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How Surface Gravity Affects Hot Jupiters' Atmospheres

To understand the compositions and formation processes of giant exoplanets, also need to understand the structure of their atmospheres. I will discuss the results of recent ground- and space-based spectroscopic eclipse observations of a transiting brown dwarf and a hot Jupiter, which indicate a transition in atmospheric structure as a function of planetary surface gravity. This transition agrees with predictions made by "cold-trap" atmosphere models, and these results are the first observational evidence for cold-trap processes occurring in hot Jupiters. Further observations of this phenomenon will allow us to place constraints on cloud formation processes in hot Jupiters. This will enhance planetary abundance measurements, by improving our ability to differentiate between clouds or variable abundances in the spectroscopic signatures of individual planetary atmospheres. In this way, understanding what sets the structure of hot Jupiters' atmospheres will allow us to understand their compositions, and hence their formation processes.

Oral Presentation

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Using Gaia To Identify Targets for WFIRST Imaging

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Rahul Patel (JPL), Tiffany Meshkat (IPAC), Geoff Bryden (JPL)

The WFIRST coronagraph will provide an unprecedented ability to detect and characterize gas giant planets via reflected starlight. A knowledge of the orbits of WFIRST targets will be important in scheduling imaging observations and measurements of planet masses will be important in the interpretation of the imaging data. Many WFIRST targets will be drawn from planets already known from radial velocity studies. However, the availability of astrometrically detected candidates from the Gaia mission will make a new set of candidates available, e.g. orbiting stars earlier than ~F5 which are inaccessible to RV measurements. Gaia will also provide full orbital solutions for previously yielding stellar masses, not just M x sin(i). We are carrying out a preliminary study of the overlap between WFIRST and Gaia samples to assess how many new targets, or targets with improved parameters, Gaia might bring to the WFIRST.

Poster

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Methods to Directly Image Exoplanets around Alpha Centauri and Other Multi-Star Systems

Ruslan Belikov, Dan Sirbu, Eduardo Bendek, Eugene Pluzhnik, Stuart Shaklan, AJ Riggs

The majority of FGK stars exist as multi-star star systems, and thus form a potentially rich target sample for direct imaging of exoplanets. A large fraction of these stars have starlight leakage from their companion that is brighter than rocky planets. This is in particular true of Alpha Centauri, which is 2.4x closer and about an order of magnitude brighter than any other FGK star, and thus may be the best target for any direct imaging mission, if the light of both stars can be suppressed. Thus, the ability to suppress starlight from two stars improves both the quantity and quality of Sun-like targets for missions such as WFIRST, LUVOIR, and HabEx.
We present an analysis of starlight leak challenges in multi-star systems and techniques to solve those challenges, with an emphasis on imaging Alpha Centauri with WFIRST. For the case of internal coronagraphs, the fundamental problem appears to be independent wavefront control of multiple stars (at least if the companion is close enough or bright enough that it cannot simply be removed by longer exposure times or post-processing). We present a technique called Multi-Star Wavefront Control (MSWC) as a solution to this challenge and describe the results of our technology development program that advanced MSWC to TRL~3. Our program consisted of lab demonstrations of dark zones in two-star systems, validated simulations, as well as simulated predictions demonstrating that with this technology, contrasts needed for Earth-like planets are in principle achievable. We also demonstrate MSWC in Super-Nyquist mode, which allows suppression of multiple stars at separations greater than the spatial Nyquist limit of the deformable mirror.

Oral Presentation

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The Very Low Albedo of WASP-12b from Spectral Eclipse Observations with Hubble

Optical reflected light observations of short-period, massive exoplanets (hot Jupiters) often result in stringent non-detections, suggesting that these planets are remarkably black (<10% reflective). This is in stark contrast to Spitzer observations of the thermal emissions from these planets which suggest that they reflect ~40% of the total incident stellar energy; this apparent paradox has been termed the Albedo Problem. However, most reflected light observations have used broadband photometry (Kepler, CoRoT, and MOST). It is assumed that the atmospheres of these planets will demonstrate Rayleigh scattering which has a wavelength to the negative fourth power dependence, so the faint, red component of these past observations may have drowned out the stronger reflection towards the blue end of the spectrum. This theory can be tested with UV-blue reflected light observations of hot Jupiters during secondary eclipse (planet passing behind star) using HST/STIS spectra. I will present the results of my recent analysis of such measurements made for WASP-12b and the insight they can give into the Albedo Problem.

Oral Presentation

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Enabling Super-Nyquist Wavefront Control on WFIRST

A large fraction of sun-like stars are contained in Binary systems. There are 70 FGK stars within 10pc from which, 43 belong to a multi-star system, and 28 of them have companion leak that is greater than 1e-9 contrast, assuming typical Hubble-quality space optics. Currently those binary stars are not included in the WFIRST target list. Therefore, enabling high-contrast imaging in binary system would increase by 70% the number of possible FGK targets for the mission.

The Multi-Star Wavefront Control (MSWC) algorithm can be used to suppress the companion star leakage. However, for the case of WFIRST, about half of the targets that can be observed using MSWC have angular separations beyond the Nyquist controllable region of the 48x48 actuator Deformable Mirror (DM) to be used. Thus, the MSWC must operate in its Super-Nyquist (SN) mode, which requires a target star replica within the SN region in order to provide the energy, and coherent light, to null speckles at SN angular separations.

Here, we discuss multiple alternatives to generate those PSF replicas with minimal or no impact to the WFIRST Coronagraph instrument such as: 1) the addition of a movable diffractive pupil mounted of the Shape Pupil wheel, 2) design of a modified Shape Pupil design able to create a dark zone and at the same time diffract a small fraction of the starlight on the SN region, 3) determine the minimum residual quilting on Xinetics DM that would allow observing a given target.

Oral Presentation

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The WFIRST Exoplanet Microlensing Survey

The observational study of exoplanets has been characterized by surprising results virtually every time that a new observing method has advanced our sensitivity to previously unexplored regions of exoplanet parameter space. We can expect that this trend will continue with the exoplanet microlensing survey of the WFIRST mission. This survey will perform a statistical census of exoplanets in orbits wider than 0.5 AU, extending out to infinity (i.e. unbound planets). The space-based WFIRST observations will provide mass and distance measurements for most of the planetary systems discovered, yielding an exoplanet mass function as a function of Galactocentric distance. This census will include a census of the H2 Habitable Zone, which makes use of collision induced H2 opacity to produce habitable surface temperatures for planets in wider orbits than the traditional habitable zone.

Oral Presentation

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The Keck Observatory Archive: A Resource for Exoplanet Astronomy

The Keck Observatory Archive (KOA) (https://koa.ipac.caltech.edu) curates data acquired by all ten instruments at the Keck Telescope since operations began in 1994. As new instruments are commissioned, their data will be archived in KOA.

KOA creates browse-quality images of raw data for all instruments and browse-quality reduced data for five: an echelle spectrograph, HIRES; a long-wavelength spectrograph, LWS; a high-resolution imager, NIRC2, an infrared echelle spectrograph, NIRSPEC; and an integral field spectrograph, OSIRIS. Complete and fully validated keywords and optimized association of calibration files are available for HIRES, a low-resolution spectrograph, LRIS; NIRC2, NIRSPEC, and OSIRIS. KOA offers a web-based interactive search engine, a VO-program interface for image data, and a dedicated search service for solar system objects.

The archive is a rich resource for studying exoplanets and their host stars. Thirty-one of a total of 160 peer-reviewed papers that cite KOA are concerned with exoplanets astronomy.

As of May 2017, a total of 1,566 exoplanet systems, 60% of the stars with confirmed planets, have public data in KOA. These include 1,363 systems observed with HIRES (32,406 files), 145 (25,928 files) with NIRSPEC, and 852 with NIRC2 (44,534 files). The Keck Telescopes and KOA play an important role in the follow-up of objects discovered with Kepler and K2, including exoplanets, variable stars, and binary systems. There are 40,914 public files acquired in the Kepler footprint, including 23,151 observed with NIRSPEC and 9,333 observed with HIRES; and there are 96,164 files for 4,096 targets acquired with the K2 mission campaigns 0-14. KOA also archives 35,000 observations of all major Solar System planets, including 20,000 observations of Pluto and its satellites.

The Keck Observatory Archive (KOA) is funded by NASA as collaboration between the NASA Exoplanet Science Institute (NExScI) and the W. M. Keck Observatory (WMKO).

Poster

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Effects of refraction in transmission spectroscopy

Refraction by an exoplanet’s atmosphere creates a refractive boundary below which the atmosphere cannot be observed, resulting in the decrease of the strength of absorption features by chemical species in transmission spectra. This effect is increasingly important for exoplanets on wider orbits. We discuss the physics of refraction as it pertains to the geometry of transiting exoplanets, give examples of the location of the refractive boundaries for solar system analogs, and the expected differences with results from stellar/solar occultation observations of solar system planets from spacecrafts. We also discuss how refraction can help constrain the abundances of chemical species which are detected.

Oral Presentation

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Characterizing Low Mass Wide Orbit Planets with WFIRST Microlensing Program

Microlensing is the only method that have been able to detect low mass planets beyond the snow line. Due to this uniqueness of microlensing, it is selected as one of the main missions of NASA's top priority project WFIRST, whose main goal is to complete the exoplanet census by detecting and characterizing the wide orbit planets. But most microlensing events analyzed till date do not provide with the mass and distance to the host and planetary systems. We developed the method to determine the mass and distance to the planetary systems by measuring the lens-source relative proper motion in the high resolution images. This will be the primary mass measurement method of WFIRST. I will demonstrate how we successfully built the method and the softwares for characterizing the microlensing exoplanets from high resolution HST and Keck images with an example of the event OGLE-2005-BLG-169. We have measured the relative lens-source proper motion and confirmed a Uranus mass planet orbiting OGLE-2005-BLG-169 host star at 4 kpc distance from the earth - the first direct confirmation of a microlensing planetary system. Also I will refer to various challenges faced and how to overcome them with the events MOA-2008-BLG-310 and MOA-2008-BLG-379. In WFIRST era, this method will be the primary method to characterize the wide orbit low mass planets beyond the snowline and consequently to formulate the exoplanet mass distribution as a function of their host star masses and distance.

Oral Presentation

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Resolved spectroscopy of protoplanetary disks with SPHERE

In the recent advancement of exoplanets research, the instrument SPHERE at the VLT has demonstrated the achievement of very high contrasts, allowing to search for faint material around young stars. Direct imaging of protoplanetary disks is an efficient technique to study morphologies, spectral characteristics, in order to derive dust grains properties and to ultimately understand the planet-disk interactions. SPHERE comes with an Integral Field Spectrograph (IFS) working for a wavelength range of 0.95 to 1.65 μm which has the ability to observed disks at high spatial resolution but low spectral resolution. We have initiated a program which aims to determine locally the spectral characteristics of protoplanetary disks with the goal to distinguish dust clumps from planet formation sites. Given that young protoplanetary disks are faint compared to their host stars, their detection mostly relies on post processing techniques like angular differential imaging (ADI), which in turn causes biases in the intensity map of the disk structure. Several types of models have been developed as tools to mitigate this issue and retrieve the spectral information of disk features like rings or clumps. Our procedure involves the generation of a model grid, proceed this grid through an ADI algorithm, and then fit this result on the data, channel per channel to build the

spectrum of a disk or part of the disk. We will present our first results obtained on a transitional disk as well as a debris disk observed with SPHERE.

Poster

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Discovering the youngest free-floating planets: a transformative survey of Taurus with the novel Wband filter

Low mass brown dwarfs and free-floating planets in star-forming regions are vital tracers of the low mass end of the star-formation and key analogues to exoplanets around stars. However, only a handful of objects with masses below 13 MJup are known because they are difficult to distinguish from reddened background stars using traditional methods. An efficient method of searching for these young objects is to identify them via spectral features, such as the 1.45 um H2O absorption band seen in spectra of MLTY type objects. Allers & Liu 2010 pioneered this method with a 6% wide filter centered at 1.45 um for ULBCAM at the UH88' telescope, achieving a 90% spectroscopic confirmation rate. This filter is now decommissioned and, on a 2m class telescope, was only able to identify fairly bright candidates. We have acquired a 1.45 um filter with specifications appropriate to CFHT and have been using it with WIRCam to survey the Taurus star-forming region in order to detect the lowest mass components of this cluster. I will discuss results from this survey and prospects for extending this technique to high contrasts as a method of confirming candidate exoplanet companions.

