AASTCS 5
Palm Springs, CA – May, 2017
Meeting Abstracts

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100 – Stellar Activity and Star-Planet Interaction I

100.01 – Exoplanetary Habitability: Radiation, Particles, Plasmas, and Magnetic Fields

Exoplanetary environments are made of an intricate mixture of plasmas, radiation, energetic particles, winds, and magnetic fields; these all play crucial roles for the structure and evolution of planetary atmospheres and the formation and possibly protection of planetary habitable environments. Interactions between planetary atmospheric particles and solar-wind ions result in various non-thermal loss mechanisms that are relevant for atmospheric erosion; energetic neutral atoms from charge exchange interactions can even deposit their energy in upper atmospheres and contribute to their heating. We present results from simulations and discuss the effects of magnetospheric obstacles, the resulting atmospheric loss rates and neutral hydrogen clouds detectable through Ly a absorption. We also present estimates for secondary X-ray production as a result of charge exchange interactions. Combined modeling of expanding hydrogen clouds resulting from such interactions are now also used to estimate magnetic moments of exoplanets. We emphasize that the interplay between all these mechanisms, also including radiation-driven thermal escape of atmospheres, changes with stellar evolution; for a full understanding of the state of an observed exoplanetary atmosphere, the long-term evolution of the host star, in particular its rotation and magnetic activity, needs to be studied. In this respect, radio astronomy plays a central role as it sensitively probes these environments and their constituents in time, such as magnetospheres, high-energy particles, stellar magnetic fields and winds, and therefore contributes to our understanding of the emergence of habitable planetary environments.

Author(s): Manuel Guedel[1]
Institution(s): *1. University of Vienna*

100.02 – Magnetic properties of low mass stars: new discoveries and future prospects

Measuring properties of surface magnetic fields is the path towards our understanding of stellar dynamos and environment of stars with convective envelopes. In this talk I will summarize what have we learned about magnetism in low-mass stars over last decades from numerous spectroscopic and polarimetric studies, and discuss on newest discoveries of strongest magnetic fields ever found in these objects since early eightees.

Author(s): Denis Shulyak[1]
Institution(s): *1. Goettingen University*

100.03 – Stellar Ro

Our understanding of the interior dynamics that give rise to a stellar dynamo draws heavily from investigations of similar dynamics in the solar context. Unfortunately, an outstanding gap persists in solar dynamo theory. Convection, an indispensable component of the dynamo, occurs in the midst of rotation, and yet we know little about how the influence of that rotation manifests across the broad range of convective scales present in the Sun. We are nevertheless well aware that the interaction of rotation and convection profoundly impacts many aspects of the dynamo, including the meridional circulation, the differential rotation, and the helicity of turbulent EMF. The rotational constraint felt by solar convection ultimately hinges on the characteristic amplitude of deep convective flow speeds, and such flows are difficult to measure helioseismically. Those measurements of deep convective power which do exist disagree by orders of magnitude, and until this disagreement is resolved, we are left with the results of models and those less ambiguous measurements derived from surface observations of solar convection. I will present numerical results from a series of nonrotating and rotating convection simulations conducted in full 3-D spherical geometry. This presentation will focus on how convective spectra differ between the rotating and non-rotating models and how that behavior changes as simulations are pushed toward more turbulent and/or more rotationally-constrained regimes. I will discuss how the surface signature of rotationally-constrained interior convection might naturally lead to observable signatures in the surface convective pattern, such as supergranulation and a dearth of giant cells.

Author(s): Nicholas Featherstone[1]
Institution(s): *1. University of Colorado*

100.04 – Modelling the dynamo in fully convective M-stars

M-stars are among the most active and numerous stars in our galaxy. Their activity plays a fundamentally important role in shaping the exoplanetary biosphere since the habitable zones are very close to these stars. Therefore, modeling M-star activity has become a focal point in habitability studies. The fully convective members of the M-star population demand more immediate attention due to the discovery of Earth-like exoplanets around our stellar neighbors Proxima Centauri and TRAPPIST-1 which are both fully convective. The activity of these stars is driven by their convective dynamo, which may be fundamentally different from the solar dynamo due the absence of radiative cores. We model this dynamo mechanism using high-resolution 3D anelastic MHD simulations. To understand the evolution of the dynamo mechanism we simulate two cases, one with a fast enough rotation period to model a star in the `saturated' regime of the rotation-activity realtionship and the other with a slower period to represent cases in the `unsaturated' regime. We find the rotation period fundamentally controls the behavior of the dynamo solution: faster rotation promotes strong magnetic fields (of order kG) on both small and large length scales and the dipolar component of the magnetic field is dominant and stable, however, slower rotation leads to weaker magnetic fields which exhibit cyclic behavior. In this talk, I will present the simulation results and discuss how we can use them to interpret several observed features of the M-star activity.

Author(s): Rakesh Kumar Yadav[1], Ulrich Christensen[3], Julien Morin[5], Scott Wolk[1], Katja Poppenhaeger[4], Ansgar Reiners[6], Thomas gastine[2]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. Institut de Physique du Globe de Paris, 3. MPI for Solar System Research, 4. Queen's University Belfast, 5. Université de Montpellier, 6. University of Goettingen*

100.05 – Constraints on magnetism, buoyancy, and dissipation in convective stars and planets

All stars, and many planets, possess magnetism somewhere in their interiors. In most cases the magnetic fields are built by the action of a magnetic dynamo, a process that converts kinetic energy to magnetic, but a comprehensive theoretical understanding of this process has remained elusive. Here, we describe some recent results from large-scale simulations of stellar and planetary dynamos, which have helped reveal how orderly fields might be generated amidst the convection in these objects, how strong these fields can be, and what effects they may have. We discuss claims that particularly strong magnetic fields may affect the structure and radii of low-mass stars; we argue that the extreme field strengths needed in some of these models are ruled out by the complementary constraints of buoyancy and Ohmic dissipation. We also provide thermodynamic constraints, tested via numerical simulation, on the overall rate of dissipation in stratified convection. In some cases this dissipative heating can exceed the energy carried by convection itself. We briefly note some possible consequences of this dissipation for the structure of low-mass stars.

Author(s): Matthew Browning[2], Laura Currie[2], Maria A Weber[2], Felix Sainsbury-Martinez[2], Lewis Ireland[2], Lucia Duarte[2], Gilles Chabrier[1]
Institution(s): *1. ENS-Lyon, 2. University of Exeter*

100.06 – Extrapolating from the geodynamo to exodynamos

Planetary magnetic fields are unique in providing a window into the dynamics of the deep interior while being remotely detectable. However, direct detection of exoplanet magnetic fields, or “exodynamos”, have remained elusive. We discuss the basic requirements for generating a planetary dynamo and the physical parameters that control it’s intensity, morphology, and evolution. Given that predictions for terrestrial exodynamos rely on extrapolations from our knowledge of the geodynamo we review recent ideas about the evolution of the geodynamo and how they compare to paleomagnetic data. Considering the potential importance of terrestrial magnetic fields for habitability we focus on the thermal and magnetic evolutions of Earth-like exoplanets. In particular, we explore the influence of tectonic mode, radioactivity, and tidal heating on terrestrial exodynamos.

Author(s): Peter Driscol[1]
Institution(s): *1. Carnegie Institute for Science*

101 – Stellar Activity and Star-Planet Interaction II

101.01 – The Sun as a star: empirical estimates of stellar coronal mass ejection rates and properties

Our nearest star provides exquisite, up-close views of the physical processes driving energetic phenomena we observe on stars and cannot yet spatially resolve. Stars provide a statistical ensemble of solar analogs spanning a range of ages representing snapshots along our Sun's full life cycle. In this talk, I will share a project bringing the astronomer's large scale statistical approach to bear on solar data. Combining a decades' worth of solar flare and CME data, we characterize for the first time a relationship between flare and CME properties in order to extend analogy to readily observable stellar flares. We aim to better understand the properties and evolution of magnetic activity on Sun-like stars and exoweather on planets about distant Suns.

Author(s): Alicia Aarnio[1]
Institution(s): *1. University of Colorado Boulder*

101.02 – Age, rotation, and activity in M dwarfs and the implications for planet-hosting stars

Understanding stellar rotation and magnetic activity is critical to both the detection and characterization of exoplanets. This is particularly pertinent for planets around M dwarf stars, which remain magnetically active for Gyrs and for which the habitable zone is at only a few tenths of an AU. While these low-mass stars are the most common type of star in the galaxy, a lack of observational constraints at ages beyond 1 Gyr has hampered studies of rotational evolution and magnetic activity. To address this, we have made new measurements of rotation and magnetic activity in nearby, field-age M dwarfs. Our rotation period measurements are derived from photometry from the MEarth planet-search data, and include detections from 0.1 to 140 days. Using galactic kinematics as a proxy for age, we find that mid M dwarfs in the field are slowly-rotating, with periods of approximately 100 days at 5 Gyr. We combine our 387 rotation period measurements and 247 new optical spectra with data from the literature. We confirm that the activity of rapidly rotating M dwarfs maintains a saturated value and our data show a clear power-law decay in relative H-alpha luminosity as a function Rossby number. I will discuss planet-hosting M dwarfs in the context of the relationship between age, rotation, and activity.

