# EXTREME SOLAR SYSTEMS II

**September 11-17, 2011**
**Jackson Lake Lodge, Grand Teton National Park**
**Moran, Wyoming**

# CONFERENCE ABSTRACTS

**Schedule**
**Abstracts**
**Author Index**

# Schedule

Schedule ........ 3

Abstracts ........ 5

Monday, September 12, 2011, 8:30 AM - 10:00 AM ........ 5

01: Overview of Observations and Welcome ........ 5

Monday, September 12, 2011, 10:30 AM - 12:00 PM ........ 7

02: Radial Velocities ........ 7

Monday, September 12, 2011, 2:00 PM - 3:30 PM ........ 10

03: Transiting Planets ........ 10

Monday, September 12, 2011, 4:00 PM - 5:30 PM ........ 13

04: Transiting Planets II ........ 13

Tuesday, September 13, 2011, 8:30 AM - 10:00 AM ........ 16

05: Planets in Binaries and Star Clusters ........ 16

Tuesday, September 13, 2011, 10:30 AM - 12:00 PM ........ 19

06: R-M Measurements and Orbital Inclinations ........ 19

Tuesday, September 13, 2011, 2:00 PM - 3:30 PM ........ 23

07: Direct Imaging ........ 23

Tuesday, September 13, 2011, 4:00 PM - 5:30 PM ........ 26

08: Giant Planet Formation ........ 26

Wednesday, September 14, 2011, 8:30 AM - 10:00 AM ........ 29

09: Dynamical Evolution ........ 29

Wednesday, September 14, 2011, 10:30 AM - 12:15 PM ........ 32

10: Close Planet - Star Interactions ........ 32

Thursday, September 15, 2011, 8:30 AM - 10:00 AM ........ 36

11: Atmospheres ........ 36

Thursday, September 15, 2011, 10:30 AM - 12:00 PM ........ 40

12: Atmospheres II ........ 40

Thursday, September 15, 2011, 2:00 PM - 3:30 PM ........ 44

13: Structure and Evolution ........ 44

Thursday, September 15, 2011, 4:00 PM - 5:30 PM ........ 47

14: Hot Jupiters ........ 47

Friday, September 16, 2011, 8:30 AM - 10:00 AM ........ 51

15: Planets Around Evolved Stars ........ 51

Friday, September 16, 2011, 10:30 AM - 12:00 PM ........ 55

16: Rocky Planet Formation and Planetesimals ..... 55
Friday, September 16, 2011, 1:00 PM - 2:30 PM ..... 58
17: Earths and Super-Earths ..... 58
Friday, September 16, 2011, 3:00 PM - 4:30 PM ..... 60
18: Habitability ..... 60
Poster Session Presentations
Monday, September 12, 2011, 8:30 AM – Friday, September 16, 2011, 3:00 PM ..... 64
19: Planet Detection - Transits ..... 64
20: Planet Detection - Radial Velocities ..... 71
21: Planet Detection - Microlensing ..... 76
22: Planet Detection - Imaging ..... 78
23: Planet Detection - Other ..... 82
24: Kepler Results ..... 85
25: Transit Timing ..... 87
26: Rossiter-McLaughlin Measurements ..... 89
27: Statistical Properties of Orbits and Masses ..... 90
28: Multiple-Planet Systems ..... 92
29: Earths and Super-Earths ..... 94
30: Planets Around Evolved Stars and Compact Objects ..... 98
31: Planets in Star Clusters ..... 101
32: Planets in Binary Stars ..... 102
33: Planet Formation Theory ..... 103
34: Dynamical Evolution and Interactions ..... 110
35: Stellar Surface Deposition of Material ..... 114
36: Disks and Migration Theory ..... 115
37: Interior Structure ..... 120
38: Protoplanetary Disk Observations ..... 122
39: Planets Around Young Stars ..... 125
40: Planetary Atmospheres ..... 127
41: Future Missions and Instrumentation ..... 139
42: Habitability ..... 142
43: Theory ..... 144
44: Observational ..... 145
**Author Index ..... 149**

# Abstracts

## Monday, September 12, 2011, 8:30 AM - 10:00 AM

### 01

***Overview of Observations and Welcome***

Oral

*Explorers Room*

01.01

**Overview of Kepler Results**

**Natalie M. Batalha**[1]

[1]*San Jose State University.*

8:40 AM - 9:00 AM

*Explorers Room*

Overview of Kepler Results, Abstract TBD, Natalie Batalha (NASA Ames)

01.02

**Doppler Surveys : Super-Earths And Neptune-type Planets.**

**Michel Mayor**[1], C. Lovis[1], D. Segransan[1], M. Marmier[1], F. Pepe[1], S. Udry[1], D. Queloz[1], W. Benz[2], J. Bertaux[3], F. Bouchy[4]

[1]*Geneva University, Switzerland,* [2]*Bern University, Switzerland,* [3]*Aeronomie, France,* [4]*Observatoire de Haute-Provence, France.*

9:00 AM - 9:15 AM

*Explorers Room*

On the last 7 years a large survey has been carried out with the HARPS spectrograph at la Silla Observatory. An impressive population of low-mass planets with masses in the range of Super-Earths and Neptune-type planets, orbiting solar-type stars, has been discovered. Part of these planets have quite small masses (as small as 1.3 Earth-mass). An important fraction of these low-mass planets are part of multiplanetary systems as for example HD10180 with seven planets. If most of the detected Super-Earths are on tight orbits, already a few ones have been discovered in the habitable zone. These early discoveries of Super-Earths in the HZ confirm the possibility to detect by Doppler spectroscopy a significant list of stars with planets with suitable conditions for life development. Establishing a list of similar targets among our closest stellar neighbours is probably a prerequired condition for any future experiment designed to search for life signatures. The number of planetary systems with Super-Earths and Neptune-type planets is large enough to allow a first estimation of statistical properties of that subpopulation of planets (distributions of period, masses as well as the metallicity of their host stars).

01.03

**Recent Results from Gravitational Microlensing**

**Takahiro Sumi**[1], MOA and OGLE collaboration

[1]*Osaka University, Japan.*

9:15 AM - 9:30 AM

*Explorers Room*

Since 1995, more than 500 exoplanets have been detected using different techniques, of which 12 were detected with gravitational microlensing. Most of these are gravitationally bound to their host stars. There is some evidence of free-floating planetary mass objects in young star-forming regions, but these objects are limited to massive objects of 3 to 15 Jupiter masses with large uncertainties in photometric

mass estimates and their abundance. Here, we report the discovery of a population of unbound or distant Jupiter-mass objects, which are almost twice ($1.8_{-0.8}^{+1.7}$) as common as main-sequence stars, based on two years of gravitational microlensing survey observations toward the Galactic Bulge. These planetary-mass objects have no host stars that can be detected within about ten astronomical units by gravitational microlensing. However a comparison with constraints from direct imaging suggests that most of these planetary-mass objects are not bound to any host star. An abrupt change in the mass function at about a Jupiter mass favours the idea that their formation process is different from that of stars and brown dwarfs. They may have formed in proto-planetary disks and subsequently scattered into unbound or very distant orbits.

01.04

**Picturing the Extreme: Planetary Systems Revealed through Direct Imaging**

**Paul Kalas**[1]

[1]*UC, Berkeley.*

9:30 AM - 9:45 AM

*Explorers Room*

Picturing the Extreme: Planetary Systems Revealed through Direct Imaging - ABstract TBD

01.05

**Overview of Atmospheres Observations**

**Giovanna Tinetti**[1]

[1]*University College London, United Kingdom.*

9:45 AM - 10:00 AM

*Explorers Room*

Overview of Atmospheres Observations, Abstract TBD, Giovanna Tinetti (UC London)

## Monday, September 12, 2011, 10:30 AM - 12:00 PM
**02**
***Radial Velocities***
Oral
*Explorers Room*

02.01
**Properties of Sub-Neptune-Size Planets**
**Andrew Howard**[1]
*[1]UC Berkeley.*
10:30 AM - 10:50 AM
*Explorers Room*
Watershed discoveries from the Kepler mission have shaped our understanding of the properties of small planets. Mass and radius measurements of individual planets show that their densities vary by an order of magnitude, owing to great diversity in composition and atmospheric content. The ensemble of small planets discovered by Kepler have a radius distribution that rises steeply with decreasing size. Close-in sub-Neptune-size planets are an order of magnitude more common than hot Jupiters. However, the detailed structure of the planet radius distribution remains partially veiled by poorly known stellar host properties from the Kepler Input Catalog (KIC). Correlations of planet properties with stellar properties are similarly out of focus or unknown. My talk will concentrate on initial results from the California Kepler Survey (CKS) that provide precise stellar parameters from LTE modeling of high-resolution Keck-HIRES spectra of Kepler planet hosts. With this catalog of stellar properties, we expect the detailed structure of the planet radius distribution to emerge, including deviations from a power-law model that suggest common planet sizes and preferred formation scenarios. This improved catalog will also shed light on the variations of planets occurrence with orbital distance and stellar mass/metallicity, offering important clues for the formation of small worlds.

02.02
**HARPS Long-Term Results: Effects of Stellar Magnetic Cycles, and Planet Detection Limits**
**Christophe Lovis**[1], X. Dumusque[1], N. C. Santos[2], S. Udry[1], M. Mayor[1]
*[1]University of Geneva, Switzerland, [2]Centro de Astrofisica da Universidade do Porto, Portugal.*
10:50 AM - 11:10 AM
*Explorers Room*
We present a global analysis of the long-term radial-velocity behavior of solar-type stars, based on the HARPS exoplanet survey. Various spectroscopic indicators allow us to measure stellar magnetic cycles, derive their statistical properties, and study their impact on radial velocities. We discuss their effects on exoplanet detection and present strategies to separate stellar and planetary signals. We also confirm the existence of a population of quiet, non-cycling stars. We finally show that HARPS is able to detect planets of a few Earth masses in the habitable zone of quiet late-G and K dwarfs, using the datasets available today on well-measured stars.

02.03
**Planet Detection Statistics From the HARPS Low-Precision, Volume Limited Sample, After 8 Years of Data Taking.**
**Gaspare Lo Curto**[1]
*[1]E.S.O., Germany.*
11:10 AM - 11:30 AM
*Explorers Room*

The HARPS volume limited sample targets main sequence stars within a shell around Earth from 50pc to 57.5pc. From the still ongoing low precision (2-3m/s) survey started 8 years ago, we detected up to now 46 planets, of which 11 in multiple systems. The giant planet yield from our data is of more than 10% when considering only the stars observed with enough data points to reconstruct an orbit. Among those, 15% show long term drifts which are compatible with a signal from an orbiting companion, and 70% have a large, but yet unexplained radial velocity signal. I will describe the original sample and compare it with the subsample of our target stars with detected planets. Finally I will discuss our detections in the context of all the planet candidates to date.

02.04

**The Penn State - Torun Planet Search**

**Andrzej Niedzielski**[1], A. Wolszczan[2]

*[1]N. Copernicus University, Torun Center for Astronomy, Poland, [2]Department of Astronomy & Astrophysics, Penn State.*

11:30 AM - 11:40 AM

*Explorers Room*

The PennState - Torun Planet Search (PTPS) is devoted to search and detailed characterization of planetary system around intermediate-mass stars.

These stars, due to their high effective temperature are not accessible to the radial velocity (RV) technique during the Main Sequence (MS) evolution. In principle one can look for planetary-mass companions to such stars using other methods (direct imaging, transits) instead. However, the most efficient way to detect and study planets around such objects is to apply the RV technique when they leave the MS and moving toward the giant branch lower effective temperatures and rotation velocities to allow for precise RV measurements.

Within PTPS precise radial velocities (RV) of approx.1000 targets are being obtained from spectra continuously gathered with the Hobby-Eberly Telescope and its High Resolution Spectrograph. The project resulted in discovery of planetary or brown dwarf mass companions to 5 stars. Recently 7 new systems were found, mainly around K giants (Gettel et al. in preparation, Nowak et al. in preparation). In parallel to the RV survey the sample properties are studied in detail. Here we present current status and forthcoming results of the project. Detailed description of the samples (red clump giants, sub-giants and giants, evolved dwarfs) including mass, radius, metallicity and age distributions of target stars will be presented. Since complete description of planetary system hosts requires also information on their rotation velocities and abundances (including lithium abundance) we will presented them as well. As we collected multiple RV observations for all our stars and completed a detailed cross-correlation study we will also discuss binary contamination and present preliminary results on frequency of planetary companion candidates in all 3 samples.

We acknowledge the financial support from the Polish Ministry of Science and Higher Education through grants N203 510938 (AN) and from NASA grant NNX09AB36G (AW).

02.05

**Laser Frequency Comb Supported Stellar Radial Velocity Determination in the NIR: Initial Results.**

**Steve Osterman**[1], S. Diddams[2], F. Quinlan[2], G. Ycas[2], S. Mahadevan[3], L. Ramsey[3], C. Bender[3], R. Terrien[3], B. Botzer[3], S. Redman[4]

*[1]Center for Astrophysics and Space Astronomy, University of Colorado, [2]Time and Frequency Division, National Institute of Standards and Technology, [3]Department of Astronomy & Astrophysics, Pennsylvania State University, [4]Atomic Physics Division, National Institute of Standards and Technology.*

11:40 AM - 11:50 AM

*Explorers Room*

The laser frequency comb presents the potential for a revolutionary increase in radial velocity precision by providing a calibration reference of unprecedented quality in terms of wavelength knowledge, repeatability, number, density and regularity of lines. Promising first steps have been taken leading to the derivation of stellar radial velocities in the NIR H band, a wavelength range well suited to the observation of M dwarfs. These stars, with low mass and low luminosity, are the most prevalent class of stars within 10 parsecs and can be expected to yield a higher reflex velocity for a terrestrial mass planet in the liquid water habitable zone than would be the case with a more massive star such as our own. We present the design and both laboratory and on-sky performance of an H-band laser frequency comb used in conjunction with the Penn State Pathfinder testbed spectrograph and discuss lessons learned and plans for follow on testing.

02.06

**Precision Rvs In The Nir: First On-sky Velocities With A U/ne Lamp And A Laser Frequency Comb**

**Suvrath Mahadevan**[1], L. Ramsey[1], S. Redman[1], C. Bender[1], R. Terrien[1], A. Roy[1], B. Botzer[1], S. Osterman[2], S. Diddams[3], G. Ycas[3], F. Quinlan[3]
*[1]Penn State, [2]CASA, [3]NIST.*

11:50 AM - 12:00 PM

*Explorers Room*

Precision radial velocities in the near infrared (NIR) can help detect terrestrial mass planets around mid and late M dwarfs that are typically too faint in the optical for effective monitoring. The NIR poses a new set of calibration and technology challenges. We will discuss the current state of the art in NIR spectroscopy, and RV precision and present ongoing work at Penn State with the Pathfinder NIR testbed. With the Pathfinder we have demonstrated 10-20 m/s radial velocity precision in the NIR Y band at the 9m Hobby Eberly telescope using a Uranium-Neon hollow cathode lamp as a simultaneous wavelength reference. We shall present these results and also new velocity results from recent first on-sky observations with an H band laser frequency comb developed at NIST and CASA. The innate stability and known frequencies of the comb lines provides an excellent calibrator in the H band, but numerous systematics like fiber modal noise, tellurics, and detector calibration need to be overcome. We will discuss progress made on all these fronts with experiments on the Pathfinder testbed.

We acknowledge support from NSF, NASA, NAI, NIST, Penn State, and the Center for Exoplanets & Habitable Worlds.

## Monday, September 12, 2011, 2:00 PM - 3:30 PM
**03**
***Transiting Planets***
Oral
*Explorers Room*

03.01
**Kepler Results**
**Eric B. Ford**[1], D. Fabrycky[2], A. V. Moorhead[1], J. F. Rowe[3], J. Steffen[4], Kepler Science Team
*[1]Univ. of Florida, [2]UCSC, [3]NASA Ames Research Center, [4]Fermilab.*
2:00 PM - 2:15 PM
*Explorers Room*
We report on the progress of a project to confirm Kepler planet candidates in systems with multiple transiting planet candidates based on correlated transit timing variations (TTVs) among pairs of planet candidates in the same system. We provide an overview of putative TTV signals identified in the Kepler data set (Ford et al. 2011). We describe algorithms for assessing the statistical significance of correlated TTV signals and the results when applied to Kepler data. Kepler was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA, Science Mission Directorate.

03.02
**New Kepler Results**
**Jason Rowe**[1]
*[1]NASA Ames Recenter Center.*
2:15 PM - 2:30 PM
*Explorers Room*
New Kepler Results - Update Title and Abstract Content (ROWE)

03.03
**The Validation of a 2 R_Earth Planet Showing Transit Timing Variations with Kepler and Warm Spitzer**
**Sarah Ballard**[1], D. Charbonneau[1], J. Desert[1], F. Fressin[1], G. Torres[1], Kepler Team
*[1]Harvard-Smithsonian Center for Astrophysics.*
2:30 PM - 2:45 PM
*Explorers Room*
We present evidence for the validation of KOI 84, a 2 R_Earth candidate identified by the Kepler Mission. We gathered 4.5 micron observations of KOI 84 as part of a Warm Spitzer campaign to observe exoplanetary candidates identified by the Kepler mission. The Spitzer light curves provide an independent test of the planetary nature of this candidate. We combine the results of the Spitzer observations with those from BLENDER (a software package to model Kepler light curves as astrophysical false positives) and spectroscopy to present the full body of evidence in favor of the planetary hypothesis. The transit times of KOI 84 also deviate significantly from a linear ephemeris, though there is no evidence for an additional transiting body in the system. We discuss several scenarios that could explain the transit timing variations, including possible planetary companions.

03.04
**Koi-730 As A System Of Four Planets In A Chain Of Resonances**
**Daniel C. Fabrycky**[1], M. J. Holman[2], J. A. Carter[2], J. Rowe[3], D. Ragozzine[2], W. J. Borucki[3], D. G. Koch[3], Kepler team

[1]*University of California, Santa Cruz,* [2]*Harvard-Smithsonian Center for Astrophysics,* [3]*NASA Ames Research Center.*
2:45 PM - 3:00 PM
*Explorers Room*
Among the multiplanet candidates discovered by Kepler, the four-candidate system KOI-730 stands as exceptional because the observed periods lie in a chain of first-order resonances. The period are in the ratios 3:4:6:8 to within a part in 1000, which would be extremely improbable if distinct eclipsing systems were blended together. Yet if all four objects orbit the same star, their masses must be in the planetary regime to fit the transit times and to satisfy long-term stability. Thus we interpret KOI-730 as a planetary system. We investigate the properties orbital migration must have had to assemble such an astounding chain of resonances. The configuration is complicated due to the high number of planets participating, yet the transit observations give precise constraints on architecture, so KOI-730 is a testing ground for any future theories of resonance capture via migration. Funding for this Discovery Mission is provided by NASA's Science Mission Directorate.

03.05
**Spectroscopic Orbits Of *Kepler's* Gas Giants**
**John A. Johnson**[1], T. D. Morton[1], A. W. Howard[2], G. W. Marcy[2], S. Pineda[1]
[1]*Caltech,* [2]*UC Berkeley.*
3:00 PM - 3:15 PM
*Explorers Room*
We will present the preliminary results of our Doppler follow-up program at Keck Observatory focused on Kepler's largest transiting planets (Rp > 5 Rearth). Our sample comprises 50 gas giant planets with periods spanning 1-200 days around stars with a wide range of effective temperatures. Our primary goal is to understand the dependence of the bulk density of gas giant planets on semimajor axis and stellar insolation.

03.06
**Analysis Of Kepler Observations Of HAT-P-7 b**
**Brian Jackson**[1], D. Deming[1]
[1]*Goddard Space Flight Center.*
3:15 PM - 3:30 PM
*Explorers Room*
HAT-P-7 b is among the hottest hot Jupiters ever discovered. Its orbital distance of about 4 stellar radii from an F star suggests the planet has a dayside temperature in excess of 2700 K. Moreover, HAT-P-7 b exerts tremendous tidal influence on its host star, significantly distorting the star's equilibrium shape. Prompted in part by these expectations, the Kepler mission observed the HAT-P-7 system in its short-cadence mode (i.e. 60 second integration times) from May 2009 till December 2010. Early analyses of a subset of these data have revealed the unique phenomena exhibited by this system. Borucki et al. (2009) analyzed the first ten days of observations (quarter 0) and identified atmospheric emission from the planet, suggesting a dayside temperature of 2650 K and little day-to-nightside redistribution of stellar heating. Welsh et al. (2010) followed with an analysis of 34 days of observations (quarter 1) and found an increase in flux from the system as the planet passed through quadrature. These oscillations are consistent with variations in the host star's projected surface area resulting from its tidal distortion (ellipsoidal variations). Since those analyses, another 90 days (quarter 2) of Kepler data have been made public, nearly tripling the number of planetary transits observed. This increase in the number of transits allows more complete removal of other systematic variations, facilitating a search for planetary variability. In this presentation, we will discuss our analysis of the publicly available Kepler transit data of

HAT-P-7 b. We will present improved constraints on transit parameters and the ellipsoidal variations exhibited by the host star. We will also discuss our search for changes from one orbit to the next in the planet's phase curve, indicative of meteorological variability.

Jackson was funded through the NASA Postdoctoral Program (NPP).

## Monday, September 12, 2011, 4:00 PM - 5:30 PM
**04**
***Transiting Planets II***
Oral
*Explorers Room*

04.01
**Status of the WASP-South Search for Transiting Planets**
**Coel Hellier**[1]
[1]*Keele University, United Kingdom.*
4:00 PM - 4:15 PM
*Explorers Room*
WASP-South has now found over 30 transiting exoplanets in the Southern hemisphere. Combining with winnowing of
candidates by the TRAPPIST robotic photometric telescope and with radial velocities from Euler/CORALIE makes an efficient team for transiting-planet detection around stars of magnitudes 9 to 13. I review the current status of the WASP-South search and the latest planet discoveries, and discuss emerging patterns in the distribution of hot Jupiters.