Oral Presentation

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The NASA Exoplanet Exploration Program

The ExEP implements NASA's space science vision for exoplanets: detection, characterization, and the search for habitable worlds. Detection is advanced by the Kepler final catalog and planetary occurrence rates. The demographics of exoplanets will be further extended by the WFIRST microlensing survey. Characterization is enabled by the ExEP to understand the physics of the planets, the planetary systems, and exoplanet atmospheres. A community follow-up observing program coordinated through the NASA Exoplanet Science Institute (NExScI), including use of NASA's time on the W. M. Keck Observatory, validates discoveries and delivers mass estimates for high value targets. NExScI will deliver a new community pipeline for the High Resolution Echelle Spectrometer (HIRES) pipeline in order to broaden community access to radial velocity observations on the on the W. M. Keck Observatory. The ExEP and Penn State will deliver the NEID precision radial velocity spectrometer for commissioning in 2019 on the 3.5 meter WIYN telescope for guest observations in 2019. The Coronagraph Instrument on the Wide-Field Infrared Survey Telescope will perform the first direct imaging and spectroscopy of cool gas and ice giants in nearby planetary systems. The search for habitable worlds will require further advances in capability (contrast and aperture) beyond WFIRST, therefore the ExEP is conducting mission studies, technology investments in high-contrast imaging (coronagraphs and starshades) and in ground-based precursor science to enable spectroscopy for detection of biosignatures in the reflected light of exo-Earths in the habitable zones of sun-like stars. The Large Binocular Telescope Interferometer (LBTI) is completing a mid-infrared survey of exozodiacal dust, a parameter necessary to understand for the design of future Earth-characterization missions.

Poster

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(Spectrum of ROXs 12 B and Its Spin-Orbit Alignment)

ROXs 12 B is a substellar companion near the deuterium-burning limit orbiting a young star in Ophiuchus/Upper Scorpius. We present moderate-resolution near-infrared spectroscopy of this little-studied object, which shows clear signs of low surface gravity and youth. Although ROXs 12 B does not possess obvious signs of a circumplanetary disk, we find that at least half of young (<15 Myr) companions with masses <20 Mjup have accretion subdisks. The combination of a K2 rotation period for the host star, its projected rotation velocity, and initial orbit constraints for ROXs 12 B allow us to examine spin-orbit alignment in this system. The rotation axis of ROXs 12 A and the orbital axis of ROXs 12 B are likely misaligned by at least 50 deg, suggesting this companion formed more akin to fragmenting binary stars than planets in an equatorial disk.

Poster

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CSIM: A High-Performance, Robust Coronagraph Design System

Modern coronagraph design for the imaging of exoplanets involves sophisticated components that can present difficult high-dimensional optimization challenges. We describe CSIM, a general high-performance C++ coronagraph design system that addresses many of these challenges. CSIM conceptualizes a coronagraph as a series of components that transform an incoming electric field. Using such object-oriented design principles as strong encapsulation, CSIM allows any coronagraph component to be implemented without knowledge of the overall system or other components in the system. This creates a “component plug-in” architecture that makes it easy to experiment with different coronagraph designs in a robust simulation environment. A general abstraction of optimization allows multiple components to be jointly optimized, using whatever optimization method is most appropriate.

A major design goal of CSIM is to make it easy to add new components without having to understand the overall architecture or other components. Components have a simple yet powerful interface to the CSIM system, including to optimization methods. Example code templates will be provided so that a new

component can be designed by simply “filling in the blanks”. The Armadillo template library, with its MATLAB-like syntax for manipulating matrix-type objects, provides a comfortable environment for the creation of new components.

CSIM is designed to be high performance, robust, and will support multiple architectures including GPUs. The driving problem for CSIM is the design of PIAA complex mask coronagraphs for segmented mirror systems, such as the HabEx and LUVOIR mission concepts. Various types of masks, propagators, and error sources, such as time varying coronagraph geometry, will be in the base CSIM release. CSIM will facilitate the design and testing of coronagraphs that address current challenges in coronagraph design.

Oral Presentation

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Missing Water Vapor in the Beta Pictoris System

Debris disks are the remnants of planetary system formation. With a typical dust/gas ratio of ~100, these circumstellar disks represent the late stages of planet formation, in which most gas has dissipated and dust exists on scales from planetesimals to micrometer-sized grains.
Collisions between kilometer-sized bodies produce dust and gas of secondary origin. An example of this is the spatially-resolved clump of CO gas observed in the debris disk system Beta Pictoris, which also hosts a confirmed planet.
If the CO emission is the result of collisions of objects with the same chemical composition as comets in the Solar System, we would expect water vapour to also be produced. Using Herschel/HIFI data, I have examined the Beta Pictoris system for H2O emission lines. My analysis shows no such emission, putting an upper limit on the observed flux. This translates into an upper limit on the H2O gas mass that is inconsistent with the mass expected from colliding bodies of Solar System composition. The results suggest either an incomplete understanding of the gas-producing mechanism or a chemical composition different from Solar System comets.

Oral Presentation

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The Habitable Zone Gallery 2.0: an Online Exoplanet System Visualization Suite

We present the Habitable Zone Gallery 2.0 (HZG2), an online service that provides visualizations of known exoplanet systems. We utilize the NASA Exoplanet Archive data along with the latest climate models to compute and render planetary orbits, stellar parameters, and the Habitable Zone boundaries that indicate where liquid water may be present on the surface of a rocky planet. The HZG2 delivers new perspectives via interactive plotting and data analysis tools. We have crafted algorithms that intelligently discern the most appropriate view of an exoplanetary system, along with publication-ready vector-based plots that are available on-demand. Users can easily copy and modify any figure we host using tools that we provide. Anyone may download the plots in myriad file formats, or directly access the data in table form. The HZG2 supplies animated 3D visualizations of exoplanet systems with an aim to demonstrate orbital characteristics. Each exoplanet system has a dedicated webpage that, in addition to the plots, contains an integrated Aladin Lite module that summons actual imagery in an interactive view of the area of sky the exoplanet host system occupies. The HZG 2.0 upgrade promises to facilitate insights into the nature of exoplanetary systems while providing invaluable visualization tools and publication assets to the astronomical community.

Oral Presentation

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Imaging discovery of a 400K companion to a nearby RV exoplanet host star

Using high-contrast imaging with the SPHERE instrument at the VLT, we report the detection of a brown dwarf companion to an exoplanet host star. The newly imaged brown dwarf is the coldest known companion to a solar-like star, with an effective temperature of 400K and a spectral type at the T/Y transition. By combining the imaging data with 17 years of radial velocity monitoring, we are able to precisely measure the dynamical mass, temperature, luminosity and orbital parameters of the brown dwarf, making it a crucial benchmark for formation and evolutionary models. The system is also a complex dynamical environment, with simulations showing that the brown dwarf may be interacting strongly with the exoplanet through Lidov-Kozai interactions, which could be the cause of the planet's extremely large orbital eccentricity (e~0.9).

Oral Presentation

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Using modern imaging techniques to old HST data: a summary of the ALICE program

The Archival Legacy Investigations of Circumstellar Environments (ALICE) program is a consistent re-analysis of the 10 year old coronagraphic archive of HST's NICMOS infrared imager. Using post-processing methods implementing PSF subtraction algorithms developed for ground-based observations, we significantly improved NICMOS's detection limits over previous analyses. After completion of the re-analysis of the archive, we have now delivered ALICE-reprocessed science products back to the community. The ALICE program has already enabled the detection of 10 debris disk systems never imaged before in the near-infrared, and several substellar companion candidates that we are in the process of characterizing through follow-up observations. I will provide a summary of the results of the ALICE program, advertize its science products and discuss the prospects of the program.

Oral Presentation

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Assessing the Impact of Stellar Companions on the Determination of Planet Properties for Transiting Planets

Unknown stellar companions to Kepler planet host stars dilute the transit signal, causing the planetary radii to be underestimated. We report on the effects of the stellar companions detected with high-resolution imaging to be within 2" KOI host stars. The majority of the planets and planet candidates in these systems have nominal radii smaller than 6 REarth. Using multi-filter photometry on each companion, we assess the likelihood that the companion is bound and estimate its stellar properties, including stellar radius and flux. We then recalculate the planet radii in these systems, determining how much each planet's size is underestimated if it is assumed to 1) orbit the primary star, 2) orbit the companion star, or 3) be equally likely to orbit either star in the system. We demonstrate the overall effect of unknown stellar companions on our understanding of Kepler planet sizes.

Oral Presentation

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Probing the atmosphere of the young neptune-sized planet K2-25 b

The repurposed Kepler, K2, has been as productive as the original mission, providing a wealth of fascinating new planetary systems. Among them, of particular interest is the system K2-25, composed by a neptune-sized planet transiting a M4.5 dwarf in nearly 3.5 days (Mann et al. 2016).
The parent star belongs to the Hyades open cluster, and it can be characterized with exquisite precision, e.g., the young age of the system is well measured (625 Myr).

The number of detected planets transiting young stars is exiguous, and studying their properties is a crucial step in understanding the evolution of the architecture and the dynamics of planetary systems. Furthermore, the measured planetary size, larger than those found around similar stars, suggests that the planet is in an early phase of its evolution, when the distended atmosphere has not been completely lost.

Given the faintness of the system, studying the atmosphere of this planet with transmission spectroscopy is extremely challenging with current instruments. An alternative and more accessible approach is to obtain simultaneous multi-wavelength imaging observations of the planetary transit and to measure the variation of the planet's radius at different wavelength.

For this purpose, we obtained multi-band photometry (g, r, i, z) of few K2-25 b transits, using the Large Binocular Cameras at the Large Binocular Telescope. I will present the results obtained from these observations, in particular the refined values of the planet's physical parameters. We compare the radius-wavelength variations with transmission spectra built using state-of-the-art atmospheric models.

We therefore can put the first constraints on the atmosphere composition of this young neptune-sized planet orbiting a cool dwarf star.

Oral Presentation

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Forming long period giant planets from core accretion through scattering

The formation of giant planets on wide orbits remains unknown. Two different theories of planet formation, the core accretion and gravitational instability, are able to form such planets but a number of problems need to be overcome. Such problems in the core accretion model mainly arise due to the formation of giant planet cores, which can typically only take place in the inner regions of the protoplanetary disc, due to shorter settling times of solids. In the outer regions of the disc, these settling and formation timescales are longer than the disc lifetime. Gravitational instability requires very massive discs which can fragment into clumps before these clumps collapse in on themselves through self-gravity. This seems a viable way to form planets with longer periods, since the outer regions of protoplanetary discs are more prone to fragmentation than the inner discs. However since massive discs are required, most clumps that do collapse into massive planets undergo significant type II migration, causing these planets to migrate into the inner regions of the disc, leaving few giant planets on wide orbits.
Here I present a possible formation scenario from core accretion, where giant planet cores are scattered onto wide orbits where they then accrete surrounding gas forming in giant planets. Since scattering can occur irrespective of the age of the disc, these giant planets will then undergo insignificant migration as they continue to accrete the remaining gas from the protoplanetary disc. I will detail the conditions required for such scattering events, and will also estimate the probabilities of such events, and possible occurrence rates of giant planets on wide orbits.

Poster

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Space-Based Direct Imaging: WFIRST, HabEx, and LUVOIR

In order to characterize the atmosphere and surface of an Earth-like exoplanet orbiting a Sun-like star, we need to spatially resolve the planet from its star despite the minuscule angular separation and enormous flux contrast. Current ground-based efforts like SPHERE andGPI measure the thermal emission of young planets in newly-formed systems, but they have neither the resolution nor the contrast to image Earth twins. When the coronagraph-enabled WFIRST mission launches in the mid 2020's, it will be the first experiment capable of directly imaging exoplanets in reflected light and hence will provide
out first images of mature exoplanets. WFIRST should be able to characterize the atmospheres and clouds of nearby Jupiter analogs and a handful of smaller planets. The addition of a starshade after the

primary mission could open the door to imaging terrestrial planets orbiting in the habitable zones of nearby stars. Moreover, by proving that space-based coronagraphy is a mature technology, WFIRST will pave the way for more ambitious missions to come. HabEx and LUVOIR are possible flagship missions being considered by NASA for launch in the 2030's. Both missions are being designed to meet the challenge of directly-imaging Earth twins orbiting nearby stars. I will give an overview of the direct imaging component of these three missions, and take a look at what exoplanet science we can expect from them.

