety of signature behaviors and may be grouped accordingly. Additional characteristics such a binary period, magnetic field strengths, X-ray properties, and distance estimates are examined in context with long-term observations.

Author(s): Joshua Santana[1], Paul A. Mason[1]
Institution(s): *1. New Mexico State University*

219.26 – Full Bayesian hierarchical light curve modeling of core-collapse supernova populations

While wide field surveys have yielded remarkable quantities of photometry of transient objects, including supernovae, light curves reconstructed from this data suffer from several characteristic problems. Because most transients are discovered near the detection limit, signal to noise is generally poor; because coverage is limited to the observing season, light curves are often incomplete; and because temporal sampling can be uneven across filters, these problems can be exacerbated at any one wavelength. While the prevailing approach of modeling individual light curves independently is successful at recovering inferences for the objects with the highest quality observations, it typically neglects a substantial portion of the data and can introduce systematic biases. Joint modeling of the light curves of transient populations enables direct inference on population-level characteristics as well as superior measurements for individual objects. We present a new hierarchical Bayesian model for supernova light curves, where information inferred from observations of every individual light curve in a sample is partially pooled across objects to constrain population-level hyperparameters. Using an efficient Hamiltonian Monte Carlo sampling technique, the model posterior can be explored to enable marginalization over weakly-identified hyperparameters through full Bayesian inference. We demonstrate our technique on the Pan-STARRS1 (PS1) Type IIP supernova light curve sample published by Sanders et al. (2015), consisting of nearly 20,000 individual photometric observations of more than 70 supernovae in five photometric filters. We discuss the Stan probabilistic programming language used to implement the model, computational challenges, and prospects for future work including generalization to multiple supernova types. We also discuss scientific results from the PS1 dataset including a new relation between the peak magnitude and decline rate of SNe IIP, a new perspective on the distinction between Type IIP and Type IIL supernovae, and a technique for systematically estimating the progenitor properties of the objects in our sample.

Author(s): Nathan Sanders[1], Michael Betancourt[2], Alicia Margarita Soderberg[1]
Institution(s): *1. Harvard University, 2. University of Warwick*

219.27 – Spitzer and near-infrared observations of the young supernova remnant 3C397

We present Spitzer IRS, IRAC and MIPS observations and near-infrared imaging and spectroscopy of the young supernova remnant 3C397 (G41.1-0.2). Near-infrared observations were made using the Palomar 200 inch telescope. Both mid- and near-infrared spectra are dominated by Fe lines and near-infrared imaging shows bright Fe emission with a shell-like morphology. There is no molecular hydrogen line belong to the SNR and some are in background. The Ni, Ar, S and Si lines are detected using IRS and hydrogen recombination lines are detected in near-infrared. Two nickel lines at 18.24 and 10.69 micron are detected. 3C397 is ejecta-dominated, and our observations support 3C397 to be a Type Ia supernova.

Author(s): Jeonghee Rho[1], Tom Jarrett[2]
Institution(s): *1. SETI Institute and NASA Ames Research Center, 2. University of Capetown*

219.28 – Supernova Remanents in the Magellanic Clouds: Are there any surprises?

This is an exciting time for the discovery of supernova remnants (SNRs) in galaxies other than our Milky Way. SNRs reflect a major process in the elemental enrichment of the interstellar medium (ISM). The study of this interaction in different domains including radio, optical, IR and X-ray, allow a better understanding of these remnants and their environments. Nearby external galaxies offer an ideal laboratory, since they are near enough to be resolved, yet located at relatively known distances.

We highlight our radio studies of SNRs in both the Small and Large Magellanic Clouds (LMC), and share some of our multi-wavelength analytics for these objects. We also present new unpublished combined radio observations at 5.5 GHz of SNR 1E 0102–7219 in the Small Magellanic Cloud (SMC). These observations used the Australia Telescope Compact Array (ATCA) with the Compact Array Broadband Backend (CABB). The 2 GHz bandwidth from CABB not only increases sensitivity but also allows the data to be split into channels that can be used to measure the object's Faraday rotation. We show our new combined 5.5 GHz image, a full 2 GHz bandwidth polarization image having fractional polarization vectors up to 39% and a rotation measure image.

Author(s): Jeffrey L. Payne[1], M.D. Filipovic[1], Luke Bozzetto[1], Jordan Collier[1], Andrew O'Brien[1]
Institution(s): *1. Western Sydney University*

219.29 – A Treasure Trove of Molecules: Uncovering the Molecular Content of Planetary Nebulae

We have undertaken a systematic study of the molecular content of planetary nebulae (PNe) using the facilities of the Arizona Radio Observatory (ARO). A search for HCN and HCO^+ in seventeen PNe in which CO had previously been detected has been carried out. The J=1→0 and J=3→2 transitions of both molecules were searched for using the ARO 12-M Telescope and ARO Sub-Millimeter Telescope respectively. At least one transition of either molecule was detected in thirteen sources. Assuming a kinetic temperature of 20 K, the abundances of these two molecule, relative to H_2, were determined to be $f(HCN) \sim 0.1 - 9.1 \times 10^{-7}$ and $f(HCO^+) \sim 0.04 - 7.4 \times 10^{-7}$. The abundances of both species were found to remain relatively constant with nebular age, in contrast to predictions of chemical models. A subset of eleven of these PNe were subsequently searched for the J=1→0 and J=3→2 transitions of CCH and HNC. HNC was detected in ten sources, resulting in HCN/HNC ratios of ~2-6, while CCH has been detected in eight. The most current results for the abundances of both molecules will be reported. The correlation of CCH and C_{60} will also be presented. Establishing molecular abundances in PNe is vital to our understanding of their environments as well as the nature of their ejecta, which populate the interstellar medium (ISM).

Author(s): Deborah Rose Schmidt[1], Lucy M. Ziurys[1]
Institution(s): *1. University of Arizona*

300 – 2015 Newton Lacy Pierce Prize Lecture: The Elephant in the Room: Effects of Distant, Massive Companions on Planetary System Architectures, Heather Knutson (CIT)

300.01 – The Elephant in the Room: Effects of Distant, Massive Companions on Planetary System Architectures

Over the past two decades ongoing radial velocity and transit surveys have been astoundingly successful in detecting thousands of new planetary systems around nearby stars. These systems include apparently single gas giant planets on short period orbits, closely packed systems of up to 5-6 “super-Earths”, and relatively empty systems with either one or no small planets interior to 0.5 AU. Despite our success in cataloguing the diverse properties of these systems, we are still struggling to develop narratives that can explain their apparently divergent formation and migration histories. This is in large part due to our lack of knowledge about the potential presence of massive outer companions in these systems, which can play a pivotal role in the shaping the final properties of the inner planets. In my talk I will discuss current efforts to complete the census for known planetary systems by searching for outer gas giant planets with long term radial velocity monitoring and wide separation stellar companions with high contrast imaging and spectroscopy. I will then demonstrate how statistical constraints on this population of outer companions can be used to test current theories for planet formation and migration.

Author(s): Heather Knutson[1]
Institution(s): *1. California Institute of Technology*

301 – The Polarization of the Cosmic Microwave Background: Current Status and Future Prospects

This session will concentrate on recent results from on-going experiments and projections for upcoming Cosmic Microwave Background instruments. Theoretical and experimental results will be presented as will initial discussions regarding the Cosmic Microwave Background "Stage 4" experiment.

301.01 – Measuring the Polarized CMB with ACT

The Atacama Cosmology Telescope is a special-purpose 6m telescope designed for cosmic microwave background (CMB) measurements at arcminute resolution. We will describe recent results using the second-generation camera called ACTPol. The camera comprises three sets of optics and detectors. Two operate at 150 GHz, and the third is the first multichroic detector array deployed for the CMB. The latter operates at 90 and 150 GHz.

Author(s): Suzanne Staggs[1]
Institution(s): *1. Princeton University*

301.02 – Recent Results from the 2015 flight of Spider

Spider is a balloon borne mm-wave polarimeter designed to provide high fidelity measurements of the large scale polarization of the microwave sky. Spider flew a 17 day mission in January 2015, mapping roughly 10% of the full sky (4500 square degrees) in the southern Galactic hemisphere at each of 94 and 150 GHz. Spider achieved an instrumental sensitivity of 4 $\mu K_{CMB}\sqrt{s}$, providing maps that exceed the sensitivity of the Planck data. We discuss these data, the current status of our science analysis, and our understanding of the Galactic
foreground emission in this high latitude region.

Author(s): William C. Jones[1]
Institution(s): *1. Princeton University*

301.03 – Probing Inflation, Reionization, and Neutrinos with CLASS

We are beginning a survey to provide a robust detection and characterization of the imprint of inflationary gravitational radiation in the CMB polarization (the so-called "B modes"). The same polarization measurement will provide the ultimate CMB-based cosmic-variance-limited measurement of the optical depth to reionization. When combined with CMB temperature, lensing and Baryon Acoustic Oscillation data, the optical depth measurement will yield twofold improvements on cosmology-based estimates of the sum of the neutrino masses. To carry out the survey we have built the Cosmology Large Angular Scale Surveyor (CLASS), which is an array of millimeter-wave polarimeters sited at 5200 m in the Atacama Desert. Unique in the field of CMB polarization measurements, CLASS is especially designed to survey 70% of the sky at four frequencies (40-220 GHz) and recover the CMB polarization on all angular scales relevant to inflation and reionization. In this talk I will give an overview of CLASS and discuss progress to date.

Author(s): Tobias Marriage[1]
Institution(s): *1. Johns Hopkins University*
Contributing team(s): CLASS Collaboration

301.04 – C-BASS: The C-Band All Sky Survey

The C-Band All Sky Survey (C-BASS) is a project to image the whole sky at a wavelength of 6 cm (frequency 5 GHz), measuring both the brightness and the polarization of the sky. Correlation polarimeters are mounted on two separate telescopes, one at the Owens Valley Observatory (OVRO) in California and another in South Africa, allowing C-BASS to map the whole sky. The OVRO instrument has completed observations for the northern part of the survey. We are working on final calibration of intensity and polarization. The southern instrument has recently started observations for the southern part of the survey from its site at Klerefontein near Carnarvon in South Africa. The principal aim of C-BASS is to allow the subtraction of polarized Galactic synchrotron emission from the data produced by CMB polarization experiments, such as WMAP, Planck, and dedicated B-mode polarization experiments. In addition it will contribute to studies of: (1) the local (< 1 kpc) Galactic magnetic field and cosmic-ray propagation; (2) the distribution of the anomalous dust emission, its origin and the physical processes that affect it; (3) modeling of Galactic total intensity emission, which may allow CMB experiments access to the currently inaccessible region close to the Galactic plane. Observations at many wavelengths from radio to infrared are needed to fully understand the foregrounds. At 5 GHz, C-BASS maps synchrotron polarization with minimal corruption by Faraday rotation, and complements the full-sky maps from WMAP and Planck. I will present the project status, show results of component separation in selected sky regions, and describe the northern survey data products.

C-BASS (http://www.astro.caltech.edu/cbass/) is a collaborative project between the Universities of Oxford and Manchester in the UK, the California Institute of Technology (supported by the National Science Foundation and NASA) in the USA, the Hartebeesthoek Radio Astronomy Observatory (supported by the Square Kilometre Array project) in South Africa, and the King Abdulaziz City for Science and Technology (KACST) in Saudi Arabia.

Author(s): Timothy J. Pearson[1]
Institution(s): *1. Caltech*
Contributing team(s): C-BASS collaboration

301.05 – The Polarization of the CMB with Planck

In this talk I will give an overview of Planck data and Cosmological results focusing on the analysis of polarized data. I will present new insights into the polarization of foregrounds rendered by the Planck satelite and an account of current constraints on the optical depth due to reionization, τ, and the scalar to tensor ratio, r.

Author(s): Graca Rocha[1]
Institution(s): *1. JPL*
Contributing team(s): Planck Collaboration

301.06 – Polarimeter Arrays with Comprehensive Frequency Coverage for the Next Generation of Precision Microwave Background Experiments

Spectral resolution at (sub-)millimeter wavelengths is now understood to be crucially important in precision measurements of the cosmic microwave background (CMB). Recent results from the Planck and BICEP/KECK experiments have established that measurements of the CMB polarization signal is limited, in part, by polarized foreground emission. In particular, polarized emission from galactic dust has been found to dominate and obscure potential signals of cosmic inflation, even in regions of the sky specifically identified as having relatively low galactic emission. Current and future experiments aim to address foreground contamination by conducting high-sensitivity observations with broad spectral coverage that will allow for differentiation within the measured signal between foreground sources of polarization and that of the CMB, which each have distinct spectral characteristics. To efficiently achieve these goals within a limited focal plane area, NIST-Boulder has developed multi-band TES-based polarimeters that simultaneously measure multiple spectral bands in each of two orthogonal polarizations. This acts to both increase pixel sensitivity through an increased total bandwidth, as well as providing broad spectral information for differentiation of emission sources. Here, we describe recent achievements and ongoing efforts at NIST-Boulder in the development of millimeter and sub-millimeter detector and focal plane technologies for future experiments, including the stage-IV CMB experiment, CMB-S4. NIST-Boulder provides critical cryogenic components to a large number of current and in-development CMB experiments. Recent milestones include the fielding of the first broadband multi-chroic mm-wave polarimeters in the ACTPol experiment, multi-band array fabrication on large-format 150 mm wafers, and development of matching 150 mm silicon platelet feedhorn arrays. We also review several related development efforts in detector, optical coupling, and readout technologies and the roles they could play in fielding the O(500,000) detectors envisioned for CMB-S4.

Author(s): Jason Edward Austermann[1], James Beall[1], Dan Becker[1], Hsiao-Mei Cho[2], Shannon Duff[1], jiansong gao[1], Gene Hilton[1], Johannes Hubmayr[1], Kent Irwin[2], dale li[2], Christopher McKenney[1], Joel Ullom[1], jeffrey van lanen[1], Michael Vissers[1]
Institution(s): *1. National Institute of Standards and Technology, 2. Stanford University*

301.07 – The Next Generation Ground-based CMB experiment, CMB-S4

This talk will review the goals and status of the community planning for the next generation ground-based CMB experiment, CMB-S4. Following the detection of CMB polarization in 2002, the current generation of ground-based experiments each fielding of order 1000 superconducting detectors (Stage II experiments) have led to the first detection of the much fainter lensing B-mode polarization signal and the most stringent constraints on the level of the B-mode signal from inflationary gravitational waves. We can expect significant advances in the next few years as the ongoing ground-based experiments deploy of order 10,000 detectors (Stage III). The CMB community is now planning an ambitious next generation (Stage IV) ground-based program with order of 500,000 detectors, CMB-S4, to achieve critical threshold crossing goals of 1) detecting or ruling out large field inflationary models, 2) determining the effective number and masses of the neutrinos, and 3) providing precision constraints on dark energy through its impact on structure formation.

Author(s): John E. Carlstrom[1]
Institution(s): *1. Univ. of Chicago*
Contributing team(s): CMB-S4 Collaboration

301.08 – The LiteBIRD Space Mission and the Search for Inflation at the Beginning of the Universe

Inflation is the leading theory to explain the first instant of the universe. The case for inflation
is building, and now we may have the opportunity to observe the signature of gravitational waves from the inflation event
embedded in the cosmic microwave background. If seen, these signals would confirm inflation, point to the correct model for inflation,
and, given the high energies involved, teach us about fundamental physics such as quantum gravity and string theory.

I will describe the LiteBIRD cosmic microwave background space mission which is currently in collaborative Phase A studies in both Japan
and the U.S. LiteBIRD will use a 50 cm diameter telescope and a ~2000 detector focal plane cooled to 100 mK to probe degree and larger angular scales in polarization. It will measure the entire sky with ~2 microK*arcmin noise (150 GHz), and measure in 15 bands from 40 to 400 GHz to measure and subtract foregrounds. A rapidly spinning Half-Wave Plate will be used to rapidly "chop" between two polarization states. It will orbit at the second Lagrange point (L2).

Author(s): Adrian T Lee[1]
Institution(s): *1. UC Berkeley*

301.09 – A CubeSat for Calibrating Ground-Based and Sub-Orbital Millimeter-Wave Polarimeters

We describe a low-cost, open-access, CubeSat-based calibration instrument that is designed to support ground-based and sub-orbital experiments searching for various polarization signals in the cosmic microwave background (CMB). All modern CMB polarization experiments require a robust calibration program that will allow the effects of instrument-induced signals to be mitigated during data analysis. A bright, compact, and linearly polarized astrophysical source with polarization properties known to adequate precision does not exist. Therefore, we designed a space-based millimeter-wave calibration instrument, called CalSat, to serve as an open-access calibrator, and this paper describes the results of our design study. The calibration source on board CalSat is composed of five "tones'" with one each at 47.1, 80.0, 140, 249 and 309 GHz. The five tones we chose are well matched to (i) the observation windows in the atmospheric transmittance spectra, (ii) the spectral bands commonly used in polarimeters by the CMB community, and (iii) The Amateur Satellite Service bands in the Table of Frequency Allocations used by the Federal Communications Commission. CalSat will be placed in a polar orbit allowing visibility from observatories in the Northern Hemisphere, such as Mauna~Kea in Hawaii and Summit Station in Greenland, and the Southern Hemisphere, such as the Atacama Desert in Chile and the South Pole. CalSat also will be observable by balloon-borne instruments launched from a range of locations around the world. This global visibility makes CalSat the only source that can be observed by all terrestrial and sub-orbital observatories, thereby providing a universal standard that permits comparison between experiments using appreciably different measurement approaches.

Author(s): Bradley Johnson[1]
Institution(s): *1. Columbia University*

301.10 – New Measurements of CMB Polarization with SPTpol

All-sky surveys of the primary temperature anisotropies of the Cosmic Microwave Background (CMB) are now cosmic variance limited on large to intermediate scales. To place tighter constraints on cosmology from CMB primary anisotropies we turn to measurements of CMB polarization. Not only is polarization another probe of ΛCDM cosmology, but secondary anisotropies are expected to have low polarized emission, which opens more of the so-called CMB damping tail to cosmological study. In this talk, we present new 150 GHz measurements of the CMB E-mode polarization auto-power and temperature-E-mode cross-power spectra from a 500 deg^2 patch of sky observed with the SPTpol instrument, the second-generation receiver installed on the South Pole Telescope. Over a range of spherical harmonic multipoles $50 \le l < 10000$ we detect 9 acoustic peaks in the E-mode spectrum. With these spectra we constrain ΛCDM cosmology independently from temperature-only measurements, and present new joint constraints with the Planck temperature auto-power spectrum. The CMB is also gravitationally lensed by large-scale structure. We use our high-fidelity map of E-mode polarization, in conjunction with SPTpol maps of B-mode polarization and temperature, to map the lensing potential of the CMB and measure its corresponding power spectrum. Finally, the CMB lensing potential can be combined with our E-mode map to estimate lensing B modes present in our field, which can be delensed to improve constraints on primordial B modes and the energy scale of inflation through the tensor-to-scalar ratio, r.

Author(s): Jason Henning[1]
Institution(s): *1. University of Chicago*
Contributing team(s): SPTpol Collaboration

302 – Bridging Laboratory & Astrophysics: Atomic Physics in X-rays

Laboratory astrophysics is the Rosetta Stone that enables astronomers to understand and interpret the cosmos. This session will focus on the interplay between astrophysics with theoretical and experimental studies into the underlying atomic processes, which drive our Universe, with special attention to observations done with Astro-H.

302.01 – Recent Advances in Computational Studies of Charge Exchange X-ray Emission

Interest in astrophysical sources of charge exchange (CX) has grown since X-ray emission from comet Hyakutake was first observed, the origin of which is primarily due to CX processes between neutral species in the comet's atmosphere and highly charged ions from the solar wind. More recent observations have shown that CX may have a significant contribution to the X-ray emission spectra of a wide variety of environments within our solar system including solar wind charge exchange (SWCX) with neutral gases in the heliosphere and in planetary atmospheres, as well as beyond the solar system in galaxy clusters, supernova remnants, and star forming galaxies.

While the basic process of CX has been studied for many decades, the reliability of the existing data is not uniform, and the coverage of the astrophysically important projectile and target combinations and collisional velocities is insufficient. The need for reliable and robust CX X-ray emission models will only be amplified with the with the high resolution X-ray spectra expected from the soft X-ray imaging calorimeter spectrometer (SXS) onboard the *Hitomi* X-ray observatory. In this talk, I will discuss recent advances in theoretical CX cross sections and X-ray modeling with a focus on CX diagnostics. The need for experimental X-ray spectra and cross sections for benchmarking current theory will also be highlighted. This work was performed in collaboration with David Lyons, Patrick Mullen, David Schultz, Phillip Stancil, and Robin Shelton. Work at UGA was partially supported by NASA grant NNX09AC46G.

Author(s): Renata Cumbee[1]
Institution(s): *1. University of Georgia*

302.02 – Atomic Data Needs for the New Generation

of X-ray Observatories

Modeling X-ray spectra produced by photoionized plasmas is crucial for the physical interpretation of many astrophysical sources. These models rely on theoretical and numerical techniques, but importantly also on the availability of reliable atomic data. The need for accurate data continues to grow with the advent of new and more sensitive instruments. I will describe atomic-data requirements for addressing three astrophysical problems: (1) atomic, molecular, and dust absorption in the ISM; (2) detection and characterization of inner-shell lines from various trace elements or Fe-peak elements (e.g., P, K, Cr, Mn, Co); and (3) modeling X-ray spectra reflected from black hole accretion disks in the high-density limit. I will discuss the importance of
these studies, and the limitations of the theoretical models presently being used to fit data from such current missions as NuSTAR and Astro-H (Hitomi).

Author(s): Javier Garcia[1]
Institution(s): *1. Harvard-Smithsonian CfA*
Contributing team(s): 6174967980

302.04 – Laboratory measurements of the x-ray emission following dielectronic recombination onto highly charged argon ions

We have used the LLNL EBIT-I electron beam ion trap to measure the X-ray emission following resonant dielectronic recombination (DR) onto helium-like and lithium-like argon as a function of electron energy. These measurements were completed by sweeping the energy of EBIT-I's near mono-energetic electron beam from below threshold for DR resonance to above threshold for direct excitation of K-shell transitions in helium-like argon. The X-ray emission was recorded as a function of electron beam energy using the EBIT Calorimeter Spectrometer, whose energy resolution is ~ 5 eV, and also a relatively low resolution, solid-state X-ray detector. These results will be useful when analyzing and interpreting high resolution spectra from celestial sources measured with the Soft X-ray Spectrometer (SXS) calorimeter instrument recently launched on the Hitomi X-ray Observatory (formerly known as Astro-H), as well as data measured using instruments on the Chandra and XMM-Newton X-ray Observatories. Specifically, these data will help determine if the feature detected at ~ 3.56 keV (Bulbul et al. 2014, Boyarsky et al. 2014) in clusters is the result of the decay of a sterile neutrino, a long sought after dark matter particle candidate.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and Chandra Grant AR5-16012A.

Author(s): Gregory V. Brown[2], Peter Beiersdorfer[2], Esra Bulbul3, Natalie Hell[2], Adam Foster[1], Gabriele Betancourt-Martinez5, Frederick Scott Porter[4], Randall K. Smith[1]
Institution(s): *1. Harvard-Smithsonian CfA, 2. LLNL, 3. MIT Kavli Institute for Astrophysics and Space Research, 4. NASA/GSFC, 5. University of Maryland*

303 – The Limits of Scientific Cosmology: Town Hall

The purpose of the third session is to allow AAS members to present short written contributions and to ask longer questions. It is expected that this devolve into a general discussion. Special attention will be given to engaging younger and junior members of the AAS.

303.01 – Panel Discussion Moderated by Roger Blandford and Joe Silk

304 – Star Formation in a Range of Environments

304.01 – The Connection Between Galaxy Environment and the Luminosity Function Slopes of Star-Forming Regions

We present the first study of GALEX far ultra-violet (FUV) luminosity functions of individual star-forming regions within a sample of 258 nearby galaxies spanning a large range in total stellar mass and star formation properties. We identify ~65,000 star-forming regions (i.e., FUV sources), measure each galaxy's luminosity function, and characterize the relationships between the luminosity function slope (α) and several global galaxy properties. A final sample of \ntot galaxies with reliable luminosity functions are used to define these relationships and represent the largest sample of galaxies with the largest range of galaxy properties used to study the connection between luminosity function properties and galaxy environment. We find that α correlates with global star formation properties, where galaxies with higher star formation rates and star formation rate densities (Σ_{SFR}) tend to have flatter luminosity function slopes. In addition, we find that neither stochastic sampling of the luminosity function in galaxies with low-number statistics nor the effects of blending due to distance can fully account for these trends. We hypothesize that the flatter slopes in high Σ_{SFR} galaxies is due to higher gas densities and higher star formation efficiencies which result in proportionally greater numbers of bright star-forming regions. Finally, we create a composite luminosity function composed of star-forming regions from many galaxies and find a break in the luminosity function at brighter luminosities. However, we find that this break is an artifact of varying detection limits for galaxies at different distances.

Author(s): David O. Cook5, Daniel A. Dale5, Janice C. Lee[2], David A. Thilker[1], Daniela Calzetti4, Robert Kennicutt3
Institution(s): *1. Johns Hopkins University, 2. Space Telescope Science Institute, 3. University of Cambridge, 4. University of Massachusetts , 5. University of Wyoming*

304.02D – The structure and Stellar Populations of Nuclear Star Clusters in Late-type Spiral Galaxies From HST/WFC3 Imaging

Luminous, compact stellar systems known as nuclear clusters (NCs) are commonly found in the centers of galaxies across the entire Hubble sequence. I present an analysis of the structure and stellar populations of a sample of ten of the nearest and brightest NCs residing in late-type spiral galaxies, using imaging data from Hubble Space Telescope Wide Field Camera 3 in seven bands that span the near-ultraviolet to the near-infrared. The intrinsic shapes and sizes of the NCs, disentangled from the effects of point spread function (PSF) blurring, were measured using GALFIT. For six of the ten NCs in our sample, we find changes in the effective radius with wavelength, which suggests that many NCs contain radially varying stellar populations. There is also a general trend of increasing roundness of the NCs at longer wavelengths, suggesting that the youngest stars in NCs typically form in disks. I developed a Monte Carlo code to fit linear combinations of simple stellar population models to the observed spectral energy distribution (SED) of each NC and assess the uncertainties in the fit parameters. Tests using mock SEDs with known input parameters demonstrate that although the method is susceptible to degeneracies between model SEDs, the code is robust and accurately recovers the total stellar mass for a wide range of NC colors and ages. I present global star formation histories and stellar mass estimates for each cluster, which are in good agreement with previous dynamical studies. The clusters are generally dominated by an old (> 1 Gyr) population, but are best described by multi-age models. The spatially resolved properties of the stellar populations of each NC were also studied by performing SED fits on a pixel-by-pixel basis. These fits reveal radial age gradients in the same NCs that exhibited variation in the effective radius with wavelength. Finally, I present deprojected density profiles and estimates of the central stellar density of each cluster.

Author(s): Daniel Carson[1]
Institution(s): *1. University of California Irvine*

304.03 – On the Lyman continuum escape fraction of galaxies at z~2-3

Escaping Lyman-continuum (LyC) radiation from star-forming galaxies is likely responsible for the reionization of the Universe, yet direct detection of LyC has proven to be exceptionally challenging.

