Exploring Strange New Worlds:
From Giant Planets to Super Earths

May 1 – 6, 2011

High Country Conference Center

Flagstaff, Arizona

Program and Abstracts

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Conference Agenda

Monday, May 2, 2011

Planet Formation and Disks: Lessons from the Solar System and Expectations for JWST

Time	*Title*	*Speaker*	*Page*
7:30 am	Continental Breakfast in Agassiz-Fremont Rooms		
8:15 am	**Welcoming Comments**	Chas Beichman and Malcolm Fridlund	
8:30 am	**Formation of the Solar System: Follow the Water**	Hal Levison	
9:10 am	**Dusty Disks with Herschel: From Protoplanetary to Debris Systems**	Jean-Charles Augereau	29
9:50 am	*Morning Break*		
10:20 am	**Overview of the James Webb Space Telescope and its Capabilities for Exoplanet Characterization**	Mark Clampin	30
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11:40 am	DUNES Observations of Debris Disks Around Nearby Stars with Exoplanets	Jonathan Marshall	31
11:55 am	Gas and Dust within 1 AU of Young Stars	Josh Eisner	31
12:10 pm	The LBT Interferometer: Observing Disks and Planets in the Thermal Infrared	Phil Hinz	32
12:25 pm	*Lunch (provided at the conference center)*		
1:30 pm	**Debris Disks with Spitzer, Herschel, and JWST**	Kate Su	33
2:10 pm	Exo-Zodiacal Dust Levels for Nearby Main-Sequence Stars: A Survey with the Keck Interferometer Nuller	Rafael Millan-Gabet	33
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2:55 pm	Three-Dimensional Atmospheric Circulation on Generic Eccentric Hot Jupiters	Tiffany Kataria	35
3:10 pm	Direct Imaging Search for Extrasolar Planets Using VLT/NACO's APP Coronagraph	Sascha P. Quanz	35
3:25 pm	Giant Planet Companions to T Tauri Stars	Christopher Crockett	36
3:40 pm	*Afternoon Break*		
4:10 pm	**Potentially Habitable Worlds in Our Solar System: Planetary Exploration and JWST**	Heidi Hammel	36
4:50 pm	Migration and Scattering: Constraints on the Dynamical History of the Solar System	Rebekah Dawson	37
5:05 pm	The Strange World We Call Home: Earth in the Context of an Exoplanet	Tyler D. Robinson	38
5:20 pm	Adjourn		
7:30 pm	**Public Lecture at Prochnow Auditorium: *Earth-Size Planets and Intelligent Life in the Universe***	**Geoff Marcy**	10

Tuesday, May 3, 2011

Characterization of Exoplanets

Time	***Title***	***Speaker***	***Page***
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9:10 am	**Interiors and Evolution of Giant Planets**	Tristan Guillot	39
9:50 am	*Morning Break*		
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11:00 am	**Review of HST and Spitzer Spectroscopy to EChO**	Giovanna Tinetti	40
11:40 am	On the Mass of CoRoT-7b	Malcolm Fridlund	41
11:55 am	New Optical Observations of Hot Jupiters with HST STIS and GTC OSIRIS	David Sing	42
12:10 pm	HST/WFC3 Observations of Giant Hot Exoplanets	Drake Deming	43
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2:50 pm	The Atmosphere of the Transiting Super-Earth GJ 1214b	Eliza Kempton	45
3:05 pm	The Role of Drag in the Energetics of Hot Jupiter Atmospheres	Emily Rauscher	45
3:20 pm	Three Dimensional Structure of Exoplanet Atmospheres	David Spiegel	46
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4:00 pm	**Transit and Eclipse Spectroscopy of Giant Planets with JWST**	Tom Greene	46
4:40 pm	Early Results from SEEDS and the Subaru's Next Step	Motohide Tamura	47
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5:10 pm	*Adjourn*		
6:30-9:00 pm	**Reception at Lowell Observatory**		

Wednesday, May 4, 2011

Towards Other Earths

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10:20 am	**Mini-Debate: Observability of Earths and Super Earths and Life with JWST**	PRO: Drake Deming CON: Lisa Kaltenegger	49 49
11:00 am	Magnetic Fields in Earth-like Exoplanets and Implications for Habitability of Planets Around M-dwarfs	Mercedes Lopez-Morales	50
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12:00 pm	Sand, Iron, and Ice: The Role of Clouds in Directly Imaged Exoplanet Spectra	Mark Marley	53
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	Box Lunch provided to afternoon Meteor Crater and Anderson Mesa tour participants *only*. Buses/vans depart HCCC at 1:00 pm		

Thursday, May 5, 2011

Architecture of Planetary Systems

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8:30 am	**Architecture of Planetary Systems (0.1 – 100 AU)**	Christoph Mordasini	54
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9:50 am	*Morning Break*		
10:15 am	**How RV and Astrometry Will Contribute to the Future of Indirect Detection**	RV: Debra Fischer Astrometry: Dimitri Pourbaix	55 56
11:15 am	**Microlensing: Probing the Extremes of Parameter Space**	Andrew Gould	56
11:55 am	**Survey of Present and Future Ground-Based Imaging Systems**	Olivier Guyon	57
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4:30 pm	Planet Occurrence within 0.25 AU	Andrew Howard	62
4:45 pm	"Small Black Shadows": Using All-Sky Transit Surveys to Detect and Characterize Terrestrial Planets	Scott Gaudi	63
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6:00-9:30 pm	**Banquet Dinner at Forest Highlands** **6:00 pm Cocktail Hour and 7:15 pm Dinner** **8:30 pm Dessert and Lecture by Bryan Bates "Archeoastronomy of Northern Arizona"**		

FRIDAY, MAY 6, 2011

Free-floating Planets

Time	***Title***	***Speaker***	***Page***
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9:25 am	Isolated Planet Population Found by Gravitational Microlensing	David Bennett	65
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9:55 am	*Morning Break*		
10:20 am	**Planets Around Massive Stars**	John Johnson	66
11:00 am	Direct Detection of Exoplanets with Polarimetry	Sloane Wiktorowicz	66
11:15 am	The Heavy Element Mass of Giant Planets, and its Correlation with Stellar Metallicity	Neil Miller	67
11:30 pm	Secular Chaos and the Production of Hot Jupiters	Yoram Lithwick	67
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***** AFTERNOON SESSION IN 1899 BALLROOM *****			
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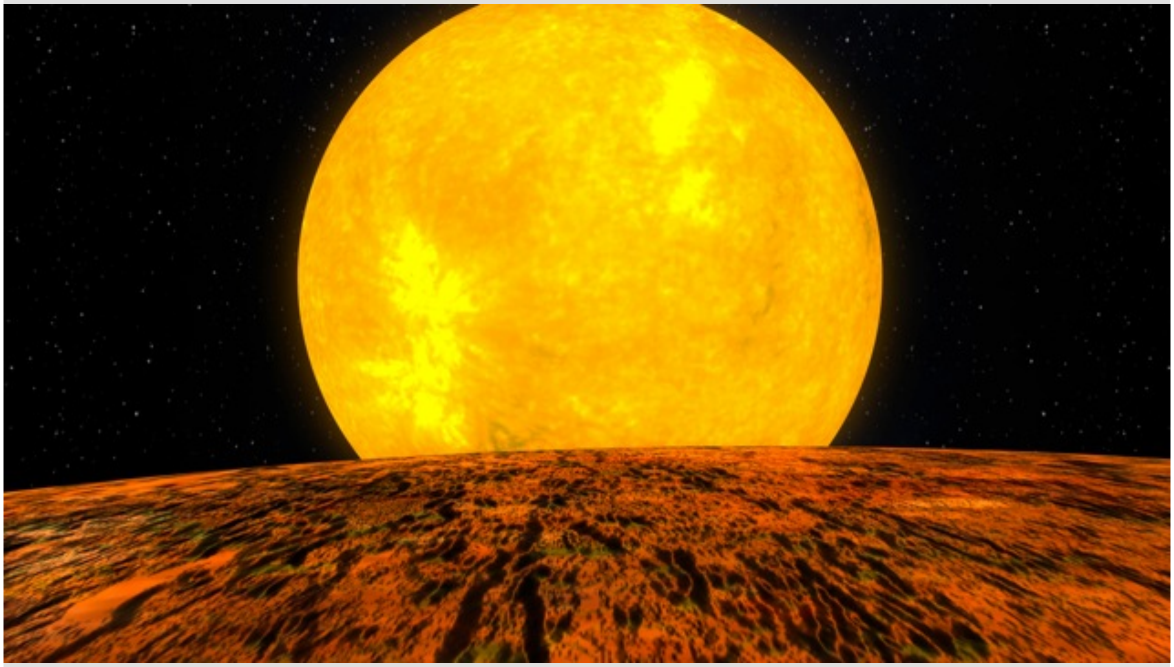
2:10 pm	New Near-Infrared Techniques for Precision Radial Velocities	Peter Plavchan	69
2:25 pm	**Panel Discussion: Future Exoplanet Missions: The Next 5, 10, and 25 Years**	Malcolm Fridlund Wes Traub Motohide Tamura Scott Gaudi Jean-Philippe Beaulieu Neill Reid	
3:50 pm	**Closing Comments**	Chas Beichman Malcolm Fridlund	
4:00 pm	*Adjourn*		

Earth-Size Planets and Intelligent Life in the Universe

A free public lecture by Dr. Geoffrey Marcy, Univ. of California, Berkeley

7:30 pm Monday, May 2, 2011, Prochnow Auditorium at NAU

Brought to you by NASA's Exoplanet Exploration Program
tickets for this free event will be available at the door or
By request from at StrangeNewWorlds@ipac.caltech.edu



Science fiction portrays our Milky Way Galaxy as filled with habitable planets populated by advanced civilizations engaged in interstellar trade and conflict. Back in our real universe, Earth-like planets and alien life have proved elusive. Has science fiction led us astray? NASA recently launched a new space-borne telescope, Kepler, dedicated to discovering the first Earth-like worlds around other stars. The first results are startling and profound. How common are worlds that are suitable for life? What properties make a planet livable? How common is life in the universe, especially intelligent life? New telescopic and biological observations are providing the first answers to these questions. Dr. Marcy's planet-hunting team has confirmed the highest number of exoplanet discoveries to date.

Posters Listed by Author

Conference posters will be displayed in the Agassiz-Fremont rooms during the conference. Breakfast and break food will be served in this room to facilitate poster viewing.

In the table below, posters are listed in alphabetical order by first author. In the Poster Abstract section in the book, abstracts are categorized in the following subjects and listed alphabetically within each category.

A. Disks
B. Exoplanet Characterization
C. Habitability
D. Missions
E. Planet Formation
F. Planet-hosting Stars
G. Planetary System Architecture

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E. Planet Formation
F. Planet-hosting Stars
G. Planetary System Architecture

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Invited and Contributed Talk Abstracts

Abstracts for invited and contributed talks are listed in their order on the agenda.

Monday, May 2 – Morning Session

Invited talk
Formation of the Solar System: Follow the Water
Hal Levison (Southwest Research Institute)

Invited talk
Dusty Disks with Herschel: From Protoplanetary to Debris Systems
Jean-Charles Augereau (Institut de Planétologie et d'Astrophysique de Grenoble (IPAG)

Almost exactly two years ago, the ESA far-infrared and sub-millimeter space observatory, Herschel, was launched together with the Planck satellite. With a 3.5 m effective telescope diameter, Herschel is the largest mirror ever built for an astronomy space telescope until the JWST flies. Herschel represents a new opportunity to sensitively probe gas and cold dust in protoplanetary and debris systems. It provides an invaluable database to study planet formation and planning future ground and space missions such as ALMA and JWST. In this talk, I will review the most recent Herschel observations of circumstellar disks around young stars forming new worlds, and present images of remnant populations of planetesimals in planetary systems around Main Sequence stars. These observations shall be complemented by statistical results obtained with the Spitzer space telescope that trace the evolution of circumstellar dust in time at the early stages of planet formation.

Invited Talk

Overview of the James Webb Space Telescope and its Capabilities for Exoplanet Observations

Mark Clampin (NASA Goddard Space Flight Center)

The James Webb Space Telescope is a large aperture (6.5 meter), cryogenic space telescope with a suite of near and mid-infrared instruments covering the wavelength range of 0.6 μm to 28 μm. JWST's primary science goal is to detect and characterize the first galaxies. It will also study the assembly of galaxies, star formation, and the formation of evolution of planetary systems. JWST's instrument complement offers numerous capabilities to study the formation and evolution of exoplanets via direct imaging, high contrast coronagraphic imaging, integral field spectroscopy, and slit spectroscopy. I will review recent progress in hardware development for the observatory, including a discussion of the status of JWST's systems including the optical train, sunshield, and spacecraft, together with plans for integration and cryogenic optical testing. The expected scientific performance of the observatory for observations of exosolar planets based on test results from recent hardware deliveries will also be presented, together with a discussion of JWST's operational capabilities emphasizing exoplanet observations.

Invited talk

Protoplanetary Disks: from Spitzer and Herschel to ALMA and JWST

Ewine F. van Dishoeck (Leiden Observatory/MPE Garching)

An overview of Spitzer and Herschel spectroscopic observations of the ingredients of protoplanetary disks (ices, silicates, PAHs and hot gases) will be given. Spitzer has opened up the possibility to obtain high quality mid-infrared spectra for large numbers of low-mass protostars and disks around solar-mass pre-main sequence stars for the first time, whereas Herschel does the same for the far-infrared wavelength range. Both wavelength ranges are very rich in solid and gaseous features. The results of systematic studies of grain growth, crystallization and gas chemical composition with stellar parameters (e.g., spectral type, accretion rate), disk parameters (e.g., flaring, presence of holes) and evolutionary state will be summarized. The diagnostic values of the various lines and bands will be emphasized, and the importance of laboratory data to interpret them will be illustrated. The data have triggered the development of a new generation of disk models. Evolutionary models that describe how material is transported from cores through collapsing envelopes to disks will be presented. The prospects for future facilities, in particular JWST and ALMA, will be discussed and their complementarity for probing the inner and outer disks will be emphasized.

Contributed talk

DUNES Observations of Debris Disks Around Nearby Stars with Exoplanets

Jonathan Marshall (Universidad Autonoma de Madrid)

A debris disk is the by-product of a planet formation process around another star. These disks are composed of dust grains ranging in size from microns to millimetres, and usually observed at far infra-red wavelengths as emission in excess of that predicted from the stellar photosphere. Although more than 200 of these debris disk systems have been identified through surveys by (for example) IRAS and Spitzer, only a handful of the disks have been resolved. Imaging these systems is vital if a connection is to be made between the visible dust disk and any larger bodies in the system. This is due to the degeneracy between physical parameters of the dust grains and their spatial location in modeling the emission from these systems. In several systems where the disk has been imaged, evidence suggesting the dynamical influence of an unseen planetary mass body working on the dust has been observed, e.g. the warp in the Beta Pictoris disk or the positional offset of the disk around Fomalhaut. The Herschel DUNES program has observed a volume limited (< 20pc) sample of 133 sun-like (FGK spectral type) stars with the PACS and SPIRE instruments, of which 19 are known to be host to one or more exoplanets. Several of these have also been identified as debris disk systems, both from previous Spitzer surveys and new Herschel/DUNES detections. The key factor is the ability of Herschel to resolve the physical extent of the dust disk, uniquely constraining the dust location and thereby breaking the model degeneracy based on unresolved emission alone. I will present results of the DUNES observations of these exoplanet host stars, focusing on two specific examples, HIP7978 and HIP15371, where the observed dust spatial distribution implies the existence of an unseen exoplanet shaping the debris disk.

Contributed talk

Gas and Dust within 1 AU of Young Stars

Josh Eisner (University of Arizona)

The structure of protoplanetary disks within 1 AU of their central stars has important implications for terrestrial planet formation, giant planet migration, and disk accretion. Infrared interferometry probes these regions and provides constraints on the spatial distribution, temperature, and density structure of inner disk material. I will discuss spatially and spectrally resolved observations of gas and dust within 1 AU of young stars, and describe resultant constraints on star and planet formation processes. I will focus on hydrogen gas at stellocentric radii smaller than a tenth of an AU, which traces energetic accretion and outflow processes. I will also describe how similar observations will probe volatile gases that are important constituents of potentially habitable planets.

Contributed talk

The LBT Interferometer: Observing Disks and Planets in the Thermal Infrared

Phil Hinz (University of Arizona)

The direct imaging of extrasolar debris disks and gas giant planets is a demanding goal, requiring a combination of spatial resolution, photometric sensitivity, and high contrast imaging. The Large Binocular Telescope Interferometer (LBTI) is a NASA funded project that is specifically designed to observe nearby stars for the presence of faint zodiacal dust disks at 8-13 microns wavelength. A second camera operating at 3-5 microns wavelength will be well matched to detect and characterize gas giant planets. I will report on first on-sky engineering tests carried out in fall 2010 for the system and describe anticipated performance with the LBTI. The LBTI observations will provide useful input for future missions to detect rocky, Earth-like planets. Space missions that aim to detect objects 7 to 10 decades fainter than a star first need to know what exists 3-6 decades fainter at these locations.

Monday, May 2 – Afternoon Session

Invited talk
Debris Disks from Spitzer and Herschel to JWST
Kate Su (University of Arizona)

Debris disks provide us with a long-lived record of planet formation in exoplanetary systems and help us to understand the evolution of our own solar system. These disks consist of dust particles generated from collisions of leftover planetesimals, such as asteroids, KBOs and comets, that failed to form giant planets. Therefore, their emission characteristics and disk structures provide insights into the nature of unseen minor body populations and massive perturbers around other stars. Modern space facilities such as Spitzer and Herschel have provided significant breakthroughs in our understanding of debris disks. In this talk, I will illustrate these breakthroughs by discussing (1) the time evolution of disk emission at mid- and far-IR as a tracer of minor body populations, (2) signposts for massive planets on large radial orbits by combining the detailed disk SED behavior and spatially resolved disk images, (3) other mechanisms that influence the structure of disks in systematic ways, and (4) systems that are likely the sites of recent large collisions or episodes of a high level of dynamical activity. I will also discuss how these advances provide foundation for future work with ALMA and JWST.

Contributed talk
Exo--Zodiacal Dust Levels for Nearby Main-Sequence Stars: A Survey with the Keck Interferometer Nuller
Rafael Millan-Gabet (NASA Exoplanet Science Institute)

The Keck Interferometer Nuller (KIN) was used to survey 25 nearby main sequence stars in the mid--infrared, in order to assess the prevalence of warm circumstellar (exozodiacal) dust around nearby solar-type stars. The KIN measures circumstellar emission by spatially blocking the star but transmitting the circumstellar flux in a region typically 0.1-4 AU from the star. We find one significant detection (eta Crv), two marginal detections (gamma Oph and alpha Aql), and 22 clear non-detections. Using a model of our own Solar System's zodiacal cloud, scaled to the luminosity of each target star, we estimate the equivalent number of target zodis needed to match our observations. Our three zodi detections are eta Crv (1400 x 300), gamma Oph (200 ± 80) and alpha Aql (660 ± 200), where the uncertainties are 1-sigma. The 22 non-detected targets have an ensemble-weighted average consistent with zero, with an average individual uncertainty of 150 zodis (1-sigma). These measurements represent the best limits to date on exozodi levels for a sample of nearby main sequence stars. A statistical analysis of the population of 23 stars not previously known to contain circumstellar dust (excluding eta Crv and gamma Oph) suggests that, if the measurement errors are uncorrelated (for which we provide evidence) and if these 23 stars are representative of a single class with respect to the level of exozodi brightness, the mean exozodi level for the class is < 156 zodis (3-sigma upper-limit).

Contributed talk

Disk Dispersal and the Formation of Planetary Systems

Ilaria Pascucci (University of Arizona)

The lifetime of protoplanetary disks is thought to be set by the combination of viscous accretion and photoevaporation driven by the central star. While diagnostics of accretion are numerous and mass accretion rates are routinely measured, diagnostics of disk photoevaporation are just emerging. In this talk, I will review newly discovered gas lines that can be used to trace star-driven photoevaporative flows with special emphasis on infrared lines accessible with NIRSPEC and MIRI on JWST. I will also demonstrate what combination of gas lines are necessary to estimate the rate at which disks lose their mass via photoevaporation. Finally, I will discuss the impact of photoevaporation on planet formation and on the final architecture of the Solar System and other planetary systems.

Contributed talk

A Young Exoplanet Caught at Formation

Adam L. Kraus (University of Hawaii)

Young and directly imaged exoplanets offer critical tests of planet-formation models that can't be matched by RV surveys of mature stars. These targets have been extremely elusive to date, with no exoplanets younger than 10-20 Myr and only a handful of direct-imaged exoplanets at all ages. We will report the first direct detection of a young exoplanet during its epoch of formation (T~2 Myr); this discovery was achieved using adaptive optics imaging combined with nonredundant mask interferometry, a technique that achieves extremely deep sensitivity at the diffraction limit of the telescope. The new planet is embedded in a protoplanetary disk with a large cleared gap (a ``transitional disk'') and orbits within that gap. I will discuss this discovery in the context of ongoing and future surveys to identify newly formed exoplanets around young stars, including the prospect of additional discoveries and the implications for the process, epoch, and duration of planet formation.

Contributed talk

Three-Dimensional Atmospheric Circulation on Generic Eccentric Hot Jupiters

Tiffany Kataria (University of Arizona)

Of the ~500 exoplanets detected to date, over one-tenth of these are on highly eccentric orbits (e> 0.5). Such orbits lead to highly time-variable stellar heating on the giant planet, which has a large effect on its meteorology. However, little is known about the basic dynamical regime of such planets, and how it may compare to the dynamics of giant planets on more circular obits. Therefore, we present results from our systematic study of eccentric hot Jupiters using the Substellar and Planetary Radiation and Circulation (SPARC)/MITgcm, which couples the MITgcm with a multi-stream, non-grey radiative transfer model. In our simulations, we vary the eccentricity of the planet over a wide range to assess the role of time-variable heating on the atmospheric circulation, considering both synchronous and pseudo-synchronous rotation. In each of these cases, we analyze the planet's temperature structure, jet streams and waves, and diagnose dynamical mechanisms for their formation. We expand on previous work by focusing on observational implications, noting to what extent meteorological properties can be inferred from from lightcurves and spectra. These observations will be shaped not only by the geometry of the system as seen from Earth but by the time variability of the temperatures throughout the orbit and the position of any hot and cold points on the planet itself.

Contributed talk

Direct Imaging Search for Extrasolar Planets Using VLT/NACO's APP Coronagraph

Sascha P. Quanz (ETH Zurich)

The direct detection of faint objects - such as exoplanets - close to a bright star is observationally challenging as it requires both, high spatial resolution and high contrast. However, it is exactly these direct information that boost our understanding of the immediate physical properties of the imaged exoplanets and help us to constrain their formation. In this talk we will present results obtained with the versatile NACO instrument at ESO's VLT. NACO was recently equipped with an Apodizing Phase Plate coronagraph enabling unprecedented high contrast imaging performance at 4 micron wavelength. With NACO/APP we were able to confirm the exoplanet beta Pic b. Additional results from more recent (and partly still ongoing) observing campaigns are discussed and put into context with other high-contrast imaging campaigns. Finally, I will briefly discuss the prospects of using NACO/APP in combination with a grism to enable high contrast spectroscopy of faint companions.

Contributed talk

Giant Planet Companions to T Tauri Stars

Christopher Crockett (Lowell Observatory)

Timescale is a critical test for proposed planet formation scenarios. Ongoing campaigns to characterize the planets around main sequence stars cannot directly identify the planet formation timescale. Observations of pre-main sequence T Tauri stars, however, could provide a snapshot of the early stages of planet formation. These 1 - 3 Myr old stars present significant challenges to traditional radial velocity surveys. The presence of strong magnetic fields gives rise to large, cool star spots. These spots introduce significant radial velocity jitter that can mimic the velocity modulation from a planet-mass companion. However, spot-induced radial velocity variability exhibits a wavelength dependence that companion-induced variability does not. By observing at widely separated wavelengths, one can therefore distinguish between stellar activity and low-mass companions. I will present results from an ongoing multiwavelength radial velocity survey of the Taurus-Auriga star forming region, discuss our targets' unique challenges, and show evidence for what may be the youngest planets found via radial velocity techniques.

Invited talk

Potentially Habitable Worlds in our Solar System: Planetary Exploration and JWST

Heidi Hammel (Association of Universities for Research in Astronomy)

"Planetary Habitats" was identified as a major cross-cutting theme in the recent planetary decadal Survey ("Visions and Voyages for Planetary Exploration in the Decade 2013-2022", NRC, 2011). For Earth-like life forms to arise and survive, a habitat must provide: liquid water; availability of organic ingredients including carbon, nitrogen, hydrogen, oxygen, phosphorus, and sulfur; and, absent sunlight, some form of chemical energy to drive metabolism. Mars, Europa, and Enceladus hold the greatest potential as modern habitats for Earth-like life, and Titan affords the greatest potential as a prebiotic organic laboratory. I will review the priorities for exploration of these worlds as outlined in the planetary decadal, and also discuss how future telscope missions like the James Webb Space Telescope can also be used to explore these places.