Author(s): Elisabeth Newton[4], Jonathan Irwin[3], David Charbonneau[3], Perry Berlind[3], Calkins Michael[3], Jessica Mink[3], Zachory Berta-Thompson[2], Jason Dittmann[4], Andrew West[1]
Institution(s): *1. Boston University, 2. CU Boulder, 3. Harvard-Smithsonian Center for Astrophysics, 4. MIT*

101.03 – Transient Mass Loss in Active Stars and Observation Methods

One factor important to habitability is the impact of stellar eruptive events on nearby exoplanets.
This is currently poorly constrained due to heavy reliance on solar scaling relationships and a lack of experimental evidence. The potential impact of space weather and atmospheric stripping due to the impacts of coronal mass ejections, a large eruption of magnetic field and plasma, are not yet understood. Low frequency dynamic spectra of radio bursts from nearby stars offer the best chance to directly detect and characterize the stellar signature of transient mass loss on low mass stars. By using solar solar observations, analogous to those found in stellar studies, we test the validity and accuracy of the results obtained by the multi-wavelength methodology proposed in Crosley et. al 2016. We find that, when a pre-event temperature can be determined, that the accuracy of CME speeds are within a few hundred km/s, and are reliable when specific criteria has been met while CME mass and kinetic energies are only useful in determining approximate order of magnitude.
We take these results and apply them to 15 hr of observation of YZ Canis Minoris (YZ CMi), a nearby M dwarf flare star, taken in LOFAR's beam-formed observation mode. The observations utilized the Low Band Antenna (10–90 MHz) or High Band Antenna (110–190 MHz) for five three-hour observation periods. There were no confirmed type II events in this frequency range. We explore the range of parameter space for type II bursts constrained by our observations. Assuming the rate of shocks is a lower limit to the rate at which CMEs occur, no detections in a total of 15 hr of observation places a limit of $\nu\_{type\ II} < 0.0667$ type II shocks / hr $< \nu\_{CME}$ for YZ CMi due to the stochastic nature of the events and the limits of observational sensitivity. Preliminary results on 60 hours of JVLA observations on EQ Peg are also reported on.

Author(s): Michael Crosley[1], Rachel A. Osten[2]
Institution(s): *1. Johns Hopkins Univeristy, 2. Space Telescope Science Institute*

101.04 – Observational Constraints on Stellar Winds from the Hubble Space Telescope

Planetary atmospheres are affected by both radiation and particle fluxes from their host stars. The former is well constrained by observations, but there are unfortunately few such constraints on the latter. The only means by which the coronal winds of Sun-like stars have ever been perceived at all is by detecting circumstellar H Lyman-alpha absorption from the wind/ISM interaction regions (i.e., "astrospheres"). I will review the existing Lyman-alpha constraints on stellar winds, all of them based on UV spectra from the Hubble Space Telescope. One unexpected result is that the two most active main sequence stars with detected astrospheres, EV Lac (M3.5 V) and Pi1 UMa (G1.5 V), are inferred to have winds comparable to or even weaker than the solar wind. I will explore the utility of the solar example for interpreting this result.

Author(s): Brian Wood[1]
Institution(s): *1. Naval Research Laboratory*

101.05 – Space Weather Affected Habitable Zones Around Active Stars

Our Sun, a magnetically mild star, exhibits space weather in the form of magnetically driven solar explosive events (SEEs) including solar flares, coronal mass ejections (CME) and solar energetic particle (SEP) events. Extreme SEEs from magnetically active stars can significantly perturb magnetosphere, cause strong geomagnetic storms, initiate escape and introduced chemical changes in exoplanetary atmospheres. We use Kepler data and reconstruction of X-ray and UV emission from young solar-like stars to recover the frequency and energy fluxes from extreme events from active stars including the young Sun. I present our recent simulation results based on multi-dimensional multi-fluid hydrodynamic and magnetohydrodynamic models of interactions of extreme CME and SEP events with magnetospheres and lower atmospheres of early Earth and exoplanets around active stars. We also discuss observational bio-signatures of life "highlighted" by space weather events, the beacons of life.

Author(s): Vladimir S. Airapetian[1]
Institution(s): *1. NASA/GSFC*

101.06 – Space Weather Characterization of Exoplanets

M dwarfs are the most feasible targets for finding planets orbiting in the habitable zone (HZ). However, their intense magnetic activity makes it very challenging for these planets to sustain an atmosphere. Using MHD, we model the coronae of planet hosting stars and the interaction of the stellar wind with the planets' atmosphere in order to asses their "habitability". These space weather conditions could result in strong atmospheric stripping and evaporation and should be taken into account for any realistic assessment of habitability.
In this talk I will discuss these conditions for the exciting newly discovered temperate terrestrial planets around Proxima Centauri and TRAPPIST-1, and will highlight a new and quite extreme magnetospheric configuration that most of the TRAPPIST-1 planets are likely to experience.

Author(s): Cecilia Garraffo[1], Jeremy J Drake[1], Ofer Cohen[2], Julian D Alvarado-Gomez[1], Sofia P Moschou[1]
Institution(s): *1. Harvard-Smithsonian Center for Astrophysics, 2. University of Massachusetts, Lowell*

200 – Stellar Activity and Star-Planet Interaction III

200.01 – A Review and Preview of Magnetic Star-Planet Interactions

Planets interact with their host stars through gravity, radiation and magnetic fields, and for those giant planets that orbit their stars within ~20 stellar radii (=0.1 AU for a sun-like star), star-planet interactions (SPI) are observable with a wide variety of photometric, spectroscopic and spectropolarimetric studies. At such close distances, the planet orbits within the sub-alfvénic radius of the star in which the transfer of energy and angular momentum between the two bodies is particularly efficient. The nature of magnetic SPI is modeled to be strongly affected by both the stellar and planetary magnetic fields, possibly influencing the magnetic activity of both, as well as affecting the irradiation and even the migration of the planet. As we refine our observational techniques for hot Jupiter systems, we can begin to extend them to other tightly orbiting stellar systems, such as smaller planets close to M dwarfs where the region near tens of stellar radii begins to coincide with the classical habitable zone. Future studies of SPI with space-based telescopes and the next generation of ground-based telescopes will be informative pursuits for the study of the internal dynamics and atmospheric evolution of exoplanets.

Author(s): Evgenya Shkolnik[1]
Institution(s): *1. Arizona State Univeristy*

200.02 – Exoplanet environments and radio signatures

The nature of a star's magnetic field is determined primarily by the stellar mass and rotation rate. Using spectropolarimetric techniques, we have now mapped the surface magnetic fields of some 100 stars across a wide range of these fundamental parameters. Some of the biggest surprises have been in the nature of the magnetic fields of low mass, fully convective stars. These appear to show a different type of field geometry to higher mass stars, with a larger ratio of poloidal to toroidal field. Their lower surface differential rotation also leads to a more slowly evolving coronal field and a longer timescale to form and eject the flux ropes believed to be the precursors of coronal mass ejections. Searches are ongoing for the radio signature of the interaction of exoplanets with the winds and coronal mass ejections of their parent star. For low mass stars, this is a particularly pressing issue, as the habitable zone is very close to the star and the probability of impact with a coronal mass ejection is high.

In this talk I will review the current state of our knowledge of stellar magnetic field geometry, winds and coronal mass ejections and discuss how this informs searches for exoplanetary radio signatures.

Author(s): Moira Jardine[1]
Institution(s): *1. University of St Andrews*

200.03 – Detecting magnetic fields on brown dwarfs and exoplanets

There is growing evidence that brown dwarfs may possess rather strong magnetic fields, similar to active, early M-type red dwarf stars. Strong clues come from extremely energetic flares detected in UV, X-ray and optical line emission as well as quiescent and transient radio emission and bursts. Our recent spectropolarimetric study of one such active brown dwarf has revealed a 5 kG magnetic spot on its surface. The emitting region topology recovered using spectral line profile inversions indicates the presence of a hot plasma large-scale loop of at least 7000\,K with a vertical stratification of the sources producing both optical and radio emission. This loop rotates with the dwarf in and out of view causing the emission bursts. The 5 kG magnetic field is detected at the base of the loop. This result provides the first direct observational constraint for a magnetically driven non-thermal emission mechanism and for generation of magnetic fields in fully convective brown dwarfs. It also paves a path towards magnetic studies of hot Jupiters of similar temperatures. We model relevant atomic lines and molecular bands in order to predict spectropolarimetric signals due to magnetic fields on brown dwarfs, hot Jupiters and other types of exoplanets. This exercise helps to determine instrumental requirements for magnetic surveys of brown dwarfs and exoplanets.