Despite numerous efforts only a few galaxies have yet been confirmed as LyC leakers, leading people to use indirect methods to infer the escape fraction. Using a 10-orbit WFC3/UVIS F275W filter image of the Cosmic Horseshoe (a lensed galaxy at z=2.4), we show that these indirect determinations should be interpreted only as upper-limits on the escape fraction. We will also present Hubble measurements of the LyC escape fraction of more than 30 galaxies at z~3.1 in the SSA22 field, including 11 candidate emitters from deep Keck imaging. These data include the deepest near-UV images with Hubble and will probe escape fractions of 5-10% (at 3 sigma). Finally, we will conclude with implications for galaxy contributions to the ionizing background and Reionization.

Author(s): Kaveh Vasei[1]
Institution(s): *1. UCR*

304.04 – What can Simple Models tell us about Star Formation?

Star formation includes a large amount of nonlinear physics (turbulence, cooling, feedback etc.) making it a challenge to run simulations with detailed physical models. A possible approach is to formulate simple, easily testable models to try to find the minimum physics required to reproduce different aspects of star formation.
In this talk I will present a highly flexible semi analytical model that allows one to easily 'plug in' and test different physics. Using this tool we have shown that a universal IMF model requires the presence of an invariant mass scale. Although both feedback and equation of state thermodynamics can provide a mass scale, we showed EOS mass scales are inherently sensitive to initial conditions.
Unlike most analytical models this framework provides both spatial and temporal information allowing us to investigate the clustering and binarity in different models. So far we have shown that isothermal common core fragmentation (which is scale free) is able to reproduce the stellar correlation function at long distances. This result is robust to changes in the small scale physics (e.g. adding protostellar feedback, non-isothermal equation of state). With the addition of feedback from protostellar heating, this agreement continues down to the protostellar disk scale. We have also found that such a model can reproduce most binarity properties of low mass stars, hinting that low mass binaries are formed primarily through common core fragmentation.

Author(s): David Guszejnov[2], Philip F. Hopkins[2], Mark R. Krumholz[1]
Institution(s): *1. Australian National University, 2. Caltech*

304.05 – Failures no More: The Radical Consequences of Realistic Stellar Feedback for Dwarf Galaxies, the Milky Way, and Reionization

Many of the most fundamental unsolved questions in star and galaxy formation revolve around star formation and "feedback" from massive stars, in-extricably linking galaxy formation and stellar evolution. I'll present simulations with un-precedented resolution of Milky-Way (MW) mass galaxies, followed cosmologically to redshift zero. For the first time, these simulations resolve the internal structure of small dwarf satellites around a MW-like host, with detailed models for stellar evolution including radiation pressure, supernovae, stellar winds, and photo-heating. I'll show that, without fine-tuning, these feedback processes naturally resolve the "missing satellites," "too big to fail," and "cusp-core" problems, and produce realistic galaxy populations. At high redshifts however, the realistic ISM structure predicted, coupled to standard stellar population models, naively leads to the prediction that only ~1-2% of ionizing photons can ever escape galaxies, insufficient to ionize the Universe. But these models assume all stars are single: if we account for binary evolution, the escape fraction increases dramatically to ~20% for the small, low-metallicity galaxies believed to ionize the Universe.

Author(s): Philip F. Hopkins[1]
Institution(s): *1. Caltech*

304.06 – Small Scale Chemical Segregation Within Keplerian Disk Candidate G35.20-0.74N

In the study of high-mass star formation, hot cores are empirically defined stages where chemically rich emission is detected toward a massive protostar. It is unknown whether the physical origin of this emission is a disk, inner envelope, or outflow cavity wall and whether the hot core stage is common to all massive stars. With the advent of the highly sensitive sub-millimeter interferometer, ALMA, the ability to chemically characterize high mass star forming regions other than Orion has become possible. In the up-and-coming field of observational astrochemistry, these sensitive high resolution observations have opened up opportunities to find small scale variations in young protostellar sources.

We have done an in depth analysis of high spatial resolution (~1000 AU) Cycle 0 ALMA observations of the high mass star forming region G35.20-0.74N, where Sánchez-Monge et al (2013) found evidence for Keplerian rotation. After further chemical analysis, numerous complex organic species have been identified in this region and we notice an interesting asymmetry in the distribution of the Nitrogen-bearing species within this source. In my talk, I will briefly outline the case for the disk and the consequences for this hypothesis following the chemical segregation we have seen.

Author(s): Veronica Allen3, Floris van der Tak3, Álvaro Sánchez-Monge[1], Riccardo Cesaroni[2], Maria T. Beltrán[2]
Institution(s): *1. I. Physikalisches Institut, 2. INAF, Osservatorio Astrofisico di Arcetri, 3. Kapteyn Astronomical Institute*

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305 – Plenary Talk: From the First Stars and Galaxies to the Epoch of Reionization: 20 Years of Computational Progress, Michael Norman (UC San Diego)

305.01 – From the First Stars and Galaxies to the Epoch of Reionization: 20 Years of Computational Progress

I give a progress report on computational efforts to reconstruct the first billion years of cosmic evolution beginning with the formation of the first generation of stars and galaxies, culminating in the complete photoionization of the intergalactic medium. After 20 years of intense effort, the picture is falling into place through the development and application of complex multiphysics numerical simulations of increasing physical complexity and scale on the most powerful supercomputers. I describe the processes that govern the formation of the first generation of stars, the transition to the second generation of stars, the assembly of the first galaxies, and finally the reionization of the universe. I discuss how these simulations guide the interpretation of relevant observations of the high redshift (and local) universe, along with some observational predictions of these simulations which will be tested with the next generation observatories.

Author(s): Michael L. Norman[1]
Institution(s): *1. UC, San Diego*

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308 – Star Formation, Associations, and Young Stellar Objects in the Milky Way

308.01 – Episodic Accretion among the Orion Protostars

Episodic accretion, where a young stellar object undergoes stochastic spikes in its disk-to-star accretion rate one or more times over its formation period, may be a crucial process in the formation of low-mass stars. These spikes result in a factor of 10 to 100 increase in the source luminosity over the course of several months that may persist for years. Six years after the Spitzer survey of the Orion molecular clouds, the WISE telescope mapped Orion with similar wavelength coverage. Thus, the two surveys can be used to explore the mid-infrared variability of young stars on this timescale, which is suitable for discovering episodic accretion events. Out of 319 Orion protostars that were targets of the Herschel Orion Protostar Survey, we identified two examples of episodic accretion with this method. One of them, HOPS 223, was previously known. The other, HOPS

383, is the first known example of episodic accretion in a Class 0 protostar (age < 0.2 Myr). With these and one other outburst that began early in the Spitzer mission, we estimate that the most likely interval between protostellar outbursts is 740 years, with a 90% confidence interval of 470 to 6200 years. These outbursts are weaker than the optically revealed FU Ori events. We will update the mid-infrared light curves of HOPS 223 and HOPS 383 with recent data from FORCAST aboard SOFIA; HOPS 223 shows signs of fading.

Author(s): William J. Fischer[2], Emily Safron[1], S. Thomas Megeath3
Institution(s): *1. Lorain County Community College, 2. NASA Goddard Space Flight Center, 3. University of Toledo*

308.02 – The nature of IRAS 19312+1950 revealed using Herschel: A massive YSO with peculiar maser properties

IRAS 19312+1950 is a bright, compact infrared source that has eluded firm characterization since its discovery. The SiO and OH maser properties are indicative of a high mass-loss evolved star, yet the complex chemistry and rising far-infrared SED are more characteristic of the envelope of a young stellar object (YSO). In order to elucidate the physical properties of IRAS 19312+1950, we obtained Herschel PACS and HIFI observations of gas and dust in the range 54-550 micron. Numerous detections of CO and H2O rotational lines were obtained, spanning a broad range of upper-state energy levels and probing different excitation regimes of the source. The PACS maps exhibit a compact, slightly asymmetric continuum source, indicative of a large mass of cool dust, whereas the far-IR CO spectrum reveals the presence of an excited gas component at around 200 K. Our HIFI observations show a complex kinematic structure indicative of a cool circumstellar envelope and fast outflow with a velocity up to 90 km/s along the line of sight. From Spitzer spectroscopy, we identify the presence of ice absorption bands due to H2O at 5.8 micron and CO2 at 15 micron, characteristic of interstellar/protostellar material. Combining the Herschel and Spitzer data with previous continuum measurements, the SED is found to be consistent with a massive, luminous central source surrounded by a dense, warm disk and a dusty envelope with large bipolar outflow cavities. The distinctive infrared SED and far-IR spectral features with broad, Gaussian-like outflow wings strongly suggest that IRAS 19312+1950 should be classified as a rare example of an isolated, accreting high-mass YSO with unusual maser properties, rather than an evolved star. In this presentation, the implications of the unique properties of this source will be discussed, along with our proposed ALMA observations required to confirm the classification of this object.

Author(s): Martin Cordiner4, Steven B. Charnley4, Adwin Boogert3, Kay Justtanont[2], Nick Cox[6], Robert G. Smith5, Xander Tielens[1], Eva S. Wirström[2]
Institution(s): *1. Leiden Observatory, University of Leiden, 2. Chalmers University of Technology, Onsala Space Observatory, 3. NASA Ames Research Center, 4. NASA Goddard Space Flight Center, 5. The University of New South Wales, Australian Defence Force Academy, 6. Universit'e de Toulouse*

308.03 – Hydride Ions, HCO^+ and Ionizing Irradiation in Star Forming Region

Hydrides are fundamental precursor molecules in cosmic chemistry and many hydride ions have become observable in high quality for the first time thanks to the *Herschel Space Observatory*. Ionized hydrides, such as CH^+ and OH^+ and also HCO^+ affect the chemistry of molecules such as water. They also provide complementary information on irradiation by far UV (FUV) or X-rays and gas temperature.
We explore hydrides of the most abundant heavier elements in an observational survey covering star forming regions with different mass and evolutionary state. Twelve YSOs were observed with HIFI on *Herschel* in 6 spectral settings providing fully velocity-resolved line profiles. The YSOs include objects of low (Class 0 and I), intermediate, and high mass, with luminosities ranging from 4 L_S to 2 105 L_S.
The targeted lines of CH^+, OH^+, H_2O^+, and C^+ are detected mostly in blue-shifted absorption. H_3O^+ and SH^+ are detected in emission and only toward some high-mass objects. For the low-mass YSOs the column density ratios of CH^+/OH^+ can be reproduced by simple chemical models implying an FUV flux of 2 – 400 times the ISRF at the location of the molecules. In two high-mass objects, the UV flux is 20 – 200 times the ISRF derived from absorption lines, and 300 – 600 ISRF using emission lines. Upper limits for the X-ray luminosity can be derived from H_3O^+ observations for some low-mass objects. If the FUV flux required for low-mass objects originates at the central protostar, a substantial FUV luminosity, up to 1.5 L_S, is required. For high-mass regions, the FUV flux required to produce the observed molecular ratios is smaller than the unattenuated flux expected from the central object(s) at the *Herschel* beam radius. This is consistent with an FUV flux reduced by circumstellar extinction or by bloating of the protostar.
The ion molecules are proposed to form in FUV irradiated cavity walls that are shocked by the disk wind. The shock region is turbulent, broadening the lines to some 1 – 12 km/s. It is driven by the outward motion of the wind to blue shifts of 0 to -10 km/s. The blue-shifted H_2O emission line (Kristensen et al. 2013) may be related but not coincident with the CH^+ and OH^+ emitting region.

Author(s): Arnold O. Benz[1], Simon Bruderer[1], Ewine van Dishoeck[2]
Institution(s): *1. ETH Zurich, Switzerland, 2. Leiden Observatory*

308.04 – Tracing Slow Winds from T Tauri Stars via Low Velocity Forbidden Line Emission

Protoplanetary disks are a natural result of star formation, and they provide the material from which planets form. The evolutional and eventual dispersal of protoplanetary disks play critical roles in determining the final architecture of planetary systems. Models of protoplanetary disk evolution suggest that viscous accretion of disk gas onto the central star and photoevaporation driven by high-energy photons from the central star are the main mechanisms that drive disk dispersal. Understanding when photoevaporation begins to dominate over viscous accretion is critically important for models of planet formation and planetary migration. Using Keck/HIRES (resolution of ~ 7 km/s) we analyze three low excitation forbidden lines ([O I] 6300 Å, [O I] 5577 Å, and [S II] 6731 Å) previously determined to trace winds (including photoevaporative winds). These winds can be separated into two components, a high velocity component (HVC) with blueshifts between ~30 – 150 km/s, and a low velocity component (LVC) with blueshifts on the order of ~5 km/s (Hartigan et al. 1995). We selected a sample of 32 pre-main sequence T Tauri stars in the Taurus-Auriga star-forming region (plus TW Hya) with disks that span a range of evolutionary stages. We focus on the origin of the LVC specifically, which we are able to separate into a broad component (BC) and a narrow component (NC) due to the high resolution of our optical spectra. We focus our analysis on the [O I] 6300 Å emission feature, which is detected in 30/33 of our targets. Interestingly, we find wind diagnostics consistent with photoevaporation for only 21% of our sample. We can, however, conclude that a specific component of the LVC is tracing a magnetohydrodynamic (MHD) wind rather than a photoevaporative wind. We will present the details behind these findings and the implications they have for planet formation more generally.

Author(s): Molly Simon5, Ilaria Pascucci5, Suzan Edwards4, Wanda Feng[1], Elisabetta Rigliaco[2], Uma Gorti3, David J. Hollenbach3, James Tuttle Keane5
Institution(s): *1. Arizona State University, 2. ETH Zurich, 3. SETI, 4. Smith College, 5. University of Arizona*

308.05 – The Evolution of FU Orionis Disks

Do protoplanetary disks undergo regular (or irregular) bursts of accretion? FU Orionis objects (FUors) are the strongest direct evidence for episodic accretion in low mass young stellar objects. FUors exhibit rapid changes in disk chemistry, both because they are temporarily bright IR sources relative to their core mass, and vary on day, month, year, and decade timescales. With improved spatial and spectral resolution from FORCAST, and a ten year time baseline compared with Spitzer-IRS data, we can observe and constrain the properties of silicate dust, and disk profiles, as they are altered by the outburst. We also consider the occurrence of binarity and whether any connection exists between multiplicity and evidence of recent outburst behavior.

Author(s): Joel D. Green[1]
Institution(s): *1. Space Telescope Science Institute*

309 – Bridging Laboratory & Astrophysics: Atomic, Nuclear, & Particles Physics in X-rays

Laboratory astrophysics is the Rosetta Stone that enables astronomers to understand and interpret the cosmos. This session will focus on the interplay between astrophysics with theoretical and experimental studies into the underlying nuclear processes, which drive our Universe, with special attention to observations done with Astro-H and NuSTAR.

309.01 – Laboratory Astrophysics in Support of High-Resolution X-ray Astronomy

X-ray astronomy entered a new era with the advent of high-spectral resolution grating spectrometers aboard the *Chandra* and *XMM-Newton* X-ray observatories and, very recently, with the launch of the high-resolution calorimeter (SXS) aboard the *Hitomi* mission. The ability to perform spectrally resolved observations has necessitated increasing accuracies in the spectral models used to analyze astrophysical data. Our laboratory measurements have responded to that need by assessing the fidelity of the atomic data used in the models and by calibrating specific spectral diagnostics. Our spectroscopy measurements are mostly carried out at the electron beam ion trap facility at Livermore, which produces the relevant ions in a density and temperature environment similar to those of astrophysical plasmas. Recent measurements include the identification of lines seen with *Chandra's* LETGS in astrophysical spectra but missing in the models; wavelength determinations of K-shell transitions in L-shell ions and of L-shell transitions in M-shell ions needed for the interpretation of absorption line features; and the calibration of the line emission of key spectroscopic diagnostics, such as the L-shell lines of Fe XVII. Observations with *Hitomi's* SXS will be sensitive to X-ray line formation by charge exchange, which has already been associated with the X-ray emission from comets and which has been suggested as an alternative explanation of the 3.55 keV line, both so far only observed with CCD resolution. Line formation by charge exchange has been another area of our laboratory astrophysics work, and we have recently uncovered that a large fraction of double charge exchange events decay unexpectedly by double X-ray emission. Moreover, we have shown that electron rearrangement following double charge exchange can lead to X-ray energies well in excess of those predicted by current charge exchange models.

This work was performed under the auspices of the U.S. Department of Energy by LLNL under Contract DE-AC52-07NA27344 and supported by NASA's Astrophysics Research and Analysis Program under contracts NNG14WF24I, NNH16AC34I, and NNG13WF99I.

Author(s): Peter Beiersdorfer[1]
Institution(s): *1. LLNL*

309.02 – Recent Discoveries in Nuclear Line Astrophysics

Nuclear gamma-ray lines provide a unique probe of supernovae and nuclear astrophysics. The potential for significant contributions to the understanding supernovae, as well as the large potential for new discoveries, has long been recognized. I will review several major discoveries in the past few years from the NuSTAR and INTEGRAL missions, including observations of SN 1987A, Cas A, and SN 2014J. In addition, I will look forward to the next generation of gamma-ray line instruments currently under development, including wide-field Compton telescopes and focusing lens telescopes.

Author(s): Steven E. Boggs[1]
Institution(s): *1. UC, Berkeley*

309.03 – Modeling Plasmas with a Kappa Electron Energy Distribution

Nonthermal kappa electron energy distributions have been observed in the Earth's magnetosphere and the solar wind, and are likely also present in the solar corona and in solar flares. In order to model the spectra of these plasmas, it is necessary to obtain the appropriate collision rate coefficients. We show that this can be done simply by summing appropriately weighted Maxwellian rate coefficients. The resulting data have similar or better accuracies than are obtained with other approaches. Summing Maxwellians has the additional advantages of being easy to implement and extendable to many different collision processes. We apply this technique to modeling the charge state distribution (CSD) of kappa-distribution plasmas. In particular, we examine the influence of electron impact multiple ionization on the equilibrium CSD and calculate the time variation of the CSD during a solar flare.

Author(s): Michael Hahn[1], Daniel Wolf Savin[1]
Institution(s): *1. Columbia University*

310 – The Limits of Scientific Cosmology: The Way Forward

The goals of the final session are to synthesize what has has already been heard and to present conclusions as to a future program from three quite different perspectives. The first is that of an observational cosmologist actively engaged in the future research program. The second is that of a theoretical physicist who sees parallel issues arising in topics such as string theory, quantum entanglement, holography etc and communicate the connections to cosmology for an astronomical audience. The third talk will be a balanced summary that should draw together the various threads from the preceeding discussions.

310.01 – Surveying Future Surveys

The now standard model of cosmology has been tested and refined by the analysis of increasingly sensitive, large astronomical surveys, especially with statistically significant millimeter-wave surveys of the cosmic microwave background and optical surveys of the distribution of galaxies. This talk will offer a glimpse of the future, which promises an acceleration of this trend with cosmological information coming from new surveys across the electromagnetic spectrum as well as particles and even gravitational waves.

Author(s): John E. Carlstrom[1]
Institution(s): *1. Univ. of Chicago*

310.02 – Theoretical Perspective

I will discuss the role of event horizons in limiting our ultimate knowledge of phenomena, from those taking place behind the horizons of black holes to phenomena beyond our cosmic horizon.

Author(s): Lenny Susskind[1]
Institution(s): *1. Stanford University*

310.03 – Concluding Summary

I will offer a summary and assessment of the discussions of the Limits of Scientific Cosmology

Author(s): P. J. E. Peebles[1]
Institution(s): *1. Princeton Univ.*

311 – Surveys, Computation, and Instrumentation

311.01 – What does it mean to manage sky survey data? A model to facilitate stakeholder conversations

Astronomy sky surveys, while of great scientific value independently, can be deployed even more effectively when multiple sources of data are combined. Integrating discrete datasets is a non-trivial exercise despite investments in standard data formats and tools. Creating and maintaining data and associated infrastructures requires investments in technology and expertise. Combining data from multiple sources necessitates a common understanding of data, structures, and goals amongst relevant stakeholders.

We present a model of Astronomy Stakeholder Perspectives on Data. The model is based on 80 semi-structured interviews with astronomers, computational astronomers, computer scientists, and others involved in the building or use of the Sloan Digital Sky Survey (SDSS) and Large Synoptic Survey Telescope (LSST). Interviewees were selected to ensure a range of roles, institutional affiliations, career stages, and level of astronomy education. Interviewee explanations of data were analyzed to understand how perspectives on astronomy data varied by stakeholder.

Interviewees described sky survey data either intrinsically or extrinsically. “Intrinsic” descriptions of data refer to data as an object in and of itself. Respondents with intrinsic perspectives view data management in one of three ways: (1) “Medium” - securing the zeros and ones from bit rot; (2) “Scale” - assuring that changes in state are documented; or (3) “Content” - ensuring the scientific validity of the images, spectra, and catalogs.

“Extrinsic” definitions, in contrast, define data in relation to other forms of information. Respondents with extrinsic perspectives view data management in one of three ways: (1) “Source” - supporting the integrity of the instruments and documentation; (2) “Relationship” - retaining relationships between data and their analytical byproducts; or (3) “Use” - ensuring that data remain scientifically usable.

This model shows how data management can mean different things to different stakeholders at different times. The model is valuable to those who build and maintain infrastructures because it can be used as a tool to facilitate recognition, understanding, and thus communication between relevant astronomy data stakeholders.

Author(s): Ashley E. Sands[1], Peter T Darch[2]
Institution(s): *1. UCLA, 2. UIUC*

311.02 – It’s about time: How do sky surveys manage uncertainty about scientific needs many years into the future

Sky surveys, such as the Sloan Digital Sky Survey (SDSS) and the Large Synoptic Survey Telescope (LSST), generate data on an unprecedented scale. While many scientific projects span a few years from conception to completion, sky surveys are typically on the scale of decades. This paper focuses on critical challenges arising from long timescales, and how sky surveys address these challenges.

We present findings from a study of LSST, comprising interviews (n=58) and observation. Conceived in the 1990s, the LSST Corporation was formed in 2003, and construction began in 2014. LSST will commence data collection operations in 2022 for ten years.

One challenge arising from this long timescale is uncertainty about future needs of the astronomers who will use these data many years hence. Sources of uncertainty include scientific questions to be posed, astronomical phenomena to be studied, and tools and practices these astronomers will have at their disposal. These uncertainties are magnified by the rapid technological and scientific developments anticipated between now and the start of LSST operations.

LSST is implementing a range of strategies to address these challenges. Some strategies involve delaying resolution of uncertainty, placing this resolution in the hands of future data users. Other strategies aim to reduce uncertainty by shaping astronomers’ data analysis practices so that these practices will integrate well with LSST once operations begin.

One approach that exemplifies both types of strategy is the decision to make LSST data management software open source, even now as it is being developed. This policy will enable future data users to adapt this software to evolving needs. In addition, LSST intends for astronomers to start using this software well in advance of 2022, thereby embedding LSST software and data analysis approaches in the practices of astronomers.

These findings strengthen arguments for making the software supporting sky surveys available as open source. Such arguments usually focus on reuse potential of software, and enhancing replicability of analyses. In this case, however, open source software also promises to mitigate the critical challenge of anticipating the needs of future data users.

Author(s): Peter T Darch[2], Ashley E. Sands[1]
Institution(s): *1. University of California, Los Angeles, 2. University of Illinois at Urbana-Champaign*

311.03 – Analyzing Kepler/K2 pixel data using open source tools

I will demonstrate three new open source command-line tools which have been developed at Kepler/K2 Guest Observer Office to help the community analyze and interpret pixel data from NASA's K2 mission: (1) "k2flix" enables the visual inspection of pixel files for artifacts; (2) "k2mosaic" enables pixel files to be mosaiced into contiguous images; and (3) "k2lightcurve" extracts and detrends photometry. I will also highlight the "k2ephem" and "k2fov" tools which aid target selection, and the "kadenza" tool which enables access to the raw spacecraft data during the Campaign 9 microlensing experiment. Finally, I will explain how these tools may be adapted to aid the upcoming TESS and PLATO missions.

Author(s): Geert Barentsen[1]
Institution(s): *1. NASA Ames*

311.04D – An Instrumentation Systematic for Weak Lensing from WFIRST

The Wide Field Infra-Red Space Telescope (WFIRST), which is planned to be launched in 2025, will image the Universe in the near-Infrared bands and help measure shapes of ~400M galaxies according to the current survey design. Given such a big dataset, in order to be able to make precise weak lensing measurements and thereby understand the dark sectors of the Universe, it is necessary to not be biased by systematic effects. An understanding of systematic effects that arise from both astrophysical situations and from the instrumentation becomes crucial. The detectors used in WFIRST are made of HgCdTe and have CMOS based readout electronics, thus suffering from systematic effects that are different from that of CCDs. In this talk, I will focus on one such effect called the 'Interpixel Capacitance' (IPC) effect, which is a form of electrical crosstalk between neighboring pixels. I will show some results on how the shape of observed PSF, which will include the effect of IPC, varies as a function of the IPC parameters. I will also show how the shear measurement bias is affected if the IPC in the individual exposures is not perfectly corrected for, due to the misestimation of the IPC parameters. The requirements on PSF shapes and measurement biases can be translated into requirements on the IPC parameters and thus be used to specify the desired level of detector performance.

Author(s): Arun Jayaraman[1], Charles Shapiro3, Rachel Mandelbaum[1], Christopher M. Hirata4, Jeffrey W. Kruk[2], Jason Rhodes3
Institution(s): *1. Carnegie Mellon University, 2. Goddard Space Flight Center, 3. Jet Propulsion Laboratory, 4. Ohio State University*

311.05 – First Report on the 2016 March 9 Total Solar Eclipse Observations

Totality swept across Indonesia and into the Pacific on 2016 March 9, lasting up to 2 min 45 s on Ternate in the Spice Islands (Malukus). I provide a first report on our observations. Our scientific goal is to follow changes in the corona over the solar-activity cycle, now past its 2012 and 2014 double peak, and to measure temporal changes in the corona on the scale of minutes or hours by comparing eclipse observations made at several sites along the path. I also discuss the near-simultaneous coronal observations made with *SOHO*/LASCO, *SDO*/AIA, *STEREO*/SECCHI, *PROBA2*/SWAP, and *Hinode* XRT.

For the forthcoming 2017 eclipse, we acknowledge grants to JMP and Williams College from the Solar Terrestrial Program of the Atmospheric and Geospace Sciences Division of the National Science Foundation and from the Committee for Research and Exploration of the National Geographic Society.<div> </div>

Author(s): Jay M. Pasachoff[1]
Institution(s): *1. Williams College*

311.06 – eROSITA: Status and Scientific Prospects

eROSITA (extended ROentgen Survey with an Imaging Telescope Array) is the core instrument on the Russian Spektrum-Roentgen-Gamma (SRG) mission which is currently scheduled for launch in 2017. eROSITA will perform a deep survey of the entire X-ray sky. In the soft band (0.5-2 keV), it will be about 30 times more sensitive than ROSAT, while in the hard band (2-8 keV) it will provide the first ever true imaging survey of the sky. The design driving science is the detection of large samples of galaxy clusters to redshifts z > 1 in order to study the
large scale structure in the Universe and test cosmological models including Dark Energy. In addition, eROSITA is expected to yield a sample of a few million AGN, including obscured objects, revolutionizing our view of the evolution of supermassive black holes. The survey will also provide new insights into a wide range of astrophysical phenomena, including neutron stars and pulsars, X-ray binaries, active
stars and diffuse emission from supernova remnants. The talk reports on the status of eROSITA and its scientific prospects.