04.02
**Update to Intrinsic Planetary Frequencies Based on Kepler Observations**
**William J. Borucki**[1], D. G. Koch[1]
[1]*NASA Ames Research Center.*
4:15 PM - 4:30 PM
*Explorers Room*
The initial estimates of the intrinsic exoplanet frequencies were based on the first 132 days of Kepler observations and on the stellar properties listed in the Kepler Input Catalog (KIC). Improved estimates of stellar temperatures, sizes, and metallicities are being obtained from spectroscopic observations of individual target stars and SME analysis. In turn, the new values of stellar properties contribute to more accurate estimates of candidate size and association with stellar characteristics. Continued analysis of the candidates has increased the certainty for separating false positives from true candidates. Based on the improved candidate and stellar parameter values, we present updated and extended estimates of intrinsic frequencies and the associations of exoplanets with stellar parameters.

04.03
**Spitzer Observations Suggest a Low Kepler False Postive Rate.**
**Jean-Michel Desert**[1], D. Charbonneau[1], F. Fressin[1], S. Ballard[1], and the Kepler Team
[1]*Harvard University.*
4:30 PM - 4:45 PM
*Explorers Room*
I present the results from a large project that uses 800 hours of the Spitzer Space Telescope to gather near-infrared photometric measurements of Kepler Object of Interest (KOI). The project's main purposes are to validate the planetary status of the Kepler candidates and to estimate observationally the Kepler false positive rate. A small amount of this telescope time is also dedicated to study the atmospheres of confirmed planets.
I revue the project and introduce our target sample which is composed of 34 candidates selected amongst the first 400 KOIs. This list contains mainly sub-Neptune sizes candidates orbiting a wide range of spectral type stars. I present the analysis of the complete sample. By comparing the transit light

curves of candidates observed with Kepler and Spitzer, we can exclude significant sources of astrophysical false positives resulting from blends (eclipsing binaries, hierarchical triples, etc...) that can mimic an exoplanetary signature in the Kepler bandpass. I show that our measured Spitzer transit depths are almost entirely in agreement with the Kepler depths. Our results suggest that the Kepler false positive rate is extremely low.

04.04

**The validation of Kepler planet detections**

**Francois Fressin**[1], G. Torres[2], Kepler team

*[1]Harvard CFA, [2]Harvard-Smithsonian CFA.*

4:45 PM - 5:00 PM

*Explorers Room*

Many of the most interesting candidate transiting planets identified by the Kepler Mission can not be confirmed by spectroscopic means, with the detection of the reflex motion of the star. These include rocky planets in the habitable zone of their parent stars. The Kepler team has developed ways of "validating" candidates by modeling the photometry to place constraints on the wide range of false positives ("blends") that can mimic the transit light curves. We model Kepler transit light curves assuming they are the result of the brightness variations of an eclipsing binary being attenuated by the brighter candidate star. This so-called 'Blender' study allows identifying the range of spectral type and magnitude difference compared to the target for possible blends.

We combine the frame of the Blender results with constraints from the different follow-up observations. Speckle interferometry, Adaptive optics imaging, and the detection of a centroid shift during the transit in the Kepler photometric aperture, all combine to constrain the possible separation of an unseen background star. We also observe the most interesting targets with WarmSpitzer to check the achromaticity of the transit signal. This presentation will describe the Blender modeling, and how it is combined with complementary constraints from follow-up observations to estimate the frequency of blends, and ultimately the probability that a candidate is a bona-fide planet. We illustrate this technique with the discoveries of several Super-Earths.

04.05

**Kepler-11: Oddball Or Extreme Member Of A Class Of Densely-packed Planetary Systems?**

**Jack J. Lissauer**[1], Kepler Science Team

*[1]NASA Ames Research Center.*

5:00 PM - 5:15 PM

*Explorers Room*

With 6 transiting planets orbiting closer to their star than Venus is to our Sun, Kepler-11 is unique among the 160,000+ exoplanet targets being observed by NASA's Kepler mission. We examine Kepler-11 in the context of the distribution of candidate multi-planet systems identified in Kepler data in order to constrain just how rare this type of densely-packed planetary system is likely to be.

04.06

**Investigating the planet-metallicity correlation with Kepler**

**Tim Morton**[1], J. Johnson[1], G. Marcy[2], A. Howard[2], H. Isaacson[2], K. Hawkins[3]

*[1]Caltech, [2]Berkeley, [3]Ohio University.*

5:15 PM - 5:30 PM

*Explorers Room*

One of the most striking results from the early days of exoplanet science is the strong correlation between a star's metallicity and the probability of it hosting a giant planet. This planet-metallicity correlation is predicted to be weaker for smaller planets but remains unmeasured for Neptune- and

Earth-sized planets. The planet detections from the Kepler mission provide an enticing opportunity to test the planet-metallicity relationship for small planets, but the host stars in the Kepler field have unknown metallicities. To this end, we present preliminary results from the California Kepler Survey (CKS), which is designed to measure the stellar properties of Kepler Objects of Interest, as well as characterizing the metallicity distribution of parent sample of Kepler target stars.

## Tuesday, September 13, 2011, 8:30 AM - 10:00 AM
## 05
### *Planets in Binaries and Star Clusters*
Oral
*Explorers Room*

05.01

**The Search for Transiting Circumbinary Planets**

**Joshua A. Carter**[1], L. Doyle[2], The Kepler Science Team
*[1]Smithsonian Astrophysical Observatory, [2]SETI Institute.*

8:30 AM - 8:50 AM

*Explorers Room*

We report on the progress of a project to search for planets on circumbinary orbits around eclipsing stars in the Kepler field with a special focus on systems where the planet is seen to transit one or both stars. We describe the unique photometric signatures in such systems and the degree to which they are affected by both dynamical and light time effects. Kepler was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA, Science Mission Directorate.

05.02

**The Kepler Search for Non-Transiting Circumbinary Planets**

**William F. Welsh**[1], Kepler Team
*[1]San Diego State Univ..*

8:50 AM - 9:05 AM

*Explorers Room*

Kepler is observing over 2000 eclipsing binary stars, and we have carefully measured the eclipse times of those systems with orbital periods greater than 1.5 days. We have found that a sizable number of systems possess significant periodic eclipse timing variations in their O-C figures, indicating the presence of (at least) a third body. The signal-to-noise of a stellar eclipse is much larger than that of a planet transit, allowing us to measure very small timing variations, in some cases as small as 20-25 seconds. The amplitude and period of the O-C variations allow us to constrain the mass of the unseen third body: a small amplitude O-C implies a small mass, perhaps substellar. In this talk we report the results of our search for candidate circumbinary non-transiting planets.

Kepler was selected as the 10th mission of the Discovery Program with funding provided by NASA Science Mission Directorate.

05.03

**Companion Candidates around Transiting Planetary Systems: SEEDS First/Second Year Results**

**Norio Narita**[1], Y. H. Takahashi[2], SEEDS/HiCIAO/AO188 teams
*[1]NAOJ, Japan, [2]University of Tokyo, Japan.*

9:05 AM - 9:20 AM

*Explorers Room*

It is well known that a significant fraction of known extrasolar planets has significant orbital eccentricity. Moreover, recent measurements of the Rossiter-McLaughlin effect have revealed that about one-third of transiting planets have tilted orbits. Those eccentric or tilted planets are believed to evlolved through dynamical planetary migration due to the interaction with some kind of outer massive bodies. We started high-contrast direct imaging observations as a part of SEEDS (Strategic Explorations of Exoplanets and Disks with Subaru) project to search for counterparts of planetary migration

mechanisms. In this talk, we report SEEDS first/second year results which may shed light on the relation between eccentricity/obliquity of inner planets and the existence of outer companions.

05.04

**Hd196885, The Most Extreme Planetary System?**

**Gael Chauvin**[1]

*[1]IPAG/CNRS and MPIA-Heidelberg, Germany.*

9:20 AM - 9:30 AM

*Explorers Room*

Rare close binaries hosting giant planets offer an ideal laboratory to explore the properties and the stability of extreme planetary systems. In 2005, we identified one of the most extreme planetary with the discovery of a close (about 20 AU) secondary stellar companion to the exoplanet host HD196885A. Combining radial velocity observations and deep imaging, we derived the complete orbital parameters of the stellar binary (including its orbital inclination and its accurate mass). It enabled us to investigate the stability of the inner giant planet HD196885 Ab. Our dynamical simulations show that the system is currently and surprisingly more stable in a high mutual inclination configuration that falls in the Kozai resonance regime. If confirmed, this system would constitute one of the most compact non-coplanar systems known so far, and would raise several questions about its formation and stability.

05.05

**A Collision Model For Planet Formation**

**Zoe Leinhardt**[1], S. T. Stewart[2], S. Paardekooper[3]

*[1]University of Bristol, United Kingdom, [2]Harvard University, [3]University of Cambridge, United Kingdom.*

9:30 AM - 9:45 AM

*Explorers Room*

Collisions are a core component of planet formation. Using new high-resolution simulations of collisions between planetesimals for a wide range of projectile-to-target mass ratios, impact angles, and impact velocities, we derive a complete analytic description of the dynamical outcome for any collision between gravity-dominated bodies (from 100 m planetesimals to planets). The range of impact parameters encountered during growth from planetesimals to planets span multiple collision outcome regimes: cratering, merging, disruption, hit-and-run, and erosive hit-and-run events. We derive equations to demarcate the transition between collision regimes and to describe the size and velocity distributions of the post-collision bodies. The scaling laws include only four material parameters, which are tightly constrained by the available data. All collision outcomes are described in terms of the impact conditions and the catastrophic disruption criteria, the specific energy required to disperse half the total colliding mass. The collisional model presented here will significantly improve the physics of collisions between gravity-dominated bodies in numerical simulations of planet formation and collisional evolution.

This work is made possible by STFC and NASA.

05.06

**Planets in Dense Star Clusters**

**Sourav Chatterjee**[1], F. A. Rasio[2], E. B. Ford[1]

*[1]University of Florida, [2]Northwestern University.*

9:45 AM - 10:00 AM

*Explorers Room*

Star-formation studies indicate that most stars are formed in clusters. While hundreds of planets have been discovered around field stars, few planets are discovered in star clusters, despite extensive searches for planets in the nearest globular cluster (GC) 47 Tuc. One of the long-standing questions is are there planets in clusters around normal main-sequence stars? It is suggested that the low

metallicities of GCs might result in a low abundance of giant planets. Alternatively, the high rate of stellar encounters may have influenced planet formation and evolution in dense clusters. We revisit these questions in light of the vast amount of data available from Kepler. The Kepler field contains low-density open clusters where the metallicities are close to Solar (or even higher). We have started detailed numerical simulations of star-clusters with a large range of masses and central densities (spanning values typical for the Galactic GCs as well as the Kepler clusters) including all relevant physics and including planet-hosting stars. I will present our results from this study.

## Tuesday, September 13, 2011, 10:30 AM - 12:00 PM
**06**
***R-M Measurements and Orbital Inclinations***
Oral
*Explorers Room*

06.01
**New Observations of Spin-Orbit Alignment: Hot Stars, Cool Stars, Kepler Stars**
**Joshua N. Winn**[1]
*[1]MIT.*
10:30 AM - 10:45 AM
*Explorers Room*
In the Solar system, the planets follow orbits that are aligned with the Sun's equatorial plane to within about 7 degrees. Exoplanets show a wider variety of orbits, including some that are highly tilted and even retrograde with respect to the rotation of the host star. Thissuggests that planet migration involves few-body gravitational interactions, which frequently disrupt the initial coplanarity of planetary systems. Last year a possible pattern emerged: hot stars (T>6250K) with hot Jupiters have high obliquities. I will present stronger evidence for this pattern, based on more than a dozen new observations of the Rossiter-McLaughlin effect. I will also discuss the status of proposed explanations for this pattern, including the possibility that the low obliquities of cool stars are a consequence of the stronger tidal dissipation within their convective envelopes. Finally, I will present new observations of spin-orbit alignment for selected Kepler systems, which are qualitativelydifferent than the systems which have been examined to date.

06.02
**New Measurements Of Spin-orbit Angles In Planetary And Binary Star Systems**
**Simon Albrecht**[1]
*[1]MIT.*
10:45 AM - 10:55 AM
*Explorers Room*
In this talk I will present new measurements of the Rossiter-McLaughlin (RM) effect to determine spin-orbit angles for exoplanetary systems and binary star systems, and discuss the implications for the formation of close-in planets and close binary stars. Five new observations of transiting planets were undertaken with the newly-installed Planet Finding Spectrograph at the Magellan observatory. Particular attention will be given to statistical biases associated with fitting low signal-to-noise RM data, in which care must be taken to avoid deriving a seemingly significant result when one has observed only noise. This problem has not yet been recognized by the community, but is similar to a more familiar problem that occurs when measuring orbital eccentricity. This issue will become more important for spin-orbit measurements of smaller planets, or Kepler planets with faint host stars. Finally I will present new results from our "BANANA" survey of close binary systems, including some misaligned systems similar to the case of DI Herculis. Measurements such as these are fundamental input to theories of binary star formation and may help to interpret the observed diversity of spin-orbit angles among exoplanetary systems.

06.03
**Inclination Distribution of Exoplanetary Systems**
**Darin Ragozzine**[1], K. Team[2]
*[1]Harvard University, [2]NASA.*

10:55 AM - 11:10 AM

*Explorers Room*

The Kepler Space Telescope is revealing for the first time valuable constraints on the inclination distribution of planetary systems with the discovery of systems of candidate multiple transiting planets. As an ensemble, the 170 candidate multi-transiting systems discovered by Kepler reveal a large population of 3-4 small nearly-coplanar planets with periods less than 125 days (Lissauer, Ragozzine, et al. 2011). The presence of multiple transiting planets does not measure the true mutual inclinations, but transit timing and duration variations (or lack thereof), multi-Rossiter-McLaughlin, and/or exoplanet mutual events can measure or put good constraints on true mutual inclinations in individual systems (Ragozzine & Holman 2010). I will discuss the recent results from Kepler observations on the inclination distributions of different exoplanet population. I will also discuss a new method for validating candidates in multi-transiting systems that uses the coplanarity of planetary systems to minimize the probability that such candidates are false positives. A summary of our understanding of exoplanetary inclinations and implications for the formation and evolution of planetary systems will also be provided.
ESSII SOC:
It is possible that I will focus my talk on a detailed analysis of KOI-500, the Kepler system with 5 candidate planets with new results showing that all the candidates are planets and discussing the intricate three-body resonance structure seen in this system.

This work is supported by the Institute for Theory and Computation at Harvard University. Kepler was competitively selected as the tenth Discovery mission. Funding for this mission is provided by NASA's Science Mission Directorate.

06.04

**The Latest Rossiter-McLaughlin Measurements of WASP Systems and Their Impact on Theories of Planetary Misalignment**

**David Brown**[1], A. Collier Cameron[1], D. R. Anderson[2], B. Enoch[1], C. Hellier[2], P. F. L. Maxted[2], G. R. M. Miller[1], D. Pollacco[3], D. Queloz[4], E. Simpson[3], B. Smalley[2], A. H. M. Triaud[4], I. Boisse[5], F. Bouchy[6], M. Gillon[7], G. Hebrard[6], WASP Consortium

*[1]University of St Andrews, United Kingdom, [2]Keele University, United Kingdom, [3]Queen's University, United Kingdom, [4]University of Geneva, Switzerland, [5]Institut d'Astrophysique de Paris, France, [6]Observatoire de Haute Provence, France, [7]University of Liege, Belgium.*

11:10 AM - 11:25 AM

*Explorers Room*

The number of planetary systems for which the sky-projected angle between the orbital and stellar spin axes has been measured is rapidly increasing. It is now possible to examine the ensemble of results to determine trends that point towards potential mechanisms for the creation of misaligned planetary orbits. We present the latest Rossiter-McLaughlin observations of hot Jupiters discovered by the WASP survey, discuss their level of alignment, and examine their impact on the theoretical underpinnings of said mechanisms.

06.05

**The Origin of Retrograde Hot Jupiters**

**Smadar Naoz**[1], W. Farr[2], Y. Lithwick[2], F. Rasio[2], J. Teyssandier[2]

*[1]Harvard University, [2]Northwestern University.*

11:25 AM - 11:40 AM

*Explorers Room*

The search for extra-solar planets has led to the surprising discovery of many Jupiter-like planets in very close proximity to their host star, the so-called ``hot Jupiters'' (HJ). Even more surprisingly, many of these HJs have orbits that are eccentric or highly inclined with respect to the equator of the star, and some (about 25%) even orbiting counter to the spin direction of the star. This poses a unique challenge to all planet formation models. We show that secular interactions between Jupiter-like planet and another perturber in the system can easily produce retrograde HJ orbits. We show that in the frame of work of secular hierarchical triple system (the so-called Kozai mechanism) the inner orbit's angular momentum component parallel to the total angular momentum (i.e., the z-component of the inner orbit angular momentum) need not be constant. In fact, it can even change sign, leading to a retrograde orbit. A brief excursion to very high eccentricity during the chaotic evolution of the inner orbit allows planet-star tidal interactions to rapidly circularize that orbit, decoupling the planets and forming a retrograde hot Jupiter. We estimate the relative frequencies of retrograde orbits and counter to the stellar spin orbits using Monte Carlo simulations, and find that the they are consistent with the observations. The high observed incidence of planets orbiting counter to the stellar spin direction may suggest that planet--planet secular interactions are an important part of their dynamical history.

06.06

**Orbital Evolution of Exoplanets Caused by Scattering and Tides**

**Makiko Nagasawa**[1], S. Ida[1]
*[1]Tokyo Institute of Technology, Japan.*

11:40 AM - 11:50 AM

*Explorers Room*

We have investigated formation of Hot-Jupiters by a combination of mutual scattering, secular effects and tidal circularization. We perform N-body simulations of three gas giant planets including the effect of the general relativity and inclusion of inertial modes in additions to fundamental modes in the tides. We found that in about 350 cases out of 1200 runs (about 30%), the eccentricity of one of planets is excited highly enough for the tidal circularization by mutual close scatterings followed by Kozai effect or the effect of secular chaos due to outer planets and the planet becomes a close-in planet. The formation probability of close-in planets is the same order of that of simulations without the general relativity and the inertial modes. The formation probability of close-in planets is about 20-30%
almost independent of planetary mass/radius except in the cases of massive/compact planets.
The fraction of formation of eccentric close-in planets is about 4% in all the close-in planets. They are formed by long term secular perturbations between remaining two planets after ejection of one planet (two-body circularization), rather than chaotic perturbations among three planets before the ejection (three-body circularization).The fraction we get here is the minimum value of a limit of unstable system. If the 3-planets' system is kept in a tentatively stable stage for longer time, the portion of eccentric close-in planets would be enhanced.
We found in our simulations that as much as 29% of close-in planets have retrograde orbits. The retrograde planets are formed by three-body circularization and tend to have small eccentricities due to the exchange of eccentricities and inclinations.
This work was supported by MEXT-KAKENHI(21740324) Grant-in-Aid for Young Scientists (B).

06.07

**Frequency of Highly Inclined Planets from Planet-Planet Scattering plus Tidal Damping**

**Matthew J. Payne**[1], A. C. Boley[1], E. B. Ford[1]
*[1]University of Florida.*

11:50 AM - 12:00 PM

*Explorers Room*

Previous studies of planet-planet scattering (e.g. Chatterjee et al. 2008 and Nagaswa et al. 2008) have predicted a broad range of inclination distributions for planetary orbits at the end of the scattering

phase.
We demonstrate that essentially all apparent discrepancies between such studies disappear if:
(i) tidal effects are included for all close approaches within a critical tidal radius, r_crit, and
(ii) consistent measurement metrics are implemented.
Having reconciled previous results, we demonstrate that among planetary systems which have undergone planet-planet scattering, the orbital inclination distribution for planets with a pericenter distance less than a critical tidal damping radius, r_crit, is expected to differ significantly from that of planets beyond r_crit. Thus, we predict that if planet-planet scattering occurs in a significant fraction of planetary systems, then future Rossiter-McLaughin observations of the more distant transiting planets being revealed by NASA's Kepler mission will have a significantly different inclination distribution to that of the previously observed hot-Jupiters.

## Tuesday, September 13, 2011, 2:00 PM - 3:30 PM
**07**
***Direct Imaging***
Oral
*Explorers Room*

07.01

**Direct Detection of Extra-solar Planets Using High Contrast Imaging and the Gemini Planet Imager**

**James Graham**[1]
[1]*Dunlap Institute for Astronomy and Astrophysics, Canada.*

2:00 PM - 2:15 PM
*Explorers Room*

Large astronomical telescopes coupled with new adaptive optics technologies enable high contrast imaging. Current systems approach a dynamic range of nearly a million to one on scales near the diffraction limit. In the coming decade a new generation of instruments will improve contrast by another one to two orders of magnitude and provide images of extra-solar planetary systems. The Gemini Planet Imager (GPI) is one of these instruments, which will see first light in 2012. Recently the Gemini Observatory has approved an 890 hour campaign to directly detect planets and image debris disks using GPI.

07.02

**The Gemini NICI Planet-Finding Campaign: Statistical Constraints on Planet Populations**

**Eric L. Nielsen**[1], M. C. Liu[1], Z. Wahhaj[1], B. A. Biller[2], M. Chun[1], L. M. Close[3], C. Ftaclas[1], T. L. Hayward[4], D. W. Toomey[5], Gemini NICI Planet-Finding Campaign Team
[1]*Institute for Astronomy, University of Hawaii,* [2]*MPIA, Germany,* [3]*Steward Observatory, University of Arizona,* [4]*Gemini Observatory, Chile,* [5]*Mauna Kea Infrared.*

2:15 PM - 2:30 PM
*Explorers Room*

The Gemini NICI (Near Infrared Coronagraphic Imager) Planet-Finding Campaign is already the largest, deepest direct imaging survey for close-in extrasolar planet ever conducted, given the >200 stars observed to date, with median contrasts of 15 magnitudes at 1". We describe the quantitative methodology used to design the campaign target list and survey design, in order to maximize the likelihood of detecting planets with NICI, and to study the dependence of planet distributions on stellar mass and age. We also present early results from our analysis of the statistical constraints placed on extrasolar planet populations. Using Monte Carlo simulations of planet populations, and the first 120 stars observed by the survey, we are able to place much stronger constraints on the distribution of long-period extrasolar planets than has been found to date, closing the gap between direct imaging and radial velocity studies of the semi-major axis distribution of extrasolar giant planets, providing a key test of planet formation theory. Our analysis shows that fewer than 20% of solar-type stars can have planets more massive than two Jupiter masses in orbits beyond 10 AU. Using a mass and orbital distribution for Jovian planets derived from radial velocity planets, we find an outer semi-major axis for gas-giant planets of 33 AU at 95% confidence.