Oral Presentation

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Disentangling Stellar Spectra With Gaussian Processes: Data-Driven Models for Radial Velocity Analysis

Measurements of radial velocity variations from the spectroscopic monitoring of stars and their companions are essential for exoplanetary study; these measurements provide access to the fundamental physical properties that dictate all phases of stellar evolution and facilitate the quantitative study of planetary systems. The conversion of those measurements into constraints on both the orbital architecture and individual component spectra can be a serious challenge, however, especially for extreme flux ratio systems and observations with relatively low sensitivity. We introduce a new technique for spectral disentangling using Gaussian processes, where the posterior distributions of the orbital parameters and intrinsic, rest-frame stellar spectra are explored simultaneously without needing to invoke cross-correlation templates. To demonstrate its potential, we deploy this technique on red-optical time-series spectra of the mid-M-dwarf eclipsing binary LP661-13 recently discovered by the MEarth project. We report orbital parameters with improved precision compared to traditional radial velocity analysis and successfully reconstruct the primary and secondary stellar spectra. We discuss potential applications for identifying and downweighting spectral regions responsible for radial velocity jitter, and highlight ongoing work of the time-variable spectra of the pre-Main Sequence planet host star LkCa 15.

Oral Presentation

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Breaking the low gravity/high metallicity degeneracy in substellar atmospheres using the potassium doublet: the instance of the candidate free-floating planet CFBDSIR2149

We conducted a multi-wavelength, multi-instrument observational characterisation of the candidate free-floating planet CFBDSIR~J214947.2-040308.9, a late T-dwarf with possible low-gravity features, in order to constrain its physical properties. While our new spectrum confirms the low gravity and/or high metallicity of CFBDSIR2149, the parallax and kinematics safely rule out membership to any known young moving group, including AB~Doradus. We used the equivalent width of the KI doublet at 1.25μm to

discriminate the effects of low-gravity from the effects of high-metallicity. In the case of CFBDSIR2149, the observed KI doublet favours the low-gravity solution.
Since low gravity and high metallicity usually have a very similar effect on the spectrum of substellar objects the study of the potassium doublet could be a promising tool to discriminate planetary mass objects (low gravity), from older, brown dwarfs mass objects with higher gravity. By lifting part of the degeneracy of solutions between gravity and metallicity, this could help characterising both bound exoplanets and free-floating, planetary mass objects.

Oral Presentation

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The puzzling atmospheric properties of the moderately young but extremely red substellar companion HD206893B

We investigate the atypical properties of the substellar companion HD206893b, recently discovered by direct imaging of its disc-bearing host star with the SPHERE instrument by Milli et al. 2017ims. We conducted a follow up of the companion, that has the reddest near infrared colours among all known substellar objects, with adaptive optic imaging and spectro-imaging with SPHERE. We present extensive atmosphere model fitting for the companions and the host star in order to derive their age, mass and metallicity based on discovery data as well as a R=30 spectrum from 0.95 to 1.64 micron and additional photometry at 2.11 and 2.25 micron of the companion.
We found no additional companion in the system in spite of exquisite observing conditions resulting in sensitivity to 6MJup (2MJup) at 0.500 for an age of 300 Myr (50 Myr). We constrain the age of the system to a minimum of 50 Myr and a maximum of 700 Myr, and determine that the host-star metallicity is nearly solar. The comparison of the companion spectrum and photometry to model atmospheres indicates that the companion is an extremely dusty late L dwarf, with an intermediate gravity (log g =4.5-5.0) which is compatible with the independent age estimate of the system. Though our best fits correspond to a brown dwarf of 15–30MJup aged 100-300 Myr, our analysis is also compatible with a range of masses and ages going from a 50 Myr 12MJup planetary-mass object to a 50 MJup Hyades-age brown dwarf. We highlight that though this companion is extremely red, it is more probable it has an intermediate gravity rather than the very low gravity that is often associated with very red L dwarfs.

Oral Presentation

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Ice Line Truckers: How much water did the Trappist-1 planets haul?

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The Trappist-1 system contains 7 transiting planets, all be roughly Earth size [1], and transit timing variations have constrained their masses to be roughly Earth mass as well [1,2]. Extended H2/He atmospheres are not expected for such small planets [3]. Trappist-1 f and g are notably less dense than Earth and must contain abundant (>50wt%) water ice [2]; but Trappist-1 b and c are apparently Earth-like rocky planets. We have used the ExoPlex mass-radius code [4] to constrain their water fraction: b must be ≥ 6-8wt% water, but c must be ≤ 6-8wt% [5]. Since b should be less volatile-rich than c, the simplest interpretation is that b and c each contain ≈7wt% water. We infer that b and c formed inside the snow line and f and g outside it. The boundary between them, ≈ 0.02-0.03 AU, is far inside the snow line location in the Trappist-1 disk, 0.05 – 0.20 AU [5]. As in the Kepler 32 system [6], substantial inward migration of the Trappist-1 planets is demanded. Depending on how quickly the Trappist-1 planets formed, they are presently at 1/2 - 1/8 of their starting distances. Remarkably, either b or c (or both) is much wetter (7wt%) than Earth (<0.1wt%), despite having formed inside the snow line. This suggests that the gradient of volatiles in the Trappist-1 disk, and by extension other M dwarf disks, was more gradual than in the Solar System.

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Oral Presentation

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(Observational Signatures of Super-Earths)

We investigate the observational signatures of super-Earths, the most common type of exoplanet discovered to date, in their natal disks of gas and dust. Combining two-fluid global hydrodynamics simulations with a radiative transfer code, we calculate the distributions of gas and of sub-mm-sized dust in a disk perturbed by a super-Earth, synthesizing images in near-infrared scattered light and the mm-wave thermal continuum for direct comparison with observations. In low viscosity gas ($\alpha\lesssim10^{-4}$), a super-Earth opens two annular gaps to either side of its orbit by the action of Lindblad torques. This double gap and its associated gas pressure gradients cause dust particles to be dragged by gas into three rings: one ring sandwiched between the two gaps, and two rings located at the gap edges farthest from the planet. Depending on system parameters, additional rings may manifest for a single planet. A double gap located at tens of AUs from a host star in Taurus can be detected in the dust continuum by the Atacama Large Millimeter Array (ALMA) at an angular resolution of 0.03 arcsec after two hours of integration. Ring and gap features persist in a variety of background disk profiles, last for thousands of orbits, and change their relative positions and dimensions depending on the speed and direction of planet migration. Candidate double gaps have been observed by ALMA in systems like HL Tau (D5 and D6) and TW Hya (at 37 and 43 AU); we submit that each double gap is carved by one super-Earth in nearly inviscid gas.

Oral Presentation

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Maximizing the TESS Mission's Yield of Long-Period Planets

The upcoming TESS mission will discover thousands of transiting planets around bright stars. However, during its primary mission TESS will observe most of the sky for just 27 days (and for at most one year even in its continuous viewing zones near the ecliptic poles), thus limiting the mission's yield of long-period planets. We can increase by several hundred - and potentially double - the number of planets with periods longer than 10 days that TESS will discover, by pursuing single and double transit signals, in addition to the "traditional" planet candidates that show at least three transits. I will show how strategic planning and the judicious use of high-resolution imaging, ground- and space-based photometric observations, and/or radial velocity measurements can confirm these planets and refine their ephemerides. Through this program, we will generate a sample of long-period planets transiting bright stars that are ripe for detailed characterization studies such as mass measurements and atmospheric observations. In turn, these studies will provide important constraints on the composition and formation of long-period planets.

Oral Presentation

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Long-periodic exoplanets from radial velocity surveys

A handful of long-duration radial velocity surveys around the globe have stubbornly monitored several hundred stars in the solar neighborhood for planetary companions. Their time baselines are now approaching - and exceeding - 20 years and we are beginning to probe a poorly sampled parameter space in exoplanet research: planets with orbital periods longer than Jupiter and orbital semi-major axis of a=6-7~AU. In this talk I will review the various programs and their results, and highlight a few interesting examples for giant planets at very large orbital distances. I will conclude with a discussion on future direct detection of these exoplanets using WFIRST, and other upcoming instruments/projects.

Oral Presentation

Dr. Fabo Feng
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Agatha: disentangling periodic signals from correlated noise in a periodogram framework

Radial velocity is one of the most promising method for the detection of Earth analogs. However, the sub-meter radial velocity variation caused by Earth-like planets is comparable with noise correlated in time and wavelength. To disentangle the Keplerian signal from correlated noise, we develop a framework of periodograms based on likelihood marginalization and optimization. This framework is further implemented to produce an online application, called "Agatha". We compare Agatha with other periodograms for the detection of Keplerian signals in synthetic radial velocity data produced for the Radial Velocity Challenge as well as in radial velocity datasets of several Sun-like stars. We find that Agatha outperforms other periodograms in terms of removing correlated noise and assessing the significances of signals with more robust metrics. Moreover, it can be used to select the optimal noise model and to test the consistency of signals in time. Agatha is intended to be flexible enough to be applied to time series analyses in other astronomical and scientific disciplines. Agatha is available at http://www.agatha.herts.ac.uk.

Oral Presentation

Prof. Kate Follette
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The MagAO Giant Accreting Protoplanet Survey (GAPlanetS): Recent Results

I will summarize recent results of the MagAO Giant Accreting Protoplant Survey (GAPlanetS), a search for accreting protoplanets at H-alpha inside of transitional disk gaps. These young, centrally-cleared circumstellar disks are often hosted by stars that are still actively accreting, making it likely that any planets that lie in their central cavities will also be actively accreting. Through differential imaging at Hydrogen-alpha using Magellan's visible light adaptive optics system, we have completed the first systematic search for accreting protoplanets in fifteen bright Southern hemisphere transitional disks. I will present recent results from this survey including: multiepoch imaging of the close (~13AU) accreting M-dwarf companion to HD142527, a second epoch on the LkCa 15 system, and recent joint MagAO+GPI results constraining the nature of the HD100546 planet candidates.

Oral Presentation

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Reaching a good contrast at small angles thanks to high pace Reference Differential Imaging (RDI) from the ground with VLT/SPHERE

Wishing to demonstrate the power of RDI to achieve the best possible contrast at small separations, we put together a test that would allow to compare angular differential imaging (ADI) and RDI. We chose an ideal visual binary (55 Eri) and hopped from one star to the other every 160 seconds during 90 minutes and during meridian crossing. The conditions were stable an excellent. We show that with this dataset we can compare ADI and RDI in a fair manner (same on-source time, a decent amount of field rotation). This test produced a contrast gain in the 2 to 6 lambda/D regime (H-band using the usual Apoldized Lyot

Coronagraph) and it represents a great pathfinder for systems like alpha Cen but also to design snapshot RDI surveys, confirm candidate companions at small angles and moderate contrasts.

Oral Presentation

Ms. Claire Guimond
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Biases and Planetary False Positives in the Search for Earth Twins

Direct imaging may be the best way to characterize the atmospheres of Earth-size exoplanets in the habitable zone of Sun-like stars. Following in the footsteps of the Terrestrial Planet Finders, the LUVOIR and HabEx mission concepts propose to search for and characterize the atmospheres of these Earth twins. But a blind search using direct imaging is not necessarily the most efficient path to characterizing Earth-like planets. Previous studies have estimated the Earth twin yield of direct imaging missions (Stark et al. 2014, 2015, 2016). We take an important next step by extending this analysis to other flavours of planets, which will act as false positives for bona fide Earth twins. Using both analytic and Monte Carlo analyses, we quantify the biases and false-positive rate of such blind searches.

Oral Presentation

Dr. Alex Howe
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A Retrieval Architecture for Spectroscopic Observations of Directly Imaged Exoplanets

I present a new modeling and retrieval code for atmospheres of directly imaged exoplanets designed for use on JWST observations, extending my previous work on transiting planets. I perform example retrievals of temperature-pressure profiles, common molecular abundances, and basic cloud properties on existing lower-resolution spectra and on simulated JWST data using forward model emission spectra for planned NIRISS and NIRCam targets. From these results, I estimate the expected return on prospective JWST observations in information-theoretic terms using the mutual information metric.