Author(s): Svetlana Berdyugina[1]
Institution(s): *1. Kiepenheuer Institut fuer Sonnenphysik*

200.04 – Prospects for planet detection using pulsed radio emission from UCD's

Pulsed radio emission from ultra-cool dwarfs is thought to be due to the electron-cyclotron maser instability (ECMI) from mildly relativistic electrons precipitating in large kilogauss magnetic loops above the stellar photosphere. This emission, which highly circularly polarized and highly beamed, may be altered by the presence of close-in planets, and therefore provide a means for inferring the presence of the planet. I will discuss the basic plasma physics of ECMI emission, as well as recent observations of ECMI emission at the Earth, Jupiter, and Saturn. These observations, especially the beaming properties, are highly relevant to predicting whether and how close-in planets can effect ECMI pulses from the parent star.

Author(s): Robert Mutel[1]
Institution(s): *1. University of Iowa*

200.05 – Lessons from our Own Solar System: Generation Mechanisms of Radio Emissions from Earth, Saturn and Jupiter and Atmospheric Loss from Magnetized versus non-magnetized planets

The understanding of the engines and mechanisms behind kilometric and decametric radio emissions from the planets in our own solar system have taken great leaps with missions such as the NASA/Cassini, IMAGE and Galileo missions. The periodic Saturn Kilometric Radiation (SKR), the Auroral Kilometric Radiation (AKR) at Earth and the periodic decametric radio emissions from Jupiter all point to the same generation mechanisms: very large-scale explosive plasma heating events in the magnetotail of each of the planets. The character and periodicity of the associated radio emissions not only tells us about the presence of a magnetic field but also about the plasma content and size of the planetary magnetosphere, and the nature of the interaction with the solar wind.
The presence of a planetary magnetic field, as could be established for exoplanets by the positive detection of low-frequency exoplanetary radio emissions, has been thought to shield a planet from atmospheric loss to space. However, recent data from Mars Express, MAVEN, and Venus Express, together with the wealth of terrestrial measurements of atmospheric escape to space has brought a surprising question in to light: Does a planetary magnetic field suppress or enhance atmospheric loss? While at the non-magnetized planets such as Mars and Venus, the solar wind has a more direct access to the ionized upper atmosphere, these planets do set up self shielding currents that do limit escape. Furthermore, it is not clear if Mars have lost the majority of its atmosphere by condensation in to surface and sub-surface frost, or through atmospheric escape. At Earth, the geomagnetic field sets up a relatively large cross section to the solar wind, that allows the induced solar-wind electric field to transfer substantial energy to the upper ionosphere and atmosphere resulting in substantial loss. It is therefore not clear how a planetary magnetic field correlates to the atmospheric loss, or if it does at all.
In this presentation we will summarize the recent findings in these two areas and what that implies for our understanding of stellar-wind interactions with exoplanetary magnetized and non-magnetized systems, and its possible constraints on habitability.

Author(s): Pontus Brandt[1]
Institution(s): *1. JHU/APL*

200.06 – Simulating Electron Cyclotron Maser Emission for Low Mass Stars

Zeeman-Doppler Imaging (ZDI) is a powerful technique that enables us to map the large-scale magnetic fields of stars spanning the pre- and main-sequence. Coupling these magnetic maps with field extrapolation methods allow us to investigate the topology of the closed, X-ray bright corona, and the cooler, open stellar wind.

Using ZDI maps of young M dwarfs with simultaneous radio light curves obtained from the VLA, we present the results of modeling the Electron-Cyclotron Maser (ECM) emission from these systems. We determine the X-ray luminosity and ECM emission that is produced using the ZDI maps and our field extrapolation model. We compare these findings with the observed radio light curves of these stars. This allows us to predict the relative phasing and amplitude of the stellar X-ray and radio light curves.

This benchmarking of our model using these systems allows us to predict the ECM emission for all stars that have a ZDI map and an observed X-ray luminosity. Our model allows us to understand the origin of transient radio emission observations and is crucial for disentangling stellar and exoplanetary radio signals.

Author(s): Joe Llama[1], Moira Jardine[2]
Institution(s): *1. Lowell Observatory, 2. University of St Andrews*

201 – Stellar Activity and Star-Planet Interaction IV

201.01 – Planetary Consequences of Sub-Alfvenic Space Environment in Close-in Planets

Close-in gas giant planets, as well as close-in terrestrial planets may reside in a sub-Alfvenic environment, at which the surrounding plasma's speed is slower than the local Alfven speed. Such an environment is very different from the typical space environment near the Earth and the other solar system planets. I will review the unique conditions of this situation and will point out crucial consequences in the context of star-planet interaction, detectibility, radio emissions, and planet habitability.

Author(s): Ofer Cohen[3], Jeremy J Drake[1], Cecilia Garraffo[1], Vinay Kashyap[1], Tamas Gombosi[2]
Institution(s): *1. Harvard-Smithsonian CfA, 2. U. of Michigan, 3. University of Massachusetts Lowell*

201.02 – Magnetically Controlled Flows in Planetary Outflows and Star/Planet Interactions

This talk considers two related problems involving magnetically controlled flows in star formation, young stellar objects, and exoplanets. [1] First we consider magnetic field effects on outflows from exoplanets, which have now been observed. For typical parameters, the magnetic field pressure dominates the ram pressure of the outflow by many orders of magnitude. Magnetically controlled outflows differ significantly from previous spherical models: The outflow rates are somewhat smaller, and the flow is launched primarily from the polar regions of the planet. [2] Next we consider the V773 system as an analog of star/planet interactions. This system is an interacting T Tauri binary with a 51 day eccentric orbit, where the two magnetospheres overlap and produce a burst of synchrotron radiation near periastron. In our model, the observed emission arises from the change in energy stored in the composite magnetic field of the system. We describe the fields using the leading order (dipole) components, and show that this picture is consistent with current observations. Finally, we show how Hot Jupiter magnetospheres can interact with their host stars in an analogous manner.

Author(s): Fred C Adams[1]
Institution(s): *1. University of Michigan*

201.03 – What Can TRAPPIST-1 Tell Us About Radiation From M-Dwarf Chromospheres And Coronae

The recent discovery of 7 planets orbiting the nearby star TRAPPIST-1 (Gillon et al. Nature 2017) and the discovery that this M8 V host star has very weak chromospheric compared to coronal emission (Bourrier et al. A+A 2017) raises the broader question of the relation of chromospheres to coronae in host stars. This question is important because chromospheric emission, primarily in the Lyman-alpha line, controls photochemical reactions in the outer atmospheres of exoplanets, whereas coronal X-ray emission and associated coronal mass ejections play critical roles in atmospheric mass loss. Both chromospheric and coronal emission from the host star can, therefore, determine whether a planet is habitable. I will show that the amount of emission in the Lyman-alpha line is proportional to that in X-rays for F-K dwarf stars, but that chromospheric emission becomes relatively weak in the early M dwarfs and very weak in the late-M dwarfs such as TRAPPIST-1.

Stellar emission lines formed in a star's chromosphere and transition region can be separated into narrow and broad Gaussian components with the broad components formed by microflaring events or high speed flows. I will show how the broad component activity indicator depends on stellar effective temperature and age.

I will also describe the results concerning star-planet interactions obtained by MUSCLES Treasury Survey team.

Author(s): Jeffrey Linsky[1]
Institution(s): *1. University of Colorado*
Contributing team(s): MUSCLES Treasury Survey team

201.04 – The effect of tidal heating on core dynamos in the TRAPPIST-1 system

The recent discovery of seven Earth-sized planets orbiting a nearby (12 pc) M8 dwarf TRAPPIST-1 (T1) presents the best opportunity yet to study the magnetic fields of small exoplanets. The T1 planets likely experience significant tidal heating due to their interaction with each other as well as their host star. The system bears a striking resemblance to an expanded version of the Galilean moons of the Jovian system. This similarity suggests that there may be magnetic interaction between the inner T1 planets and the host star, similar to Io and its flux tube, Europa’s induced magnetic field, and Ganymede’s intrinsic dynamo field. This work examines whether tidal effects enhance or suppress magnetic field generation in the T1 planets. Existing interior models developed in Stamenkovic et al. (2012) are adapted to include tidal heating and tailored specifically to the T1 planets in order to determine whether the interior energetics are favorable or unfavorable to a sustained magnetic dynamo over the lifetime of the system. Allowing for a range of planetary input parameters (core fraction, bulk composition, initial temperature, etc.), we quantify the influence of tidal heating on the likelihood of sustained core dynamos in the T1 planets.