07.03

**Probing Nearby Planetary Systems by Debris Disk Imaging**

**Karl R. Stapelfeldt**[1]
[1]*JPL and GSFC.*

2:30 PM - 2:45 PM

*Explorers Room*

Many main-sequence stars possess tenuous circumstellar dust clouds believed to trace extrasolar analogs of the Sun's asteroid and Kuiper Belts. While most of these "debris disks" are known only from far-infrared photometry, a growing number of them are now spatially resolved. In this contribution, I review recent imaging results on debris disk structures from the Hubble, Spitzer, and Herschel Space Telescopes. Specific cases of disk interactions with imaged and radial velocity exoplanets will be discussed. I will show how combined modeling of the optical and infrared datasets can place strong constraints on dust particle properties in the disks.
Future developments in debris disk imaging will be discussed.

07.04

**Supermassive Planets or Ultralight Brown Dwarfs? A New Population of Wide Substellar Companions**

**Ray Jayawardhana**[1], M. Janson[1], D. Lafreniere[2], M. Bonavita[1]
*[1]Univ. of Toronto, Canada, [2]Univ. of Montreal, Canada.*

2:45 PM - 3:00 PM

*Explorers Room*

Numerous radial velocity and direct imaging studies have noted a deficit of brown dwarf companions to (solar-type) stars at a range of orbital separations. Yet recent observations have revealed a number of substellar companions in wide orbits. We are now completing a systematic, high-contrast adaptive optics (AO) imaging search with sensitivity well into the planetary regime at large separations, targeting over 200 nearby young stars, most of which have never been observed with AO before. Here we will present thesurvey highlights, including the discovery, proper motion confirmation, and spectroscopic characterization of several substellar companions with mass ratios as low as ~0.01 and in orbits as wide as 300-900 AU. These objects may represent the bottom end of the stellar companion mass function or the top end of the planet population, though both scenarios pose challenges to conventional formation models.

07.05

**Orbital Properties of the HR 8799 Planetary System**

**Quinn M. Konopacky**[1], B. Macintosh[1], D. Fabrycky[2], C. Marois[3], T. Barman[4]
*[1]LLNL, [2]UC Santa Cruz, [3]HIA, Canada, [4]Lowell Observatory.*

3:00 PM - 3:15 PM

*Explorers Room*

We present a new dynamical analysis of the HR 8799 planetary system. This analysis takes advantage of improved astrometry from all data taken with the Keck II telescope by correcting for biases introduced by the NIRC2 camera's focal plane mask. We now have sufficient time coverage to constrain the orbital properties of these planets independent of stability considerations. We find that the planets cannot have high eccentricities (<0.4) and likely have similar inclinations, implying they formed in a common disk. Applying stability criteria to astrometrically-allowed orbits allows us to put constraints on the masses of these planets. The addition of a fourth planet makes it difficult, if not impossible, to find stable configurations for planetary masses greater than 7 Mjup. This argues that the lower masses predicted for a younger system age (~30 Myr) are preferred. Using the lessons learned from this analysis, we perform simulations that show that we will be able to successfully constrain the eccentricity distribution of widely separated planets discovered by the upcoming Gemini Planet Imager Exoplanet Survey (GPIES). These constraints will be vital in determining the formation pathways for planets like those in the HR 8799 system.

07.06

**High Spatial Resolution Imaging of a Dynamically Perturbed Circumstellar Debris Disk**

**Michael P. Fitzgerald**[1], P. Kalas[2], J. R. Graham[3]
*[1]University of California, Los Angeles, [2]University of California, Berkeley, [3]University of Toronto, Canada.*
3:15 PM - 3:30 PM
*Explorers Room*
Circumstellar debris disks, consisting of freshly produced dust grains around main sequence stars, act as tracers of planet formation. The directly detected planets around A stars are all associated with circumstellar debris disks. The structure of such a disk can encode useful information about the associated planets and their orbits. The archetypal example is the belt around Fomalhaut. The offset of this belt is a result of secular perturbations by the eccentric planet. The sculpting of the inner edge of this belt has been used to constrain the planet's mass. HD 61005 is a nearby (35 pc) dusty G dwarf. Its debris disk has been imaged in scattered light by HST, revealing a near-edge-on inner disk, with a 'swept' outer disk of small grains. The initial physical interpretation of this system has focused on ISM interaction as the root cause the swept morphology. Limits on interstellar NaI absorption require the purported ISM cloud to be warm and tenuous, acting only to secularly perturb grains on bound orbits. Recent AO imaging observations show the inner disk is a ring-like structure offset from the star. We will present the results of our high-angular-resolution Keck AO imaging of this system. Our models of the scattered light show that if the inner disk is intrinsically circular, it has a radius of ~70 AU and is offset by ~18 AU from the star. We explore the possibility that the offset is caused by secular perturbations from an eccentric planet. We will show how a planet inclined relative to the parent body population can cause small grain orbits to have the appearance of a swept morphology. We will use these dynamical models to constrain the mass and orbit of an eccentric, inclined giant planet, providing a hypothesis testable with upcoming direct imaging surveys using next-generation instruments.

## Tuesday, September 13, 2011, 4:00 PM - 5:30 PM

**08**

***Giant Planet Formation***

Oral

*Explorers Room*

08.01

**The Evolution of Protoplanetary Disks and the Diversity of Giant Planets**

**Benjamin Bromley**[1], S. J. Kenyon[2]

*[1]University of Utah, [2]Smithsonian Astrophysical Observatory.*

4:00 PM - 4:15 PM

*Explorers Room*

We report new results for simulations of planets growing from a sea of planetesimals within a protoplanetary disk. We track the viscous evolution of the disk, coagulation and fragmentation of planetesimals, grain removal by gas drag and radiation forces, gravitational dynamics of protoplanets, and accretion of gas by icy or rocky cores. Key physical parameters for our code include the initial mass of the disk (M_disk), the gas viscosity (α), the disk's photoevaporation rate (ϕ), and the fraction of accretion energy that is lost to radiation by accreting massive planets (η). Our new results demonstrate how each of these parameters impact the numbers, masses, and orbital parameters of newly-formed planetary systems. In our published results, we show how high M_disk and low α promote the formation of more massive planets. In this talk, we illustrate how high photoevaporation rates favor formation of Neptunes over Jupiters, in line with observations of exoplanetary systems.

08.02

**The Grand Tack Scenario: Reconstructing The Migration History Of Jupiter And Saturn In The Disk Of Gas**

**Alessandro Morbidelli**[1], K. Walsh[2], S. Raymond[1], D. O'Brien[3], A. Mandell[4]

*[1]CNRS, France, [2]SWRI, [3]PSI, [4]NASA Goddard Space Flight Center,.*

4:15 PM - 4:30 PM

*Explorers Room*

Extrasolar planetary systems provide evidence for extensive migration of giant planets. However, it is usually assumed that Jupiter and Saturn did not migrate significantly. Hydrodynamical simulations show that Jupiter should have migrated inwards in the solar nebula when Saturn was not yet formed. Then Saturn, once close to its final mass, could have migrated faster than Jupiter until being caught in their mutual 2:3 mean motion resonance. Once in resonance, the two planets could have migrated outwards. We find that the inward-then-outward migration of Jupiter, with a migration reversal at 1.5AU, explains the current structure of the Solar System at an unprecedented level. It would have truncated the disk of planetesimals at about 1AU, explaining the large Earth/Mars mass-ratio. It would have also depleted, then re-populated the asteroid belt region, with inner-belt bodies originating between 1 and 3AU and outer belt bodies originating between and beyond the giant planets, thus explaining the significant compositional differences across the belt. Finally, the orbits of the giant planets when the gas is removed would correspond to the initial conditions of the "Nice model", which explains the current configuration of the outer Solar System. Therefore, we conclude that there is substantial evidence for a wide-range migration of Jupiter and Saturn in the solar nebula. Assuming that giant planets form in sequence at increasing distances from the central star, most of the observed diversity of planetary systems could stem from the occurrence or avoidance of two events: (i) the capture in resonance of the first, inner planet by the second, initially smaller one, which triggers outward migration and (ii) the growth of the outer planet beyond the mass of the inner one, which causes inward migration of both planets to resume. The Solar System structure results from the occurrence of (i) and avoidance of (ii).

08.03

**In Situ Accretion Of Hot Neptunes And Super Earths**

**Bradley M. Hansen**[1]

*[1]UC, Los Angeles.*

4:30 PM - 4:45 PM

*Explorers Room*

We present the results of calculations of the in situ accretion of planets on sub-Au scales, for a range of disk masses. We show that massive planetesimal disks can reproduce the properties of observed Hot Neptune systems, suggesting that migration is not required to produce large core, gaseous envelope planets on small scales. For lower mass planetesimal disks, rocky planets are more common, and are compared to the emerging Kepler results.

08.04

**Core Accretion at Wide Separations: The Critical Role of Gas**

**Ruth Murray-Clay**[1], K. Kratter[1], A. Youdin[1]

*[1]Harvard-Smithsonian Center for Astrophysics.*

4:45 PM - 5:00 PM

*Explorers Room*

Core accretion enjoys wide acceptance as the standard model of giant planet formation. However, traditional implementations of this model have difficulty generating gas giants at large stellocentric distances, where a core cannot grow quickly enough to accrete a gas envelope before the dispersal of its host disk. Direct imaging studies indicate that gas giants exist at wide separations, leading to speculation that another formation process, such as gravitational instability, may be at work. Here, we demonstrate that when embedded in a gas disk, planetary cores grow substantially faster than previously estimated, allowing core accretion to operate at large separations. In particular, we argue that a growing core can quickly accrete a population of small planetesimals that occupy orbits damped by gas. For a range of planetesimal sizes, these small bodies form a thin enough layer in the disk that fast accretion is possible, but nevertheless can decouple from the gas and accrete onto the core. This process of drag-mediated gravitational focusing leads to fast growth, rendering core accretion plausible out to distances at which directly imaged planets have been observed.

08.05

**Imaging The Candidate Proto-planet HL Tau B**

**Jane Greaves**[1], K. Rice[2], A. Richards[3], T. Muxlow[3], D. Forgan[2], B. Sibthorpe[4]

*[1]University of St Andrews, United Kingdom, [2]University of Edinburgh, United Kingdom, [3]JBCA, United Kingdom, [4]UK-ATC, United Kingdom.*

5:00 PM - 5:10 PM

*Explorers Room*

Our VLA and MERLIN radio images of the HL Tau system trace the emission from the proto-planetary disc at ultra-high resolution. A candidate proto-planet is seen at tens of AU from the star, at these long wavelengths where it stands out from the bright background disc. A simulation shows that gravitational instability within the disc is capable of forming this ~10 Jupiter-mass object. Submillimetre images made recently with SCUBA-2 show that HL Tau's disc is perturbed by an interaction with XZ Tau, and this may have helped trigger disc fragmentation, in a flyby event as recent as a few thousand years ago.

08.06

**The Evolution of Wide-Orbit Proto-Gas Giants Born by Disk Instability: The Pre-Dissociative Collapse Phase**

**Aaron C. Boley**[1]
*[1]University of Florida.*

5:10 PM - 5:20 PM
*Explorers Room*

At very large separations from the star, gravitational instabilities can fail to self-regulate, leading to fragmentation of spiral structure into substellar companions. In this mechanism, clumps will evolve for a period of time in a massive disk. It remains unclear whether gas giants can be a typical outcome of this process, or whether mass accretion to brown dwarf masses is inevitable. Following fragmentation, clumps have considerable angular momentum and are subject to tidal perturbations from the star. Only the low-angular momentum material will undergo rapid collapse, due to molecular hydrogen dissociation, and form a planet-size core. The rest of the material will form a circumplanetary disk. We use hydrodynamics simulations of clumps during their pre-collapse evolution to explore the angular momentum transport during these early stages. We compare the contraction timescales for rotating cases with those expected for clumps in isolation. Angular momentum and tidal effects play a fundamental role in determining the mass scale of the post-collapse cores, as well as the observability of these objects. ACB acknowledges support through a Sagan Fellowship.

08.07

**From Star Formation to Exoplanets**

**Kaitlin M. Kratter**[1]
*[1]Harvard-Smithsonian CfA.*

5:20 PM - 5:30 PM
*Explorers Room*

The formation of planets is intimately connected with the birth of stars and the dynamics of accretion disks. I will discuss how the star formation process influences the initial conditions for planet formation, and show how the formation of binary star systems differs from that of giant planets. Finally, I will describe how next-generation telescopes can place constraints on the expected mass ratio distribution of stellar and substellar objects formed via disk fragmentation.

## Wednesday, September 14, 2011, 8:30 AM - 10:00 AM
**09**
***Dynamical Evolution***
Oral
*Explorers Room*

09.01
**New Results On Chaotic Motion In The Solar System**
**Jacques Laskar**[1]
[1]*Observatoire de Paris, France.*
8:30 AM - 8:45 AM
*Explorers Room*
The motion of the planets in the Solar System is chaotic (Laskar, 1989, 1990, Sussman and Wisdom, 1992). The resulting exponential divergence sets limits on the time validity of long-term integrations aimed for paleoclimate studies. The solution La2004 (Laskar et al, 2004)
is valid over 40 Myr, and has been recently extended to 50 Myr (Laskar et al, 2011a). The big question is then : how far can we extend this time of validity, knowing that every additional 10 Myr, the model needs an improvement by a factor of 10 due to exponential divergence.
In the most recent models, we consider the full Solar System including (1) Ceres and some of the main asteroids, (2) Pallas, (4) Vesta, (7) Iris, and (324) Bamberga. We show that close encounters among these small bodies induce strong chaotic behavior in their orbits and in
those of many asteroids that are much more chaotic than previously thought. Even if space missions will allow very precise measurements
of the positions of Ceres and Vesta, their motion will be unpredictable over 400 kyr. As a result, it will never be possible to recover the precise evolution of the Earth's eccentricity beyond 60 Myr. Ceres and Vesta thus appear to be the main limiting factors for any precise reconstruction of the Earth orbit, which is fundamental for the astronomical calibration of geological timescales. Moreover, collisions of Ceres and Vesta are possible, with a collision probability of 0.2% per Gyr (Laskar et al, 2011b).
Laskar, J., Fienga, A., Gastineau, M., Manche, H.: 2011a, La2010: a new orbital solution for the long-term motion of the Earth , A&A, 532, A89
Laskar, J., Gastineau, M., Delisle, J.-B., Farrés, A., Fienga, A.: 2011b, Strong chaos induced by close encounters with Ceres and Vesta, A&A, 532, L4

09.02
**Secular Chaos and the Formation of Hot Jupiters**
**Yoram Lithwick**[1]
[1]*Northwestern University.*
8:45 AM - 9:00 AM
*Explorers Room*
In a planetary system with well-spaced planets, the planets' orbits can evolve chaotically due to secular interactions. The orbit of one of the planets (usually the inner one) can gradually be driven to a high eccentricity, whereupon the planet approaches the star and its orbit is then tidally circularized. As we have previously shown, this can explain the numerous Jupiter-mass planets that have been discovered to orbit very close to the central star ("hot Jupiters"). Here we describe recent work that shows with a multitude of numerical simulations that this process (secular chaos) can quantitatively explain many of the observed properties of hot Jupiters, including how frequently they occur and the range of Rossiter-McLaughlin angles. If this explains the bulk of the hot Jupiters, it would imply that systems with multiple giant planets are common.

09.03

**Analytic Study of Long-Term Variations in Kozai Oscillations**

**Boaz Katz**[1]

[1]*Institute for Advanced Study.*

9:00 AM - 9:15 AM

*Explorers Room*

It was recently shown that the addition of the Octupole term to the expansion of the potential of a distant perturber to a Keplerian orbit can lead to long term variations of the known Kozai Oscillations. These variations can have very interesting effects including extremely high eccentricities and the generation of retrograde orbits with respect to the perturber. We solve this problem analytically for the test particle case at high inclinations. In particular we give analytic expressions for the requirements to produce retrograde orbits and high eccentricities. This may have important implications for understanding the properties of Hot Jupiters, tight binaries and possibly many other systems. We show that a similar effect occurs for other non-axisymetric deviations, such as from a triaxial tidal field.

09.04

**Planetesimal Disks As Tracers of Planet-Planet Scattering, at Home and Abroad**

**Rebekah Ilene Dawson**[1], R. Murray-Clay[1]

[1]*Harvard-Smithsonian Center for Astrophysics.*

9:15 AM - 9:30 AM

*Explorers Room*

Planet-planet scattering likely plays a major role in shaping the architecture of planetary systems, producing observed populations of planets on highly eccentric orbits and on orbits misaligned from the stellar spin axis. A planetesimal disk, if present during the time of dynamical upheaval, can damp the excited orbit of a scattered planet, yet also record signatures of the planet's inclined and eccentric period. Thus observations of remnant planetesimal disks not only serve as signposts for misaligned planets that are not directly detectable, but may also reveal the violent history of planetary systems that appear peaceful in their current configuration. Here we consider two such cases. Our own solar system's classical Kuiper belt contains a population of dynamically "hot" objects with inclinations up to 30° overlying a flat dynamically "cold" population, with distinct physical properties. Accounting for these two populations is an outstanding problem in understanding the formation of our solar system. We fully explore a generalized model in which Neptune undergoes some combination of planet-planet scattering and planetesimal-driven migration. We assess which regions of the parameter space of Neptune's semi-major axis; post-scattering eccentricity and inclination; and timescales of migration, precession, and eccentricity and inclination damping could account for the observed orbits of classical Kuiper Belt Objects. We then consider whether the warped disk of Beta Pictoris -- recently found to be misaligned with the known planet Beta Pictoris b -- could have been sculpted by a yet-to-be-discovered second planet. Our results will provide a framework for interpreting the structure of planetary debris disks in future high-resolution observations with ALMA and JWST.

RID gratefully acknowledges support by the National Science Foundation Graduate Research Fellowship under grants DGE 0644491 and DGE 0946799.

09.05

**Formation and Evolution of Close-in Planets**

**Soko Matsumura**[1], D. Hamilton[1]

[1]*University of Maryland.*

9:30 AM - 9:45 AM

*Explorers Room*

Recent observations indicate a high fraction of multiple-planet systems for Neptune- or Super-Earth-size planets. On the other hand, close-in giant planets tend to be singletons, and their formation could involve the so-called Kozai migration. We discuss the effects of a Kozai-migrating giant planet on formation and evolution of smaller planets like Hot Neptunes and/or Super Earths.

09.06

**Warm Saturns: Rings Around Exoplanets That Reside Inside The Ice Line**

**Hilke Schlichting**[1], P. Chang[2]

*[1]UCLA, [2]CITA, Canada.*

9:45 AM - 10:00 AM

*Explorers Room*

We discuss the nature of rings that may exist around extrasolar planets. Taking the general properties of rings around the gas giants in the Solar System, we infer the likely properties of rings around exoplanets that reside inside the ice line. Due to their proximity to their host star, rings around such exoplanets must primarily consist of rocky materials. However, we find that despite the higher densities of rock compared to ice, most of the observed extrasolar planets with reliable radii measurements have sufficiently large Roche radii to support rings. For the currently known transiting extrasolar planets, Poynting-Robertson drag is not effective in significantly altering the dynamics of individual ring particles over a time span of 10^8 years provided that they exceed about 1 m in size. In addition, we show that significantly smaller ring particles can exist in optically thick rings, for which we find typical ring lifetimes ranging from a few times 10^6 to a few times 10^9 years. Most interestingly, we find that many of the rings could have nontrivial Laplacian planes due to the increased effects of the orbital quadrupole caused by the exoplanets' proximity to their host star, allowing a constraint on the J_2 of extrasolar planets from ring observations. This is particular exciting, since a planet's J_2 reveals information about its interior structure. Furthermore, measurements of an exoplanet's oblateness and of its J_2, from warped rings, would together place limits on its spin period. Based on the constraints that we have derived for extrasolar rings, we anticipate that the best candidates for ring detections will come from transit observations by the Kepler spacecraft of extrasolar planets with semi-major axes \sim 0.1 AU and larger.

## Wednesday, September 14, 2011, 10:30 AM - 12:15 PM
**10**
***Close Planet - Star Interactions***
Oral
*Explorers Room*

10.01
**Stellar Pulsations Excited by Planetary Tides in WASP-33**
**Andrew Cameron**[1], E. Guenther[2], J. M. Matthews[3], P. J. Amado[4], I. McDonald[5], E. Shkolnik[6], A. M. S. Smith[7], J. Telting[8], G. A. H. Walker[9], MOST Science Team
*[1]University of St Andrews, United Kingdom, [2]Thueringer Landessternwarte Tautenburg, Germany, [3]University of British Columbia, Canada, [4]Instituto de Astrofsica de Andalucia, Spain, [5]Jodrell Bank Centre for Astrophysics, United Kingdom, [6]Carnegie Institution of Washington, [7]Keele University, United Kingdom, [8]Nordic Optical Telescope Scientific Association, Spain, [9]1234 Hewlett Place, Canada.*
10:30 AM - 10:45 AM
*Explorers Room*
The bright, rapidly-rotating A5 star HD 15082 (= WASP-33) has a transiting gas-giant planet in a 1.22-day retrograde orbit, only 5.5 stellar radii from the stellar photosphere (Collier Cameron et al 2010, MNRAS 407, 507). Time-resolved spectra of the system during several transits revealed a complex pattern of non-radial pulsations of the gamma Dor and/or delta Scuti type. The extreme proximity of the planet to the host star raises the possibility that some of these pulsation modes could be excited by planetary tides (Herrero et al 2011 A&A 526, L10). The system was observed continuously by the MOST satellite(*) from 2010 October 07.0 to October 31.0. The MOST data establish the frequency spectrum of the stellar pulsations, providing a direct test of theories of planetary tidal evolution via excitation of inertial waves in the host star. The ellipsoidal variation of the host star places limits on the mass of the planet. During the MOST run, a ground-based support campaign of time-resolved echelle spectroscopy yielded tomographic data sets suitable for mode identification and precise determination of the orientation of the planet's orbit.
(*) MOST is a Canadian Space Agency mission, operated by Microsat Systems Canada Inc. (formerly the space division of Dynacon Inc.), the University of Toronto Institute for Aerospace Studies and the University of British Columbia, with support from the University of Vienna.