Contributed talk

Migration and Scattering: Constraints on the Dynamical History of the Solar System

Rebekah Dawson (Harvard-Smithsonian Center for Astrophysics), Ruth Murray-Clay (Harvard-Smithsonian Center for Astrophysics)

Planetary migration and scattering are two promising mechanisms to explain the surprising orbits and architecture of exo-planetary systems. In our own Solar System, orbits of Kuiper Belt Objects (KBOs) are thought to have been sculpted during an early upheaval period, when the giant planets underwent scattering and/or migration. Thus the Kuiper Belt is a rich local archaeological site for investigating the dynamical processes that shape planetary systems. In the "classical" Kuiper Belt region (40-50 AU), a population of "hot" objects with inclinations up to 30° overlies a flat "cold" population, with distinct physical properties; a third population is in orbital resonance with Neptune. Migration of Neptune, the standard explanation for capturing KBOS into resonance, preserves a cold population formed in situ but does not produce a hot population. Alternatively, Neptune may have undergone a high eccentricity period during which it scattered hot objects from the inner disk into the classical region, but this scenario does not produce or preserve a cold population. To investigate which histories produce both hot and cold objects, we fully explore the parameter space of Neptune's initial semi-major axis (a) and eccentricity (e) as well as migration, eccentricity damping, and precession timescales. We determine which processes affect the orbital evolution of KBOs and model them analytically. We find that to produce an eccentricity distribution of KBOs consistent with major qualitative observed features, Neptune must be scattered to one of two particular parameter space regions, both located within $e > 0.15$ and $25 < a < 29$ AU, and then migrate to its current location at 30 AU. Its eccentricity must either damp on a timescale < 0.3 Myr or precess* on a timescale < 0.5 Myr. Thus scattering and migration both play roles in the dynamical history of the Solar System. * Batygin 2011 (in prep)

Contributed talk

The Strange World We Call Home: Earth in the Context of an Exoplanet

Tyler D. Robinson (University of Washington)

NASA's EPOXI mission observed the whole-disk Earth, obtaining visible photometry and near-infrared spectroscopy at distances between 0.11-0.34 AU. We have used the EPOXI data and phase dependent Earthshine observations to upgrade and validate the NASA Astrobiology Institute's Virtual Planetary Laboratory 3-D spectral Earth model, which can be used to accurately simulate Earth's appearance to a distant observer over a large range of wavelengths, timescales, and phases. We have simulated Earth's reflected-light spectrum through an entire orbit, to better understand information obtained in phase-dependent Earth observations. At crescent phases, specular reflectance from Earth's oceans (glint) increases the visible reflectivity of the planet, but forward scattering from clouds can mimic this phenomenon. Our model, which includes both glint and realistic cloud scattering, shows that the glinting Earth has a distinct phase curve from the non-glinting Earth, even in the presence of realistic clouds, and that the James Webb Space Telescope paired with an external occulter could distinguish these two worlds. Our Earth model was also combined with a model of the lunar thermal infrared (TIR) spectrum to understand the influence of the Moon on unresolved TIR observations of the Earth-Moon system. When observing the system at full phase, the Moon consistently comprises about 20% of the total signal, approaches 30% of the signal in the 9.6 μm ozone band and the 15 μm carbon dioxide band, makes up as much as 80% of the total signal in the 6.3 μm water band, and more than 90% of the signal in the 4.3 μm carbon dioxide band. These excesses translate to brightness temperature measurement errors of 20-40 K, and demonstrate that the presence of an undetected satellite can have a significant impact on the spectroscopic characterization of terrestrial exoplanets.

Tuesday, May 3 – Morning Session

Invited talk

Overview of Kepler Results

Alan Boss (Carnegie Institution of Washington)

NASA's Kepler Mission is revolutionizing the field of exoplanet discoveries. Launched in March 2009, Kepler has already effectively tripled the total number of candidate exoplanets, from roughly 500 to well over 1500, based only on the first four months of science operations. While these transit photometry candidate exoplanets undoubtedly include false positives, the analysis to date suggests that the great majority of these candidates will turn out to be true exoplanets. The latest Kepler data release, on February 1, 2011, listed planetary candidates with the following distribution of sizes: 68 of Earth size, 288 of super-Earth size, 668 of Neptune size, 165 of Jupiter size, and 15 of super-Jupiter size. When corrected for the detection biases, these candidates suggest that the underlying population of exoplanets contains an intrinsic frequency of candidates per star of 10% for Earth size, 7% for super-Earth size, 21% for Neptune size, and 5% for Jupiter size. These estimates apply only to exoplanets on short-period orbits, with orbital periods less than about 60 days. This implies that on average roughly half of the Kepler target stars have exoplanets with orbital periods less than 60 days. Multiple planet systems are common: 170 Kepler planet host stars (~17%) have more than one transiting exoplanet candidate, while 54 host stars have 3 or more candidates, including the spectacular Kepler-11 system with six transiting planets. 54 of the Kepler candidate planets orbit in the habitable zones of their host stars, loosely defined as equilibrium temperatures between 240 K and 390 K, to account for uncertainties in the host star and orbital properties and the effects of possible planetary atmospheres. These early results suggest that planetary systems are the rule rather than the exception.

Invited talk

Interiors and Evolution of Giant Planets

Tristan Guillot (l'Observatoire de la Côte d'Azur)

Knowing what is inside giant planets is key to understand the formation of planetary systems. With advances in the theories of evolution of planets and statistical analyses of the now significant ensemble of known transiting exoplanets, an accurate determination of the compositions of giant exoplanets seems to be within reach. I will show that a precise understanding of the properties of the atmospheres of giant exoplanets (dynamics, cloudiness) is necessary to complete this understanding and how future photometric and spectroscopic observations will play an important role. Future spacecraft measurements of Jupiter will also be crucial in providing fine details of the internal structure of "our" giant planet.

Invited talk

CoRoT: An Overview of CoRoT Results

Daniel Rouan (LESIA - Observatoire de Paris)

CoRoT, the French-European satellite of high-precision photometry was put in operation early 2007 and the mission has recently been extended for 2.5 years. Its extrasolar planets program is based on the transit detection technique. Thanks to its high sensitivity, the contribution of the satellite to the discovery and characterization of Strange New worlds is indubitable. A status report on the discoveries made by CoRoT is given in this talk. After a brief description of CoRoT specifications and in-flight performances, a summary of the 20 discovered exoplanets and brown dwarves will be done. Emphasis will be put on several specific cases and in particular on the first small size rocky planet Corot-7b, of which the most recent analysis of the mass and physical conditions will be discussed. The results will be also presented in terms of statistical analysis. Finally, the prospects for the extended period will be discussed in the light of the experience gained by the CoRoT team.

Invited talk

Review of HST and Spitzer Spectroscopy to EChO

Giovanna Tinetti (University College London)

Spectroscopic observations of transiting exoplanets are providing an unprecedented view of the atmospheres of planets around nearby stars. As we learn more about the atmospheres of these remote bodies, we begin to build up a clearer picture of their composition and thermal structure. Most recent observations with Hubble and Spitzer Space Telescopes or from the ground, in fact, have proved being possible to use the wavelength/time dependence of the combined light star-planet to identify key chemical components and the thermal structure of the planet's atmosphere.

The European Space Agency is currently assessing a space mission that is fine-tuned to this purpose: the Exoplanet Characterisation Observatory (EChO). Using mid- to high-resolution spectroscopy between 0.4 and 16 μm, this mission will allow a detailed study of the chemistry and physics of gas and ice giants, and Super-Earths, in orbits close to their parent stars. In the quest for habitable worlds outside our Solar System, EChO will be able to observe, among other targets, Super-Earths in the habitable-zone of M dwarfs: these are clearly not the Earth's and Sun's twins, but rather their cousins. Will they present equal opportunities for habitability?

Contributed Talk

On the Mass of CoRoT-7b

A. P. Hatzes (University of Texas), M. Fridlund, L. Carone, M. Pätzold, D. Valencia, G. Hebrard, P. Borde, F. Bouchy, M. Deleuil, C. Moutou, H. Deeg, B. Tingley, R. Dvorak, D. Gandolfi, S. Ferraz-Mello, T. Guillot, H. Rauer, A. Erikson, J. Cabrera, S. Csizmadia, A. Leger, H. Lammer, T. Mazeh, D. Queloz, R. Alonso, D. Rouan, J. Schneider, G. Wuchterl, E. Guenther

CoRoT-7b, the first superearth exoplanet, has a wide range of masses that have been reported in the literature. Although most mass measurements give a density consistent with a rocky planet, a recent determination by Pont et al. (2010) yields a significantly lower mass of 2.3 ± 1.8 $M_\oplus$. Such a low mass allows a bulk composition that can be up to 50% water. Furthermore, because of the contribution to the radial velocity variations due to activity jitter Pont et al. argue that the mass of CoRoT-7b can be anywhere between 1-5 $M_\oplus$. We present an analysis of the CoRoT-7b radial velocity measurements that uses very few and simple assumptions in treating the activity signal. By only analyzing those radial velocity data for which multiple measurements were made in a given night we effectively remove the activity related radial velocity contribution without any a priori model. We demonstrate that the contribution of activity to the final radial velocity curve is negligible and that the K-amplitude due to the planet is well constrained. This yields a mass of 7.38 ± 0.34 $M_\oplus$ and a mean density of 10.3 ± 2.0 gm/cm. The largest uncertainty in the mean density comes from the planet radius and not its mass. CoRoT-7b is similar in mass and radius to the second rocky planet to be discovered, Kepler-10b, and within the errors they have identical bulk densities - they are virtual twins. These bulk densities lie above the density - radius relationship for terrestrial planets similar to what is seen for Mercury. We suggest that both CoRoT-7b and Kepler-10b may represent a new type of exoplanets: short-period SuperEarths with large mean densities that may be significantly higher than that for Earth-like planets. In terms of structure CoRoT-7b and Kepler-10b may be more Mercury-like. Given that both space missions, CoRoT and Kepler, discovered such objects so soon after the start of the missions suggests that there may be a large population of such objects.

Contributed talk

New Optical Observations of Hot-Jupiters with HST STIS and GTC OSIRIS

David Sing (University of Exeter)

Space and ground-based transit observations of hot Jupiters are now regularly detecting atmospheric features, confirming some of the initial detections, and finding previously undiscovered atmospheric constituents. I will highlight a few recent discoveries using the repaired STIS instrument aboard the Hubble Space Telescope and 10.4 meter GTC Telescope. New very high S/N STIS observations of HD189733b have confirmed the presence of a high-altitude atmospheric haze on the planet at near-UV and optical wavelengths. These findings indicate that haze may be a globally dominant atmospheric feature of the planet, which could result in a high optical albedo at shorter optical wavelengths. The effect of the haze on the global energy budget of the planet would be significant. STIS observations of the sodium line-core on HD189733b have also recently been obtained, and we confirm its presence at a very high confidence level (8.6-sigma). Sodium survives to very high altitudes and the observed line core indicates very hot temperatures likely linked to the presence of a thermosphere associated with atmospheric escape. Finally, I will present ground-based results of a large ongoing program with the 10.4 meter GTC telescope aimed at detecting atmospheric features for a wide variety of hot-Jupiter. We are regularly obtaining sub-mmag photometry at spectral resolutions near 600. Our initial results on XO-2b indicate the presence of potassium, a previously unseen element in the atmosphere that is thought to play an important role.

Contributed talk

HST/WFC3 Observations of Giant Hot Exoplanets

D. Deming (NASA GSFC), Eric Agol (Univ. Washington), A. Burrows (Princeton Univ.), D. Charbonneau (CfA), M. Clampin (GSFC), J.-M. Desert (CfA), R. Gilliland (STScI), H. Knutson (UC Berkeley), N. Madhusudhan (Princeton Univ.), A. Mandell (GSFC), S. Ranjan (CfA), S. Seager (MIT), and A. P. Showman (Univ. Arizona)

Low resolution thermal emission spectra of several dozen extrasolar planets have been measured using Spitzer, and HST observations of a few key exoplanets have reported molecular abundances via transmission spectroscopy. However, current models for the atmospheric structure of these worlds exhibit degeneracies wherein different combinations of temperature and molecular abundance profiles can fit the same Spitzer data. The advent of the IR capability on HST/WFC3 allows us to address this problem. We are currently obtaining transmission spectroscopy of the 1.4-micron water band in a sample of 13 planets, using the G141 grism on WFC3. This is the largest pure-exoplanet program ever executed on HST (115 orbits). Among the abundant molecules, only water absorbs significantly at 1.4 microns, and our measurement of water abundance will enable us to break the degeneracies in the Spitzer results with minimal model assumptions. We are also using the G141 grism to observe secondary eclipses for 7 very hot giant exoplanets at 1.5 microns, including several bright systems in the Kepler and CoRoT fields. The strong temperature sensitivity of the thermal continuum at 1.5-microns provides high leverage on atmospheric temperature for these worlds, again helping to break degeneracies in interpreting the Spitzer data. We here describe preliminary results for several exoplanets observed in this program.

Tuesday, May 3 – Afternoon Session

Invited talk
Atmospheres of Giant Planets
Travis Barman (Lowell Observatory)

The majority of known extrasolar planets fall into the "giant" category. These large gaseous bodies hold important clues within their atmospheres concerning planet formation and evolution; however, accessing these clues is an ongoing struggle. Observations of giant planet atmospheres have revealed a variety of new and interesting properties and continue to grow in number and quality. Models of giant planet atmospheres are evolving in tandem with the observations and are playing an ever increasing role in giant planet characterization. This talk will attempt to bridge the gap between transiting giant planets (the "hot-Jupiters" and "hot-Neptunes") and those found in decade or century-long orbits by direct imaging surveys. These two seemingly distinct groups of planets are related by our ability to obtain multi-wavelength followup data that directly probe atmospheric conditions. More importantly, their relation extends well beyond observational convenience as they share similar atmospheric physics and perhaps common origins. Model atmospheres and observations from short and long period planets will be discussed along with the unique challenges presented by each type of giant planet.

Invited talk
Atmospheres of Earths and Super Earths
Jonathan Fortney (University of California, Santa Cruz)

The era of the characterization of low-mass planets is now just beginning. In this talk I first review the observations of GJ 1214b, with a view towards understanding the planet within its class--what appears to be a large group of low-density super-Earths. Given the Kepler-11 system and the dramatic number of 2-3 $R_\oplus$ candidates found by Kepler (the most-common radius for Kepler candidates), "mini-Neptunes" appear to be an extremely common form of "super-Earth." I will review mechanisms for the loss of steam- and hydrogen-dominated atmospheres from small worlds, which have previously been applied to studies of Venus and Earth is some detail. This will lead into a survey of the various kinds of atmospheres possible on low-mass worlds. I will discuss prospects for the characterization of the atmospheres of Earth-size and larger planets within the next 10 years.

Contributed talk

The Atmosphere of the Transiting Super-Earth GJ 1214b

Eliza Kempton (Miller-Ricci) (University of California, Santa Cruz)

GJ 1214b is the first extrasolar super-Earth to have its atmosphere observed and characterized. Transit observations by Bean et al. reveal a flat transmission spectrum at wavelengths from 780 to 1000 nm. A flat spectrum is also obtained at 3.6 and 4.5 microns with Spitzer by Desert et al. However, observations by Croll et al. at J and K_s band reveal a deeper transit at Ks band than at any of the other observed wavelengths at high significance. A number of hypotheses have been put forth to explain the transmission data. One possible interpretation is that GJ 1214b's atmosphere is water-rich and has a small scale height. Alternatively, GJ 1214b's atmosphere could be hydrogen-rich with a large scale height, but in this case hazes or clouds must flatten the planet's transmission spectrum at short wavelengths. A final possibility is that GJ 1214b's atmosphere is hydrogen-rich, but the overall atmospheric composition is determined by non-equilibrium chemical processes. A combination of modeling work and further observations are needed to break the degeneracy between the different possibilities. I will discuss the current state of modeling work to interpret the observations of GJ 1214b's atmosphere in transmission. A photochemical model has been applied to the planet's atmosphere and reveals a complex carbon chemistry in GJ 1214b's atmosphere, which can complicate the interpretation of transmission spectra.

Contributed talk

The Role of Drag in the Energetics of Hot Jupiter Atmospheres

Emily Rauscher (University of Arizona)

Several complications have been identified in trying to correctly model hot Jupiter atmospheric dynamics, including drag mechanisms that are absent from the atmospheres in our solar system, such as shocks or MHD drag. While these powerful processes may work to reduce wind speeds, it is also possible that they could alter the entire nature of the atmospheric circulation if the dissipation of kinetic energy results in a significant source of localized heating. I will present an analytic framework from which we can estimate the importance of this effect and discuss the drag strength at which frictional heating should be explicitly included in numerical models for self-consistent results.

Contributed talk

Three Dimensional Structure of Exoplanet Atmospheres

Dave Spiegel (Princeton University)

The three dimensional structures of the atmospheres of hot exoplanets are coming into focus. Some of the most highly irradiated planets show evidence of thermal inversions in their upper atmospheres, the origin of which is, as yet, unclear. Furthermore, the 'hot-spots' caused by stellar irradiation appears to be blown downstream by different amounts at different wavelengths (and differently on different planets). I will present models of the vertical structure of HAT-P-7b, the planet with perhaps the largest thermal inversion yet observed. I will critically examine the hypothesis that TiO is responsible for thermal inversions. Finally, I will present simulated secondary-eclipse measurements and phase-curve observations that are generated from three-dimensional circulation models, and I will discuss how multi-wavelength phase-curve observations can provide clues to the vertical dependence of wind speeds.

Invited talk

Transit and Eclipse Spectroscopy of Giant Planets with JWST

Tom Greene (NASA Ames Research Center)

The James Webb Space Telescope (JWST) will be a nearly ideal machine for acquiring the transmission and emission spectra of transiting exoplanets over its large wavelength range 700 nm - 20+ microns. The NIRSpec, NIRCam, and MIRI instruments will have spectroscopic capabilities that span spectral resolutions from 20 - 3000 and can cover up to 2 - 3 octaves in wavelength simultaneously. This will allow observing multiple molecular features at once, facilitating the separation of atmospheric temperature and abundance effects on spectra. Many transiting planets will also be able to be observed with both transmission and eclipse spectroscopy, providing further insights and constraints on planetary thermal structures and energy transport. Simulated JWST spectra of planets ranging from mini Neptunes to gas giants will be presented. These simulations show that JWST will be able to determine the atmospheric parameters of a wide variety of planets, often when observing only one or a few transit or eclipse event sequences. The thermal emissions of rocky super-Earths will also be quickly detectable via mid-IR eclipse observations if such planets are found around nearby M star hosts beforehand.

Contributed talk

Early Results from SEEDS and the Subaru's Next Step

Motohide Tamura (National Astronomical Observatory)

SEEDS (Strategic Exploration of Exoplanets and Disks with Subaru) is the first Subaru Strategic Program, whose aim is to conduct a direct imaging survey for giant planets as well as protoplanetary/debris disks at a few to a few tens of AU region around 500 nearby solar-type or more massive young stars devoting 120 Subaru nights for 5 years. The survey employs the new high-contrast instrument HiCIAO. We will finish the first 26 nights by the conference. We present its early results including detection of companion candidates to be followed-up and discovery of unprecedentedly details of several protoplanetary disks. We also outline our plan on the exoplanet instrument development on the Subaru telescope.

Contributed Talk

Thermal Emission of Hot Jupiters and the Spectral Features of Super-Earths in the Near-Infrared

Bryce Croll (University of Toronto)

I will present results from our ongoing program using the Wide-field Infrared Camera (WIRCam) on the Canada-France-Hawaii Telescope (CFHT) to detect thermal emission from hot Jupiters in the near-infrared, as well as to search for spectral features in the broadband transmission spectrum of the super-Earth GJ 1214b. On the hot Jupiter front, we've already detected the thermal emission of several hot Jupiters in Ks-band (TrES-2b, TrES-3b, and WASP-3b) as well as for WASP-12b in three near-infrared bands (JHK). I will present our recent near-infrared detections including reobservations of the thermal emission of WASP-12 in JHK, as well as the first thermal emission measurement in Y-band (~1.04 microns). As for our observations of the super-Earth GJ 1214b, we've detected a deeper transit depth in Ks-band than in J-band likely indicative of a spectral absorption feature; for the absorption feature to be this prominent GJ 1214b must have a large scale height and thus a low mean molecular weight. I'll therefore argue that our observations, when combined with those at other wavelengths, suggest that although a water-world composition cannot be confidently ruled out, GJ 1214b is likely a hydrogen/helium dominated mini-Neptune with a significant haze layer that obscures transmission spectroscopy observations at shorter wavelengths.

Wednesday, May 4 – Morning Session

Invited talk
Interior Structure of Rocky and Vapor Worlds
Diana Valencia (Massachusetts Institute of Technology)

In the quest to find habitable worlds, super-Earths are an opportunity that only now is beginning to unfold given the reported masses and radii of three transiting low-mass planets: CoRoT-7b, GJ 1214b and Kepler-10b. These are the first of many expected to come, especially thanks to the capabilities of the space mission Kepler. I will present results on the composition and structure of these planets, as well as discuss challenges and future venues for inferring the composition and early evolution of super-Earths.

Invited talk
Beyond Hot Jupiters: Spitzer Observations of the Smallest Transiting Planets
Heather Knutson (University of California, Berkeley)

We are currently confronted with an ever-growing assortment of sub-Neptune-sized transiting planets, with masses and radii that hint at a diversity of bulk compositions ranging from rocky to icy to gas-dominated. Many of these objects appear to represent entirely new classes of planets, with properties distinct from those of the better-studied hot Jupiters or more earth-like rocky planets. Although these new worlds provide tempting targets for characterization studies, their small masses and radii present a considerable challenge for observers. In my talk I will provide an overview of recent studies of low-mass planets using warm Spitzer, which is capable of obtaining precision infrared photometry at 3.6 and 4.5 microns with near-continuous coverage spanning hundreds of hours. These data have proven to be invaluable for improving our understanding of these unusual worlds, as they allow us to (1) test blend scenarios in order to validate new transiting planet candidates, (2) search for transits of super-Earths detected using the radial velocity technique, (3) detect the presence of additional transiting planets in systems with known planets, (4) place constraints on the presence or absence of a significant atmosphere, as well as it's composition, and (5) measure time- and wavelength-dependent dayside emission from these planets. In many cases these planets are inaccessible to more traditional ground-based techniques, such as radial velocity measurements, and these observations therefore offer our only opportunity to study the properties of these systems prior to the launch of JWST.

Invited talk

The Pro Side of Earth/Super-Earth Observability with JWST

Drake Deming (NASA Goddard Space Flight Center)

Results from Doppler and microlensing surveys, as well as the large number of validated super-Earths found by Kepler, suggest that super-Earths orbit GKM stars in abundance. I here describe an updated simulation that defines the yield from an all-sky transit survey targeted to the nearest stars. The simulation includes photometric and spectroscopic characterization of the most favorable Earth- to super-Earth planets using JWST. The JWST sensitivity model includes all currently known and anticipated sources of random and systematic error for NIRSpec and MIRI. These calculations indicate that JWST will be capable of characterizing the major molecular constituents of the atmospheres of dozens of Earth- to super Earth-sized planets with temperatures above the habitable range, using both MIRI and NIRspec. An all-sky survey will discover a handful of these planets with temperatures in the habitable range, all orbiting lower main sequence stars. The principal source of uncertainty in the prospects for JWST characterization of habitable super-Earths is the nature of super-Earth atmospheres. I project that JWST will be able to measure the temperature, and identify molecular absorptions (water, carbon dioxide) in 1 to 4 nearby habitable super-Earths orbiting lower main sequence stars.

Invited talk

The Con Side: Earth Itself is a Challenge - or Why Earth-like Planets Orbiting Smaller Stars Might be Better Targets for JWST

Lisa Kaltenegger (Max Planck Insitute for Astronomy/Harvard-Smithsonian Center for Astrophysics)

Earth is the one planet we know that harbors life. We use Earth as our template for remotely detectable habitats, and extrapolate to potential conditions of life on other rocky planets (e.g. Super-Earths). But in the context of observing atmospheric features during transits for potentially rocky planets with JWST, an analog to our Earth orbiting a Sun-like star is not the best target.

Earth has a small total atmospheric height and the size added to its radius at certain wavelengths due to its atmospheric spectral feature is below 50km (see e.g. Kaltenegger & Traub 2009). It also only transits its star once per year for about 12 hours. During the nominal mission time of JWST of 5 years this leads to a total of about 60hrs transiting time for an Earth-Sun-analog system to detect the atmospheric absorption features. (Here we assume one can add up transiting observations with JWST.) This constrains the accuracy of the measurements of atmospheric chemicals in an atmosphere (for Earth we focus on water, oxygen/ozone, carbon dioxide and methane). Even though Earth-analog planets around Sun-analog stars are often invoked as the best targets to search for life as we know it, we will show that Earth-like planets around smaller stars, that transit more frequently, and can offer longer total transit time during JWST's lifetime, may be better targets to search for biomarkers during transits with JWST. That will provide us the great opportunity to learn about potential habitats - a little different from our own.

Contributed Talk

Magnetic Fields in Earth-like Exoplanets and Implications for Habitability of Planets Around M-dwarfs

Mercedes Lopez-Morales (Carnegie Institution of Washington), Natalia Gomez-Perez (Carnegie Institution of Washington), Thomas Ruedas (Universidad de los Andes)

We present an estimation of the magnetic moment from internal dipolar dynamos for a set of terrestrial exoplanets with masses between $0.6M_\oplus$ and $12M_\oplus$, and radii between $0.6R_\oplus$ and $2.3R_\oplus$, using a scaling law presented in Olson & Christensen (2006). We assume that the interior of the planets is stratified into a mantle and a core, which have chemical compositions similar to Earth. Using those assumptions on composition and adiabatic thermal balances for the interior, we predict the size and density of the metallic core as well as the density and thickness of the mantle in those exoplanets. Our calculations indicate that the dipole moment of terrestrial exoplanets may amount up to 80 times the magnetic moment of Earth, M_E, for at least part of the lifetime of the planets, as long as they have a partially liquid core and enough convective flux of energy to keep a dynamo. Applying our calculations to CoRoT-7b and Kepler-10b we find that the radius of CoRoT-7b is too large to fit our two-layer models, and therefore we predict that the planet is likely to have a substantial ocean layer. Its largest possible core may sustain a magnetic dipole moment ~0.9 M_E. In the case of Kepler-10b, we find that the measured radius and mass are consistent with a terrestrial planet, and it may have a magnetic moment of up to ~3.8 M_E. Finally, and most importantly, our results indicate that the magnetic moment of terrestrial exoplanets is independent of their rotation rate, but depends instead on the formation history, thermal state, age and composition of the planets. These results have important implications for the particular case of exoplanets in the Habitable Zone of M-dwarfs, where the rotation rates are affected by tidal effect.