Author(s): Werner Becker[1]
Institution(s): *1. Max Planck Institute for extraterr. Physics*
Contributing team(s): eROSITA Team

311.07 – M@TE - Monitoring at TeV Energies

A dedicated long-term monitoring programm at TeV energies has been started by the FACT project about four years ago. Being limited to one site, gaps due to the rotation of the Earth remain in the measured light curves. This makes it difficult to study typical variability time scales of few hours to one day. To allow for systematic studies of continuous observations over up to 12 hours, a second telescope is being installed at a site in about six hours distance in longitude. For the M@TE (Monitoring at TeV energies) telescope, a mount from a previous experiment is being refurbished and will be equipped with a new camera. Using silicon based photo sensors like in FACT, an excellent and stable performance will be achieved. M@TE is a joint project of German and Mexican universities which aims at extending the blazar monitoring to so far unexplored time ranges. In the presentation, the status of this emerging project will be reported.

Author(s): Gagik Tovmassian[1], Daniela Dorner[4], Thomas Bretz[3], Magdalena González[1], Ruben Alfaro[2]
Institution(s): *1. Instituto de Astronomia, UNAM, 2. Instituto de Fisica, UNAM , 3. RWTH Aachen, 4. Universität Würzburg*

312 – Plenary Talk: Things That Go Bump in the Night: The Transient Radio Sky, Dale Frail (NRAO)

312.01 – Things That Go Bump in the Night: The Transient Radio Sky

It is the advent of a new era in radio astronomy, brought on by a new generation of wide-field imaging telescopes that are capable of making synoptic surveys of the sky. The exploration of the dynamic radio sky is a core science goal for all of these new facilities. With the time-domain capabilities of these new instruments, astronomers will make contributions on topics as diverse as extra-solar planets, the counterparts of gravitation waves, and hidden explosions from gamma-ray bursts, supernovae and tidal disruption events.

Author(s): Dale A. Frail[1]
Institution(s): *1. NRAO*

314 – AGN, QSOs, and Blazars Poster Session

314.01 – The Emission Signatures of Tidal Disrption Events in the UV and Optical

A Tidal Disruption Event (TDE) occurs when a star approaching a Supermassive Black Hole (SMBH) is torn apart by tidal forces. Sometimes these events are accompanied by X-ray, UV and/or optical flares. TDEs can help us study SMBHs, accretion physics and possibly galactic dynamics. Using observations obtained by the Swift Ultra-Violet Optical Telescope (UVOT), we study the emission of several TDEs classified by broad H and/or He II lines in their optical spectra. This recently-identified class of transients emits mostly in the UV. UV data is thus important for constraining the total luminosity and effective temperatures of these events - parameters crucial for modeling the still undetermined emission mechanisms.

Author(s): Valentina Hallefors[1], Iair Arcavi[2]
Institution(s): *1. Santa Barbara City College, 2. UC Santa Barbara*

314.02 – Tidal Disruption Events Prefer Unusual Host Galaxies

A star passing close to a supermassive black hole (SMBH) can be torn apart in a Tidal Disruption Events (TDE). TDEs that are accompanied by observable flares are now being discovered in transient surveys and are revealing the presence and the properties of otherwise-quiescent SMBHs. Recently, it was discovered that TDEs show a strong preference for rare post-starburst galaxies, (i.e. galaxies that have undergone intense star formation but are no longer forming stars today). We quantify this preference and find that TDEs are approximately 30-200 times more likely to occur in post-starburst hosts (compared to the general SDSS galaxy population), with the enhancement factor depending on the star formation history of the galaxy. This surprising host-galaxy preference connects the until-now disparate TDE subclasses of UV/optical-dominated TDEs and X-ray-dominated TDEs, and serves as the basis for TDE-targeted transient surveys. Post-starburst galaxies may be post-mergers, with binary SMBH systems that are still spiraling in. Such systems could enhance the TDE rate, but it is not yet clear if models can quantitatively reproduce the observed enhancement. Alternative explanations for enhanced TDE rate in post-starbursts include non-spherical post-merger central potentials and enhanced rates of giant stars.

Author(s): Iair Arcavi[2], K. Decker French[1], Ann I. Zabludoff[1]
Institution(s): *1. Steward Observatory, University of Arizona, 2. UC Santa Barbara*

314.03 – Searching for Tidal Disruption Events in Post-Starburst Galaxies

Tidal Disruption Events (TDEs) are a class of transient phenomena that occur when a star passes sufficiently close to a supermassive black hole (SMBH) to be destroyed by tidal forces. Increasing the number of known TDEs will facilitate the study of SMBHs and black hole accretion physics. Recently it has been shown that TDEs occur most often in quiescent post-starburst galaxies (identified by strong Balmer absorption), some of which are know as "E+A" galaxies. These galaxies may have undergone a merger possibly contributing to the likelihood of TDEs. Using Las Cumbres Observatory Global Telescope (LCOGT) we are conducting a transient survey, called SEATiDE (Searching E+A Galaxies for Tidal Disruption Events), of 100 E+A galaxies. We experiment with different image subtraction techniques to improve our ability of detecting TDE flares in the centers of these galaxies. A future survey will cover an order of magnitude more post-starburst galaxies to measure their TDE rates in more detail with the aim of understanding why TDEs so strongly prefer post-starburst environments.

Author(s): David Guevel[1], Iair Arcavi[1]
Institution(s): *1. UC Santa Barbara*

314.04 – An Infrared Method for Discovering AGN: Lick Spectroscopy of New Seyfert I's in the Kepler Fields

Spectra of Active Galactic Nuclei (AGN) candidates in the Kepler fields were observed at Lick Observatory. We used the Shane 3.0-meter telescope with the Kast double spectrograph, covering from 0.35-0.8 µm. Using IRAF, we extracted 1D spectra from the original 2D long-slit images of the candidates. Our main goals are to determine the redshift of the candidates and identify any new AGN. The wavelength and flux calibration are fairly accurate, and most spectra have a good signal-to-noise ratio. Twenty- seven nights of data (consisting of 106 candidates) have been analyzed. For 89% of them, we have determined the redshifts to a precision of $\delta z = 0.0005$ in most cases. The rest give inconclusive results. 19 of the candidates turn out to be galactic stars. The most commonly identified emission lines are Hα+[NII], the [OIII] doublet, and Hβ. 44 of the candidates show a Broad Line Region, meaning that their wide permitted lines classify them as either Seyfert I's or quasars. 6 of these have redshifts above 0.5, indicating that they are highly luminous quasars. One candidate appears to be a bl-lac object. We are now analyzing the Kepler light curves of these Seyfert galaxies.

Author(s): Tran Tsan[1], Rick Edelson[2], Krista Lynne Smith[2], Matthew Arnold Malkan[1]
Institution(s): *1. University of California, Los Angeles, 2. University of Maryland*

314.05 – In the Dusty Recesses: Characterizing the Dark Matter Halos of Obscured Quasars via Clustering and CMB Lensing

The spatial clustering of obscured and unobscured quasars provides an interesting constraint on the connection between the growth of supermassive black holes and the evolution of galaxies and large-scale structure. In pursuit of these constraints, we update our recent measurements of quasar clustering using WISE and Planck data. We carefully assess how alterations in these missions' data reduction pipelines result in different systematics on a range of angular scales, and define samples of WISE-selected quasars that appear to be least-influenced by differences in data calibration. With these samples we analyze quasar clustering via two complementary methods; the angular autocorrelation function and cosmic microwave background lensing cross-correlations. We measure a higher bias and halo mass for obscured quasars ($b \sim 2.1$) as compared to unobscured quasars ($b \sim 1.8$). This is at odds with simple orientation models but at a reduced significance (1.5σ) as compared to our work with previous survey data. Assuming that some fraction (as high as 75%) of obscured quasars are intrinsically similar to unobscured quasars but viewed through a "dusty torus," we infer that the remaining non-torus obscured quasar population must have a large clustering bias of ~3, and inhabit typical halo masses of $\sim 3 \times 10^{13}\ h^{-1} M_{\odot}$ at a redshift of $z \sim 1$. These massive halos are likely the descendants of high-mass unobscured quasars at high redshift, and will evolve into members of galaxy groups by $z \sim 0$. This work was supported in part by NSF grants 1211112, 1515404 and 1515364.

Author(s): Adam D. Myers3, Michael A. DiPompeo[1], Ryan C. Hickox[1], Jessie C. Runnoe[2]
Institution(s): *1. Dartmouth College, 2. The Pennsylvania State University, 3. University of Wyoming*

314.06 – Towards Parsec-Scale Jet Speed Measurements for the Full TeV Blazar Sample

We present new multi-epoch Very Long Baseline Array (VLBA) observations of TeV blazars drawn from our VLBA program to monitor all TeV-detected high-frequency peaked BL Lac objects (HBLs) at the parsec scale. Many of these sources are faint in the radio (flux densities of a few millijanskys) so they have not been previously well observed with VLBI techniques by other surveys. Our previous measurements of apparent jet speeds in of order a dozen TeV HBLs showed apparent jet speeds that were subluminal or barely superluminal; suggesting jets with velocity structures at the parsec-scale. Here we present apparent jet speed measurements for eight new sources, which for the first time show a superluminal tail to the apparent speed distribution for the TeV HBLs.

Author(s): B. Glenn Piner[2], Phillip Edwards[1]
Institution(s): *1. CSIRO, 2. Whittier College*

314.07 – Broadband Photometric Monitoring of SDSS J143450.62+033842.5

We present the results of a broadband photometric monitoring campaign of intermediate-mass black hole candidate SDSS J143450.62+033842.5. Sloan r and g band images were obtained using the fully robotic 24 inch telescope at the Madrona Peak Observatory. Data was obtained for 50 epochs between JD 2457137.5 and JD 2457282.5.

Author(s): Mark Bottorff[2], Taylor Hutchison[2], Mark Williams[1]
Institution(s): *1. Madrona Peak Observatory, 2. Southwestern Univ.*

314.08 – The Host Galaxies of LoBAL QSOs at Low z: A Perspective from HST UVIS Images

We present GALFIT models of a complete optically-selected volume-limited sample of Low-Ionization Broad Absorption Line QSOs (LoBALs) in the redshift range 0.5-0.6 observed with HST WFC3 UVIS F475W. We investigate the morphologies in the rest frame *u* which map the younger stellar populations. In addition, we present statistics on the number of neighborhood galaxies within 150 kpc and possible trends between clustering and host galaxy properties. This sample of LoBALs is selected from QSOs characterized by their extreme blue-shifted absorption in the Mg II line—which is a signature of high velocity winds towards the observer. Only ~1-3% of optically selected QSOs are LoBALs. Their low fraction could be explained by their orientation or by a short period of outflow manifest in all QSOs during their lifetime. We aim to better understand the possibility of the evolutionary model by studying their morphologies in detail. Previous work on this sample, from images with F125W filter (rest frame *i*), shows that at least 60% of these objects exhibit signs of recent merger activity. We complement those results with our results from the UVIS observations and neighborhood clustering statistics.

Author(s): Wyatt Alan Behn[2], Mariana Lazarova[2], Gabriela Canalizo[1]
Institution(s): *1. University of California-Riverside, 2. University of Nebraska at Kearney*

314.09 – A VLA Survey of "Polar?" BAL QSOs

Recent evidence has shown that broad absorption line outflows in quasars are almost certainly seen from a wide range of viewing angles, including nearly pole-on, using the shapes of radio spectra and Monte-Carlo modeling. It also seems that outflow properties are similar along all lines of sight, suggestive of a single mechanism driving winds in all directions. However, a larger number of known "polar" outflows is needed for proper study. Radio variability between the FIRST and NVSS surveys, combined with brightness temperature arguments, seem to have identified a significant number of "polar" BAL quasars. There are some questions still surrounding these objects, and most only have information at one frequency. We report results from new VLA observations of 23 objects, both to confirm the variability at 1.4 GHz, and to extend the spectral coverage in order to analyze the shape of the spectrum.

Author(s): Vikram Singh[1], Michael S. Brotherton[1], Michael A. DiPompeo[1], Adam D. Myers[1]
Institution(s): *1. University of Wyoming*

314.10 – A Spectral Variability Study Using the Entire FERMI Data from the Blazar 3C 454.3

3C454.3 is one of most active and bright blazars that have been observed by the LAT instrument on board the gamma-ray satellite FERMI. The data show multiple large flares where the flux in the energy interval of 100MeV-300000MeV has exceeded 1 x 10^(-5) photons/cm^2/s. We are analyzing the entire LAT-data from 3C454.3 spanning ~7.5 years, and conducting spectral and temporal variability studies. We have divided the entire energy interval into 14 sub-intervals (three per decade) and examining the spectrum for deviations from power-law. We are also looking at the hardness ratios between a smaller set of energy intervals to gain insight into the relative importance of the various inverse-Compton mechanisms that contribute to gamma-ray emission at these energies.

Author(s): Giridhar Nandikotkur[1], Daniel Gomez[1], Johanna Dovale[1], Daniel Clarke[1], Kaitlyn Komstead[1], Raj Shah[1], Stephen Aboasu[1]
Institution(s): *1. University College, Fairleigh Dickinson University*

314.11 – Anomalous H-beta Variability in the 2014 NGC 5548 AGN-STORM Monitoring Campaign

Reverberation mapping programs generally find that the continuum and H-beta flux variations in AGNs are well correlated. In the 2014 AGN STORM monitoring program for NGC 5548, we observed a distinct decorrelation of the emission-line light curves from the AGN continuum light curve during the second half of the six-month campaign. This effect was first detected for the C IV, Ly a, HeII 1640 and SiIV/OIV] 1400 lines in Hubble Space Telescope data, then observed for the H-beta line in ground-based data taken during the same monitoring period. We present measurements of the H-beta lags, equivalent width variations, and line responsivity changes during our campaign. We show that the AGN demonstrated unusual behavior in that the broad H-beta responsivity to flux variations decreased significantly during the second half of the campaign. The discovery of this decorrelation phenomenon was made possible by the high cadence and long duration of our monitoring campaign. More multi-wavelength observing campaigns with high sampling cadence, high signal-to-noise ratio, and long temporal baseline are needed for other AGNs in order to determine the prevalence of this phenomenon and to understand its physical origin.

Author(s): Liuyi Pei[1]
Institution(s): *1. Unviersity of Californina Irvine*
Contributing team(s): AGN STORM Collaboration

314.12 – Reverberation mapping of two radio-loud quasars

We present results of a reverberation mapping (RM) campaign on two radio-loud quasars, 3C 382 and PG 2209+184, using the Wyoming Infrared Observatory (WIRO). For 3C 382 we determine a Hβ time lag of $\tau = 47.2 ^{16.8}_{-30.4}$ days, with a RMS line dispersion of 2317$\pm$195 km s^{-1}, and a corresponding mass of 2.12$^{0.92}_{-1.46} \times 10^8 M_\odot$. For PG 2209+184, we determine a Hβ time lag of $\tau = 38.9 ^{11.9}_{-21}$ days, with a RMS line dispersion of 2114$\pm$121 km s^{-1}, and a corresponding mass of 1.45$^{0.58}_{-0.87} \times 10^8 M_\odot$. These two objects are consistent with the radius-luminosity relationship for Hβ and bring the total of radio-loud quasars reverberation mapped to seven. Radio-loud quasars bring the potential of investigating orientation biases in quasar black hole mass determination.

Author(s): Anirban Bhattacharjee[7], Michael S. Brotherton[11], Michelle Mason[11], Caroline Anna Roberts[2], Vikram Singh[11], Mara Johnson-Groh[10], Nicholas Erickson[9], Michael J. Lundquist[11], Michael J Alexander[4], Shawn Staudaher[11], Sabrina Cales[3], Michael A. DiPompeo[1], Rachel Smullen[6], Sarah Eftekharzadeh[11], Henry A. Kobulnicky[11], My Nyugen[11], Ritaban Chatterjee[5], Suchetana Chatterjee[5], Jessie C. Runnoe[8], Daniel A. Dale[11]
Institution(s): *1. Dartmouth University, 2. Georgia State University, 3. Institute for Defense Analyses , 4. Lafayette University , 5. Presidency University, 6. Steward Observatory, University of Arizona, 7. Sul Ross State University, 8. The Pennsylvania State University, 9. University of Colorado-Boulder, 10. University of Victoria , 11. University of Wyoming*

315 – Cosmology and CMB Poster Session

315.01 – IFU Spectroscopy of 32 SweetSpot Supernova Host Galaxies

SweetSpot is an NOAO Survey program from 2012B-2015A that gathered NIR lightcurves for 114 Type Ia supernovae (SNeIa) located in the Hubble flow. The aims of this survey are to test the standard nature of SNeIa in the NIR, explore their color evolution, study the dust of host galaxies, and provide an anchor for upcoming high redshift NIR surveys. Another primary goal of this survey is to explore relationships between SNeIa observed in the NIR with their host galaxy properties previously done with optical lightcurves.

Correlations between the residual brightness of SNeIa with their host galaxy properties have been found in a series of recent papers, but have yet to be studied in the NIR. We study the NIR brightness of SNIa compared to both photometric and spectroscopic properties of the host galaxies. We use SDSS data to explore host galaxy color and mass relations with peak brightness of SNeIa. In order to examine local environment relationships, we obtained optical spectra of 32 host galaxies of NIR SNeIa using the WIYN 3.5-m Bench Spectrograph IFU HexPak. These spectra extend from H-beta through H-alpha and allow us to study the local surface brightness of very recent star formation.

We here present preliminary results from these investigations.

Author(s): Kara Ann Ponder[5], W. Michael Wood-Vasey[5], Lori Allen[1], Peter M. Garnavich[2], Saurabh Jha[3], Jessica Rose Kroboth[5], Richard R. Joyce[1], Thomas Matheson[1], Armin Rest[4], Anja Weyant[5]
Institution(s): *1. National Optical Astronomy Observatory, 2. Notre Dame, 3. Rutgers University , 4. Space Telescope Science Institute, 5. University of Pittsburgh*

315.02 – The HST Frontier Fields: High-Level Science Data Products for the First 4 Completed Clusters, and for the Last 2 Clusters Currently in Progress

The Hubble Space Telescope Frontier Fields program (PI: J. Lotz) is a large Director's Discretionary program of 840 orbits, to obtain ultra-deep observations of six strong lensing clusters of galaxies, together with parallel deep blank fields, making use of the strong lensing amplification by these clusters of distant background galaxies to detect the faintest galaxies currently observable in the high-redshift universe. The first four of these clusters are now complete, namely Abell 2744, MACS J0416.1-2403, MACS J0717.5+3745 and MACS J1149.5+2223, with each of these having been observed over two epochs, to a total depth of 140 orbits on the main cluster and an associated parallel field, using ACS (F435W, F606W, F814W) and WFC3/IR (F105W, F125W, F140W, F160W). The remaining two clusters, Abell 370 and Abell S1063, are currently in progress, with the first epoch for each having been completed. Full sets of high-level science products have been generated for all these clusters by the team at STScI, including cumulative-depth v0.5 data releases during each epoch, as well as full-depth version 1.0 releases after the completion of each epoch. These products include all the full-depth distortion-corrected mosaics and associated products for each cluster, which are science-ready to facilitate the construction of lensing models as well as enabling a wide range of other science projects. Many improvements beyond default calibration for ACS and WFC3/IR are implemented in these data products, including corrections for persistence, time-variable sky, and low-level dark current residuals, as well as improvements in astrometric alignment to achieve milliarcsecond-level accuracy. The full set of resulting high-level science products are publicly delivered to the community via the Mikulski Archive for Space Telescopes (MAST) to enable the widest scientific use of these data, as well as ensuring a public legacy dataset of the highest possible quality that is of lasting value to the entire community.

Author(s): Anton M. Koekemoer[1], Jennifer Mack[1], Jennifer M. Lotz[1], Jay Anderson[1], Roberto J. Avila[1], Elizabeth A. Barker[1], David Borncamp[1], Heather C. Gunning[1], Bryan Hilbert[1], Harish G. Khandrika[1], Ray A. Lucas[1], Sara Ogaz[1], Blair Porterfield[1], Ben Sunnquist[1], Norman A. Grogin[1], Massimo Robberto[1], Kenneth Sembach[1], Kathryn Flanagan[1], Matt Mountain[1]
Institution(s): *1. STScI*
Contributing team(s): HST Frontier Fields Team

315.03 – Clustering on very small scales from a large, complete sample of confirmed quasar pairs

We present by far the largest sample of spectroscopically confirmed binary
quasars with proper transverse separations of $17.0 \le R_{prop} \le 36.6$ h^{-1} kpc. Our sample, which
is an order-of-magnitude larger than previous samples, is selected from Sloan Digital Sky Survey (SDSS) imaging over an area corresponding to the SDSS 6th data release (DR6). Our quasars are targeted using a Kernel Density Estimation technique (KDE), and confirmed using long-slit spectroscopy on a range of facilities.
Our most complete sub-sample of 44 binary quasars with g<20.85, extends across angular scales of 2.9" < Δθ < 6.3", and is targeted from a parent sample that would be equivalent to a full spectroscopic survey of nearly 300,000 quasars.
We determine the projected correlation function of quasars (\bar W_p) over proper transverse scales of $17.0 \le R_{prop} \le 36.6$ h^{-1} kpc, and also in 4 bins of scale within this complete range.
To investigate the redshift evolution of quasar clustering on small scales, we make the first self-consistent measurement of the projected quasar correlation function in 4 bins of redshift over $0.4 \le z \le 2.3$.

Author(s): Sarah Eftekharzadeh4, Adam D. Myers4, Stanislav G. Djorgovski[1], Matthew J. Graham[1], Joseph F Hennawi3, Ashish A. Mahabal[1], Gordon T. Richards[2]
Institution(s): *1. California Institute of Technology, 2. Department of Physics, Drexel University, 3. Max Planck Institute for Astronomy, 4. University of Wyoming*

315.04 – Multi-redshift limits on the 21cm power spectrum from PAPER 64: XRays in the early universe

Here we present new constraints on 21cm emission from cosmic reionization from the 64 element deployment of the Donald C. Backer Precision Array for Probing the Epoch of Reionization (PAPER). These results extend the single redshift 8.4 result presented in Ali et al 2015 to include redshifts from 7.3 to 10.9. These new limits offer as much as a factor of 4 improvement in sensitivity compared to previous 32 element PAPER results by Jacobs et al (2015). Using these limits we place constraints on a parameterized model of heating due to XRays emitted by early collapsed objects.

Author(s): Matthew Kolopanis[1], Danny Jacobs[1]
Institution(s): *1. Arizona State University*
Contributing team(s): PAPER Collaboration

315.06 – Measuring the cosmic microwave background gravitational lensing potential from 500 deg^2 of SPTpol data

Weak gravitational lensing by large-scale structure in the universe causes deflections in the paths of cosmic microwave background (CMB) photons. This effect introduces non-Gaussian correlations in the observed CMB temperature and polarization fields. The signature of lensing can be used to reconstruct the projected gravitational lensing potential with a quadratic estimator technique; this provides a measure of the integrated mass distribution out to the surface of last scattering, sourced primarily from redshifts between 0.1 and 5. The power spectrum of the lensing potential encodes information about the geometry of the universe and the growth of structure and can be used to place constraints on the sum of neutrino masses and dark energy. High signal-to-noise mass maps from CMB lensing are also powerful for cross-correlating with other tracers of large-scale structure and for delensing the CMB in search for primordial gravitational waves. This poster will describe recent progress on measuring the CMB gravitational lensing potential and its power spectrum using data from 500 deg^2 of sky observed with the polarization-sensitive receiver installed on the South Pole Telescope, SPTpol.

Author(s): Laura Monica Mocanu[1]
Institution(s): *1. The University of Chicago*
Contributing team(s): The South Pole Telescope Collaboration

315.07 – Weak lensing by galaxy troughs

Galaxy troughs, i.e. underdensities in the projected galaxy field, are a weak lensing probe of the low density Universe with high signal-to-noise ratio. I present measurements of the radial distortion of background galaxy images and the de-magnification of the CMB by troughs constructed from Dark Energy Survey and Sloan Digital Sky Survey galaxy catalogs. With high statistical significance and a relatively robust modeling, these probe gravity in regimes of density and scale difficult to access for conventional statistics.

Author(s): Daniel Gruen[1]
Institution(s): *1. SLAC*

315.08 – Resonant Production of Sterile Neutrinos in the Early Universe

This study examines the cosmological impacts of a light resonantly produced sterile neutrino in the early universe. Such a neutrino could be produced through lepton number-driven Mikheyev-Smirnov-Wolfenstein (MSW) conversion of active neutrinos around big bang nucleosynthesis (BBN), resulting in a non-thermal spectrum of both sterile and electron neutrinos. During BBN, the neutron-proton ratio depends sensitively on the electron neutrino flux. If electron neutrinos are being converted to sterile neutrinos, this makes the n/p ratio a probe of possible new physics. We use observations of primordial Yp and D/H to place limits on this process.

Author(s): Lauren Gilbert[1], Evan Grohs[2], George M. Fuller[1]
Institution(s): *1. University of California San Diego, 2. University of Michigan*

315.09 – Dynamical Formation of Black Hole Binaries in Globular Clusters and the Origins of GW150914

We show that GW150914, the binary black hole merger detected last year by LIGO, could easily have been formed dynamically through interactions in the dense core of an old globular cluster. Using models of globular clusters with detailed N-body dynamics and stellar evolution, we show that a typical cluster can very naturally form a binary black hole with "heavy" components that will merge at low redshift, like GW150914. We describe in some detail the dynamical interaction processes that could form such a system. Finally, we also show that theoretical predictions for this dynamical formation channel are in general far more robust than those from "population synthesis" studies for isolated massive binaries in the field.

Author(s): Frederic A. Rasio[1], Sourav Chatterjee[1], Carl L. Rodriguez[1]
Institution(s): *1. Northwestern Univ.*

315.10 – What We've Learned from LIGO's Detection of Gravitational Waves

The twin Advanced LIGO detectors captured their first clear gravitational-wave event on September 14, 2015 -- a truly remarkable signal from two heavy stellar-mass black holes merging at a distance of about 400 Mpc. I will present a high-level summary of what we have learned from this signal and general observations so far.

Author(s): Peter S. Shawhan[1]
Institution(s): *1. Univ. of Maryland*
Contributing team(s): LIGO Scientific Collaboration, Virgo Collaboration

316 – Extrasolar Planets Poster Session

316.01 – Flux-Level Transit Injection Experiments with NASA Pleiades Supercomputer

Flux-Level Transit Injection (FLTI) experiments are executed with NASA's Pleiades supercomputer for the *Kepler* Mission. The latest release (9.3, January 2016) of the *Kepler* Science Operations Center Pipeline is used in the FLTI experiments. Their purpose is to validate the Analytic Completeness Model (ACM), which can be computed for all *Kepler* target stars, thereby enabling exoplanet occurrence rate studies. Pleiades, a facility of NASA's Advanced Supercomputing Division, is one of the world's most powerful supercomputers and represents NASA's state-of-the-art technology. We discuss the details of implementing the FLTI experiments on the Pleiades supercomputer. For example, taking into account that ~16 injections are generated by one core of the Pleiades processors in an hour, the "shallow" FLTI experiment, in which ~2000 injections are required per target star, can be done for 16% of all *Kepler* target stars in about 200 hours. Stripping down the transit search to bare bones, i.e. only searching adjacent high/low periods at high/low pulse durations, makes the computationally intensive FLTI experiments affordable. The design of the FLTI experiments and the analysis of the resulting data are presented in "Validating an Analytic Completeness Model for *Kepler* Target Stars Based on Flux-level Transit Injection Experiments" by Catanzarite et al. (#2494058).
Kepler was selected as the 10th mission of the Discovery Program. Funding for the *Kepler* Mission has been provided by the NASA Science Mission Directorate.