10.02
**Are Young Hot Jupiters Tidally Disrupted And "downsized" To Super-Earths?**
**Sergei Nayakshin**[1]
*[1]University of Leicester, United Kingdom.*
10:45 AM - 11:00 AM
*Explorers Room*
Boley, Nayakshin and others have recently suggested that young massive gaseous proto-planets migrate faster than they contract and are therefore tidally disrupted. The disruption may "downside" the planets into Neptunes or Earth-sized planets. However, this potentially interesting scenario for planet formation has not yet been detailed.
We present detailed calculations that may shed unbiased light on the utility of these ideas. In particular, we (Nayakshin and Lodato, in prep.) model numerically the viscous gas disc evolution together with the radial migration of the giant gaseous planet embedded in the disc. The planet typically fills its Roche lobe at the planet-star separation of about 0.05 to 0.1 AU. The material overflowing the Roche lobe is deposited in the disc interior of the planet, which fuels a major protostellar accretion outburst rising on the time-scales of years.

The result of the planet's disruption depends on the radius-mass relation for the planet and whether the gap in the disc remains opened or not. If planet does not expand as it looses mass, or does so slowly, then there is a quasi-steady regime. This regime is well known from stellar binaries. The secondary (the planet here) looses mass to the primary and moves OUTWARD due to the conservation of angular momentum (overpowering the outer disc torques).
When the gap is partially closed, the planet's steady-state outward migration< falters, and the gaseous envelope can be destroyed very rapidly. Only solid cores survive such disruptions. However, if the partially disrupted giant contracts faster than it migrates, the result is a solid core surrounded by smaller (than the original) gaseous envelope, e.g. Neptune or Saturn-type planets. We plan to include detailed theoretical planet models (a la Baraffe et al) for detailed comparisons of our calculations with observations of "hot" exoplanets and the FU Ori outburst lightcurves.

10.03

**Are Hot Neptunes Partialy Evaporated Hot Jupiters?**

**Nuno Santos**[1], G. Boue[1], P. Figueira[1], A. Correia[2]
*[1]CAUP, Portugal, [2]Universidade de Aveiro, Portugal.*
11:00 AM - 11:15 AM
*Explorers Room*

The detection of short period planets (hot Jupiters and their lower mass counterparts, hot neptunes and super-earths) still defies the models of planet formation and evolution. Several possibilities have been proposed to explain the nature and formation process of the lower mass population, including in situ formation, disk migration, planet-planet scattering and kozai evolution, and the evaporation of a higher mass hot Jupiter. Using dynamical models and the best estimates for evaporation velocities, we show that under reasonable (and observed) physical conditions, hot Jupiter evaporation can explain the observed population of hot Neptunes/super-Earths.

10.04

**Magnetically Controlled Outflows from Hot Jupiters**

**Fred C. Adams**[1]
*[1]Univ. of Michigan.*
11:15 AM - 11:30 AM
*Explorers Room*

Recent observations that indicate that some extrasolar planets observed in transit can experience mass loss from their surfaces. Motivated by these findings, we consider outflows from Hot Jupiters in the regime where the flow is controlled by magnetic fields. Given the mass loss rates estimated from current observations (and from theory) magnetic fields will dominate the flow for planets with surface fields greater than 1 gauss, comparable to the fields of the Sun and Jupiter. More specifically, the magnetic pressure is larger than the ram pressure of the wind by a factor of 1,000,000 at the planet surface and a factor of 10,000 at the sonic surface. The problem can be separated into an inner regime, near the planet, where the outflow is launched, and an outer regime where the flow follows (primarily) stellar field lines and interacts with the stellar wind. We consider a variety of field configurations, but start with a dipole planetary field with a spatially constant background contribution from the star. For each field configuration, we construct a set of orthogonal coordinates that follow the field lines and determine the corresponding differential operators. Under the assumption of polytropic flow, we can analytically find the conditions required for escaping material to pass smoothly through the sonic transition, and can then estimate the mass outflow rates. These magnetically controlled outflows differ significantly from previous spherical models: The outflow rates are somewhat smaller, and the flow is launched primarily from the polar regions of the planet. In addition, if the stellar wind is strong enough,

the flow could be reversed and the planet could gain mass from the star; this latter scenario may operate in the earliest (and hence most extreme) stages of evolution.

10.05

**Tidal Dissipation in Convective Regions of Planets and Stars**

**Gordon Ogilvie**[1]

*[1]University of Cambridge, United Kingdom.*

11:30 AM - 11:45 AM

*Explorers Room*

I present two new sets of calculations relevant to determining the rate of tidal evolution of short-period extrasolar planetary systems from first principles. First, I calculate analytically a frequency-averaged rate of tidal dissipation in a simplified planetary model and show that it can depend strongly on the size of a solid or fluid core. Second, I investigate analytically the response of a three-dimensional fluid flow (such as convection) to tidal shear of high frequency and low amplitude. Numerical simulations by G. Lesur are used to calculate the frequency-dependent effective viscosity of turbulent convection and aspects of the analytical theory are confirmed. I discuss the application of these results to the survival of planets around late-type stars.

10.06

**Nonlinear Tides in Exoplanet Host Stars**

**Phil Arras**[1], N. Weinberg[2], E. Quataert[3], J. Burkart[3]

*[1]University of Virginia, [2]MIT, [3]U. C. Berkeley.*

11:45 AM - 12:00 PM

*Explorers Room*

Dissipation of the tide raised in the host star by a planet may lead to orbital circularization as well as spin up of the star and decay of the planet's orbit. Previous theoretical investigations have computed the tidally-induced fluid flow in the star using the linear approximation in which nonlinear terms in the fluid equation were ignored. Dissipation and secular evolution were then computed using standard heat diffusion in radiative zones or turbulent viscosity from eddies in convection zones to compute the effective tidal lag angle.

We have extended the theory of tidally-induced fluid motion to include leading order nonlinear effects due to wave-wave interactions and nonlinear tidal forces. Results are presented for the case of a Sun-like star perturbed by a planetary mass companion. We find that the linear tide so often assumed in previous studies is unstable in large ranges of parameter space, and causes gravity waves in the radiative zone to grow exponentially on short timescales. The resulting turbulent state may have larger dissipation rate than the linear tide case in some circumstances, with a corresponding increase in orbital decay and circularization. We present numerical results for close in exoplanets, contrasting linear with nonlinear theory.

10.07

**Thermal Tides: An Explanation for the Inflated Radii of the Hot Jupters**

**Aristotle Socrates**[1]

*[1]IAS, Princeton.*

12:00 PM - 12:15 PM

*Explorers Room*

As a newly discovered class of astrophysical objects, the hot Jupiters have provided some clearly-posed, but difficult to explain, physical problems. For example, the inferred radii of transiting hot Jupiters are far too large to be explained by internal heating due to passive gravitational contraction. I'll describe how a subtle tidal mechanism resulting from asymmetric day-night heating, known as "thermal tides,"

leads to asynchronous spin in the steady state. The ongoing dissipation of the gravitational tide provides the necessary internal dissipation to inflate hot Jupiters for the lifetime of the system. I will describe the basic physics of thermal tides in gas giant fluid planets and explain how this mechanism may be important in understanding the observed properties of the hot Jupiters. In particular, I will show that the observed inflated radii of the hot Jupiters can be understood in terms of a "thermal tidal main sequence."

## Thursday, September 15, 2011, 8:30 AM - 10:00 AM

## 11

### *Atmospheres*

Oral

*Explorers Room*

11.01

**New Results from Ground-Based Transit Spectroscopy Observations**

**Jacob Bean**[1]

[1]*Harvard-Smithsonian CfA.*

8:30 AM - 8:45 AM

*Explorers Room*

It has recently been demonstrated that multi-object spectroscopy with wide slits is a powerful technique for obtaining ground-based transit spectroscopy data based on the first measurement of the transmission spectrum of the super-earth GJ1214b. I will present new results that were obtained with this method to investigate a number of compelling questions in the area of exoplanet atmospheres. I will show transmission and occultation spectroscopy observations of hot-jupiters in the optical that contribute to our understanding of the emerging classes of such planets. I will also show measurements of the transmission spectrum of GJ1214b in the H- and K-bands from the first use of the multi-object technique in the near-infrared. These data have bearing on the claim that this planet's transmission spectrum exhibits strong absorption in the K-band, which can only arise if the planet's atmosphere has a hydrogen-dominated composition.

11.02

**The Complete Transmission Spectrum Of An Exoplanet From UV To IR**

**Frederic Pont**[1]

[1]*University of Exeter, United Kingdom.*

8:45 AM - 9:00 AM

*Explorers Room*

Transmission spectroscopy of transiting planets is one tool to obtain atmospheric spectra of planets outside the solar system. Using four different instruments on the HST - STIS, ACS, NICMOS and WF3 - we combined wide-band and narrow-band spectrophotometry over dozens of HST orbits to piece together the complete transmission spectrum of the hot Jupiter prototype HD 189733b.

These observations paint a very different picture of the atmosphere of this planet than predicted by the models. The transmission spectrum is dominated by Rayleigh scattering over the whole visible and near-infrared range, with narrow sodium and potassium lines, and excess absorption in the UV. This is interpreted as indicating an atmosphere dominated by haze over at least six scale heights, with residual alkali metal absorption above the haze, and possible opacity from photochemical products in the UV. Altogether the atmosphere of HD 189733b seems to be more dominated by hazes or/and clouds than expected for hot Jupiters, not unlike Solar System planets like Venus or Titan. The only other well-studied case, the planet HD 209458b, has a transparent, absorbing atmosphere, suggesting the existence of at least two families of hot gas giant planet atmospheres.

11.03

**Hubble Observations of a Super-Earth Atmosphere**

**Zachory K. Berta**[1], D. Charbonneau[1], C. J. Burke[2], J. Desert[1], J. Irwin[1], P. Nutzman[3], P. McCullough[4], E. Kempton[3], J. Fortney[3], D. Homeier[5]

*[1]Harvard University, [2]NASA Ames Research Center, [3]UC Santa Cruz, [4]Space Telescope Science Institute, [5]Institute for Astrophysics, Germany.*
9:00 AM - 9:15 AM
*Explorers Room*
I will present new Hubble Space Telescope observations of the atmosphere of the enigmatic super-Earth GJ1214b. According to theoretical models, GJ1214b's low density requires it has either an H-rich outer envelope or a bulk composition with a large water-to-rock ratio. Because GJ1214b transits a very small M dwarf, these possibilities can be distinguished observationally using transmission spectroscopy, which probes the scale height (and thus H-content) of the planet's atmosphere. Using the Wide Field Camera 3 (WFC3)'s grism mode, we are measuring GJ1214b's transmission spectrum between 1.1 and 1.7 microns, where models predict absorption features due to water vapor to be strongest. Other observations of GJ1214b's atmosphere have been made, but are seemingly contradictory and difficult to interpret, in part because they do not probe this important wavelength range. Two of our three HST visits have already been completed; the data are of superb quality and will provide a robust test of the nature of GJ1214b's outer envelope. Our final HST visit is scheduled for 17 July 2011, so the results will presented for the first time at the Jackson Hole meeting. I am a member of the team that discovered GJ1214b and the principal investigator of the HST/WFC3 observations.

11.04
**Near-infrared Thermal Emission Of Hot Jupiters And The Spectral Features Of Super-earths**
**Bryce Croll**[1]
*[1]Massachusetts Institute of Technology.*
9:15 AM - 9:30 AM
*Explorers Room*
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, I will present new detections of their near-infrared thermal emission including reobservations of the secondary eclipse of WASP-12 in the JHK-bands, as well as the first thermal emission measurement in Y-band (~1.04 microns). On the super-Earth front, I'll present new near-infrared observations of the transit of GJ 1214b from the 2011 observing season to see whether our repeated observations reconfirm a deeper Ks-band transit depth. A deeper Ks-band transit depth would argue for a spectral absorption feature, and that GJ 1214b is likely a hydrogen/helium dominated mini-Neptune with a significant haze layer that obscures transmission spectroscopy observations at shorter wavelengths.

11.05
**Gaussian Processes: the Next Step in Exoplanet Data Analysis**
**Suzanne Aigrain**[1], N. Gibson[1], S. Roberts[1], T. Evans[1], A. McQuillan[1], S. Reece[1], M. Osborne[1]
*[1]University of Oxford, United Kingdom.*
9:30 AM - 9:40 AM
*Explorers Room*
When searching for or characterising exoplanets, we typically need to isolate a deterministic signal from stochastic processes - astrophysical or instrumental "noise" - in time-series data. Gaussian processes (GPs) enable us to construct distributions over random functions, and to infer the properties of "signal" and "noise" in a way that is both flexible and robust. I will give a brief overview of the principles of GPs and show two example applications which are both interesting in their own right, and highlight some specific strengths of the technique. The first is a new re-analysis of the controversial HST/NICMOS

transmission spectrum of HD189733b. The second is the measurement of stellar rotation periods from light curves, when the spot distribution evolves over the duration of the dataset.
NB: I could also present another topic: stellar variability studies in Kepler data, based on a new systematics correction which preserves stellar variability. I opted for the GPs because I think it's important to alert the exoplanet community to the potential of this technique, but I'm happy to talk about either.

11.06

**NIR Transmission Spectra of HD189733: Application of Gaussian Processes for Removing Systematics**

**Neale Gibson**[1], S. Aigrain[1], S. Roberts[1], T. Evans[1], M. Osborne[1], F. Pont[2], D. Sing[2]
*[1]Oxford University, UK, United Kingdom, [2]University of Exeter, United Kingdom.*

9:40 AM - 9:50 AM

*Explorers Room*

The interpretation of HST transmission spectroscopy signals has recently been the subject of much debate, in particular the NIR NICMOS data of HD 189733. At optical wavelengths, a high-altitude haze has been confirmed with both STIS and ACS, whereas the presence of molecules has been claimed with NICMOS. However, this detection of molecules has been disputed based on the ad hoc model used to remove the systematics, the choice of which changes the interpretation of the transmission signal. Here, we introduce a powerful new technique, Gaussian Processes (GPs), to model the systematics and simultaneously extract the transmission spectrum, and demonstrate its application to the NICMOS data. GPs are a Bayesian technique widely used in the machine learning community, which allow us to define a distribution over functions. Rather than impose a strict, functional form of systematics correction, we marginalise over potentially infinite numbers of basis functions, effectively inferring the form of the systematics correction from the data itself. This results in a more robust interpretation of the signal. We also present similar analyses of HST/WFC3 observations of HD 189733, which bridge the gap between the current optical and NIR spectrum.

11.07

**Combining Abundance/Temperature Retrieval with 3D Atmospheric Circulation Simulations of Hot Jupiters**

**Kevin Heng**[1]
*[1]ETH Zurich, Switzerland.*

9:50 AM - 10:00 AM

*Explorers Room*

The atmospheres of hot Jupiters are three-dimensional, non-linear entities and understanding them requires the construction of a hierarchy of models of varying sophistication. Since previous work has either focused on the atmospheric dynamics or implemented multi-band radiative transfer, a reasonable approach is to combine the treatment of 3D dynamics with dual-band radiative transfer, where the assumption is that the stellar irradiation and re-emitted radiation from the exoplanet are at distinct wavelengths. I report on the successful implementation of such a setup and demonstrate how it can be used to compute self-consistent temperature-pressure profiles on both the day and night sides of a hot Jupiter, as well as zonal-wind profiles, circulation cell patterns and the angular/temporal offset of the hotspot from the substellar point. In particular, the hotspot offset should aid us in distinguishing between different types of hot Jupiter atmospheres. Together with N. Madhusudhan, we combine the dual-band simulation technique with the abundance/temperature retrieval method of Madhusudhan & Seager, by empirically constraining a range of values for the broad-band opacities which are consistent with the current observations. The advantage of our novel method is that the range of opacities used improves with time as the observations get better. The ability to thoroughly, efficiently and systematically explore the interplay between atmospheric dynamics, radiation and synthetic spectra is an important step forward, as it prepares us for the theoretical interpretation of exoplanetary spectra which will be obtained by future space-based missions such as JWST and EChO. I acknowledge generous support from the Zwicky Prize Fellowship and the Star and Planet Formation Group (PI: Michael Meyer) at ETH Zurich.

## Thursday, September 15, 2011, 10:30 AM - 12:00 PM
**12**
***Atmospheres II***
Oral
*Explorers Room*

12.01
**A Warm Spitzer Survey of Atmospheric Circulation Patterns**
**Heather Knutson**[1], E. Agol[2], A. Burrows[3], D. Charbonneau[4], N. Cowan[5], D. Deming[6], J. Desert[4], J. Fortney[7], E. Kite[8], J. Langton[9], G. Laughlin[7], N. Lewis[10], A. Showman[10]
*[1]Caltech, [2]University of Washington, [3]Princeton University, [4]Harvard University, [5]Northwestern University, [6]University of Maryland, [7]University of California, Santa Cruz, [8]University of California, Berkeley, [9]Principia College, [10]University of Arizona.*
10:30 AM - 10:45 AM
*Explorers Room*
The atmospheres of close-in extrasolar planets experience strong, asymmetrically distributed radiative forcing that can potentially lead to dramatic variations in both temperature and composition between the day- and night-side hemispheres. However, secondary eclipse observations only tell us about the properties of the dayside atmosphere, while transmission spectroscopy probes the region around the day-night terminator. By measuring changes in the infrared emission spectra of these planets as a function of orbital phase, we can resolve thermal and compositional gradients in these atmospheres, allowing us to obtain a complete picture of their local properties. The most extensively studied planet to date, HD 189733b, appears to have a relatively modest day-night temperature gradient as seen in the 8 and 24 micron Spitzer bands, suggesting that compositional gradients in this atmosphere are likely to be minimal. We present new, full-orbit phase curves at 3.6 and 4.5 um obtained with warm Spitzer, which we use to construct improved multi-color maps and to constrain variations in the pressure-temperature profile and atmospheric composition as a function of longitude. We also present preliminary results for complementary full-orbit observations of HAT-P-7b in the same bands, and discuss an emerging pattern in which the most highly irradiated (>2000 K) planets appear to undergo a shift towards large day-night temperature gradients, perhaps due to Lorentz braking or other MHD processes.

12.02
**GTC Transiting Exoplanet Atmospheric Survey: Comparative Exoplanetology From Narrowband Spectrophotometry**
**David Sing**[1], J. Desert[2], P. Wilson[1], F. Pont[1], A. Lecavelier des Etangs[3], G. Ballester[4], J. Fortney[5], M. Lopez-Morales[6], D. Ehrenreich[7], A. Vidal-Madjar[3]
*[1]University of Exeter, United Kingdom, [2]Harvard-Smithsonian Center for Astrophysics, [3]Institute d'Astrophysique de Paris, France, [4]University of Arizona, [5]UC Santa Cruz, [6]CSIC-IEEC, Spain, [7]Laboratoire d'Astrophysique de Grenoble, France.*
10:45 AM - 10:55 AM
*Explorers Room*
I will present results on an ongoing large ESO program on the 10.4 meter Gran Telescopio Canarias (GTC) telescope performing an optical survey of transiting exoplanet atmospheres, including 10 hot-Jupiters and a super-Earth. Our observations use a unique tunable filter, capable of photon-limited sub-mmag narrowband transit spectrophotometry, capable of detecting Na, K, TiO and other important atmospheric species. With a large aperture coupled with fast photometry, our observations can perform transmission spectrophotometry for a wide range of hot-Jupiter atmospheres, including fainter targets, allowing for comparative exoplanetary atmospheric studies. The first observations from this program

detected potassium in XO-2b, the first time this important alkali metal was found on an exoplanet. I will detail the further results of our survey including the hot-Jupiters Hat-P-1b, Tres-2b, Hat-P-6b, and XO-2b, as well as the super-Earth GJ1214b, and compare the different atmospheres we are detecting.

12.03

**Observations of Optical Secondary Eclipses of Transiting Hot Jupiters with the GTC**

**Jayne Birkby**[1], I. Snellen[1], E. de Mooij[1], J. Koppenhofer[2], B. Nefs[1], S. Albrecht[3], I. Skillen[4], A. Burrows[5]
*[1]Leiden Observatory, Netherlands, [2]University Observatory Munich, Germany, [3]Massachusetts Institute of Technology, [4]Isaac Newton Group, Spain, [5]Princeton University.*

10:55 AM - 11:05 AM

*Explorers Room*

We present observations of optical secondary eclipses of several hot Jupiters using the OSIRIS imager on the 10.4m Gran Telescopio Canarias (GTC) at the Observatorio del Roque de los Muchachos, La Palma. Detections of optical thermal emission and possible reflective flux from hot Jupiters provide a unique insight into the chemical and physical processes in planetary atmospheres. We have initiated a large ESO program (90 hours) on the GTC to perform photometric monitoring of secondary eclipses, taking advantage of the CCD windowing capabilities of the OSIRIS instrument and defocussing the telescope to achieve a rapid cadence of 5-14 seconds with a precision of approximately 5x10^-4 per 5 minutes for our faintest target, CoRoT-1b (V=13.6). By measuring the secondary eclipse depth ratios between several optical and near-infrared pass-bands (u, r, i and z) we can constrain planetary models that predict global heat circulation by zonal winds, as well as studying the effects of stellar irradiation on the planetary atmospheric structure. We present here the detection of optical thermal emission from CoRoT-1b, and we will also show our latest results from further GTC observations of TrES-3b, WASP-3b and HATP-7b scheduled for the summer of 2011, adding valuable new insight into this thrilling field of exoplanet characterization.