Contributed talk

Time-Resolved Photometry of Exoplanets: Distinguishing between Temperate and Snowball Climates

Nick Cowan (Northwestern University)

Directly imaged rocky planets will be characterized by their disk-integrated reflected light and thermal emission. We obtained disk-integrated observations of Earth from a variety of viewing geometries with the Deep Impact spacecraft, and combine these data with analytic and numerical models to show how broadband colors, rotational color variability and thermal phase variations can be used to distinguish between two climate states one might find in the habitable zone of nearby stars: temperate and snowball. Earth has spent time in both of these climate regimes over its geological history; the transitions between the two states are associated with changes in the latitudinal distribution of continents and small (~1%) changes in insolation, and exhibit hysteresis. It is unlikely that we will know an exoplanet's continent configuration or power budget with sufficient precision to accurately model its climate. Instead, we study whether time-resolved photometry at optical or infrared wavelengths could distinguish between a temperate world and a snowball planet. The broadband colors of a snowball planet are very different from those of modern Earth, even when viewed from the poles. We use the outgoing longwave radiation from general circulation models to compare the thermal phase variations from temperate and snowball worlds, as these data are sensitive to the thermal inertia of the planet's surface. We also consider how knowing a planet's radius - and hence absolute albedo- could help distinguish between these worlds, or even between different viewing geometries of Earth: the obliquity of imaged planets will not be known a priori. The planet's radius could be estimated if both thermal and optical imaging of an exoplanet was obtained.

Contributed Talk

Spin/Orbit Angle Measurements and Implications

Amaury Triaud (Observatoire Astronomique de l'Université de Genève)

I will review the observations that have been conducted using the Rossiter-McLaughlin effect, present new results from the WASP/HARPS survey and discuss the implications these observations have had on notably the origins of hot Jupiters in the light of other observational evidence and recent theoretical papers. This will allow a discussion on whether the knowledge we acquired for gas giants can be applied for smaller planets.

Contributed talk

Carbon-Rich Exoplanets

Nikku Madhusudhan (Princeton University)

Carbon-rich planets (CRPs) are exotic new members in the repertoire of extrasolar planets. The first CRP atmosphere was discovered recently for the extremely irradiated hot Jupiter WASP-12b. In this talk, we will report several candidate carbon-rich planets along with follow-up theoretical and observational efforts towards confirming these candidates. We also discuss the atmospheric chemistry and temperature structure of carbon-rich planets in all regimes, from hot Jupiters to super-Earths, their formation scenarios, and the chemistry and apportionment of ices, rock, and volatiles in their envelopes. Our results show that CRP atmospheres probe a unique region in composition space, especially at high T. For C/O >= 1, most of the oxygen is occupied by CO for T > 1400 K and P < 1bar, causing a substantial depletion in water vapor, and an overabundance of methane compared to equilibrium chemistry with solar abundances. Adopting gas phase elemental abundances in the disk similar to those estimated for the star gives a C/O ratio in planetesimals, and then in the planetary envelope, that is similar to or below the stellar C/O. However, a C/O > 1 requires substantial depletion of water ice in the planetesimals. We find, for example, that a $C/O \geq 1$ in WASP-12b would require that the oxygen abundance in the primordial disk be depleted by a factor of 0.41. We report the resulting sequences of condensates in the planetesimals.

Contributed talk

Sand, Iron, and Ice: The Role of Clouds in Directly Imaged Exoplanet Spectra

Mark Marley (NASA Ames Research Center), Didier Saumon, and Mike Cushing (NASA Jet Propulsion Laboratory)

Iron and silicate clouds sculpt the spectra of all the directly imaged exoplanets observed to date. As in the case of their more massive cousins the L dwarfs, an understanding of these clouds is critical to properly interpreting exoplanet spectra and photometry. Indeed the persistence of clouds to cooler effective temperatures in the directly imaged exoplanets, such as those orbiting HR 8799, than in the L dwarfs has become a key theme in the literature and there have been a number of claims that these exoplanets have unusual cloud properties. To better understand the role of clouds in exoplanets we have computed a large grid of atmospheric models employing the same cloud and atmospheric physics approaches that have proved highly successful in reproducing the spectra of L and T dwarfs. We find that the HR 8799 planets can be understood within our standard modeling framework albeit with clouds persisting to lower effective temperatures than seen in the L dwarfs. At cooler effective temperatures we find clouds sharply suppress Y and J band fluxes while H and K band fluxes for even the cloudiest planets will be similar to those expected for cloudless atmospheres by 400 K. However at such effective temperatures water clouds begin to become very important and they in turn dramatically alter the thermal emission spectra of cold exoplanets. In our presentation we will discuss why clouds play such an important role for exoplanet spectra and we will compare their signature to other effects, such as metallicity and atmospheric mixing that also affect exoplanet spectra.

Thursday, May 5 – Morning Session

Invited talk
Architecture of Planetary Systems (0.1 - 100 AU)
Christoph Mordasini (Max Planck Institute for Astronomy)

The understanding of planet formation experiences presently a second major change after the first one induced by the detection of close-in giant planets sixteen years ago. This is thanks to the wealth of data provided by already flying (e.g. CoRoT and Kepler), future (e.g. Gaia) or in-project (PLATO, EUCLID) space missions. One common characteristic of these missions is that they aim at providing observations of a large number of extrasolar planets. This data should therefore be treated as a statistical ensemble. In this talk I will discuss what aspects of this new dataset can currently be understood by theoretical planet formation models, in which points in contrast differences exist, and what could be the reasons for them. I will present the most important principles of planet formation theory like solid and gas accretion, and migration. It will be discussed how these mechanisms manifest themselves in observable quantities in the architectures of planetary systems, like for example in the planetary initial mass function, or the semi-major axis distribution. Also, some of the typical imprints of the two competing giant planet formation paradigms (core accretion and disk instability) will be addressed.

Invited talk
Planet Formation at Large Separations via Disk Instability: Pro
Sally Dodson-Robinson (University of Texas)

Although the viability of disk instability as a planet formation mechanism has not been fully established, it is by far the best explanation for the origins of massive planets on ultra-wide orbits. I will assess the viability of three possible giant planet formation mechanisms—in situ core accretion, scattering from the inner disk, and gravitational instability—for forming wide-orbit giants such as Fomalhaut b and HR 8799 b, c and d. I will demonstrate that gravitational instability is the only possible formation pathway to gas giants on stable orbits with semimajor axes greater than 35 AU. I also argue that the occurrence ratio of long-period to short-period gas giants should be highest for M dwarfs due to the inefficiency of core accretion and the expected small fragment mass (~10 M_J) in their disks.

Invited talk

Objects Formed by Gravitational Instability are Unlikely to be Planets: Con

Ruth Murray-Clay (Harvard-Smithsonian Center for Astrophysics)

Fragmentation due to gravitational instability (GI) most plausibly leads to massive objects formed in the outer regions of their natal disks. Directly imaged planets such as those orbiting HR 8799 are therefore more promising candidates for formation by GI than solar system giants. However, fragments formed at large distances have large isolation masses and are embedded in massive disks. Typically, they will quickly grow into objects larger than planets. I will argue that any planetary mass objects formed by this mechanism must be the runts of the brown dwarf litter, and would most appropriately be considered low mass brown dwarfs. Whether such a population exists will be tested in the near future, as the population of wide separation planets is shown to have properties connecting it to brown dwarf companions or to closer-in planets. More generally, in order to understand whether GI can lead to planet or brown dwarf formation at large separations, we must understand the disk histories that can generate the conditions required for fragmentation. I will discuss these histories and comment on the robustness of the cooling time criterion for gravitational collapse. I will conclude with a few thoughts about how planet formation by core accretion at large separations might be achieved.

Invited talk

How RV Will Contribute to the Future of Indirect Detection

Debra Fischer (Yale University)

In the mid-1990's the Doppler technique ushered in the new era of exoplanet discoveries. At that time, the typical RV precision of 3 to 5 m/s was thought to have reached the fundamental limit imposed by stellar noise. It seemed likely that this technique would have a finite lifetime, characterizing planets with velocity amplitudes greater than 10 or 15 m/s. However, steady and hard won advances in Doppler precision have continued to breathe new life into this technique, allowing the discovery of lower mass and longer period planets. We do not yet appear to be at the astrophysical noise level for late G and K dwarfs, and the Doppler technique should continue as a groundbreaking method for detecting lower mass planets around these stars. It will also continue to partner with other techniques, like transit discoveries, to improve the detection and characterization of exoplanets in the next decade.

Invited talk

How Astrometry Will Contribute to the Future of Indirect Detection

Dimitri Pourbaix (Universite Libre de Bruxelles)

Even though astrometry was the first technique ever considered for exoplanet detection (e.g. van de Kamp), it is the only one that has not been successful yet. So far, it has only been used to constrain or determine the mass of some of the known planets (e.g. Perryman et al. 1996, Benedict et al. 2002). Whereas the technique is clearly distance limited, unlike spectroscopy and photometry, it is not restricted to edge-on systems: what is lost in distance is somehow gained in orientation! Europe will soon release some instruments that will definitively change the poor results of astrometry in this field. With PRIMA on VLT, ESO aims at 30 micro arcsecond epoch precision on a few hundred targets (pointing instrument) whereas with Gaia, ESA will reach the same epoch precision for tens of millions of stars all over the sky (survey). The outcome of this space mission is expected to be of the order of a few thousands orbital solutions of newly discovered exoplanets. With the Jasmine series, Japan also becomes a key player in space astrometry in general.

Invited talk

Microlensing: Probing The Extremes of Parameter Space

Andrew Gould (Ohio State University)

Microlensing planet searches are already routinely finding Neptune-mass planets beyond the snow line and will in the future probe several extremes of parameter space that are difficult or impossible to access by other techniques. Comparison of microlensing and RV measurements of the frequency of Saturns indicates that most giant planets do not migrate very far. With next generation ground-based surveys microlensing will carry out a broad census of planets from Earth to super-Jupiter masses, almost equally sensitive to all hosts, from brown dwarfs to G dwarfs. It will provide the first census of free-floating planets, which is crucial to testing planet-formation theories. And future space-based searches will reach down to Mars-mass planets and perhaps even planet-moon systems.

Invited talk

Survey of Present and Future Ground-Based Imaging Systems

Olivier Guyon (National Astronomical Observatory of Japan)

Adaptive optics on large ground-based telescopes has enabled direct imaging searches for exoplanets. While early attempts were limited by image quality and limited ability to calibrate residual light in the PSF's halo, recent improvements have paid off, allowing direct imaging of a handful of young massive exoplanets. A new generation of more capable systems, highly optimized for high contrast observations, is about to be deployed on several telescopes. These "ExAO" systems directly address the limits of current "general-purpose" AO systems by combining high performance coronagraphy, "extreme" wavefront correction, and speckle calibration. The major upcoming ExAO systems, GPI and SPHERE, will greatly improve our understanding of how planetary systems form and evolve, and will provide a statistically significant sample of massive exoplanets, complementing RV searches which are not sensitive at large (> few AUs) separations. GPI and SPHERE will be about an order of magnitude from detecting reflected light from exoplanets. Recent advances in coronagraphic and wavefront control techniques indicate that this gap could be overcome on 8-m class telescopes, and that larger 30-m class telescopes will almost certainly image exoplanets in reflected light. Our group is deploying some of these new techniques on the Subaru Coronagraphic Extreme-AO (SCExAO) system, optimized for high contrast at very small inner working angle. Crossing the performance limit required for reflected light imaging will have huge scientific benefits: (1) detections will offer a large overlap with RV detections, allowing extensive exoplanet characterization (2) in reflected light, low-mass planets are not significantly harder to detect than massive planets, so moderate performance improvements will offer large scientific gains (3) planets in the habitable zone of nearby stars will be prime targets for reflected light imaging, and (4) reflected light surveys will not be limited to relatively distant young systems, and will instead target our closest (easiest) neighbors.

Thursday, May 5 – Afternoon Session

Invited talk

Introduction to Coronagraphs: MIRI 4-Quadrant Phase Mask Coronagraphs

Anthony Boccaletti (l'Observatoire de Paris)

With the upcoming James Webb Space Telescope in space and planet finders on the 8m ground-based telescopes, the field of extrasolar planets will be an important topic of the next decade. Of particular interest, MIRI, the mid IR instrument of JWST (5-28 microns) will take advantage of a star/planet reduced contrast both in direct imaging and transit spectroscopy, and will surpass any current mid IR facilities. We will present the instrumental choices of the MIRI coronograph and its expected performance as well as the capabilities for spectroscopy of transiting planets.

Invited talk

SPICA Coronagraphic Capabilities

Keigo Enya (Japan Aerospace Exploration Agency)

SPICA Coronagraphic Instrument (SCI) is presented together with expected scientific results with this instrument. SPICA mission provides us with a unique opportunity to make high contrast observations because of its large telescope aperture, the simple pupil shape, and the capability for making infrared observations from space. The primary objectives for the SCI are the direct coronagraphic detection and spectroscopy of Jovian exoplanets in infrared. In the SCI, coronagraph is applicable for both imaging and spectroscopy observation. The core wavelength range and the goal contrast of the coronagraphic mode are 3.5-27 micron, and 10^{-6}, respectively. The SCI has capability of simultaneous observations of one target using a short channel with an InSb detector and a long wavelength channel with a Si:As detector. The current progress in the development of key technologies for the SCI is also reported.

Invited talk

The JWST/NIRCam Coronagraph

John Krist (NASA Jet Propulsion Laboratory)

The NIRCam instrument on JWST will include a coronagraphic mode to provide high contrast imaging of exoplanets and circumstellar disks over a wavelength range of 2 to 5 microns. It will allow photometric characterization of planets as old as 1 Gyr and spatially-resolved measurements of the water ice absorption line in debris disks. The Lyot coronagraph will include a variety of occulting spots and wedges allowing imaging to within 0.25"-0.9" of the star, depending on wavelength. Its capabilities will complement upcoming ground-based imaging programs, revealing older planets and objects at larger angles from the stars.

Invited talk

Introduction to Coronagraphs: TFI Non-Redundant Mask

Anand Sivaramakrishnan (Space Telescope Science Institute)

Non-redundant masking (NRM) is a high resolution high contrast technique relevant to JWST and future space missions dedicated to either general astrophysics or extrasolar planetary astronomy. The technique succeeds because it sidesteps the effects of speckle noise that plague direct diffraction-limited imaging. On the ground NRM has opened a rich target space between 0.5 to 4 resolution elements from bright stars. NRM enabled very high angular resolution observations that provide dynamical masses for targets beyond the resolution of the Hubble Space Telescope, challenging the best models of ultra-cool dwarf stars' atmospheres and interiors. The mask operating between 3.8 and 5 microns in JWST's Tunable Filter Imager (TFI) will mitigate instrument-induced speckle noise, enabling imaging that is complementary to both JWST coronagraphs as well as future 30-m class ground-based telescopes. JWST TFI NRM's parameter space is also complementary to future 30-m class ground-based telescopes. Our simulations show that TFI's NRM will open up a search space between ~75 and 500 mas, with point source contrast of ~10 magnitudes. We model a 10ks exposure on an M=7.5 star, with the observing, target acquisition, and data calibration methods being developed at STScI for JWST. Stars as bright as M~3 will be observable with TFI's NRM, meshing well with next-generation ground-based extreme adaptive optics (ExAO) coronagraphs. TFI's NRM will also reach targets too faint for ExAO systems. We also report on the utility of space-based NRM for high-resolution observations of extended sources such as dusty tori around active galactic nuclei (AGNs), and show how it mitigates JWST mission risk associated with JWST's active primary mirrors.

Invited talk

Overview of JWST High-Contrast Imaging

René Doyon (Université de Montréal)

All four science instruments onboard the James Webb Space Telescope (JWST) will feature high-contrast imaging modes implemented through a variety of coronagraphs and Integral Field Units spanning the wavelength range between ~2 and 23 microns. These instruments will not only enable new direct imaging detection of exoplanets, impossible from ground-based observatories, they will also open a wide range of detailed characterization studies. After presenting a brief overview of all high-contrast imaging modes offered by JWST, I will discuss the various challenges facing JWST for high-contrast imaging work. I will also present a few examples of simulated high-contrast imaging observations from NIRCam, MIRI and TFI and discuss how these observations will be unique for understanding the nature of exoplanets.

Contributed talk

High-fidelity Simulations of Planetary Transit Spectroscopy with JWST/NIRSpec

Bernhard Dorner (University of Lyon)

The spectrograph NIRSpec is one of the four science instruments of the James Webb Space Telescope (JWST), a joint project by NASA, ESA, and CSA. Besides its multi-object spectroscopic capability, it will also be used to obtain exoplanet transit spectra in the near infrared wavelength range from 0.6 to 5.0 micron at various spectral resolutions. To study the instrument performance, optical and geometrical effects, and to create realistic calibration and science exposures, the Centre de Recherche Astrophysique de Lyon (CRAL), as subcontractor to EADS Astrium GmbH, developed the Instrument Performance Simulator (IPS) software for NIRSpec. The IPS uses a combination of Fourier and geometrical optics, classic radiometry, and a detector readout simulation to simulate NIRSpec observations. In combination with as-built instrument model data, partly verified during the instrument ground calibration, it is capable of producing highly accurate mock exposures. We use the IPS output to present general observation properties and the influence of different effects on the signal, such as the instrument efficiency and the truncation of the PSF in the slit. In addition, we study simulated exposures of exemplary planet host stars using stellar model data, and finally show reduced spectra using a custom NIRSpec extraction pipeline.

Contributed talk

HST/FGS Astrometry of Nearby Stars - Exoplanet Masses and Exoplanetary System Architecture

G. Fritz Benedict (University of Texas), B. E. McArthur (University of Texas), Rory Barnes (University of Washington)

We describe our methods and review recent progress in determining masses for and system mutual inclinations of companions to nearby stars, using Hubble Space Telescope Fine Guidance Sensor (HST/FGS) astrometry. Specific recent examples will include efforts to determine the mutual inclination of HD 128311 b and c, and a re-determination of the mass of the companion to HD 33636, the latter using additional FGS data secured in late 2008.

Contributed talk

Overview of Kepler Systems with Multiple Transiting Planet Candidates

Darin Ragozzine (Harvard-Smithsonian Center for Astrophysics)

By simultaneously observing over 150000 stars, the Kepler Space Telescope has discovered over 1200 transiting exoplanet candidates, as revealed at the beginning of February 2011, including 470 candidates in multi-candidate systems (Borucki et al. 2011, Lissauer et al. 2011b). All Kepler candidates have a relatively high probability of being actual planets, especially those in multi-candidate systems (Latham et al. 2011), so that this revolutionary new dataset from Kepler certainly contains more transiting planets in multi-transiting systems than all known transiting planets to date while nearly tripling the number of planetary systems discovered by any technique. Multi-transiting systems are extremely valuable (Ragozzine & Holman 2010) and these new observations have already begun to transform of our understanding of the formation and evolution of planetary systems (Lissauer et al. 2011b), though a huge amount of theoretical study remains. I will review Kepler's new multi-transiting systems (including Kepler-9,-10, and -11; Holman et al. 2010, Batalha et al. 2011, Lissauer et al. 2011a) to illustrate the value of such systems and summarize the early implications and potential future of these observations, especially for determining the inclination distribution of exoplanetary systems.

Contributed talk

Eta-Sub-Earth Projections from Kepler and RV Surveys

Wesley Traub (NASA Jet Propulsion Laboratory)

We estimate the projected likelihood of finding a terrestrial-mass planet in the habitable zone around a star, i.e., the probability known as eta-sub-Earth. We start with two published radial-velocity surveys, and convert their mass distribution functions to radius distribution functions, in order to compare directly with current Kepler survey results from transits. We then extrapolate to the case of terrestrial, habitable-zone planets, and estimate the relevant uncertainties, to derive a current projected value of eta-sub-Earth.

Contributed talk

Planet Occurrence within 0.25 AU

Andrew Howard (University of California, Berkeley)

The architectures of extrasolar planetary systems provide key properties that inform theories of planet formation and evolution. Until recently, these properties were largely limited to the occurrence fractions of giants planets and their distributions in planet mass and orbital period. The NASA-UC Eta-Earth Survey probes close-in planet occurrence down to 3 Earth masses. Doppler measurements from Keck Observatory provided the first measurement of the planet mass function from Jupiters down through super-Earths. This mass function rises steeply toward lower mass and, extrapolating down to 1 Earth mass, we predict that one in four Sun-like stars have a close-in planet of approximately Earth mass. The patterns of planet occurrence in the mass-orbital period plane, including the notable absence of the predicted desert of close-in low-mass planets, inform theories of planet formation and migration. My talk will focus on recent detections of low-mass planets and how the ensemble of these planets provides powerful constraints on theories of planet formation and migration.

Contributed talk

"Small Black Shadows": Using All-Sky Transit Surveys to Detect and Characterize Terrestrial Planets

Scott Gaudi (Ohio State University)

Transiting systems orbiting bright, nearby stars offer the best prospects for characterizing low-mass planets. In particular, discovering transiting terrestrial planets located in the habitable zones of their parent stars in time for follow-up with JWST may provide a viable alternative to direct imaging missions as a way to detect and study nearby habitable planets. Finding the transiting planets around the brightest stars generally requires an all-sky (or nearly all-sky) photometric survey. I present general scaling relations for the expected yields of all-sky transit surveys. I use these relations to show how the yields depend on the properties of the planets and hosts, focusing in particular on habitable systems. I also show how various choices regarding the survey design, instrumentation and strategy impact the planet yield. I explore the potential of all-sky transit surveys to probe intrinsically rare systems, and consider their synergy with upcoming missions such as GAIA. Finally, I place these ideas in context by comparing and contrasting various planned transit surveys.

Friday, May 6 – Morning Session

Invited talk

Free-Floating (Solivagant) Low Mass Objects with WISE

J. Davy Kirkpatrick (Infrared Processing and Analysis Center/California Institute of Technology)

NASA's Wide-field Infrared Survey Explorer (WISE) was designed in part to detect nearby brown dwarfs with temperatures colder than the coldest known examples (Teff ~ 450-600K). To date, spectroscopic follow-up of WISE brown dwarf candidates has confirmed roughly 100 new brown dwarfs in the solar neighborhood, a dozen of which are later in type and presumably cooler than UGPS 0722-0540, the latest published object. Because of their cold temperatures and presumed low masses, these solivagant field objects are ideal tests of exoplanet-like atmospheric theory because they remove the complication of irradiation effects by host stars. In addition to finding extremely cold objects, WISE is also capable of finding brown dwarfs having applicability to other exoplanet atmospheric studies. One such example is the search in nearby stellar associations (TW Hydrae, Tucana-Horologium, beta Pictoris, etc.) for young brown dwarfs, whose low-gravity atmospheres can be compared to those of directly imaged planets in systems such as HR 8799.

Contributed talk

Characterizing the Coldest Brown Dwarfs Discovered with WISE

Michael C. Cushing (NASA Jet Propulsion Laboratory), J.D. Kirkpatrick (Infrared Processing and Analysis Center/California Institute of Technology), Mark S. Marley (NASA Ames Research Center), Didier Saumon (Los Alamos National Laboratory)

One of the primary science goals of the Wide-field Infrared Survey Explorer (WISE), a NASA mission that recently completed its survey of the sky at four mid-infrared wavelengths, is to identify very cold (Teff < 600 K) brown dwarfs. With atmospheric conditions similar to that of giant planets, brown dwarfs are ideal exoplanet analogs that can be studied free from the contaminating light of host stars. To date, we have identified nearly one hundred new brown dwarfs (see talk by J.D. Kirkpatrick), roughly ten of which have spectral types as late as or later than the current record holder UGPS 0722-0540 (Teff~500 K). I will discuss these late-type brown dwarfs and will focus on our modeling effort aimed at deriving their atmospheres parameters using the model atmospheres of Marley and Saumon. The continued study of ultracool brown dwarfs such as these will directly inform the interpretation and characterization of exoplanets discovered with the next generation of high-contrast imagers like GPI and SPHERE.

Contributed talk

Isolated Planet Population Found by Gravitational Microlensing

David Bennett (University of Notre Dame) and Taka Sumi (Nagoya University)

The microlensing event timescale distribution observed by the MOA Collaboration is well fit by standard mass functions for stars and brown dwarfs, except for a significant excess of events with timescales less than 2 days. These short events indicate a previously unseen population of planetary-mass objects. This new population can be modeled as a delta-function at ~1 Jupiter-mass with an abundance of ~1.8 Jupiters per main sequence star. A power-law for masses < 10 Jupiter-masses with an index of 1.5 also gives an acceptable fit. These planets are isolated in the sense that no microlensing signal is seen from a host star, which implies a separation of > 5-30 AU. Comparison to direct imaging results suggests that many of these planets are not bound to host stars.

Contributed talk

Phase Mapping of Giant Exoplanets and Brown Dwarfs

Daniel Apai (University of Arizona)

Spatially unresolved photometry and spectroscopy provide exciting, but limited probes of ultracool atmospheres, capable of testing only one-dimensional models. However, with temperatures close to the condensation temperatures of refractory minerals and the stable P-T regime for methane, many brown dwarfs and giant exoplanets are hypothesized to harbor patchy cloud cover and potentially a heterogenous gas-phase composition. Phase-mapping can provide spatially and spectrally resolved (2D) maps of rotating ultracool objects. We show results from an ongoing joint HST-Spitzer program that obtains very high signal-to-noise and high cadence infrared spectroscopy and photometry of L/T transition brown dwarfs. The observations reveal both photometric and spectroscopic variations with an exciting pattern. We will also present results from a photometric monitoring of the HR8799bcde system in search for rotation periods and cloud properties. Finally, we will briefly discuss how similar measurements will enable JWST and 30m telescopes to map jupiter-mass exoplanets and their cloud covers.

Invited talk

Planets Around Massive Stars

John A. Johnson (California Institute of Technology)

Until the middle of the last decade, much of what we know about exoplanets centered on those around Solar-mass stars. Since then, evolved stars have emerged as one of the primary means of expanding the stellar mass range encompased by Doppler-based planet searches. I will provide an overview of surveys of planets around stars more massive than about 1.5 solar, and the surprising statistical trends that have emerged. Compared to planets around Sun-like stars, planets around these former A-type stars are more numerous, more massive, more eccentric and orbit further from their central stars. These findings have important implications for theoretical models of planet formation and inform future planet surveys.