Oral Presentation

Mr. Yuichi Ito
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Hydrodynamic escape of mineral atmospheres on close-in rocky super-Earths: Case of 55 Cnc e

Characterization of close-in high-density super-Earths (e.g., CoRoT-7 b) has become possible, thanks to development of observational instruments. Those planets have substellar equilibrium temperatures hot

enough to vaporize rock. Thus, if rocky, they likely have atmospheres composed of rocky materials (Scheafer & Fegley 2009, Ito et al. 2015). In this study, we call such atmospheres mineral atmospheres. Recently, Ridden-Harper et al. (2016) reported possible detection of sodium in the observed transmission spectrum of the relatively high-density super-Earth 55 Cnc e with radius of 2 Earth radii. This signal is interpreted as an expanding sodium atmosphere whose radius is approximately 5 Earth radii (2.5 times planetary radius) as observed at sodium D line. This may indicate that the sodium is substantially escaping from the planet. If this is the case, it is puzzling why the sodium still survives until today, despite of its low abundance in normal rocky planets. Also, there is no theoretical study of the hydrodynamic escape of such sodium atmospheres that are highly UV-irradiated.
In this study, we construct a 1-D hydrodynamic model that includes photo-/thermo-chemistry, UV heating and line cooling. We determine the outflow structure of the mineral atmosphere under the 55 Cnc e-like condition, assuming that the atmosphere consists of sodium, oxygen and their ions, which are the major species of such an atmosphere. This model shows that EUV efficiently heats the atmosphere above 1.1 times planetary radius. We find that the hydrodynamic escape of the mineral atmosphere is not massive enough to explain such a sodium expansion observationally suggested. Instead, the sodium in our model expands only to 1.1 times planetary radius at D line. This is because FUV ionizes almost all of the sodium at this radius from which the atmosphere expands due to EUV. Further observational and theoretical works to characterize the exosphere will help clarify the composition of 55 Cnc e.

Oral Presentation

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Interpreting Polarized Scattered Light Images of Planet-Forming Disks

Polarimetric imaging is a powerful way of producing high-contrast images of circumstellar disks because light scattered from a disk surface is preferentially polarized compared to light coming directly from the star. However, the interpretation of structure from polarized light images can be complicated because of variations in disk geometry. Here, we present radiative transfer models of scattered light from protoplanetary disks showing how their appearance can be markedly altered by viewing them in polarized light as opposed to total intensity. These effects should be treated carefully when interpreting structure in planet-forming disks. When properly accounted for, we can search for and identify signatures of planet formation.

Poster

Markus Janson
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STARE: Assessing the prospects for Earth twins in the alpha Cen system

Proximity is the single most important factor for the possibility of directly detecting and characterizing rocky extrasolar planets in the habitable zones of their stars. In this context, the highest priority system for study is alpha Centauri at 1.3 pc, consisting of the Sun-like stars alpha Cen A and B, and the very low-mass star Proxima Cen. Recently a planet candidate in the (classical) habitable zone of Proxima has been observed, but while this is highly intriguing planet worthy of further study, habitability around such a late-type star remains a questionable concept. A priori, planets in the habitable zones of alpha Cen A and B would be more promising, and any such planets would thus be the top priority for further characterization, if they exist. I will present prospects for detection of Earth-like planets around alpha Cen A and B, in particular with the astrometric concept STARE currently in development. STARE would lay the necessary groundwork for optimal characterization of Earth-like potentially habitable planets with future telescopes such as the E-ELT, opening up the possibility for studying life and habitability in potentially very Earth-like environments beyond the Solar system.

Oral Presentation

Prof. Ray Jayawardhana
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Searching for `Rogue Planets' from the Ground and with JWST.

Surveys of nearby star-forming regions suggest that free-floating planetary-mass objects are relatively scarce, even though we and others have found and spectroscopically confirmed a few objects down to about 6 Jupiter masses. However, a microlensing study claims that free-floating or wide-orbit planets may be twice as common as stars. Such 'rogue planets' could have formed in protostellar disks and ejected subsequently, or formed through a 'star-like' mechanism. I will review recent ground-based efforts and upcoming JWST observations to search for a population of ultra-low-mass brown dwarfs or rogue planets, and the implications for star and planet formation.

Oral Presentation

Mr. Jeff Jennings
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Assessing a bias in planet masses recovered with transit timing variations

In multi-planet systems, gravitational interactions between bodies induce small departures from Keplerian orbit, and in this aperiodicity is encoded information on the planets' masses and orbital elements. Transit timing variations (TTVs) can in turn be used to dynamically constrain physical and orbital properties for both a transiting planet and its (often unseen) gravitational perturber, in some cases out to ~AU scales. This technique is useful not only for detection of planet perturbers but also characterisation of the transiting body, for which TTV data can be paired with a radius measurement to constrain density and by extension bulk composition. However in the inversion of a TTV signal arises a mass-eccentricity degeneracy for both planets, which I will demonstrate can in some cases bias recovered masses to erroneously low or high values. This effect persists even for high signal-to-noise measurements, and to this end I will elucidate the bias' sensitivities to signal fidelity and to the planets' orbital and physical parameters, as well as the duration and cadence of observations. I will then present our work to

understand and correct for this bias analytically, demonstrating the effect on recovered masses for Kepler-like systems. Finally I will offer prescriptions for addressing the bias in future use of TTVs to improve our understanding of the exoplanet population.

Oral Presentation

Samantha Johnson
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Ultra-Short-Period K2 Exoplanets

Samantha Johnson (1), Brian Jackson (1), & Elisabeth Adams (2)
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The K2 Mission, an extension of NASA's Kepler Mission, collects the light curves of stars with the aim of finding transiting planets. Our group, the Short-Period Planets Group (SuPerPiG), focuses on finding transiting planets very close to their host stars. Our search scheme involves considerable data conditioning to remove longer-period signals due to astrophysical and instrumental effects, followed by a robust analysis for periodic signals. However, even after these processing steps, it is still expedient to examine each of these light curves by hand to weed out objects that are obviously not planets, such as eclipsing binary stars and light curves that are clearly sinusoidal. For the candidates whose light curves that pass this level of scrutiny, further follow-up observations, such as low-precision radial velocity and adaptive optics observations, as well as spectral characterization of the host star, are necessary to weed out false positives. Radial velocity observations allow us to ensure that the candidates are not instead stellar companions in binary systems. Using data from the K2 Missions Campaigns 6, 7, and 8, we have discovered dozens of ultra-short-period planetary candidates through this process.

Prof. N. Jeremy Kasdin
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The WFIRST Coronagraph Instrument

The Wide Field Infrared Survey Telescope, or WFIRST, is NASA's next flagship mission. Originally conceived of as a wide-field survey facility for cosmology and dark energy, with an exoplanet science component via microlensing, it now includes a coronagraphic instrument (CGI) for exoplanet direct imaging. The baseline architecture for CGI includes a hybrid lyot or shaped pupil coronagraph, feeding an imager and integral field spectrograph. This will allow imaging and photometry of mature nearby planets and zodiacal disks in reflected light, as well as spectroscopy of the brightest targets. The CGI is also considered a technology demonstrator, proving out critical high-contrast imaging technologies in space for the first time. In this talk I will discuss the scientific motivations of the mission and show simulated science capabilities of CGI, and discuss the process towards definition of a science mission. I will also present a summary of the instrument design and critical new technologies. With the instrument reaching the end of

Phase A, I will also describe the status of laboratory development program and progress toward a final flight design.

Oral Presentation

Ms. Yui Kawashima
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Possible origin of diverse transmission spectra of warm transiting exoplanets: Growth and settling of atmospheric haze produced via UV irradiation

Recently, transmission spectra of several transiting exoplanets have been obtained. Transmission spectrum provides information of absorption and scattering by molecules and small particles such as hazes and clouds in the planetary atmosphere. Thus, comparison between the observational and theoretical transmission spectra can constrain the composition of the planetary atmosphere. Some of the recent observations, detected steep Rayleigh slope features in the visible and/or featureless spectra in the near-infrared, inferring the existence of haze in the atmospheres, which prevents us from probing the atmospheric molecular composition. Also, the transmission spectra are somewhat diverse: Some contain the Rayleigh slope features in the visible, some show molecular and atomic features. While a few studies addressed theoretical modeling of transmission spectra of hydrogen/helium-dominated atmospheres with the effect of hydrocarbon haze, they did not necessarily use physically-based values of the haze layer parameters (namely, the size and number density of haze particles and the altitude and thickness of the haze layer). In this study, to derive the physically-based distribution of haze particles, we develop a first self-consistent theoretical model for the creation, growth, and settling of hydrocarbon haze particles in hydrogen/helium-dominated atmospheres of close-in warm (< 1000 K) exoplanets. Also, with obtained properties of hazes, we model transmission spectra of the atmospheres to explore whether the recently-observed diversity of transmission spectra can be explained by the variation in the production rate of haze monomers. We find that the haze tends to spread in a wider region than previously thought and consists of particles of various sizes. We also find that the observed diversity of transmission spectra can be explained by the difference in the production rate of haze monomers, which may relate to the strength of UV irradiation from the host stars.

Oral Presentation

Mr. Dylan Keating
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Reflected Light Matters in the Near Infrared: Revisiting the Energy Budget of WASP-43b

Hot Jupiters have been the most thoroughly studied class of exoplanet. Previous analyses of the infrared spectra, phase curves, and atmospheric models of Hot Jupiters have assumed that reflected light from these planets contributes a negligible amount of flux and can be safely ignored. As we show for the Hot Jupiter WASP-43b, this assumption may not always be valid- even for modest values of geometric albedo, reflected light can contribute a significant amount of the near infrared flux detected by HST/WFC3. We then revisit the energy budget and heat transport of this planet.

Oral Presentation

Prof. Matthew Kenworthy
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Transits of giant exoring systems: J1407, PDS 110 and Beta Pictoris b

The star J1407 underwent a complex series of dimming events lasting two months, which we interpret as the transit of rings hundreds of times larger than Saturn's rings, filling a large fraction of the Hill sphere of a secondary companion. These rings are ultimately unstable, accreting into moons or onto the surface of the exoplanet, and disappearing after a few tens of megayears. Since circumplanetary disks are considered part of the formation and evolution of planets and their attendant moons, the discovery and characterisation of more of these systems around young stars provides a unique insight. No other eclipses towards J1407 have occurred to date, so we are now monitoring two other young stellar systems that may harbour Hill sphere filling rings.

PDS 110 is a 10 Myr old star that underwent two eclipses in 2008 and 2011, with the next eclipse predicted to occur in September 2017. The eclipses last two weeks and are 30% deep, with rapid nightly fluctuations that indicate the presence of rings. The star is in Orion and is visible from both hemispheres, making it an ideal target for a global monitoring campaign.

The Hill sphere of the directly imaged 13 Jupiter mass exoplanet Beta Pictoris b transits its parent star in 2017 and the start of 2018. We have two dedicated observatories, called bRing, that are monitoring this star with a precision of 0.5% every five minutes. We will report on our photometric monitoring to date looking for the signature of Hill sphere rings crossing the star and discuss the possible observations and science from these systems.

Oral Presentation

Dr. Taisiya Kopytova
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Robust Spectral Indices for Exoplanets Observed with JWST

Due to the expected high allocation time pressure for JWST and a large number of objects of interest, it is essential to be able to extract the most important information for determining exoplanet parameters with minimal amount of observing time. Howe et al. (2017) and Batalha & Line (2017) suggested the use of information content methods to determine the optimal observing modes for characterizing transiting exoplanets.

We build upon this work by determining spectral indices that would enable us to rapidly classify exoplanet spectra and measure critical exoplanet atmosphere parameters (temperature, gravity, metallicity, carbon-to-oxygen ratio, disequilibrium chemistry, and cloud properties) using flux measurements at only 2-4 channels in JWST emission/transmission spectra. We pursue this aim by using well-tested machine learning approaches.

The basic approach is to “train” the method on a set of spectra for which we know the basic properties. From this training set, a vector of coefficients as a function of desired parameters at each wavelength can be constructed. Hence, from the training set we “learn” what the parameter dependencies are. This trained empirical model can then be applied to other objects to determine their basic properties.

By representing the flux at each wavelength as a linear combination of the obtained coefficients, we are able to identify spectral indices for equilibrium temperature, gravity, metallicity, and carbon-to-oxygen ratio. With such diagnostic wavelengths and their relationship with the desired parameters will allow for a rapid empirical determination of the atmospheric properties of a newly measured spectrum. This approach will become a powerful method for characterization of exoplanet atmospheres in the era of JWST.

Oral Presentation

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Water and Clouds in the Atmosphere of the Warm Neptune WASP-107b

I will report the first atmosphere characterization of the newly discovered exo-Neptune WASP-107b. Thanks to its low surface gravity and small, bright host star, WASP-107b is the highest signal-to-noise target for transmission spectroscopy discovered in the last decade -- rivaled only by HD 209458b and HD 189733b. The planet is in the intriguing transition region between ice and gas giants, with a mass comparable to Neptune and a radius similar to Jupiter. Relative to other benchmark systems, WASP-107b has a cool equilibrium temperature (780 K), where methane and water are both expected to be abundant. The planet therefore provides a unique opportunity for spectroscopic characterization of carbon and oxygen chemistry prior to the launch of JWST. With its large expected signal, WASP-107b also provides an excellent laboratory to study aerosol formation. The features are so large that even if thick clouds/haze are present at very high altitudes (0.1 mbar), it will still be possible to detect absorption features peeking out above them. In this talk, I will present the first constraints on the planet's atmospheric metallicity, carbon/oxygen chemistry, and aerosol properties, based on recent near-infrared transit spectroscopy observations from the Hubble Space Telescope.