12.04

**Detection of H-alpha Absorption in Exoplanetary Exospheres**

**Seth Redfield**[1], A. G. Jensen[1], W. D. Cochran[2], M. Endl[2], L. Koesterke[2], T. Barman[3]
*[1]Wesleyan University, [2]University of Texas, [3]Lowell Observatory.*

11:05 AM - 11:20 AM

*Explorers Room*

The number of exoplanets with detected atmospheres is rapidly increasing. Particularly intriguing are detections of hydrogen that are attributed to the upper, unbound portion of their atmospheres (i.e., the exospheres) and indicate that some gas giants may be evaporating. Exospheric hydrogen has been detected in Lyman-alpha in the ultraviolet. We present the first detection of hydrogen absorption in H-alpha in the optical, which can be used to study hydrogen level populations and make measurements of the excitation temperature and density of hydrogen in these exospheres. We present a comparative survey of four transiting systems, based on high resolution optical spectra taken with the 9.2 meter Hobby-Eberly Telescope. We clearly detect H-alpha absorption (1.5% over the H-alpha feature) at the 4.6 sigma level for HD189733, and put strong limits on detections in our other systems. These measurements will provide important constraints on models of hydrodynamical atmospheric escape from these planets. Two systems (HD209458 and HD189733) have complementary Lyman-alpha detections. The detection of exospheric absorption in the optical of H-alpha provides a new window into the physical properties of these planetary atmospheres, and ensures access to exospheric measurements even after the end of HST and our capability to acquire UV spectra. This work is supported by the National Science Foundation through an Astronomy and Astrophysics Research Grant (AST-0903573).

12.05

**C/O Ratios In Exoplanetary Atmospheres: A New Classification System And Implications For Planet Formation.**

**Nikku Madhusudhan**[1]
[1]*Princeton University.*

11:20 AM - 11:35 AM

*Explorers Room*

Recent observations are allowing unprecedented constraints on the carbon-to-oxygen (C/O) ratios of exoplanetary atmospheres. C/O ratios place important constraints on planet formation scenarios, planetary interiors, and on the atmospheric temperature profiles. In this talk, we will present observational constraints on atmospheric C/O ratios for an ensemble of transiting exoplanets, along with corresponding constraints on their formation conditions in the protoplanetary disks. Based on these observational inferences and new theoretical work, we introduce a new classification scheme for strongly irradiated exoplanets. In the past, giant exoplanets were classified solely on the basis of the degree of irradiation received from the host star - the so called TiO/VO hypothesis, in which the hotter class is expected to host thermal inversions, and the cooler class to not host thermal inversions. Observations in recent years have revealed several anomalies to this one-dimensional hypothesis; irradiation being the single dimension. In this work, we demonstrate that almost all the extreme anomalies reported in the literature, can be explained based on a new two-dimensional classification scheme, in which irradiation and the atmospheric C/O ratio are the two dimensions. One of the four quadrants in this 2-D phase space corresponds to the exotic new class of high-temperature carbon-rich atmospheres, such as that of WASP-12b, which are readily observable with existing and forthcoming instruments. We will report several candidate carbon-rich exoplanets along with ongoing efforts towards confirming these candidates. We will discuss the atmospheric chemistry and temperature structure of planets in the four quadrants, their formation scenarios, and the chemistry and apportionment of ices, rock, and volatiles in their interiors.

12.06

**Characterizing Hot Jupiter Atmospheres with Hubble WFC3**

**Sukrit Ranjan**[1], D. Charbonneau[1], D. Deming[2], E. Agol[3], A. Burrows[4], M. Clampin[5], J. Desert[1], R. Gilliland[6], H. Knutson[7], N. Madhusudhan[4], A. Mandell[5], S. Seager[8], A. Showman[9]
[1]*Harvard-Smithsonian Center for Astrophysics,* [2]*UMD,* [3]*University of Washington,* [4]*Princeton University,* [5]*Goddard Space Flight Center,* [6]*Space Telescope Science Institute,* [7]*California Institute of Technology,* [8]*Massachusetts Institute of Technology,* [9]*University of Arizona.*

11:35 AM - 11:45 AM

*Explorers Room*

We present transit and eclipse spectroscopy of Very Hot Jupiter atmospheres using the newly installed Wide Field Camera 3 (WFC3) spectrograph on the Hubble Space Telescope (HST). We include results from several hot Jupiter planets, but we focus particularly on spectra of WASP-4b in both transmission and emission, the first time this has been achieved using this instrument. These data are already in hand. Our preliminary analysis indicates they do not require substantial decorrelation against external measurements to correct for systematic errors, resulting in robust results that avoid the ambiguities in interpretation faced by earlier work with NICMOS. Recent work by Madhusudhan and Seager highlighted degeneracies in the interpretation of low-resolution Spitzer spectra of hot Jupiters. The G141 grism on WFC3 (1.1-1.7 microns) spans a 1.4 micron water feature, allowing us to constrain water vapor abundance and break this degeneracy. We measure the 1.5 micron continuum flux, which in conjunction with the Spitzer data allows us to constrain the thermal spectrum of the planet and obtain a more precise energy budget relevant to understanding WASP-4b's abnormally large radius. This work is

part of the Cycle-18 Large Program 12181, and we acknowledge support by NASA, NSF GRFP, and the HST Project.

12.07

**The Role Of Atmospheres In The Evolution Of Exoplanets**

**Tristan Guillot**[1], V. Parmentier[1]

[1]*Obs. de La Cote D' Azur, France.*

11:45 AM - 12:00 PM

*Explorers Room*

Atmospheres control the temperatures and structure of planets both by the amount of radiation that they absorb, reflect or reemit and by the rate at which they allow internal heat to escape. This is particularly important for close-in (transiting) fluid exoplanets (both traditional giant planets, so-called "ice-giants" and brown dwarfs) because of their progressive contraction and the possibility to determine their composition from the measurement of their size, mass, age and from evolution models. However, their atmospheres exhibit significant latitudinal and longitudinal temperature variations, strong winds, their chemistry and cloud structure is probably complex, and non-radiative processes (e.g. linked to ionization and magnetic fields) may affect their properties in a significant way. On the basis of a simple but consistent model to link atmosphere and interior, we will detail how these unknowns affect our knowledge of these planets, in particular, how they prevent us from inferring reliably their global composition. We will discuss the role of clouds and of heating mechanisms such as Ohmic dissipation. We will show that the evolution of these objects differ slightly depending on whether heavy elements are mostly embedded in a central core or distributed throughout their envelope. Through the measurement of atmospheric properties and chemical abundances and through statistical analyses of the ensemble of known transiting planets, observational tests will be crucial to distinguish between the various possibilities.

## Thursday, September 15, 2011, 2:00 PM - 3:30 PM
### 13
***Structure and Evolution***
Oral
*Explorers Room*

13.01
**Theory of Exoplanet Atmospheres and Radii**
**Adam Seth Burrows**[1]
[1]*Princeton University.*
2:00 PM - 2:15 PM
*Explorers Room*
Direct measurements of the radii and masses of giant exoplanets, and indirect measurements of their temperatures, temperature profiles, and compositions have inaugurated the era of the remote sensing and characterization of planets beyond the solar system. Theoretical interpretation both of these atmospheres and of their mass-radius relationship has been challenging, but much progress has been made. I will summarize the general theory of the atmospheres and structures of giant exoplanets, focussing on what can and has been gleaned from secondary and primary transit data using state-of-the-art spectral, atmosphere, and structural theory. The issues concerning the radii, spectra, and light curves of strongly irradiated exoplanets will be explored and paths forward in the theoretical interpretation and understanding of these fascinating objects will be discussed.

13.02
**Thermal Evolution of Hot Jupiters Subject to Ohmic Dissipation**
**Konstantin Batygin**[1], D. J. Stevenson[1], P. H. Bodenheimer[2]
[1]*California Institute of Technology,* [2]*University of California, Santa Cruz.*
2:15 PM - 2:30 PM
*Explorers Room*
The atmospheres of Hot Jupiters are often hot enough to allow for thermal ionization of trace alkali metals, resulting in considerable electrical conductivity. Consequently, the interaction between the characteristic extreme weather and the background planetary magnetic field gives rise to electrical currents that flow through out the planet. The resulting Ohmic dissipation in the planetary interior has been suggested to be the dominant energy source, responsible for inflation of the planetary radii. Here, we present calculations of thermal evolution of Hot Jupiters with various masses and effective temperatures under Ohmic dissipation. The computed evolutionary sequences show a clear tendency towards inflated radii for effective temperatures that correspond to the onset of significant electrical conductivity in the atmosphere, compatible with the trend of the data. The degree of inflation shows that Ohmic dissipation, along with the likely variability in heavy element content can account for all of the currently detected radius anomalies. Furthermore, we find that in absence of a massive core, low-mass hot Jupiters can over-flow their Roche-lobes and evaporate on Gyr time-scales, possibly leaving behind small rocky cores.

13.03
**Radii and Orbits of Hot Jupiters**
**Yanqin Wu**[1]
[1]*University of Toronto, Canada.*
2:30 PM - 2:45 PM
*Explorers Room*

Hot jupiters suffer extreme external (stellar) and internal (tidal, Ohmic and wind-power) heating. These lead to peculiar thermal evolution, which is potentially self-destrutive. For instance, the amount of energy deposited during tidal dissipation far exceeds the planets' binding energy. If this energy is mostly deposited in shallow layers, it does little damage to the planet. However, the presence of stellar insolation changes the picture, and Ohmic/wind-power heating further modifies the subsequent evolution of these jupiters. A diversity of planetary sizes results. We tie these thermodynamical processes together with the migration history of hot jupiters to explain the orbital distribution and physical radii of hot jupiters. Moreover, we constrain the location of tidal heating inside the planet.

13.04

**The Impact of Tides on Transiting Planet Structure and Evolution and Light Curve Analysis.**

**Gilles Chabrier**[1]

[1]*ENS-Lyon, France.*

2:45 PM - 3:00 PM

*Explorers Room*

We examine two key consequences of tidal forces on the transiting planet observed and theoretical properties.

First, based on consistent calculations coupling gravothermal evolution with complete tidal equations, we revisit the viability of the tidal heating hypothesis to explain the anomalously large radius of some transiting planets. We demonstrate, both analytically and numerically, that calculations based on tidal models truncated at second order in eccentricity, as done in all previous studies, lead to severely erroneous tidal evolutions. Such truncated calculations yield characteristic timescales for dynamical evolution that can be wrong by orders of magnitude, leading accordingly to completely erroneous tidal energy dissipation rates during the planet's evolution. We demontrate that these results do not stem from uncertainties in the tidal quality factor, as often (erroneously) suggested, but from the exact calculations of the tidal equations. We show that, although tidal heating provides a substantial contribution to the planet's heat budget, this mechanism can not explain alone all the anomalously inflated planets. We examine alternative mechanisms to explain these puzzling properties.

Furthermore, due to strong tidal forces, transiting planets exhibit a non-spherical shape. Such a departure from sphericity has a measurable impact on the observed transit depth and leads to a bias in the derivation of the transit radius from the light curve. As the tidally deformed planet projects its smallest cross section area during the transit, the measured effective radius is smaller than the one of the unperturbed genuine spherical planet. To correct this bias, we present analytical expressions that can easily be used to calculate the shape of observed planets (and Love number) and its impact on the transit lightcurve. These expressions enable us to convert the planet’s measured cross section into its real equilibrium radius, the one to be used when comparing measurements with theoretical models.

13.05

**The Interplay Between a Hot Jupiter’s Thermal Evolution and its Atmospheric Circulation**

**Emily Rauscher**[1], A. Showman[1]

[1]*Univ. of Arizona, LPL.*

3:00 PM - 3:15 PM

*Explorers Room*

Gas giant exoplanets cool and shrink as they age. A planet subject to intense stellar irradiation will have a thick radiative zone above its deep, convective interior. It is well known that this surface boundary condition will alter the thermal evolution of the planet, keeping it hotter and larger for longer. The three-dimensional temperature structure of the radiative zone is in large part determined by the atmospheric circulation at work in that region. In addition, it is possible that a downward transport of kinetic energy from the atmospheric dynamics can provide an additional source of heating at depth and slow evolutionary cooling (a possible explanation for the anomalously large radii of some hot Jupiters). Unfortunately, cooling rates that are derived from one-dimensional, static, globally averaged temperature-pressure profiles must either neglect or parameterize the effect of atmospheric dynamics. Here we present three-dimensional numerical simulations (with coupled radiation and hydrodynamics) that model a hot Jupiter's atmospheric circulation at several ages throughout its cooling history. These results show both: a) how atmospheric circulation is influenced by the evolutionary state of the planet, and b) how the thermal evolution of the planet may be influenced by its atmospheric circulation.

13.06

**Doppler Signatures of the Atmospheric Circulation of Hot Jupiters**

**Adam P. Showman**[1], J. J. Fortney[2], N. K. Lewis[1], M. Shabram[3]
*[1]Univ. of Arizona, [2]U.C. Santa Cruz, [3]Univ. of Florida.*

3:15 PM - 3:30 PM

*Explorers Room*

To date, the exotic meteorology of hot Jupiters has primarily been characterized with thermal measurements, providing only indirect clues to the wind regime. Recently, however, Snellen et al. (2010) presented high-resolution groundbased transit spectra of HD209458b containing an apparent ~2 km/sec blueshift, which they interpreted as a signature of atmospheric winds flowing from dayside to nightside toward Earth along the planet's terminator. Motivated by these observations, we describe the types of Doppler signatures generated by the atmospheric circulation and show how Doppler measurements can place powerful constraints on the meteorology. We show that, depending on parameters, the atmospheric circulation--and Doppler signature--of hot Jupiters splits into two regimes. At moderate stellar insolation, the day-night thermal forcing generates fast east-west jet streams from the interaction of standing planetary-scale waves with the mean flow. In this regime, air along the terminator (as seen during transit) flows toward Earth in some regions and away from Earth in others, leading to a bimodal Doppler signature exhibiting distinct, superposed blue- and redshifted velocity peaks. Under more intense stellar insolation, however, the thermal forcing is so strong that it damps these planetary-scale waves, inhibiting their ability to generate jet streams. As a result, this second regime exhibits a circulation dominated primarily by high-altitude, day-to-night airflow along both terminators rather than longitudinally symmetric jets. This causes air to flow toward Earth along most of the terminator, leading to a predominantly blueshifted Doppler signature during transit. We present state-of-the-art 3D circulation models including nongrey radiative transfer to quantify this regime shift and the resulting Doppler signatures; these models suggest that HD189733b lies in the first regime while HD209458b lies in the second regime. Moreover, we show how the amplitude of the Doppler shifts place strong constraints on the strength of frictional drag in the upper atmospheres of hot Jupiters.

## Thursday, September 15, 2011, 4:00 PM - 5:30 PM

**14**

***Hot Jupiters***

Oral

*Explorers Room*

14.01

**Measuring Wind Speeds in the Atmospheres of Extrasolar Hot Jupiters**

**Eliza Kempton**[1], E. Rauscher[2]

*[1]U.C. Santa Cruz, [2]Lunar and Planetary Laboratory, University of Arizona.*

4:00 PM - 4:15 PM

*Explorers Room*

3-D dynamical models of hot Jupiter atmospheres predict strong winds in the atmospheres of these planets. For tidally locked hot Jupiters, winds at high altitude in the planet's atmosphere advect heat from the day side to the cooler night side of the planet. Net wind speeds on the order of 1-10 km/s directed towards the night side of the planet are predicted at ~mbar pressures, which is the approximate pressure level probed by transmission spectroscopy. These winds should result in an observed blue shift of spectral lines in transmission on the order of the wind speed. Indeed, Snellen et al. (2010) recently observed a 2 (+/-) 1 km/s blue shift of CO transmission features for HD 209458b, which has been interpreted as a detection of the day-to-night winds that have been predicted by 3-D atmospheric dynamics modeling. In this talk, I present the results of a coupled 3-D atmospheric dynamics and transmission spectrum model, which predicts the Doppler-shifted spectrum of a hot Jupiter during transit resulting from winds in the planet's atmosphere. We show how Doppler shifted transmission spectra can be used to diagnose wind speeds in the planet's atmosphere, and in certain cases can be used to map wind speeds across the planet's terminator and as a function of altitude.

14.02

**Thermal Phase Variations of WASP-12b**

**Nicolas B. Cowan**[1], P. Machalek[2], B. Croll[3], D. Deming[4], A. Burrows[5], J. Hora[6], T. Greene[2]

*[1]Northwestern University, [2]NASA Ames, [3]MIT, [4]University of Maryland, [5]Princeton University, [6]Harvard-Smithsonian Center for Astrophysics.*

4:15 PM - 4:30 PM

*Explorers Room*

The short-period planet WASP-12b is among the hottest known transiting planets. Space- and ground-based secondary eclipse depths imply that this planet has a C/O ratio greater than 1 (Madhusudhan et al. 2011), in stark contrast to the chemistry in the Solar System and the assumed chemistry of other planets. These same eclipse data put the planet's day-side effective temperature at ~3000 K. This indicates a low albedo and poor recirculation of heat to the night-side, as has been found for all of the hottest transiting giant planets (Cowan & Agol 2011b). But these trends were based solely on day-side observations (eclipse depths) rather than full phase variations, which directly probe night-side temperature. The short period (1.1 day) and inflated radius (1.8 R_J) of WASP-12b has led to speculation that it may be undergoing Roche-lobe overflow (Li et al. 2010, Lai et al. 2010), and UV observations by Fossati et al. (2010) seem to support this idea. We have recently obtained thermal phase curves of this planet with Warm Spitzer (PI:Machalek; PID 70060). Our data include two eclipses, a transit, and full phase coverage at each of 3.6 and 4.5 micron. Because of the planet's high temperature and large size, this is one of the highest S/N phase curves yet obtained with Spitzer. These data (currently being analyzed) will allow us to directly measure the planet's night-side temperature and the longitudinal offset of its day-side hot-spot. Since the 3.6 and 4.5 micron bands probe different depths in the atmosphere, we will strongly constrain climate models for the hottest gas giants. The high precision transit and eclipse photometry offered by Spitzer will also allow us to search for signs of accretion in this system.

14.03

**Observational Evidence for Tidal Effects in Hot Jupiters**

**Nawal Husnoo**[1], F. Pont[1], T. Mazeh[2], D. Fabrycky[3], G. Hebrard[4], F. Bouchy[4], C. Moutou[5], A. Shporer[6]
*[1]University of Exeter, United Kingdom, [2]Tel Aviv University, Israel, [3]Harvard-Smithsonian Centre for Astrophysics, [4]Institut d'Astrophysique de Paris, France, [5]Laboratoire d'Astrophysique de Marseille, France, [6]Las Cumbres Observatory Global Telescope network.*

4:30 PM - 4:45 PM

*Explorers Room*

Several hundred hot Jupiters are now known to orbit very close to their host star, where tidal effects are expected to have a significant impact on the planet's evolution. We search for evidence of tidal effects in the sample of known transiting planets by analysing new radial velocity measurements using the HARPS and SOPHIE spectrographs, as well as re-analysing existing radial velocity measurements and photometric constraints on the orbital elements from the literature.
We show that the orbital eccentricities and the projected spin-orbit alignment angles as measured from the Rossiter McLaughlin effect for known transiting planets, where available, are in fact fully compatible with classical tidal theory, without having recourse to special scenarios such as eccentricity pumping from a second companion in the system, etc. We also show that planets on circular orbits gather in a well-defined region in the mass-period plane at the shortest possible period for a given mass, and we reexamine the recent hypothesis that the presence of a convective stellar envelope leads to a spin-orbit alignment.

14.04

**New Photometry for the Extremely Eccentric Giant HD 80606 b**

**Jonathan S. Langton**[1], G. Laughlin[2], D. Deming[3]
*[1]Principia College, [2]University of California at Santa Cruz, [3]University of Maryland.*

4:45 PM - 5:00 PM

*Explorers Room*

Due to the combination of its extreme eccentricity and its fortuitous orbital geometry, the transiting giant exoplanet HD 80606 b offers a unique opportunity to place observational constraints on exoplanetary parameters which have never before been measured. Here we report the results of a 50-hour observational campaign during the periastron passage of HD 80606 b, taken with the 4.5-micron channel of the Spitzer Space Telescope. Our observations indicate a significantly larger baseline planetary flux than expected, implying a 4.5-um brightness temperature of at least ~1000 K. This indicates either that the planet is currently experiencing very strong tidal dissipation, or that the atmosphere is relatively transparent at 4.5 um, so that emission at this wavelength originates in deeper, hotter layers of the atmosphere. Additionally, we are able to impose the first observational constraints on an exoplanet's rotation rate, requiring a rotation period greater than ~20 h. We predict a resurgence in flux ~30-40 h after the periastron passage, as the heated hemisphere rotates back into our line of sight, with the exact timing depending on the rotation rate.