Author(s): Mary Knapp[2], Vlada Stamenkovic[1]
Institution(s): *1. Caltech, 2. Massachusetts Institute of Technology*

202 – Poster Session

202.01 – We too may find new planets

Significant Scintillation of Radio Waves is caused by Plasma Instabilities. Radio Frequency radiation is emitted by a large amount extra-terrestrial sources. These radio waves contains information about these objects through the large portion of the electromagnetic spectra. Propagation of electromagnetic waves, like optical or radio waves, through a medium with random fluctuations in Refractive Index results in amplitude and phase fluctuations. In this poster we will present an amateur project exploring the possible different mechanisms of the influence of a central star or solar activity on a possible planet (e.g magnetospheric, atmospheric etc) parameters(Perez-Peraza et.al 2007). Examples of sonified spectral analysis techniques , (using earth and our sun as a probe) for the amateur astronomer are demonstrated following strict accessibility guidelines. Sunspot and magnetometer data (interplanetary magnetic field (ACE satellite) and geomagnetic field (GOES satellite)) as well as decametric antenna signals are analyzed in context of the Sun-Earth connection. Those are compared with the predictions of theoretical models of the influence of Solar activity on a possible atmosphere (Perez-Peraza et.al 2007): our amateur results and methodologies confirm the relationship between the variations of geomagnetic/atmospheric parameters and variations of galactic and solar cosmic rays modelled by Perez-Peraza et.al 2007.

Author(s): Wanda Liz Liz Diaz-Merced[1]
Institution(s): *1. South African Astronomical Observatory*
Contributing team(s): Team 1: Office of astronomy for Development ;

202.02 – Searching for Radio Emission from Young Stars and Exoplanets with the VLA Low-Frequency Sky Survey Redux

We will present recent efforts in searching for radio emission emanating from young stars in nearby star-forming regions as well as exoplanet-hosting stars. In our own solar system, cyclotron maser instability produces powerful emission associated with the interactions between plasmas and planetary magnetic fields. With its large magnetic field, cyclotron maser emission coming from Jupiter provides a significant contribution to our local radio spectrum at decameter wavelengths. By utilizing the VLA Low-Frequency Sky Survey Redux at 74 MHz, we applied image stacking analysis and Bayesian statistics in order to probe for the presence of corresponding types of emission in other systems. We look for evidence of this physical mechanism, which may provide insight into the existence and possible detection of exoplanetary magnetic fields.

Author(s): Jason Ling[1], Andrea Isella[1], Christopher Johns-Krull[1]
Institution(s): *1. Rice University*

202.03 – Occultations of Astrophysical Radio Sources as Probes of (Exo)Planetary Environments

The passage of a radio signal through a planetary atmosphere, ionosphere, or magnetosphere affects the polarization, frequency, and power of the radio signal. Radio occultations are a common experiment used to measure planetary atmospheres, but they traditionally rely on radio transmissions from a spacecraft near the planet. We explore whether similar measurements of planetary and exoplanetary environments can be made using distant astrophysical radio sources such as pulsars, active galactic nuclei, and masers. We find that occultations by solar system planets, such as Jupiter, can be used to measure planetary magnetic field strength, plasma density, and neutral density. Based on the number of known distant astrophysical radio sources, occultations by solar system planets are likely to occur often. Occultations are most likely when the solar system planets are near the intersection of the ecliptic and galactic planes. For even the closest exoplanetary systems, the low probability of alignment of the Earth, an exoplanet, and a suitable distant astrophysical radio source presents a considerable challenge. The concentration of both exoplanets and galactic radio sources in the galactic plane may alleviate this challenge somewhat, but it still appears formidable. An alternative type of occultation may be more promising for exoplanets: high-resolution radio imaging of an exoplanet as it transits in front of its parent star.

Author(s): Paul A Dalba[1], Paul Withers[1], Marissa F Vogt[2]
Institution(s): *1. Astronomy Department, Boston University, 2. Center for Space Physics, Boston University*

202.04 – Radio emission from the Ganymede-Jupiter interaction and consequence for radio emissions from exoplanets

Analysis of a catalog of 26 years of radio decameter observations from Jupiter in Nançay (France) allowed us to detect unambiguously the radio emissions resulting from the Ganymede-Jupiter interaction. The duration and power of the 189 events detected suggest sporadic reconnection with an average radio power released in the Ganymede-Jupiter decameter emission 15 times smaller than in the Io-Jupiter one. This compares well with the ratio of the magnetic power (Poynting flux) dissipated at the Ganymede-Jupiter and Io-Jupiter interactions, confirming the radio-magnetic Bode's law of Zarka et al. (2001), that serves as a basis for predicting exoplanetary radio emissions. This result improves our understanding of the interaction between a magnetized flow and an obstacle, the general paradigm of star-planet plasma interactions.

Author(s): Philippe Zarka[3], Manilo Soares-Marques[2], Corentin Louis[3], Vladimir Ryabov[1], Laurent Lamy[3], Ezequiel Echer[2], Baptiste Cecconi[3], Sébastien Hess[4], Andrée Coffre[5], Laurent Denis[5]
Institution(s): *1. Complex and Intelligent Systems Department, Future Univ. Hakodate, 2. INPE, 3. LESIA, Observatoire de Paris, CNRS, PSL, UPMC/SU, UPD, Place J. Janssen, 4. ONERA/DESP, 5. Station de Radioastronomie de Nançay, USN, Obs. Paris, CNRS, PSL, Univ. Orléans,*

202.05 – EvryFlare: Flare rates and intensities for every 10 < g' < 15 solar-type and red dwarf star in the Southern sky

Habitable-zone rocky planets orbit nearly all stars; however, stellar flares make detecting these planets and discovering their actual habitability challenging. Although *Kepler* measured flare rates for various spectral-types around distant stars, the flare rates and intensities of nearby stars available to planet searches and follow-up remain poorly characterized. High-cadence, long-timescale photometry of such stars will provide the intensity and frequency of flares incident upon nearby HZ planets. At the same time, optical counterparts to CME-exoplanet-magnetosphere searches in the radio, and potentially-reduced flare interference for radial-velocity planet searches are obtained. The EvryFlare project employs the CTIO-based Evryscope, a combination of twenty-four telescopes, together giving instantaneous sky coverage of 8000 square degrees. Solar-type and red dwarf stars are selected by color and searched with an automated flare detector. We are currently sensitive to flares down to about 10 milli-magnitudes at g' ~ 12 and about 0.2 of a magnitude at g' ~ 15. With 2-minute cadence and a projected 5-year timeline with 1.5 years already recorded, we are precisely characterizing the flare rates and intensities of bright, nearby stars. With this information, we provide insight into the frequency and relative insolation incident upon HZ planets discovered orbiting nearby stars, as well as provide optical counterparts for radio planetary magnetosphere searches.

Author(s): Ward Howard[1], Octavi Fors[1], Jeff Ratzloff[1], Hank Corbett[1], Daniel del Ser[2], Nicholas Law[1]
Institution(s): *1. The University of North Carolina at Chapel Hill, 2. Universitat de Barcelona*

202.06 – A Wire Grid Paraboloid for Large Low Frequency Telescopes

Planetary magnetic fields are usually studied remotely through their electron cyclotron maser (ECM) emission from electrons trapped in their magnetic fields. Jupiter has been well studied since the 1960's because its strong magnetic field allows emissions up to about 40 MHz to be observed. The emission from Earth and other outer planets is mostly below 1 MHz and can only be observed from space. It is reasonable to assume that most exoplanets with ECM must be observed at low frequencies from space. Even optimistic assumptions about the strength of such emission leads one to conclude that very large filled aperture telescopes, with a diameters of a kilometer or more, will be needed.

This paper reports on a study of a copper wire reflector with a diameter of 1 km operating between 100~kHz and 3.75~MHz. It would require 200~kg of 0.5~mm diameter copper wire (AWG~24)) to be lifted to and deployed in space. For aluminum, the mass would be about 100~kg. By optimizing the wire spacing the mass can be reduced to 80\% of a simple radial-azimuthal arrangement. A relatively flat reflector ($0.6 \le f/D \le 1.0$) needs to be anchored at about 5 points from center to ring along 24 radii. Station-keeping CubeSats could serve as anchors. A total of about 100-120 anchors would be needed for an $f/D = 1$ reflector, adding 200-300~kg. to the mass of the reflector. It would be possible to carry several such reflectors into space in a single payload.