Contributed talk

Direct Detection of Exoplanets with Polarimetry

Sloane Wiktorowicz (University of California, Berkeley)

The detection of scattered light from exoplanets gives direct access to physical conditions and composition of their atmospheres. Currently, most scattered light experiments focus on nearly edge-on, transiting systems. The temporal changes that occur during planetary occultations are used to suppress systematic errors that would otherwise overwhelm the planetary signal. Linear polarimetry also has the potential to detect scattered light from exoplanets, because the polarization state of light scattered from a planetary atmosphere distinguishes it from both the direct light from the host star and thermal re-radiation from the planet. This scattered flux should be identifiable even in face-on systems, because both degree and position angle of polarization are modulated continuously throughout the orbit. We report on searches for exoplanetary scattered light using the POLISH2 polarimeter on the Lick 3-m telescope. This instrument has recently been upgraded with new detectors and a high-speed data acquisition system, and these give a factor of five improvement in precision with respect to the previous POLISH system (Wiktorowicz 2009). This polarimeter has achieved precision better than one part per million on $V < 9$ stars, and it is ideally suited for direct detection of close-in exoplanets. This work was supported by a UC Lab Fees Research Grant and UCO/Lick Observatory.

Contributed talk

The Heavy Element Mass of Giant Planets, and its Correlation with Stellar Metallicity

Neil Miller (University of California Santa Cruz)

Planetary transit observations have revealed a population of “hot Jupiters” with unexpectedly large radii. The physical mechanism that inflates the planets appears to be correlated with the average stellar flux incident upon the planet. Transit observations combined with radial velocity data yield the masses and densities of these planets, which in principle constrain their composition, including abundances of heavy elements. However, for the highly irradiated large-radius planets the composition cannot be determined because this radius inflation counteracts the effects of heavy elements (those heavier than helium, also known as “metals” in astronomy), which would otherwise lead to a smaller planet. Fortunately, a sample of transiting planets is now emerging at larger orbital distances and smaller incident fluxes that appear to be unaffected by this inflation mechanism. In this work we determine the interior heavy element mass for this population of less irradiated transiting giant planets. There is a correlation between the stellar metallicity and the mass of heavy elements in its transiting planet. It appears all giant planets posses a minimum of ~10-15 Earth masses of heavy elements, with planets around metal-rich stars having larger heavy element masses. This relationship provides an important constraint on planet formation pointing to a core accretion scenario. In addition, since the observed correlation can also be applied to inflated planets, it yields the heavy element abundance in these planets as well. Therefore structure models can be used to determine the magnitude of the energy source that inflates the more highly irradiated planets. Saturn- and Jupiter-like enrichments above solar composition are a hallmark of all the gas giants in the sample.

Contributed talk

Secular Chaos and the Production of Hot Jupiters

Yoram Lithwick (Northwestern University)

In a planetary system with two or more well-spaced, eccentric, inclined planets, secular interactions may lead to chaos. The innermost planet may gradually become very eccentric and/or inclined. Secular chaos is known to be responsible for the eventual destabilization of Mercury in our own Solar System. Here we focus on systems with multiple giant planets. We show that after an extended period of eccentricity diffusion, the inner planet's pericentre can approach the star to within a few stellar radii. Strong tidal interactions with the star pull the planet inward, creating a hot Jupiter. In contrast to other proposed channels for the production of hot Jupiters, such a scenario (which we term "secular migration") explains a range of observations: the pile-up of hot Jupiters at 3-day orbital periods, the fact that hot Jupiters are in general less massive than other RV planets, that they may have misaligned inclinations with respect to stellar spin, and that they have few easily detectable companions (but may have giant companions in distant orbits). Based on Wu & Lithwick 2011 at arxiv.org

Contributed talk

OGLE-2008-BLG-513: Measuring the Orbit of a Microlensing Planet

Jennifer Yee (Ohio State University)

Microlensing has often been criticized because it is only able to measure the mass ratio and projected separation of the planet and the host star. In the case of microlensing event OGLE-2008-BLG-513, many of the normal microlensing degeneracies are broken, allowing us to measure the most complete orbital solution ever found for a microlensing planet. Because we observe both orbital motion of the lens and microlens parallax, we measure not only the physical mass of the planet and star, but also the semimajor axis, eccentricity, and time of periastron of the orbit. Additionally, we are able to place constraints on the three-space orientation of the orbit, which encompass the remaining parameters required to fully describe a Keplerian orbit. We find that the host star is 0.17<0.24 M_Sun, and the planet is 4.7<6.8 M_Jup (q = 0.027 ± 0.001). The semimajor axis of the orbit is 1.2<2.5 AU, and there is a strong preference for extremely eccentric orbits, 0.92<0.98. Current theories of planet formation are unable to form such a massive planet in situ so close to its M dwarf host, so its origin remains a mystery.

Friday, May 6 – Afternoon Session

Invited talk

Challenges and Opportunities of M Dwarf Planet Hosts

Jacob Bean (Harvard-Smithsonian Center for Astrophysics)

M dwarfs are attractive targets for planet searches using the radial velocity and transit techniques because they represent the shortest route to the detection and characterization of potentially habitable planets. However, despite their many advantages, there are also unique challenges to studying planetary systems around M dwarfs. These challenges include the stars' faintness at optical wavelengths, their typically higher levels of activity, and the difficulty of determining accurate parameters for them. I will discuss the challenges and opportunities of M dwarf planet searches, review the current state of ongoing projects, and describe planned new instrumentation that could truly usher in the era of studying habitable worlds beyond the Solar System.

Contributed talk

New Near-Infrared Techniques for Precision Radial Velocities

Peter Plavchan (NASA Exoplanet Science Institute)

Near-infrared and high-precision have historically been disjoint adjectives to describe precision radial velocity searches. Recent advances have pushed precision in the near-infrared from ~50 m/s with telluric wavelength calibration to ~5 m/s with absorption gas cells. We have built a single gas, near-infrared absorption cell with greater line density and bandpass coverage than recently reported in the literature. We are currently carrying out a survey to detect exoplanets around red, low mass, and young stars. We discuss new near-infrared instrumentation techniques that we are designing to complement optical radial velocity work.

Poster Abstracts

Abstracts for posters are listed alphabetically by first author within the following science categories.

A. Disks
B. Exoplanet Characterization
C. Habitability
D. Missions
E. Planet Formation
F. Planet-Hosting Stars
G. Planetary System Architecture

DISKS

Poster ID: *Disks.01*

Holey Debris Disks, Batman! Where Are the Planets?

Vanessa Bailey (University of Arizona)

The location of the giant planets in our Solar System may have played a crucial role in creating habitable conditions on Earth. Finding observational signatures of giant planets in similar configurations could be key to locating systems with habitable planets. One intriguing possibility is to search for the effect of such giant planets on their circumstellar debris disks. Theoretical studies indicate giant planets will carve sharp boundaries and gaps in their disks, and this has been seen in the cases of HR 8799 and Fomalhaut. If substantiated, this observational link would help guide target selection for next generation instruments such as the Large Binocular Telescope Interferometer and James Webb Space Telescope. We combine direct imaging and spectroscopy to search for evidence of this phenomenon in other systems. We have utilized Spitzer spectral energy distributions (SEDs) to identify roughly a dozen systems with interesting disk morphology. Using NICI (Gemini South) and Clio (MMT) we are carrying out imaging of each in the near to mid-IR to search for giant planets at large orbital separations. We are additionally developing dynamical models of systems without detected planets in order to ascertain whether companions below our detection threshold could be shaping the disk or whether some other mechanism is at work. We are also mining the Spitzer archives to understand the frequency of spectrally indicated sharp boundaries in disks. We will determine the fraction of systems with previously known companions (and with existing Spitzer SED data) that exhibit disk clearing. In this way we will refine the conditions under which the gap/sharp boundary selection method is likely to be valid, as well as learn more about the planet-disk interactions.

Poster ID: *Disks.02*

Transitional Disks as Signposts of Young, Multiplanet Systems

Sally Dodson-Robinson (University of Texas) and Colette Salyk (University of Texas)

Although there has yet been no undisputed discovery of a still-forming planet embedded in a protostellar disk, the cleared inner holes of transitional disks are thought to be signposts of planet formation. Here we show that the subset of accreting transitional disks with wide, optically thin inner holes of 15 AU or more can only be sculpted by multiple planets orbiting inside each hole. We demonstrate that the confined, non-axisymmetric flow patterns produced by multiple planets produce fluxes consistent with observed transitional disk SEDs. We also establish that other clearing mechanisms, such as photoevaporation, cannot explain our subset of accreting transitional disks with wide holes. Transitional disks are therefore high-value targets for observational searches for young planets.

Poster ID: *Disks.03*

An Extended Halo in the Fomalhaut Debris System

Pablo Espinoza (University of Arizona), Kate Su (University of Arizona), George Rieke (University of Arizona), Karl Stapelfeldt (NASA Jet Propulsion Laboratory)

Fomalhaut, a bright A3V star located 7.7 pc away, is a particularly interesting system for the study of planetary formation and evolution because it possesses a debris disk and a planet revealed by direct imaging. The whole system provides a unique opportunity to explore the connection between debris disk structure and planetary configuration. In this work we present deep Spitzer MIPS observations of Fomalhaut. The new data combined with detailed models lead to the following conclusions: (1) a confirmation of a central, unresolved warm (~150 K) component, analogous to the asteroid belt, and (2) the dust emission of the cold disk can be traced, at least, to ~800 AU from the star. The measured size is much larger than the previous estimates of the cold outer ring (160-260 AU in radius) from the scattered-light and submillimeter images respectively, suggesting the presence of an extended halo around the system. We model the spectral energy distribution (SED) of the debris by using dust components fixed at the locations inferred from the spatial decomposition of the disk emission. From this we establish that the extended halo is originated mainly from small grains ($\leq$ 10 μm), that are likely being ejected and/or on highly eccentric orbits under the influence of radiation pressure. From modeling the surface brightness distributions, we estimate the halo is as bright as 18% of the total emission at 70 μm. We also compare these results with the halo in the Vega system, and conclude that the larger rate of stirring of the parent bodies around Vega contradicts the hypothesis that the amount of halo emission is a natural output of disk evolution.

Poster ID: *Disks.04*

Imaging of Circumstellar Disks with an Adaptive Secondary at MMT and (Coming Soon) Magellan

Katherine Follette (University Arizona)

A great deal of information about the process of grain growth and planet formation can be revealed by the study of circumstellar disks in the near IR with high spatial resolution adaptive optics techniques using adaptive secondary mirrors (ASMs). With current ASM technology on the MMT, we are able to probe the existence of water ice (likely a key component of planet formation) and average grain properties of circumstellar disks. This method, pioneered by Honda et al. (2009), takes advantage of the high albedo of icy circumstellar disks at the 3.09 micron ice feature relative to the nearby continuum to constrain the water ice abundance and average grain properties of the disk. With the success of the LBT ASM (Esposito et al. 2010), the future of disk imaging at the high spatial resolutions achievable by high actuator count adaptive secondary mirrors appears bright. In fact, the simulated performance of the soon-to-be-integrated Magellan ASM reveals that the system is likely to achieve moderate Strehls and high spatial resolutions (~20mas) into the visible wavelength regime. This gives Magellan AO the potential to reveal disk morphology on scales as small as 2-3AU, and may reveal heretofore unresolved disk features such as disk gaps where planets may be forming.

Poster ID: *Disks.05*

A New Numerical Model of Collisional Cascades in Debris Disks

Andras Gaspar (University of Arizona)

We present a numerical model of collisional cascades in debris disks. Our code introduced here concentrates on the collisional physics and numerics. We improve on the collisional treatment presented by other groups by solving a full scattering equation that describes physically and mathematically the collisional evolution of a system of particles. Our model presents a new method for dealing with erosive (cratering) collisions and a continuous set of outcomes as a function of colliding masses. Although our particle-in-a-box code is currently limited to modeling narrow debris rings, we are able to follow the evolution of the particle size distribution in collision dominated debris disks around a range of central star types, with the disks placed at several typical observed disk radii. The distributions in all of these cases settle in a characteristic $n(a) \sim a^{-3.7}$ power-law, which is steeper than the classic Dohnanyi (1969) solution, generally used in debris disk spectral energy distribution models. We show examples of observed debris disks, where the modified distribution of particles is necessary to explain the mid-IR observations (see e.g., Krist et al. 2010, Golimowski et al. 2011). We also explore the evolution of mass and infrared luminosity in debris disks. We show that the total mass decays following a t^{-1} power-law (after reaching quasi steady-state evolution), in accordance with analytic approximations. We also show that the fractional infrared luminosity evolves somewhat faster than the total mass of the system.

Poster ID: *Disks.06*

Simulating Circumstellar Disks on a Moving Voronoi Mesh

Diego Munoz (Harvard-Smithsonian Center for Astrophysics)

We present a novel approach to the numerical study of gas disks around young stars using the Voronoi-tessellation cosmological code AREPO (Springel,2010). This finite-volume code is shock-capturing and second-order-accurate in time and space. Its moving mesh makes it a Lagrangian/Eulerian code that satisfies Galilean invariance and has a very low diffusivity due to its unbiased unstructured grid. Its pseudo-Lagrangian nature makes it ideal for problems that show large dynamical range in density, such as gravitationally unstable systems with clustering and collapse. The self-gravity solver is implemented consistently for collisionless particles as well as for gas "particles" (Voronoi cells) in an N-body fashion using a tree algorithm. The hydrodynamics+N-body approach of AREPO is unparalleled in its ability to treat self-gravitating systems that lack of a symmetric configuration while retaining the resolution and accuracy of conventional grid codes. Thus, it combines the benefits of both particle- and mesh-based codes. Precisely, these two approaches are used in numerical studies of circumstellar disks depending on the physical process of interest. For example, those studies that choose particle based codes - such as SPH - focus on gravitationally unstable disks or the tidal interaction of disks. On the other hand, grid codes are preferred in studies of planet-disk interaction, where proper treatment of shocks, wakes and gaps requires an accurate shock-capturing method. We present examples of how the flexible approach of AREPO can be used to simulate these and other types of problems.

Poster ID: *Disks.07*

Circumstellar and Circumbinary Disk Evolution in a Binary System

Andrew F. Nelson (Los Alamos National Laboratory)

We simulate the evolution of the circumstellar and circumbinary disks in a system configured to appear similar to that observed for the GG Tau A binary. We find that mass transfer onto the circumstellar disks is episodic with maximal transfer rates which change from orbit to orbit, but which occur following each apoapse passage. Accretion rates onto the stars themselves do not display such periodicities, so the disk masses vary somewhat over the binary orbit. Averaged over time, mass transfer into and out of the disks equilibrates at a disk mass of $<\sim 1M_J$, for both the primary and secondary. The transfer rate of material through the disks is rapid enough to effectively replace the entire disk in less than 10^4 yr. We discuss the implications of our results on planet formation in this and similar systems.

Poster ID: *Disks.08*

YSOVAR: Early Results in Orion

Luisa Rebull (Spitzer Science Center/IPAC)

We present initial results from the YSOVAR time series imaging at 3.6 and 4.5 microns of 0.9 sq. degrees in the Orion Nebula Cluster (ONC). We extracted light curves with ~3% photometric accuracy for ~2000 ONC members ranging from several solar masses down to well below the hydrogen burning mass limit. For many of the stars, we also have time-series photometry obtained at optical (Ic) and/or near-infrared (JKs) wavelengths. Our primary focus is the unique ability of 3.6 & 4.5 μm variability information to improve our understanding of inner disk processes and structure in the Class I and II young stellar objects (YSOs). We highlight our light curves for AA-Tau analogs - YSOs with narrow dips in flux, most probably due to disk density structures passing through our line of sight.

Poster ID: *Disks.09*

Spatially Resolving the Ice Line in Debris Disks

Timothy J. Rodigas (University of Arizona)

Knowing the location of the ice line, and the spatial distribution of water ice in debris disks, is critical for a better understanding of planet formation. Recently Inoue et al. 2008 showed that near-infrared (NIR) color analysis of a disk, particularly near 3 μm, is a powerful tool for spatially resolving the ice line. We have undertaken a program to spatially resolve the ice line in 6 previously resolved debris disks. Four of the targets are debris disks discovered by Hubble at 0.5-1.5 μm. We are imaging in the L' band (3.8 μm), the H2O band (3.1 μm), and in the K band with Clio/AO on the MMT. Disk photometry at these three wavelengths allows us to distinguish ice-poor regions of the disks from ice-rich regions. In this way, our observations will test current theories on the location of the ice line, which predict that it should reside within 3-10 AU. The most interesting disks may serve as targets for NIR imaging with LBTI, which will be able to probe deeper and closer in to each star. Here I will present the preliminary results of this study, as well as new techniques for accurate disk detection from the ground at 2-4 μm.

Poster ID: *Disks.10*

Evidence Against an Edge-On Disk Around the Extrasolar Planet 2MASS 1207 b and a New Thick Cloud Explanation for its Under-Luminosity

Andrew Skemer (University of Arizona)

Since the discovery of the first directly imaged, planetary-mass object, 2MASS 1207 b, several works have sought to explain a disparity between its observed temperature and luminosity. Given its known age, distance, and spectral type, 2MASS 1207 b is under-luminous by a factor of ~10 (~2.5 mags) when compared to standard models of brown-dwarf/giant-planet evolution. In this paper, we study three possible sources of 2MASS 1207 b's under-luminosity. First, we investigate Mohanty et al. (2007)'s hypothesis that a

near edge-on disk, comprising large, gray-extincting grains, might be responsible for 2MASS 1207 b's under-luminosity. After radiative transfer modeling we conclude that the hypothesis is unlikely due to the lack of variability seen in multi-epoch photometry and unnecessary due to the increasing sample of under-luminous browndwarfs/ giant-exoplanets that cannot be explained by an edge-on disk. Next, we test the analogous possibility that a spherical shell of dust, could explain 2MASS 1207 b's under-luminosity. Models containing enough dust to create ~2.5 mags of extinction, placed at reasonable radii, are ruled out by our new Gemini/TReCS 8.7 micron photometric upper-limit for 2MASS 1207 b. Finally, we investigate the possibility that 2MASS 1207 b is intrinsically cooler than the commonly used AMES-DUSTY fits to its spectrum, and thus it is not, in fact, under-luminous. New, thick cloud model grids by Madhusudhan et al. (2011) fit 2MASS 1207 b's 1-10 micron SED well, but they do not quite fit its near-infrared spectrum. However, we suggest that with some "tuning", they might be capable of simultaneously reproducing 2MASS 1207 b's spectral shape and luminosity. In this case, the whole class of young, under-luminous brown-dwarfs/giant-exoplanets might be explained by atmospheres that are able to suspend thick, dusty clouds in their photospheres at lower temperatures than field brown-dwarfs.

Poster ID: *Disks.11*

A Resolved Debris Disk Around a Nearby G Star

Karl Stapelfeldt (NASA Jet Propulsion Laboratory)

The Herschel Space Observatory is providing unprecedented sensitivity and angular resolution in the far-infrared. The DUNES Key Project (DUst around NEarby Stars, PI Carlos Eiroa) has nearly finished its survey of 133 FGK stars within 25 pc of the Sun using the PACS photometer at 100 and 160 microns. We report the detection of a resolved debris ring around HIP 32480, a G0 star 16.5 parsecs distant. The ring is almost 300 AU in diameter and inclined 30 degrees from edge-on. We present a thermal emission model for the system that fits the Spitzer spectroscopy and Herschel images of the system. We find a minimum grainsize of ~4 microns in the main ring and a distinct warm dust population interior to it. Faint detached emission features just outside the ring may trace a separate, more distant ring in the system.

Poster ID: *Disks.12*

Fingerprints of Clearing Process - Spitzer Spectroscopy of Atomic Lines in Transitional Disks

Judit Szulagyi (Konkoly Observatory, Hungarian Academy of Science)

Transitional disks are protoplanetary disks characterized by an optically thin inner region of a few AU radii. The inner gap/hole might be caused by several mechanisms among which grain growth, photoevaporation, or a forming planet. Transitional disks could constitute the evolutionary link between the optically thick disks of young T Tauri and Herbig Ae stars and debris disks found around many main-sequence stars. In order to understand better the processes related to disk photoevaporation we initiated a program to

analyze infrared spectra of a sample of transitional disks observed with the Spitzer Space Telescope. We present detections and upper limits of infrared lines from [Ar II] at 6.98 μm, [NeII] at 12.81 μm, and [Ne III] at 15.55 μm lines that trace the hot disk atmosphere and can be used to constrain disk photoevaporation rates. This rate determines the timescale of gas dissipation from the disk, thus sets an upper limit for planet formation timescale.

Poster ID: *Disks13.*

A Search for Planet Signatures in the Innermost Parts of Protoplanetary Disks with Long Baseline Interferometry

Yamina Touhami (CHARA/Georgia State University)

Long baseline interferometry represents a primary way to investigate directly structures and sub-structures down to the milliarcsecond scale of protoplanetary disks. This technique is not only suitable for determining the physical and geometrical properties of protoplanetary disks, but also for searching for planets in the innermost regions of the protoplanetary disk. A planet in the inner-disk region clears out a gap in the circumstellar material, and this gap has a clear signature on the interferometric visibility and closure phases, as well as on the spectral energy distribution of the system. The CHARA Array interferometer, operating with baselines as large as 330 meters, has proved its ability of characterizing circumstellar disks, such as disks around Be stars, and has the potential of finding gaps in the innermost parts of protoplanetary disks trigged by planets. The output of CHARA observations ultimately will help us understand the big picture: from protoplanetary disk formation, to the formation of earth-like planets, to protoplanetary disk evolution.

B. Exoplanet Characterization

Poster ID: *Characterization.01*
The Discovery and Characterisation of Transiting Planets by SuperWASP
David Anderson (Keele University)

I will present new transiting planets discovered by SuperWASP as well as summarise recent efforts to characterise other SuperWASP systems. As the number of well-characterised systems grows parameter correlations are becoming evident. It is by studying these correlations along with the most extreme systems (e.g. WASP-19b, the shortest period planet, and WASP-17b, the most bloated planet) that we can hope to better understand planet formation and evolution.

Poster ID: *Characterization.02*
Upper Atmospheres of Close-in Exoplanets
Phil Arras (University of Virginia)

Upper atmospheres of short orbital period exoplanets are heated by ionizing radiation from the parent star. The resultant large-scale height, in combination with stellar tides, may allow mass to escape the planet, as has been inferred for HD 209458b based on the Lyman alpha transmission spectrum. However, the planet's intrinsic magnetic field may reduce atmospheric escape rates through confinement of the partially ionized gas. I will discuss calculations of upper atmosphere structure, mass loss rates, and Lyman alpha transmission spectrum for models which include the intrinsic planetary magnetic field.

Poster ID: *Characterization.03*
Secondary Eclipse Photometry of WASP-3b and WASP-4b with Warm Spitzer
Ingrid M. Beerer (University of California, Berkeley)

We present photometry of the giant extrasolar planet WASP-3b at 3.6, 4.5, and 8.0 μm and the extrasolar planet WASP-4b at 3.6 and 4.5 μm taken with the Infrared Array Camera on board the Spitzer Space Telescope as part of Spitzer's extended warm mission. We find secondary eclipse depths for WASP-3b that are well fit by model emission spectra exhibiting a temperature inversion in the upper atmosphere. The eclipse depths for WASP-4b are well fit by model emission spectra with water and other molecules in absorption, similar to those used for TrES-3 and HD 189733b. Depending on our choice of model, these results indicate that this planet has either a weak dayside temperature inversion or no inversion at all. The absence of a strong thermal inversion on this highly irradiated planet is contrary to the idea that highly irradiated planets are expected to have inversions, perhaps due the presence of an unknown absorber in the upper atmosphere. This result might be explained by the modestly enhanced activity level of WASP-4b's G7V host star, which could increase the amount of UV flux received by the planet, therefore reducing the abundance of the unknown stratospheric absorber in the planetary atmosphere as suggested in Knutson et al. We also find no evidence for an offset in the timing of the secondary eclipse and place a 2σ upper limit on |ecos ω| for both planets.

Poster ID: *Characterization.04*

Fast-Photometry Ground-Based NIR Detection of the Thermal Emission from Extrasolar Planetary Atmospheres

Claudio Caceres (Universidad Catolica de Chile)

The observation of the occultations of transiting extrasolar planets is a powerful tool to detect the thermal emission from the atmosphere of the planet, and to constraint its physical parameters. We developed a fast-photometry near-IR method with ground-based telescopes able to detect the thermal emission from the atmospheres of some extrasolar planets. We present the application of this method to the highly irradiated planet WASP-4b, with an analysis of some atmospheric properties of this system.

Poster ID: *Characterization.05*

High-resolution Infrared Transmission Spectroscopy of GJ 1214 b

Ian Crossfield (University of California, Los Angeles)

We report the results of high-resolution, near-infrared transmission spectroscopy of the low-mass planet GJ 1214 b. Our analysis is consistent with prior, optical observations: by comparing to atmospheric models we rule out a cloud-free atmosphere near chemical equilibrium with both solar and enhanced (10x solar) composition. Either (i) GJ 1214 b's atmosphere has a small scale height (e.g., because it is dominated by heavy molecular species), (ii) the planetary atmosphere is out of chemical equilibrium and depleted in methane, or (iii) the planet's atmosphere is obscured by high-altitude clouds. We demonstrate the ability to rule out atmospheres with wavelength-dependent transit depth variations >≈m 8 x 10^4 over our wavelength range; our sensitivity is limited by instrumental and telluric effects endemic to narrow, single-slit spectrographs.

Poster ID: *Characterization.06*

Analysis of XO-2 b Observed with HST NICMOS

Nicolas Crouzet (Space Telescope Science Institute)

We present results from the white-light photometry and spectroscopic analysis of the transiting planet XO-2 b, obtained with HST NICMOS. The field of view contains not only the XO-2 star but also a second star of very similar properties, which we use as a comparison star. Three transits of the planet have been observed. We first perform a white-light photometric analysis of the data. The high signal to noise ratio yields improved parameters for the planet and host star. We then build the spectrum of the system, leading to constraints on the atmospheric composition of the planet. In the context of a debate about planetary spectra obtained with NICMOS, this study provides new information about the analysis of NICMOS data and other similar data.