14.05

**Atmospheric Circulation Of Hot Jupiters On Highly Eccentric Orbits**

**Tiffany Kataria**[1], A. P. Showman[1], N. K. Lewis[1], J. J. Fortney[2], M. S. Marley[3], R. S. Freedman[3]
*[1]University of Arizona, [2]University of California at Santa Cruz, [3]NASA Ames Research Center.*

5:00 PM - 5:10 PM

*Explorers Room*

Of the ~500 extrasolar planets detected, over half of these are on non-circular orbits, with eccentricities as high as 0.97. Such planets experience highly time-variable heating that greatly affects their overall temperature structure and atmospheric circulation. A number of these eccentric planets transit their host stars (e.g. HD80606b, GJ436b, HAT-P-2b), allowing us to probe their atmospheres from transit to secondary eclipse. However, extracting planetary information from the data can be challenging, as the convolution of spatial effects (hot spots rotating into/out of view) and temporal effects (planet getting colder/warmer at apoapse/periapse) can complicate its interpretation. Hence, a comprehensive study that establishes the dynamical regime, temperature structure, and observational implications of this unique class of planets is crucial. Therefore, we present results from our systematic study of generic hot Jupiters on highly eccentric orbits (e=0.0-0.75) using the SPARC/MITgcm, a model that couples a state-of-the-art general circulation model, the MITgcm, with a plane-parallel, two-stream, multi-band radiative transfer model. In this study, we compare pseudo-synchronously rotating eccentric planets to those on circular orbits with equal average stellar flux. This direct comparison serves to disentangle the heating effects due to circulation from those due to varying orbital position. In previous presentations, we have shown that the simulations possess a superrotating equatorial jet that is maintained throughout the planet's orbit. As the planet's eccentricity is increased, the equatorial jet narrows, and symmetric high latitude jets develop. We expand on this previous work by determining their observational implications. For each simulation, we will present synthetic full-orbit light curves to determine the extent to which the meteorological wind structure, day-night temperature differences, and temporal changes in temperature can be extracted from the data. This is a vital step to understanding what current and upcoming lightcurve data can say about the physical nature of planets on eccentric orbits.

14.06

**The Atmospheric Circulation of Eccentric Hot Jupiter HAT-P-2b**

**Nikole Lewis**[1], H. Knutson[2], A. P. Showman[1], J. J. Fortney[3], E. Agol[4], A. Burrows[5], D. Charbonneau[6], N. B. Cowan[7], D. Deming[8], J. Desert[6], J. Langton[9], G. Laughlin[3], K. Mighell[10]

*[1]University of Arizona, [2]UC Berkeley, [3]UC Santa Cruz, [4]University of Washington, [5]Princeton University, [6]Harvard University, [7]Northwestern University, [8]NASA Goddard, [9]Principia College, [10]NOAO.*

5:10 PM - 5:20 PM

*Explorers Room*

The Spitzer warm mission has already greatly expanded the field of exoplanet characterization with over 3000 hours of time dedicated to exoplanet observations.  Observations of eclipsing systems with Spitzer are at the heart of these advances, as they allow us to move beyond simple mass and period estimates to determine planetary radius, dayside emission, and emission variations as a function of orbital phase.  The eclipsing system HAT-P-2 is of special interest because the massive Jovian sized planet in this system is on a highly eccentric orbit (e=0.5171). Because HAT-P-2b's orbit is eccentric, the planet is subject to time variable heating and probable non-synchronous rotation.  Circulation patterns that we expect to develop in HAT-P-2b's atmosphere will likely vary with both planetary local time and orbital phase. Here we present an analysis of two full-orbit light curves for the HAT-P-2 system obtained at 3.6 and 4.5 microns during the first two years of the Spitzer warm mission and discuss the observational constraints imposed on the atmospheric circulation of HAT-P-2b. Additionally, three-dimensional atmospheric models that incorporate realistic radiative transfer will be presented to further elucidate possible global scale circulations patterns present in the atmosphere of HAT-P-2b. Support for this work was provided by NASA.

14.07

**Polarimetry of Hot Inflated Jupiters Reveals Their Neptune-like Blue Appearance**

**Svetlana Berdyugina**[1], A. Berdyugin[2], V. Piirola[2]
*[1]KIS, Germany, [2]FINCA, Finland.*

5:20 PM - 5:30 PM

*Explorers Room*

Polarimetry is a powerful technique for detecting directly exoplanetary atmospheres and probing their geometry, chemistry, and thermodynamics. The light scattered in the planetary atmosphere is linearly polarized perpendicular to the scattering plane. In general, when the planet revolves around the parent star, the scattering angle changes and the Stokes parameters vary. Therefore, the observed polarization variability exhibits the orbital period of the planet and reveal the inclination, eccentricity, and orientation of the orbit as well as the nature of scattering particles in the planetary atmosphere. Recently, we have started a polarimetric survey of nearby planetary systems with hot Jupiters closely orbiting their host stars.

Here we will present first polarimetric detection of Upsilon And b which identifies this planet to have low density (0.36 g/cm3) and relatively high average geometrical albedo (0.35) with the maximum in the blue. Together with HD189733b and Kepler-7b, these constitute a small group of inflated and highly reflective hot Jupiters, with albedo defined by Rayleigh scattering on, most probably, condensates in high altitude haze or clouds. The scattering results in the blue shine similar to Neptune. Some other planet parameters determined from polarimetry agree well with those which could be previously evaluated from spectroscopy.

We will also present upper limits on polarimetric detections of HD209458b, 51 Peg b, and Tau Boo b. Spurious polarization effects, e.g. due to starspots or limb polarization, will be evaluated.

## Friday, September 16, 2011, 8:30 AM - 10:00 AM
## 15
### *Planets Around Evolved Stars*
Oral
*Explorers Room*

15.01

**The Great Escape: How Exoplanets and Smaller Bodies Desert Dying Stars**

**Dimitri Veras**[1], M. C. Wyatt[1], A. J. Mustill[1], A. Bonsor[1], J. J. Eldridge[1]

[1]*Univ. of Cambridge, United Kingdom.*

8:30 AM - 8:45 AM

*Explorers Room*

Mounting discoveries of extrasolar planets orbiting post-main sequence stars motivate studies aimed at understanding the fate of these planets. In the traditional ``adiabatic" approximation, a secondary's eccentricity remains constant during stellar mass loss. Here, we remove this approximation, investigate the full two-body point-mass problem with isotropic mass loss, and illustrate the resulting dynamical evolution. We then combine these results with stellar evolution models for stars with progenitor masses from 0.7-150 Solar masses. The magnitude and duration of a star's mass loss combined with a planet's initial orbital parameters might provoke ejection, modest eccentricity pumping, or even circularization of the planetary orbit. We find that the vast majority of planetary material which survive a supernova from a 7-20 Solar-Mass progenitor will be dynamically ejected from the system, placing limits on the existence of first-generation pulsar planets. Oort Clouds and wide-orbit planets may be dynamically ejected from 1-7 Solar Mass progenitor stars during AGB evolution; remaining bound comets are likely to assume a wide range of eccentricities. Planets orbiting black hole progenitors of at least 20 Solar masses may easily survive or readily be ejected depending on the core collapse and superwind models adopted. The consequences of this work directly relate to a wide range of "Extreme Solar Systems", as well as the free-floating planetary population. Material ejected during stellar evolution could represent the primary contribution to this population, and suggest regions of the Milky Way which are the most likely to harbor free-floaters.

15.02

**Planets Around Evolved Stars**

**Eva Villaver**[1], M. Livio[2]

[1]*Universidad Autonoma De Madrid, Spain,* [2]*Space Telescope Science Institute.*

8:45 AM - 9:00 AM

*Explorers Room*

With searches of planets around evolved pulsating B sub-dwarfs, red giant stars, and white dwarfs underway, it is paramount to advance theoretical research in how stellar evolution affects the architecture of planetary systems. This will not only maximize the discovery potential of said searches, but also aid in the interpretation and understanding of planet formation in a broader context. To acquire a full picture of the planet´s survival process we compute the evolution of the planet´s orbit coupled with the evolution of the star from the main sequence all the way to the white dwarf domain. We explore the range of planetary masses that might survive a common envelope stage during the giant phases of the star and, finally, we investigate how the presence of a planet might influence the evolution of the star itself.

15.03

**Discovery and Characterization of the Coolest Known Brown Dwarf**

**Kevin Luhman**[1], A. Burgasser[2], J. Bochanski[1]
[1]*Penn State Univ.,* [2]*UCSD.*
9:00 AM - 9:15 AM
*Explorers Room*
We recently reported the discovery of a faint proper motion companion to a nearby white dwarf using 4.5um images from the Spitzer Space Telescope. We estimated a mass of 7 Jupiter masses and a temperature of 300 K for this companion if it has the distance and age of the primary, which would make it the coolest object directly observed outside of the solar system. Since our publication of these initial data, we have obtained images at additional wavelengths with the Very Large Telescope and the Spitzer Space Telescope to confirm its common proper motion and to better constrain its temperature. We present these unpublished results, and discuss the implications for direct imaging surveys for objects near 300 K and below.

15.04
**Planetary Debris Around Young White Dwarfs**
**Boris Gaensicke**[1], C. Brinkworth[2], D. Koester[3], T. Kinnear[1], J. Girven[1], T. Marsh[1], J. Farihi[4]
[1]*University of Warwick, United Kingdom,* [2]*Spitzer Science Center,* [3]*University of Kiel, Germany,* [4]*University of Leicester, United Kingdom.*
9:15 AM - 9:30 AM
*Explorers Room*
At ESS I, we presented the discovery of gaseous debris disks around two relatively young (~100Myr) white dwarfs that appeared to be the "warm" extension to the handful of cooler white dwarfs with dusty debris disks known at the time. Much has happened since then, and we will present a range of recent and forthcoming results.
Two dozen white dwarfs with dusty debris disks are known, spanning cooling ages of ~100Myr to ~1Gyr. We have identified five white dwarfs with gaseous disks, and our Spitzer observations detect strong infrared excess in four of them. Comparing the white dwarfs with gaseous disks and those with dust-only, there is no charactistic (white dwarf temperature and mass, accretion rate) that singles them out. We suggest that these disks are fresh disruption or re-impact events. Our spectroscopy spanning many years demonstrates dramatic variability of both line shape and strength, with a possible period of ~10 years for SDSS1228+1040. Our CLOUDY model reproduces the observed emission characteristics of the gaseous disks seen in both our optical and HST/COS spectroscopy, and accomodates the simultaneous presence of the dust.
We also report first results from our large, unbiased HST/COS survey of young hydrogen-rich white dwarfs. ~15% of the 52 stars observed so far are metal-polluted, but only four of them have detected dusty disks. The diffusion time scales of these stars are ~days, i.e. the detection of metals implies that accretion is *ongoing*. Because of the short diffusion time scales, the photospheric abundances precisely reflect the bulk abundances of the planetary debris material. We find large variations in the metal-to-metal abundances, particularly so in carbon, suggesting a substantial variety among the rocky debris around these stars. Most noticeable is GALEX1931+0117 with an C/Fe abundances that is a factor ~10 lower than that of the Earth's crust.

15.05
**Evolved Planetary Systems: Debris Discs and Metal Polluted White Dwarfs**
**Amy Bonsor**[1], M. Wyatt[1], A. Mustill[1]
[1]*University of Cambridge, United Kingdom.*
9:30 AM - 9:40 AM
*Explorers Room*

Some of the most extreme planetary systems are those around evolved stars. There are as yet no planet detections around white dwarfs, but there are observational signatures potentially associated with evolved planetary systems. Both metal lines in white dwarf atmospheres and hot, dust discs around some metal polluted white dwarfs may be signatures of material scattered inwards from an evolved planetary system. I present models that provide the link between these observational signatures and main sequence planetary systems. I show that the altered dynamics in a debris disc, after stellar mass loss on the giant branches, can scatter sufficient material from an outer belt, in order to explain the observations. The architecture of the inner planetary system determines whether this material can end up on star-grazing orbits. I make use of analytical dynamics and the circular restricted three-body problem to place constraints on the structure of planetary systems capable of scattering particles from an outer belt onto star-grazing orbits. This analytical dynamics is applicable to any system with an outer belt and inner planets, including our solar system and stars with warm, dust discs.

15.06

**How to Find Earths in the Habitable Zones of Cool White Dwarfs with Transit Surveys**

**Eric Agol**[1]

[1]*Univ. of Washington.*

9:40 AM - 9:50 AM

*Explorers Room*

White dwarf stars cool gradually enough that a planet would spend 8 Gyr in the liquid-water habitable zone if it orbited at 0.01 AU, which coincides with twice the Roche limit. If terrestrial-size planets can re-form or migrate inwards to just outside the Roche limit after the red giant phase, they can be detected in edge-on orbits with deep transits that last a couple of minutes each. Such a survey would be biased towards finding Earth-sized and Earth-temperature planets if it targets the nearest white dwarfs with moderate sized ground-based telescopes. The planets would have similar rotation periods to Earth and orbit stars similar in color to the Sun; however, the planets would be tidally-locked and would need to retain or reform an atmosphere after the white dwarf cools. A targeted survey could probe habitable planet frequencies as small as 1%, while the Large Synoptic Survey Telescope could probe even smaller frequencies.

15.07

**Planetary Dynamics and Evolution in Evolved Binary Systems**

**Hagai Perets**[1], K. Kratter[1], S. Kenyon[1]

[1]*Harvard Smithsonian Center for Astrophysics.*

9:50 AM - 10:00 AM

*Explorers Room*

Exo-planets typically form in protoplanetary disks left over from the formation of their host star. We discuss additional evolutionary routes which may may exist in old evolved binary systems. Stellar evolution in binaries could lead to the formation of symbiotic stars, where mass is lost from one star and (partially) transferred to its binary companion, forming an accretion disk. Planetary orbits around the mass losing star can expand and destabilize, and may result in chaotic evolution. Possible outcomes include exchange of the planet to the companion star, ejection, collision, or tidal capture by one of the binary components. We show that the conditions in the newly formed accretion disk could be very similar to protoplanetary disks. Planets around the accreting companion may interact with the disk, leading to (re)growth and (re)migration of the planets. The disk may also provide the necessary environment for the formation of a new, second generation of planets in both circumstellar or circumbinary configurations. Pre-existing planets and/or planetesimals may serve as seeds for the formation of the second generation planets. Such systems should be found in white dwarf binary systems, and may show various unique observational signatures. Most notably, second generation planets could form in environments which are unfavorable for first generation planets. The phase space available for these planets could be forbidden (unstable) to first generation planets in the pre-evolved progenitor binaries. Planets may also form in double compact object binaries and in metal poor environments. Observations of exo-planets in such unfavorable regions could possibly serve to uniquely identify their second generation character. Finally, we point out a few observed candidate second generation planetary systems (Gl 86, HD 27442 and observed circumbinary planet candidates). A second generation origin for these systems could explain their unique configurations.

## Friday, September 16, 2011, 10:30 AM - 12:00 PM
**16**
***Rocky Planet Formation and Planetesimals***
Oral
*Explorers Room*

16.01
**Testing Planet Formation Theory with Exoplanets**
**Andrew Youdin**[1]
[1]*Harvard-Smithsonian Center for Astrophysics.*
10:30 AM - 10:45 AM
*Explorers Room*
Exoplanet discoveries can be used to evaluate and develop planet formation theories. I will describe, and critically evaluate, two complementary approaches. The first examines a single mechanism in detail, such as orbital evolution due to secular dynamics or planetesimal formation via streaming instabilities. The effects of that mechanism on exoplanet statistics can be assessed. The second approach is commonly known as planetary population synthesis. It attempts to combine simplified versions of all processes relevant to planet formation and evolution. I will describe how the wealth of planet candidates provided by the Kepler survey can constrain both types of models. Finally, I will provocatively discuss whether a deterministic and/or predictive theory of planet formation is possible, or even necessary.

16.02
**Kepler-11: On the Formation of an Extremely Compact Six-Planet System**
**Elisa V. Quintana**[1], J. E. Chambers[2], J. J. Lissauer[3], Kepler Team
[1]*SETI Institute / NASA Ames Research Center,* [2]*Carnegie Institution of Washington,* [3]*NASA Ames Research Center.*
10:45 AM - 11:00 AM
*Explorers Room*
Kepler-11 is a G dwarf star with a system of six transiting planets that were announced by the Kepler Team in February 2011.  All six planets orbit within 0.5 AU of Kepler-11, with the inner five on nearly circular, coplanar orbits within 0.25 AU of the star.  This extremely dense system provides a remarkable testbed for planet formation theories. Formation and migration scenarios are considered that are consistent with the composition and orbital parameters of these planets. We also present results from a suite of numerical simulations of the final stages of planet formation within a massive protoplanetary disk around Kepler-11.  We recently modified the Mercury integration package to include eccentricity damping to mimic the presence of small bodies and gas in the disk, and will discuss the feasibility of the In Situ formation of this dynamically compact system. 

16.03
**Locating Planetesimal Belts in Planetary Systems**
**Amaya Moro-Martin**[1]
[1]*Centro de Astrobiologia (INTA-CSIC), Spain.*
11:00 AM - 11:15 AM
*Explorers Room*

Debris disks are disks of dust that surround a significant fraction of stars of a wide range of masses and ages. From dust lifetime arguments it is inferred that these dust particles originate from the

collision/sublimation of planetesimals, similar to the asteroids, comets and KBOs in our Solar system. Therefore, the presence of debris disk around planet-bearing stars indicate that these stars also harbor planetary systems composed of planets and planetesimals belts. We use Spitzer and new Herschel data to set constraints on the location of these dust-producing planetesimals; we use a radiative transfer model to analyze the spectral energy distributions and images of the dust disks, and a dynamical model to assess the long-term stability of the planetesimals' orbits. With the new Herschel data, we revisit the question on whether or not debris disks and planets are correlated. These studies can help us learn about the diversity of planetary systems.

16.04

**HD 207129: Dusty Debris at the Very Outer Edge of a Planetary System**

**Torsten Loehne**[1], J. Augereau[2], S. Ertel[3], J. Marshall[4], C. Eiroa[4], DUNES consortium

*[1]Jena University, Germany, [2]IPAG, France, [3]Kiel University, Germany, [4]Universidad Autonoma de Madrid, Spain.*

11:15 AM - 11:30 AM

*Explorers Room*

Debris disks are considered natural by-products of planet formation, and as such, they are important witnesses and tracers of this process. These disks of planetesimals and dust are left over where no planets could grow, typically at a system's cold periphery.

The Herschel Open Time Key Program "DUNES" (DUst around NEarby Stars, PI: C. Eiroa) is a volume-limited survey that aims at the detection, characterization, and modeling of circumstellar debris disks as faint as a few times the Edgeworth-Kuiper Belt. Due to Herschel's wavelength coverage, sensitivity, and angular resolving power, the program was able to provide valuable new data points for known disks and to discover additional disks. For about one quarter of the stars in our unbiased sample, significant excess is detected, almost doubling the previous detection rates for Sun-like stars. Notably, a completely new regime of disks was explored, best described as extremely cold, both in terms of temperature and dynamical excitation.

We will present these observational and modeling results, focusing on the particular case of HD 207129. That system is among the brighter, well-resolved objects of our sample and may thus serve as a calibrator for the study of unresolved disks. From HST observations, the dust in that system is known to originate from a belt at about 160 AU from the star -- the most distant birth ring known so far. Due to its sheer size, the surprisingly large grains, and the potentially major role of transport towards the star, that system may well be characterized as a key piece in a so-far poorly sampled region of the jigsaw puzzle of planet formation.

16.05

**Predictions By Population Synthesis For Planetary Systems - Comparison With Observation And Constraints On Theory**

**Shigeru Ida**[1], D. N. C. Lin[2]

*[1]Tokyo Inst. of Tech., Japan, [2]UCO/Lick observatoty.*

11:30 AM - 11:40 AM

*Explorers Room*

We have studied effects of dynamical interactions between planets/embryos (eccentricity excitation and ejection due to close scattering, merging, and resonant trapping) on mass-semimajor axis-eccentricity distributions and frequency of extrasolar giant planets and super-Earths, using our sequential planet formation model with newly added the effects of the dynamical interactions.

Our model clearly reproduces dependences of eccentricity distributions on planetary mass or semimajor axis for giant planets that are found by radial velocity surveys, while the semimajor axis distribution of

gas giants is not fully reproduced, which suggests some important physical processes (e.g., migration trap) are missing in the calculations. We also found that distant jupiters on nearly circular orbits, which are observed by direct imaging, are formed by scattering of cores and eccentricity damping followed by runaway gas accretion that is induced by very low planetesimal accretion rate in the distant regions. The scattering also produces a large population of free floating planets, which are detected by gravitational microlensing.
Our model produces a large population of close-in super-Earths. We will discuss comparison with radial velocity and Kepler data. We found that in most massive disks, super-Earths do not survive scattering by gas giants, while they are not formed in least massive disks. Close-in super-Earths are formed in moderately massive disks, if type I migration is halted near disk inner edge. We also found that close-in super-Earths are mostly rocky, while they tend to be icy around M dwarfs.

16.06

**Planetary Population Synthesis: Comparison of Updated Model Results and Observations.**

**Christoph Mordasini**[1]

[1]*Max Planck Institute for Astronomy, Germany.*

11:40 AM - 11:50 AM

*Explorers Room*

The field of extrasolar planet research is currently undergoing an fast, impressive gain of observational knowledge on the architectures and characteristics of planetary systems around other stars. This is thanks to the results of both observations from the ground, as well as observations from space.
Some of these detections, in particular from the KEPLER satellite and from high precision radial velocity searches have recently challenged existing planet formation models. This has triggered intense theoretical work in order to understand the origins of the differences between observation and theory.
In my talk I will present updated core accretion formation models which were used to conduct population synthesis simulations. Besides many other improvements contain these models a much more detailed description of planetary migration, allow for the concurrent formation of many fully interacting embryos in one disk, and include now also the subsequent evolution of the planets after formation on Gyr timescales. The latter improvement gives us all major quantities characterizing a planet, like its mass, composition, radius, luminosity and effective temperature. It also means that the results can be directly compared not only to the observed mass - distance diagram, but also to the observed radius distribution and the luminosity measured by direct imaging.
Thanks to such improvement of the models, allowing new physical phenomena like the capture into mean motion resonances, or the existence of convergence zones for type I migration, it is found that the properties of the population of synthetic close-in, low mass planets, and of the corresponding observed population are much more similar than in earlier models, even though that some differences still exist. An example is that the models predict an bimodal distribution of planetary radii, which is not observed. I will discuss the reasons for both the better agreement, as well as the remaining differences.