Author(s): Jie Li[4], Christopher J. Burke[4], Joseph Catanzarite[4], Shawn Seader[3], Michael R Haas[2], Natalie Batalha[2], Christopher Henze[2], Jessie Christiansen[1]
Institution(s): *1. California Institute of Technology, 2. NASA Ames Research Center, 3. Raytheon, 4. SETI Institute*
Contributing team(s): Kepler Project, NASA Advanced Supercomputing Division

316.02 – Atmospheric and Climate Effects on Planets Orbiting Fast-Rotating Stars

Fast rotation in stars can induce pole-to-equator temperature gradients of up to several thousand Kelvin that affect both the star's luminosity and peak wavelength as a function of stellar latitude. When orbiting a fast-rotating star, a planet's average annual insolation can strongly vary depending on its orbit geometry. For example, an inclined orbit results in more direct exposure to the host star's hotter poles, potentially causing much stronger temperature variations between seasons. This gradient, known as gravity-darkening, can also affect chemical processes in a planet's atmosphere as it is exposed to solar irradiance corresponding to different stellar effective temperatures over time. My model accounts for gravity-darkening and models the instantaneous insolation that a planet receives from a fast-rotator for any orbit geometry. These results are an important step toward modeling climates and seasonal variations of planets orbiting fast-rotating stars, and also lay the groundwork for performing transmission spectroscopy in gravity-darkened systems.

Author(s): Jonathon Ahlers[1]
Institution(s): *1. University of Idaho*

316.03 – Evolution of Noncoplanar Disks and Planets in Binary Systems

We have been analyzing the evolution of a gaseous disk and planet that orbit a member of a binary star system. The disk and planet lie in orbital planes that are initially tilted with respect to the binary orbital plane. Some of our main results are as follows.
1) A disk without a planet that is tilted by more than about 40 degrees can undergo coherent Kozai-Lidov tilt oscillations that cause oscillations in disk eccentricity and enhanced dissipation.
2) A disk and planet that are initially mutually coplanar, but tilted by a small angle with respect to the binary orbital plane, do not remain mutually coplanar. They undergo mutual tilt oscillations that are amplified by a secular resonance.
3) A disk and planet that are initially mutually coplanar, but somewhat tilted with respect to the binary orbital plane, each undergo Kozai-Lidov oscillations, in addition to the mutual tilt oscillations discussed in item 2. The latter oscillations can boost a relatively small initial tilt into the Kozai-Lidov regime.
4) Kozai-Lidov disk oscillations of a disk with some self-gravity expedite disk fragmentation. The fragmentation may in turn result in planet formation.

Author(s): Stephen H. Lubow[1], Rebecca G. Martin[2]
Institution(s): *1. STScI, 2. UNLV*

316.04 – ExoPlex: A code for calculating interior structure and mineralogy and mass-radius relationships for exoplanets

We present a computer code we have written for general release that calculates the interior structure and mass-radius relationships of solid exoplanets up to a few Earth masses. The basic algorithm is that of Seager et al. (2007), Zeng & Sasselov (2013) and Dorn et al. (2015): the code integrates the 1-D (spherical) equation of hydrostatic equilibrium to find pressure in shells of various depths assuming a gravitational acceleration, uses the bulk modulus of the materials as inputs to an equation of state to convert pressures into density and volume in each shell, recomputes the shell thicknesses and gravitational acceleration, and iterates the solution to convergence. Unlike most existing codes, we do not impose a particular mineralogy in each shell. Instead we adopt the approach of Dorn et al. (2015), in which we impose a stoichiometry in each shell; for rocky shells and the metal core the code calls the PerpleX code (Connolly et al. 2005) to compute the mineralogy and material properties appropriate to that shell's stoichiometry, pressure and temperature. Unique attributes of the code are as follows. The mineralogy is complete in the Fe-Mg-Si-O system, including species like FeSi and FeO in the core. We also include FeS (VII) in the core. We have also included an approximate phase diagram for water ice to account for an icy mantle. We also include the effects of adiabatic temperature profiles and a temperature jump at the core-mantle boundary. Finally, we have created a user-friendly interface allowing the code to be downloaded and used as a teaching tool. Results of the code and a demonstration of its use will be presented at the meeting.

Author(s): Steven Desch[1], Alejandro Lorenzo[1], Byeongkwan Ko[1]
Institution(s): *1. Arizona State Univ.*

316.05 – A New Method for Detecting Transiting Circumbinary Planets in Kepler Data

The discovery of Kepler-16 started a new branch of exoplanet research: observations of transiting circumbinary planets. To date, eleven transiting circumbinary planets have been discovered. The detection of a circumbinary planet is much more difficult than the detection of a planet around a single star because the transit times are not strictly periodic, the transit widths and depths can change dramatically, and the deep binary star eclipses overwhelm the much smaller planetary transits. Because of these complications, most of the known circumbinary planets were discovered via visual inspection of the Kepler light curves. This requires that the transits be easily detectable by eye, which translates to large-radii planets. Here we present a new method for visual dectection of circumbinary planets, based on the idea of phase-folding the light curve into a "trailed eclipsogram" image. While this method works well for deep transits (and hence will work for new, large circumbinary planets to be found by TESS), in principle it can also be extended to much smaller planets below the threshold for visual detection using image pattern recognition tools.

Author(s): William F. Welsh[1], Jerome A. Orosz[1], Gur Windmiller[1], Donald R Short[1]
Institution(s): *1. San Diego State University*

316.06 – Improved Dynamical Parameters for

Transiting Circumbinary Planets

To date, the Kepler space telescope has detected about a dozen transiting circumbinary planets (i.e. planets that orbit a binary star system). Here we present improved dynamical parameters for the following four circumbinary planets: Kepler-16b (Doyle et al. 2011), 34b and 35b (Welsh et al. 2012), and 38b (Orosz et al. 2012). The original analyses contained only a subsample of the entire Kepler dataset available today. In the case of Kepler-16b, we have also obtained additional spectra and an additional transit not present in the Kepler photometry. We present updated parameters for these four systems, including a preliminary search for additional bodies in the Kepler-16 system.

Author(s): Pantelis C. Thomadis[1], Jerome A. Orosz[1], William F. Welsh[1], Matan Friedmann[2], Tsevi Mazeh[2], Donald R Short[1], Gur Windmiller[1]
Institution(s): *1. San Diego State University, 2. Wise Observatory*

316.07 – A transiting circumbinary planet in KIC 10753734

KIC 10753734 is an eclipsing binary discovered by NASA's Kepler mission. The binary period is about 19.4 days with a moderately large eccentricity of e=0.52. Spectroscopic observations from McDonald Observatory show the system is double-lined, which allow us to derive masses for the primary and secondary stars, both of which are roughly solar-like. Two weak transit-like events separated by 6.5 days appear in the Kepler light curve near the end of the nominal mission. A careful examination of the light curve at earlier times reveals two weak transit events (separated by about 7 days) that occurred about 250 days earlier. We show that the two pairs of events represent transits of both stars at successive conjunctions of a circumbinary planet with a period of about 260 days and a radius of about 6 Earth radii. The lack of large eclipse timing variations limit the third body to be sub-stellar in mass, i.e. a planet. Despite the deep primary and secondary eclipses, the analysis is hampered by spots on both stars. We present a progress report on the modelling effort to date, and present preliminary characteristics of the planet.

Author(s): Jerome A. Orosz[1], William F. Welsh[1], Donald R Short[1], Michael Endl3, William D. Cochran3, Marshall C. Johnson3, Sean Mills[2], Daniel Fabrycky[2], Nader Haghighipour4, Gur Windmiller[1]
Institution(s): *1. San Diego State Univ., 2. University of Chicago, 3. University of Texas, 4. Universityof Hawaii*

316.08 – The Latest Results from Project NIRRVS: Precise Near Infrared Radial Velocity Surveys

We will present the latest results from a prototype PRV survey with CSHELL. With CSHELL at the NASA Infrared Telescope Facility atop Mauna Kea (R~46,000), we have completed a PRV 2.3 micron survey to detect exoplanets around ~30 red, low mass, and young stars. We are able to reach long-term radial velocity dispersions of ~30 m/s on our survey targets. We are following up candidate RV variables, and have confirmed other previously known RV variables. With a spectral grasp of only 5 nm at 2.3 microns, this performance with CSHELL is limited by detector artifacts, and fringing in the data and flatfields. iSHELL will replace CSHELL at IRTF, with first light expected in May 2016. iSHELL is a 1.15-5.4 micron high spectral resolution (R~70,000) immersion grating, cross-dispersed, white pupil spectrograph. With iSHELL we should be able to obtain a precision of less than 5 m/s in the NIR with iSHELL from the improvements in spectral grasp alone.

Author(s): Peter Plavchan[1]
Institution(s): *1. Missouri State University*
Contributing team(s): NIRRVS Collaboration

316.09 – MICRONERVA: A Novel Approach to Large Aperture Astronomical Spectroscopy

MICRONERVA (MICRO Novel Exoplanet Radial Velocity Array) is a project to measure precise spectroscopic radial velocities. The cost of telescopes are a strong function of diameter, and light gathering power as opposed to angular resolution is the fundamental driver for telescope design for many spectroscopic science applications. By sacrificing angular resolution, many multiple smaller fiber-fed telescopes can be combined to synthesize the light gathering power of a larger diameter telescope at a lower effective cost. For our MICRONERVA prototype, based upon the larger MINERVA project, we will attempt to demonstrate that an array of four 8-inch CPC Celestron telescopes can be automated with sufficient active guiding precision for robust nightly robotic operations. The light from each telescope is coupled into single mode fibers, which are conveniently matched to the point spread function of 8-inch telescopes, which can be diffraction limited at red wavelengths in typical seeing at good observing sites. Additionally, the output from an array of single mode fibers provides stable output illumination of a spectrograph, which is a critical requirement of future precise radial velocity instrumentation. All of the hardware from the system is automated using Python programs and ASCOM and MaxIm DL software drivers. We will present an overview of the current status of the project and plans for future work. The detection of exoplanets using the techniques of MICRONERVA could potentially enable cost reductions for many types of spectroscopic research.

Author(s): Ryan Hall[1], Peter Plavchan[1], Claire Geneser[1], Frank Giddens[1], Sophia Spangler[1]
Institution(s): *1. Missouri State University*

316.10 – High-contrast astronomy with Starshades at 10 arcseconds inner working angle and a flight-like Fresnel number.

Starshades have been identified as a leading technology to achieve the starlight suppression needed to detect and spectroscopically characterize Earth-like exoplanets. Efforts are currently underway to demonstrate and develop starshade technology by using small-scale starshades in astronomical observations. We report the latest results using the McMath-Pierce Solar Telescope at Kitt Peak National Observatory to enable suppression of astronomical sources with a 30cm starshade. The results presented here are an extension of previous work at McMath-Pierce (Novicki et al., 2016) utilizing a longer baseline between starshade and telescope to reach a smaller inner working angle. With the 2.4km baseline in this configuration, we reach 10 arcseconds inner working angle at a flight-like Fresnel number. We report the contrast achieved on astronomical sources in this new configuration.

Author(s): Anthony Harness[2], Steve Warwick[1], Ann Shipley[2], Webster C. Cash[2]
Institution(s): *1. Northrop Grumman Aerospace Systems, 2. University of Colorado Boulder*

316.11 – Combining VPL tools with NEMESIS to Probe Hot Jupiter Exoclimes for JWST

Hot Jupiters are the most readily detected exoplanets by present technology. Since the scorching temperatures (>1000K) from high stellar irradiation levels do not allow for cold traps to form in their atmospheres, we can constrain their envelope's elemental composition with greater confidence compared to our own Jupiter. Thus highly irradiated giant exoplanets hold keys to advancing our understanding of the origin and evolution of planetary systems. Constraining the atmospheric constituents through retrieval methods demands high-precision spectroscopic measurements and robust models to match those measurements. The former will be provided by NASA's upcoming missions such as *JWST*. We meet the latter by producing self-consistent retrievals. Here I present modeling results for the temperature structure and photochemical gas abundances of water, methane, carbon dioxide and carbon monoxide, in the dayside atmospheres of selected H2-dominated hot Jupiters observed by present space missions and JWST/NIRSpec simulations, for two [C]/[O] metallicity ratios.
The photochemical models were computed using a recently upgraded version of the NASA Astrobiology Institute's VPL/Atmos software suite. For the radiative transfer and retrieval work, I have utilized a combination of two different numerical approaches in the extensively validated NEMESIS Atmospheric Retrieval Algorithm (Oxford Planetary Group). I have also represented the temperature profile in an analytical radiative equilibrium form to ascertain their physical plausibility. Finally, high-temperature (T> 1000K) spectroscopic opacity databases are slowly but continually being improved. Since

this carries the potential of impacting irradiated atmospheric models quite significantly, I also talk about the potential observable impact of such improvements on the retrieval results.

Author(s): Mahmuda Afrin Badhan3, Ravi Kumar Kopparapu[1], Shawn Domagal-Goldman[1], Eric Hébrard[1], Drake Deming3, Joanna Barstow4, Mark Claire5, Patrick GJ Irwin4, Avi Mandell[1], Natasha Batalha[2], Ryan Garland4
Institution(s): *1. NASA Goddard Space Flight Center, 2. Pennsylvania State University, 3. University of Maryland College Park, 4. University of Oxford , 5. University of Washington*

317 – Computation, Surveys, and Data Poster Session

317.01 – The DECam Legacy Survey

The DECam Legacy Survey (DECaLS) is conducting a 3-band imaging survey of the Sloan Digital Sky Survey (SDSS) extragalactic footprint as part of the Legacy Survey, which is associated with the Dark Energy Spectroscopic Instrument (DESI) redshift survey. The Legacy Survey covers 14000 square degrees in the g, r, and z bands and is being executed on the Blanco 4-m, Mayall 4-m, and Bok 2.3-m telescopes.

For DECaLS, the Dark Energy Camera (DECam) will image the footprint overlapping SDSS in the region -20 < Dec < +30 deg, to depths of g=24.7, r=23.9, z=23.0 and will eventually cover a total of 7500 square degrees. The survey began in 2014 and will run through Spring 2017. Images and catalogs were introduced in Public Data Release 2 (DR2), which occurred in January 2016. The algorithm "Tractor" applies multi-wavelength forced photometry to DECam and WISE data to produce galaxy (and star) magnitudes (as well as shape and other information) for the catalogs. In total, the optical data in DR2 cover a disjoint footprint in 2078, 2141 and 5322 square degrees in g, r, and z bands, respectively; 1807 square degrees has been observed in all three optical filters. There are approximately 260 million unique sources in DR2 spread over 97,554 0.25 x 0.25 square degree bricks.

The Dark Energy Spectroscopic Instrument (DESI) will observe 30+ million galaxies and quasars in a 14,000 square degree extragalactic footprint. The targeting in that footprint will be provided by a combination of these DECam data, the MOSAIC camera on the Mayall 4-meter, and the 90Prime camera on the Bok telescope.

Author(s): Robert D. Blum5, Kaylan Burleigh[8], Arjun Dey5, David J. Schlegel4, Aaron M. Meisner4, Michael Levi4, Adam D. Myers9, Dustin Lang7, John Moustakas[6], Anna Patej3, Francisco Valdes5, Jean-Paul Kneib[1], Shan Huanyuan[1], Brian Nord[2], Knut A. Olsen5, Timothée Delubac[1], Abi Saha5, David James5, Alistair R. Walker5
Institution(s): *1. EPFL, 2. FNAL, 3. Harvard, 4. LBNL, 5. NOAO, 6. Siena College, 7. U Toronto, 8. UCB, 9. UWyo*
Contributing team(s): The DECaLS Team

317.02 – The Mayall z-band Legacy Survey

The Mayall z-band Legacy Survey (MzLS) is conducting a deep z-band imaging survey covering 5000 square degrees in the north Galactic cap as part of the Legacy Survey, which is associated with the Dark Energy Spectroscopic Instrument (DESI) redshift survey. The Legacy Survey covers 14000 square degrees in the g, r, and z bands and is being executed on the Blanco 4-m, Mayall 4-m, and Bok 2.3-m telescopes. The MzLS footprint will be observed in the g and r bands using the Bok 2.3-m telescope also on Kitt Peak. The Beijing Arizona Sky Survey (BASS) is being conducted by a parallel team from Beijing and the University of Arizona.

MzLS will cover the sky north of declination 30 degrees and reach a depth of z=23.0. The survey began in January 2016 and will run through June 2017 comprising approximately 230 nights on the Mayall telescope. The data are being obtained with an upgraded Mosaic camera that deploys with new red-sensitive CCDs from Lawrence Berkeley Lab (LBL) whose throughput is in excess of 80% at 8000 to approximately 9800 Angstrom. The upgrade project was a collaboration of Yale, LBL, and NOAO. MzLS images are public as soon as they are taken and delivered to the NOAO archive. Catalogs based on Tractor photometry for all available Legacy Survey images are released soon after they are constructed and MzLS sources will be included in next release planned for summer 2016.

The Dark Energy Spectroscopic Instrument (DESI) will observe 30+ million galaxies and quasars in a 14,000 square degree extragalactic footprint. The targeting in that footprint will be provided by a combination of these MzLS data, DECam data from the DECam Legacy Survey, and data from the BASS survey.

Author(s): David R. Silva3, Robert D. Blum3, Lori Allen3, Arjun Dey3, David J. Schlegel[2], Dustin Lang[6], John Moustakas5, Aaron M. Meisner[2], Francisco Valdes3, Anna Patej[1], Adam D. Myers[8], David Sprayberry3, Abi Saha3, Knut A. Olsen3, Sasha Safonova7, Qian Yang4, Kaylan J Burleigh[2]
Institution(s): *1. Harvard, 2. LBNL, 3. National Optical Astronomy Observatory, 4. Peking University, 5. Siena College, 6. U Toronto, 7. University of Arizona, 8. UWyo*
Contributing team(s): The MzLS Team

317.03 – Improving JWST Coronagraphic Performance with Accurate Image Registration

The coronagraphs on the James Webb Space Telescope (JWST) will enable high-contrast observations of faint objects at small separations from bright hosts, such as circumstellar disks, exoplanets, and quasar disks. Despite attenuation by the coronagraphic mask, bright speckles in the host's point spread function (PSF) remain, effectively washing out the signal from the faint companion. Suppression of these bright speckles is typically accomplished by repeating the observation with a star that lacks a faint companion, creating a reference PSF that can be subtracted from the science image to reveal any faint objects. Before this reference PSF can be subtracted, however, the science and reference images must be aligned precisely, typically to 1/20 of a pixel. Here, we present several such algorithms for performing image registration on JWST coronagraphic images. Using both simulated and pre-flight test data (taken in cryovacuum), we assess (1) the accuracy of each algorithm at recovering misaligned scenes and (2) the impact of image registration on achievable contrast. Proper image registration, combined with post-processing techniques such as KLIP or LOCI, will greatly improve the performance of the JWST coronagraphs.

Author(s): Kyle Van Gorkom[1], Laurent Pueyo[1], Charles-Philippe Lajoie[1]
Institution(s): *1. Space Telescope Science Institute*
Contributing team(s): JWST Coronagraphs Working Group

317.04 – Spherical Panorama Visualization of Astronomical Data with Blender and Python

We describe methodology to generate 360 degree spherical panoramas of both 2D and 3D data. The techniques apply to a variety of astronomical data types - all sky maps, 2D and 3D catalogs as well as planetary surface maps. The results can be viewed in a desktop browser or interactively with a mobile phone or tablet. Static displays or panoramic video renderings of the data can be produced. We review the Python code and usage of the 3D Blender software for projecting maps onto 3D surfaces and the various tools for distributing visualizations.

Author(s): Brian R. Kent[1]
Institution(s): *1. NRAO*

317.05 – SpecViz: Interactive Spectral Data Analysis

The astronomical community is about to enter a new generation of scientific enterprise. With next-generation instrumentation and advanced capabilities, the need has arisen to equip astronomers with the necessary tools to deal with large, multi-faceted data. The Space Telescope Science Institute has initiated a data analysis forum for the creation, development, and maintenance of software tools for the interpretation of these new data sets. SpecViz is a spectral 1-D interactive visualization and analysis application built with Python in an open source development environment. A user-friendly GUI allows for a fast, interactive approach to spectral analysis. SpecViz supports handling of unique and instrument-specific data, incorporation of advanced spectral unit handling and conversions in a flexible, high-performance interactive plotting environment. Active spectral feature analysis is possible through interactive measurement and statistical tools. It can be used to build wide-band SEDs, with the capability of combining or overplotting data products from various instruments. SpecViz sports advanced toolsets for filtering and detrending spectral lines; identifying, isolating, and manipulating spectral features; as well as utilizing spectral templates for renormalizing data in an interactive way. SpecViz also includes a flexible model fitting toolset that allows for multi-component models, as well as custom models, to be used with various fitting and decomposition routines. SpecViz also features robust extension via custom data loaders and connection to the central communication system underneath the interface for more advanced control. Incorporation with Jupyter notebooks via connection with the active iPython kernel allows for SpecViz to be used in addition to a user's normal workflow without demanding the user drastically alter their method of data analysis. In addition, SpecViz allows the interactive analysis of multi-object spectroscopy in the same straight-forward, consistent way. Through the development of such tools, STScI hopes to unify astronomical data analysis software for JWST and other instruments, allowing for efficient, reliable, and consistent scientific results.

Author(s): Nicholas Michael Earl[1]
Institution(s): *1. Space Telescope Science Institute*
Contributing team(s): STScI

317.06 – SciServer Compute brings Analysis to Big Data in the Cloud

SciServer Compute uses Jupyter Notebooks running within server-side Docker containers attached to big data collections to bring advanced analysis to big data "in the cloud." SciServer Compute is a component in the SciServer Big-Data ecosystem under development at JHU, which will provide a stable, reproducible, sharable virtual research environment.

SciServer builds on the popular CasJobs and SkyServer systems that made the Sloan Digital Sky Survey (SDSS) archive one of the most-used astronomical instruments. SciServer extends those systems with server-side computational capabilities and very large scratch storage space, and further extends their functions to a range of other scientific disciplines.

Although big datasets like SDSS have revolutionized astronomy research, for further analysis, users are still restricted to downloading the selected data sets locally – but increasing data sizes make this local approach impractical. Instead, researchers need online tools that are co-located with data in a virtual research environment, enabling them to bring their analysis to the data.

SciServer supports this using the popular Jupyter notebooks, which allow users to write their own Python and R scripts and execute them on the server with the data (extensions to Matlab and other languages are planned). We have written special-purpose libraries that enable querying the databases and other persistent datasets. Intermediate results can be stored in large scratch space (hundreds of TBs) and analyzed directly from within Python or R with state-of-the-art visualization and machine learning libraries. Users can store science-ready results in their permanent allocation on **SciDrive**, a Dropbox-like system for sharing and publishing files. Communication between the various components of the SciServer system is managed through SciServer's new Single Sign-on Portal.

We have created a number of demos to illustrate the capabilities of **SciServer Compute**, including Python and R scripts accessing a range of datasets and showing the data flow between storage and compute components.

Demos, documentation, and more information can be found at www.sciserver.org.

SciServer is funded by the National Science Foundation Award ACI-1261715.

Author(s): Jordan Raddick[1], Dmitry Medvedev[1], Gerard Lemson[1], Barbara Souter[1]
Institution(s): *1. Johns Hopkins University*

317.07 – A Catalog of GALEX Ultraviolet Emission from Asymptotic Giant Branch Stars

We present the results of a search for ultraviolet emission from stars on the asymptotic giant branch (AGB). Our input sample of nearly 500 AGB stars were selected from existing catalogs, as detailed in the our earlier search for X-ray emission from AGB stars (Ramstedt et al. 2012). We determined that 67% of the input sample were observed in the imaging surveys of the Galaxy Evolution Explorer (GALEX). More than half of the individual AGB stars observed by GALEX were detected in at least one of the NUV or FUV bandpasses. The sample of NUV- and FUV-detected AGB stars includes a range of chemical types (M-, C-, and S-types) that when combined with multiwavelength photometry indicate the influence of the distinct circumstellar environments. We analyze multiwavelength photometry for both the detections and non-detections to maximize the return from this emerging UV view of cool, evolved, mass losing giants.

Author(s): Rodolfo Montez[3], Sofia Ramstedt[4], Joel H. Kastner[2], Wouter Vlemmings[1]
Institution(s): *1. Chalmers University, 2. Rochester Institute of Technology, 3. Smithsonian Astrophysical Observatory, 4. Uppsala University*

317.08 – The Chandra Xbootes Survey - IV: Mid-Infrared and Submillimeter Counterparts

In this work, we use a Bayesian technique to identify mid-IR and submillimeter counterparts for 3,213 X-ray point sources detected in the Chandra XBoötes Survey so as to characterize the relationship between black hole activity and star formation in the XBoötes region. The Chandra XBoötes Survey is a 5-ks X-ray survey of the 9.3 square degree Boötes Field of the NOAO Deep Wide-Field Survey (NDWFS), a survey imaged from the optical to the near-IR. We use a likelihood ratio analysis on Spitzer-IRAC data taken from The Spitzer Deep, Wide-Field Survey (SDWFS) to determine mid-IR counterparts, and a similar method on Herschel-SPIRE sources detected at 250μm from The Herschel Multi-tiered Extragalactic Survey to determine the submillimeter counterparts. The likelihood ratio analysis (LRA) provides the probability that a(n) IRAC or SPIRE point source is the true counterpart to a Chandra source. The analysis is comprised of three parts: the normalized magnitude distributions of counterparts and background sources, and the radial probability distribution of the separation distance between the IRAC or SPIRE source and the Chandra source. Many Chandra sources have multiple prospective counterparts in each band, so additional analysis is performed to determine the identification reliability of the candidates. Identification reliability values lie between 0 and 1, and sources with identification reliability values ≥0.8 are chosen to be the true counterparts. With these results, we will consider the statistical implications of the sample's redshifts, mid-IR and submillimeter luminosities, and star formation rates.

Author(s): Arianna Brown[1], Ketron Mitchell-Wynne[2], Asantha R. Cooray[2], Hooshang Nayyeri[2]
Institution(s): *1. CSU - Los Angeles, 2. UC Irvine*

317.09 – PyXel: A Python Package for Astronomical X-ray Data Modeling

PyXel is an new Python package for modeling astronomical X-ray imaging data. It is built on NumPy, SciPy, matplotlib, and Astropy, and distributed under an open-source license. The package aims to provide a common set of image analysis tools for astronomers working with extended X-ray sources. I will present an overview of its existing and planned features, and analysis examples based on public Chandra data.

Author(s): Georgiana Ogrean[1]
Institution(s): *1. Stanford University*

317.10 – Large Data at Small Universities: Astronomical processing using a computer classroom

The use of large computing clusters for astronomy research is becoming more commonplace as datasets expand, but access to these required resources is sometimes difficult for research groups working at smaller Universities. As an alternative to purchasing processing time on an off-site computing cluster, or purchasing dedicated hardware, we show how one can easily build a crude on-site cluster by utilizing idle cycles on instructional computers in computer-lab classrooms. Since these computers are maintained as part of the educational mission of the University, the resource impact on the investigator is generally low.

By using open source Python routines, it is possible to have a large number of desktop computers working together via a local network to sort through large data sets. By running traditional analysis routines in an “embarrassingly parallel” manner, gains in speed are accomplished without requiring the investigator to learn how to write routines using highly specialized methodology.