The Deep Space Network is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

Author(s): Tom Kuiper[1]
Institution(s): *1. Jet Propulsion Laboratory*

202.07 – Enabling Future Large Searches for Exoplanet Auroral Emission with the EPIC Correlator Architecture

Extrasolar planets are expected to emit strong ``auroral'' emission at radio frequencies generated by the interaction of the host star's stellar winds with the planet's magnetosphere through electron-cyclotron maser emission. This transient emission lasts a few seconds to days and is almost fully circularly polarized. Detecting this emission in exoplanets is a critical probe of their magnetospheres and thus their interior compositions and habitability. The intensity and detectability of the emission depends on the suitability of many factors to the observing parameters such

as the strength of the stellar wind power, the planetary magnetosphere cross-section, the highly beamed and coherent nature of electron-cyclotron emission, and narrow ranges of the planet's orbital phase. Large areas of sky must be surveyed continuously to high sensitivity to detect auroral emission. Next-generation radio telescopes with wide fields of view, large collecting areas and high efficiency are needed for these searches. This poses challenges to traditional correlator architectures whose computational cost scales as the square of the number of antennas. I will present a novel radio aperture synthesis imaging architecture -- E-field Parallel Imaging Correlator (EPIC) -- whose all-sky and full Stokes imaging capabilities will not only address the aforementioned factors preventing detection but also solve the computational challenges posed by large arrays. Compared to traditional imaging, EPIC is inherently fast and thus presents the unique advantage of probing transient timescales ranging orders of magnitude from tens of microseconds to days at no additional cost.
Author(s): Nithyanandan Thyagarajan[1], Adam P. Beardsley[1], Judd D. Bowman[1], Miguel F. Morales[2]
Institution(s): *1. Arizona State University, 2. University of Washington*

202.08 – Exoplanetary Detection by Multifractal Spectral Analysis

Owing to technological advances, the number of exoplanets discovered has risen dramatically in the last few years. However, when trying to observe Earth analogs, it is often difficult to test the veracity of detection. We have developed a new approach to the analysis of exoplanetary spectral observations based on temporal multifractality, which identifies timescales that characterize planetary orbital motion around the host star and those that arise from stellar features such as spots. Without fitting stellar models to spectral data, we show how the planetary signal can be robustly detected from noisy data using noise amplitude as a source of information. For observation of transiting planets, combining this method with simple geometry allows us to relate the timescales obtained to primary and secondary eclipse of the exoplanets. Making use of data obtained with ground-based and space-based observations we have tested our approach on HD 189733b. Moreover, we have investigated the use of this technique in measuring planetary orbital motion via Doppler shift detection. Finally, we have analyzed synthetic spectra obtained using the SOAP 2.0 tool, which simulates a stellar spectrum and the influence of the presence of a planet or a spot on that spectrum over one orbital period. We have demonstrated that, so long as the signal-to-noise-ratio >= 75, our approach reconstructs the planetary orbital period, as well as the rotation period of a spot on the stellar surface.
Author(s): Sahil Agarwal[1], Fabio del Sordo[1], John S. Wettlaufer[1]
Institution(s): *1. Yale University*

202.09 – Development of Exoplanet database "ExoKyoto" aiming for inter-comparison with different criteria of Habitable zones

An integrated database of confirmed exoplanets has been developed and launched as “ExoKyoto,” for the purpose of better comprehension of exoplanetary systems in different star systems. The HOSTSTAR module of the database includes not only host stars for confirmed exoplanets, but also hundreds of thousands of stars existing in the star database listed in (HYG database). Each hoststar can be referred to in the catalogue with its habitable zone calculated, based on the observed/estimated star parameters. For outreach and observation support purpose, ExoKyoto possesses Stellar Windows, developed by the Xlib & Ggd module, and interfaces with GoogleSky for easy comprehension of those celestial bodies on a stellar map. Target stars can be identified and listed by using this database, based on the target magnitude, transit frequency, and photon decrease ratio by its transit.

If we interpolate deficient data using assumed functions about the exoplanets that were discovered until now, Sub-Neptune size (1.9-3.1R_Earth) are the most common (971); then Super Earth size (1.2-1.9 R_earth) have been allocated (681).

Using the Solar Equivalent Astronomical Unit (SEAU), most of the exoplanets discovered are within a Venus equivalent orbit (3029), and 197 are located within the habitable zone (Venus to Mars equivalent orbit). If we classify them using Kopparapu et al.(2013), within Recent Venus equivalent orbit (3048), there are 130 located in the habitable zone (runaway greenhouse-maximum greenhouse). For example, Kepler-560b is defined as in the habitable zone by its SEAU, but not by Kopparapu et al. (2013). Furthermore, based on an exoplanet’s solar revolution, radius, assumed mass (Larsen & Geoffrey, 2014), transit parameters , and main start information (location, class, spectral class, etc.); observation target selection is practical and possible.

In addition to the previous habitable zone based on the normal radiation flux from the host star, we’ll discuss stellar flares activities which may disturb planets located in the habitable zone through high energetic particles.

*those numbers are in February 2017
Author(s): Yosuke Yamashiki[1], Yuta Notsu[1], Takanori Sasaki[1], Natsuki Hosono[1], Ryusuke Kuroki[1], Shota Notsu[1], Keiya Murashima[1], Fuka Takagi[1], Takao Doi[1]
Institution(s): *1. Kyoto University*
Contributing team(s): Astrobiology & Habitability Research Group

202.10 – Surveying the Sky at Low Frequencies with the Commensal VLITE System

We present details of a new commensal observing program on NRAO's Karl G. Jansky Very Large Array (VLA). The VLA Low-band Ionosphere and Transient Experiment (VLITE) provides a simultaneous sub-GHz data stream during all Cassegrain (1-50 GHz) observations. This unique low frequency opportunity opens up over 6000 hours per year of VLA observing time to the low frequency community. In the first 2 1/4 years of operation, VLITE processed images cover regions containing 2,322 unique exoplanets in 62,000 individual scans. VLITE observations provide a large database to observe samples of nearby stellar systems, enabling a powerful means of monitoring these systems for stellar activity as well as emission from exoplanets.

Author(s): Tracy Clarke[2], Namir E. Kassim[2], Emily Richards[1], Wendy Peters[2], Emil Polisensky[2]
Institution(s): *1. NRC, 2. NRL*

202.11 – Expanding CME-flare relations to other stellar systems

Stellar activity is one of the main parameters in exoplanet habitability studies. While the effects of UV to X-ray emission from extreme flares on exoplanets are beginning to be investigated, the impact of coronal mass ejections is currently highly speculative because CMEs and their properties cannot yet be directly observed on other stars. An extreme superflare was observed in X-rays on the Algol binary system on August 30 1997, emitting a total of energy 1.4x 10^{37} erg and making it a great candidate for studying the upper energy limits of stellar superflares in solar-type (GK) stars. A simultaneous increase and subsequent decline in absorption during the flare was also observed and interpretted as being caused by a CME. Here we investigate the dynamic properties of a CME that could explain such time-dependent absorption and appeal to trends revealed from solar flare and CME statistics as a guide. Using the ice-cream cone model that is extensively used in solar physics to describe the three-dimensional CME structure, in combination with the temporal profile of the hydrogen column density evolution, we are able to characterize the CME and estimate its kinetic energy and mass. We examine the mass, kinetic and flare X-ray fluence in the context of solar relations to examine the extent to which such relations can be extrapolated to much more extreme stellar events.

Author(s): Sofia P Moschou[2], Jeremy J Drake[2], Ofer Cohen[1]
Institution(s): *1. Lowell Center for Space Science and Technology, 2. Smithsonian Astrophysical Observatory*

Tuesday Discussion

300 – Observations of Stars, Brown Dwarfs, and Exoplanets I

300.01 – Ultraviolet Observations of Star-planet Interactions – Current Status and Future Directions

Interactions between exoplanets and their host stars are the dominant factors in determining the composition, chemical state, and stability of planetary atmospheres. In this talk, I will discuss the various forms that these Star-Planet Interactions (SPI) can take, and in particular how these processes are traced with ultraviolet (90 – 320 nm) observations. I will first address stellar inputs into exoplanetary atmospheres, focusing on how the high-energy radiation and particle environments influence atmospheric photochemistry and escape, on both rocky and gas giant planets. I will then consider magnetic interactions between planets and their host stars, and discuss how ultraviolet stellar observations may be used to infer the presence of exoplanetary magnetic fields. I will discuss these SPIs in the context of recent observations made by the Hubble Space Telescope and present future observational directions using small satellites, Hubble, and large missions such as LUVOIR and HabEx.

Author(s): Kevin France[1]
Institution(s): *1. University of Colorado*
Contributing team(s): MUSCLES Treasury Survey, CUTE mission

300.02 – Simultaneous Radio and UV Observations of Brown Dwarfs: Looking for the UV Counterpart to Auroral Radio Emission

The strong rotationally pulsed radio emission observed from some ultracool dwarfs provides strong evidence for the existence of highly accelerated energetic electron beams powered by strong magnetospheric current systems pervading their magnetospheres. These beams precipitate into the cool atmosphere, depositing their energy, and generating a host of multi-wavelength auroral emissions, like Hα. We report on our simultaneous VLA and HST-COS observations of known radio brown dwarfs looking to observe the electronically excited emissions of molecular hydrogen in the far ultraviolet and their relation to known auroral radio emissions. Our monitoring observations of the radio ultracool dwarfs TVLM513-46546 and LSRJ1836+3259 show no strong indications of any FUV emission, despite significant rotational phase coverage over the course of the Hubble orbits. We discuss potential implications of these results for the strength of the auroral electron beams, atmospheric energy deposition and the possibility of significant atmospheric absorption. We use these results to motivate considerations for the ability of future missions like LUVOIR to detect brown dwarf UV auroral emissions.