Poster ID: *Characterization.07*

Understanding the Systematic Noise Floor for Exoplanet Characterization

Pieter Deroo (NASA Jet Propulsion Laboratory)

The most successful method to date to characterize exoplanet atmospheres is the transit method, in which a transiting system is spectrophotometrically monitored during its orbit. The required dynamic range of these measurements has pushed astronomers into previously unexplored instrument systematics. Mitigating these previously irrelevant effects is core to exoplanet science and the methodology how to remove these effects is frequently a source of controversy. We will present a simulation of how uncertainties in the pointing and point-spread-function set the instrument systematics noise floor. We will focus on near-IR spectroscopic characterization of exoplanet atmospheres using HgCdTe detectors. We show how we can understand the observed Hubble/NICMOS systematics and derive the expected systematic noise floor for WFC3 and JWST/NIRspec. In addition, we calculate how the noise floor is improved upon with standard decorrelation techniques. We also show how the FINESSE instrument, an Explorer mission concept optimized and dedicated for exoplanet spectroscopic characterization, is designed to be robust against instrument induced systematic errors.

Poster ID: *Characterization.08*

Towards Understanding the Nature of Small Planets: Multi-Wavelength Transmission Spectroscopy of the Forerunner GJ1214b

Jean-Michel Desert (Harvard University)

The bulk composition of Super-Earth planets cannot be uniquely determined using measurements of their mass and radius alone because of the inherent degeneracy between their interior and atmosphere in theoretical models. Breaking this degeneracy can be accomplished by obtaining knowledge of the planet's atmospheric composition. I will present a combined study of ground- and space-based transmission spectroscopy observations of the transiting super-Earth GJ1214b that together cover wavelengths from the UV to the IR. The comparison of these measurements to various atmospheric models provides important constraints on the planet's atmospheric composition, and by extension, its bulk composition, formation, and evolution. This investigation is a forerunner for future atmospheric studies that aim to reveal the nature of small planets, and I will discuss the important next observations that should be done to better understand these intriguing worlds.

Poster ID: *Characterization.09*

A Search for Transits of GJ 581e Using MOST Space-based Observations

Diana Dragomir (University of British Columbia)

We have obtained MOST space-based photometry of GJ 581. The nearly continuous observations span 3 orbits of the innermost planet (GJ 581 e). We have carried out a search for transits of GJ 581 e and place upper limits on its radius for 4 values of the inclination. For edge-on orbital inclinations, we rule out radii greater than 1.5 R_earth with 95% confidence. We present the results of our analysis as well as an assessment of photometric variability for GJ 581.

Poster ID: *Characterization.10*

Photometric Phase Variations of Long-Period Eccentric Planets

Dawn M. Gelino (NASA Exoplanet Science Institute, Caltech), Stephen Kane (NASA Exoplanet Science Institute, Caltech)

The field of exoplanetary science has diversified rapidly over recent years as the field has progressed from exoplanet detection to exoplanet characterization. For those planets known to transit, the primary transit and secondary eclipse observations have a high yield of information regarding planetary structure and atmospheres. The refinement of orbital parameters allows precision targeting of transit windows and phase variations of known long-period planets which constrain the dynamics of the orbit and the geometric albedo of the atmosphere. Here we describe the expected phase function variations at optical wavelengths for long-period planets, particularly those in the high-eccentricity regime and multiple systems in resonant and non-coplanar orbits. We investigate the effects of orbital inclination on the flux ratio as it interacts with the other effects induced by orbital eccentricity. We further extend this work to the thermal detection of long-period eccentric planets during periastron passage. We apply this to the known exoplanets and discuss detection prospects and how observations of these signatures may be optimized.

Poster ID: *Characterization.11*

Observational Constraints on the Composition of Exoplanets

C. A. Griffith (University of Arizona), G. Tinetti (University College London), M. Swain (NASA Jet Propulsion Laboratory), Pieter Deroo (NASA Jet Propulsion Laboratory), and Simon Schuler (NOAO)

Two kinds of spectra can be measured for transiting extrasolar planets. The primary transit provides a transmission spectra of the exoplanet's limb as the planet passes in front of the star. The secondary transit measures the emission of mainly the planet's dayside atmosphere; the combined planet and star's emission is compared to the emission of star alone, when it eclipses the planet. Infrared transmission and emission spectroscopy, have over the past 3 years, revealed the presence of the primary carbon and oxygen molecular species (CH_4, CO_2, CO, and H_2O). However, efforts to constrain the abundances to within several orders of magnitude are thwarted by the degenerate effects of the

temperature and composition in the emission spectra. Similarly, transmission spectra, while less sensitive to the atmospheric temperatures, are difficult to interpret because the composition derived depends delicately on the assumed radius. We find, however, that an analysis of the combined transmission and emission spectra provide strong constraints on the molecular abundances of the planet for both the dayside and terminator atmospheres. We present an analysis of primary and secondary transit observations of HD209458b's optical to infrared spectra, which correlate the degenerate effects of the atmospheric parameters, using a principal components analysis, and constrains the atmospheric composition of the exoplanet. The derived oxygen and carbon composition of the HD209458b's atmosphere is considered in conjunction with the primary star's composition in order to start to address questions regarding the evolution of the exoplanet.

Poster ID: *Characterization.12*

An Accurate Comparison of the Global Composition of Two Exoplanets Transiting the Same Star

Mathieu Havel (l'Observatoire de la Côte d'Azur)

The discovery of multiple transiting planetary systems offers new possibilities for the characterisation of exoplanets and the understanding of their formation. The Kepler-9 system contains two Saturn-mass planets, Kepler-9b and 9c. In order to precisely model such a system, we present our new code SET (Stars & Exoplanets modelling Tool) that relies on a database of stellar and planetary evolution models. Using this code with evolution models of gas giants that reproduce the sizes of known transiting planets and accounting for all sources of uncertainties we show that Kepler-9b (respectively 9c) contains 45^{+17}_{-12} M⊕ (resp. 31^{+13}_{-10} M⊕) of hydrogen and helium and 35^{+10}_{-15} M⊕ (resp. 24^{+10}_{-12} M⊕) of heavy elements. More accurate constraints are obtained when comparing planets 9b and 9c: the ratio of the total mass fractions of heavy elements are Zb/Zc= 1.02±0.14, indicating that although the masses of the planets differ, their global composition is very similar, a unexpected result for formation models.

Poster ID: *Characterization.13*

Improving Exoplanetary Transmission Spectroscopy with Stellar Limb Darkening Coefficients Derived from 3D Models

Wolfgang Hayek (University of Exeter)

Exoplanetary transmission spectroscopy with the HST has reached a level of precision where stellar limb darkening becomes an important ingredient for determining the wavelength-dependent radius of the planet, which allows us to constrain the composition of its atmosphere. The slope of the transmission spectrum in the blue and UV is affected by the choice of limb darkening treatment: the planetary radii of HD 189733b derived from direct fits are significantly smaller compared to an analysis in which the limb darkening law is determined from classical 1D models of the stellar atmosphere and no longer a free parameter. However, it is known from solar observations that 1D models

overestimate the strength of limb darkening. The latest generation of 3D time-dependent hydrodynamical models is capable of reproducing solar limb darkening with very good accuracy. In this talk, I will show how the transmission spectrum of HD 189733b is affected when the limb darkening is based on the predictions of 3D models, which enable fits of the light curve data with fewer free parameters but with the same quality as a direct fit. Thanks in large part to this improved understanding of stellar limb darkening, high-altitude haze in the atmosphere of HD 189733b could be characterized with the STIS spectrograph of HST.

Poster ID: *Characterization.14*

Atmospheric Circulation Simulations of Exoplanets

Kevin Heng (ETH Zurich)

The ability of astronomers to measure phase curves from and wind speeds on hot Jupiters has legitimized the study of their climates. To attain full understanding of the atmospheric circulation on these exoplanets, a hierarchy of theoretical models of varying sophistication is needed. Three-dimensional simulations occupy an important place in this hierarchy and are relevant towards the eventual goal of matching synthetic versus observed spectra. I will highlight past and present work performed using the Princeton-GFDL Flexible Modeling System (FMS), including simulations with radiative transfer.

Poster ID: *Characterization.15*

Model Spectra of the First Potentially Habitable Super-Earth - Gl581d

Lisa Kaltenegger (Harvard-Smithsonian Center for Astrophysics)

Gl581d has a minimum mass of 7 $M_\oplus$ and is the first detected potentially habitable rocky Super-Earth. Our models confirm that a habitable atmosphere can exist on Gl581d. We derive spectroscopic features for atmospheres with and without, assuming an Earth-like composition for this planet, from high oxygen atmosphere analogous to Earth's to high CO_2 atmospheres with and without biotic oxygen concentrations. We find that a minimum CO_2 partial pressure of about 7 bar, in an atmosphere with a total surface pressure of 7.6 bar, are needed to maintain a mean surface temperature above freezing on Gl581d. We model transmission and emergent synthetic spectra from 0.4μm to 40μm and show where indicators of biological activities in such a planet's atmosphere could be observed by future ground- and space-based telescopes. The model we present here only represents one possible nature – an Earth-like composition - of a planet like Gl581d in a wide parameter space. Future observations of atmospheric features can be used to examine if our concept of habitability and its dependence on the carbonate-silicate cycle is correct, and assess whether Gl581d is indeed a habitable super-Earth.

Poster ID: *Characterization.16*

Disentangling Exoplanet Atmosphere and Surface Inhomogeneities Using Polarimetry

T. Karalidi (Netherlands Institute for Space Research), D. M. Stam (University of Amsterdam) and J. W. Hovenier (University of Amsterdam)

Future efforts to detect signatures of habitable conditions or even life on rocky exoplanets will face many challenges. Two of these will be disentangling signals of clouds and surface features on the planet and determining the existence of continents, oceans and variable weather patterns. Because of the extremely small number of photons that we will receive from rocky exoplanets, it will be crucial to distill as much information from them as possible, for example by measuring not only the flux of the exoplanets signal but also its state of polarisation. While fluxes of horizontally inhomogeneous exoplanets have been presented before, the polarised signals of these planets have received little attention. Indeed, the polarised signals that have been published so far pertain to horizontally homogeneous planets or to quasi horizontally homogeneous planets that are weighted averages of several homogeneous planets. We will present results of our newly developed radiative transfer code to simulate flux and polarisation signals of realistically, horizontally inhomogeneous exoplanets. We will show the different traces that horizontal surface inhomogeneities leave in flux and polarisation signals and the effects of cloud patches on these traces. Finally, we will discuss for which inhomogeneous planets the weighted average approach (which takes much less computing time) seems adequate.

Poster ID: *Characterization.17*

A Photochemical Model for the Carbon Rich Planet WASP-12b

Ravi Kumar Kopparapu (Pennsylvania State University)

The hot Jupiter Wasp-12b is a heavily irradiated exoplanet in a very short period orbit around a late F-star with twice the metallicity than the Sun. A recent thermochemical equilibrium analysis based on Spitzer and ground-based infrared observations suggests that the presence of CH_4 in it's atmosphere and the lack of H_2O features can only be explained if the carbon-to-oxygen ratio in the planet's atmosphere is much greater than the solar ratio (C:O = 0.54). At solar C:O ratios, H_2O would be expected to be the dominant species. Here we use a 1-D photochemical model to study the effect of disequilibrium chemistry on the observed abundances of H_2O, CO, CO_2 and CH_4 in the Wasp-12b atmosphere. We consider two cases: one with solar C:O and another with C:O = 1.08. The solar case shows that H_2O and CO are more abundant than CO_2 and CH_4 (with CH_4 being the least abundant) as expected, whereas the model with C:O = 1.08 shows CH_4 and CO are more abundant than H_2O and CO_2 (with CO_2 being the least abundant). This indicates that the extra carbon from C:O = 1.08 is in CH_4, confirming results from equilibrium models. Although our analysis qualitatively supports the results from equilibrium models, the abundances (mixing ratios) from both the photochemical models diverge significantly, sometimes by as much as three orders of magnitude, from equilibrium models in the regimes where photochemistry becomes important (10 mbar - 1 bar). Our results also indicate that disequilibrium mechanism such as photochemistry does not necessariliy enhance the abundances in Wasp-12b.

Poster ID: *Characterization.18*

Constraints on the Thermal Evaporation Rates of HD189733b

Tommi Koskinen (University of Arizona)

We studied the energy balance and mass loss from the upper atmosphere of the extrasolar planet HD189733b in light of recent observations of transits in the stellar H I 121.6 nm line. The observations imply that the planet is surrounded by an extended, hot thermosphere but the extent and mass loss rate are poorly constrained. In order to estimate the likely mass loss rates, we characterized the upper atmosphere by using a theoretical model that calculates the outflow velocity, temperature and composition of the upper atmosphere self-consistently. Contrary to expectations, the atmosphere may be loosing mass at a slower rate than HD209458b – despite the fact that the X-ray and EUV (XUV) flux that heats the thermosphere is expected to be larger than that facing HD209458b. This is because the surface gravity of HD189733b is higher and because much of the additional XUV heating is offset by radiative cooling from a hot plasma. The results indicate that mass loss rates cannot be determined accurately without knowledge of the photochemistry and radiative transfer of the upper atmosphere. They also imply that currently available FUV transit measurements cannot be used to infer mass loss rates directly.

Poster ID: *Characterization.19*

Photochemistry of Extrasolar Giant Planets: A Comparative Study

Panayotis , Tommi Koskinen, Roger V. Yelle (all of Lunar and Planetary Laboratory University of Arizona)

We have developed detailed photochemical models for the description of the atmospheric composition of extrasolar giant planets and apply them to the cases of planets HD 209458 b, HD 189733 b and GJ 436 b. Our models are able to simulate the chemical processes from deep inside the planet's troposphere, where thermochemical equilibrium prevails, up to the thermosphere where the impact of stellar radiation has an important contribution. The parent stars of these exoplanets are of G, K and M stellar types, respectively; therefore they provide a significantly different spectral output, which affects the low-pressure chemical composition of the planetary atmospheres in different ways. It is commonly assumed that Ly-alpha emission, being the most intense stellar line, will have the strongest impact in the atmospheric photochemistry, as is the case in our solar system atmospheres. Nevertheless, the large H abundance in the upper atmospheres of these planets can effectively screen the underlying atmosphere from the impact of Ly-alpha, rendering photochemistry at this wavelength inactive. In that case the stellar flux at longer wavelengths will have a dominant role in the resulting chemical composition, with the latter varying strongly with stellar spectral type. We will present results for the impact

of the stellar type spectrum in the resulting composition of each planet and discuss the role of the stellar Ly-a emission in the overall photochemistry.

Poster ID: *Characterization.20*
Composition and Mass-Loss in Kepler-11
Eric Lopez (University of California, Santa Cruz)

The low density Super-Earths of Kepler-11 are an excellent test bed for models of planet structure and evolution. We use structure and cooling models to estimate possible compositions for the five inner planets. For systems like Kepler-11, mass-loss models can help break the degeneracy between water and hydrogen layers. We examine the survivability of hydrogen and helium atmospheres in Kepler-11 to XUV driven mass-loss.

Poster ID: *Characterization.21*
"Hot Jupiter" Spectroscopy from the Ground: A Progress Report
Avi Mandell (NASA Goddard Space Flight Center)

High-resolution ground-based NIR spectroscopy offers an excellent complement to the expanding dataset of transit and secondary eclipse observations of exoplanets with Spitzer and ground-based photometry that have provided the bulk of our understanding of the atmospheres and internal structure of these objects. High-resolution data can quantify the vertical temperature structure by isolating specific spectral lines formed at various depths. The presence of an opaque absorbing layer can also be inferred - and its pressure level determined quantitatively - via its effect on spectral line intensities. We have analyzed data for a single secondary eclipse of the bright transiting exo-planet host star HD189733 at L-band wavelengths (3-4 microns) using the NIRSPEC instrument on Keck-II. We utilize a sophisticated first-order telluric absorption modeling technique that, combined with a calibration star, has already been proven to remove the effects of varying atmospheric transmittance and allow us to reach unprecedented S/N. We are conducting validation of the final data reduction products and developing high-resolution atmospheric models for comparison, but we have already been able to rule out emission from methane as reported by Swain et al 2010. We will present preliminary results and discuss future plans for analysis and observations.

Poster ID: *Characterization.22*
The Radius Anomaly of Transiting Hot Jupiters Explained?
Eduardo Martin (Centro de Astrobiología/Instituto Nacional de Técnica Aeroespacial)

The radius anomaly displayed by several transiting hot Jupiters has motivated the development of new models that try to account for this strange trait. These theoretical approaches include a wide variety of physical processes such as diffusion of irradiation; enhanced opacities; inefficient convection; tidal heating; ohmic heating; heat burial by turbulence; and strong winds. Recently Martin & Spruit have found that the degree of inflation of the planets correlates with their expected spiral-in lifetime by tidal dissipation. In this presentation we compare the predictions of different models and we discuss how their validity constrained by the observational constraints.

Poster ID: *Characterization.23*

Equatorial Superrotation on Tidally Locked Exoplanets

Adam Showman (University of Arizona) and Lorenzo Polvani (Columbia University)

The increasing richness of exoplanet observations has motivated a variety of three-dimensional atmospheric circulation models of these planets. Under strongly irradiated conditions, models of tidally locked, short-period planets (both hot Jupiters and terrestrial planets) tend to exhibit a circulation dominated by a fast eastward, or "superrotating," jet stream at the equator. When the radiative and advection times are comparable, this phenomenon can cause the hottest regions to be displaced eastward from the substellar point by tens of degrees longitude. Such an offset has been subsequently observed on HD 189733b, supporting the possibility of equatorial jets on real hot Jupiters. Despite its relevance, however, the dynamical mechanisms responsible for generating the equatorial superrotation in hot Jupiter models have not been identified. Here, we show that the equatorial jet results from the interaction of the mean flow with standing Rossby waves induced by the day-night forcing. The strong longitudinal variations in radiative heating--namely intense dayside heating and nightside cooling--trigger the formation of standing, planetary-scale equatorial Rossby and Kelvin waves. The Rossby waves develop phase tilts that pump eastward momentum from high latitudes to the equator, thereby inducing equatorial superrotation. We demonstrate this mechanism in a sequence of one-layer (shallow-water) calculations and fully 3D models. This wave-mean-flow interaction tends to produce an equatorial jet whose latitudinal width is comparable to that of the Rossby waves, namely the equatorial Rossby deformation radius modified by radiative and frictional effects. For conditions typical of synchronously rotating hot Jupiters, this length is comparable to a planetary radius, explaining the broad scale of the equatorial jet obtained in most hot Jupiter models. We describe the implications for the dependence of the equatorial jet speed on forcing amplitude, strength of friction, and other parameters, as well as for the conditions under which jets can form at all.

Poster ID: *Characterization.24*

Characterising the WASP Planets with Infra-Red Occultation Measurements

Alex Smith (Keele University)

Planets that transit their host star are often also occulted by them, allowing us to detect the emergent flux from the planet. The timing of such occultations, when combined with radial velocity data, allows a precise determination of the system's orbital eccentricity. Near-infrared measurements of the occultation depth yield the brightness temperature of the system at a particular wavelength, which can provide an estimate of how much heat is redistributed to the night-side of the planet. Measurements of the occultation depth at several wavelengths allow the construction of a spectral energy distribution for the planet and enable the atmospheric structure and composition to be inferred.

Here I present recent ground-based and space-based occultation measurements of several transiting planets discovered by the WASP project. For each system, the occultation data is combined with all available transit photometry and radial velocities in a global MCMC analysis to calculate the system parameters which represent the best fit to all the available data.

Poster ID: *Characterization.25*

Warm Spitzer Secondary Transit Photometry of Hot Jupiters HAT-P-6b, HAT-P-8b and XO-4b

Kamen O. Todorov (Pennsylvania State University), Drake Deming (NASA Goddard Space Flight Center), Heather Knutson (University of California, Berkeley), A. Burrows (Princeton University), P. Sada (Universidad de Monterrey), Eric Agol (University of Washington), Jean-Michel Desert (Harvard-Smithsonian Center for Astrophysics), Jonathan Fortney (University of California, Santa Cruz), David Charbonneau (Harvard-Smithsonian Center for Astrophysics), Nick Cowan (Northwestern University), G. Laughlin (University of California, Santa Cruz), J. Langton (University of California, Santa Cruz)

An increasing number of transiting exoplanets have been observed at secondary eclipse. By measuring the depth of these eclipses at different wavelengths it is possible to distinguish between planets that have a temperature inversion in the upper layers of their atmospheres and ones that do not. We observed XO-4b, HAT-P-6b and HAT-P-8b during secondary eclipse with the IRAC instrument on Warm Spitzer at 3.6 and 4.5 microns. We compare the resulting eclipse depths to atmospheric models with and without temperature inversions, and thereby place constraints on the properties of their dayside atmospheres and heat redistribution efficiencies. The XO-4b and HAT-P-6b eclipse depths agree best with inverted models, while HAT-P-8b exhibits no temperature inversion. Knutson et al. (2010) hypothesized a correlation between lack of a temperature inversion and host star activity. Also, Cowan & Agol (2011), investigated the dependence between planetary effective temperatures, assuming no redistribution, and heat redistribution efficiency, finding that the hottest planets re-distribute heat inefficiently. We compare our planets with the Knutson and Cowan-Agol relations, and we find that they are consistent with the Knutson et al. activity hypothesis, but they are not hot enough to test the Cowan & Agol hypothesis.

Poster ID: *Characterization.26*
Mantle Convection and Volcanism for Exoplanets with Strong Surface Temperature Contrasts
Joost van Summeren (University of Hawaii)

Many recently discovered (approximately) Earth-sized exoplanets inhabit short-period, close-in orbits and are likely tidally locked and synchronously rotating around their parent stars. Synchronous rotation results in asymmetric insolation patterns that can induce strong (100's to 1000's K) temperature differences between the planets' permanent day and night side, in absence of a substantial atmosphere. We investigated how strong surface temperature contrasts influence convective structures, tectonic regimes, and volcanic activity for Earth-sized rocky exoplanets. For this purpose, we conducted numerical simulations of planetary mantle convection and studied a range of imposed surface temperature contrasts, Rayleigh numbers, and viscosity parameterizations. To account for plate-like behavior we employ a temperature-dependent viscous/pseudo-plastic rheology. We assess volcanic activity by calculating decompression melting, triggered by hot convective upwelling. Our modeling results show how high (~1000 K) substellar temperatures can initiate mantle-wide asymmetries in convective overturn. Near the hot substellar point, persistent mantle upwelling triggers vigorous volcanic activity. On the cold permanent night side, platelike behavior occurs and this is associated with moderate volcanism. These planet-wide asymmetric patterns of tectonics and volcanism are distinct from globally uniform patterns, calculated for models that lack strong surface temperature contrasts (expected for close-in planets with an atmosphere), and have the potential to become astronomically detectable in the future.

Poster ID: *Characterization.27*
CoRoT - Theory, Transits and Planet Migration
Günther Wuchterl (Thüringer Landessternwarte Tautenburg)

A self-consistent theoretical approach is presented that allows calculation of mass- and radii-distributions of exoplanet populations from basic physical principles and avoids the usual parametrisation of a multitude of processes. Thus we describe a physical concept for the statistical determination of planetary masses.

The planetary mass spectra are obtained by counting the number of planetary equilibria that are physically possible inside arbitrary but gravitationally stable protoplanetary nebulae. The planetary radii are determined by solving for all the planetary evolutions with the above planetary equilibria as initial conditions. The resulting theoretical distributions of planetary masses and radii are presented in probabilistic mass-radius diagrams for host star masses of 0.4 to 2 times the one of the Sun, orbital periods from 1 to 128 days and ages of 0 - 12 Ga. We compare the theoretical distributions to CoRoT-planet properties and Kepler-candidate mass- and period distributions and give a natural explanation of the dominance of Neptunes. We outline tests of planet formation theory and the importance of orbital migration.

Poster ID: *Characterization.28*

SiIII and Cloud Formation on HD 209458b

Roger Yelle (University of Arizona), Tommi Koskinen (University of Arizona), Panayotis Lavvas (University of Arizona), C. Visscher (Universities Space Research Association), J. Moses (Space Sciences Institute)

Linsky et al. (Ap.J. 71, 1291-1299, 2010) detected SiIII in the upper atmosphere of HD 209458b through COS/HST measurements of the transit signature in the resonance line at 120.6 nm; however, models based on thermochemical equilibrium (Visscher et al. Ap. J. 71, 1060-1075, 2010) predict that Si will be sequestered in silicate clouds deep in the atmosphere and should be absent from the upper atmosphere. We investigate this problem in several ways. First we investigate further the observational constraints through construction of detailed models for the transit signature, following the methodology of Koskinen et al. (ApJ 723, 116-128, 2010). We find that the observed transit depths require a significant fraction of the Si in the atmosphere be in the form of SiIII, assuming a solar allotment of Si. We also construct photochemical models for the distribution of Si in the upper atmosphere and find that much of the Si is in the form of SiIII because of the large photoionization rates on this planet. Finally, we consider whether disequilibrium processes, such as rapid convection, could prevent sequestration of Si in clouds in the deep atmosphere.

C. Habitability

Poster ID: *Habitability.01*
Estimating the Distribution of Habitable Surface Area in the Solar Neighborhood
Ruslan Belikov (NASA Ames Research Center)

The true distribution of habitable planets and life in the solar neighborhood will likely remain unknown for some time to come. However, right now, we can make progress towards understanding the distributions of habitable planets in the solar neighborhood and of life in the universe using models based on the statistical properties of current observations. This paper presents such a model, informed by the latest results from the Kepler space telescope. We build our model around the following (optimistic) assumptions: (a) all habitable zones contain equal-mass planets and are dynamically packed, so that adding additional planets would make them dynamically unstable; (b) the distribution of planet radii, from star to star, is that observed among the newly cataloged Kepler planet candidates. We show that these assumptions suffice to derive a number of interesting results about the frequency of habitable planets, their distribution in the solar neighborhood among stars of different types, and among habitable worlds of different types. We consider habitable surface area, so we can take into account that the quantity of life on a planet is roughly proportional to the available surface area. We find that cumulatively there is a significant amount of potentially habitable surface area distributed across tidally locked planets as well as Jovian moons, though less than for conventional Earth-like planets. We also find that the distribution of this surface area peaks around planets and stars about one-half Earth-mass and Solar-mass, respectively.