We demonstrate this concept here applied to 1. photometry of large-format images and 2. Statistical significance-tests for X-ray lightcurve analysis. In these scenarios, we see a speed-up factor which scales almost linearly with the number of cores in the cluster. Additionally, we show that the usage of the cluster does not severely limit performance for a local user, and indeed the processing can be performed while the computers are in use for classroom purposes.

Author(s): Nathaniel James Fuller[1], William I. Clarkson[1], Bill Fluharty[1], Zach Belanger[1], Kristen Dage[1]
Institution(s): *1. The University of Michigan-Dearborn*

317.11 – Methods of Spectral Analysis in C++ (MOSAIC)

Stellar spectroscopic classification is most often still done by hand. MOSAIC is a project focused on the collection and classification of astronomical spectra using a computerized algorithm. The code itself attempts to accurately classify stellar spectra according to the broad spectral classes within the Morgan-Keenan system of spectral classification, based on estimated temperature and the relative abundances of certain notable elements (Hydrogen, Helium, etc.) in the stellar atmosphere. The methodology includes calibrating the wavelength for pixels across the image by using the wavelength dispersion of pixels inherent with the spectrograph used. It then calculates the location of the peak in the star's Planck spectrum in order to roughly classify the star. Fitting the graph to a blackbody curve is the final step for a correct classification. Future work will involve taking a closer look at emission lines and luminosity classes.

Author(s): Michael Engesser[1]
Institution(s): *1. SUNY Oneonta*

318 – Molecular Clouds, Interstellar Medium, and Dust Poster Session

318.01 – Evidence from SOFIA Imaging of Polycyclic Aromatic Hydrocarbon Formation along a Recent Outflow in NGC 7027

We report spatially resolved (FWHM ~ 3.8 - 4.6") mid-IR imaging observations of the planetary nebula (PN) NGC 7027 taken with the 2.5-m telescope aboard the Stratospheric Observatory for Infrared Astronomy (SOFIA). Images of NGC 7027 were acquired at 6.3, 6.6, 11.1, 19.7, 24.2, 33.6, and 37.1 μm using the Faint Object Infrared Camera for the SOFIA Telescope (FORCAST). The observations reveal emission from Polycyclic Aromatic Hydrocarbon (PAH) and warm dust (T_D ~ 90 K) from the ionized inner edge of the molecular envelope surrounding the central star of the planetary nebula (CSPN). The DustEM code was used to fit the spectral energy distribution of fluxes obtained by FORCAST and the archival infrared spectrum of NGC 7027 acquired by the Short Wavelength Spectrometer (SWS) on the Infrared Space Observatory (ISO). Best-fit dust models reveal a total dust mass of ~6 × 10^{-3} $M_\odot$, where carbonaceous large (a = 1.5 μm) and very small (a ~ 12 Å) grains, and PAHs (3.1 Å < a <12 Å) compose 96.5, 2.2, and 1.3% of the dust by mass, respectively. The 37 μm optical depth map reveals minima in the dust column density at regions in the envelope that are coincident with a previously identified highly collimated outflow from the CSPN. The column density minima are also spatially coincident with enhancements in the 6.2 μm PAH feature, which is derived from the 6.3 and 6.6 μm maps. We interpret the spatial anti-correlation of the dust column density and PAH 6.2 μm feature strength and their alignment with the outflow from the CSPN as evidence of dust processing and rapid PAH formation via grain-grain collisions in the post-shock environment of the dense photo-dissociation region (PDR) and molecular envelope.

Author(s): Ryan M. Lau[1], Michael W. Werner[1], Raghvendra Sahai[1], Michael E. Ressler[1]
Institution(s): *1. Caltech/JPL*

318.02 – Creating a full-sky map of PAH emission

Accurate characterization of foreground components has been a pressing issue in the CMB community for some time. In particular, the Anomalous Microwave Emission (AME), first detected in 1995 and confirmed by WMAP and Planck, has remained mysterious, though the leading hypothesis proposes that this excess emission is due to electric dipole emission from spinning dust grains. The leading candidate for such ‘spinning dust’ is Polycyclic Aromatic Hydrocarbons (PAHs). PAHs have characteristic emission lines in the mid-IR and can be analyzed using archived data from the WISE satellite.

We have been working using publicly available data from WISE to create a full-sky map across the four WISE frequency bands: 3.4um, 4.6um, 12um and 22um. PAH emission is brightest in the 12um band; however it is possible to localize this population more accurately by linearly combining the maps across all four frequencies to create a full-sky map tracing the small-grain population of PAHs. We present preliminary results from this work.

Author(s): Matthew Berkeley[2], Alan J. Kogut[1], David T. Chuss3
Institution(s): *1. NASA Goddard Space Flight Center, 2. The Catholic University of America, 3. Villanova University*
Contributing team(s): WISE

318.03 – Dust Temperatures in the Galactic Center Lobe

The Galactic Center Lobe (GCL), located toward positive latitudes above the Galactic center and extending to a distance of ~150 pc, is apparently a bubble of hot gas that is manifested at all wavelengths from radio to X-rays. In mid- to far-infrared dust emission, the GCL shows several superposed, elongated structures oriented perpendicular to the Galactic plane. Among them are the dust ridge centered on AFGL5376 and another defining the Double Helix Nebula (DHN). Using temperature maps constructed from a combination of archival WISE and SPITZER data, we have found that these features exhibit dramatic spatial variations in their dust temperatures, with the DHN and the AFGL5376 ridge being much warmer, and therefore substantially brighter in the 20 - 25 μm range, than several other linear features. Furthermore, the cooler linear structures tend to have rather constant dust temperatures, in sharp contrast to the highly variable emission within the warmer features. We will summarize the implications of these results for the nature of the dust heating sources. The candidate heating mechanisms are direct photon heating by stars in the central cluster, thermal heating by exposure to a hot coronal gas, and the impact of ions driven by magnetosonic waves or shocks.

Author(s): Luis G. Chinchilla-Garcia[1], Mark Morris[1]
Institution(s): *1. University of California, Los Angeles*

318.04 – A Sensitive CO(1-0) Survey in Pegasus-Pisces; Reducing the Dark Gas Inventory the Old-Fashioned Way

The idea that substantial molecular gas is present in the ISM but is not detectable by the CO(1-0) emission line at 115 GHz has become fairly prevalent in the last decade. This component has come to be known as "dark gas" in the sense that it is hard to trace using the standard spectral line tracers. It is usually identified by gamma-ray or infrared emission, or via the C^+ spectral line at 158 microns. However, in determining the dark gas component and comparing it to the molecular gas traced by the CO(1-0) line, existing CO surveys of varying sensitivity are employed. Even the most sensitive CO surveys typically employed in this fashion have at best 1-sigma rms values of about 0.1 K in antenna temperature. We surveyed a small region in the vicinity of the high-latitude molecular cloud MBM 55 in the CO(1-0) line using the Arizona Radio Observatory 12-meter telescope. The 1-sigma rms of our survey (0.02 – 0.03 K) was significantly better than that of typical CO surveys. We detected more CO emission than previous work had found and increased the known H_2 in the region by nearly 80%, thereby reducing significantly the contribution from dark gas.

Author(s): Loris A. Magnani[1], Emmanuel Donate[1]
Institution(s): *1. Univ. of Georgia*

318.05 – Thermal OH Emission, A New Tracer for Galaxy Structure: Z-Thickness and Rolling Motion of the Perseus Arm

Recent observations with the Green Bank Telescope (Allen et al. 2015) have shown that high-sensitivity measurements of OH 18-cm emission can be a useful alternative tracer for the large-scale distribution of molecular gas in the Galactic ISM. This component of the ISM is not well traced by 3-mm CO(1-0) emission. In the quiescent regions examined so far, fewer than half of the OH spectral features found show corresponding CO emission in the CfA survey (Dame el al. 2001). The intensities of the two main-line OH transitions at 1665 and 1667 MHz are in the "thermal" or LTE ratio of 5:9 and emanate from low-opacity gas with a wide spatial distribution similar to the HI. This morphology resembles that of the "dark gas" (or "dark neutral medium") postulated by Grenier et al. (2005) as the possible source of target nucleii required to explain the excess gamma ray emission from the Galactic ISM. OH 18-cm emission provides a new tool for studies of the quantity, distance, and kinematics of this new CO-dark molecular component of the ISM. As a demonstration of the utility of this new tool, we apply it to two questions about the molecular structure of the Perseus Arm: the thickness in the z-direction, and the rolling motions of the arm discovered in the earliest HI maps of the Galaxy (e.g. Oort 1962, Rougoor 1964). Using OH emission as a molecular tracer, we find that the molecular component of gas in the Perseus Arm has a comparable z-thickness to that measured using HI, although it appears to be clumpier. OH also shows that the molecular component experiences the "rolling motions" known from the HI data. As a molecular tracer, OH allows more regions to be observed than can be observed using CO(1-0), and as an optically-thin emission line, OH can provide direct column density measurements.

Author(s): Philip Engelke[1], Ronald J. Allen3, David E. Hogg[2]
Institution(s): *1. Johns Hopkins University, 2. National Radio Astronomy Observatory, 3. Space Telescope Science Institute*

318.06 – Simulating the [CII] emission of high redshift galaxies

The fine structure line of [CII] at 158 microns can arise throughout the interstellar medium (ISM) and has been proposed as a tracer of star formation rate (SFR). But the origin of [CII] and how it depends on e.g. metallicity and radiation field of a galaxy remain uncertain. Simulating [CII] can be done by combining the output from galaxy simulations with prescriptions for the subgrid physics, as has now been demonstrated by several groups. However, these models are either built on analytical discs or contain other simplifying assumptions. SÍGAME (Simulator of GAlaxy Millimeter/submillimeter emission) avoids these issues by using cosmological simulations and calculates [CII] emission reliably on resolved scales within each galaxy. The local metallicity is that of the simulation, whereas the far-ultraviolet radiation field and cosmic ray intensity are both scaled with local star formation rate density. For the chemistry and radiative transfer, the photoionization code CLOUDY is implemented. I will show results for z=2 star-forming galaxies yet to be observed, as well as preliminary results for galaxies at z~6-7 where observations have presented contradictory detections and non-detections of star-forming galaxies.

Author(s): Karen Pardos Olsen[1], Thomas Greve7, Desika Narayanan4, Christian Brinch[6], Jesper Rasmussen3, Jesper Sommer-Larsen[2], Andrew Zirm[2], Sune Toft[2], Robert Thompson5, Luis Rios[1], Stephanie Mae Stawinski[1]
Institution(s): *1. Arizona State University, 2. Dark Cosmology Centre, 3. DTU, 4. Haverford College, 5. National Center for Supercomputing Applications, 6. NBI, 7. UCL*

318.07 – New Measurements of the Solar Wind Charge Exchange, Local Bubble, and Halo 3/4 keV Emission from *XMM-Newton* and *Suzaku* Shadowing Observations

We report on the analyses of *XMM-Newton* and/or *Suzaku* observations of 6 on-cloud and off-cloud shadowing pairs. This study provides the first analysis of two of these pairs and the first uniform analysis of the larger dataset. For every shadowing pair, we determined the foreground and halo components by simultaneously fitting the spectra from both members of the pair with a model that included a foreground component and an absorbed background component. In the past, foreground X-ray emission was thought to come from the Local Bubble of hot gas surrounding the solar neighborhood and so thermal spectral models were used. Now that solar wind charge exchange is recognized as a source of foreground X-ray photons, it is appropriate to consider charge exchange models as well. For this reason, we repeated the analyses using one of 3 possible foreground models: a charge exchange spectral model whose line ratios come from atomic physics calculations and are presented in Cumbee et al. (2014), a charge exchange model based on the AtomDB Charge Exchange code, or a thermal spectrum. The analyses of the larger dataset enabled us to place an upper limit on the Local Bubble's O VII contribution, provide measurements of the local and halo contributions in the 0.4 to 1.0 keV band, comment on the abilities of the various solar wind models to fit the data, and comment on the sensitivity of the fit parameters to the choice of foreground model, metal abundance tables, and X-ray observatory.

Author(s): Robin L. Shelton[1], David Henley[1]
Institution(s): *1. Univ. of Georgia*

318.08 – On Stellar Wind Bow Shocks with External Magnetic Fields

Stellar wind bow shocks have been seen driven by stars of many types, from O to AGB stars as well as pulsars. Recent simulations (e.g. van Marle et al. 2014) have considered the bubble created by a stellar wind of a stationary star in a region of constant magnetic field. By applying a thin-shell formalism, I consider the problem of a stellar wind from a star moving supersonically with respect to a magnetized medium. The properties of the resulting shell are derived, and limitations to the application of the resulting solution are discussed.

Author(s): Francis P. Wilkin[1]
Institution(s): *1. Union College*

318.09 – The Small Magellanic Cloud Investigation of Dust and Gas Evolution (SMIDGE): The Dust Extinction Curve in the Small Magellanic Cloud from Red Clump Stars

We present preliminary measurements of the average dust extinction curve in a 200 pc x 100 pc region in the Small Magellanic Cloud (SMC) using multi-band *Hubble Space Telescope* observations of resolved stellar populations from SMIDGE. Extinction curve determinations from a fully-sampled region of the SMC are of great interest. SMC-like extinction is widely used to correct for the effects of dust in low metallicity or high redshift galaxies, however, there are currently very few extinction curve measurements in the SMC. We measure the extinction curve using color-magnitude diagrams of red clump stars experiencing reddening by dust along a vector from which the curve shape can theoretically be directly measured. In addition, our analysis of the extincted and unextincted red clump stars shows a substantial line-of-sight depth for the stellar distribution of the SMC, consistent with recent observations of Cepheids. With the deep multi-band photometry from SMIDGE we are able to separate these two effects and measure both the extinction curve and the line-of-sight depth. Our study implies that extinction curve measurements in nearby galaxies need to take into account the impact of an extended galactic structure on dust extinction along the line of sight.

Author(s): Petia Yanchulova Merica-Jones[1], Karin Sandstrom[1], Lent C. Johnson[1]
Institution(s): *1. University of California, San Diego*
Contributing team(s): SMIDGE Team

318.10 – The Small Magellanic Cloud Investigation of Dust and Gas Evolution (SMIDGE): Young, Low-mass Stars in the SW Bar of the SMC

We identify young, pre-main sequence stars in the SW Bar region of the Small Magellanic Cloud (SMC) using color magnitude diagrams obtained by the Hubble Space Telescope as part of the SMIDGE survey. Deep, panchromatic, high spatial resolution Hubble imaging provides an excellent dataset for studying young, low-mass (~2-0.5 $M_{\odot}$) stellar populations. The SW Bar region observed by SMIDGE contains multiple low mass star forming regions in various stages of evolution. These regions provide contrast to massive regions previously surveyed by Hubble in the SMC (e.g., NGC346, NGC602), and allow us to explore the evolution from quiescent clouds to HII regions. We analyze the spatial distribution of these young stars and their association with the local ISM, inferred from observations of molecular gas and dust emission. Additionally, we use Hα imaging to constrain accretion rates for the pre-MS stars. Finally, we analyze the characteristics and multiplicity of Spitzer YSO detections as revealed by high spatial resolution imaging.

Author(s): Lent C. Johnson[1], Karin Sandstrom[1]
Institution(s): *1. University of California, San Diego*
Contributing team(s): SMIDGE Team

318.11 – The Small Magellanic Cloud Investigation of Dust and Gas Evolution (SMIDGE): Overview and Science Goals

Because of its proximity, the Small Magellanic Cloud (SMC) has become a cornerstone in our understanding of the low metallicity interstellar medium. Many lines of evidence suggest that dust at low metallicity is substantially different from dust in the Milky Way and other high metallicity galaxies in its abundance, grain size distribution, composition and optical properties. The distinct characteristics of low metallicity dust are expected to alter the structure and properties of gas in the ISM, particularly its molecular phase, where dust shielding and grain surface chemistry play important roles. To investigate the interlocking evolution of dust and gas at low metallicity, we present new observations from the Small Magellanic Cloud Investigation of Dust and Gas Evolution (SMIDGE) survey. SMIDGE uses multiwavelength, high spatial resolution imaging from the Hubble Space Telescope to map dust extinction and extinction curve shape, as well as observations from the Atacama Large Millimeter Array to map the molecular gas. We present an overview of the survey and data products, outlining the scientific goals and early results from SMIDGE.

Author(s): Karin Sandstrom[1]
Institution(s): *1. University of California, San Diego*
Contributing team(s): SMIDGE Team

318.12 – SOFIA/FORCAST Observations of the Arched Filamentary Region in the Galactic Center

Abstract: We present 19.7, 25.2, 31.5, and 37.1 μm maps of the Thermal Arched Filament region in the Galactic Center taken with the Faint Object Infrared Camera for the SOFIA Telescope (FORCAST) with an angular resolution of 3.2-3.8". We calculate the integrated infrared luminosity of the Arched Filaments and show that they are consistent with being heated by the nearby Arches cluster. Additionally, using our observations, we infer dust temperatures (75 – 90 K) across the Arched Filaments which are remarkably consistent over large spatial scales (~ 25 pc). We discuss the possible geometric effects needed to recreate this temperature structure. Additionally, we compare the observed morphology of the Arches in the FORCAST maps with the Paschen-α emission in the region to study what fraction of the infrared emission may be coming from dust in the HII region versus the PDR beneath it. Finally, we use Spitzer/IRAC 8 μm data to look for spatial variations in PAH abundance in the rich UV environment of the young (~2-4 Myr) and massive Arches cluster.

Author(s): Matthew Hankins[2], Ryan M. Lau[1], Mark Morris[3], Terry L. Herter[2]
Institution(s): *1. Caltech/JPL, 2. Cornell University, 3. UCLA*

318.13 – Formation and properties of astrophysical carbonaceous dust

The classical theory of grain nucleation suffers from both theoretical and predictive deficiencies. We strive to alleviate these deficiencies in our understanding of dust formation and growth by utilizing an atomistic model of nucleation. Carbon cluster geometries are determined with a set of global minimization algorithms. Using density functional theory, the binding energies of carbon clusters from $n=2$ to $n=99$ are then calculated. These energies are used to calculate the critical size and nucleation rate of carbon clusters.

We find that the critical cluster size is largely determined by the changes in geometry of the clusters. Clusters with size $n=27$ and $n=8$, roughly corresponding to the transition from ring-to-fullerene geometry and chain-to-ring geometry respectively, are the critical sizes across the range of temperature and saturation where nucleation is significant. In contrast to the classical theory, nucleation is enhanced at low-temperatures, and suppressed at high temperatures. These results will be applied to a modified chemical evolution code using results from supernova simulations.

Author(s): Christopher Mauney[1], Davide Lazzati[1]
Institution(s): *1. Oregon State University*

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319 – Star Formation, Associations, and Stellar Objects Poster Session

319.01 – The large scale view of the young stellar populations in the Orion OB1 Association

The Orion OB1 association, at ~400 pc and with a wide range of ages (~1-10 Myr) and environmental conditions, is an ideal place to look at how stars form, first evolve and disperse among the general population of field stars. Also to study disk dispersal and the duration of the planet formation phase.
However, despite spanning nearly 200 deg2 on the sky, almost all we know about Orion comes from studies of a limited fraction of the entire region, mostly of the youngest objects (~<1 Myr) in the A and B molecular clouds and the ~3 Myr old sigma Ori cluster.
We will present here the results of our 180 sq deg photometric multi-epoch survey across the Orion OB1 association, using the known variability of T Tauri stars to pick them among the general field population, and following with spectroscopy to confirm members and characterize them.
The ~2000 newly identified young low-mass stars are mostly located away from the molecular clouds, across tens of sq. deg. in the Orion OB1a and OB1b sub-associations, with ages in the range ~4-10 Myr. But within this general population we identify a significant fraction concentrated in distinct overdensities, most notably the ~7 Myr old 25 Orionis cluster. These stellar aggregates point to a previously unknown degree of substructure that has survived the dissipation of the parent molecular clouds. We also find that the Orion Nebula Cluster is surrounded by a few sq.deg. halo of young stars, as has been suggested by recent sudies.

Author(s): Cesar Briceno[1], Nuria Calvet[2]
Institution(s): *1. NOAO, 2. University of Michigan*

319.02 – The Infrared Signature of Accretion Luminosity in Protostars

Mass accretion from the disk onto the star is an important mechanism by which a star increases in mass during the formation phase. If the mass accretion rate is time variable then the brightness of the star should also change with time. We use the HOCHUNK3D radiative transfer code to investigate how disk accretion rate (Mdot) affects the protostar spectral energy distribution (SED). The biggest changes in brightness occur at infrared wavelengths ranging from approximately 5 to 100 microns. The results show that the protostar luminosity doubles from 1 to 2 $L_\odot$ when the disk accretion rate is increased to Mdot=3.0e-7 $M_\odot$/year. We conclude that the models are a useful tool to study mass accretion rates and time variability in protostars.

Author(s): Susan Terebey1, Ethan G. Villarama1, Lizxandra Flores-Rivera1
Institution(s): *1. Cal. State Univ. at Los Angeles*

319.03 – Hour-Scale Variability in NGC 663 and NGC 1960

Since 2010 we have been monitoring massive emission-line (mainly Be) stars in young open clusters using narrowband imaging at Hα (656nm) and the nearby continuum (645nm) (Souza, Davis, and Teich 2013, *BAAS.* **45**, PM354.22; Souza, Beltz-Mohrmann, and Sami 2014. *JAAVSO*, **42**, 154). To supplement longer-timescale data taken at Williams College we obtained high-cadence observations, in both filters, of NGC 663 on the night of 12/10/15, and of NGC 1960 on the nights of 12/10/14, 1/23/15, 1/25/15, 11/11/15, and 12/13/15 at the 0.5m ARCSAT at Apache Point Observatory. After raw magnitude extraction using *Aperture Photometry Tool* (Laher et al. 2012, *PASP*, **124**, 737), we used inhomogeneous ensemble photometry (Bhatti et al., 2010, *ApJ Supp.*, **186**, 233) to correct for transparency and seeing variations. The NGC 663 field is crowded; of 29 known Be stars in the observed field, 10 have nearby interferers. None of the remaining 19 Be stars showed significant variation during ~5.5 hours of observation. 1σ uncertainty estimates range from 0.02mag at R~10 to 0.15mag at R~14. To verify the observing and reduction procedure, we recovered hour-scale variability in known variables BY Cas (δ Cephei type, ~0.05mag decline) and V1155 Cas (β Cephei type, ~0.04mag amplitude). In NGC 1960, of 5 known and suspect Be stars observed, two not previously reported as variable (BD+34 1110 and USNOB1.0 1241-0103450) showed irregular variation on timescales of hours. In NGC 1960 we also report the incidental discovery of two non-Be suspect variables: a likely eclipsing binary (0.07mag), and a possible δ Scuti star (maximum amplitude ~0.02mag). We gratefully acknowledge support for student research from NSF grant AST-1005024 to the Keck Northeast Astronomy Consortium, and the Office of the Dean of Faculty and the DIII Research Funding Committee of Williams College. Based on observations obtained with Apache Point Observatory's 0.5-m Astrophysical Research Consortium Small Aperture Telescope.

Author(s): Steven P. Souza2, Aylin Garcia Soto1, Hallee Wong2
Institution(s): *1. Wesleyan University, 2. Williams College*

319.04 – Star Formation as a Function of Neutral Hydrogen Gas Density in Local Group Galaxies

We present a study of the efficiency and timescales of star formation as a function of local neutral hydrogen gas density in four Local Group galaxies: M33, NGC 6822, the LMC, and the SMC. In this work, we conceptualize the process of star formation as a cycle of two major phases – (1) a gas dynamics phase in which neutral hydrogen gas coalesces into clouds, and (2) a stellar phase in which stars have formed and interrupt further gas coalescence during their active lifetimes. By examining the spatial distribution and number densities of stars on maps of neutral hydrogen, we estimate the timescale of the gas coalescence phase relative to the timescale of the stellar phase and infer an efficiency of star formation as a function of neutral hydrogen gas density. From these timescales and efficiencies, we will calculate star formation rates as a function of neutral hydrogen gas density in these galaxies.

Author(s): Erika K. Carlson1, Barry F. Madore1, Wendy L. Freedman2
Institution(s): *1. Carnegie Observatories, 2. University of Chicago*

319.05 – Studying globular clusters and ultra-compact dwarfs in NGC 247 using Subaru Hyper Suprime Cam

We analyze and look for globular clusters (GCs) and ultra-compact dwarfs (UCDs) around the nearby spiral dwarf galaxy NGC 247, located in the Sculptor Filament, based on wide-field imaging data from Subaru Hyper Suprime -Cam (HSC). HSC is the upgraded wide field optical imaging camera built for 8.2 m Subaru telescope. The field of view is 1.77 square degree (1.5 degrees in diameter). With the extremely wide-area coverage and high sensitivity, this camera offers us great opportunities in exploring and finding new GCs and UCDs. The colors, magnitudes, and sizes of the GC and UCD candidates are examined and spectroscopic follow-up is conducted to confirm the candidates.

Author(s): Vakini Santhanakrishnan3, Aaron J. Romanowsky3, David J. Sand4, Beth Willman1, Jean P. Brodie5, Jeffrey L. Carlin1, Paul A. Price2
Institution(s): *1. LSST, 2. Princeton University, 3. San Jose State University, 4. Texas Tech University, 5. UC Santa Cruz*

319.06 – Globular Cluster Orbits from HST Proper Motions: Constraining the Formation and Mass of the Milky Way Halo

The globular cluster (GC) system of the Milky Way (MW) provides important information on the MW's present structure and past evolution. GCs in the halo are particularly useful tracers; because of their long dynamical timescales, their orbits retain imprints of their origin or accretion history. Full 3D motions are required to calculate past orbits. While most GCs have known line of sight velocities, accurate proper motion (PM) measurements are currently available for only a few halo GCs. Our goal is to create the first high-quality PM database for halo GCs. We have identified suitable 1st-epoch data in the HST Archive for 20 halo GCs at 10-100 kpc from the Galactic Center. We are in the process of obtaining the necessary 2nd-epoch data to determine absolute PMs of the target GCs through our HST program GO-14235. We will use the same advanced astrometric techniques that allowed us to measure the PMs of M31 and Leo I. Previous studies of the halo GC system based on e.g., stellar populations, metallicities, RR Lyrae properties, and structural properties have revealed a dichotomy between old and young halo GCs. This may reflect distinct formation scenarios (in situ vs. accreted). Orbit calculations based on our PMs will directly test this. The PMs will also yield the best handle yet on the velocity anisotropy profile of any tracer population in the halo. This will resolve the mass-anisotropy degeneracy to provide an improved estimate of the MW mass, which is at present poorly known. In summary, our project will deliver the first accurate PMs for halo GCs, and will significantly increase our understanding of the formation, evolution, and mass of the MW.