Author(s): J. Sebastian Pineda[2], Gregg Hallinan[1], Kevin France[2]

Institution(s): *1. California Institute of Technology, 2. University of Colorado Boulder Laboratory for Atmospheric and Space Physics*

300.03 – The Breakthrough Listen Initiative and the Future of the Search for Intelligent Life

Unprecedented recent results in the fields of exoplanets and astrobiology have dramatically increased the interest in the potential existence of intelligent life elsewhere in the galaxy. Additionally, the capabilities of modern Searches for Extraterrestrial Intelligence (SETI) have increased tremendously. Much of this improvement is due to the ongoing development of wide bandwidth radio instruments and the Moore's Law increase in computing power over the previous decades. Together, these instrumentation improvements allow for narrow band signal searches of billions of frequency channels at once.
The Breakthrough Listen Initiative (BL) was launched on July 20, 2015 at the Royal Society in London, UK with the goal to conduct the most comprehensive and sensitive search for advanced life in humanity's history. Here we detail important milestones achieved during the first year and a half of the program. We describe the key BL SETI surveys and briefly describe current facilities, including the Green Bank Telescope, the Automated Planet Finder and the Parkes Observatory. We also mention the ongoing and potential collaborations focused on complementary sciences, these include pulse searches of pulsars and FRBs, as well as astrophysically powered radio emission from stars targeted by our program.
We conclude with a brief view towards future SETI searches with upcoming next-generation radio facilities such as SKA and ngVLA.

Author(s): J. Emilio Enriquez[2], Andrew Siemion[1], Steve Croft[1], Greg Hellbourg[1], Matt Lebofsky[1], David MacMahon[1], Danny Price[1], David DeBoer[1], Dan Werthimer[1]
Institution(s): *1. UC Berkeley, 2. UC Berkeley / Radboud University Nijmegen*
Contributing team(s): Breakthrough Listen

300.04 – SETI Observations of Low Mass Stars at the SETI Institute

Are planets orbiting low-mass stars suitable for the development of life? Observations in the near future, including radio, will help to assess whether atmospheres do persist over long timescales for planets orbiting nearby M dwarfs, and clarify the nature of the radiation that penetrates to the surface of these planets. These are important ingredients for assessing planetary habitability, yet the question of habitability can be answered only with the positive measurement of an unambiguous biosignature. Radio and optical SETI observations capable of detecting technological activities of intelligent inhabitants could provide the most compelling evidence for the habitability of exoplanets orbiting M dwarfs. In this presentation we shall consider what information can be gleaned from our observations so far. The SETI Institute is currently undertaking a large survey of 20,000 low mass stars that is now about 30% complete. The frequency coverage on each star is about 450 MHz bandwidth (per star) over a range of selected frequencies from 1-10 GHz. From these observations we derive quantitative results relating to the probability that M dwarfs are actually inhabited.

Author(s): Gerald R Harp[1]
Institution(s): *1. SETI Institute*

400 – Observations of Stars, Brown Dwarfs, and Exoplanets II

400.01 – Chasing Low Frequency Radio Bursts from Magnetically Active Stars

Flaring activity is a common characteristic of magnetically active stars. These events produce emission throughout the electromagnetic spectrum, implying a range of physical processes. A number of objects exhibit short-duration, narrow band, and highly circularly polarised (reaching 100%) radio bursts. The observed polarisation and frequency-time structure of these bursts points to a coherent emission mechanism such as the electron cyclotron maser. Due to the stochastic nature of these bursts and the sensitivity of current instruments, the number of stars where coherent emission has been detected is few, with numbers limited to a few tens of objects. Observations of a wider sample of active stars are necessary in order to establish the percentage that exhibit coherent radio bursts and to relate the observed emission characteristics to stellar magnetic properties. New wide-field, low frequency radio telescopes will probe a frequency regime that is mostly unexplored for many magnetically active stars and where coherent radio emissions are expected to be more numerous. M dwarf stars are of particular interest as they are currently favoured as most likely to host habitable planets. Yet the extreme magnetic activity observed for some M dwarf stars places some doubt on the ability of orbiting planets to host life. This presentation reports the first results from a targeted Murchison Widefield Array survey of M dwarf stars that were previously detected at 100 - 200 MHz using single dish telescopes. We will discuss robust flare-rate measurements over a high dynamic range of flare properties, as well as investigate the physical mechanism(s) behind the flares.

Author(s): Christene Lynch[2], Tara Murphy[2], David Kaplan[1]
Institution(s): *1. Univeristy of Wisconsin, Milwaukee, 2. University of Sydney*

400.02 – Radio Optical Multiwavelength Stellar Flares and Constraints on the Electron Population from a Joint Analysis

The accelerated particles produced in stellar magnetic reconnection events are important in shaping the habitable environment around the star. Radio gyrosynchrotron flares trace the presence and action of accelerated electrons high in the stellar atmosphere, while flares observed at optical wavelengths probe the response lower in the stellar atmosphere to the heating provided by electron beams. We present the results of a several day multi wavelength observing campaign on the nearby flare star EV Lac. The multifrequency radio observations probe the non thermal particle energy and its dependence on the index of the power-law distribution of particle energy as well as the magnetic field strength, while optical observations constrain optical radiated energy and limits on total bolometric flare radiated energy. We discuss how the spectral shape of the optical flares can potentially constrain the lower limit of the electron population, and what the coincidence or lack thereof of simultaneously observed flares tells us about the generalness of flare processes.

Author(s): Rachel Osten[1], Adam Kowalski[2]
Institution(s): *1. Space Telescope Science Institute, 2. University of Colorado Boulder*

400.03 – Statistical studies of superflares on G-, K-, M- type stars from Kepler data

Flares are thought to be sudden releases of magnetic energy stored around starspots. Recent space high-precision photometry shows “superflares”, 10-10^4 times more energetic than the largest solar flares, occur on many G, K, M-type stars (e.g., Maehara+2012 Nature). Harmful UV/X-ray radiation and high-energy particles such as protons are caused by such superflares. This may suggest that exoplanet host stars have severe effects on the physical and chemical evolution of exoplanetary atmospheres (cf. Segura+2010 Astrobiology, Takahashi+2016 ApJL).

We here present statistical properties of superflares on G, K, M-type stars on the basis of our analyses of Kepler photometric data (Maehara+2012 Nature, Shibayama+2013 ApJS, Notsu+2013 ApJ, Canderaresi+2014 ApJ, Maehara+2015 EPS, Maehara+2017 PASJ). We found more than 5000 superflares on 800 G, K, M-type main-sequence stars, and the occurrence frequency (dN/dE) of superflares as a function of flare energy (E) shows the power-law distribution with the index of -1.8~-1.9. This power-law distribution is consistent with that of solar flares. Flare frequency increases as stellar temperature decreases. As for M-type stars, energy of the largest flares is smaller compared with G,K-type stars, but more frequent “hazardous” flares for the habitable planets since the habitable zone around M-type stars is much smaller compared with G, K-type stars.

Rotation period and starspot coverage can be estimated from the quasi-periodic brightness variation of the superflare stars. The intensity of Ca II 8542 line of superflare stars, which is measured from spectroscopic observations with Subaru Telescope, has a well correlation with the brightness variation amplitude (Notsu+2015a&b PASJ).

Flare frequency has a correlation with rotation period, and this suggests young rapidly-rotating stars (like “young Sun”) have more severe impacts of flares on the planetary atmosphere (cf. Airapetian+2016 ApJL). Flare energy and frequency also depends on starspot coverage, and this suggests existence of large starspots is important factor of superflares.

These statistical properties of superflares discussed here can be one of the basic information for considering the impacts of flares on planet-host stars.

Author(s): Yuta Notsu[2], Hiroyuki Maehara[3], Satoshi Honda[4], Shota Notsu[2], Kosuke Namekata[2], Kai Ikuta[2], Daisaku Nogami[2], Kazunari Shibata[1]
Institution(s): *1. Kwasan and Hida Observatories, Kyoto University, 2. Kyoto University, 3. NAOJ, 4. University of Hyogo*

400.04 – Wideband radio dynamic spectroscopy and astrometry of magnetic storms on active M dwarfs

Coronal mass ejections (CMEs) and stellar energetic particles may dramatically impact habitability and atmospheric composition of planets around magnetically active stars, including young solar analogs and many M dwarfs. I will present the results of a search for the spectral and spatial signatures of stellar eruptions on active M dwarfs with the Karl G. Jansky Very Large Array (VLA) and the Very Long Baseline Array (VLBA). The 58-hour VLA survey uses wideband dynamic radio spectroscopy from 0.25-6 GHz to characterize the population of coherent radio bursts on these stars and search for frequency drift indicative of source motion. 24 hours of simultaneous 8.5-GHz VLBA imaging reveal the location of coherent and incoherent radio bursts relative to the star's quiescent radio corona, identifying extended or off-limb components during flares. The coherent radio emission at the observed frequencies is dominated by long-duration bursts with strong circular polarization, originating from a continuously replenished supply of energetic electrons in the large-scale stellar magnetic field.