Poster ID: *Habitability.02*
Revisiting and Revising the Habitable Zone
Shawn Domagal-Goldman (NASA Headquarters)

We have reached an age where the "strange new worlds" being discovered are growing increasingly familiar. Approximately Earth-sized planets that receive approximately the same amount of stellar energy as the Earth receives from the Sun are currently being discovered, spawning conversations about the habitability of such objects. In this presentation, we will describe the classical limit of the habitable zone (Kasting, 1997), and apply these limits to known extrasolar planets. The habitable zone is defined as the distances around the star for which liquid water may be stable at the planet's surface. This limit is a function of the interaction between stellar and planetary properties, and therefore cannot be simply related to the planet's calculated equilibrium temperature. Instead, the inner edge of the classical habitable zone is the further of two distances: 1.) the distance at which a runaway greenhouse is triggered, and 2.) the distance at which stratospheric water vapor concentrations are high enough to drive rapid escape of H atoms (and thus loss of water) to space. The outer edge of the classical habitable zone is the distance from the star at which a carbon dioxide-water greenhouse can no longer prevent global glaciations. We will discuss this concept, and explain the relationship

between the distance units usually used by theorists to define the habitable zone with the effective temperature units often used by observers to discuss habitability. We will also show Earth-sized planets that are within their respective habitable zones. Finally, we will briefly discuss the habitable zones of "strange new worlds" where the habitable zone might be affected by a planet's orbital kinematics, atmospheric redox state, or stellar energy distribution.

Poster ID: *Habitability.03*

Ocean-Bearing Planets Beyond the Habitable Zone

Eric Gaidos (University of Hawaii) and Ray Pierrehumbert (University of Chicago)

We demonstrate that primordial atmospheres consisting exclusively of hydrogen and helium can maintain surface temperatures above the freezing point of water for billions of years on Earth- to super-Earth size planets beyond the classical "habitable zone". The outer edge of this zone is conventionally defined as the point where CO2 condenses onto the surface before it can reach levels sufficient to maintain liquid surface water. For an Earth mass planet orbiting a solar-luminosity star this occurs near 2AU, or 0.22AU for a typical M dwarf. Protoplanets may acquire up to hundreds of bars of H/He from the primordial disk and some of this component may survive the interval of giant impact accretion. At pressures of several bars, molecular hydrogen has enough collision-induced opacity at infrared wavelengths to function as a greenhouse gas. We use a radiative-convective model to calculate the minimum surface pressure to maintain liquid water as a function of stellar insolation, taking into account increasing albedo due to Rayleigh scattering with pressure. For a 3 Earth mass planet orbiting a G star, 10bar of H/He is sufficient to maintain liquid water out to 6AU; 20bar can maintain the same conditions 1.14AU from an M star. We calculate the total hydrogen loss due to EUV heating of the upper atmosphere: A 3 Earth-mass planet >3AU from a G-type star loses <1bar in 4.5Gyr: for the M star case the corresponding distance is 1.8AU. Microlensing has found planets in this distance and mass range around M stars and such objects may be among the most numerous habitable planets in the Cosmos.

Poster ID: *Habitability.04*

Exploring the Habitable Zone for Kepler Planetary Candidates

Lisa Kaltenegger (Harvard-Smithsonian Center for Astrophysics)

This poster outlines simple approaches to evaluate the surface temperature of terrestrial planets in and near the habitable zone (HZ) of different stars by assuming different types of planetary atmospheres and using corresponding model calculations. Our approach can be applied for current and future candidates provided by the Kepler mission and other searches. The resulting uncertainties and changes in the number of planetary candidates in the HZ for the current Kepler data release are discussed. To first order the HZ depends on the effective stellar flux distribution in wavelength and time, the planet albedo, and greenhouse gas effects. We provide a simple set of parameters that can be used for evaluating future planet candidates from transit searches.

Poster ID: *Habitability.05*

Super-Earths

Lisa Kaltenegger (Harvard-Smithsonian Center for Astrophysics)

SUPER-EARTHS: The scope of the Super-Earths Research Group lead by Lisa Kaltenegger is to build an interdisciplinary research group, based in the MPIA, focused on the identification of extrasolar planets, with a strongly interdisciplinary component. The main goal of this theoretical effort is to model atmospheric spectral signatures, including biosignatures, of known and hypothetical exoplanets that are potentially habitable. We focus on planets orbiting stars bright enough for future atmosphere follow-up: especially Super-Earths (rocky terrestrial planets of 1-10 Earth masses) orbiting in the "Habitable Zones" around their host stars. The atmospheric characterization of such Super-Earths, will allow us to explore the condition on the first detectable rocky exoplanets and potentially characterize the first detectable Habitable Exoplanet. We present first results here.

Poster ID: *Habitability.06*

Determining Extrasolar Planetary Habitability: Sensitivity to Surface Temperature

Victoria Meadows (University of Washington)

A planet's position within the habitable zone does not guarantee habitability. A more definitive determination of a planet's ability to support liquid water on the surface will come via direct measurements of phenomena such as the phase-dependent reflectivity from liquid water, surface temperature, or a more detailed assay of environmental characteristics. To explore our ability to directly detect surface temperature on a realistic habitable planet we have used the Virtual Planetary Laboratory's 3-D spectral Earth model (Robinson et al., 2011) to quantify the effect of clouds and gases on retrieved disk-integrated brightness temperatures in the Earth's 8-13μm spectral window. We find that within the window, the disk-integrated effect of clouds and gases can contribute a 12-16K underestimate of the actual surface temperature depending on the sub-observer latitude. This is enough to push a clearly habitable surface temperature average down to a marginally habitable or uninhabitable one. Even without clouds, water vapor alone causes a 3-5K underestimate in the window region in the equatorial disk average, due to the high water vapor concentrations in the Earth's tropics. We explore the effect of viewing geometry on temperature retrieval for an Earth twin and present quantitative estimates of temperature sensing biases inherent in the planetary data. We also provide initial recommendations for the optimum wavelengths and spectral resolution for disk-integrated temperature sensing for Earth-like, and other atmospheric compositions.

Poster ID: *Habitability.07*
Habitable Zones Around a Star of Given Specifications
Harsh Nayak (University of Mumbai)

We investigate the possibility of a planet reaching the Habitable zone around a star through capture. We simulate the gravitational potential of a star and randomly throw ten thousand earth size objects from a distance of 100 AU with random velocity vector. Since any such trajectory will take the object out, we simulate a drag on the object as a decelerating force. We define the limits in such a way, that an object at 5 AU is just captured and the lower limit is defined so that a planet a 0.1 AU(Exclusion zone) does not spiral in. Based on that the capture probability for a planet between 1 and 5 AU is calculated. Within these limits we show that only a certain fraction f of the planets have orbits of ellipticity less than 0.01 so that the planet remains within the habitable zone. Based on these calculations we estimate the probability of a Sun like star capturing an earth size planet and placing it in a stable habitable zone.

Poster ID: *Habitability.08*
A Magnetic Habitable Zone?
Pablo Cuartas Restrepo (Universidad de Antioquia)

The intensity of the planetary magnetic field is a key factor in the development of the conditions for the existence of an atmosphere and the emergence of life. The magnetic field plays a role as a shield against the erosion of the atmosphere caused by the stellar wind and cosmic rays. We took the results from a thermal evolution model (Gaidos et.al. 2010) and scaling laws for convection driven dynamos (Aubert et.al. 2009, Olson & Christensen 2006) to predict the evolution in time of the local Rossby number that determines the nature and geometry of the core's magnetic field: dipolar, stable or unstable and multi-polar. It is possible to obtain constraints for the existence of an intense and protective planetary magnetic field. We found that the duration and intensity of the magnetic field depends not only on the mass, but also on the rotation period of the planet in many interesting ways. We calculated the size of the standoff distance (Rs) (Griebmeier et.al. 2004, 2007, 2009) for the planetary magnetosphere, depending on the time, planetary mass and star mass. We propose a new Magnetic Habitable Zone (MHZ) based on the capability of the magnetic field to protect the planet.

Poster ID: *Habitability.09*
Model of Transit Simulation of Planets with Moons and Rings
Luis Ricardo Moretto Tusnski (National Institute for Space Research - INPE)

Since the first exoplanet discoveries, researchers have tried to select those most adequate for life to begin and evolve, using the concept of habitable zone. However, most of the discovered planets so far are gas giants, precluding their habitability. Recently, it was proposed that if these planets have moons, these moons may be habitable. In this work we present a model for planetary transit simulation considering the presence of moons

and planetary rings around the planet. The model was developed in IDL. Moon and planetary orbits are coplanar, and both are circular. The other physical and orbital parameters of the star, the planet, the moon and the ring can be adjusted in each simulation. It is possible to add spots to the surface of the star, and to simulate as many successive transits as wanted. The result of the simulation is the light curve. It is also possible to add white noise to the light curves, in order to produce curves similar to those obtaineds by the CoRoT and Kepler space telescopes. The objective is to determine if these events are detectable or not using photometry. Using this model, we show that it is possible to detect moons with radii as little as 1.3 $R_{\oplus}$ with CoRoT and 0.3 $R_{\oplus}$ with Kepler. Timing variations are also considered, caused by the planet position and movement with respect to the planet-moon barycenter.

D. Missions

Poster ID: *Missions.01*
Exoplanet Spectrophotometry with SOFIA
Daniel Angerhausen (Hamburg Observatory)

We present the prospects of observing extrasolar planets with the Stratospheric Observatory for Infrared Astronomy (SOFIA). Our analysis shows that optical and near-infrared photometric and spectrophotometric follow-up observations during planetary transits and eclipses will be feasible with SOFIA's instrumentation, especially with the HIPO-FLITECAM optical/NIR instruments. SOFIA has unique advantages in comparison to ground- and space-based observatories in this field of research that will be outlined.

Poster ID: *Missions.02*
Precision Radial Velocities in the K-band with a 13-CH4 Absorption Cell
Guillem Anglada-Escude (DTM/CIW), Peter Plavchan (NExScI) and collaborators

Precision radial velocities in the optical is the most successful technique to detect exoplanet candidates. Precisions of the order of 10 cm/s are required to detect Earth mass planets in the habitable zone of sun-like stars. However, for an M-dwarf, the RV signal of a rocky planet on its habitable zone is at the few m/s level. Most of the flux of M-dwarf is in the near infrared, so an efficient planet finding technique for such low mass stars is required to operate at wavelengths between 0.8 and 2.5 microns. A number of high resolution infrared spectrographs will become on-line in the forthcoming years. A suitable wavelength calibration technique will be required to operate at such wavelengths. As a proof of concept, we have built and installed a new absorption gas cell at the CSHELL/IRTF spectrograph. The cell contains the 13CH4 isotopologue of methane that is almost harmful, very safe and easy to manipulate. Like Iodine in the optical, it provides a large number of sharp absorption features in the K-band. The absorption spectra is similar to the more common 12CH4 isotopologue but shifted several nanometers, preventing blends with telluric features. The cell operates at room temperature (stabilized at 10 C) and can be moved in and out of the beam remotely. We show the first light observations and first radial velocity measurements using this technique.

Poster ID: *Missions.03*
The Detection Sensitivities of Radial Velocity Surveys using Multi-Object Spectrographs
Thomas G. Beatty (Ohio State University)

We analyze the sensitivity of multi-object radial velocity (RV) searches for exoplanets. Such surveys will operate in a manner quite distinct from traditional RV surveys, in that the targets are primarily determined by the brightness distribution of stars in the target fields, the field-of-view of the instrument, and the number of fibers. We use an analytic approximation for the signal-to-noise ratio of eccentric RV orbits to quantify the detectability of exoplanets as a function of mass and period. Then, using theoretical spectra and published descriptions of several RV searches, we develop an analytic estimate of the uncertainty of RV measurements as a function of stellar mass, rotation velocity, metallicity, and instrument parameters. As a first application, we consider the yield a multi-object RV survey for stars in an open cluster, showing how the number of expected planet detections scales with host star mass. Finally, using the present day mass function and a simplified Galactic structure model, we also touch on the sensitivity of multi-object RV searches of field stars.

Poster ID: *Missions.04*

EUCLID-ML: Free Floating Telluric Planets, Frozen Mars and Habitable Earth via Microlensing

Jean-Philippe Beaulieu (Institut d'Astrophysique de Paris)

The discovery of extrasolar planets is arguably the most exciting development in astrophysics during the past 15 years, rivalled only by the detection of dark energy. Two projects are now at the intersection of the two communities of exoplanet scientists and cosmologists: EUCLID, proposed as an ESA M-class mission; and WFIRST, the top-ranked large space mission for the next decade by the Astro 2010 Decadal Survey report. The missions are to have several important science programs: a dark energy survey using weak lensing, baryon acoustic oscillations, Type Ia supernova, a survey of exoplanetary architectures using microlensing, and different surveys. The WFIRST and EUCLID microlensing planet search programs will provide a statistical census of exoplanets with masses greater than the mass of Mars and orbital separations ranging from 0.5~AU outwards, including free-floating planets. This will include analogs of all Solar System planets except for Mercury, as well as most types of planets predicted by planet formation theories. In combination with Kepler's census of planets in shorter period orbits, EUCLID and WFIRST's planet search programs will provide a complete statistical census of the planets that populate our Galaxy. As of today, EUCLID is proposed to ESA as a M class mission (the result of the selection will be known in october 2011). A 3 months microlensing program will already efficiently probe for planets down to the mass of Mars at the snow line, for free floating terrestrial or gaseous planets and habitable super Earth. A 9+ months survey would give a census on habitable Earth planets around solar like stars. This is the perfect complement to the statistics that will be provided by the KEPLER satellite, and these missions combined will provide a full census of extrasolar planets from hot, warm, habitable, frozen to free floating.

Poster ID: *Missions.05*

The ELEKTRA Explorer Mission to Find Transiting Earth Like Planets

C. Beichman (NASA Exoplanet Science Institute) and the ELEKTRA Team

The scientific goals of the "Earth LiKe Transit" Explorer (ELEKTRA) are to conduct a census of nearby planetary systems and to search for nearby, potentially habitable planets. ELEKTRA will survey more than 80% of the sky to discover a large and diverse sample of transiting planets orbiting nearby stars. ELEKTRA's near-IR operation (0.65-1.7 um) emphasizes late type K and M stars around which habitable zone planets are most readily detectable. Because these planets orbit bright stars (J~5 - 10 mag), they will be amenable to the detailed physical characterization impossible for most Kepler/CoRoT planets. ELEKTRA will find thousands of gas and icy giant planets, hundreds of earth- and super-earths. Fifty or more rocky planets will be orbiting in the so-called “habitable zone (HZ)" where stellar heating could produce temperatures at which water might be found in a suitably dense atmosphere. Spectroscopic follow-up of ELEKTRA planets will be possible with JWST, Keck and other ground-based facilities.

Poster ID: *Missions.06*

Laboratory Demonstration of High Contrast Imaging at sub-2 l/D Inner Working Angles

Ruslan Belikov (NASA Ames Research Center)

Coronagraph technology is advancing and promises to directly image and spectrally characterize extrasolar Earth-like planets in the foreseeable future (such as the 2020 decade) with a telescope as small as 1.5m. A small Explorer-sized telescope can also be launched in the 2010 decade capable of seeing debris disks as dim as tens of zodis and potentially a few large planets. The Phase Induced Amplitude Apodization (PIAA) coronagraph makes such aggressive performance possible, providing high throughput and high contrast close to the diffraction limit. We report on the latest results from a testbed at NASA Ames that is focused on developing and testing the PIAA coronagraph. This laboratory facility was built in 2008 and is designed to be flexible, operated in an actively thermally stabilized air environment, and to complement collaborative efforts at NASA JPL's High Contrast Imaging Testbed. For our wavefront control we are using small Micro-Electro-Mechanical-System deformable mirrors (MEMS DMs), which promise to reduce the size of the beam and overall instrument, a consideration that becomes very important for small telescopes. We describe our lab progress and results, which includes (as of February 2010): the demonstration of 5.4e-8 average raw contrast in a dark zone from 2.0 - 5.2 l/D and of 3.6e-6 contrast from 1.5-2.5 l/D (in monochromatic light); the testing

of the next-generation reflective PIAA mirror set built by Tinsley and designed for broadband; and finally, the testing of a slightly modified PIAA coronagraph that is capable of achieving 1e-6 contrasts at 1 l/D.

Poster ID: *Missions.07*

High Precision Astrometry Laboratory Demonstration for Exoplanet Detection Using a Diffractive Pupil

Eduardo Bendek (University of Arizona)

Detection of earth-size exoplanets using the astrometric signal of the host star requires sub microarcsecond measurement precision. One major challenge in achieving this precision using a medium-size (< 2m) space telescope is the calibration of dynamic distortions. We propose a diffractive pupil technique, which uses an array of approximately 50um dots on the primary mirror that generate polychromatic diffraction spikes in the focal plane. The diffraction spikes encode all distortions in the optical system and therefore serve as a reliable calibration for high precision astrometric measurements. This concept can be used simultaneously with coronagraphy for exhaustive characterization of exoplanets (mass, spectra, orbit). At University of Arizona a high precision astrometry laboratory is being developed to demonstrate the capabilities of this diffractive pupil concept. We aim to achieve 10 μas single-axis precision in the laboratory, simulating 0.14 uas precision on a 1.4 m space telescope. Here we describe this laboratory and present the results obtained so far.

Poster ID: *Missions.08*

The Exoplanet Program of the WFIRST Mission

David Bennett (University of Notre Dame) and Scott Gaudi (Ohio State University)

The gravitational microlensing exoplanet survey of the Wide Field Infrared Survey Telescope (WFIRST) will complete the census of exoplanets begun by Kepler to wider orbits. WFIRST will detect planets with orbital separation ranging from 0.5 AU to infinity and masses down to 0.1 Earth masses. The basic science and current status of this mission will be presented, and the differences between the exoplanet science from WFIRST and the earlier Microlensing Planet Finder (MPF) concept will be discussed.

Poster ID: *Missions.09*

Apodized Coronagraph Designed for Wavefront Control

Alexis Carlotti (Princeton University)

All coronagraphs achieve high contrast by removing the diffracted starlight from the discovery zone. This is done in one of two ways: the first uses pupil masks (apodization) to change the PSF and transfer energy outside the discovery zone directly in the image plane. The second uses focal plane masks to transfer energy outside the exit pupil so it never gets focused into the final image plane. Examples of the first approach include all apodized and pupil mapping coronagraphs. Examples of the second include all Lyot type (bandlimited and otherwise), phase masks, and vector vortex coronagraphs. Combinations of pupil and focal masks are also possible; the leading example is the APLC. We show in this paper that for every such coronagraph the energy amplitude distribution in the exit pupil is changed. This makes the ultimate performance extremely sensitive to amplitude errors; although one deformable mirror can be used to correct for phase errors, it cannot correct for these amplitude errors everywhere in the image plane. As a result, a coronagraphic system cannot be designed without an amplitude-correcting device; the most likely such device employs two deformable mirrors in series. This also implies that the coronagraph need only produce contrast to the point where amplitude errors dominate. Thus we focus our work on hybrid systems that include a pupil mask and two deformable mirrors. We optimize the transmission of the pupil mask so that it achieves contrast to the level at which amplitude errors dominate, and the remaining contrast is then achieved via the amplitude correcting device. We consider several shaped pupil designs. Each of them is associated to a different mirror profile, and we discuss the design tradeoffs of this hybrid concept.

Poster ID: *Missions.10*
Status of the Integral Field Spectrograph for the Gemini Planet Imager
Jeffrey Chilcote (University of California, Los Angeles)

We present the status of construction and testing of the Integral Field Spectrograph (IFS) for the Gemini Planet Imager (GPI). The IFS is being constructed in the UCLA Infrared Laboratory as the science instrument. GPI is a facility class instrument for the Gemini Observatory being led by Bruce Macintosh at LLNL and involving eight institutions. The goals of GPI are to detect and characterize young, Jovian-mass planetary companions by distinguishing them from PSF speckle noise, to detect and measure debris disks through polarization, and to record low-resolution spectra from 0.98-2.4 microns. The IFS design is similar to the OSIRIS instrument at Keck and utilizes an infrared transmissive lenslet array to sample a rectangular field of view behind the "extreme" adaptive optics system. The IFS uses a Hawaii-2RG detector to produce a field of view greater than 2.8 x 2.8 arcseconds, with a spectral resolution in H band of R~45. The all transmissive powered optics of the IFS uses a prism instead of a grating. A cryogenic Wollaston prism can be inserted into the reimaging optic path to produce two images of orthogonal polarization states. We will present the current status of the IFS and test results.

Poster ID: *Missions.11*
Predicting Lensing Rates in Wide-Field Surveys
Amanda Fournier (University of California, Santa Barbara)

The proliferation of wide-field surveys provides many serendipitous opportunities to study rare transients such as microlensing events. We present a simulation tool to predict microlensing rates in surveys, building on the work of Han et al. Our simulation accounts for realistic experimental conditions, including sky coverage, cadence, photometric precision, and possible separate target-of-opportunity observations. We apply this tool to predict the number of chance microlensing events caught by several in-progress and upcoming surveys.

Poster ID: *Missions.12*

An Integral Field Spectrograph for a Terrestrial Planet-Finding Mission

Sally Heap (NASA Goddard Space Flight Center)

We describe a conceptual design for an integral field spectrograph for characterizing exoplanets that we developed for NASA's Terrestrial Planet Finder Coronagraph (TPF-C), although it is equally applicable to an external-occulter mission. The spectrograph fulfills all four scientific objectives of a terrestrial planet finding mission by: -- Spectrally characterizing the atmospheres of detected planets in search of signatures of habitability or even biological activity; -- Directly detecting terrestrial planets in the habitable zone around nearby stars; -- Studying all constituents of a planetary system including terrestrial and giant planets, gas and dust around sun-like stars of different ages and metallicities -- enabling simultaneous, high-spatial-resolution, spectroscopy of all astrophysical sources regardless of central source luminosity, such as AGN's, proplyds, etc.

Poster ID: *Missions.13*

Concept Study for an Exoplanet Spectroscopy Mission

Oliver Krause (Max Planck Institute for Astronomy)

We present results of a conceptual study for an optical/infrared payload suite capable to perform high-stability spectroscopy of transiting exoplanet systems. The study was conducted in the framework of the mission proposal EChO (Exoplanet Characterisation Observatory) which was recently accepted as candidate mission within ESA's Cosmic Vision 2015-2025 space science program. The mission foresees a passively cooled 1.4m off-axis telescope onboard a Soyuz-launched spacecraft in a thermally stable L2 halo orbit. With a spectral coverage from 0.5 to 16 micron its science instrument covers important molecular bands of the targeted exoplanet atmospheres. During its 5-year mission the spacecraft will be able to perform a comprehensive survey of a broad variety of exoplanet systems ranging from extreme hot-Jupiters to warm Neptunes and Super-Earths.

Poster ID: *Missions.14*

Brown Dwarfs and Giant Planets Around Young Stars

Naved Mahmud (Rice University)

How dry is the brown dwarf (BD) desert at young ages? Previous radial velocity (RV) surveys have revealed that the frequency of BDs as close companions to solar-age stars in the field is extraordinarily low compared to the frequency of close planetary and stellar companions. Is this a formation or an evolutionary effect? Do close-in BDs form at lower rates, or are they destroyed by migration via interactions with a massive circumstellar disk, followed by assimilation into the parent star? To answer these questions, we are conducting an RV survey of 130 T Tauri stars in Taurus-Auriga (a few Myr old) and a dozen stars in the Pleiades (100 Myr old) to search for stellar reflex motions resulting

from close substellar companions. Our goal is to measure the frequency of BDs at young ages. Detecting a higher frequency of BDs in young systems relative to the field will provide evidence for the migration theory as well as set limits on the migration timescale. Two additional goals are (1) to investigate the effect of star spots in young stars on RV observations, and (2) to detect the youngest-known giant exoplanet. We present results from the first few years of this survey. Strikingly, after completing observations of a third of our sample, we have yet to detect a single BD. Thus we can set limits on the dryness of the BD desert at young ages and shed light on the mysterious early lives of these objects.

Poster ID: *Missions.15*

The Future of XO Planets

Peter McCullough (Space Telescope Science Institute)

The XO Project in its original form discovered five transiting gas giant planets, XO-1b, XO-2b, ... XO-5b. XO continues now in an expanded, globally networked mode of operation with longitudinally dispersed sites and fully autonomous robotic observatories in individual enclosures. XO's objectives are both scientific and cultural. Scientifically, XO seeks the longer-period, cooler gas-giant planets of the brighter stars to which the first-generation transit surveys were relatively insensitive. Culturally, XO seeks to assist in preparing a larger, international community to participate in the discovery and characterization of transiting gas giants, with an eye toward ~2017 when space-based all-sky transit survey(s) will inundate the community with them by the thousands, orbiting stars bright enough to enable suitable characterization of representative subsets.

Poster ID: *Missions.16*

Spatial Scanning with HST for Exoplanet Transit Spectroscopy and Other High Dynamic Range Observations

Peter McCullough (Space Telescope Science Institute) and John MacKenty (Space Telescope Science Institute)

We are reviving an old technique of spatially scanning the telescope to improve observations, in this case with the Hubble Space Telescope's Wide Field Camera 3 (HST WFC3). Spatial scanning will turn stars into well-defined streaks on the detector, or, for example, spread a stellar spectrum perpendicular to its dispersion. There are at least two motivations for implementing such a capability: 1) reducing the fraction of overhead in observations of very bright stars such as those suitable for spectral characterization of transiting planets, and 2) enabling observations of very bright primary calibrators that otherwise would saturate the IR detector. Results from engineering tests in which a star is imaged with WFC3 IR under various parameterizations of HST's scanning speed and orientation, and with or without a grism in place, are expected before the Exploring Strange New Worlds conference and before the HST time allocation committee convenes May 16, 2011.