Author(s): S. Tony Sohn1, Roeland P. Van Der Marel3, Alis J. Deason2, Andrea Bellini3, Gurtina Besla4, Laura Watkins3
Institution(s): *1. Johns Hopkins University, 2. Stanford University, 3. STScI, 4. University of Arizona*

319.07 – Applying Gaussian mixture models to the Na-O plane to separate multiple populations in globular clusters

We present the results of an analysis using Gaussian mixture models (GMM) to separate multiple populations in Milky Way globular clusters based on the Na and O abundances of their members. Recent studies have shown that the method used to separate the populations in globular clusters (e.g. photometry, molecular band strengths, light element abundances) can result in different fractions of primordial and second generation stars. These fractions have important implications on the mass lost by globular clusters during their evolution, and the mechanism responsible for creating the second generation. For many previous studies, the first generation (FG) stars, with primordial Na and O, were classified as such by falling below a maximum [Na/Fe] abundance based on the estimated [Na/Fe] of the Milky Way field population most similar to a given cluster. Stars that were above this [Na/Fe] threshold were classified as second generation (SG) stars, representing the Na enhanced and O depleted population in the cluster. The method we present here is based on separating these populations in the [Na/Fe] vs [O/Fe] plane by constructing a multi-component, and multi-dimensional, GMM. The dataset provided by Carretta et al. 2009 provides a homogeneous sample of [Na/Fe] and [O/Fe] abundances in ~1,000 stars in southern globular clusters. Using all of the stars available in this sample, we created a general GMM that was subsequently used to classify the stars in individual clusters as FG or SG. To perform this classification, the stars in each cluster are assigned a probability of belonging to each of the Gaussian components in the GMM calculated from the entire Carretta sample. Based on these probabilities, we can assign a given star to the FG or SG. Here we present how the fractions of FG and SG stars present in a given globular cluster, as calculated by our GMM, compare to those determined from a single [Na/Fe] threshold. We will also characterize how the fractions of FG and SG stars are related to the structural and chemical properties of the clusters.

Author(s): Owen M. Boberg[1], Eileen D. Friel[1], Enrico Vesperini[1]
Institution(s): *1. Indiana Univeristy*

319.08 – Carbon and Nitrogen Abundance Variations Among Red Giant Branch Stars in M10

We present analysis of the CN and CH molecular band strengths derived for red giants in M10 as part of a first pilot study in the WIYN Indiana Northern Globular Survey (WINGS). This survey plans to use a combination of low-resolution spectroscopy taken with Hydra and wide-field SDSS filter photometry taken with the newly upgraded ODI to study the multiple populations and dynamics of a sample of Milky Way globular clusters. Our sample comes from the first in a series of observation runs conducted in Aug. 2014 using Hydra on the WIYN 3.5m telescope. CN and CH bands are measured for ~100 red giant branch stars and used to characterize the distribution in band strength and to derive carbon and nitrogen abundances by comparing observed band strengths to synthetic spectra produced by the Synthetic Spectrum Generator (SSG), which makes use of MARCS model atmospheres. Band strengths and CN abundances are used to investigate the distribution of stars in nitrogen normal and enhanced populations and to compare these to other ways of characterizing multiple stellar populations with other light elements (such as Na and O).

Author(s): Jeffrey M Gerber[1], Eileen D. Friel[1], Enrico Vesperini[1]
Institution(s): *1. Indiana University*

319.09 – Cataloging the Youngest Protostars in NGC2264

Protostars are young stars in their earliest stages of development. We can determine the current stage of development of a young star depending on its relative brightness at varying wavelengths. Protostars are brightest at far-infrared wavelengths, typically peaking at 70-100um. A previous catalog of young stars in NGC 2264 is based on Spitzer data with 24um being the longest available wavelength data. Herschel data at 70um was used to improve the census of protostars. We found 11 new class 0 and 1 protostar candidates that were previously not found in the Spitzer catalog and are bright at 70um. We describe the properties of these candidates.

Author(s): Jonathan Barnes[2], Arianna Brown[1], Susan Terebey[1]
Institution(s): *1. Cal State University LA, 2. Norfolk State University*
Contributing team(s): CSI2264

319.10 – The Role of Radiation Pressure in Assembling Super Star Clusters

Super star clusters are the most extreme star-forming regions of the Universe - they occupy the most massive end of the Kennicutt-Schmidt relation, forming stars at exceptionally high rates and gas surface densities. The radiation feedback from the dense population of massive stars is expected to play a dynamic role during the assembly of the clusters, and represents a potential mechanism for launching large-scale galactic outflows. Observationally, large distances and dust obscuration have been withholding clues about the early stages of massive cluster formation; theoretically, the lack of accurate and efficient radiation transfer schemes in multi-dimensional hydrodynamic simulations has been deterring our understanding of radiative feedback. By extending the adaptive mesh refinement code FLASH with a closure-free, Monte Carlo radiation transport scheme, we perform 3D radiation hydrodynamical simulations of super star cluster formation from the collapse of turbulent molecular clouds. Our simulations probe the star formation in densities typical for starbursts, with both non-ionizing UV and dust-reprocessed IR radiation treated self-consistently. We aim to determine the role of radiation pressure in regulating star formation, and its capacity in driving intense outflows.

Author(s): Benny Tsz-Ho Tsang[1], Milos Milosavljevic[1]
Institution(s): *1. The University of Texas at Austin*

319.11 – The Evolution of Pristine Gas: Implications for Milky Way Halo Stars

We implement a new subgrid model for turbulent mixing to accurately follow the cosmological evolution of the first stars, the mixing of their supernova ejecta and the impact on the chemical composition of the Galactic Halo. Using the cosmological adaptive mesh refinement code *RAMSES*, we implement a model for the pollution of pristine gas as described in Pan et al. (2013). This allows us to account for the fraction of $Z < Z_{crit}$ stars formed throughout the simulation volume, even in regions in which the average metallicity is well above Z_{crit}. Further, as a result of modeling the pristine fraction of gas, we also improve our modeling of the metallicity of the polluted fraction, f_{pol}, of both the gas and stars. Additionally, we track the evolution of the “primordial metals” generated by Pop III supernovae. These metals are taken up by second-generation stars and are likely to lead to unique abundance signatures characteristic of carbon enhanced, metal poor (CEMP) stars. As an illustrative example, we associate primordial metals with abundance ratios used by Keller at al (2014) to explain the source of metals in the star SMSS J031300.36- 670839.3, finding good agreement with the observed [Fe/H], [C/H], [O/H] and [Mg/Ca] ratios in CEMP Milky Way (MW) halo stars.

Author(s): Richard J Sarmento[1], Evan Scannapieco[1], Liubin Pan[2]
Institution(s): *1. ASU, 2. Harvard-Smithsonian Center for Astrophysics*

319.12 – Multi-Wavelength Study of Segue 3

Segue 3 is a very faint and distant star cluster, first identfied as being [Fe/H]=-1.7 dex, but later reclassified as [Fe/H]=-0.8. We study the stellar population in Washington and SDSS filters, adding to VI-photometry in the literature. We show the importance of multi-wavelength coverage, careful filter-selection, and use of the sub-giant and lower red-giant branch populations, to break the age-metallicity degeneracy.

Author(s): Joanne D. Hughes[1], Spencer Schiefelbein[1], Donna Le[1], Olivia Corrin[1], Hanah Joudi[1], Brianna I. Lacy[2]
Institution(s): *1. Seattle Univ., 2. University of Washington*

319.13 – A Search for X-ray Emitting Binary Stars in the Globular Cluster Omega Centauri

Omega Centauri is one of the most widely studied globular clusters, and is expected to harbor a significant population of binary stars. Binaries play a crucial role in determining the progression of stellar dynamics within globular clusters, and as such are relevant to questions concerning the possible formation of intermediate black holes at their centers. One effective way to identify certain classes of binary systems is to first locate X-ray sources in the cluster and then to search for their optical counterparts. Using Chandra X-ray Observatory's ACIS-I instrument we have identified 275 X-ray sources in and toward Omega Cen, more than 50 of which lie within the cluster's core radius. Here we present a search for the optical counterparts of these core sources using an extensive database of archival Hubble Space Telescope images. Using WFC3/UVIS data from 11 different filters, we construct color-magnitude diagrams that reveal a diverse array of objects, including (in addition to background and foreground objects) cataclysmic variables, coronally active binaries, and, interestingly, stars that lie on Omega Cen's anomalous giant branch. We discuss the significance of these results in the context of studies of the formation and evolution of binary stars in globular clusters.

Author(s): Sarah Deveny3, Michael Gallien3, Ryan Rickards Vaught3, Miranda Waters3, Adrienne Cool3, Andrea Bellini4, Jay Anderson4, Simon Henleywillis[1], Daryl Haggard[2], Craig O. Heinke5
Institution(s): *1. University College Cork, 2. McGill University, 3. San Francisco State University, 4. Space Telescope Science Institute, 5. University of Alberta*

320 – Stellar Atmospheres and Circumstellar Disks Poster Session

320.01 – Keck Observations of the UV-Bright Star Barnard 29 in the Globular Cluster M13 (NGC 6205)

In color-magnitude diagrams of globular clusters, stars brighter than the horizontal branch and bluer than the red-giant branch are known as UV-bright stars. Most are evolving from the asymptotic giant branch (AGB) to the tip of the white-dwarf cooling curve. To better understand this important phase of stellar evolution, we have analyzed a Keck HIRES echelle spectrum of the UV-bright star Barnard 29 in M13. We begin by fitting the star's H I (Hα, Hβ, and Hγ) and He I lines with a grid of synthetic spectra generated from non-LTE H-He models computed using the TLUSTY code. We find that the shape of the star's Hα profile is not well reproduced with these models. Upgrading from version 200 to version 204M of TLUSTY solves this problem: the Hα profile is now well reproduced. TLUSTY version 204 includes improved calculations for the Stark broadening of hydrogen line profiles. Using these models, we derive stellar parameters of T_{eff} = 21,100 K, log g = 3.05, and log (He/H) = -0.87, values consistent with those of previous authors. The star's Keck spectrum shows photospheric absorption from N II, O II, Mg II, Al III, Si II, Si III, S II, Ar II, and Fe III. The abundances of these species are consistent with published values for the red-giant stars in M13, suggesting that the star's chemistry has changed little since it left the AGB.

Author(s): William Van Dyke Dixon[1], Pierre Chayer[1], Iain N. Reid[1]
Institution(s): *1. Space Telescope Science Institute*

320.02 – Rovibrational excitation of H2 and HD due to H: the contribution of reactive scattering

Utilizing the hyperspherical method as implemented in the ABC computational suite of codes (Skouteris et al. 2000), the time-independent Schroedinger equation is solved for the reactive and inelastic scattering probabilities for interactions between hydrogen and its isotopes, particularly H, H2, and HD. A high quality potential energy surface (Miekle et all 2002) was adopted in the scattering Hamiltonian construction. Additionally, we aim to explore uses of GPU-centric computing to increase the efficiency of this method (Baraglia et al.) in order to obtain collisional rate coefficients for the full range of rovibrationally excited H2 and HD, extending the recent study of Lique (2015).

Baraglia, R. et al. 2011, in Computational Science and Its Applications
Lique, F. 2015, MNRAS, 453, 810
Mielke, S. L. et al., 2002, J. Chem. Phys., 116, 4142
Skouteris, D. et al., 2000, Comp. Phys. Comm., 133, 128

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Author(s): Alexander Watson Cook[2], Benhui H. Yang[2], Phillip C. Stancil[2], Robert C. Forrey[1], Balakrishnan Naduvalath3
Institution(s): *1. Penn State University, 2. University of Georgia, 3. University of Nevada, Las Vegas*

320.03 – A Study of ro-vibrational OH Emission from Herbig Ae/Be Stars

We present a study of ro-vibrational OH and CO emission from 21 disks around Herbig Ae/Be stars. We find that the luminosity of the OH emission is proportional to the luminosity of the CO emission over five orders of magnitude in stellar ultraviolet luminosity. We also find that the profiles of the OH and CO emission lines are similar indicating that they arise from the same radial region of the disk.The CO and OH emission are both correlated with the far ultraviolet (1300-1840Å) luminosity of the stars while the luminosity of the PAH emission is correlated with the longer wavelength ultraviolet (2450-3200Å) luminosity of the stars. Our interpretation of the observations is that the OH and CO are heated by ultraviolet photons in the same region of the disk. We also find that while disk flaring affects the PAH luminosity, it is not a factor in the luminosity of the OH and CO emission. However, transition disks with large inner holes do have systematically lower OH and CO luminosities.

Author(s): Sean D. Brittain[1], Mate Adamkovics4, John S Carr3, Joan R. Najita[2]
Institution(s): *1. Clemson Univ., 2. NOAO, 3. NRL, 4. UC Berkeley*

320.04 – Radiation Hydrodynamical Models of the Inner Rim in Protoplanetary Disks

Many stars host planets orbiting within one astronomical unit (AU). These close planets' origins are a mystery that motivates investigating protoplanetary disks' central regions. A key factor governing the conditions near the star is the silicate sublimation front, which largely determines where the starlight is absorbed, and which is often called the inner rim. We present the first radiation hydrodynamical modeling of the sublimation front in the disks around the young intermediate-mass stars called Herbig Ae stars. The models are axisymmetric, and include starlight heating, silicate grains sublimating and condensing to equilibrium at the local, timedependent temperature and density, and accretion stresses parametrizing the results of MHD magneto-rotational turbulence models. The results compare well with radiation hydrostatic solutions, and prove to be dynamically stable. Passing the model disks into Monte Carlo radiative transfer calculations, we show that the models satisfy observational constraints on the inner rims's location. A small optically-thin halo of hot dust naturally arises between the inner rim and the star. The inner rim has a substantial radial extent, corresponding to several disk scale heights. While the front's overall position varies with the stellar luminosity, its radial extent depends on the mass accretion rate. A pressure maximum develops at the position of thermal ionization at temperatures about 1000 K. The pressure maximum is capable of halting solid pebbles' radial drift and concentrating them in a zone where temperatures are su ciently high for annealing to form crystalline silicates.

Author(s): Mario Flock[1]
Institution(s): *1. Caltech/JPL*

320.05 – Determining the Location of the Water Snowline in an Externally-Photoevaporated Solar Nebula

Recent studies using the Atacama Large Millimeter Array (ALMA) have imaged the location of the CO snowline in protoplanetary disks [1][2]. Water snowlines are present closer to the star and thus harder to detect, though their location may be inferred [3][4]. In the light of future direct observations of water snowlines, it is important to consider how photoevaporation may affect the snowline's location, as half of all disks are likely to be externally photoevaporated by a nearby massive star [5]. In the solar nebula, the water snowline is argued to be present at 2.7 AU, corresponding to the water sublimation temperature (~170K). But snowlines should depend as much on radial transport of volatiles, such as the outward diffusion of water vapor and the inward drift of ices, which can both settle into a steady cyclical flow across the snowline in the first few Myr [6][7].

We argue that external processes (e.g. photoevaporation) can disturb this cycle, potentially shifting the snowline inward and dehydrating the disk.
To test this hypothesis, we have first built a 1+1D disk evolution model, incorporating viscosity from the magnetorotational instability with a non-uniform α across disk radius, ionization equilibrium with dust, and external photoevaporation [8]. Our simulation results suggest that the structure of the photoevaporated disk is likely more complex than previously thought, with the following features: (i) very steep Σ profile ($\Sigma(r)=\Sigma_0\ r^{-p}$, where slope p = 3 – 5, > p_{MMSN}=1.5) due to the varying α profile, that is further steepened by the presence of dust and photoevaporation, and (ii) transition radius (where net disk mass flow changes from inward flow to outward) present very close to the star (~3AU). We now apply these new results and radial transport processes to study the distribution of water in the solar nebula. References: 1]Qi, C., et al. (2013), Science, 341, 360 [2] Mathews, G.S. et al. (2013), A&A, 557, A132 [3]Zhang, K., et al. (2015), ApJ, 806, L7[4] Meijerink, R., et al.(2009), ApJ, 704, 1471 [5]Lada, C.J. & Lada, E.A.(2003), ARA&A, 41, 57 [6]Cuzzi, J .N ., & Zahnle, K .J., (2004), ApJ, 614, 490 [7]Ciesla, F. J., & Cuzzi, J. N. (2006) *Icarus*,181,178 [8] Kalyaan, A. et al. (2015) ApJ, 815, 112

Author(s): Anusha Kalyaan[1], Steven Desch[1]
Institution(s): *1. Arizona State University*

320.06 – HST/WFC3 Imaging and Multi-Wavelength Characterization of Edge-On Protoplanetary Disks

Edge-on views of protoplanetary disk systems provide a unique observing opportunity to assess the vertical dust structure of the disk, an opportunity that is not possible at any other viewing angle due to projection effects and the acute brightness of the central star. Comparing high-resolution scattered light images of edge-on disks with synthetic images from radiative transfer modeling is a powerful approach to constrain the disk mass, structure and dust content, although analyses based on single-wavelength images lead to ambiguous conclusions. In order to resolve these ambiguities, and to probe the most tenuous regions at high elevation above the disk midplane, it is critical to obtain high-resolution images of such objects at the shortest possible wavelengths, where dust opacity is maximized. In this contribution, we present new WFC3 F475W Hubble Space Telescope images of 6 known edge-on protoplanetary disks. We produced color maps across the visible band to identify and characterize wavelength-dependent properties of these disks. In turn, these allow us to differentiate features that are related to the dust properties (opacity, scattering phase function) from those tracing the physical structure of the disk (in particular its vertical density profile). By probing a diverse set of disks with a uniform approach, we will be able to probe possible signs of evolution in this critical stage of planet formation.

Author(s): Carolina Gould[5], Gaspard Duchene[5], Karl R. Stapelfeldt[3], Francois Menard[6], Deborah Padgett[2], Marshall D. Perrin[4], Christophe Pinte[6], Schuyler Wolff[1]
Institution(s): *1. Johns Hopkins University, 2. NASA GSFC, 3. NASA JPL, 4. STSCI, 5. UC Berkeley, 6. Universite de Grenoble Alpes*

320.07 – Experimentally Determined Binding Energies of Astrophysically Relevant Hydrocarbons

Small hydrocarbons represent an important organic reservoir in a variety of interstellar environments. Constraints on desorption temperatures and binding energies of hydrocarbons are thus necessary for accurate predictions of where and in which phase these molecules exist. Through a series of temperature programmed desorption experiments, we determined the desorption temperatures and binding energies of 1, 2, and 3-carbon interstellar hydrocarbons (CH_4, H_3CCH_3, H_2CCH_2, C_3H_8, $HCCCH_3$, and C_3H_6). These empirically determined values can be used to inform observations and models of the molecular spatial distribution in protoplanetary disks, thus providing insight into planetesimal composition. In addition, knowledge of hydrocarbon binding energies will refine simulations of grain surface chemistry, allowing for better predictions of the chemical conditions that lead to the production of complex organic molecules vital for life.

Author(s): Aida Behmard[1], Dawn Graninger[1], Karin I. Oberg[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics*

400 – AGN, QSOs, and Blazars

400.01 – AGN identification and host galaxies properties in the MOSDEF survey

We present new results on the identification and host galaxy properties of X-ray, IR and optically-selected AGN at 1.4 < z < 3.8, using spectroscopic data from the on-going MOSDEF survey, which is obtaining rest-frame optical spectra of ~1,500 galaxies and AGN using the new Keck/MOSFIRE instrument. We find clear selection effects when identifying AGN at different wavelengths, in that optically-selected AGN are more likely to be found in galaxies with low SFR, while IR AGN are typically found in galaxies with higher SFR. There is also a bias against finding AGN at any wavelength in low mass galaxies. We find that optical AGN selection identifies less powerful AGN that may be obscured at other wavelengths. Combining the AGN we identify at different wavelengths, we find that AGN host galaxies have similar stellar age and dust content as inactive galaxies of the same stellar mass. Finally, we do not find a significant correlation between either SFR or stellar mass and $L_{[OIII]}$, which argues against the presence of strong AGN feedback.

Author(s): Mojegan Azadi[1], Alison L. Coil[1]
Institution(s): *1. University of California, San Diego*
Contributing team(s): The MOSDEF team

400.02 – QUART: Quasar hosts Unveiled by high Angular Resolution Techniques

We present results from the new QUART survey that aims to resolve high-redshift (z = 1.5 - 2.5) radio-quiet and radio-loud quasi stellar object (QSO) host galaxies using the integral field spectrograph (IFS) OSIRIS, and the Keck Adaptive Optics (AO) system. The combination of AO and IFS provides the necessary contrast to disentangle the bright-unresolved QSO from the underlying faint host galaxy with unprecedented sensitivity. We study the ionized gas in these systems to sub-kiloparsec scales, yielding essential constraints on the resolved host galaxies dynamics, morphologies, star formation rates, metallicities, and nebular emission diagnostics. We combine OSIRIS and AO observations with multi-wavelength data sets from Atacama Large Millimeter/submillimeter Array, Hubble Space Telescope, and Very Large Array to better understand the multiple phases of the ISM and stellar population properties of the hosts. Radio-quiet QSOs have shown little-to-no star formation and no evidence of extended QSO narrow line emission. In contrast, our latest OSIRIS results of radio-loud z~1.5-2 quasars have revealed evidence for both concurrent star formation and extended quasar narrow line emission with strong outflows. These outflows are co-spatial with structure observed in the radio data, typically with the path of the quasar jet and/or lobe structure. These winds are highly extended (8-12 kpc) and show broad emission line profiles (extending up to 2,500 km/s), indicating strong evidence of quasar "feedback" in their host galaxies.

Author(s): Andrey Vayner[3], Shelley Wright[3], Norman W. Murray[4], Lee Armus[1], James E. Larkin[2]
Institution(s): *1. IPAC, 2. University of California, Los Angeles, 3. University of California, San Diego, 4. University of Toronto*

400.03 – The Merger-Free Co-Evolution of Galaxies and Supermassive Black Holes

Calm, "secular" accretion and evolutionary processes, once thought to be relegated to the sidelines of galaxy evolution, are now understood to play a significant role in the buildup of stellar mass in galaxies. Most galaxies are formed and evolve via a mix of secular-driven evolution and more violent processes like strong disk instabilities and galaxy mergers; this makes isolating the effects of secular evolution in galaxies very difficult. Massive pure disk galaxies, lacking the classical or "pseudo" bulge components that arise naturally from mergers and disk instabilities (respectively), are a unique opportunity to study galaxy evolution in the absence of violent processes. Previous studies have disagreed on whether the black hole-galaxy mass correlation is driven by galaxy-galaxy interactions or something more fundamental. Here we present new evidence using a statistically significant sample of AGN hosted in bulgeless disk galaxies at $z < 0.2$ to constrain black hole-galaxy co-evolution in the absence of mergers.

Author(s): Brooke Simmons[1], Rebecca Jane Smethurst[2], Chris Lintott[2]
Institution(s): *1. UC San Diego, 2. University of Oxford*
Contributing team(s): the Galaxy Zoo Team

400.04 – Studying the Role of Mergers in Black Hole - Galaxy Co-evolution via a Morphological Analysis of Redshift 1 Galaxies

We study the role of mergers in the quenching of star formation in galaxies at the dominant epoch of their evolution, by examining their color-mass distributions for different morphology types. We use HST ACS data from the CANDELS/GOODS North and South fields for galaxies in the redshift range $0.7 < z < 1.3$ and use GALFIT to fit them with sersic profiles, enabling us to classify each as bulge-dominated (early type) or disk-dominated (late type). We find that spirals and ellipticals have distinct color-mass distributions, similar to studies at z=0, in that each have quenching modes of differing time scales. The smooth decay to the red sequence for the disky galaxies corresponds to a slow exhaustion of gas, while the lack of elliptical galaxies in the `green valley' indicates a faster quenching time for galaxies that underwent a major merger. We compare the inactive galaxies to the AGN hosts and find that the AGN phase lasts well into the red sequence for both types of host galaxy, spanning the full color space. The results suggest that the AGN trigger mechanism, as well as the significance of AGN feedback, is dependent on the merger history of the host galaxy.

Author(s): Meredith Powell[1], C. Megan Urry[1]
Institution(s): *1. Yale University*

400.05 – Further Rehabilitating CIV-based Black Hole Mass Estimates in Quasars

Virial black hole masses are routinely estimated for high-redshift quasars using the C IV lambda 1549 emission line using single-epoch spectra that provide a gas velocity and a continuum luminosity. Such masses are very uncertain, however, especially because C IV likely possesses a non-virial component that varies with the Eddington ratio. We have previously used the 1400 feature, a blend of S i IV and O IV] emission that does not suffer the problems of C IV, to rehabilitate C IV-based mases by providing a correction term. The C IV profile itself, however, provides enough information to correct the black hole masses and remove the effects of the non-virial component. We use Mg II-based black hole masses to calibrate and test a new C IV-based black hole mass formula using only C IV and continuum measurements superior to existing formulations, as well as to test for additional dependencies on luminosity.

Author(s): Michael S. Brotherton[2], Jessie C. Runnoe[1], Zhaohui Shang[2], Melinda Varju[2]
Institution(s): *1. Penn State, 2. Univ. of Wyoming*

400.06 – First X-ray Statistical Tests for Clumpy-Torus Models: Constraints from RXTE monitoring of Seyfert AGN

In two papers (Markowitz, Krumpe, & Nikutta 2014, and Nikutta et al., in prep.), we derive the first X-ray statistical constraints for clumpy-torus models in Seyfert AGN by quantifying multi-timescale variability in line of-sight X-ray absorbing gas as a function of optical classification.

We systematically search for discrete absorption events in the vast archive of RXTE monitoring of 55 nearby type Is and Compton-thin type IIs. We are sensitive to discrete absorption events due to clouds of full-covering, neutral/mildly ionized gas transiting the line of sight. Our results apply to both dusty and non-dusty clumpy media, and probe model parameter space complementary to that for eclipses observed with XMM-Newton, Suzaku, and Chandra.

We detect twelve eclipse events in eight Seyferts, roughly tripling the number previously published from this archive. Event durations span hours to years. Most of our detected clouds are Compton-thin, and most clouds' distances from the black hole are inferred to be commensurate with the outer portions of the BLR or the inner regions of infrared-emitting dusty tori.

We present the density profiles of the highest-quality eclipse events; the column density profile for an eclipsing cloud in NGC 3783 is doubly spiked, possibly indicating a cloud that is being tidally sheared.

We discuss implications for cloud distributions in the context of clumpy-torus models. We calculate eclipse probabilities for orientation-dependent Type I/II unification schemes.

We present constraints on cloud sizes, stability, and radial distribution. We infer that clouds' small angular sizes as seen from the SMBH imply 107 clouds required across the BLR + torus. Cloud size is roughly proportional to distance from the black hole, hinting at the formation processes (e.g., disk fragmentation). All observed clouds are sub-critical with respect to tidal disruption; self-gravity alone cannot contain them. External forces, such as magnetic fields or ambient pressure, are needed to contain them; otherwise, clouds must be short-lived.

Author(s): Alex Markowitz3, Mirko Krumpe[1], R. Nikutta[2]
Institution(s): *1. Leibniz Institute for Astrophysics Potsdam, 2. Pontifica Universidad Catolica de Chile, 3. UC, San Diego*

400.07 – Evidence for the Thermal Sunyaev-Zel'dovich Effect Associated with Quasar Feedback

Using a radio-quiet subsample of the Sloan Digital Sky Survey spectroscopic quasar catalog, spanning redshifts 0.5–3.5, we derive the mean millimetre and far-infrared quasar spectral energy distributions (SEDs) via a stacking analysis of Atacama Cosmology Telescope and *Herschel*-SPIRE data. We constrain the form of the far-infrared emission and find 3–4σ evidence for the thermal Sunyaev-Zel'dovich (SZ) effect, characteristic of a hot ionized gas component with thermal energy $(6.2 \pm 1.7) \times 10^{60}$ erg. This amount of thermal energy is greater than expected assuming only hot gas in virial equilibrium with the dark matter haloes of $(1-5) \times 10^{12} h^{-1} M_{\odot}$ that these systems are expected to occupy. Modeling this signal as energy injection due to quasar feedback, our measurements are found to be consistent with a scenario in which quasars deposit up to $(14.5 \pm 3.3)\ \tau_8^{-1}$ per cent of their radiative energy into their circumgalactic environment if their typical period of quasar activity is $\tau_8 \times 10^8$ years.