Oral Presentation

Dr. Katherine Kretke
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Planet Formation Near and Far

Exoplanet studies have clearly demonstrated that planet formation is a robust process and a natural outcome of the star formation process. In this talk I will review current ideas in planet formation theory, particularly focusing on the potential importance of small particles known as "pebbles" and what the Solar System appears to be telling us about the planet formation process.

Oral Presentation

Mr. Steven Kreyche
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Eclipse Variability Observed by Kepler

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Exoplanetary eclipses occur when a planet passes behind its host star, causing the planet's reflected and emitted light to be blocked. We search for variability in the eclipses of the hot Jupiter HAT-P-7b using data from NASA's Kepler mission. This variability could provide insight into the meteorology of the planet and how the atmosphere changes with each orbit. The model phase curve is composed of three signals: the planetary reflected and emitted radiation, ellipsoidal variations due to tidal forces acting on the planet, and Doppler flux variations due to reflex motion with the host star as well as instrumental effects. The relationship between these signals, as well as the transit, may allow for planetary variability to be distinguished from other forms of variability. We will apply this model to all of the available data and perform fits to the transit and eclipse of each orbit. The optimal number of eclipses will be stacked to improve the signal-to-noise ratio while preserving any detectable variability.

Poster

Dr. Jonas Kuhn
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Doing things because they are hard: High-contrast imaging of compact, resolved binary systems.

More than half of the stars in the solar neighborhood reside in binary/multiple stellar systems, but these systems are usually overlooked in direct imaging survey. Yet recent studies suggest that gas giant planets may be more abundant around binaries than single stars. Here we present preliminary results of an on-going Palomar pilot survey (~ 15 target systems) searching for low-mass companions around young stars in a challenging binary configuration, with separations as close as 0''.3 and near-equal K-band magnitudes. Using the new Stellar Double Coronagraph (SDC) instrument on the 200-inch Telescope in a modified optical configuration, we are able to align any binary system behind two vector vortex coronagraphs in cascade, effectively nulling each stellar component by more than an order of magnitude, therefore accessing a new contrast parameter space at very close angular separation. This approach makes use of the absence of sky rotation on the Hale Telescope, hence it is not readily compatible with Angular Differential Imaging (ADI), but we end up introducing a prospective technological pathway to simultaneously null two (or more) stars in pupil-tracking mode, using liquid crystal display panels as focal-plane “digital adaptive coronagraphs”.

Oral Presentation

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A Vector Vortex Coronagraph for the Subaru Coronagraphic Extreme-Adaptive Optics (SCExAO) System: First Light and Commissioning Results

The vector vortex is one of the baseline coronagraphic imaging mode of the newly-commissioned Subaru Coronagraphic Extreme-Adaptive Optics (SCExAO) “planet-imager” instrument equipping the Subaru 8-m Telescope. SCExAO is not only intended to serve as a VLT-class “planet-imager” instrument in the Northern hemisphere, similarly to SPHERE or GPI in the South, but also to operate as a technology demonstration testbed ahead of the ELTs-era, with a particular emphasis on small inner-working angle (IWA) coronagraphic capabilities. This given priority to small-IWA imaging led to incorporate an H-band vector vortex liquid crystal waveplate into SCExAO, which can potentially reach within 1 l/D from the star. Here we present a detailed overview of the instrumental performances of the SCExAO vector vortex coronagraph, as well as first-light and early commissioning results, obtained in extreme AO regime during the 2016B and 2017A semesters. Finally, we also provide a few recent on-sky imaging examples, notably high-contrast ADI-only detection of the planetary-mass companion kappa Andromedae b, with a signal-to-noise ratio of about 100 reached in less than 10 mn exposure time.

Poster

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Direct imaging of exoplanets

Direct imaging of exoplanets orbiting a few au from their parent stars requires high quality images provided by space telescopes or ground based telescopes equipped with Adaptive Optics to correct for

the perturbations of the Earth atmosphere. It also requires coronagraphs that act as eclipsing devices, to block as much as possible the star light. Finally, dedicated reduction algorithms are needed to still increase the contrast. All these constraints explain why only few exoplanets have been imaged so far. Yet, the few directly imaged planets bring unique information on planetary systems formation and evolution, very complementary to indirect detections. Direct imaging is also expected to allow looking for signatures of life around Earth twins in the future. After a brief overview of the history of direct imaging, and the results obtained, I will report on the recent results obtained with the extreme adaptive optics instruments. I will then propose a roadmap towards Earth-like planets imaging and characterization.

Oral Presentation

Dr. Eric Lopez
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Predictions for the Transition Between Rocky Super-Earths and Gaseous Sub-Neptunes

One of the most significant advances by NASA's Kepler Mission was the discovery of an abundant new population of highly irradiated planets with sizes between that of the Earth and Neptune, unlike anything found in the Solar System. Subsequent analysis showed that at 1.5 Earth Radii there is a transition from a population of predominantly rocky super-Earths to non-rocky sub-Neptunes, which must have substantial volatile envelopes to explain their low densities. Determining the origin of these highly irradiated rocky planets will be critical to our understanding of low-mass planet formation and the frequency of potentially habitable Earth-like planets. These short-period rocky super-Earths could simply be the stripped cores of sub-Neptunes, which have lost their envelopes due to atmospheric photo-evaporation or other processes, or they might instead be a separate population of inherently rocky planets, which never had significant envelopes. I will suggest an observational path forward to distinguish between these scenarios. Using models of atmospheric photo-evaporation I will show that if most bare rocky planets are the evaporated cores of sub-Neptunes then the transition radius should decrease as surveys push to longer orbital periods. On the other hand, if most rocky planets formed after their disks dissipate then these planets will have formed without initial gaseous envelopes. Moreover, I will show that distinguishing between these two scenarios should be possible in coming years with radial velocity follow-up of planets found by TESS. Finally, I will discuss the broader implications of this work for current efforts to measure eta-Earth, which may yield significant overestimates if most rocky planets form as evaporated cores.

Oral Presentation

Prof. Bruce Macintosh
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Exoplanet coronagraph science with WFIRST

The WFIRST mission was originally ended as a wide-field survey facility, with an exoplanet science component via microlensing. With the change to a 2.4-m telescope, the mission is capable of carrying an effective coronagraph for exoplanet imaging. The baseline architecture allows use of a hybrid lyot or shaped pupil coronagraph, feeding a imager and integral field spectrograph. This will allow imaging and photometry of mature nearby planets and zodiacal disks in reflected light, as well as spectroscopy of the brightest targets. I will discuss the scientific motivations of the mission and show simulated science capabilities, and discuss the process towards definition of a science mission.

Poster

Dr. Avi Mandell
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Improving Community Coordination and Concensus In Exoplanet Research with The GSFC Exoplanet Modeling & Analysis Center

Our ability to characterize the atmospheres of extrasolar planets will be revolutionized by JWST, WFIRST and future ground- and space-based telescopes. The GSFC Exoplanet Modeling and Analysis Center will be a web-accessible high-performance computing platform with science support for modelers and software developers to host and integrate their products, with the goal of leveraging the scientific contributions from the entire exoplanet community to improve our interpretations of future exoplanet discoveries.

Oral Presentation

Dr. Christian Marois
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Direct Imaging of Other Earths Around Nearby Sun-Like Stars Using 10
Microns ExAO Coronagraphy.

The quest to find Earth-like planets around Sun-like stars is still in its infancy and beyond our current capabilities. The Earth’s thermal emission peak is found at 10 microns, and the contrast to detect such planets at that wavelength and around a Sun-like star is about 1E7, similar to what is currently achieved with the world-best ExAO systems. The 10 microns band also contains important biomarkers, such as water, methane, ozone and CO_2. Given that the planet is detected in thermal light, a surface temperature can also be estimated. I will discuss our current project to build a 10-microns ExAO direct imaging system for Gemini South (TIKI), an instrument that could in theory detect, at 5 sigma, an Earth-analog in less than 100h of observing time around Alpha Centauri A & B. This instrument is also a prototype for a TMT MICHI module that will be 200 times more efficient, allowing the discovery and characterization of nearby Earth-like planets in less than an hour.

Oral Presentation

Ms. Raquel Martinez

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Searching for the Elusive Photospheric Continuum of the Wide-Orbit, Planetary-Mass Companion FW Tau b with HET LRS2

Adaptive optics imaging of nearby star-forming regions have found a population of wide-orbit, planetary-mass companions (PMCs), indicating these objects are a normal product of star and planet formation. It is unclear whether these systems represent the low-mass extreme of stellar binary formation, or the high-mass and wide-orbit extreme of planet formation. The final determination of which theory prevails will require a statistical sample of PMCs from which general properties and demographics can be obtained.

The large separation (>2") and moderate contrast between a PMC and its host star make such systems amenable to direct imaging and spectroscopic study. While the dominant formation mechanism of PMCs is to be determined, if they did form similarly to planets, studying PMC atmospheres would provide much needed insight into the more "traditional" giant planets that orbit closer to their host stars.

FW Tau is a close binary system that harbors the PMC FW Tau b. Spectroscopic observations have found that the companion is accreting and driving outflows, but those observations have failed to detect any photospheric features. In this work, we present observations of FW Tau with the newly commissioned 9 m Hobby-Eberly Telescope (HET) second generation Low Resolution Spectrograph (LRS2). We have obtained >8 hours of data over 12 nights in an attempt to detect the continuum of FW Tau b. We will describe the LRS2 integral-field unit and provide details of our observing strategy. We will detail the data reduction pipeline and current progress in combining our observations to produce a detection of FW Tau b's continuum. We will conclude by discussing our plans to further characterize this planetary-mass companion that has been caught in mid-assembly.

Poster

Prof. Ben Mazin
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First light of DARKNESS and MEC: Pathfinders for exoplanet imaging with Microwave Kinetic Inductance Detectors

High-contrast astronomy is a powerful technique for the study of extrasolar systems, allowing the direct imaging of exoplanets and circumstellar disks by suppressing the light from their host star through a combination of extreme Adaptive Optics (XAO) and coronagraphy. The primary challenge faced by high-contrast imagers is a varying background of "speckles" in the final image, caused by starlight that escapes coronagraphic rejection. While techniques exist to reliably correct static speckles from diffraction and instrumental aberrations, speckles resulting from residual atmospheric aberrations are especially troublesome – with decorrelation times on the order of 1s, they average slowly over long exposures and impose the current state-of-the-art contrast limits of ~10^-6 from the ground (roughly corresponding to detectable planet masses >1 Jupiter mass). Optical and near-infrared Microwave Kinetic Inductance Detectors (MKIDs) offer great potential for overcoming this limitation: read-noise free photon counting will

enable real-time focal plane wavefront control (FPWFC) at frame rates much faster than the atmospheric speckle decorrelation time, and intrinsic energy resolution enables wavefront correction over a broad bandwidth. DARKNESS (the DARK-speckle Near-infrared Energy-resolving Superconducting Spectrophotometer) is the first of several planned integral field spectrographs (IFSs) to demonstrate the use of optical/near-infrared MKIDs for high-contrast astronomy. DARKNESS saw first-light in July 2016 at Palomar Observatory, and has subsequently travelled to Palomar again in November 2016 and April 2017 for ongoing commissioning and science verification. Here I will present the completed instrument and early science results, including a study of temporospatial speckle correlations across millisecond to hour timescales, with implications for using these statistics to discriminate speckles from true faint companions.

Oral Presentation

Dr. Tiffany Meshkat
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Occurrence of giant planets around stars with dusty debris disks

Debris disks may be the signposts of recent planet formation. The dust, which is generated in collisional cascades of asteroids and comets, is enhanced by the gravitational stirring of gas giant planets. Thus bright debris disk systems are natural targets for imaging searches for planets, as it indicates that the host star likely possesses some kind of planetary system. In this work, we describe a joint high contrast imaging survey for planetary mass companions at Keck and VLT of the last significant sample of debris disks identified by the Spitzer Space Telescope. No new substellar companions were discovered in our survey of Spitzer-selected targets. We combine these observations with from three published surveys, to put constraints on the frequency of planets around debris disk stars in the largest sample to date. We also obtained published data on stars which do not show infrared excesses for a control sample. We assume a double power law distribution of the form f(m,a) = Cm^alpha a^beta for this population of companions. We find that the frequency of giant planets with masses 5-20 MJup and separations 10-1000 au around stars with debris disks is 6.2% (68% confidence interval 3.6-9.7%), compared to 0.68% (68% confidence interval 0.2-1.7%) for the control sample of stars without disks. For the first time, we show that the occurrence of young giant planets around stars with debris disks is higher than those without debris disks at the 89% confidence level, tentatively suggesting that these distributions are distinct.