Poster ID: *Missions.17*

Broadband Deep Nulling with Savart-Plate Lateral-Shearing Interferometric Nuller for Exoplanet Detection (SPLINE)

Naoshi Murakami (Hokkaido University)

SPLINE (Savart-plate lateral-shearing interferometric nuller for exoplanet detection) is a common-path and stable nulling interferometer proposed for monolithic telescopes with arbitrary pupil geometries (Murakami & Baba 2010, Opt. Lett., 35, 3003). SPLINE uses a Savart plate, a kind of polarizing beam splitter, to split an entrance pupil into two with lateral shift (x shear). By placing the Savart plate between two crossed polarizers, a fully-achromatic nulling interference occurs in a superimposed area of the two beams. SPLINE is advantageous because of its highly stable performance without an OPD control by virtue of a common-path configuration. We carried out laboratory demonstration of SPLINE using broadband visible light source (a spectral range of 500-700nm). For constructing SPLINE, we used two Savart plates in cascade for generating four beams with x and y shears. This four-beam configuration enables to reach higher contrast for partially resolved stars because of its fourth-order nulling performance. As a result, we realized a stable, achromatic, and deep nulling (a peak-to-peak contrast of about 10^5). In the latter part of our poster, we propose to apply SPLINE to the Thirty Meter Telescope (TMT). We present a preliminary design of the proposed instrument called Second-Earth Imager for TMT (SEIT), in which SPLINE is combined with a pupil remapping interferometer (Perrin et al. 2006, MNRAS, 373, 747). The pupil remapping interferometer eliminates the effect of residual wavefront errors from atmospheric turbulence and internal optics, thanks to spatial filtering and a precise measurement of wavefront errors. We present a concept of SEIT for directly imaging habitable Earth-like planets around nearby K and M dwarfs in Y and J bands.

Poster ID: *Missions.18*

Experimental Results with Axi-Symmetric Circular Phase Mask Coronagraphs

Mamadou N'Diaye (Astronomy Observatory of Marseilles Provence)

Stellar coronagraphy is a key technology for current and future instruments for exoplanet imaging and spectroscopy, both on the ground and in space. In this context, phase mask stellar coronagraphs constitute very interesting solutions for exoplanet imagers since they enable observations of the companions very close to a bright star. Focus is made here on stellar coronagraphs with axi-symmetric circular phase masks (Roddier & Roddier 1997; Soummer et al. 2003a, 2003b) since they are promising concepts, well suited for any arbitrary aperture. Other interesting aspects of using circular phase masks include the absence of blind axes in the coronagraphic images. While the more recent concepts of circular phase mask coronagraphs were developed almost a decade ago, most of them have still not been demonstrated in laboratory. We decide to address this issue leading some tests to validate these coronagraphs experimentally. Last year, we reported the experimental validation of a second generation Roddier & Roddier phase mask (RRPM) coronagraph with a 10^5 contrast level measured at 5.7lambda/D (M. N'Diaye et al. 2010). Our works is now focused on more advanced concepts, such as the Apodized pupil

Roddier & Roddier (ARPM) and the Dual Zone phase mask (DZPM) coronagraphs. The ARPM coronagraph is supposed to achieve complete starlight suppression in the monochromatic case while the DZPM coronagraph is assumed to provide high contrast gains over a large spectral bandwidth, typically 10^6 at 3λ/D over a 20% bandwidth. We also investigate the Zernike sensor phase mask (ZSPM), a phase mask concept dedicated to the calibration of the quasi-static aberrations. To test all these concepts, a new coronagraphic test bench working in the visible has recently been mounted in our laboratory and phase masks and pupil apodizers have been manufactured. In this conference, we will present the first results obtained with these phase mask systems.

Poster ID: *Missions.19*
CARMENES
Andreas Quirrenbach (University of Heidelberg)

CARMENES, Calar Alto high-Resolution search for M dwarfs with Exo-earths with Near-infrared and visible Echelle Spectrographs, is a next-generation instrument for the 3.5m Calar Alto Telescope currently under construction. It is being designed, built, integrated, and operated by a consortium of eleven German and Spanish institutions. Our main objective is finding habitable exoplanets around M dwarfs, which will be achieved by radial velocity measurements on the m/s level in the near-infrared, where low-mass stars emit the bulk of their radiation. CARMENES is expected to become operational in early 2014. CARMENES will cover the wavelength range from 500 to 1800 nm at a spectral resolution of 85,000 with two cross-dispersed echelle spectrographs, coupled to the telescope with optical fibers. The spectrographs will be calibrated with the simultaneous emmission lamp method; our goal is to reach a radial velocity precision close to 1 m/s. The large wavelength range will facilitate the discrimination between radial-velocity signals induced by planetary companions and by stellar activity. It will also allow us to monitor activity indicators (H alpha and the Ca triplet) simultaneously with the radial velocity. Using at least 600 clear nights over a period of five years, CARMENES will be able to search for planets in a sample of 300 M dwarfs.

Poster ID: *Missions.20*
Characterizing Extra-Solar Planets with Low Resolution Spectroscopy
Emily Rice (American Museum of Natural History)

In the next few years, several high contrast imaging instruments equipped with integral field spectrographs will allow the direct spectral characterization of a variety of companions, from low-mass stars to Jupiter-mass extra-solar planets, at Solar System-like separations (4–40 AU). The spectra obtained by these instruments will be low resolution (R ~ 30 to 60), making detailed thermo-chemical analysis difficult. Therefore, we have developed a technique that quantitatively compares observed low-resolution spectra with a set of synthetic spectra in order to obtain physical parameters, such as temperature and surface gravity, quickly and robustly. The technique requires no assumptions about age, mass, radius or metallicity of the companion or the primary. I will describe this technique

and demonstrate its effectiveness with simulated and observed spectra from Project 1640, the high contrast imager and integral field spectrograph on Palomar. The technique can also be used to optimize observing efficiency by determining the ideal wavelength range (for multi-filter instruments such as the Gemini Planet Imager) and signal to noise ratio for a desired precision and accuracy of inferred parameters. The current analysis uses the PHOENIX models as a basis for comparison, but the technique can be applied to any set of models and even used to quantify the differences between models created by different groups. This tool provides a necessary, fast, and comprehensive method of characterizing faint companions of stars, whether they be stellar, sub-stellar or planetary in nature.

Poster ID: *Missions.21*

Spectroscopy of Companions with Project 1640

Lewis Roberts (NASA Jet Propulsion Laboratory)

The Project 1640 instrument is designed to find and characterize warm exoplanets and brown dwarfs. It is mounted on the Hale 5m telescope at Palomar Observatory. It couples an integral field unit (IFU) spectrograph and a diffraction limited apodized Lyot coronagraph with the Palm-3000 high order adaptive optics system. The resulting spectra have a resolution of 33-58 over a passband from 1.06 to 1.78 microns. This is well suited for the spectral typing of late type companions and the characterization of brown dwarfs and exoplanets. The instrument has been operating since 2009 with the current lower order Palomar Adaptive Optics system. We present our spectral calibration methodology and the near-IR spectra of the late type stellar companions to HD 112176 and HD 91782. These have been used to determine spectral classifications of both of these stars in agreement with published photometry. Furthermore, we show examples of what brown dwarf spectra are expected to look like.

Poster ID: *Missions.22*

Exploring Hot Jupiter Atmospheres Via Ground-Based Secondary Eclipse Detections: Biases, Limitations, and Lessons Learned

Justin Rogers (Johns Hopkins University)

One of the most powerful techniques to explore the physics of exoplanetary atmospheres is the direct measurement of a planet's thermal emission during a secondary eclipse. Even a single wavelength-band detection can constrain a planet’s dayside temperature, albedo, and atmospheric energy circulation, and multiple wavelength detections can lead to more detailed conclusions about the atmospheric profile and chemical composition. A number of atmospheric emission detections from hot Jupiters have been made with Spitzer, Hubble, CoRoT, and Kepler, and in just the past three years, these tiny signals have become possible to detect with ground-based instruments. Puzzlingly, many of the ground-based results suggest planets that are hotter than expected by any models, particularly in the 2 micron (K-band) regime (Gillon et al. 2009, Rogers et al. 2009, Gibson et al. 2010, Croll et al. 2011). These results may have an interesting physical cause, or may be related to systematic effects in the analytical methods used to make the eclipse detections. We examine the process by which ground-based secondary eclipse light curves are modeled and fitted, with particular focus on the Monte Carlo Markov Chain (MCMC) algorithm, and the potential biases and limitations of the analysis process. We then provide a series of benchmark tests to determine the reliability of any secondary eclipse data set and analysis pipeline. Finally, we discuss several of the planets with reported detections, summarize the picture emerging from the entire suite of detections, and conclude with lessons learned and prospects for future observations.

Poster ID: *Missions.23*

STRESS - STEREO TRansiting Exoplanet and Stellar Survey: Introduction and Data Pipeline

Vinothini Sangaralingam (University of Birmingham)

The Solar TErrestrial RElations Observatory - STEREO, is a system of two identical spacecraft in Heliocentric Earth orbit. We use the two Heliospheric Imagers (HI), which are wide angle imagers with multi-baffle systems to do high precision stellar photometry in order to search for exoplanetary transits and understand stellar variables. The cadence (40 min for HI-1 and 2 hrs for HI-2), high precision, wide magnitude range (R mag - 4 to 12) and broad sky coverage (nearly 20 per cent just for HI-1A and 60 per cent of the sky in the zodiacal region for all the instruments combined) of this instrument marks this in a space left largely devoid by other current projects. Here we describe the semi-automated pipeline devised for the reduction of this data, some of the interesting characteristics of the data obtained, data analysis methods used along with some early results.

Poster ID: *Missions.24*

Enabling Small-Angle High-Contrast Observations with a Vortex Coronagraph

Gene Serabyn (NASA Jet Propulsion Laboratory)

The vortex coronagraph has great potential for enabling high-contrast observations very close to bright stars, and for reducing the size of space telescopes needed for exoplanet characterization missions. Several promising recent developments related to vortex coronagraphy will be discussed, including the production of vector vortex masks, their measured performance, and unique wave front sensing architectures that vortex phase masks enable. New optical approaches also enable the effective use of vortex phase masks with on-axis telescopes and in the direct measurement of speckle phase.

Poster ID: *Missions.25*

Lunar Based Observations of the Earth as a Planet

William Sparks (Space Telescope Science Institute)

The Camera for Lunar Observations of the Variable Earth (CLOVE) is a concept for a moon-based instrument to characterize the remotely detectable physical and biological signatures of Earth over time. The study is being undertaken as part of the NASA Lunar Science Institute's program "Scientific and Exploration Potential of the Lunar Poles". The lunar polar surface deployment enables these data to be obtained continuously over long timescales and this unique vantage point makes it possible to track Earth's ever-changing photometric, spectral and polarimetric signatures in a manner analogous to future observations of extrasolar terrestrial planets. Empirical data from observations of the Earth from space, from Earthshine and from the field and laboratory will be integrated with state-of-the-art models to help us understand our ability to characterize Earth-like exoplanets, their habitability and evidence for extant life. In the NLSI study we include investigation of circular polarization as a biosignature, try to detect ocean glint from polarization of the Earthshine, and enhance our ability to model the Earth using observations from recent space missions.

Poster ID: *Missions.26*

Characterizing Transiting and Microlensing Exoplanets with the LCOGT Network

Rachel Street (Las Cumbres Observatory Global Telescope Network)

The Las Cumbres Observatory Global Telescope Network is in the first of 4 years of major expansion. This year, we are deploying 1m telescopes at 3 southern hemisphere sites: CTIO, SAAO and Siding Spring, Australia. These, in common with our operational 2m telescopes, will initially be equipped with imagers and a set of 18 filters (NUV, optical, NIR) that will be homogeneous across the network. This offers us a unique and highly flexible tool for the characterization of exoplanets. The distributed-but-homogeneous nature of the network allows us to observe targets intensively and easily combine datasets to achieve high precision over extended timescales. Here we present LCOGT programs designed to characterize exoplanets.

Exploiting our unusually large filter set we are targeting carefully selected anomalous microlensing events for multiband calibrated photometry which will enable us to fully determine the mass, radius and metallicity of the source star, thereby removing a key uncertainty in the complex modeling of these events. The distributed network brings many more opportunities to observe the transits of any given exoplanet system, a fact we already exploit to confirm the discoveries of a number of surveys (WASP, HAT, CoRoT, PTF...). Through intensive photometry we are able to measure key physical and orbital properties to high precision.

Poster ID: *Missions.27*

The FINESSE Mission for Exoplanet Characterization

Mark Swain (NASA Jet Propulsion Laboratory)

FINESSE, the Fast Infrared Exoplanet Spectroscopy Survey Explorer, is the first mission dedicated to finding out what exoplanet atmospheres are made of, what conditions or processes are responsible for the composition, and how our own solar system fits into the larger family of planets. The last 15 years have witnessed extraordinary success in finding exoplanets; ground-based surveys, Kepler, and Corot have collectively identified hundreds of planets outside of our solar system. FINESSE is designed to take the next step - characterizing exoplanet atmospheres. Using proven methods and an instrument optimized for stability, FINESSE would be the first mission dedicated to the spectroscopic characterization of exoplanets as a class of objects. During a two-year mission, FINESSE would survey 200 transiting exoplanets ranging from the most extreme hot-Jovians to cool Neptunes and Super-Earths. FINESSE's science instrument, a spectrograph covering 0.7-5.0 microns, provides excellent sensitivity to important molecular bands of water, methane, carbon monoxide, carbon dioxide, and other molecules. Interpretation of FINESSE measurements will reveal the composition, temperature structure, and chemistry of exoplanet atmospheres and provides a basis for comparing exoplanets in a uniform way. Significantly, all wavelengths in the FINESSE passband are measured simultaneously to remove the confusing effects of any temporal variability in the star/planet system. Engineered for exquisite 100 ppm stability, FINESSE will determine the differences between the dayside and nightside of exoplanet atmospheres by precision measurements of the system phase curve. FINESSE will also make routine observations of calibrator targets allowing spectra taken months apart to be compared, enabling the study of atmospheric dynamics. Implemented as a rapid, low-cost, high-heritage mission, FINESSE is scientifically well matched to the rapidly expanding field of exoplanets.

Poster ID: *Missions.28*

Recent Improvements in the Kepler Mission's Transiting Planet Detection Algorithm

Peter Tenenbaum (SETI Institute)

We describe recent developments in the algorithm used by the Kepler Mission to detect the periodic reductions in stellar flux that are the characteristic signature of a transiting planet. The algorithm has been extended to allow searches in which the flux from a given star falls on different detectors within the focal plane at different times, which is necessary in order to accommodate the spacecraft's periodic axial rotations ("quarterly rolls"). A robust estimator of stellar noise characteristics allows the noise analysis process to function correctly in the presence of extremely deep transits such as those produced by an eclipsing binary or a Jovian or super-Jovian transit. Techniques for eliminating false detections due to step changes in pixel sensitivity or other non-transit phenomena have been incorporated into the algorithm. We also discuss future improvements to the

detection algorithm, including a robust detection statistic that will permit far more effective filtering of false-positive detections.

Poster ID: *Missions.29*
An Exoplanet Mission Concept for the Astro2010 Decade -- Status and Challenges
John Trauger (NASA Jet Propulsion Laboratory)

Can the exoplanet community reach consensus on a single NASA mission concept by mid decade? The answer will depend on objective assessments of both science requirements and technology readiness in the coming three years. The space coronagraph is among the mission architectures under consideration by NASA's Exoplanet Program Assessment Group (ExoPAG). We discuss the capabilities and readiness of the space coronagraph concept, with focus on the demonstrated technologies for precision wavefront control and coronagraphic suppression of diffracted light.

Poster ID: *Missions.30*
Observing Exoplanet Debris Disks with Zodiac II
Stephen C. Unwin (NASA Jet Propulsion Laboratory)

Debris disks are signposts of planet formation, and high-contrast imaging of disks around nearby stars will help us develop a more complete picture of the planet formation process. As proposed, Zodiac II will use a high-altitude (35 km) balloon-borne gondola as a platform for observing disk emission at a level 7 orders of magnitude below the brightness of the parent star, with a detection threshold about a factor of 10 lower than the speckle background. The instrument comprises a 1.1-m off-axis telescope, a band-limited Lyot coronagraph with low-order and high-order wavefront sensing and correction, and dichroics splitting the light into four wavelength bands covering the VRI range. The 3 λ/D inner working angle corresponds to 0.5 arcsec at V. The Zodiac II facility will be capable of long-duration (several week) flights, allowing us to image a large number of exoplanet disks, as well as warm young exoplanet systems such as HR 8799 b and c.

Poster ID: *Missions.31*
Operational Constraints on Exoplanet Observations with JWST
Jeff Valenti, Space Telescope Science Institute

JWST will image and characterize exoplanets. I will briefly summarize the relevant capabilities and discovery space of the four science instruments (NIRCam, NIRSpec, MIRI, and TFI) and present two exoplanet observing scenarios. Operational issues that may affect scientific yield include field of regard, roll constraints, event-driven operations, target acquisition precision, target drift, pointing transients, thermal stability, electronic stability, bad pixels, and persistence. I will solicit feedback from the community on what can be done now to maximize data quality and scientific impact.

Poster ID: *Missions.32*

Searching For Planets Around Low Mass Stars in the Infrared Using the Dispersed Fixed Delay Interferometer Method

Ji Wang (University of Florida)

We briefly review the principle of the dispersed fixed delay interferometer (DFDI) method and present a new method of calculating the fundamental photon-limited radial velocity (RV) uncertainty of DFDI. The Q factor is a measure of flux-normalized doppler sensitivity. We calculate the Q factor as a function of stellar effective temperature Teff, stellar projected rotational velocity V sin i, spectral resolution R and optical path delay (OPD) of the interferometer. In DFDI, OPD is an important parameter determining doppler sensitivity. We find an optimal OPD that maximizes QDFDI. We investigate how QDFDI is affected by OPD and find that a 5 mm deviation from the optimal OPD does not significantly affect QDFDI very much for a wide range of R. We compare QDFDI and QDE, the Q factors for the conventional Echelle (DE) method. We find that QDFDI is a factor of 1.5 to ~4 higher than QDE at R ranging from 5,000 to 20,000. QDFDI and QDE converge at very high R. QDFDI increases as R increases and V sin i deceases. We define a new merit function Q, which is directly related to photon-limited RV uncertainty. We find that DFDI is more advantageous compared to DE if a limited detector resource and multi-object instrument capability are taken into consideration. We simulate the performance of the InfraRed Exoplanet Tracker (IR-ET) which is a DFDI mode of the IRET/FIRST instrument that will be installed at the 3.5 m telescope of Apache Point Observatory in the winter of 2011. The predicted photon-limited RV uncertainty suggests that IR-ET is capable of detecting several-Earth-mass exoplanet in habitable zone of M dwarfs. We develop a new method of quantitatively estimating the influence of telluric lines on RV uncertainty. We will be able to achieve photon-limited RV uncertainty if we can model and remove 99% of the strength of telluric lines. At low telluric line reconstructing level, we have to use both telluric line masking and telluric line modeling in order to reach an optimal RV uncertainty, which is larger than photon-limited RV uncertainty.

E. Planet Formation

Poster ID: *Formation.01*
New Observations of the Beta Pictoris b Exoplanet
Mickaël Bonnefoy (Max Planck Institute for Astronomy)

The 12 Myr old star Beta Pictoris is well known for being surrounded by a warped and extended debris disk. In 2008, Lagrange and collaborators announced the detection of a candidate companion from L'-band (3.8 microns) deep imaging observations collected in 2003 with the VLT/NaCo instrument. In fall 2009, we finally redetected the candidate on the other side of its star. This new result brought the definitive proof that giant planets can form within a few million years inside disks. We have recently obtained new near-infrared deep-imaging observations of the Beta Pictoris system with NaCo. The companion is re-detected again at a position compatible with its expected orbital motion. The companion colors and absolute fluxes enable us to start its empirical characterization. Provided that Beta Pictoris b has been formed via the classical core-accretion scheme, our results notably confirm that the so-called "cold-start" evolutionary model fails to reproduce self-consistently its observed properties.

Poster ID: *Formation.02*
Signs of Accretion in a Wide Planetary-Mass Companion
Brendan Bowler (University of Hawaii), Michael Liu (University of Hawaii), Adam L. Kraus (University of Hawaii), Michael Ireland (University of Sydney)

A growing population of planetary-mass companions on wide orbits (>100 AU) is emerging from adaptive optics imaging surveys of young stars, but the formation mechanism of these objects remains unclear. We obtained Keck/OSIRIS near-infrared integral-field spectroscopy of the recently discovered companion GSC 0062140-00210 b (Ireland et al. 2011), a member of the Upper Scorpius OB association with an age of ~5 Myr. We infer a spectral type of L0 ± 1 and our spectrum exhibits multiple signs of youth. Most notable is strong PaBeta emission, likely originating from accretion of a circum-planetary disk. At ~14 M_J, GSC 0062140-00210 b is the lowest-mass companion to show evidence of accretion. I will discuss the implications of our results for the formation of this object and of planetary-mass companions as a whole.

Poster ID: *Formation.03*
The Inner 10 AU of HR 8799
Sasha Hinkley (California Institite of Technology)

We report the results of Keck L'-band non-redundant aperture masking of HR 8799, a system with four confirmed planetary mass companions at projected orbital separations of 14 to 68 AU. We use these observations to place constraints on the presence of planets and brown dwarfs at projected orbital separations inside of 10 AU---separations out of reach to more conventional direct imaging methods. No companions were detected at

better than 99% confidence between orbital separations of 0.8 to 10 AU. Assuming an age of 30 Myr and adopting the Baraffe models, we place upper limits to planetary mass companions of 80, 60, and 11 Jupiter Masses at projected orbital separations of 0.8, 1, and 3-10 AU respectively. Our constraints on massive companions to HR 8799 will help clarify ongoing studies of the orbital stability of this multi-planet system, and may illuminate future work dedicated to understanding the dust-free hole interior to ~6 AU. These are the first mass upper limits to additional companions at such small projected orbital separations. Further, our contrast of ~8 magnitudes at the L'-band diffraction limit of the Keck Telescopes is one of the most sensitive achieved using this technique, and these limits are within ~2 magnitudes of the 9.5 - 10 magnitude contrast sensitivity expected with the upcoming aperture masking capabilities of the Tunable Filter Imager to be deployed with the James Webb Space Telescope. Our results highlight the importance of achieving moderate contrast at very small inner working angles for the purpose of detecting young Jovian mass planets in nearby star forming regions at ~140 pc.

Poster ID: *Formation.04*

Planetesimal Compositon in Exoplanet Systems

Torrence V. Johnson (NASA Jet Propulsion Laboratory)

Although stellar metallicity is believed to an important factor in the probablity of forming planets around other stars, the composition of the materials available for planet formation will depend, as it does for the Solar System, on the detailed composition of the circumstellar nebula. The C/O ratio is particularly important in determining the relative proportions of silicate, metal and condensed volatile ice. An analysis of surveys of the composition of the host stars of known exoplanet systems suggests that the initial condensates beyond the 'snow-line' in these systems may range from more volatile rich than the Solar System to much more refractory. For instance, C-rich systems, such as those discussed by Bond, J. C., et al. (2010) Astrophys. J. 715, 1050-1070, may have high silicate fractions and be water-poor (with condensed volatiles rich in CO, CO2 and hydrocarbon ices). We present calculations of the expected icy planetesimals in these systems for a variety of circumstellar nebula conditions, using methods outlined in Johnson, T. V. and J. I. Lunine (2005) Nature 435, 69-71 and Mousis, O., et al. (2009) Astron. Astrophys. 507, 1671-1674. These characteristics may be investigated for extrasolar systems in the future through their impact on the refractory and volatile content of extrasolar planetesimal belts and the amount of heavy element enrichment of extrasolar giant planets.

Poster ID: *Formation.05*

Constraining Interior Structure Models of Extrasolar Planets with the Love Number k2

Ulrike Kramm (University of Rostock)

The recent ground- and space-based transit surveys have brought to light an overwhelming number of exoplanets. The variety of these planets cover giant Hot Jupiters to rocky Super-Earths of only a few Earth masses. However, even with the combined data of transit and radial velocity measurements the interior structure of exoplanets remains highly unconstrained. For example, the data available for the Neptune-sized planet GJ436b allows for a composition of a water planet as well as a Super-Earth (1), see also the case of GJ1214b (2,3). Only a new planetary parameter sensitive to the planet's density distribution could help constraining this large amount of possible models further. We investigate whether the planet's tidal Love number k2 can be such a constraining parameter, if known, k2 quantifies the quadrupolic gravity field deformation at the surface of the planet in response to an external perturbing body and is, to first order, equivalent to J2 for the solar system planets. We find that, while k2 only depends on the density distribution of the planet, the inverse deduction of the density distribution from a given k2 is non-unique. There is a degeneracy of k2 with respect to a density discontinuity in the planet's envelope (4). As a consequence, a precise value for the core mass cannot be derived. However, a maximum possible core mass can be infered which equals the core mass predicted by homogeneous zero metallicity envelope models. Using the example of the extrasolar transiting planet HAT-P-13b we show to what extend planetary models can be constrained by taking into account the tidal Love number k2. (1) Nettelmann, N., Kramm, U., Redmer, R. & Neuhäuser, R. (2010), A&A, 523, A26 (2) Rogers, L.A. & Seager, S. (2010), ApJ, 716, 1208 (3) Nettelmann, N., Fortney, J.J., Kramm, U. & Redmer, R. (2011), ApJ submitted (4) Kramm, U., Nettelmann, N., Redmer, R. & Stevenson, D.J. (2011), A&A 528, A18

Poster ID: *Formation.06*

Identification and Characterization of Disks in Substellar Orion Members

Jorge Lillo Box (Astrobiology Center (CAB))

Brown dwarfs should be plenty in the Galaxy. However, only a handful -hundreds- have been ideintified so far. These substellar objects represent an important intermediate stage between planets and stars and because their role on the Initial Mass Function. Orion is one of the best regions to look for this kind of objects due to its youth (around 1 Myr), richness and distance (400 pc). Several protoplanetary disks and low-mass sources have been detected on it indicating that stellar and, maybe, planetary formation is taking place. Here, we report the identification of 29 new substellar candidates of the Orion Molecular Cloud ranging masses from 13 M_J to 75 M_J. The detection was done by using deep photometry in the near and mid infrared (JHKs bands from the ground and the [3.6] and [4.5] bands of the Spitzer/IRAC). From an initial sample of around 1200 objects we selected those with mid-infrared excess and low derived mass by a J vs. J-H color-magnitud diagram (less affected bands by disk contribution). We also applied Gutermuth

et al. (2009) techniques to reject background and foreground sources. An additional study of circumstellar disks was done in an extended region of one square degree using data in the four IRAC bands. By adding this data to optical and near-infrared photometry available in the literature, we can construct the spectral energy distribution allowing us to detect circumstellar disks and study their properties. We characterized the disk thickness by using the IRAC slope (see Lada et al. (2006)) as well as the evolutionary stage of the objects with color-color diagrams.