Author(s): Devin T Crichton[1], Megan B. Gralla[2], Kirsten Hall[1], Tobias Marriage[1], Nadia L. Zakamska[1]
Institution(s): *1. Johns Hopkins University, 2. University of Arizona*
Contributing team(s): The Atacama Cosmology Telescope Collaboration

400.08 – Obscuring Torus Geometry from the NuSTAR Survey of Swift/BAT AGN

The Nuclear Spectroscopic Telescope Array (NuSTAR) has enabled studies of the local active galactic nuclei (AGN) to extend into the spectral window above 10 keV with unprecedented spatial resolution and two orders of magnitude better sensitivity than any other instrument operating in that energy range. As a part of its long-term extragalactic program NuSTAR is surveying the nearby population of AGN detected at hard X-ray energies by the Swift Burst Alert Telescope (Swift/BAT). I will present spectroscopic results based on NuSTAR and Swift observations of ~150 Swift/BAT AGN surveyed in the first three years of NuSTAR operation. This sample forms an atlas of the highest quality hard X-ray spectra available to date for a large number of AGN, providing unprecedented insight into the variety AGN spectra in the hard X-ray band. In addition to phenomenology, which is an essential ingredient of Cosmic X-ray Background studies, it is possible to use new fitting models to directly probe the geometry of the toroidal obscurer (torus). Its main spectral features lie within the NuSTAR bandpass, making it possible to test the common assumption that a similar Compton-thick torus exists around essentially every Seyfert-type AGN. I will discuss torus geometry constraints based on the X-ray spectra in relation to those from other wavelengths, the effects on interpretation of high-redshift AGN observations, and the limitations of the current results.

Author(s): Mislav Balokovic[1], Fiona Harrison[1]
Institution(s): *1. California Institute of Technology*
Contributing team(s): NuSTAR

400.09 – Photometric Redshifts for the Large-Area Stripe 82X Multiwavelength Survey

The Stripe 82X survey currently includes 6000 X-ray sources in 31.3 square degrees of XMM-Newton and Chandra X-ray coverage, most of which are AGN. Using a maximum-likelihood approach, we identified optical and infrared counterparts in the SDSS, VHS K-band and WISE W1-band catalogs. 1200 objects which had different best associations in different catalogs were checked by eye. Our most recent paper provided the multiwavelength catalogs for this sample. More than 1000 counterparts have spectroscopic redshifts, either from SDSS spectroscopy or our own follow-up program. Using the extensive multiwavelength data in this field, we provide photometric redshift estimates for most of the remaining sources, which are 80-90% accurate according to the training set. Our sample has a large number of candidates that are very faint in optical and bright in IR. We expect a large fraction of these objects to be the obscured AGN sample we need to complete the census on black hole growth at a range of redshifts.

Author(s): Tonima Tasnim Ananna[3], Mara Salvato[1], C. Megan Urry[3], Stephanie M. LaMassa[2]
Institution(s): *1. Max Planck Institute for extraterrestrial Physics, 2. NASA GSFC, 3. Yale University*
Contributing team(s): STRIPE 82X

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401 – Extrasolar Planets: Detection

401.01 – NRES: The Network of Robotic Echelle Spectrographs

Las Cumbres Observatory Global Network (LCOGT) is building the Network of Robotic Echelle Spectrographs (NRES), which will consist of six identical, optical (390 - 860 nm) high-precision spectrographs, each fiber-fed simultaneously by up to two 1-meter telescopes and a thorium argon calibration source. We plan to install one at up to 6 observatory sites in the Northern and Southern hemispheres, creating a single, globally-distributed, autonomous spectrograph facility using up to twelve 1-m telescopes. Simulations suggest we will achieve long-term radial velocity precision of 3 m/s in less than an hour for stars brighter than V = 12. We have been funded with NSF MRI and ATI grants, and expect to deploy the first spectrograph in fall 2016, with the full network operation of 5 or 6 units beginning in 2017. We will briefly overview the NRES design, goals, robotic operation, and status. In addition, we will discuss early results from our prototype spectrograph, the laboratory and on-sky performance of our first production unit, initial science results, and the ongoing software development effort to bring this resource online.

Author(s): Robert Siverd[2], Timothy M. Brown[2], Todd Henderson[2], John Hygelund[2], Joseph Tufts[2], Jason Eastman[1], Stuart Barnes[4], Julian C. Van Eyken[3]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. Las Cumbres Observatory, 3. NExSci, Caltech, 4. Stuart Barnes Optical Design*

401.02 – A Large Hubble Space Telescope Survey of Low-Mass Exoplanets

The discovery of short-period planets with masses and radii between Earth and Neptune was one of the biggest surprises in the brief history of exoplanet science. From the Kepler mission, we now know that these “super-Earths” or "sub-Neptunes" orbit at least 40% of stars, likely representing the most common outcome of planet formation. Despite this ubiquity, we know little about their typical compositions and formation histories. Spectroscopic transit observations combined with powerful atmospheric retrieval tools can shed new light on these mysterious worlds. In this talk, we will present the main results from our 124-orbit Hubble Space Telescope survey to reveal the chemical diversity and formation histories of super-Earths. This unprecedented HST survey provides the first comprehensive look at this intriguing new class of planets ranging from 1 Neptune mass and temperatures close to 2000K to a 1 Earth mass planet near the habitable zone of its host star.

Author(s): Björn Benneke[1], Ian Crossfield[5], Heather Knutson[1], Joshua Lothringer[5], Diana Dragomir[6], Jonathan J. Fortney[4], Andrew Howard[3], Peter R. McCullough[7], Eliza Kempton[2], Caroline Morley[4]
Institution(s): *1. Caltech, 2. Grinell College, 3. IfA Hawaii, 4. UCSC, 5. University of Arizona, 6. University of Chicago, 7. University of Maryland*

401.03 – Blind extraction of exoplanetary spectra

In the last decade, remote sensing spectroscopy enabled characterization of the atmospheres of extrasolar planets. Transmission and emission spectra of tens of transiting exoplanets have been measured with multiple instruments aboard Spitzer and Hubble Space Telescopes as well as ground-based facilities, revealing the presence of atomic, ionic and molecular species in their atmospheres, and constraining their temperature and pressure profiles.
Early analyses were somehow heuristic both in measuring the spectra and in their interpretation, leading to some controversies in the literature.
A photometric precision of 0.01% is necessary to detect the atmospheric spectral modulations. Current observatories, except Kepler, were not designed to achieve this precision. Data reduction is necessary to minimize the effect of instrument systematics in order to achieve the target precision. In the past, parametric models have extensively been used by most teams to remove correlated noise with the aid of auxiliary information of the instrument, the so-called optical state vectors (OSVs). Such OSVs can include inter- and intra-pixel position of the star or its spectrum, instrument temperatures and inclinations, and/or other parameters. In some cases, different parameterizations led to discrepant results.
We recommend the use of blind non-parametric data detrending techniques to overcome those issues. In particular, we adopt Independent Component Analysis (ICA), i.e. a blind source separation (BSS) technique to disentangle the multiple instrument systematics and astrophysical signals in transit/eclipse light curves. ICA does not require a model for the systematics, and for this reason, it can be applied to any instrument with little changes, if any.
ICA-based algorithms have been applied to Spitzer/IRAC and synthetic observations in photometry (Morello et al. 2014, 2015, 2016; Morello 2015) and to Hubble/NICMOS and Spitzer/IRS in spectroscopy (Waldmann 2012, 2014, Waldmann et al. 2013) with excellent results. In this conference, I will illustrate the detrending algorithms optimized to specific instruments and the results obtained over different observations, in addition the already published ones.

Author(s): Giuseppe Morello[1], Ingo P. Waldmann[1], Giovanna Tinetti[1]
Institution(s): *1. UCL*

401.04 – Results of the 2015 *Spitzer* Exoplanet Data Challenge: Repeatability and Accuracy of Exoplanet Eclipse Depths

We examine the repeatability, reliability, and accuracy of differential exoplanet eclipse depth measurements made using the InfraRed Array Camera (IRAC) on the *Spitzer* Space Telescope during the post-cryogenic mission. At infrared wavelengths secondary eclipses and phase curves are powerful tools for studying a planet’s atmosphere. Extracting information about atmospheres, however, is extremely challenging due to the small differential signals, which are often at the level of 100 parts per million (ppm) or smaller, and require the removal of significant instrumental systematics. For the IRAC 3.6 and 4.5μm InSb detectors that remain active on post-cryogenic *Spitzer*, the interplay of residual telescope pointing fluctuations with intrapixel gain variations in the moderately under sampled camera is the largest source of time-correlated noise. Over the past decade, a suite of techniques for removing this noise from IRAC data has been developed independently by various investigators. In summer 2015, the *Spitzer* Science Center hosted a Data Challenge in which seven exoplanet expert teams, each using a different noise-removal method, were invited to analyze 10 eclipse measurements of the hot Jupiter XO-3 b, as well as a complementary set of 10 simulated measurements. In this contribution we review the results of the Challenge. We describe statistical tools to assess the repeatability, reliability, and validity of data reduction techniques, and to compare and (perhaps) choose between techniques.

Author(s): James G. Ingalls[1], Jessica E Krick[1], Sean J. Carey[1], John R. Stauffer[1], Carl J. Grillmair[1], Patrick Lowrance[1]
Institution(s): *1. Spitzer Science Center / Caltech*

401.05 – Finding False Positives Planet Candidates Due To Background Eclipsing Binaries in K2

We adapt the difference image centroid approach, used for finding background eclipsing binaries, to vet K2 planet candidates. Difference image centroids were used with great success to vet planet candidates in the original Kepler mission, where the source of a transit could be identified by subtracting images of out-of-transit cadences from in-transit cadences. To account for K2's roll pattern, we reconstruct out-of-transit images from cadences that are nearby in both time and spacecraft roll angle. We describe the method and discuss some K2 planet candidates which this method suggests are false positives.

Author(s): Fergal Mullally[1], Susan E. Thompson[1], Jeffrey Coughlin[1]
Institution(s): *1. Kepler Science Office*
Contributing team(s): The DAVE team

401.06 – Validating An Analytic Completeness Model for Kepler Target Stars Based on Flux-level Transit Injection Experiments

The Kepler Mission is developing an Analytic Completeness Model (ACM) to estimate detection completeness contours as a function of exoplanet radius and period for each target star. Accurate completeness contours are necessary for robust estimation of exoplanet occurrence rates.

The main components of the ACM for a target star are: detection efficiency as a function of SNR, the window function (WF) and the one-sigma depth function (OSDF). (Ref. Burke et al. 2015). The WF captures the falloff in transit detection probability at long periods that is determined by the observation window (the duration over which the target star has been observed). The OSDF is the transit depth (in parts per million) that yields SNR of unity for the full transit train. It is a function of period, and accounts for the time-varying properties of the noise and for missing or deweighted data.

We are performing flux-level transit injection (FLTI) experiments on selected Kepler target stars with the goal of refining and validating the ACM. “Flux-level” injection machinery inserts exoplanet transit signatures directly into the flux time series, as opposed to “pixel-level” injection, which inserts transit signatures into the individual pixels using the pixel response function. See Jie Li's poster: ID #2493668, "Flux-level transit injection experiments with the NASA Pleiades Supercomputer" for details, including performance statistics.

Since FLTI is affordable for only a small subset of the Kepler targets, the ACM is designed to apply to most Kepler target stars. We validate this model using “deep” FLTI experiments, with ~500,000 injection realizations on each of a small number of targets and “shallow” FLTI experiments with ~2000 injection realizations on each of many targets. From the results of these experiments, we identify anomalous targets, model their behavior and refine the ACM accordingly.

In this presentation, we discuss progress in validating and refining the ACM, and we compare our detection efficiency curves with those derived from the associated pixel-level transit injection experiments.

Kepler was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA, Science Mission Directorate.

Author(s): Joseph Catanzarite4, Christopher J. Burke4, Jie Li4, Shawn Seader3, Michael R Haas[2], Natalie Batalha[2], Christopher Henze[2], Jessie Christiansen[1]
Institution(s): *1. California Institute of Technology, 2. NASA AMES Research Center, 3. Raytheon, 4. SETI Institute*
Contributing team(s): Kepler Project, NASA Advanced Supercomputing Division

401.07 – Creating Kepler's Final KOI Catalog while Balancing Completeness and Reliability

We report on the Kepler Mission's plan to create the final planetary candidate catalog (Data Release 25 KOI catalog), which will be fully automated and uniformly vetted. This catalog is based on evaluating the periodic events reported in the DR25 TCE table (Twicken et al. 2016) available at the NASA exoplanet archive. As with the previous KOI catalog (DR24) the intent is to prioritize uniformity and completeness over obtaining 100% accuracy. In this way, the completeness and the reliability of the KOI table can be measured so that exoplanet occurrence rates can easily be calculated. We use, and improve upon, the DR24 rule-based vetter (Robovetter, Coughlin et al. 2016) to create the final dispositions in the catalog. As done before, the Robovetter's decisions will be tested against injected transits to show that true transit-like signatures are retained. Additionally, the Robovetter will be tested against TCEs found in inverted light curves as a way of showing that the Robovetter is effectively removing false alarms. We will discuss our current methods, any obstacles in our path, and the timeline for delvering Kepler's final planet candidate catalog.

Author(s): Susan E. Thompson3, Jeffrey L Coughlin[2], Fergal R Mullally3, Jessie Christiansen[1], Christopher J. Burke3
Institution(s): *1. NexScI, 2. SETI Institute, 3. SETI Institute/NASA Ames*
Contributing team(s): The Kepler Team

401.08 – Taking the Galactic Exoplanet Census with K2

The NASA Kepler mission was designed and executed with the goal of measuring planet occurrence rates. The stellar sample, the science pipeline, and the planet candidate sample have all been chosen and characterised with an eye to generating uniform, robust statistical measurements. The subsequent K2 mission, however, has been much more open to all science goals, and subsequently the target selection, planet candidate generation and catalogue assembly have been substantially more ad hoc. Here we discuss the pathway forward to using the Galactic latitude coverage of K2 to begin the Galactic exoplanet census that will be continued by the NASA TESS mission.

Author(s): Jessie Christiansen[1]
Institution(s): *1. NASA Exoplanet Science Institute/Caltech*
Contributing team(s): CHAI (California/Hawaii/Arizona /Indiana) K2 Follow-up Consortium

402 – Blacks Holes and Supernovae

402.01 – Shocking Results About Exploding Stars

Early light curves of supernovae are dominated by the emission of surface material that has been heated and ejected by the supernova shock. Studying this shock cooling can provide unique constraints on the radius of the progenitor, which is important for comparisons to stellar modeling, populations of massive stars, and pre-explosion imaging. Here I summarize both numerical and semi-analytic work to model this phase and apply it to current and future observations. I discuss a wide range of events, from the fairly common Type IIP supernovae to the exotic Type I superluminous supernovae for which their exact progenitors are still elusive.

Author(s): Anthony Piro[1]
Institution(s): *1. Carnegie Observatories*

402.02 – Modeling Type IIn Supernovae: Understanding How Shock Development Effects Light Curves Properties

Type IIn supernovae are produced when massive stars experience dramatic mass loss phases caused by opacity edges or violent explosions. Violent mass ejections occur quite often just prior to the collapse of the star. If the final episode happens just before collapse, the outward ejecta is sufficiently dense to alter the supernova light-curve, both by absorbing the initial supernova light and producing emission when the supernova shock hits the ejecta. Initially, the ejecta is driven by shock progating through the interior of the star, and eventually expands through the circumstellar medium, forming a cold dense shell. As the shock wave approaches the shell, there is an increase in UV and optical radiation at the location of the shock breakout. We have developed a suite of simple semi-analytical models in order to understand the relationship between our observations and the properties of the expanding SN ejecta. When we compare Type IIn observations to a set of modeled SNe, we begin to see the influence of initial explosion conditions on early UV light curve properties such as peak luminosities and decay rate.
The fast rise and decay corresponds to the models representing a photosphere moving through the envelope, while the modeled light curves with a slower rise and decay rate are powered by 56Ni decay. However, in both of these cases, models that matched the luminosity were unable to match the low radii from the blackbody models. The effect of shock heating as the supernova material blasts through the circumstellar material can drastically alter the temperature and position of the photosphere. The new set of models redefine the initial modeling conditions to incorporate an outer shell-like structure, and include late-time shock heating from shocks produced as the supernova ejecta travels through the inhomogeneous circumstellar medium.

Author(s): Janie De La Rosa[1]
Institution(s): *1. University of Texas San Antonio*

402.03 – On The Explosion Geometry of Red Supergiant Stars

From progenitor studies, type II-Plateau supernovae (SNe II-P) have been decisively and uniquely determined to arise from isolated red supergiant (RSG) stars, establishing the most homogeneous --- and well understood --- progenitor class of any type of core-collapse supernova. The physical process by which these stars explode, however, remains a mystery. A fundamental clue to the nature of the explosion mechanism is explosion geometry: In short, are supernovae round? Because young supernova atmospheres are electron-scattering dominated, their net linear polarization provides a direct probe of early-time supernova geometry, with higher degrees of polarization generally indicating greater departures from spherical symmetry. This presentation will describe the ongoing work being carried out on RSG explosion geometry by the SuperNova SpectroPOLarimetry project (SNSPOL), with a particular focus on SN 2013ej -- an SN II-P that exhibited remarkably high polarization just days after the explosion, and for which twelve epochs of spectropolarimetry trace an intriguing tale about its geometry deep into the nebular phase.

We acknowledge support from NSF grants AST-1009571 and AST-1210311, under which part of this research was carried out.

Author(s): Douglas C. Leonard[1]
Institution(s): *1. San Diego State University*
Contributing team(s): The Supernova Spectropolarimetry Project (SNSPOL)

402.05 – Searching for intermediate-mass black holes with gravitational microlensing

Despite a lot of indirect observational evidence, no intermediate-mass black hole (IMBH) has been detected unambiguously so far. A clear detection would shed light on the possible role of IMBHs in the formation of supermassive black holes, and on the evolution of Galaxies. This could be achieved with gravitational microlensing. We present the results of simulations to estimate the expected astrometric microlensing rates by IMBHs in globular clusters, and show that microlensing has the potential to detect signals that can be unambiguously attributed to an IMBH in several Galactic globular clusters. We also discuss the implication of our simulations for archival studies with available Hubble Space Telescope data, and the impact of JWST and WFIRST on possible future detections.

Author(s): Noé Kains3, Dan Bramich[2], Kailash C. Sahu3, Annalisa Calamida[1]
Institution(s): *1. NOAO, 2. Qatar Environment and Energy Research Institute, 3. Space Telescope Science Institute*

402.06 – A "high-hard" outburst of the black hole X-ray binary GS 1354-64

In the shadows of the V404 Cyg outburst in the summer of 2015, GS 1354-64 (BW Cir) went into outburst as well. We followed the evolution of the outburst at optical, UV and X-ray wavelengths using Faulkes Telescope South, SMARTS and Swift. The outburst was found to stay in the hard X-ray state, albeit being anomalously luminous with a peak X-ray luminosity exceeding 0.15 L_{Edd}, which could be the most luminous hard state observed in a black hole X-ray binary. In this talk I will present our results showing that the the outburst evolution at all wavelengths can be explained by the disk instability model with irradiation and disk evaporation/condensation. In addition, I will present our long-term optical monitoring results that show a statistically significant, slow rise of the source brightness over the 7 years prior to the 2015 outburst. This could be the much-sought observational evidence of matter slowly accumulating in the accretion disk, and subsequently getting optically brighter, as predicted by the disk instability model.

Author(s): Karri Koljonen3, David Russell3, Jesus Corral-Santana4, Montserrat Armas Padilla[1], Teo Munoz-Darias[1], Fraser Lewis[2]
Institution(s): *1. Instituto de Astrofisica de Canarias, 2. Liverpool John Moores University, 3. New York University Abu Dhabi, 4. Pontificia Universidad Catolica de Chile*

402.07 – A Chandra Observation of the Luminous Northeastern Rim of the Galactic Supernova Remnant W28 (G6.4-0.1)

We present an analysis of a pointed observation made of the luminous northeastern rim of the Galactic supernova remnant (SNR) W28 (G6.4-0.1) with the *Chandra* X-ray Observatory. W28 is the archetype for the class of SNRs known as the mixed-morphology SNRs: sources in this class of objects feature a shell-like morphology with a contrasting center-filled X-ray morphology. Almost unique amongst mixed-morphology SNRs, W28 exhibits a luminous northeastern rim which is detected in the X-ray, optical and radio: this rim is also the site of a vigorous interaction between W28 and adjacent molecular clouds, as evidenced by the high concentration of hydroxyl (OH) masers seen at this rim. Our pointed *Chandra* observation of this rim is the highest angular X-ray observation made of this feature: initial analysis and results will be presented and discussed.

Author(s): Thomas Pannuti[1]
Institution(s): *1. Morehead State University*

402.08 – A fundamental plane for Gamma Ray Bursts with X-Ray plateaus

A class of long Gamma-ray bursts (GRBs) presenting light curves with an extended plateau phase in their X-ray afterglows obey a two parameter correlation (Dainotti et al. 2008) between
the rest frame end time of the plateau, T_a, and its corresponding X-ray luminosity, L_{a}. This correlation is a useful tool towards cosmological parameter inferences and yields important constraints on physical GRB models.
We here show through an analysis of 122 {\it Swift} long GRBs with known redshifts and presenting
afterglow plateaus, that including also the peak luminosity in the

prompt emission, L_{peak}, as a third parameter, a fundamental plane appears.
A careful statistical analysis excludes the possibility of this correlation being due to detection thresholds or observational selection biases. The correlation is tightest when a class-specific GRB sample is defined excluding GRB-SNe, X-ray flashes and short GRBs with extended emission, and required also to have a good data coverage and an almost flat plateau. The intrinsic scatter, $\sigma_{int}=0.27 \pm 0.04$, for the three-parameter correlation for this specific subclass (40 GRBs) is 53.5% smaller than the (L_{a}, T_a) one,
making this the tighest three parameter correlation involving the plateau phase. This result will hence enhance cosmological parameter determinations and GRB model constraints. Finally, we also show that a slightly noisier correlation is also present between L_{peak} and a proxy of the total energy emitted during the plateau phase, the product $L_{a}T_{a}$, hinting at the presence of an energy scaling between prompt and afterglow phases.

Author(s): Maria Dainotti[1]
Institution(s): *1. Stanford University*
Contributing team(s): Vahe' Petrosian, Sergey Postnikov, Xavier Hernandez, Michal Ostrowski

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403 – Cosmology and CMB

403.01 – Foreground-induced biases in CMB polarimeter self-calibration

Precise polarization measurements of the cosmic microwave background (CMB) require accurate knowledge of the instrument orientation relative to the sky frame used to define the cosmological Stokes parameters. Suitable celestial calibration sources that could be used to measure the polarimeter orientation angle are limited, so current experiments commonly `self-calibrate.' The self-calibration method exploits the theoretical fact that the EB and TB cross-spectra of the CMB vanish in the standard cosmological model, so any detected EB and TB signals must be due to systematic errors. However, this assumption neglects the fact that polarized Galactic foregrounds in a given portion of the sky may have non-zero EB and TB cross-spectra. If these foreground signals remain in the observations, then they will bias the self-calibrated telescope polarization angle and produce a spurious B-mode signal. In this paper, we estimate the foreground-induced bias for various instrument configurations and then expand the self-calibration formalism to account for polarized foreground signals. Assuming the EB correlation signal for dust is in the range constrained by angular power spectrum measurements from Planck at 353 GHz (scaled down to 150 GHz), then the bias is negligible for high angular resolution experiments, which have access to CMB-dominated high 'ell' modes with which to self-calibrate. Low-resolution experiments observing particularly dusty sky patches can have a bias as large as 0.5°. A miscalibration of this magnitude generates a spurious BB signal corresponding to a tensor-to-scalar ratio of approximately r ~ 2×10^{-3}, within the targeted range of planned experiments.

Author(s): Maximilian H Abitbol[1], James Hill[1], Bradley Johnson[1]
Institution(s): *1. Columbia University*

403.02 – Tests of Cosmological Inhomogeneity Using WMAP

This paper reports on the latest results obtained from studies of the calibrated Time-Ordered Data of the Wilkinson Microwave Anisotropy Probe (9-yr) mission that has in the past been used to determine the anisotropy of the Cosmic Microwave Background Radiation, although with a novel objective. The purpose of this work has been to examine what can be inferred from these data about the local inhomogeneity of the CMBR, which would be in this case an apparent radial variation of the brightness (or effective temperature) at the same point of the celestial sky as seen by the WMAP spacecraft instruments from the center of observation, namely the Sun. The usual studies of anisotropy normally have averaged the observed temperature of any given point on the celestial sky over one full annual orbit of the WMAP spacecraft around the Sun to produce the well-known maps. Inhomogeneity of the kind being sought here, however, would manifest itself as a systematic variation of the apparent temperature at that point as a function of the orbital position of the spacecraft. The detection of such inhomogeneity, if it could be confirmed by subsequent observations, could significantly impact the standard cosmological paradigm. The computational approach used thus far in that search, over the last four years of study by supercomputer facilities at UCSD, has been to examine the differences of temperature seen of the same points on the sky, taken in pairs corresponding to the pointing directions of the A and B radiometer horns of the instrument, from different orbital positions of the spacecraft. From those observed differences of temperature and the corresponding angular separations of the respective orbital positions — here limited to values greater than or equal to 44 degrees out of a maximum available range of 1 – 45 degrees — an apparent radial gradient of temperature could be computed with lowest uncertainties. A small but significant gradient of temperature tentatively has been found, and plans are under way for the testing and confirmation of these findings by using the latest data from the more recent ESA Planck spacecraft archive.

Author(s): Richard Shubert[1], Mahidhar Tatineni[2]
Institution(s): *1. Institute for Fundamental Sciences, 2. San Diego Supercomputer Center*

403.03 – Constraints from Cosmological Data on Expansion and Growth of Structure Observables in a Macroscopic Gravity Averaged Universe

We report recent results from investigating the effect of averaging inhomogeneities on cosmological distances and large-scale structure growth observables using the exact and covariant framework of Macroscopic Gravity (MG) averaging. For the MG formalism applied to the Friedmann-Lemaitre-Robertson-Walker (FLRW) metric, this gives an extra dynamical term encapsulated as an averaging density parameter denoted Ω_A. We analyze constraints on this parameter and its correlations with other cosmological parameters from using the CMB (Planck), distances to supernovae, Baryon Acoustic Oscillations, Hubble constant measurements, and the CFHTLenS and other recent data. We compare the amplitude of this effect to other systematic effects considered for future high precision surveys.

Author(s): Mustapha B. Ishak-Boushaki[1], Tharake Wijenayake[1]
Institution(s): *1. Univ. Of Texas at Dallas*

403.04 – Weak Gravitational Lensing by Galaxy Troughs in the Dark Energy Survey

The Dark Energy Survey (DES) is in the process of imaging 5000 sq. deg. of the southern sky in five broad-band filters. Its primary purpose is to constrain cosmology and the physics of dark energy using weak gravitational lensing, galaxy clusters, baryonic acoustic oscillations, and supernova distance measurements.

I will give an overview of weak gravitational lensing results from early DES data, with a focus on the newly developed galaxy trough statistics. Using the latter, we have made the highest signal-to-noise lensing measurements of the low density Universe to date, probing gravity and structure formation in the underdense regime. Besides these recent results, I will give an outlook on cosmological and astrophysical applications of the trough lensing signal.