Author(s): Jacqueline Villadsen[3], Gregg Hallinan[1], Stephen Bourke[2], Ryan Monroe[1]

Institution(s): *1. California Institute of Technology, 2. Chalmers University of Technology, 3. National Radio Astronomy Observatory*

400.05 – Radio Cycles in the Lowest Mass Stars

The strength, structure and variability of stellar magnetic fields generated by internal dynamos provide one of the few means of probing stellar interiors and testing stellar magnetohydrodynamic models. While the distinct dynamo mechanisms of sun-like stars and Jovian planets are fairly well understood, these mechanisms cannot explain the generation of large-scale, structured, kilogauss fields around fully convective very low-mass (VLM) stars and brown dwarfs. Using radio emission as our probe, we are undertaking a radio monitoring survey to search for and characterize magnetic cycling in the lowest-mass stars and brown dwarfs. We report the results of our pilot program, monitoring of the M7+M7 young binary NLTT 33370AB and the L5+T7 old binary 2MASS J1315-2649AB. For NLTT 33370AB, we find both long-term (~5 yr) amplitude variations of order 0.5 mJy, and tentative evidence of a 4-month modulation with an amplitude of 0.1 mJy. The first period is close to double the binary orbit period (9.6 yr), suggesting potential star-star interaction; the latter could be associated with magnetic cycling. For 2MASS J1315–2649AB, we find an overall decline in quiescent emission from its initial ATCA detection in 2011, and evidence of a low-amplitude (0.01 mJy) oscillation with a period of ~8 months. Both sources also show regular short-term (daily) variations which may be rotationally induced or originate from flares. I briefly describe a proposed follow-up survey of 20 VLM dwarfs combining optical and radio monitoring.

Author(s): Adam Burgasser[3], Carl Melis[3], Peter K. G. Williams[1], Russell Van Linge[2]
Institution(s): *1. Harvard CfA, 2. Palomar College, 3. UC San Diego*

400.06 – Constraining Fully Convective Magnetic Dynamos using Brown Dwarf Auroral Radio Emission

An important outstanding problem in dynamo theory is understanding how magnetic fields are generated and sustained in fully convective objects, spanning stars through planets. For fully convective dynamo models to accurately predict exoplanet magnetic fields, pushing measurements to include the coolest T and Y dwarfs at the substellar-planetary boundary is critical. A number of models for possible dynamo mechanisms in this regime have been proposed but constraining data on magnetic field strengths and topologies across a wide range of mass, age, rotation rate, and temperature are sorely lacking, particularly in the brown dwarf regime.

Detections of highly circularly polarized pulsed radio emission provide our only window into magnetic field measurements for objects in the ultracool brown dwarf regime. However, these detections are very rare; previous radio surveys encompassing ~60 L6 or later targets have yielded only one detection. We have developed a selection strategy for biasing survey targets by leveraging the emergence of magnetic activity that is driven by planet-like auroral processes in the coolest brown dwarfs. Using our selection strategy, we previously observed six late L and T dwarfs with the Jansky Very Large Array (VLA) at 4-8 GHz and detected the presence of highly circularly polarized radio emission for five targets. Our initial detections provided the most robust constraints on dynamo theory in this regime, confirming magnetic fields >2.5 kG. To further probe the mechanisms driving fully convective dynamos at the substellar-planetary boundary, we present magnetic field constraints for two Y-dwarfs and 8-12 GHz radio observations of late L and T dwarfs corresponding to >3.6 kG surface fields. We additionally present initial results for a comprehensive L and T dwarf survey spanning a wide range of rotation periods to test rotation-dominated dynamo models. Finally, we present a method for comparing magnetic field measurements derived from auroral radio emission to measurements derived from Zeeman broadening and show that the dynamo operating in the lowest mass brown dwarf regime may challenge predictions from a recently proposed planetary dynamo model.

Author(s): Melodie Kao[1], Gregg Hallinan[1], J. Sebastian Pineda[4], Ivanna Escala[1], Adam Burgasser[3], Stephen Bourke[2], David Stevenson[1]
Institution(s): *1. California Institute of Technology, 2. Chalmers University Technology, 3. University of California, San Diego, 4. University of Colorado, Boulder*

401 – Observations of Stars, Brown Dwarfs, and Exoplanets III

401.01 – The OVRO-LWA: An Extrasolar Space Weather Monitoring Station

The OVRO-LWA is a new array at Caltech's Owens Valley Radio Observatory which images the entire viewable sky at 24-82 MHz (2400 channels) every ~10 seconds. It currently consists of 288 dual-polarization antennas spanning 1.6 km but will eventually expand to 352 antennas spanning 2.5 km, giving a resolution of ~5 arcminutes in each all-sky image. One of the primary science goals of the OVRO-LWA is the continuous monitoring of 1000s of stellar systems to search for extrasolar space weather, i.e., the highly variable and circularly polarized radio emission produced during stellar coronal mass ejections and planetary auroral events. Our final design sensitivity will allow all-sky Stokes I and V images with rms noise of 100 mJy in 10 seconds, all-sky Stokes V images with rms noise of 5 mJy every day and Stokes V images with 500 microJy noise after a 1000-hour integration. Simultaneous monitoring of a large fraction of our targets is provided by the Evryscope, a new optical telescope that can image 8,600 square degrees simultaneously, producing two-minute-cadence multi-year light curves for every star brighter than Sloan g = 16.5, thereby investigating the presence of flare emission associated with CMEs detected by the OVRO-LWA. I will introduce the OVRO-LWA and describe the enormous technical and data challenges in delivering continuous all-sky imaging at low frequencies in pursuit of extrasolar space weather.

Author(s): Gregg Hallinan[1], Marin M Anderson[1]
Institution(s): *1. California Institute of Technology*

401.02 – Monitoring nearly 4000 nearby stellar systems with the OVRO-LWA in search of radio exoplanets

Recent results from our own solar system demonstrate the importance of not only stellar magnetic activity, but also the critical importance of planetary magnetic field strength, in determining the conditions for planetary habitability. The detection of planetary radio emission from objects beyond the solar system will provide the first direct measurements of exoplanetary magnetic field strengths, as well as provide insight on the degree to which those magnetospheres can shield exoplanet atmospheres against the surrounding space weather environment. But despite observations spanning nearly 4 decades, previous searches for direct detection of exoplanetary radio emission have resulted in non-detections. However, these were limited by a number of factors, including limited access to sensitive telescopes operating below 100 MHz and the restriction that such observations are typically only a few hours in duration, thereby insensitive to the long term variability of planetary radio emission. Particularly, short-duration observations are insensitive to rare brightening events associated with coronal mass ejection events, similar to what we see in our own solar system, where Earth's auroral radio emission can increase by orders of magnitude during strong geomagnetic storms. What is needed are wide-field, long-duration surveys at frequencies below 100 MHz, with the capability of monitoring thousands of objects simultaneously, in order to detect exoplanetary radio emission.

We are conducting the largest survey for radio exoplanets to date with the Owens Valley Radio Observatory Long Wavelength Array (OVRO-LWA). This all-sky field-of-view, combined with high time- and frequency-resolution, makes OVRO-LWA currently the most powerful instrument for searching for the exoplanetary radio emission resulting from the interaction of the exoplanet's magnetosphere with its host star stellar wind. I will discuss initial results from our first survey of a volume-limited sample of nearly 4000 stellar and substellar objects out to 25 pc, including approximately 1100 FGK-dwarfs, 1300 M-dwarfs, and 1100 LTY-dwarfs (likely substellar).

Author(s): Marin M Anderson[1], Gregg Hallinan[1]
Institution(s): *1. California Institute of Technology*

401.03 – The Search for Radio Emission from Exoplanets Using LOFAR Low-Frequency Beam-Formed Observations: Preliminary Results on the 55 CNC System

Detection of radio emission from exoplanets can provide information on the star-planet system that is very difficult or impossible to study otherwise, such as the planet's magnetic field, magnetosphere, rotation period, orbit inclination, and star-planet interactions. Such a detection in the radio domain would open up a whole new field in the study of exoplanets, however, currently there are no confirmed detections of an exoplanet at radio frequencies. In this study, we search for non-thermal radio emission from 55 Cnc, an exoplanetary system with 5 planets. 55 Cnc is among the best targets for this search according to theoretical predictions. We observed for 18 hours with the Low-Frequency Array (LOFAR) in the frequency range 26-73 MHz with full-polarization and and covered 85% of the orbital phase of the innermost planet. During the observations four beams were recorded simultaneously on 55 Cnc, a patch of nearby "empty" sky, the nearby pulsar B0823+26, and a bright radio source in the field. The extra beams make this setup unique since they can be used for control of the telescope gain and to verify that a detection in the exoplanet beam is not a false-positive detection (e.g. ionospheric fluctuations). An automatic pipeline was created to automatically find Radio Frequency Interference (RFI) and to search for emission in the exoplanet beam. Conclusions reached at the time of the meeting, about detection of or upper limit to the planetary signal, will be presented. In the near future, we will apply this observational technique and pipeline to some more planetary targets, which were selected on the basis of theoretical predictions.