Oral Presentation

Ms. Jacqueline Monkiewicz
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JVLA and ALMA Observations of the J1407b Exoring System

In 2007, a 54-day eclipsing event of the pre-main sequence star 1SWASP J1407 revealed the presence of a large (a ~ 1 A.U.) exoring system encircling a presumed substellar companion, dubbed J1407b. Multiple ring crossing events suggest a highly-structured, dusty system. Given the age of the host star, the most favorable interpretation is of a proto-satellite disk system left over from the nebular accretion phase of the companion, with the disk possibly sculpted by young exomoons. No additional eclipses have since been observed; consequently the orbit, size, and dust mass of this exoring system remain largely unconstrained.

Only the Atacama Large Millimeter Array (ALMA) and the Jansky Very Large Array (JVLA) have adequate sensitivity and resolution to directly map the orbit of the exoring system. We will obtain JVLA Q-band (45 GHz) observations and ALMA band 7 (345 GHz) observations in order to 1.) confirm the presence of an early exoring system orbiting J1407, 2.) measure emission from the larger millimeter- and centimeter-sized dust particles, and 3.) constrain the total dust mass of the exoring system and measure the particle size distribution. If detected, these will be the first direct observations of an exo-satellite system in the process of formation, and could provide astrometric data to determine the epoch of the next eclipse.

Poster

Dr. Benjamin Montet
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Distinguishing between long-period planets and stellar activity with Kepler, TESS, and Gaia

Activity cycles in solar-type stars can induce an apparent RV shift in stellar spectra with a similar amplitude and period to that of Jupiter, complicating the detection of these planets. While efforts have been made to better understand spectroscopic tracers of magnetic activity, photometric tracers will soon be available for all stars bright enough for precision RV work. Here, I will describe the detection of magnetic activity in Sun-like stars observed in the Kepler field through photometric brightness variations observed in the Kepler Full Frame Images. I will discuss how these variations change as a function of stellar rotation period and how similar observations of rotation periods and brightness variations will be achievable in the near future by combining data from the TESS and Gaia missions, allowing for target selection in future RV surveys to be optimized without the need for as much expensive reconnaissance spectroscopy.
Oral Presentation

Dr. Christoph Mordasini
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Confronting predictions of planet formation models with observations of planet populations at intermediate and wide orbital separations

In this talk we first present key statistical predictions of different theoretical models of planet formation and compare them with observational constraints derived mainly from microlensing and direct imaging surveys. We address in particular (1) the frequency of planet types as a function of distance, (2) the mass-luminosity relation during both the formation and evolution phase and its dependency on the thermodynamics of accretion, (3) the planetary initial mass function with its imprints of physical processes that manifest in the form of breaks and bumps, and (4) the dependency on stellar properties like mass or metallicity.

We show in this way how the observations of planetary populations at intermediate and wide orbits make it possible to better understand the timescales of orbital migration and solid and gas accretion, the formation of scattered planets by core accretion, the question of cold or hot starts for direct imaging, and the relation to planets at short distances.

Oral Presentation

Coroline Morley
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The Current Status and Frontiers of Understanding Planetary Atmospheres

We have been studying brown dwarf and exoplanet atmospheres for about twenty years, and have progressed considerably in our understanding of their atmospheres. I will review the current knowledge of wide-orbit and free-floating substellar atmospheres from these past two decades of atmosphere studies. Modeling of substellar atmospheres is crucial for understanding their properties from observations, including determining their temperatures, masses, compositions, and atmospheric circulation. Model atmospheres have provided templates at different effective temperatures, gravities, and metallicities to compare to observations, allowing us to connect their spectra to these physical properties. We have learned about mixing in substellar atmospheres by comparing to models that include disequilibrium chemistry. Clouds play a key role in shaping the spectra of brown dwarfs and planets, from refractory iron and silicate clouds in hot objects to volatile clouds in colder objects. I will discuss the current frontiers of substellar atmospheric studies, including observations of the coldest objects and the youngest objects, studies of variable objects, and the development of data-driven retrieval algorithms. The youngest objects include both free-floating planet-mass brown dwarfs and directly-imaged planets; gravity may strongly effect the chemistry and cloud formation on these objects. I will discuss new observations from instruments like GPI and SPHERE, which allow us to observe spectra of directly-imaged planets. I will also discuss what we can expect for future advances in wide-orbit planet characterization, including reflected-light observations from future missions such as WFIRST, which will allow us to study planets more similar to those in our own solar system.

Oral Presentation

Prof. Ruth Murray-Clay
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Disks and Planet Formation at Wide Separations

Direct imaging observations are most sensitive to giant planets at wide separations. What sets the extent of giant planet formation, and what does this tell us about the structures of planetary systems in general? I will provide evidence that observed protoplanetary disks may be more massive than previously thought, show that gas turbulence coupled with pebble accretion may set the largest distances at which giant planets form, and discuss ways that we can use observations of wide-separation planets to constrain planet formation theories. Finally, I will comment on why Uranus and Neptune are not giants and discuss implications for the diversity of planetary systems.

Oral Presentation

Dr. Erika Nesvold
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Inside-Out Systems: Using Debris Disks to Find Exterior, Wide-Orbit Companions

Models of debris disk morphology are often focused on the effects of a planet orbiting interior to or within the disk. But a planetary-mass perturber on a wide, exterior orbit can also excite eccentricities and inclinations in a disk, producing observable features. HD 106906 is an ideal example of such a a system, as it harbors a confirmed exterior 11 M_Jup companion at a projected separation of 650 au outside a resolved, asymmetric disk. I present the results of collisional and dynamical simulations investigating the interactions between the disk and the companion, and use the disk's observed morphology to place constraints on the companion's orbit. I conclude that the disk's observed morphology is consistent with perturbations from the observed exterior companion. Generalizing this result, I suggest that exterior perturbers, as well as interior planets, should be considered when investigating the cause of observed asymmetries in a debris disk. I also propose two observational tests of a dust disk that can distinguish whether the dust was produced by an exterior, inclined companion, or an interior, eccentric planet.

Oral Presentation

Mr. Eric Nielsen
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The Gemini Planet Imager Exoplanet Survey

The Gemini Planet Imager Exoplanet Survey (GPIES) is one of the largest most sensitive direct imaging searches for exoplanets conducted to date, and having observed more than 300 stars the survey is halfway complete. We present highlights from the first half of the survey, including the discovery and characterization of the young exoplanet 51 Eri b and the brown dwarf HR 2562 B, new imaging of multiple disks, and resolving the young stellar binary V343 Nor for the first time. GPI has also provided new spectra and orbits of previous known planets and brown dwarfs and polarization measurements of a wide range of disks. Finally, we discuss the constraints placed by the first half of the GPIES campaign on the population of giant planets at orbital separations beyond that of Jupiter.

Oral Presentation

Dr. Masahiro Ogihara
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Formation of close-in super-Earths in disks evolving via disk winds and implications for the origin of outer planets

Recent observations of exoplanets that includes RV and transit surveys have revealed a large number of close-in super-Earths. To date, over 430 systems harbor multiple close-in super-Earths, allowing us to obtain statistical properties of such systems. Thus, the origin of close-in super-Earth systems has been studied in the recent literature. In our previous work (Ogihara, Morbidelli, Guillot 2015), we performed N-body simulations of super-Earth formation in a power-law disk and found that observed orbital distributions of close-in super-Earths cannot be reproduced, because planets undergo rapid inward type I migration.

The planet formation process largely depends on the evolution of a protoplanetary disk. According to magnetohydrodynamic simulations (Suzuki, Ogihara, Morbidelli, Crida, Guillot 2016), magnetically-driven disk winds would alter the surface density profile of gas in the close-in region of a protoplanetary disk, which in turn affects type I migration of low-mass planets. The surface density exhibits flat slopes or even positive in the close-in region due to the effects of disk winds. In this case, inward type I migration can be significantly suppressed.

We investigate formation of close-in super- Earths by performing N-body simulations in disks that evolve via magnetically-driven disk winds. The aim is to examine the effects of disk winds on the orbital evolution and final configuration of close-in super-Earths. We find that in MRI-active disks, type I migration can be suppressed in the whole close-in region, which provides a good match to observed distributions (e.g., period ratios) of close- in super-Earths.

Oral Presentation

Dr. Antonija Oklopcic
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Atmospheric characterization with reflected light at short wavelengths: decoding the spectral signatures of Raman scattering

Obtaining information about chemical composition and physical conditions in exoplanet atmospheres is crucial for improving our understanding of the physical processes that drive planetary formation and evolution. In order to provide more robust and reliable constraints on the properties of exoplanets, we need to keep searching for new diagnostics of exoplanet atmospheres, complementary to the currently existing methods. Spectral signatures of Raman scattering at short optical wavelengths can be used to probe the atmospheres of exoplanets, which has been previously demonstrated in studies of Solar System planets. Raman scattering on molecules in a planetary atmosphere imprints specific features in the geometric albedo spectrum of the planet that can be used to constrain the properties of the atmosphere. The intensity of Raman features is related to the depth of the atmosphere, and can therefore be used to distinguish a clear, deep atmosphere from an atmosphere with high-altitude clouds. Raman features can also be used to spectroscopically identify the main scatterer in the atmosphere, even molecules like hydrogen or nitrogen, which otherwise do not show prominent spectral signatures. The relative intensity of different Raman features depends on the initial population of different molecular levels, and can therefore be used to infer the temperature of the atmosphere. I will discuss the prospects for detecting spectral features of Raman scattering in nearby exoplanets using the next-generation observational facilities.

Oral Presentation

Mr. Blake Pantoja
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High Contrast Imaging of Radial Velocity Detected Companions

Radial velocity measurements have long proven to be a powerful method of detecting low-mass companions to bright stars, but they come with the inherent limitation that only minimum masses can be constrained for these companions, since the system inclinations are unknown. Direct imaging, on the other hand, allows us to constrain the companion's inclination relative to an Earth-bound observer, and when combined with radial velocities, allows us to directly probe into the mass/period parameter space of any detected companions. By searching for targets with long-period radial velocity trends, we are able to search for objects with a known but unseen companion. We will present our program for following up old metal-rich and giant stars with observed long period radial velocity trends with high-contrast direct imaging on SPHERE, MagAO, and SOAR. This project has shown to be successful for the detection of low-mass stars with non-detections representing possible planetary-mass companions. We will also show our comparison of methods for obtaining the highest possible contrast performance close to the primary star for extreme Adaptive Optics instruments, which will be crucial for directly detecting faint low-mass planets around old stars. This will also be crucial for future instrumentation on the E-ELT and WFIRST, when planetary detections will be achievable.

Oral Presentation (tentative)

Dr. Rahul Patel
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(File Format for Simulations of WFIRST-CGI Observations)

The science investigation teams (SIT) for the coronagraphic instrument aboard WFIRST have begun studying the capabilities of the instrument to directly image reflected light off from exoplanets at contrasts down to contrasts of ~10-9 with respect to the stellar flux. Detection of point sources at these high contrasts requires yield estimates and detailed modeling of the image of the planetary system as it propagates through the telescope optics. While the SITs might generate custom astrophysical scenes, the integrated model, propagated through the internal speckle field, is typically done at JPL. Here, we present a standard file format to ensure a single distribution system between those who produce the raw astrophysical scenes, and JPL modelers who incorporate those scenes into their optical modeling. At its core, our custom file format uses the Flexible Image Transport System (FITS), and incorporates standards on packaging astrophysical scenes. This includes spectral and astrometric information for planetary and stellar point sources, zodiacal light and extragalactic sources that may appear as

contaminants. Adhering to such a uniform data distribution format is necessary, as it ensures seamless workflow between the SITs and modelers at JPL for the goals of understanding limits of the WFIRST coronagraphic instrument. In this poster, we present an overview of the structure and content of this file format.