Poster ID: *Formation.07*

The Baroclinic Instability in Circumstellar Disks and its Impact on Planet Formation

Wladimir Lyra (American Museum of Natural History)

Turbulence and angular momentum transport in accretion disks remain a topic of debate. With the realization that dead zones are robust features of protoplanetary disks, the search for hydrodynamical sources of turbulence continues. A possible source is the baroclinic instability (BI), which has been shown to exist in unmagnetized non-barotropic disks. We present local and global simulations of baroclinicly unstable, magnetized, 3D disks, in order to assess the interplay between the BI and other MHD instabilities, finding that vortices do not survive magnetization, falling prey to the magneto-elliptic instability (MEI) even before the onset of the magneto-rotational instability (MRI). In fact, we find that the MRI is a subset of the MEI, and that the latter, in its magneto-elliptic-rotational version is a more fundamental MHD instability. We conclude that vortex excitation and self-sustenance by the baroclinic instability in protoplanetary disks is viable only in low ionization, i.e., the dead zone. Our results are thus in accordance with the layered accretion paradigm. A baroclinicly unstable dead zone should be characterized by the presence of large-scale vortices whose cores are elliptically unstable, yet sustained by the baroclinic feedback. As magnetic fields destroy the vortices, and the MRI outweighs the BI, the active layers are unmodified. When particles are introduced in the simulation, massive accumulation occurs into the vortex core, reaching densities high enough to allow for gravitational collapse into planetary mass objects.

F. Planet-Hosting Stars

Poster ID: *Stars.01*

Lithium in Planet Host Stars

Patrick Baumann (Max Planck Institute for Astrophysics)

We examine a possible connection between planet hosting and an enhanced lithium depletion in solar type stars, a correlation that would be extremely useful for the search for exoplanets. For that purpose we consistently determine the basic stellar parameters and chemical compositions of more than 100 stars that a very similar to the sun and test those findings for possible connections with planet hosting. We find a clear negative correlation between surface lithium abundance and age, as suggested by models, but we can't confirm a connection with planet hosting. However, we can explain the fact that such connections have been found before with multiple selection biases. We also find some objects with peculiarly high lithium abundances for their ages and comparably low surface gravity, which in general appear not to be planet hosts. We have no good explanation for this phenomenon so far and are planning to do some deeper investigation on those stars.

Poster ID: *Stars.02*

Correlations of Host Star and Planetary Parameters for Transiting Exoplanets

Bence Béky (Harvard University)

The rapidly growing number of transiting exoplanets (TEPs) enables in-depth statistical analysis of the correlations between planetary and host star parameters. Understanding these correlations -- especially those involving host star metallicity -- is crucial for justifying the models of planetary structures and formation. I therefore present a rigorous analysis using multiple statistical techniques, and investigate how the correlations change for different ranges of parameters, in particular for planetary mass. I compare the results to previous studies from the literature. I discuss observational biases and limitations, compare the parameter space of different surveys, and show what influence they have on the distribution and correlations of parameters of discovered TEPs. I also investigate outliers, and seek explanation for their nature.

Poster ID: *Stars.03*

Stellar Variability: Impact for the Detection of Low-mass Planets

Isabelle Boisse (Universidade do Porto), N.C. Santos (Universidade do Porto), X. Dumusque (Observatoire de Genève), J. Gomes da Silva (Universidade do Porto), X. Bonfils (IPAG)

Although many methods are currently being used to search for planets orbiting other stars, the radial-velocity (RV) technique remains the most prolific. As noted by the Astro2010 decadal review, ground-based RV surveys are needed to identify targets for future direct-detection space missions. Moreover, transit surveys need RV follow-up to

establish the planetary nature of their candidates and to measure their masses. This mass measurement, combined with the radius measurement, via the transit light-curve, is crucial to have an estimation of exoplanets density. Ground-based RV measurements are then critical to explore the physical characterization of exoplanets. Although extremely efficient, the RV technique is, however, an indirect method (as well as photometric transit detection or astrometry). One of the problems with this is the fact that periodic RV variations can in some cases be caused by some other mechanisms, not related to the presence of low-mass companions. Phenomena such as stellar pulsation, inhomogeneous convection, spots or magnetic cycles can prevent us from finding planets, they might degrade the parameters estimation, or give us false candidates, if they produce a stable periodic signal. In this poster, we will consider the different kinds of «noise » that are generated by stars, as well as the methods proposed and used to overcome this issue. These methods are based on data from the most precise RV instruments like HARPS. The impact for the detection of other earths using high-precision radial-velocity instruments will be discussed.

Poster ID: *Stars.04*

The Role of Stellar Mass in Ground-Based High-Contrast Imaging

Justin R. Crepp (California Institute of Technology) and John A. Johnson (California Institute of Technology)

We present calculations that explain why planets have only been directly imaged around A-stars in the solar neighborhood, and around late-type stars in more distant stellar clusters. Our Monte Carlo simulations indicate that extrapolation of the Doppler radial velocity planet population to separations accessible to high-contrast imaging instruments provides an excellent agreement between planet detection rates and observations using present-day contrast levels. Strong correlations between star mass and planet properties (such as occurrence rate, mass, and semimajor axis extent) make A-stars ideal high-contrast imaging targets even when stars are pre-selected for youth and brightness. The same effects responsible for creating a multitude of detectable planets around massive stars conspire to reduce the number orbiting low-mass stars. However, in the case of a young stellar cluster, where targets are approximately the same age and situated at roughly the same distance, MK-stars can easily dominate the number of detections because of an observational bias. It is therefore not surprising that planets have yet to imaged directly around FG stars. These results have implications for target selection strategies of forth-coming high-contrast imaging programs.

Poster ID: *Stars.05*

Intermediate Resolution Near-Infrared Spectroscopy of 36 Late-M Dwarfs

Rohit Deshpande (Pennsylvania State University)

We present a homogeneous dataset of intermediate resolution (R ~ 20,000) near-infrared (1.15 - 1.35 μm) spectra for a sample of 36 late-M Dwarfs (M5.0 - M9.5). The observations were carried out using the Near-Infrared Spectrograph (NIRSPEC) on the

Keck II telescope. We report measurements of pseudo-equivalent widths (p-EW) of neutral atomic lines, as well as spectroscopic absolute radial and rotational velocities. We have determined relations between p-EW and spectral type for 12 neutral atomic lines. The K I lines (11690 Å, 11772 Å, 12432 Å, 12522 Å) are well suited to derive spectral types of mid- to late-M Dwarfs, while the Fe I (11883 Å, 11973 Å) and Mn I (12899 Å) lines are better suited to derive chemical abundance because of their relative insensitivity to effective temperature. We report radial velocities for stars in our sample of which 13 are new in the literature. Our measurements of rotational velocities (v sin i) are limited by our modest resolution. We find that 13 of our stars have v sin i below our measurement threshold (12 km s^{-1}). Four of our targets are fast rotators (v sin i > 30 km s^{-1}).

Poster ID: *Stars.06*

The Worlds Next Door: Surveying Nearby M Dwarf Stars for Planets

Eric Gaidos (University of Hawaii)

Neaby M dwarf stars are attractive targets for planet searches from the ground and space and may host the most observationally accessible habitable planets. We describe our ongoing survey of nearby M dwarf stars for planets. Stars are selected from a proper-motion catalog generated from the Digitized Sky Survey and correlated with the 2MASS source catalog. This is combined with (a) moderate resolution spectroscopy at both visible and infrared wavelengths; (b) multi-band photometry from the Pan-STARRS project; and (c) time-series photometry using data from Super-WASP. Our planet search uses a staged combination of the Doppler and transit techniques, including ground-based photometry with sub-millimagnitude precision. We estimate the expected frequency of detections as well as the probability distributions for the nearest and brightest transiting planet systems using the results from Kepler. We describe our selection for metal-rich stars to produce a planet-enriched sample as well as our exploitation of orbital coplanarity to find more planets.

Poster ID: *Stars.07*

Long Term Stellar Activity Variation and its Influence on Radial-Velocity Measurements: The Case for M Dwarfs

Joao Gomes da Silva (Centro de Astrofísica da Universidade do Porto)

Solar type stars are known to have chromospheric activity cycles similar to those observed on the Sun. It was recently demonstrated that these cycles can induce periodic radial-velocity (RV) signals. This effect could difficult or even mimic the detection of an extrasolar planet. Although magnetic cycles are well studied for the case of sun-like stars, not much is known about long-term activity at the lower end of the main sequence. However, M dwarfs are important targets for RV planet searches. Here we present a study of the long time-scale activity variations of a sample of M dwarfs from the HARPS M-dwarf planet search survey. We measured four known activity indices and compared them with RV and other activity indicators with the objective of establishing whether RV can be influenced by long-term activity cycles.

Poster ID: *Stars.08*

Spectroscopic Properties of Stars with Circumstellar Debris Disks: Comparison with Star with Planets

Jesus Maldonado (Universidad Autonoma de Madrid)

Dusty debris disks are signatures of planetary systems and, therefore, constitute valuable tools to provide new light in our understanding of how planetary systems form and evolve. In this contribution we present the first results of a spectroscopic programme of a sample of stars with debris disks. High-resolution echelle spectra are used to determine metallicities, abundances, age (via lithium abundances, chomospheric activity) and kinematics (moving group membership). Properties of stars with debris disks, are compared with those stars hosting planets, as well as, "normal" stars, setting the results in the context of planetary system formation.

Poster ID: *Stars.09*

The Frequency of Planets Around Metal-Poor Stars

Annelies Mortier (Centro de Astrofísica da Universidade do Porto), N.C. Santos (Universidade de Porto), A. Sozzetti (Osservatorio Astronomico di Torino), M. Mayor (University of Geneva), S. Udry (University of Geneva), D. Latham (Harvard-Smithsonian Center for Astrophysics)

Understanding the frequency of different types of planets around stars of different mass and metallicity is providing clues about the processes of planet formation and evolution. Different samples of stars were created to search for planets with this goal in mind. Two of these were observed with the HARPS and Keck-HIRES spectrographs, respectively. The combined sample provides a tool to determine the detection limits to find planets orbiting these metal-poor stars. In this poster we will present preliminary results of the statistics of this combined sample.

Poster ID: *Stars.10*

Planet Signatures in Stellar Abundances

Ivan Ramirez (Carnegie Observatories)

The process of planet formation has likely left detectable signatures in the chemical composition of the host stars, as exemplified by the now well-established connection between high stellar metallicity and the presence of a giant planet. It has been claimed that a similar connection exists for the lithium abundances, although age and metallicity effects might be producing spurious results. Precise analyses of several other elements reveal statistically significant correlations between abundance and condensation temperature, which could be due to the formation of terrestrial planets alone, although an opposing view has appeared in the literature. I will review the status of these debates

concerning the connection between host star abundances and planet formation, as well as present suggestions for future directions that could be taken in order to solve them.

Poster ID: *Stars.11*

NIR Metallicities of M-dwarfs Within the Northern 8pc Sample

Barbara Rojas-Ayala (Cornell University)

A metal-rich environment facilitates planet formation. Therefore, metal-rich stars are the most favorable targets for surveys seeking to detect new exoplanets. Using this advantage to identify likely low-mass planet hosts, however, has been difficult: methods to determine M-dwarf metallicities required observationally expensive data (such as parallaxes and high-resolution spectra) and were limited to a few bright cool stars. Rojas-Ayala et al.(2010) introduced an empirical K-band metallicity indicator for M-dwarfs, that enables metallicity estimates to be generated for M-dwarfs that are too cool or too distant for other methods. In this poster, we present the most advantageous targets for planet searches around cool stars in the northern 8pc sample.

Poster ID: *Stars.12*

How Metal-Poor Can a Planet Host Star Be?

Johny Setiawan (Max Planck Institute for Astronomy)

Recent development in the exoplanet field has shown that planets are quite common around main-sequence stars. In particular, metal-rich main sequence stars are found so far to have higher probability to host planets. Here, we would like to present preliminary results of our pilot survey of planet search around very metal poor stars [Fe/H] < 1.0. To our surprise, our very limited test sample shows a high percentage of candidates of planetary companion around metal-poor stars ([Fe/H] < -1.5). This finding is extremely interesting and important to put constraints on the planet formation theories.

Poster ID: *Stars.13*

Understanding the Parent Stars

Kaspar von Braun (NASA Exoplanet Science Institute)

Practically all astrophysical parameters of extrasolar planets are actually functions of stellar parameters. Consequently, understanding extrasolar planets requires "understanding the parent stars". One option of directly determining fundamental astrophysical parameters of stars is long-baseline interferometry. We use the CHARA array for an ongoing survey of nearby exoplanet host stars' angular diameters. Coupled with trigonometric parallax values and literature photometry, we obtain direct estimates of the stellar physical sizes and surface temperatures, i.e., their luminosities and location / extent of their habitable zones. Furthermore, for transiting planets, a knowledge of the stellar size provides a direct determination of the planetary diameter. We present our results for two widely studied M-dwarf systems: (1) GJ 581 -- a multiplanet system with

at least one planet in the habitable zone, and (2) GJ 436 -- a system hosting a transiting hot Neptune. We elaborate on the implications consequences of the directly determined parameters and give comparisons to literature values.

G. Planetary System Architecture

Poster ID: *Architecture.01*

Occurrence Rate of Habitable Earth Analog Planets Orbiting Solar-Type Stars

Joseph Catanzarite (NASA Jet Propulsion Laboratory)

Kepler is a space telescope that searches Sun-like stars for planets. Its major goal is to determine the fraction of Sunlike stars that have planets like Earth. When a planet ‘transits’ or moves in front of a star, Kepler can measure the concomitant dimming of the starlight. From analysis of the first four months of those measurements for over 150,000 stars, Kepler’s science team has determined sizes, surface temperatures, orbit sizes and periods for over a thousand new planet candidates. Here, we show that 1.4% to 2.7% of stars like the Sun are expected to have Earth analog planets, based on the Kepler data release of Feb 2011. The estimate will improve when it is based on the full 3.5 to 6 year Kepler data set. Accurate knowledge of eta_earth is necessary to plan future missions that will image and take spectra of Earthlike planets. Our result that Earths are relatively scarce means that a substantial effort will be needed to identify suitable target stars prior to these future missions.

Poster ID: *Architecture.02*

On the Frequency of Additional Planets in Short Period Hot Jupiter Systems from Transit Timing Variations

Jason Dittmann (Harvard-Smithsonian Center for Astrophysics)

The large number of hot Jupiter planets allows one to probe these systems for additional unseen planets via transit timing variations (TTVs). Even relatively small terrestrial planets, when placed in an energetically favorable mean motion resonance (MMR), can cause detectable TTVs with an amplitude of several minutes (Haghighipour et al. 2008). In an effort to discover and characterize such companions, we have embarked on a systematic study of known transiting hot Jupiters, utilizing the 1.55 meter Kuiper telescope on Mt. Bigelow to measure multiple individual transits in an observing season to within 30 second precision, and constrain the nature of any planetary companions. Here, we present current and preliminary results on this study, and show that the systems HAT-P-5, HAT-P-6, HAT-P-8, HAT-P-9, WASP-11/HAT-P-10, HAT-P-11, TrES-2, and WASP-10 do not contain small mass companions in MMRs, or moderate mass companions in close enough proximity to induce TTVs on the order of ~1.5 minutes.

Poster ID: *Architecture.03*

Direct Detection of HR8799b, c, d in HST/NICMOS Data From 1998

J. Brendan Hagan (Space Telescope Science Institute)

HR8799 is currently the only multiple-planet system that has been detected with direct imaging. The four giant planets, with masses 7 − 10 M_J, have been detected at large separations from the star (14-68 AU). The ability to measure the planets’ orbital motion

is critical to understand this system. Indeed, orbital information brings insight into the dynamics, stability and formation mechanisms for the planets. Also, the system dynamics provides constraints on the planet masses that will help calibrate the evolutionary models, which are not well constrained in this mass regime. Yet measuring the orbital motion is a very difficult task because of the long-period orbits (50-500 yr), which requires long time baselines and high-precision astrometry. This paper presents the precovery of the three planets HR8799b, c and d using the archival data set of the star HR8799 obtained with the Hubble Space Telescope (HST) NICMOS coronagraph in 1998. These data provide a ten-year baseline with the discovery images, and therefore offer a unique opportunity to constrain their orbital motion and stability of the system.

Poster ID: *Architecture.04*
Search for Unseen Planets Using Transit Timing Variations from the Southern Hemisphere
Sergio Hoyer (Universidad de Chile)

The method of Transit Timing Variations (TTVs) is sensitive to detect additional low-mass planets in transiting exoplanetary systems that are otherwise undetectable by other methods like RVs. In 2008 we started an homogeneous monitoring of transiting planets in the Southern Hemisphere with observations of a cadence of 20 to 50 seconds. By carefully measuring of the central time we will be able to detect long- and short-term variations of the primary transit. In this contribution we will present preliminary results of the analysis of more than 15 transits on selected exoplanets.

Poster ID: *Architecture.05*
Mid-Infrared T-Dwarf Companion Limits for Nearby Planet-Host Stars
Alan Hulsebus (Iowa State University)

The sensitivity of Spitzer's IRAC in 4.5 μm provides the ability to use direct imaging to capture light from Y and T dwarfs expected to have peak emission in this band. Using PSF subtraction techniques, we can detect sources with better than 10^4 contrast at separations as close as 12 arcseconds. Potential substellar companions can be identified from their characteristically red colors between the 3.6 μm and 4.5 μm photometric bands. In a sample of 14 nearby stars already found to have planetary companions from radial velocity searches, we found no sources consistent with substellar-mass companion colors within 20 arc seconds of the stars. This corresponds with 4.5μm upper limits for objects of 5Mjupiter at 1Gy age and 10pc distance. We present a description of the point spread function and artifact subtraction process necessary to achieve this result.

Poster ID: *Architecture.06*

Improving Transit Predictions of Known Exoplanets with TERMS

Stephen Kane (NASA Exoplanet Science Institute)

Transiting planet discoveries have yielded a plethora of information regarding the internal structure and atmospheres of extra-solar planets. These discoveries have largely been restricted to the low-periastron distance regime due to the bias inherent in the geometric transit probability. Monitoring known radial velocity planets at predicted transit times is a proven method of detecting transits, and presents an avenue through which to explore the mass-radius relationship of exoplanets in new regions of period/periastron space for the brightest exoplanet host stars. Here we describe transit window calculations for known radial velocity planets, techniques for refining their transit ephemerides, and present results for radial velocity planets which have been successfully monitored during predicted transit times. These methods are currently being implemented by the Transit Ephemeris Refinement and Monitoring Survey (TERMS).

Poster ID: *Architecture.07*

Searching for Kozai Companions

Russell Knox (University of Arizona)

The formation mechanism for Hot Jupiters, large gas giants with extremely short orbital periods, is still unknown. Current thought suggests that these planets form past the ice line and subsequently migrate inwards. There are multiple proposed migration theories, but no single theory has yet been able to explain all observed planet characteristics. We have carried out observations to test the theory of Kozai Cycles with Tidal Friction (KCTF), which describes a system in which a massive distant companion secularly perturbs the planet and causes it to migrate inwards. As a consequence, the planet's orbital axis will become inclined to the host star's angular momentum axis. Using the CLIO instrument on the MMT, we have observed a number of stars with an inclined orbital axis and have found that they preferentially have nearby companion stars. Our results indicate that the KCTF mechanism plays an important role in the migration of hot Jupiters.

Poster ID: *Architecture.08*

Commensurability, Chaos and Non-Keplerian Motion in Multiple Exoplanet Systems

Valeri Makarov (U.S. Naval Observatory)

The currently known systems of multiple exoplanets include more massive planets in shorter orbits than the Solar System. They are likely to be more chaotic and dynamically variable, and to include a range of orbital and spin-orbital commensurabilities and resonances. Using a few well-known exoplanet systems (e.g., 55 Cnc) we show that complex systems can be distinctly chaotic but stable in the long term. Because of the rapid dynamical evolution, spin-orbital resonances should be common, having profound

implications for the habitability of rocky planets. We discuss the prospects of detecting non-Keplerian orbits and planets in orbital resonances with the present day techniques.

Poster ID: *Architecture.09*

Observable Retrograde Precession Periods and Sources

Michele M. Montgomery (University of Central Florida)

Of mass M, radius r, and mean separation distance d, d has the most effect on retrograde precession periods. Planets in gaps of protoplanetary disks may cause the inner disk and/or host star to retrogradely precess. Similarly, host stars may cause protoplanets or exoplanets to retrogradely precess like the tidal effect the Sun (and Moon) has on the spinning, tilted, oblate Earth. We review the physics for retrograde precession and discuss which celestial objects (e.g., WASP-33/b) have retrograde precession periods that are observable in reasonable amounts of telescope time. Otherwise unobservable exoplanets may now be "found" via gravitational tidal effects.

Poster ID: *Architecture.10*

Subaru Observations of Spin-Orbit Alignment Angles and Outer Massive Bodies

Norio Narita (National Astronomical Observatory of Japan)

Previous observations for exoplanets have revealed the diversity of exoplanetary orbits. Some planetary migration mechanisms have been proposed to explain the orbital distribution of exoplanets, including disk-planet interaction, planet-planet scattering, and Kozai migration. To test the migration mechanisms, we have worked on observations of the Rossiter-McLaughlin effect for transiting planetary systems and high-contrast direct imaging for tilted/eccentric planetary systems. We introduce results of our previous and ongoing observations with Subaru HDS and HiCIAO with AO188.

Poster ID: *Architecture.11*

Post-Capture Evolution of Potentially Habitable Exomoons

Simon Porter (Lowell Observatory)

The satellites of extrasolar planets (exomoons) have been recently proposed as astrobiological targets. However, as giant planets appear unlikely to form in habitable zones, any that exist there may have migrated from elsewhere. Neptune, the most migratory giant in our solar system, lost most of its original satellites through interactions with the proto-Kuiper Belt, but gained the large retrograde satellite Triton. Triton has been proposed to have been captured through a momentum-exchange reaction, and it is possible that a similar event could allow a giant planet to capture a formerly binary terrestrial planet or planetesimal. We therefore attempt to model the dynamical evolution of a terrestrial planet captured into orbit around a giant planet in the habitable zone of a star. Using the Kozai Cycle-Tidal Friction (KCTF) model of Eggleton & Kiseleva-Eggleton (2001), we show how a loose, elliptical capture orbit can be converted to a tight, circular one. We find that approximately half of loose elliptical orbits (apoapse >80%

Hill Radius) result in stable circular orbits at <20% Hill Radius over timescales of 1-100 Myr. This effect is mostly independent of the planet and moon's mass, assuming the planet is >10 Earth masses and the moon is <2 Earth masses. Terrestrial satellites that evolved to sufficiently tight orbits would be stable for the lifetime of the stellar system, and thus potentially long-term habitable locations. In addition, we calculate the transit timing and duration variations for the resulting systems, and thereby estimate the fraction that may be currently detectable.

Poster ID: *Architecture.12*

The Planet Next Door: A Direct Imaging Search for Sirius C

Christian Thalmann (University of Amsterdam)

Astrometric monitoring of the Sirius binary system over the past century has yielded several predictions for an unseen third system component, the most recent one suggesting a >50 Jupiter-mass object in a ~6-year orbit around Sirius A. We present high-contrast imaging observations performed with Subaru IRCS and AO188 in the 4.05 μm narrow-band Br alpha filter. These data surpass previous observations by an order of magnitude in detectable companion mass, allowing us to probe the relevant separation range down to the planetary mass regime (10 Jupiter masses at 1", 3 at 2", and 1.6 beyond 4"). We complement these data with M-band observations from MMT/AO Clio, which reach comparable performance. Neither dataset reveals any companion candidates above the 5 sigma level, allowing us to refute the existence of Sirius C as suggested by the previous astrometric analysis. We note, however, that plenty of parameter space remains for unseen planets at close separations.

Poster ID: *Architecture.13*

Secular Interactions in Multi-Planet Systems: Constraints on Characteristics and Histories from Classical Secular Theory

Christa Van Laerhoven (University of Arizona)

Secular analytical theory offers insight into the character and history of multi-planet systems. For example, major axes currently locked in alignment may indicate substantial tidal damping. And current near-separatrix behavior may suggest an early mutual scattering event. For the 61 Virginis system, classical theory reproduces the type of behavior inferred from numerical integrations. The apsides of the two outer planets librate about a mutual alignment, but in this case the secular analysis technique shows that no eigenmodes have damped. There is no evidence of tidal evolution. Rather, the apsidal alignment is a preferred behavior given the system’s basic architecture, i.e. masses and semi-major axes. For the five-planet 55 Cancri system, the orbit solution by Fischer et al. (2008) has the innermost planet with a surprisingly large eccentricity. which according to secular analysis is dominated by a single frequency, precisely the one that tides should damp out first. Moreover, the alignment of three major axes involves three different eigen frequencies, so it has nothing to do with damping, and in fact is an improbable solution. The outer two planets undergo near-separatrix libration, which

would suggest the outermost one underwent a scattering event. A more recent alias-corrected orbital fit for 55 Cancri (Dawson and Fabryky 2010) allows a circular orbit for the inner planet. Secular theory shows the orbit remains nearly circular even under the influence of the other planets. Moreover, for this orbit fit, the one eigenmode of the system that is significantly affected by tides on the inner planet has largely damped away, consistent with the inner planet's proximity to the star. Secular theory has implications for the Gliese 581, HD 181433, and HIP 14810 systems as well, demonstrating its potential value as new planetary systems continue to be discovered.

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