16.07

**Reversing Type I Migration in Gap Shadows**

**Hannah Jang-Condell**[1]

[1]*University of Wyoming.*

11:50 AM - 12:00 PM

*Explorers Room*

Type I migration refers to the radial drift of a planet resulting from tidal interactions with a protoplanetary disk. It results in rapid inward migration of a planet through a disk and may explain the preponderance of hot Jupiters in inventory of known exoplanets. However, Type I migration is so rapid compared to disk dissipation that explaining distant gas giant planets, such as the HR 8799 planets and Jupiter itself, is problematic. Here, we present a scenario for solving the Type I migration problem. As a planet grows in mass, its Type I migration rate increases. It also begins to clear material from its orbital path, creating a gap in the disk. The trough of such partially cleared gaps is shadowed from stellar illumination while the far side of the gap is illuminated. Since stellar irradiation is the primary heat source of passively accreting protoplanetary disks, gap self-shadowing can significantly change the local temperature profile. This change to the local temperature gradient can significantly slow, or even reverse Type I migration.

## Friday, September 16, 2011, 1:00 PM - 2:30 PM

### 17

### *Earths and Super-Earths*

Oral

*Explorers Room*

17.01

**Extreme Densities: Characteristics And Nature Of The High-density Super-Earths**

**Dimitar D. Sasselov**[1]

*[1]Harvard-Smithsonian CfA.*

1:00 PM - 1:15 PM

*Explorers Room*

The minimum radius for super-Earths of a given mass could be determined by planet formation history, high-density mineral phases, and evaporation. I will discuss theoretical models - of solids under extreme pressures, in particular, and constraints imposed on them by recent discoveries and observations.

17.02

**Composition of super-Earths and mini-Neptunes**

**Diana Valencia**[1]

*[1]MIT.*

1:15 PM - 1:30 PM

*Explorers Room*

The composition of super-Earths reflects the initial chemical inventory of the building blocks during formation, plus any subsequent evolution such as mass loss from evaporation and from giant impacts. With measured masses and radii of now several super-Earths, and in combination with internal structure models, it is possible to place constraints on their composition. I will discuss the results for the transiting super-Earths and mini-Neptunes and how this information can be tied to atmospheric evaporation, and the refractory composition of the host star.

17.03

**Twelve Consecutive Transits of GJ1214b in 20 Days of Continuous Observations by Spitzer**

**Drake Deming**[1], J. Fraine[1], M. Gillon[2], B. Demory[3], S. Seager[3]

*[1]Univ. Maryland, [2]Univ. Liege, Belgium, [3]MIT.*

1:30 PM - 1:45 PM

*Explorers Room*

From 29 April until 19 May, 2011, the Spitzer Space Telescope executed a continuous time series observation of the transiting super-Earth GJ1214b at a wavelength of 4.5 microns. The goals of this program are: 1) to search for transits of other planets to the outer edge of the habitable zone in this system, 2) to achieve a sensitive search for the secondary eclipse, and 3) to improve the precision of the transit parameters for GJ1214b. In this work we describe the results from goal 3, the transit analysis.

Observations of twelve transits will not only improve the precision of the planet's radius significantly, but may also help discriminate between hydrogen-rich and hydrogen-poor models of the planetary atmosphere.

17.04

**Characterization of the Transiting Super-Earth 55 Cnc e**

**Brice-Olivier Demory**[1], M. Gillon[2], D. Deming[3], S. Seager[1]

*[1]Massachusetts Institute of Technology, [2]Université de Liège, Belgium, [3]University of Maryland.*

1:45 PM - 1:55 PM

*Explorers Room*

The transiting nature of 55 Cnc e has been recently unveiled independently by the MOST satellite in the visible (Winn et al. 2011) and Warm Spitzer in the infrared (Demory et al. 2011).
55 Cnc e is the only transiting super-Earth orbiting a naked eye star, which makes this planet a true Rosetta stone in the field of low-mass exoplanets.
We will present new follow-up observations scheduled during Summer 2011 that will provide better constraints on the internal structure and immediate environment of this intriguing super-Earth.

17.05

**When Worlds Collide: Thermal Emission Spectra of Post-Giant-Impact Earths**

**Mark S. Marley**[1], K. Cahoy[2], K. Zahnle[1], B. Fegley[3], K. Lodders[3], L. Schaefer[3]

*[1]NASA Ames Research Center, [2]MIT, [3]Washington University.*

1:55 PM - 2:10 PM

*Explorers Room*

The final assembly of terrestrial planets in our Solar System is now universally thought to have occurred through a series of giant impacts--essentially collisions between planets--spread out over some 30-50 million years. It likely takes at least 10 collisions between planets to make a Venus and an Earth, as not every collision results in a merger of worlds. In the aftermath of one of these collisions the surviving planet is hot and can remain hot for a long time. As first proposed by Stern (1994) the thermal emission of an Earth-mass planet caught in the afterglow of such a giant impact renders the planet far more detectable than at any other time. Given the statistics of giant impacts and the population of nearby young stars, a few such post-impact worlds may be seen by the next generation of ground-based coronagraphs on 30-m class telescopes. Miller-Ricci et al. (2009) presented the first model spectra of such worlds, but considered only a few possible atmospheric compositions. We have now computed the actual atmospheric composition expected over a molten surface lying at hundreds of bars along with self-consistent radiative-convective temperature profiles. While major absorbers include the expected water and CO2, other species--including in some cases O2-are also detectable. We will summarize the surprising atmospheric chemistry and emission spectra of such planets and will consider the prospects for detecting and characterizing these extreme worlds.

17.06

**Kepler 11: A System Of Super-Earths Or Mini-Neptunes?**

**Eric Lopez**[1], J. J. Fortney[1], N. Miller[1], E. Kempton[1]

*[1]UC Santa Cruz.*

2:10 PM - 2:20 PM

*Explorers Room*

Low-density Super-Earths, like those in Kepler-11, represent members of a new class of planets. Basic questions about their structure and bulk composition still need to be addressed. Are they, in fact, scaled up rocky planets with thick hydrogen-rich atmospheres; or are they instead miniature Neptunes, with most of their mass in water? Using interior structure models, we constrain the present-day compositions for the five inner planets in Kepler-11. Using thermal evolution models coupled with hydrodynamic mass loss, we then explore the mass, radius, and composition history of each planet. Finally, we perform a dynamical stability check and compare to formation models to check the plausibility of these histories.

17.07

**Searching for Transits of Super-Earths Using the MOST Space Telescope**

**Diana Dragomir**[1], J. M. Matthews[1], HARPS Team

[1]*University of British Columbia, Canada.*

2:20 PM - 2:30 PM

*Explorers Room*

Using the MOST (Microvariability and Oscillations of STars) satellite, we carry out a search for transits among previously identified radial velocity planet candidates with minimum masses of the order of a few Earth masses. These super-Earths orbit F, G and K type stars with magnitudes in the range for which MOST is optimized. We present the statistical approach to analysing the MOST observations and our results for the candidates observed so far. These include BD-082823b, HD115617b and HD69830b, all of which are found in multiple planet systems.

## Friday, September 16, 2011, 3:00 PM - 4:30 PM

### 18

### *Habitability*

Oral

*Explorers Room*

18.01

**Habitable Zones Around Low-Mass Stars**

**Ravi Kumar Kopparapu**[1], J. F. Kasting[1], R. Ramirez[1]

[1]*Pennsylvania State University.*

3:00 PM - 3:15 PM

*Explorers Room*

Classically, the circumstellar habitable zone (HZ) is defined as the region inside which a terrestrial mass planet, with adequate supplies of carbon, water, and internal heat, can sustain liquid water on its surface (Kasting et al. 1993). A conservative estimate for the width of the HZ in our Solar system is 0.93-1.48 AU, assuming that the inner edge is limited by water loss and the outer edge is determined by the maximum greenhouse limit for a dense CO2 atmosphere. These numbers are revisions of ones published by Kasting et al. (1993), based on new climate modeling results. Kasting et al. obtained HZ boundaries for stars with effective temperatures between 3700 K and 7200 K--limits that do not include main-sequence M-dwarfs. In this study we use an updated 1-D radiative-convective, cloud-free climate model to estimate the width of the HZ around these low mass stars. Significant improvements in our climate model include: (1) updated collision-induced absorption coefficients for CO2 (critical for dense CO2 atmospheres at the outer edge) and (2) a revised Rayleigh scattering coefficient for H2O (important for water loss at the inner edge). Assuming Earth-like planets with CO2/H2O/N2 atmospheres, the width of the HZ is 0.24-0.44 AU around an early M star (Teff = 3600 K) and 0.05-0.09 AU for a late M star (Teff = 2800 K). As our model does not include the radiative effects of clouds, the actual HZ boundaries may extend further in both directions than our conservative estimates. Nonetheless, current ground-based surveys (e.g., the MEARTH project) and future space-based characterization missions (e.g., JWST/TPF) may be able to use these HZ boundaries to help guide their efforts to find habitable planets around main-sequence stars. (We acknowledge funding from NASA Astrobiology Institute's Virtual Planetary Laboratory, supported by NASA under cooperative agreement NNH05ZDA001C.)

18.02

**The Late Heavy Bombardment and Outer Planet Interlopers**

**Steinn Sigurdsson**[1], L. W. Legel[2], E. B. Ford[3]
*[1]Pennsylvania State Univ., [2]University of Colorado, [3]University of Florida.*

3:15 PM - 3:30 PM

*Explorers Room*

We propose a model for the Solar System where the Late Heavy Bombardment was triggered by an additional outer planet in an inclined orbit, and could trigger a bombardment from the outer disk of a magnitude and timing consistent with that inferred from the crater record.
The conjectured planet is consistent with current observational limits, but ought to be detectable in future surveys.
This research was upported in part by the NASA Astrobiology Institute.

18.03

**Liquid Water Oceans on Super Earths**

**Leslie Rogers**[1], S. Seager[1]
*[1]Massachusetts Institute of Technology.*

3:30 PM - 3:45 PM

*Explorers Room*

We present a practical method to assess whether a transiting planet could have a liquid water ocean. We focus on super Earth planets with voluminous gas envelopes (of which GJ 1214b is the exemplar). Equilibrium temperature alone is insufficient to determine whether a planet could have surface liquid water. We model energy transport through planet envelopes to quantify the range of physically plausible, steady state, interior pressure-temperature profiles. We then identify scenarios for which the profile encounters conditions where water is in the liquid phase. Our model constrains the combinations of planet parameters (mass, radius, equilibrium temperature, intrinsic luminosity) conducive to liquid water oceans.

18.04

**How Common Are Earth-Moon Planetary Systems?**

**Sebastian Elser**[1], J. Stadel[1], B. Moore[1], R. Morishima[2]
*[1]University of Zurich, Switzerland, [2]University of Colorado.*

3:45 PM - 4:00 PM

*Explorers Room*

The Earth's comparatively massive moon, formed via a giant impact on the proto-Earth, has played an important role in the development of life on our planet, both in the history and strength of the ocean tides and in stabilizing the chaotic spin of our planet. Here we show that massive moons orbiting terrestrial planets are not rare. A large set of simulations by Morishima et al., 2010, where Earth-like planets in the habitable zone form, provides the raw simulation data for our study. We use limits on the collision parameters that may guarantee the formation of a circumplanetary disk after a protoplanet collision that could form a satellite and study the collision history and the long term evolution of the satellites qualitatively. In addition, we estimate and quantify the uncertainties in each step of our study. We find that giant impacts with the required energy and orbital parameters for producing a binary planetary system do occur with more than 1 in 12 terrestrial planets hosting a massive moon, with a low-end estimate of 1 in 45 and a high-end estimate of 1 in 4.
We thank University of Zurich for the financial support.

18.05

**Formation and Detection of Habitable Trojan Planets/Super-Earths**

**Nader Haghighipour**[1]
*[1]Univ. of Hawaii.*
4:00 PM - 4:10 PM
*Explorers Room*
Since the discovery of the first transiting planet more than a decade ago, the search for Trojan planets has been a particular subject of interest. Despite a great deal of research in exploring the possibility of the detection of these objects, no Trojan planet has yet been found. However, the success of the Kepler space telescope in discovering several multiplanet transiting systems using transit timing variation method, and in identifying more than 1200 planetary candidates points to the great capability of this telescope in detecting Trojan objects. We have carried out an expansive study of the possibility of the detection of Trojan planet using transit timing variation method, and identified ranges of mass and orbital elements of these objects for which the TTV signal of a transiting giant planet due to its Trojan companion would fall within the range of the photometric sensitivity of Kepler. Given our interest in detecting habitable planets, we have focused our study on M stars where the habitable zone is in close distances. To explain the possible formation of such Trojan habitable planets, we have developed a planet formation-migration code and studied the formation of planets in resonances around M stars. While results point to the combination of giant planet migration and resonance capture as a favorable mechanism for the formation of terrestrial-class objects and super-Earths in resonance with short-period giant planets, they do not present this mechanism equally favorable for the formation of Trojan planets or satellites. However, an alternative, that is, the in-situ formation of Trojan planets around a Jovian-type body, and their simultaneous migration with this object seems to be a more promising scenario. We present the results of our study and discuss their implications for the detection of habitable Trojans using Kepler space telescope.

18.06
**Extreme Space Weather on Close-in Exoplanets**
**Ofer Cohen**[1], V. Kashyap[1], J. Drake[1], I. Sokolov[2], C. Garraffo[1], T. Gombosi[2]
*[1]Harvard-Smithsonian Center for Astrophysics, [2]University of Michigan.*
4:10 PM - 4:20 PM
*Explorers Room*
Habitability of exoplanets is commonly determined by the planetary surface temperature, which allows liquid water to exist. However, extreme space weather and interplanetary conditions that include the stellar wind and Coronal Mass Ejections (CMEs), can impact the ability of close-in planets to sustain their atmospheres, unless they are shielded by an intrinsic magnetic field. Here we present a series of numerical MHD simulations of a stellar corona harboring a close-in planet. We study the planetary impact on the stellar corona, and characterize the ability of the planetary magnetic field to shield the planetary atmosphere from erosion by both the ambient stellar wind and CMEs. We also estimate the energy transferred to the planet via the interaction with a CME and predict the global structure of the aurora generated by the space weather event. The simulations we present are highly realistic and are not based on idealized scenarios.

18.07
**Rogue Worlds and the Power of the Dark Side**
**Jason H. Steffen**[1]
*[1]Fermilab.*
4:20 PM - 4:30 PM
*Explorers Room*

Many models for WIMP dark matter (Weakly Interacting Massive Particles) have both weak-scale couplings to nucleons and the capacity to annihilate into standard-model particles. A consequence of these properties is that dark matter particles near the cores of galaxies can, through nuclear scattering in a planet interior, lose energy and become gravitationally bound to the planet. These dark matter particles can then annihilate into energetic standard model particles providing a significant source of internal heat. In some situations, dark matter annihilations and a modest greenhouse effect can raise the surface temperature of a super-Earth planet above the melting point of water. These temperatures can be sustained for many trillions of years. Thus, it may be possible for even rogue super-Earths, with no stellar host, to sustain habitable conditions almost indefinitely.

## Monday, September 12, 2011, 8:30 AM – Friday, September 16, 2011, 3:00 PM
## 19
### *Planet Detection - Transits*
Poster
*Osprey/Grizzly*

19.01

**Current Status of KELT: A Northern and Southern Survey for Bright Transiting Systems**

**Joshua Pepper**[1], R. Siverd[1], T. Beatty[2], J. Eastman[2], B. Gaudi[2], R. Kuhn[3], K. Stassun[1]
[1]*Vanderbilt University,* [2]*The Ohio State University,* [3]*The University of Cape Town, South Africa.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The KELT project photometrically surveys 50% of the sky using two robotic, wide-field, small aperture telescopes, with the primary goal of discovering transiting exoplanets in the range 8 < V < 10. In Arizona, KELT-North has been running for 4 years, and in South Africa KELT-South has been running for 1.5 years. We have implemented a variant on the ISIS difference imaging pipeline, and are achieving the < 1% photometric precision that allows us to search for transiting planets. The data are being used to create catalogs of variable stars, identify EBs for testing stellar astrophysics, and acquire lightcurves of inner solar system comets. We describe our methods for selecting promising transiting planet candidates, and present some early results from radial velocity and photometric vetting of candidates from KELT-N. KELT-South is funded by the Vanderbilt Initiative in Data-Intensive Astrophysics (VIDA).

19.02

**LUNA: A Transit Algorithm for Exomoons**

**David M. Kipping**[1]
[1]*Harvard-Smithsonian Center for Astrophysics.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Exomoons represent a formidable and alluring challenge to exoplanetary science. The detection of such objects would be of major value to planetary formation theory, astrobiology and observational astronomy. Presently, it is conceived that transit timing methods offer the most plausible route to achieving a detection but achieving the necessary signal-to-noise remains daunting. Here, we present a new algorithm which dynamically models these transit timing effects plus the eclipses of the moon itself. Our new algorithm, LUNA, computes all known observational effects which a moon imparts on a light curve and thus achieves the maximum possible sensitivity. LUNA is completely analytic and executes in almost the same computational time as generating a planet alone. Therefore, LUNA will be a potent weapon in future exomoon searches. Example implementations of LUNA will be presented.

19.03

**Spectroscopic Parameters of the Host Stars of Transiting Planets**

**Guillermo Torres**[1], D. A. Fischer[2], A. Sozzetti[3], L. A. Buchhave[4], J. N. Winn[5], M. J. Holman[1], J. A. Carter[1]
[1]*Harvard-Smithsonian, CfA,* [2]*Dept. of Astronomy, Yale University,* [3]*INAF, Italy,* [4]*Niels Bohr Institute, Copenhagen University, Denmark,* [5]*Dept. of Physics, MIT.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

In order to determine the masses and radii of extrasolar transiting planets it is essential to know those of the parent stars, which are in turn usually determined from the spectroscopic properties such as temperature, metallicity, and surface gravity. We present preliminary results from a project to

redetermine these parameters for many of the known systems in a uniform way based on new and archival spectra, with careful attention to systematics. We constrain the surface gravity (often one of the more poorly determined properties) in the spectroscopic analysis using the mean stellar density that may be obtained directly from the transit lightcurve solutions. Results are compared with the unconstrained solutions, and the impact on the stellar mass and radius is investigated. This research is supported by NASA/Origins grant NNX09AF59G.

19.04

**Transit Exoplanet Survey in Antarctic Dome A**

**Jilin Zhou**[1], Y. Sun[1], H. Zhang[1], M. Li[1], J. Yang[1], Y. Chen[1]

[1]*Nanjing University, China.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Antarctic is an ideal and unique site on Earth for astronomical observations. Due to its low water content, low turbulent atmosphere zone and 24 hours uninterrupted observations during its winter time, it is an extremely good place for transit exoplanet survey which requires high photometric precision. 4 small telescopes (CSTAR) with diameter 14.5 centimeters have been put in Antarctic Kunlun station (Dome A), and operated since 2008. Three telescopes (AST3) with diameters around 50 centimeters each will be placed in Dome A within next few years. Here we report our planned transit survey in AST3, aiming at finding exoplanets at middle distance to their host stars. The planet candidates found through AST3 will be followed by a late-coming 2.5-meter telescope called KDUST. Some preliminary exoplanet candidates revealed by the ongoing CSTAR will be presented. The work is supported by Nanjing University's 985 Funds, and Funds form NSFC.

19.05

**Vetting Kepler Planet Candidates with Multi-Color Photometry from the Gran Telescopio Canarias**

**Knicole Colon**[1], E. B. Ford[1]

[1]*University of Florida.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We present multi-color observations of small (super-Earth to Neptune-size) planet candidates recently identified by the Kepler space mission. By applying the unique capabilities of OSIRIS (installed on the 10.4-meter Gran Telescopio Canarias) for near-simultaneous multi-color photometry, we use the color of Kepler candidates as measured during predicted transit events to reject candidates that are false positives (e.g., a blend with an eclipsing binary in the background or bound to the target star). Our results include the discovery of a background eclipsing binary star (KIC 7025851) near KOI-565 (KIC 7025846). Based on the location of the eclipsing binary (~15 arcsec from KOI-565), we conclude that the eclipsing binary contaminated the light from KOI-565 to mimic the super-Earth-size transit signal that was detected by Kepler. We also compare the technique of measuring colors in two narrow (2 nm) bandpasses separated by only a few nanometers in wavelength (~790-794 nm) with measuring colors in two wider (36-58 nm) bandpasses located at bluer (~666 nm) and redder (~858 nm) wavelengths. These observations are part of a program to statistically determine the likelihood that planet candidates (e.g., with a given size) ultimately end up being false positives and are complementary to a similar program using warm-Spitzer. This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-0802270.

19.06

**Variational Bayes Techniques for Correcting Spitzer Systematics**

**Tom Evans**[1], S. Aigrain[1], S. Roberts[1], N. Gibson[1]
[1]*Oxford University, United Kingdom.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Accurate measurements of primary transit and secondary eclipse depths made with the Infrared Array Camera (IRAC) on board the Spitzer Space Telescope have been highly successful at characterising the atmospheres of exoplanets. In order to make these measurements, it is crucial to correct for intrapixel sensitivity variations in the 3.6um and 4.5um channels as well as a ramp-up effect in the 5.8um and 8.0um channels. This is typically done by modelling them simultaneously with a model for the planetary signal using Markov Chain Monte Carlo (MCMC) direct sampling methods. We present an alternative approach that makes use of variational Bayes (VB) techniques to directly approximate the posterior distribution, leading to dramatic improvements in computation time. This allows us to consider models with many more free parameters so that complex behaviour, if present, can be accurately captured. A powerful advantage of VB is that over-fitting is automatically avoided, without the need to resort to discriminating statistics such as the Bayesian Information Criterion (BIC). We demonstrate the approach on previously published Spitzer data.

19.07
**Design-considerations For A Ground-based Transit Survey To Find Habitable Planets Around L And T Dwarfs**
**Ramarao Tata**[1], E. Martin[2]
[1]*Instituto De Astrofisica De Canarias, Spain,* [2]*CAB, Spain.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Detection of planets in the habitable zone is one of the key drivers of the exoplanet science community. We present a detailed strategy for such detection around L and T dwarfs. We plan to implement the outcome of the analysis as a transit survey to search for planets around known L and T dwarfs. Understanding of the variability of these cool objects will be a worth-while byproduct of such a survey.