Poster

Dr. Radek Poleski
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Microlensing constraints on population of ice giants

The microlensing technique allows discovering planets on wide orbits, including analogs of Solar System ice giants. As an example, OGLE-2008-BLG-092Lb is an analog of Uranus: located at projected separation of 15 AU and with a mass ratio of 2.4e-4. There a few other microlensing planets on similarly wide orbits and their number continues to grow. This sample allows constraining the properties of the ice giant exoplanets. I will show what we can learn from already available sample of microlensing planets on wide orbits.

Oral Presentation

Dr. Laurent Pueyo
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Exoplanet imaging from space: from JWST to WFIRST

In this talk I will review upcoming space based coronagraphs. I will first discuss the JWST coronagraphs: I will present the science rationale underlying their design, their implementation within the Webb Science Instruments and expected performances. I will also present the key science goals of currently planned Guaranteed Time Observations. I will then present ongoing work on the WFIRST coronagraph instrument. I will provide an overview of the main envisioned science programs, along with current projected performances estimates based on both simulations and recent lab test results. I will conclude by discussing possible synergies between the JWST and WFIRST coronagraph instruments.

Oral Presentation

Dr. Darin Ragozzine
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Debiasing Kepler System-by-System to Infer Exoplanetary Architectures

The Kepler Space Telescope discovered hundreds of systems of multiple transiting planets that have revolutionized our understanding of the formation and evolution of planetary systems. In particular, the architectures of these systems (the ordering and placement of the planets within a system) have been extremely valuable. However, multi-transiting systems also present a challenge of complex biases in transiting probability for multiple planets in the same system. Quantifying the underlying distribution and occurrence rates of planetary system architectures requires debiasing the Kepler results "system-by-system" which has been mostly avoided in past analyses. To address this problem directly, we have developed the Planetary System Simulator (SysSim) that generates planetary systems based on empirical parametrizations, compares these to Kepler results using Hierarchical Bayesian Modeling, and determines the posterior distribution of parameters using Approximate Bayesian Computing. We extend the first application of SysSim from occurrence rates for individual planets (Hsu, Ford, Ragozzine & Morehead, in prep.) to studying planetary systems. We will present results on the multiplicity-inclination distribution of planetary systems with implications for the "Kepler dichotomy", the fraction of stars with planets, etc.

Oral Presentation

Dr. Abhi Rajan
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Examining the Atmosphere of the Cloudy Young Jupiter, 51 Eridani b

We present multi-wavelength spectro-photometry, including new GPI K1 and K2 spectra as well as NIRC2 Lp and Ms photometry, on the directly imaged planet, 51 Eridani b. Discovered by the Gemini Planet Imager Exoplanet Survey, the new data suggests that the planets luminosity when compared to warm start models is consistent with a planet formed via core accretion with a core mass between 15 and 127 $M_\oplus$. 51 Eri b photometry is redder than field brown dwarfs as well as known young T-dwarfs which could be caused by the planet still undergoing the transition from L-type to T-type. Our modeling effort included two complementary atmosphere model grids with different cloud properties spanning a range of cloud properties that suggest that 51 Eri b has an effective temperature ranging between 605–737 K, solar metallicity, a surface gravity of log(g) = 3.5–4.0 dex, and an atmosphere that requires a patchy cloud atmosphere to properly model the SED.

Oral Presentation

Dr. Clement Ranc
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Simultaneous Kepler-2 Photometry and Light Curves Modeling for the Analysis of K2C9 Microlensing Observations

Gravitational microlensing occupies a unique niche in exoplanet sensitivity with its ability to detect planets down to below an Earth mass, at large orbital separation, beyond the snow line. This is the region where planet formation is thought to be most efficient, because the condensation of ices provides a higher density of the solid material needed to initiate planet formation. The Kepler-2 mission was dedicated to the observation of microlensing events toward the Galactic Bulge during its campaign 9 (K2C9). While the photometric light curve of a microlensing event observed from the ground provides constraints on the lens physical parameters, in many cases the lens mass and distance from Earth remain degenerated. Measuring the microlensing parallax from simultaneous space- and ground-based observations may break this degeneracy. The analysis of the K2C9 observations is still an on-going process, primarily because extracting the microlensing light curves is very challenging. I will show that our new method to extract the K2 data produces precise photometry in crowded stellar fields, such as the K2C9 field. It is a modification of the Causal Pixel Method (CPM) developed by Wang and Hogg. CPM is a pixel-level detrending algorithm that detects systematic light curve errors via correlations with features seen in the light curves from other pixels. In particular, I will show that a simultaneous CPM and light curve modeling can produce precise photometry, not only for short timescale events, but also for long planetary/binary events. I will take the example of OGLE-2016-BLG-0241 for which the preliminary models indicate it might be a planet. These K2C9 observations help to develop the microlensing planet detection method, which will be employed by the WFIRST mission that will extend the statistical census of exoplanet to include planets in wide orbits.

Oral Presentation

Dr. Nicholas Rattenbury
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The Microlensing Observations in Astrophysics (MOA) Collaboration: Recent Results and Future Plans

The Japan/New Zealand Microlensing Observations in Astrophysics (MOA) collaboration has been running for nearly 25 years. The collaboration uses telescopes at the Mount John University Observatory in New Zealand to detect microlensing events and planetary anomalies in those events.

In this talk, I will (briefly!) review the MOA project and results to date, and describe in detail some particular challenges we face in the new era of space-based planetary microlensing and our search for solar system analogues.

Oral Presentation

Dr. Maddalena Reggiani
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Direct imaging constraints on planetary companions in the transition disk around MWC 758

Transition disks offer the extraordinary opportunity to look for newly born planets and investigate the early stages of planet formation at wide orbits. We present new L’-band images of the young (3.5 Myrs) Herbig A5 star MWC 758, obtained in two epochs with the vector vortex coronagraph installed in the near-infrared camera and spectrograph NIRC2 at the Keck II telescope. Besides the already known double-arm spiral structure, our high contrast imaging observations recover a bright feature in the vicinity of the star and a third spiral arm. A geometrical fit to the spiral pattern through linear spiral density wave theory allows us to explore the possible connection between this luminous emission and the spiral structure. We also place strong constraints on planetary companions in the system down to 5 Jupiter masses beyond 0".6 from the star. Future observations at other wavelengths and new dedicated simulations will be needed to shed light on the true nature of the bright feature and on its connection with the spiral arms.

Oral Presentation

Dr. Rachael Roettenbacher
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Cataloging Stellar Activity to Disentangle the Signatures of Planets

Stellar magnetic fields affect the surfaces of cool stars in a variety of ways including through the suppression of convection (seen as localized dark regions, or starspots). The number and size of starspots depends on the star, but these magnetic features are known to impact photometric and spectroscopic observations. In transit photometry, radial velocity, and microlensing observations, some potentially planetary signatures have been proven to be caused by starspots. Here, we discuss our efforts to improve the identification and characterization of planets hosted by active stars. To begin disentangling the signatures of stellar magnetism ands planets, we image active stellar surfaces with a variety of state-of-the-art techniques. Our combination of light-curve inversion, Doppler, and interferometric aperture synthesis images is aimed at creating a catalog of stellar activity that will allow for an understanding of how stellar activity manifests and evolves on different types of active stars. We combine single epoch observations using all three imaging methods and multi-epoch light-curve inversion of data sets such as the Kepler archive to create the most complete study of stellar surfaces possible. With this unprecedented analysis of stellar activity, we will be able to more easily diagnose a detection as that of a planet or stellar activity and provide better opportunities to pull planetary signatures out of data otherwise obscured by starspots.

Oral Presentation

Dr. Garreth Ruane
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A deep search for planets forming in the TW Hya protoplanetary disk with the Keck/NIRC2 vortex coronagraph

Gap features in the nearest protoplanetary disk, TW Hya (distance of 60 pc), may be signposts of ongoing planet formation. To test this hypothesis, we performed long-exposure thermal infrared coronagraphic imaging observations to search for accreting planets within dust gaps previously detected in scattered light and submm-wave thermal emission. Three nights of observations with the Keck/NIRC2 vortex coronagraph mode in L’ (3.4-4.1 um) did not reveal any statistically significant point sources. We thereby set strict upper limits on the masses of non-accreting planets. In the four most prominent disk gaps at 24,

41, 47, and 88 au, we obtain upper mass limits of 1.6-2.3, 1.1-1.6, 1.1-1.5, and 1.0-1.2 Jupiter masses assuming an age range of 7-10 Myr for TW Hya. These limits correspond to the contrast at 95% completeness with a 1% chance of a false positive within 1 arcsecond of the star. Our non-detection also implies that any putative 0.1 Jupiter mass planet, which could be responsible for opening the 24 au gap, is presently accreting at rates insufficient to build up a Jupiter mass within TW Hya's pre-main sequence lifetime.

Oral Presentation

Dr. Tobias Schmidt
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Atmospheric fitting & tests of speckle influence onto direct imaging candidates

The SHINE survey conducted on the SPHERE high-contrast imager at VLT aims to characterise the giant planet population beyond 5 AU around 400-500 nearby stars. Now, that about half of the observations of SHINE are performed, more and more spectro-photometric information for known and new companion candidates is collected, that can be subsequently used to extract information on planetary and sub-stellar atmospheres and how they might have formed.
While other SHINE presentations focus on giving an overview on the survey or on one unique target, here the focus is on details of special or newly characterized objects, methods used to achieve reliable spectro-photometry in the presence of strong speckles for close companions, as well as on the very youngest candidates from SHINE and additional open surveys, providing even more information how young high-mass planet candidates and brown dwarfs form.

Oral Presentation

Ms. Brigitta Sipocz
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Color-magnitude diagrams for exoplanets: an interactive tool

Color-magnitude and color-color diagrams have proved to be a powerful toolset for representing and comparing celestial objects for a long time. They are routinely used in stellar and brown dwarf studies to define populations, sub-groups and outliers, and to study the evolution of stars.
However, the full potential of extending them towards lower masses into the planetary domain is not yet recognized in the field of exoplanets, even though we expect them to be extremely useful to help surveys in the target selection process and in mapping the overall progress in the field.

In my talk, I will elaborate that these diagrams are valuable assets for both comparative exoplanetology and for population studies of exoplanets. Color-magnitude diagrams provide a unified way to compare objects that occupy the same temperature-size parameter space, such as very low-mass stars, brown dwarfs, and both transiting and directly imaged planets. Blackbody and planetary atmosphere models

also provide useful comparison data but color-magnitude diagrams can give model-free diagnostics, too. We are able to make inferences on the atmospheres of exoplanets without requiring models.

I will also present a live demo of our new browser based interactive tool that revolutionize the exploration of such parameter spaces using Near IR and Mid IR observational data. Experience shows that interactive exploration and visualisation are key to understand the physics behind noisy, multi source data.

Oral Presentation

Dr. Dan Sirbu
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BinCAT: A Binary Star Catalog for Direct Imaging Surveys

Dan Sirbu, Ruslan Belikov, Eduardo Bendek, AJ Riggs, Stuart Shaklan

Direct imaging of exoplanets represents a challenge for astronomical instrumentation due to the high-contrast ratio and small angular separation between the host star and the faint planet. Multi-star systems pose additional challenges for coronagraphic instruments due to the diffraction and aberration leakage caused by companion stars that must also be suppressed. Consequently, many scientifically valuable multi-star systems are excluded from direct imaging target lists for exoplanet surveys. We have recently developed a wavefront control technique called Multi-Star Wavefront Control (MSWC) to enable suppression of leakage from the off-axis companion in a binary star system such as Alpha Centauri.

We survey the FGK binary star population within 20pc for suitability for direct imaging surveys including upcoming future space missions such as WFIRST, HABEX, and LUVOIR. We have compiled a Binary Star Catalog that combines information from the Washington Double Star Catalog to determine the angular separations and companion leakage contributions from binary star companions. We use this catalog to estimate the background floor contrast due to the presence of currently known stellar companions. Finally, we estimate the increase in the target star populations that multi-star imaging would provide to future space missions.

Oral Presentation

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The search for Hot Jupiters using University of Wyoming's Red Buttes Observatory

The research objective for our team is to observe identified exoplanet targets in association with the KELT (Kilodegree Extremely Little Telescope) – North Transit Survey. The KELT transit survey is a photometric search for transiting exoplanets around bright main sequence stars. The KELT Follow-up Network (KELT-FUN), a collaboration of small-aperture telescope users located all over the world, confirms new planet candidates. As part of KELT-FUN, students use the University of Wyoming's Red Buttes Observatory monitors candidates identified by the KELT team in order of priority. Using the 0.6 meter telescope at Red Buttes Observatory we are able to detect transits around stars that are 8-12 mag in brightness, with a transit period of <4 hours and a transit depth of > 4 mmag. Using AIJ (AstroImageJ) to reduce the data we look for the telltale signs of a light curve that confirms the presence of the exoplanet in question. Once this data reduced we send it to the KELT team to verify and add to the accumulation of data for the target. This project gives undergraduates an authentic scientific research experience, learning how to operate a telescope, reduce data, and participate in a scientific collaboration.