Author(s): Jake Turner[4], Jean-Mathias Griessmeier [1], Philippe Zarka[3], Iana Vasylieva[2]
Institution(s): *1. Laboratoire de Physique et Chemie de l'Environment et de l'Espace (LPC2E) Université d'Orléans/CNRS, 2. Institute of Radio Astronomy, National Academy of Sciences of Ukraine , 3. LESIA & USN, Observatoire de Paris, 4. University of Virginia*

401.04 – Surveying for Exoplanetary Auroral Radio Emission with HERA

HERA, the Hydrogen Epoch of Reionization Array, is a long wavelength radio telescope under construction in South Africa. Although HERA's primary science driver is the search for radio signatures of the Epoch of Reionization, its large collecting area, excellent calibratability, and methodical observing scheme make it a world-class tool for time-domain radio astronomy as well. In particlar, the completed HERA array will be sensitive to auroral radio bursts from planets with auroral powers and magnetic field strengths comparable to (factors of a few larger than) those of Jupiter, assuming a fiducial distance of 10 pc. HERA will log thousands of hours monitoring the stellar systems in its sky footprint, including the ~40 systems found within this fiducial horizon. In this talk I will describe the current status of HERA and its future prospects for directly detecting exoplanetary magnetospheres.

Author(s): Peter K. G. Williams[1], Edo Berger[1]
Institution(s): *1. Harvard*
Contributing team(s): HERA Collaboration

401.05 – Planetary Magnetic Fields: Planetary Interiors and Habitability W. M. Keck Institute for Space Studies Report

The W. M. Keck Institute for Space Studies (KISS) sponsored the "Planetary Magnetic Fields: Planetary Interiors and Habitability" study to review the state of knowledge of extrasolar planetary magnetic fields and the prospects for their detection.

There were multiple motivations for this Study. Planetary-scale magnetic fields are a window to a planet's interior and provide shielding of the planet's atmosphere. The Earth, Mercury, Ganymede, and the giant planets of the solar system all contain internal dynamo currents that generate planetary-scale magnetic fields. In turn, these internal dynamo currents arise from differential rotation, convection, compositional dynamics, or a combination of these in objects' interiors. If coupled to an energy source, such as the incident kinetic or magnetic energy from the solar wind or an orbiting satellite, a planet's magnetic field can produce intense electron cyclotron masers in its magnetic polar regions. The most well known example of this process in the solar system is the Jovian decametric emission, but all of the giant planets and the Earth contain similar electron cyclotron masers within their magnetospheres. Extrapolated to extrasolar planets, the remote detection of the magnetic field of an extrasolar planet would provide a means of obtaining constraints on the thermal state, composition, and dynamics of its interior---all of which will be difficult to determine by other means---as well as improved understanding of the basic planetary dynamo process.

We review the findings from the Study, including potential mission concepts that emerged and recent developments toward one of the mission concepts, a space-based radio wavelength array. There was an identification of that radio wavelength observations would likely be key to making significant progress in this field.

We acknowledge ideas and advice from the participants in the "Planetary Magnetic Fields: Planetary Interiors and Habitability" study organized by the W. M. Keck Institute for Space Studies. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Author(s): T. Joseph Lazio[3], Evgenya Shkolnik[1], Gregg Hallinan[2]
Institution(s): *1. Arizona State University, 2. California Institute of Technology, 3. Jet Propulsion Laboratory, California Institute of Technology*

500 – Observations of Stars, Brown Dwarfs, and Exoplanets IV

500.01 – Radio Observations of V830 Tau

We report the discovery of radio emission from the T Tauri star, V830 Tau. Optical spectroscopic measurements have shown V830 Tau to be the host to a hot Jupiter. VLA and VLBA observations detect radio emission from the system, which is time variable and compact. This is the first detection of radio emission from a non-degenerate star with a known exoplanet. We discuss prospects for further detection and characterization of this system including requirements for exoplanet detection through light curve monitoring, low frequency observations, and astrometry.

Author(s): Geoffrey Bower[1]
Institution(s): *1. ASIAA*

500.02 – Arecibo Observations of Low-Mass Stars, Brown Dwarfs, and Exoplanets

I will discuss the Arecibo programs designed to detect flaring radio emission from the very low-mass stars, the coolest brown dwarfs, and giant exoplanets. In particular, I will present the most recent detections of flares from two T-type brown dwarfs, which suggest that the same should be possible for hot, young exoplanets such as the relatively nearby HR8799 system. I will also discuss the results of a long-term monitoring of an M9-star, TVLM 513-46546, used as a proxy for the design of a larger M-dwarf monitoring project.

Author(s): Aleksander Wolszczan[1]
Institution(s): *1. Penn State University*
Contributing team(s): Gabriel Ortiz Pena

500.03 – Are We Observing Coronal Mass Ejections in OH/IR AGB Stars?

Solar Coronal Mass Ejections (CMEs) are magnetic electron clouds that are violently ejected by the same magnetic reconnection events that produce Solar flares. CMEs are the major driving source of the hazardous space weather environments near the Earth. In exoplanet systems, the equivalent of Solar wind and CMEs can affect a planet's

atmosphere, and in extreme cases can erode it, as probably happened with Mars, or disrupt the cosmic-ray shielding aspect of the planet's magnetic field.

We (Jensen et al. 2013SoPh..285...83J, 2016SoPh..291..465J) have developed a new way to observe the electron column density and magnetic field of CMEs, namely to measure the frequency change and Faraday rotation of a spacecraft downlink carrier produced by propagation effects in the plasma. Surprisingly, this can work on other stars if they have the equivalent of the spacecraft carrier, as do OH/IR stars.

OH/IR stars are Asymptotic Giant Branch (AGB) stars, which are red giant stars burning He in their final stages of stellar evolution. They have highly convective surfaces and large mass-ejection rates in the form of expanding dense shells of molecular gas and obscuring dust, which were ejected from the star by chaotic turbulent motions and then accelerated by radiation pressure. OH masers reside in these shells, pumped by the IR emission from the dust. The OH masers on the far side of the star (i.e., the positive-velocity masers) are the surrogate for the Solar-case spacecraft signal.

The big question: Can we see CMEs in OH/IR stars? We have observed six OH/IR stars with the Arecibo Observatory for a total of about 150 hours over the past 1.5 years. We see changes in OH maser frequency and in the position angle of linear polarization. Both can be produced by electron clouds moving across the line of sight. We will present statistical summaries of the variability and interpret them in terms of CME models.

Author(s): Carl Heiles[1]
Institution(s): *1. university of california, berkeley*

500.04 – The Orion Radio All-Stars: extreme YSO radio and X-ray variability

The sensitivity upgrades of both the NRAO Very Large Array (VLA) and the NRAO Very Long Baseline Array (VLBA) have begun to provide us with a much improved perspective on stellar centimeter radio emission, particularly concerning young stellar objects (YSOs) and ultracool dwarfs. I will mainly present a deep VLA and VLBA radio survey of the Orion Nebula Cluster (ONC), where we have found 556 compact radio sources, a sevenfold increase over previous studies, and intricate detail on the radio emission of proplyds. We can now better disentangle thermal and nonthermal radio emission by assessing spectral indices, polarization, variability, and brightness temperatures (VLBA). With simultaneous radio-X-ray time domain information (Chandra), this project is providing unprecedented constraints on the magnetospheric activity of YSOs across a wide mass range, including the massive Trapezium stars and their impact on the interstellar medium. A particular focus of this talk will be the occurrence of radio flares in Orion and their correlation with X-ray flares. Starting with our ongoing Orion observations, I will additionally discuss the use of the VLBA for precision stellar astrometry in the Gaia era, highlighting how VLBI astrometry is allowing us to extend the Gaia sample of YSOs and ultracool dwarfs by including embedded objects, distant obscured sources in the Galactic plane, and faint ultracool dwarfs, while providing important opportunities for astrometric cross-calibration.

Author(s): Jan Forbrich[1]
Institution(s): *1. Harvard-Smithsonian CfA*

500.05 – Kepler-96 flares and their impact on the transiting planet

We present the occurrence of superflares seen on the lightcurve of the active star Kepler-96a. This star harbors a Neptune-size planet orbiting very close to the star. Our analysis is based on the four years of continuous short cadence observation of the star by the Kepler telescope. The model used here simulates a planetary transit and allows the insertion of a flare in the stellar disc with different size, amplitude, and position. By fitting the observational data with this model, it is possible to infer the physical properties of the flares. The model fitting of the flare peaks seeing during the transit yields the estimate of the duration (few minutes) and energy released by each flare. The biggest flare observed was found to have an energy of 9x10^35 ergs, that corresponds to the energy range of the superflares found in literature. We analyze the impact of these flares on the close by planet.

Author(s): Adriana Valio[1], Raissa Estrela[1]
Institution(s): *1. Mackenzie Presbyterian University*

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