Author(s): Daniel Gruen[1]
Institution(s): *1. SLAC National Accelerator Laboratory*
Contributing team(s): The Dark Energy Survey Collaboration

403.05 – Testing Quantum Mechanics and Bell's Inequality with Astronomical Observations

We report on an in progress "Cosmic Bell" experiment that will leverage cosmology to test quantum mechanics and Bell's inequality using astronomical observations. Different iterations of our experiment will send polarization-entangled photons through the open air to detectors ~1-100 kilometers apart, whose settings would be rapidly chosen using real-time telescopic observations of Milky Way stars, and eventually distant, causally disconnected, cosmological sources - such as pairs of quasars or patches of the cosmic microwave background - all while the entangled pair is still in flight. This would, for the first time, attempt to fully close the so-called "setting independence" or "free will" loophole in experimental tests of Bell's inequality, whereby an alternative theory could mimic the quantum predictions if the experimental settings choices shared even a small correlation with unknown, local, causal influences a mere few milliseconds prior to the experiment. A full Cosmic Bell test would push any such influence all the way back to the hot big bang, since the end of any period of inflation, 13.8 billion years ago, an improvement of 20 orders of magnitude compared to the best previous experiments. Redshift z > 3.65 quasars observed at optical wavelengths are the optimal candidate source pairs using present technology. Our experiment is partially funded by the NSF INSPIRE program, in collaboration with MIT, UC San Diego, Harvey Mudd College, NASA/JPL/Caltech, and the University of Vienna. Such an experiment has implications for our understanding of nature at the deepest level. By testing quantum mechanics in a regime never before explored, we would at the very least extend our confidence in quantum theory, while at the same time severely constraining large classes of alternative theories. If the experiment were to uncover discrepancies from the quantum predictions, there could be crucial implications for early-universe cosmology, the security of quantum encryption, and even new theoretical physics, including quantum gravity.

Author(s): Andrew S. Friedman[2], David I Kaiser[2], Jason Gallicchio[1]
Institution(s): *1. Harvey Mudd College, 2. Massachussetts Institute of Technology*
Contributing team(s): Team 1: University of Vienna, Institute for Quantum Optics and Quantum Information, Team 2: UC San Diego Cosmology Group, Team 3: NASA/JPL/Caltech

403.06 – Cosmology of Universe Particles and Beyond

For the first time in history, all properties of cosmology particles are uncovered and described concisely and systematically, known as the elementary particles in contemporary physics.
Aligning with the synthesis of the virtual and physical worlds in a hierarchical taxonomy of the universe, this theory refines the topology framework of cosmology, and presents a new perspective of the Yin Yang natural laws that, through the processes of creation and reproduction, the fundamental elements generate an infinite series of circular objects and a Yin Yang duality of dynamic fields that are sequenced and transformed states of matter between the virtual and physical worlds.
Once virtual objects are transformed, they embody various enclaves of energy states, known as dark energy, quarks, leptons, bosons, protons, and neutrons, characterized by their incentive oscillations of timestate variables in a duality of virtual realities: energy and time, spin and charge, mass and space, symmetry and antisymmetry.
As a consequence, it derives the fully-scaled quantum properties of physical particles in accordance with numerous historical experiments, and has overcome the limitations of uncertainty principle and the Standard Model, towards concisely exploring physical nature and beyond...

Author(s): Wei Xu[1]
Institution(s): *1. Virtumanity*

403.07 – A New Theory of Time

I argue that time cannot pass at the same rate throughout the duration of the universe. Specifically, clocks ran more slowly in the early universe than they do today. We can reasonably ask: "How has time varied with respect to ***proper time*** over the life of the universe?" The current Big Bang model of the universe theorizes that the universe began with an infinitely small, hot, dense entity that expanded and cooled over time. In this model, the early universe was infinitely dense, and hence the gravitational field was infinitely strong. This means that clocks ran infinitely more slowly than clocks do today. The obvious question is: What is the relationship of clocks in the early universe with respect to our current clocks? The purpose of this paper is to propose a new theory that attempts to answer this question. This paper shows the theory to be consistent with: (1) Hubble's Law; (2) Gravitational Time Dilation; and (3) The so-called Pioneer Anomaly. A Time Transform pair is introduced that permits time in earlier epocs to be calculated with respect to time in the current epoc (i.e., proper time). Am experiment is proposed to verify the data obtained from the pioneer probe and this proposed theory of time.

Author(s): Leland Langston[1]
Institution(s): *1. Raytheon*

403.08 – Principle of Spacetime and Black Hole Equivalence

Modelling the universe without relying on a set of hypothetical entities (HEs) to explain observations and overcome problems and difficulties is essential to developing a physical cosmology. The well-known big bang cosmology, widely accepted as the standard model, stands on two fundamentals, which are Einstein's general relativity (GR) that describes the effect of matter on spacetime and the cosmological principle (CP) of spacetime isotropy and homogeneity. The field equation of GR along with the Friedmann-Lemaitre-Robertson-Walker (FLRW) metric of spacetime derived from CP generates the Friedmann equation (FE) that governs the development and dynamics of the universe. The big bang theory has made impressive successes in explaining the universe, but still has problems and solutions of them rely on an increasing number of HEs such as inflation, dark matter, dark energy, and so on. Recently, the author has developed a new cosmological model called black hole universe, which, instead of making many those hypotheses, only includes a new single postulate (or a new principle) to the cosmology - Principle of Spacetime and Black Hole Equivalence (SBHEP) - to explain all the existing observations of the universe and overcome all the existing problems in conventional cosmologies. This study thoroughly demonstrates how this newly developed black hole universe model, which therefore stands on the three fundamentals (GR, CP, and SBHEP), can fully explain the universe as well as easily conquer the difficulties according to the well-developed physics, thus, neither needing any other hypotheses nor existing any unsolved difficulties. This work was supported by NSF/REU (Grant #: PHY-1263253) at Alabama A & M University.

Author(s): Tianxi Zhang[1]
Institution(s): *1. Alabama A&M University*

404 – Extrasolar Planets: Formation and Dynamics

404.02 – On the Abundance of Water in Extrasolar Planetary Systems as a Function of Stellar Metallicity

The discovery, to date, of several hundred confirmed extra solar planets and a statistical analysis of their properties has revealed intriguing patterns in the abundance and types of extrasolar planets. The metallicity of the host star appears to be a driver in determining extrasolar planetary system characteristics, although a mechanistic understanding of these relationships is not currently available. Understanding the broad relationship(s) between the characteristics of extrasolar planets and stellar metallicity thus appears timely.

Recent work examining the timescales for water production in protoplanetary disks suggest that ionizing radiation required to drive surface chemistry in protoplanetary disks is insufficient and production timescales too slow to account for a significant amount of water in protoplanetary disks. Here we focus on the timescales for water production in cold molecular clouds and examine the relationship of this timescale as a function of molecular cloud metallicity. To do this, we consider the distribution of surface area concentration (dA/dV) in molecular clouds as a function of their metallicity and various MRN-like dust grain size distributions. We find that molecular cloud metallicity is a significant factor in determining upper-limits to the availability of water in molecular clouds and by extension, protoplanetary disks. The spectral index of the MRN distribution affects the upper-limits to H_2O abundance, but the effect is not as significant as metallicity. We find that the ratio of H_2O/SiO_2 produced in a molecular cloud of solar metallicity can easily account for Earth's present day ratio , supporting the "wet" hypothesis for the origins of Earth's water. Future studies will focus on the retention of water on interstellar dust grain surfaces in protoplanetary disk environments inside the water line, the abundance of other volatile species, more detailed estimates of H_2O destruction timescales in molecular clouds, and potential dynamical implications of our findings.

Author(s): Gerardo Dominguez[1]
Institution(s): *1. California State University, San Marcos*

404.03 – Non-coplanar planet-disc interactions in binary star systems

About half of observed exoplanets are estimated to be in binary systems. Thus, understanding planet formation and evolution in binaries is essential for explaining observed exoplanet properties. We will show how planet-disc interactions in a mildly inclined disc around one component of a binary can lead to the formation of highly eccentric and highly inclined planets.

Author(s): Rebecca G. Martin[4], Stephen H. Lubow[2], Chris Nixon[3], Philip J. Armitage[1]
Institution(s): *1. JILA, University of Colorado, Boulder, 2. Space Telescope Science Institute, 3. University of Leicester, 4. University of Nevada, Las Vegas*

404.04 – Kepler-108: A Mutually Inclined Giant Planet System

The vast majority of well studied giant-planet systems, including the Solar System, are nearly coplanar which implies dissipation within a primordial gas disk. However, intrinsic instability may lead to planet-planet scattering, which often produces non-coplanar, eccentric orbits. Planet scattering theories have been developed to explain observed high eccentricity systems and possibly hot Jupiters; thus far their predictions for mutual inclination (I) have barely been tested. Here we characterize a highly mutually-inclined (I ~ 15-60 degrees), moderately eccentric (e > 0.1) giant planet system: Kepler-108. This system consists of two Saturn mass planets with periods of ~49 and ~190 days around a star with a wide (~300 AU) binary companion in an orbital configuration inconsistent with a purely disk migration origin.

Author(s): Sean M Mills[1], Daniel Fabrycky[1]
Institution(s): *1. The University of Chicago*

404.05 – The Effect of Giant Planets on Habitable Planet Formation

The giant planets in the Solar System likely played a large role in shaping the properties of the Earth during its formation. To explore their effects, we numerically model the growth of Earth-like planets around Sun-like stars with and without Jupiter and Saturn analog companions. Employing state-of-the-art dynamical formation models that allow both accretion and collisional fragmentation, we perform hundreds of simulations and quantify the specific impact energies of all collisions that lead to the formation of an Earth-analog. Our model tracks the bulk compositions and water abundances in the cores and mantles of the growing protoplanets to constrain the types of giant planet configurations that allow the formation of habitable planets. We find significant differences in the collisional histories and bulk compositions of the final planets formed in the presence of different giant planet configurations. Exoplanet surveys like Kepler hint at a paucity of Jupiter analogs, thus these analyses have important implications for determining the frequency of habitable planets and also support target selection for future exoplanet characterization missions.

Author(s): Elisa V. Quintana[1], Thomas Barclay[1]
Institution(s): *1. NASA Ames Research Center*

404.06 – Using Planet Formation Simulations to Predict the Free-floating Planet Yield Expected from WFIRST

Planets are thought to form in circumstellar disks as a product of star formation. Material in the disk ends up in one of three places, (a) it remains in the disk as part of a planet, minor body or as interplanetary material, (b) it falls into the star, or (c) it is ejected from the system. We explore the properties of this ejected material using N-body simulations. We find that in planetary systems like ours (with Jupiter and Saturn) about half the ejected material is in bodies smaller than 1 Lunar-mass and about half is in bodies larger than 1 Mars-mass. The ejections happen early and no planets more massive than half an earth-mass are ejected. When no giant planets are present in the system, very little material is ejected. We predict that future space-borne microlensing searches for free-floating terrestrial-mass planets, such as WFIRST, will discover large numbers of Mars-mass planets but will not make significant detections of Earth-mass planets.

Author(s): Thomas Barclay[1], Elisa V. Quintana[1]
Institution(s): *1. NASA Ames Research Center*

404.07 – Mapping α Centauri AB for Possible Habitable Planets

The alpha Centauri AB star system, our closest stellar neighbors, has been studied for many decades and ACESat (Belikov et al. AAS Meeting #225, #311.01, 2015) is a proposed space mission designed to directly image Earth-sized planets in the habitable zones of both of these stars. The alpha Centauri system is older than our Sun, so any resident planets are expected to occupy long-lived orbits. We evaluate the extent of these trajectories where planets are able to orbit for billion-year timescales. The distribution of long-lived orbits is mapped to the sky plane to indicate regions where planets may appear relative to each stellar component. Our results confirm qualitatively those of Wiegert & Holman (Astron. J. 113, 1445, 1997) regarding the approximate size of the regions of stable orbits, which are larger for retrograde orbits relative to the binary than for prograde orbits. Moreover, we find that orbits beyond each star's habitable zone are affected by a dynamical imprint from the binary orbit due to mean motion resonances and the Lidov-Kozai Mechanism. Stable planets can exist near the plane of the binary orbit within each stellar habitable zone, whereas highly inclined orbits are typically short-lived. These results are of special interest as they can guide the search process of our stellar neighbors in future missions.

Author(s): Billy L. Quarles[2], Jack J. Lissauer[1]
Institution(s): *1. NASA Ames Research Center, 2. University of Nebraska at Kearney*

404.08 – Obliquity Variations of a Potentially Habitable Early Venus

Planetary obliquity (axis tilt) and its variations can have strong effects on climate. Earth's glacial cycles, for instance, are driven in part by variations in Earth's obliquity of order $\pm 1.5^{o}$. Direct observations of the obliquity of habitable zone rocky exoplanets is likely a long way off. Therefore we investigate the long-term obliquity variations expected for Venus as it might have existed in the early Solar System. Although Venus presently rotates slowly owing to tidal despinning, it must have had a different rotation state early in Solar System history. At the same time, Venus was the Solar System's habitable zone under a Faint Young Sun. Because of our extensive knowledge of the Solar System's constituents, we therefore use Venus' obliquity variations as a proxy for what we might find in exoplanetary systems. We find that the obliquity variation structure is simpler for early Venus than it would be for a Moonless Earth, but that large, chaotic variability can occur for high initial obliquity values. Interestingly retrograde-rotating Venuses show higher variability than do retrograde Moonless Earths.

Author(s): Jason W. Barnes[3], Billy L. Quarles[4], Jack J. Lissauer[2], John E. Chambers[1], Matthew M. Hedman[3]
Institution(s): *1. Carnegie Institute of Washington, 2. NASA Ames Research Center, 3. University of Idaho, 4. University of Nebraska*

404.09 – A Probabilistic Analysis of the Fermi Paradox

The Fermi paradox uses an appeal to the mediocrity principle to make it seem counterintuitive that humanity has not been contacted by extraterrestrial intelligence. A numerical, statistical analysis was conducted to determine whether this apparent loneliness is, in fact, unexpected. An inequality was derived to relate the frequency of life arising and developing technology on a suitable planet in the galaxy; the average length of time since the first broadcast of such a civilization; and a constant term. An analysis of the sphere reached thus far by human communication was also conducted, considering our local neighborhood and planets of particular interest. These analyses both conclude that the Fermi paradox is not, in fact, unexpected. By the mediocrity principle and numerical modeling, it is actually unlikely that the Earth would have been reached by extraterrestrial communication at this point. We predict that under 1% of the galaxy has been reached at all thus far, and we do not anticipate to be reached until approximately 50% of stars/planets have been reached. We offer a prediction that we should not expect this until at least 1,500 years in the future. Thus the Fermi paradox is not a shocking observation- or lack thereof- and humanity may very well be contacted within our species' lifespan (we can begin to expect to be contacted 1,500 years in the future).

Author(s): Evan Solomonides[1], Yervant Terzian[1]
Institution(s): *1. Cornell University*

405 – Molecular Clouds, HII Regions, and Dust

405.01 – Halpha LEGUS: An Halpha Imaging Survey of Nearby Galaxies with HST

We present first results from the Halpha LEGUS program, an HST narrowband survey of 30 nearby galaxies aimed at probing the relationship between young stars and the warm ionized interstellar medium (ISM). The superb resolution of HST enables the study of HII regions on the parsec scales where feedback from massive stellar populations is injected into the ISM. The span of the sample, which covers a large range in morphology, star formation rate, stellar mass, metallicity, and interaction state, allows for exploration of the possible dependencies of HII region evolution on galactic environment. We give an overview of the sample, observations, and initial characterization of HII region properties, all of which build on the foundation of HST NUV, U, B, V, I imaging obtained by the parent Legacy ExtraGalactic Ultraviolet Survey.

Author(s): Janice C. Lee[3], Rupali Chandar[4], Mark R. Krumholz[1], David A. Thilker[2], Stacey N. Bright[3]
Institution(s): *1. Australian National University, 2. Johns Hopkins University, 3. Space Telescope Science Institute, 4. University of Toledo*
Contributing team(s): Halpha LEGUS

405.02 – Estimation of Fuel Rate on the Galactic Disk from High Velocity Clouds (HVCs) Infall

Continuous accretion of metal-poor gas can explain the discrepancy between the number of observed G-Dwarfs and the number predicted by the "simple model" of galactic evolution. The maximum accretion rate estimated based upon approaching high velocity clouds (HVCs) can be up to ~0.4 $M_\odot yr^{-1}$ which is comparable with the accretion rate required by many chemical evolution models that is at least ~0.45 $M_\odot yr^{-1}$. However, it is not clear to what extent the exchange of gas between the disk and the cloud can occur when a HVC collides with the galactic disk. Therefore, we examined a series of HVC-Disk collision simulations using the FLASH2.5 hydrodynamics simulation code. Our simulation results show that an HVC will more likely take away substances from the galactic disk rather than adding new material to the disk. We define this as a "negative fuel rate" event. Further outcomes in our study present that the fuel rate, which is defined as how much material is transferred to the galactic disk from the colliding HVC, can change depending on the combination among density, radius and velocity of an approaching HVC as well as the modeled galactic disk.

Author(s): Kwang Hyun Sung[1], Kyujin Kwak[1]
Institution(s): *1. Ulsan National Institute of Science and Technology*

405.03 – Comparing submillimeter polarized emission with near-infrared polarization of background stars for the Vela C molecular cloud

We present a large-scale combination of near-infrared (near-IR) interstellar polarization data from background starlight, with polarized emission data at sub-millimetric (sub-mm) bands for the Vela C molecular cloud. The sub-mm data were obtained by the Balloon-borne Large Aperture Submillimeter Telescope for Polarimetry (BLASTPol) during the 2012 flight in Antartica. The near-IR data consist of more than 6700 detections in the I-band, covering a wide area around the cloud, mostly in the range of visual extinctions between 2 and 16 mag. The main goal was to determine the polarization efficiency ratio R_{eff} , defined as $p_{500}/(p_I/\tau_V)$, where p_{500} is the polarization fraction at 500 μm and optical depths τ_V are estimated from cataloged near-IR photometry. To ensure that the same column density of material is producing both polarization from emission and extinction, we introduce a new method to select stars that are located in the near-background, the Gaussian-logistic (GL) technique. The polarization efficiency ratio is critically affected by stellar objects with background contamination from the diffuse Galactic material, emphasizing the need for a careful selection. Accounting for the statistical and systematic uncertainties from the GL method, we estimate an average R_{eff} value of 2.4 ± 0.8, which can be used to test dust grain models designed specifically for molecular clouds. R_{eff} appears to be relatively flat as a function of the cloud depth, suggesting that significant grain modification might occur only at higher densities.

Author(s): Fabio P. Santos[10], Peter Ade[3], Francesco E Angilè[14], Peter Ashton[10], Steven J Benton[11], Mark J. Devlin[14], Bradley Dober[14], Laura M. Fissel[10], Yasuo Fukui[7], Nicholas Galitzki[14], Natalie Gandilo[15], Jeffrey Klein[14], Zhi-Yun Li[16], Andrei Korotkov[1], Peter G. Martin[15], Tristan Matthews[10], Lorenzo Moncelsi[2], fumitaka nakamura[9], Calvin Barth Netterfield[15], Giles Novak[10], Enzo Pascale[3], Frédérick Poidevin[5], Giorgio Savini[12], Douglas Scott[13], Jamil Shariff[15], Juan D. Soler[4], Nicholas Thomas[8], carole tucker[3], Gregory S. Tucker[1], Derek Ward-Thompson[6]
Institution(s): *1. Brown University, 2. California Institute of Technology, 3. Cardiff University, 4. Institute d'Astrophysique Spatiale CNRS, 5. Instituto de Astrofisica de Canarias, 6. Jeremiah Horrocks Institute, 7. Nagoya University, 8. NASA Goddard Space Flight Center, 9. National Astronomical Observatory, 10. Northwestern University, 11. Princeton University, 12. University College London, 13. University of British Columbia, 14. University of Pennsylvania, 15. University of Toronto, 16. University of Virginia*
Contributing team(s): BLASTPOL

405.04 – The Magnetic Field of the L1544 Starless Dark Cloud, Traced Using Near-Infrared Background Starlight

What roles do interstellar magnetic fields play in star formation processes? We have studied the B-field of L1544, a dark cloud with a starless dense core showing active gas infall, and located only 140 pc away in Taurus, via deep near-infrared (NIR) imaging polarimetry with the Mimir instrument. We find the B-field orientations in the plane of the sky change significantly at L1544, mimicking its shape and extent. The elongated spine of L1544 is also where the dispersion of NIR linear polarization position angles is smallest, suggesting strengthening of the B-field. Archival *WISE*, SCUPOL, *Herschel*, and *Planck* data were analyzed to characterize dust extinction and emission across L1544 and the field around it. Three-dimensional modeling, constrained through matching two-dimensional integrated model properties to observed dust distributions, led us to develop maps of effective gas mass densities and non-thermal gas velocity dispersions. These were combined with the NIR polarimetry, under the Chandrasekhar & Fermi (1953) approach, to yield a map of B-field strength across the entire 400 sq-arcmin region surveyed. The trends of B-field strength with gas volume density, mass-to-flux ratio with radius, and plane-of-sky B-field strengths with Zeeman-traced line-of-sight B-field strengths were found and compared to previous published work to establish the role of B-fields in L1544. We find field strengths in the 3 - 30 uG range, quite similar to the OH Zeeman values found by Crutcher et al. (2009) for L1544.

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Author(s): Dan P. Clemens[1], Paul Goldsmith[2], Konstantinos Tassis[3]
Institution(s): *1. Boston Univ., 2. JPL, CalTech, 3. University of Crete*

405.05 – Identification of the UIR bands

Starlight undergoing multiple scattering processes within fluffy grains results in extinction, UV 2175A bump, DIBs and the UIR bands. Spectroscopic lab and DIB data has identified the highly fluorescent molecule Dipyridyl Magnesium Tetrabenzoporphyrin (MgTBP). Reflection and Raman scattering experimental data will be presented which designates this molecule as the primary source for UIR signals. MgTBP sublimes at about 500^{O}C. It is produced via high temperature plasma synthesis within and subsequently ejected from comets which in turn are by-products of solar system-planetary development. Interstellar dust is the left-over refuse which implies prodigious solar system evolution in each galaxy.

Author(s): Fred M. Johnson[1]
Institution(s): *1. California State Univ.*

405.06 – Progress of a new instrument to study molecular dynamics of interstellar ion-neutral reactions

Astrochemistry, a relatively young field of research, addresses a gap in our understanding of molecular evolution in space. With many space missions gathering data, the number of unresolved spectral lines is growing rapidly. Each year there are about three new molecules that are identified in the interstellar medium (ISM). However, our understanding of molecular processes, branching ratios, and rates are at a beginner level. For instance, we do not yet understand the chemical processes associated with the creation and evolution of even the most basic prebiotic molecules such as water and methanol in space. One of the important steps toward understanding the chemistry of the ISM is to identify, through laboratory and theoretical work, a list of potential target molecules that are likely to exist in the ISM. This work describes experimental progress towards building a spectrometer that is able to produce complex cold ions that will react with cooled neutral molecules under conditions similar to those in space. I plan to present the instrumental progress and how astronomical reaction dynamic needs will be met using the instrument, and the present status of the instrument and measurements in my lab.

Author(s): Manori Perera3, Kevin Roenitz[2], Ben Lamm5, Lydia Rudd3, Andrew Justl3, Steven Landeweer3, Danny Roadman3, Justyna Koscielniak[1], Andrew Sonnenberger 4
Institution(s): *1. Advocate Bromenn Medical Center, 2. Emory University, 3. Illinois Wesleyan University, 4. University of Minnesota, 5. University of South Carolina*

405.07 – Dusty Mass Loss from Galactic Asymptotic Giant Branch Stars

We are probing how mass loss from Asymptotic Giant Branch (AGB) stars depends upon their metallicity. Asymptotic giant branch (AGB) stars are evolved stars that eject large parts of their mass in outflows of dust and gas in the final stages of their lives. Our previous studies focused on mass loss from AGB stars in lower metallicity galaxies: the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC). In our present study, we analyze AGB star mass loss in the Galaxy, with special attention to the Bulge, to investigate how mass loss differs in an overall higher metallicity environment. We construct radiative transfer models of the spectral energy distributions (SEDs) of stars in the Galaxy identified as AGB stars from infrared and optical surveys. Our Magellanic Cloud studies found that the AGB stars with the highest mass loss rates tended to have outflows with carbon-rich dust, and that overall more carbon-rich (C-rich) dust than oxygen-rich (O-rich) was produced by AGB stars in both LMC and SMC. Our radiative transfer models have enabled us to determine reliably the dust chemistry of the AGB star from the best-fit model. For our Galactic sample, we are investigating both the dust chemistries of the AGB stars and their mass-loss rates, to compare the balance of C-rich dust to O-rich dust between the Galactic bulge and the Magellanic Clouds. We are also constructing detailed dust opacity models of AGB stars in the Galaxy for which we have infrared spectra; e.g., from the Spitzer Space Telescope Infrared Spectrograph (IRS). This detailed dust modeling of spectra informs our choice of dust properties to use in radiative transfer modeling of SEDs of Galactic AGB stars. BAS acknowledges funding from NASA ADAP grant NNX15AF15G.

Author(s): Benjamin A. Sargent[2], Sundar Srinivasan[1], Margaret Meixner3, Joel H. Kastner[2]
Institution(s): *1. Academia Sinica Institute of Astronomy and Astrophysics, 2. Rochester Institute of Technology, 3. Space Telescope Science Institute*

405.08D – Circumstellar Dust Shells: Clues to the Evolution of R Coronae Borealis Stars

R Coronae Borealis (RCB) stars are an exotic group of extremely hydrogen- deficient, carbon-rich supergiants that are known for their spectacular declines in brightness (up to 8 mags) at irregular intervals. Two scenarios are currently competing to explain the origins of these stars. One suggests that RCB stars are the products after a binary white dwarf (WD) system merges. The other takes a single, evolved star and has it undergo a final, helium-shell flash (FF) and becoming a cool giant. Recently, observations of elemental abundances in RCB stars have strongly swung the argument in favor of the WD merger model. The FF scenario has maintained its relevancy by seemingly being the only model able to offer a suitable explanation for one RCB feature that merger model has historically struggled with explaining: the presence of cold, circumstellar dust envelopes which might be fossil planetary nebulae (PNe). In reality, the shells could actually be fossil PNe, material left over from the WD merger, or mass lost during the RCB phase, itself. I will present the results of my dissertation, which is to try and discern the nature and history of the far-IR dust shells around RCB stars to help understand the origin of these enigmatic stars. I will discuss our efforts to determine the mass, size, temperature, and morphology of these diffuse structures surrounding a sample of RCB stars using multi-wavelength observations ranging from the ultraviolet to the submillimeter. These observations have provided unprecedented wavelength coverage for both the central stars and their CSM. They have been examined by eye for morphology and have been used in the construction of maximum-light spectral energy distributions (SEDs). I will present the results of our Monte Carlo radiative transfer of the maximum-light SEDs. Finally, I will highlight our work investigating the HI abundance of the envelope of R Coronae Borealis, itself, using archival 21—cm observations from the Arecibo Observatory.

Author(s): Edward J. Montiel[1], Geoffrey C. Clayton[1]
Institution(s): *1. Louisiana State University*

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