Poster

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Thermal infrared probes of exoplanetary systems with LBTI

I will discuss ongoing efforts with the Large Binocular Telescope Interferometer (LBTI) to better constrain the occurrence of wide-separation gas-giant exoplanets and to better understand the nature of their formation, evolution, and atmospheres. Specifically, I will emphasize two programs which I help lead: 1) The LEECH survey which observed 100 stars using the twin LBT deformable secondary adaptive optics systems searching for wide-orbit gas-giants. LEECH was conducted at 3.7 microns, where cool planets (Teff < 1000 K) emit most of their flux. LEECH finished observations in January of 2017 yielding 100 contrast curves. My talk will include a detailed summary of the resulting survey statistics and will provide an overview of LBTI high-contrast imaging performance; and 2) I will discuss ALES, the world's only IFS operating at thermal-infrared wavelengths. ALES provides an important window to probe gas-giant atmospheres because thermal infrared constraints can help break degeneracies between effective temperature, surface gravity, and chemistry. The power of of thermal infrared observations stems from their sensitivity to clouds and carbon chemistry, with access to fundamental transitions of both methane and carbon monoxide. I will present initial results from ALES, demonstrating the functionality and fidelity of the instrument.

Oral Presentation

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Planet Mass Ratio Function from the MOA microlensing survey

A ground-based microlensing survey enables us to detect planets down to Earth masses beyond the snow line, where temperature is cold enough for ices to condense. Due to the high surface density in the protoplanetary disks just beyond the snowline, this parameter space is most efficient for forming planets. Nevertheless, these cold planets (especially for less massive ones than Saturn mass) are hard to detect by the other detection methods, i.e., transit, radial velocity and direct imaging. Thus, it is critical to study planet distribution from microlensing survey to understand planet formation mechanism.

In this talk, I will present the MOA (Microlensing Observations in Astrophysics) survey results which include bound and unbound planet discoveries, as well as a recent statistical result, a discovery of a break in the exoplanet mass ratio function beyond the snow line. The break (possibly peak) of the mass ratio function is located around the mass ratio of 1.7e-4, which is about Neptune mass if the host star is an M-type star. The break of the mass ratio function is also confirmed with the full microlensing sample (MOA plus previous results) using 30 planets. This study implies that Neptunes and failed Jupiter cores are the most common type of planets beyond the snow line. I will also present the comparison of the mass ratio function from the microlensing survey with planet population syntheses.

Oral Presentation

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Gravitational Instability of a Porous Silicate Dust Disk

Planetesimal formation is one of the most important unsolved problems in planet formation theory. Especially, rocky planetesimal formation is difficult because silicate dust grains are easily broken when they collide. Recently, it has been proposed that they stick together when they are smaller than ~10 nm because collisional fragmentation velocity increases with the grain radius. As they grow, they become porous, which can avoid radial drift toward the central star. These dust grains are called dust aggregates and constituent small particles are called monomers. However, rocky planetesimal formation mechanism is still unsolved because the stability of the disk with such porous silicate dust aggregates has not been investigated. If the disk becomes gravitationally unstable, dense dust clumps form, which leads to planetesimal formation.
We investigate the gravitational instability of the disk consisting of porous dust aggregates of ~2.5-10 nm-sized silicate monomers. In order to evaluate the disk stability, we calculate Toomre's stability parameter Q, for which we need to evaluate the equilibrium random velocity of dust aggregates. We calculate the equilibrium random velocity considering three increasing and two decreasing mechanisms: gravitational scattering between dust aggregates, stirring by gas turbulence, gravitational scattering by gas density fluctuation due to turbulence, collisions between them, and drag by mean flow of gas.
We derive quantitatively the condition of the gravitational instability using five disk and dust parameters: disk mass, dust-to-gas ratio, turbulent strength, orbital radius, and monomer radius. We find that qualitatively the gravitational instability occurs easily in disks with large mass, high dust-to-gas ratio, and weak turbulent strength, at large orbital radius, and in disks with large monomer radius.

Oral Presentation

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Bayesian Inference of Hot Jupiter Radius Anomalies Points to Ohmic Dissipation

A wide variety of mechanisms have been proposed to explain the anomalously large radii of hot Jupiters. Thanks to the large number of detections of such planets, it has become possible to analyze them as a population to infer their heating power as a function of flux, and thereby learn about the mechanism responsible. To do this, we constructed a set of thermal evolution models which predict radius as a function of mass, bulk heavy-element abundance, age, and stellar insolation. Using our planet mass-metallicity relation derived for cool (uninflated giant planets) as a prior for the composition, we can infer the distribution of possible anomalous power for each planet. We collect the information for the population of planets into a Bayesian hierarchical model to test different functional forms of the inflation power as a function of incident flux. We considered a nonparametric Gaussian process as well as three parametric models: the power-law, logistic, and Gaussian functions. The Gaussian shape is strongly favored by the DIC (a model selection statistic) and matches the shape of the Gaussian process. We see that the inflation efficiency increases until about ~1600 K, then declines back towards zero at higher temperatures. Critically, this is a key prediction of the Ohmic dissipation scenario, which arises from magnetic drag forces inhibiting wind speeds at high temperatures (and therefore ionization). This feature is not present in other proposed inflation mechanisms, and as such our data strongly favor the Ohmic dissipation model, thus shedding new light on one of the oldest problems in exoplanet physics.

Oral Presentation

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(A Spectropolarimetric Survey of Several Hundred Brown Dwarfs with WIRC+Pol)

Polarimetry is a powerful method to directly detect and characterize exoplanets. Star light is unpolarized, unlike scattered light from planetary atmosphere. As a result, a polarizer can be employed to suppress star light, enhancing the contrast for exoplanet detection. Moreover, the polarization signature from scattering processes in planetary atmospheres reveal unique information about the scatterer properties and geometry of cloud coverage, which is not probed by photometry or spectroscopy. Spectral information of the polarimetric signature can further probe scatterers at different altitudes. Polarimetric observations of directly imaged planets are presently challenging due to the limited number of planets accessible via this method. However, gas giants atmospheres are very similar to those of isolated brown dwarfs, which are much easier to observe. We are starting a 2-year spectropolarimetric survey on several hundreds bright (J < 15) BDs to create the first large catalog of BD spectropolarization. We installed and commissioned a novel polarization grating for the wide field infrared camera (WIRC) on the 200-inch Hale Telescope at Palomar Observatory. The instrument, dubbed WIRC+Pol, covers J and H bands with a spectral resolution R ~ 100. It is sensitive enough to detect 0.5% polarization at 3-sigma level within one hour for ~ 200 BDs accessible from Palomar. Our team has been developing global circulation and radiative transfer models, in order to retrieve physical atmospheric parameters from our observations. Preliminary data from the commissioning runs indicate that our polarimetric stability is only limited by photon noise and that we can achieve the predicted sensitivity.

Oral Presentation

Dr. Cayman Unterborn

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(Terrestrial Planet Models with Equilibrium Condensation Sequence Computations and Geophysical Interior Calculations)

The Earth is unique in our Solar System. It is the only planet known to undergo plate tectonics. It has a magnetic field as result of an outer liquid iron core that protects the surface from Solar radiation. What is not known, however, is whether the Earth is unique among all terrestrial planets outside our Solar System. The population of potentially “Earth-like” planets will only continue to grow. Recent surveys of dwarf planetary host and non- host stars find variations in the major terrestrial planet element abundances (Mg, Fe, Si) of between 10% and 400% of Solar. Additionally, the terrestrial exoplanet record shows planets ranging in size from sub-Mercury to super-Earth. How this stellar compositional diversity is translated into resultant exoplanet physical proper- ties including its mineralogy, structure and potential for tectonics is not known. Here, we present results of models blending equilibrium condensation sequence computations with geophysical interior calculations adopting the inputs of multiple stellar abundance catalogues. This benchmarked and generalized approach allows us to predict the mineralogy and structure in order to characterize an “average” exoplanet in these planetary systems, thus informing their likelihood to be “Earth-like” and potentially habitable. This combination of astro- and geophysical modeling provides us with a self-consistent method with which to compare planetary systems, thus improving our ability to prioritize “Earth-like” targets for follow-up observations within the TESS and JWST dataset. Furthermore, the methods described herein afford us an opportunity to explore rocky planet diversity as a whole and truly begin to answer the question, “Is the Earth special?”

Oral Presentation

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Testing the Effect of Viewing Geometry on the Observed Colours and Variability Amplitudes of Brown Dwarfs and Exoplanet Analogues

Photometric variability has now been robustly observed in a range of L and T spectral type brown dwarfs and more recently in planetary-mass companions and free-floating exoplanet analogues. These objects occupy the same temperature and pressure regime as the directly imaged planets, thus we can expect similar atmospheric properties. We have combined variability data from the literature to study the effects of rotation period and near-IR colour on the variability properties of a sample of brown dwarfs. Additionally we have used new rotational velocity measurements to constrain the inclinations of 19 objects. We see trends related to inclination angle, colour and variability amplitude, which provide information on the latitudinal distribution of cloud structures. Understanding the effect of viewing geometry on observed atmospheric appearance will allow us to make sense of the diversity seen in exoplanet atmospheres to date.

Oral Presentation

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The Anglo-Australian Planet Search Legacy

Radial velocity searches for exoplanets have undergone a revolution in recent years: now precisions of 1 m/s or better are being demonstrated by many instruments, and new purpose-built spectrographs hold the promise of bringing Earth-mass planets into the realm of secure detectability. In the "race to the bottom," it is critical not to overlook the impact of long-running planet search programs that continue to hold the advantage of time. We highlight the continuing impact of the 18-year Anglo-Australian Planet Search: the characterisation of long-period giant planets, and the insights into the occurrence rate of Jupiter and Saturn analogs. To fully understand the origins of planetary systems and the fundamental question of how common (or rare) the architecture of the Solar system is in the Galaxy, we must continue these ""legacy"" surveys to probe ever-larger orbital separations."

Oral Presentation

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High-Contrast Imaging of Young Planets with JWST

Marie Ygouf, Chas Beichman and the NIRCam team

With a series of coronagraphs and IFUs in the near- and the mid-infrared, the James Webb Space Telescope will offer new opportunities for high-contrast imaging. Further characterization of the directly imaged exoplanets will soon be possible, helping to break the degeneracy between different models of atmospheres. It will also be possible to search for new objects at unprecedented sensitivities, probing for exoplanets down to Saturn mass. The Guaranteed Time Observer (GTO) teams are currently facing the challenge to prepare the first high-contrast imaging observations with this new observatory. In this communication, we will present the NIRCam team plans to measure the effective temperature and luminosity of young, nearby exoplanets and our search for new worlds.

Oral Presentation

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Planets around A-stars as anchors for planet migration

Very few planets have been confirmed around early type stars, since these are often too rapidly rotating for precise radial velocities to be obtained. Of the ~1900 transiting planets known today, only four have been confirmed to transit stars hotter than T>7000K. However, planets around high mass stars are key

pieces of the planet formation puzzle, they are important to understanding giant planet formation and migration. For example, the protoplanetary disk mass around A-type stars should be significantly higher than that around solar-type stars, leading to a higher planet occurrence rate, and more compact systems. The stellar multiplicity rate is also higher for higher mass stars. Will the dynamically hotter environment around A-type planet-hosting stars result in different hot-Jupiter migrational pathways than around solar-type stars? We are using the Doppler tomography technique to confirm and characterize these planets around A-stars. I will detail our recent discoveries with the K2, KELT, and HAT surveys, and describe the next steps in defining the planet migration pathways that lead to these hot-Jupiters in the context of TESS.

Oral Presentation

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Modeling Debris Disks with Varying Compositions

The circumstellar disk plays an undeniable role in exoplanet formation; the accretion of disk material causes exoplanets and planetesimals to form. However, the composition and structure of the circumstellar debris disk can drastically affect the resulting exoplanets. By identifying the main compositional components of debris disks, we hope to learn more about the formation and nature of exoplanets. We calculated the dust absorption and emission within debris disks with Mie Theory. After we find properties of the disk, we use MCMC fitting to generate several fits to the data by varying the amount of different components within it. By using various combinations of compositions, we have modeled the spectra for a variety of debris disks.

Poster