19.08
**Current status of the Qatar Exoplanet Survey**
**Neil Parley**[1], A. Collier Cameron[1], K. Horne[1], K. A. Alsubai[2], QES consortium
[1]*University of St. Andrews, United Kingdom,* [2]*Qatar Foundation, Qatar.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
The Qatar Exoplanet Survey (QES) is conducting a wide-field transit search program using a 6-camera CCD imaging system designed design to go at least 0.5 magnitudes fainter than most current wide-angle surveys such as SuperWASP and HATNet. QES uses two overlapping wide field 135mm and 200mm lenses along with four 400mm lenses mosaiced to cover the same 11x11 degree field of view. The higher angular resolution and large aperture doubles the sampling volume for low-mass stars, compared to WASP and HAT. Saturn and Neptune sized planets are more easily detected if they orbit smaller stars, therefore by extending the transit search to stars with smaller radii QES is well position to plug the gap, between SuperEarths and Hot Jupiters, left between Kepler and the current wide-angle surveys. QES detections are nonetheless still bright enough for radial-velocity follow up with 2-m and 4-m class telescopes. We present the current status of the Qatar Exoplanet Survey, along with information of the first transiting exoplanets, Qatar-1b and Qatar-2b, to be found using the instrument, which were both detected orbiting K-dwarfs stars.

19.09

**Sensitivity Analysis of the WFCAM Transit Survey**

**Gabor Kovacs**[1], S. Hodgkin[1], members of the EC funded RoPACS Initial Training Network and of the WTS consortium
[1]*Institute of Astronomy, Cambridge, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The WFCAM Transit Survey has been running on the United Kingdom Infrared Telescope since 2007. The WTS targets about 6000 M dwarfs (J<16) in four fields close to the galactic plane in the near infrared. The search for planets around M dwarfs is a young and exciting field in exoplanet hunting. Core accretion theories predict that Jovian planets should be rare in systems around low mass stars. I will present my work on the sensitivity of our survey. A Monte Carlo simulation was developed using lightcurves in one of our fields to measure transit recovery ratios. Interpreting our null-detections we can place statistical constraints on the frequency of different planetary systems around M dwarfs. I will compare our results with other surveys' discovery statistics.

19.10

**The WFCAM Transit Survey: Search For Planets Around Cool Stars**

**Brigitta Sipocz**[1], D. Pinfield[1], S. Hodgkin[2], members of the EC funded RoPACS Initial Training Network and of the WTS consortium
[1]*University of Hertfordshire, United Kingdom,* [2]*Institute of Astronomy, University of Cambridge, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The WFCAM Transit Survey (WTS) has been obtaining data on the United Kingdom Infrared Telescope since 2007. Operating in the near-infrared the WTS targets about 6000 M dwarf stars (J<16) over several square degrees of sky close to the galactic plane and aims to find planets, down to the size of the Earth, transiting around M dwarfs. In my talk I will present the goals, processing and follow-up methods of the survey. I will discuss the properties of our target stars and summarize the latest status of our most promising candidates.

19.11

**High Time Resolution Lightcurves Of Extrasolar Transits With Iqueye**

**Mauro Barbieri**[1], C. Barbieri[2], G. Naletto[2], L. Zampieri[3]
[1]*Observatoire De La Cote D'Azur, France,* [2]*University of Padova, Italy,* [3]*INAF - Osservatorio Astronomico di Padova, Italy.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Detection of Earth mass planets around nearby stars could be achieved monitoring the transit time variations and transit duration variations of the known transiting extrasolar planets. Here we present the results of the first observing run of three known planetary transits obtained with IQuEye at ESO/NTT . We observed simultaneously in optical with 4 intermediate width filters and with high temporal accuracy (about 30 ns) the transits of Corot-2b, HD 189733b, and WASP-2b.

19.12

**Search For Transits Of RV Discovered Planets In The Stereo Data**

**Zlatan I. Tsvetanov**[1], R. P. Olling[2], P. McCullough[3], G. Mandushev[4], H. Markov[5]
[1]*Johns Hopkins University,* [2]*University of Maryland, College Park,* [3]*Space Telescope Science Institute,* [4]*Lowell Observatory,* [5]*Rozhen National Astronomical Observatory, Bulgaria.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We describe an application of the photometric time series extracted from the existing data from one of the instruments on the currently operating space mission STEREO to search for transiting exoplanets. STEREO is a mission in NASA's Solar Terrestrial Probes program and uses two nearly identical spacecrafts to map coronal mass ejections as they propagate away from the Sun. In addition to observing the heliosphere STEREO also observes the background star field. The continuous series of images obtained by the Heliospheric Imager 1 (HI-1) cameras on the two STEREO spacecrafts are well suited for the search for transiting exoplanets with bright host stars.

There are approximately 50 RV-discovered planets in the STEREO field with periods ranging from a few days to several thousand days. This poster will present analysis of the existing data for all of these stars, which consists of up to ten 20-day windows of contiguous coverage of 40 min cadence. The STEREO data provide full coverage for transiting planets with periods up to 20 days and down to a certain radius, dependent on the brightness of the star. We will discuss the limitations in each individual case. In many cases, for the very bright host stars in particular, the transits of even super-Earths could be detected. In addition we will search for transits at the RV established periods. Special attention will be paid to planets with significant eccentricity because of the greatly increased probability of transit. For many of the host stars, the STEREO data provide the most precise photometric time series available; we will quantify the intrinsic variability of those stars in addition to searching for transits.

19.13

**Detailed Bayesian Analysis of the CoRoT-7 Lightcurve**

**Hannu Parviainen**[1], H. Deeg[1]

[1]*Instituto De Astrofísica De Canarias, Spain.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

With a mass of 7.4 Earth masses and radius of 1.6 Earth radii, CoRoT-7b is among the smallest transiting planets found to date. Due to its small size, the transit signal is very shallow, which makes the estimation of the planetary parameters from the light curve challenging.

We carry out a Bayesian analysis of the CoRoT-7b lightcurve using a minimalistic approach to the pre-processing of the data. We use parallel tempering Markov Chain Monte Carlo simulations to gain a comprehensive view of the geometric and planetary parameter probability distributions, including the possibility for transit timing variations.

Furthermore, we assess whether the use of a quadratic limb-darkening model is justified given the accuracy of the data, and how the choice of the limb-darkening model affects the geometric and planetary parameters inferred from the PTMCMC simulations.

This research is supported by RoPACS, a Marie Curie Initial Training Network funded by the European Commission's Seventh Framework Programme.

19.14

**Assessing the Nature and Impact of Observed Stellar Variability on Kepler's Ability to Detect Earth-Size Planets**

**Jon Michael Jenkins**[1], E. W. Dunham[2], V. S. Argabright[3], W. J. Borucki[4], D. A. Caldwell[1], W. J. Chaplin[5], J. L. Christiansen[1], T. N. Gautier[6], R. L. Gilliland[7], J. Kolodziejczak[8], P. Machalek[1], J. Van Cleve[1], G. Basri[9], D. L. Buzasi[10], M. R. Haas[4], S. B. Howell[4], P. Tenenbaum[1], L. M. Walkowicz[9], W. F. Welsh[11]

[1]*SETI Institute,* [2]*Lowell Observatory,* [3]*Ball Aerospace and Technologies Corp.,* [4]*NASA Ames Research Center,* [5]*University of Birmingham, United Kingdom,* [6]*Jet Propulsion Laboratory,* [7]*Space Telescope Science Institute,* [8]*NASA Marshall Spaceflight Center,* [9]*University of California, Berkeley,* [10]*Eureka Scientific,* [11]*San Diego State University.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The Kepler spacecraft was launched on March 6 2009 on a 3.5-year mission to determine the frequency of Earth-size and larger planets in or near the habitable zones of their stars. Kepler has been observing ~160,000 stars to detect transiting planets for over two years and has discovered more than 16 confirmed or validated planets and has identified over 1200 candidate planets. There is sufficient data and experience with the photometer to characterize Kepler's ability to detect weak signatures of small, terrestrial planets. The photometer's sensitivity depends on the total combined differential photometric precision (CDPP) and on the mission lifetime. These driving requirements for Kepler called for a total CDPP of 20 ppm for 12th magnitude G2 dwarf stars in 6.5 hours, and a mission lifetime of 3.5 years. The noise budget includes 14 ppm for shot noise, 10 ppm for instrument noise and 10 ppm adopted for intrinsic stellar variability. The CDPP requirement was necessarily set without knowledge of actual typical levels of stellar variability. We find that Kepler's noise metrics for 12th magnitude dwarf stars are dominated by stellar variability and the overall combined noise is ∼50% higher than the required value. While this does reduce Kepler's ability to achieve its scientific objectives, Kepler's originally envisioned capability to detect terrestrial planets can be recovered by extending the duration of the flight mission to 8 years.

19.15

**The TERMS Project: Systematic Transit Exclusion**

**Stephen R. Kane**[1], D. Ciardi[1], D. Dragomir[2], D. Fischer[3], G. Henry[4], A. Howard[5], E. Jensen[6], G. Laughlin[5], S. Mahadevan[7], G. Pilyavsky[7], K. von Braun[1], X. Wang[7], J. Wright[7]

*[1]NASA Exoplanet Science Institute, Caltech, [2]University of British Columbia, Canada, [3]Yale University, [4]Tennessee State University, [5]University of California, [6]Swarthmore College, [7]Pennsylvania State University.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Transiting planet discoveries have yielded a plethora of information regarding the internal structure and atmospheres of extra-solar planets. These discoveries have 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 at long periods around bright host stars. Here we describe transit window calculations for known radial velocity planets, techniques for refining their transit ephemerides, and observational methods for obtaining maximum coverage of transit windows. These methods are currently being implemented by the Transit Ephemeris Refinement and Monitoring Survey (TERMS), from which we present the latest results.

19.16

**Enabling the Ground-based Detection of Transiting Habitable-zone Earths**

**Christopher J. Burke**[1]

*[1]NASA Ames Research Center / SETI.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The small radii and cool temperatures of M dwarfs make them favorable targets for transiting planet surveys of habitable-zone Earth and super-Earth planets. The MEarth survey has detected a super-Earth orbiting the nearby M5 star GJ 1214 and estimated the planetary mass and radius precisely. Despite this success, the MEarth survey encounters photometric noise larger than expected based upon Poisson and scintillation sources alone. I have identified precipitable water vapor (PWV) variations in the Earth's atmosphere as the likely predominant source of excess systematic noise in the MEarth survey photometry. Based upon theoretical calculations of the PWV induced noise, I show potential filter choices that eliminate PWV induced noise to a sufficient level to detect transiting Earth-sized planets from the ground around M dwarf hosts. Through detecting super-Earth planets, the MEarth project provides valuable insight into exploring and eliminating any technical limitations to ground based detections of smaller, truly Earth-sized, planets in the habitable-zone of the brightest M dwarfs.

19.17

**Kepler-14b: A massive hot Jupiter transiting an F star in a close visual binary**

**Lars A. Buchhave**[1], D. W. Latham[2], J. A. Carter[3], J. D'esert[2], G. Torres[2], et al., Harvard-Smithsonian Center for Astrophysics

*[1]Niels Bohr Institute, University of Copenhagen, Denmark, [2]Harvard-Smithsonian Center for Astrophysics, [3]Harvard-Smithsonian Center for Astrophysics/Hubble Fellow.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We present the discovery of a hot Jupiter transiting an F star in a close visual (0.3" sky projected angular separation) binary system. The dilution of the host star's light by the nearly equal magnitude stellar companion (~ 0.5 magnitudes fainter) significantly affects the derived planetary parameters, and if left uncorrected, leads to an underestimate of the radius and mass of the planet by 10% and 60%, respectively. Other published exoplanets, which have not been observed with high-resolution imaging, could similarly have unresolved stellar companions and thus have incorrectly derived planetary parameters. Kepler-14b (KOI-98) has a period of P = 6.790 days and correcting for the dilution, has a mass of Mp = 8.40 +0.19-0.18 MJ and a radius of Rp = 1.136 +0.073-0.054 RJ, yielding a mean density of rho = 7.1 +- 1.1 g cm-3.

19.18

**Analysis of exoplanet XO-2 b observed with HST NICMOS**

**Nicolas Crouzet**[1], P. R. McCullough[1], C. Burke[1], D. Long[1]

*[1]STScI.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We present the photometric and spectroscopic analysis of the transiting planet XO-2 b, from HST NICMOS. Three transits of the planet have been observed. 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. 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 this system in the range 1.2-1.8 microns with a spectral resolution of R~35, taking into account systematic effects. To investigate the validity of the method and the reliability of NICMOS data, we also build a spectrum for the exoplanet XO-1 b. We find an overall shape close to Tinetti et al. (ApJL 2010), although differences appear for some particular features. In the context of a debate about planetary spectra obtained with NICMOS, this study suggests that NICMOS data, although clearly affected by systematics, contain enough information to derive planetary spectra at least at low resolution.

## 20
### *Planet Detection - Radial Velocities*
Poster
*Osprey/Grizzly*

20.01

**New Techniques for Precision Near-Infrared Radial Velocities**

**Peter Plavchan**[1], G. Anglada[2], NIR RV collaboration
*[1]Caltech, [2]Carnegie Institute of Washington.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

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 pursuing to complement optical radial velocity work.

20.02

**The Solaris Project. A Timing Survey For Cricumbinary Planets Around Eclipsing Binary Stars.**

**Maciej Konacki**[1], S. Kozlowski[1], P. Sybilski[1], M. Ratajczak[1], K. Helminiak[2]
*[1]Nicolaus Copernicus Astronomical Center, Poland, [2]Pontificia Universidad Catolica de Chile, Chile.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The photometric timing of eclipses of eclipsing binary stars opens an opportunity for detecting circumbinary planets. There have recently been a few claims of circumbinary planets discovered via eclipse timing around active very short period binary stars. These "detections" are doubtful, at best. This field is however going to evolve significant in the near future. We were granted 2.6 million USD to establish a network of at least four robotic 0.5-m telescopes on three continents (Australia, Africa and South America) dedicated to the timing search for circumbinary planets. The project is named SOLARIS. We will discuss its scientific goals and technical aspects.

20.03

**A Keck I/HIRES and TNG/SARG Radial Velocity Survey of Speckle Binary Stars**

**Milena Ratajczak**[1], M. Konacki[1], S. R. Kulkarni[2], M. W. Muterspaugh[3]
*[1]NCAC Polish Academy of Sciences, Poland, [2]California Institute of Technology, [3]Tennessee State University, Department of Mathematics and Physics.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

A sample of about 150 speckle binary stars was observed with the Keck I telescope and its echelle HIRES spectrograph over the years 2003-2007 in an effort to detect substellar and planetary companions to components of binary and multiple star systems. This data set was supplemented with the data obtained at the TNG telescope equipped with the SARG echelle spectrograph over the years 2006-2007. The high-resolution (R=65000 for HIRES and R=86000 for SARG) and high signal to noise (typically 75-150) spectra were used to derive radial velocities of the components of the observed speckle binaries. Here we present a summary of this effort which includes limits to planetary companions, new triple star systems and improved orbital solutions of a few known stellar systems.

20.04

**A HARPS Search for Low Mass Planets Around Alpha Cen B: First Resultss**

**Xavier Dumusque**[1], C. Lovis[1], N. C. Santos[2], S. Udry[1], M. Mayor[1], F. Pepe[1]
*[1]Geneva Observatory, Switzerland, [2]Centro de Astrofisica da Universidade do Porto, Portugal.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The level of precision achieved by HARPS is opening the way to the discovery of very low-mass and long-period planets. However, short-term activity, characterized by the appearance of magnetic features on the stellar surface, is the main limitation of the radial-velocity (RV) precision. Indeed, RV perturbations of the order of a few meter-per-seconds can be induced by the presence of magnetic features on solar-type stars, which is one order of magnitude higher than the signal caused by an Earth-mass habitable planet.

Alpha Cen B (HD128621), assumed up to now as the best target to search for an Earth-like habitable planet, as been showing signs of magnetic activity in recent years. The recent HARPS measurements provide an unprecedented data set to study the RV effect of activity on solar-type stars and to search for a low-mass habitable planet.

The proposed talk will focus on the characterization of the activity of Alpha Cen B, on the way to correct this noise and finally on the expected detection limits when removing the activity effect.

20.06

**Precision Radial Velocities At Red-optical Wavelengths**

**John Barnes**[1], H. R. A. Jones[1], J. Jenkins[2], P. Rojo[2], P. Arriagada[3], A. Jordán[3], D. Minniti[3]
*[1]University of Hertfordshire, United Kingdom, [2]Universidad de Chile, Chile, [3]Universidad Catolica, Chile.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We discuss use of the 0.7 - 0.9 micron region for radial velocity surveys aimed at searching for low mass planets orbiting M5 - M9.5 dwarfs. For low-mass stars, the 2.5-5 magnitude gain at I band offers a clear effciency advantage when compared with traditional V-band wavelengths. We investigate the advantages and disadvantages of different techniques used to derive radial velocities in this wavelength regime and present preliminary results from our MIKE/Magellan survey.

20.07

**ExoFit - Characterising Orbits the Bayesian Way**

**Morgan Hollis**[1], S. Balan[2], O. Lahav[1]
*[1]University College London, United Kingdom, [2]Cambridge University, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Over 500 exoplanets have now been detected using the radial velocity technique, and various methods have been adopted to estimate their orbital parameters. On their own, or combined with data from transits, the results are used to characterise planets and their environments, and statistically to address gaps in the current understanding of planetary formation and evolution. With such an abundance of data, the need is obvious for new techniques to deal with the statistics in a rigorous and systematic fashion, and to constrain the orbital parameter space in order to push the search for new and ever smaller exoplanets.

We at UCL are developing methods borrowed from cosmology to tackle this problem in a Bayesian framework. We use the ExoFit code (Balan & Lahav 2009), utilising Markov Chain Monte Carlo (MCMC) simulations with the Metropolis-Hastings algorithm, to determine the orbital characteristics of planetary systems from radial velocity measurements. We present here the result of the application of ExoFit to

the publicly-available data for over 100 stars known to host planets, approximately a quarter of the known population of planetary systems. This results in a database of uniformly-derived orbital parameters, in addition to some surprising differences between some published orbital solutions and the statistical distribution of ExoFit parameters. In addition to developments on the code (fitting for more planets, dealing with resonances etc.), this work naturally leads on to the inclusion of more planets as more data become available, resulting in an ever more comprehensive database of uniformly-derived parameters for known planetary systems.
M. Hollis is supported by an Impact/Perren studentship.

20.08
**Planets around Giant Stars**
**Andreas Quirrenbach**[1]
[1]*Landessternwarte Heidelberg, Germany.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
We present results from a radial-velocity survey of 373 giant stars at Lick Observatory, which started in 1999. The previously announced planets ι Dra b and Pollux b are confirmed by continued monitoring. Several new companion candidates are found. The frequency of detected planetary companions appears to increase with metallicity. The star ν Oph is orbited by two brown dwarf companions in orbits with a period ratio close to 6:1. It is likely that the two companions to ν Oph formed in a disk around the star.

20.09
**Soap, A Free-code Tool To Study The Impact Of Stellar Activity**
**Isabelle Boisse**[1], X. Bonfils[2], N. Santos[1]
[1]*Centro De Astrofisica Da Universidade Do Porto, Portugal,* [2]*IPAG, France.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Dark spots and bright plages are present on the surface of all stars, even low-active stars (like the Sun in its low-active phase). Their appearance and disappearance on the stellar photosphere, combined with the stellar rotation, may lead to errors and uncertainties in the characterization of planets both in radial velocimetry and photometry.
SOAP is a tool offered to the community (Boisse, Bonfils and Santos, in prep.) that enables to simulate spots and plages on rotating stars and computes their impact on RV and photometric measurements. This talk will discuss the challenges related to the knowledge of stellar activity for the next decade: detect telluric planets in the habitable zone of their stars (from G to M dwarfs), understand the activity in the low-mass end of M dwarf (on which will focus future projects like Elektra, SPIRou or CARMENES), limitation to the sum of different transit observations in order to characterize the atmospheric components (from the ground or with Spitzer, JWST), planets around young stars,... and how this can be simulated with SOAP in order to search for indices and corrections.
IB and NCS would like to thank the support by the European Research Council/European Community under the FP7 through a Starting Grant, as well from Fundacao para a Ciencia e a Tecnologia (FCT), Portugal.

20.10
**Exoplanets Search And Characterization With The Sophie Spectrograph At Ohp**
**Guillaume HÃ©brard**[1], the SOPHIE Team
[1]*IAP/OHP, France.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Several programs of exoplanets search and characterization in the Northern hemisphere are ongoing with the spectrograph SOPHIE at the 1.93-m telescope of Haute-Provence Observatory, France. SOPHIE is an environmentally stabilized echelle spectrograph dedicated to high-precision radial velocity measurements. The objectives of these programs include systematic searches for exoplanets around different types of stars, characterizations of planet-host stars, studies of transiting planets through Rossiter-McLaughlin effect, follow-up observations of photometric surveys. Latest SOPHIE results will be presented.

20.11

**Precise Radial Velocities in the IR**

**Pedro Figueira**[1], N. Santos[1], C. Melo[2], F. Pepe[3]

*[1]CAUP, Portugal, [2]ESO, Chile, [3]Observatoire de Geneve, Switzerland.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

After several decades of low-precision work, precise Radial Velocities (RV) are now expanding into the infra red (IR) domain (e.g. Figueira et al 2010, A&A 511A, 55; Bean et al. 2010, ApJ 713, 410). Exploring the infrared is extremely advantageous not only because the M-dwarfs emission peak in the IR but also because the effect of stellar spots on RV are reduced, making IR RV a powerful diagnosis tool.
Here we present our current effort to characterize the IR curve of two planet-host stars whose candidate planets were detected with optical RV: an active k-dwarf star and a giant star. The results will confirm (or not) the presence of planets orbiting these two interesting stars. In particular, they will shed new light into the frequency of planets around higher mass (giant) stars, or even their existence at all. We also describe a campaign that was used to evaluate the phenomena that dominate the precision of our calibrator, atmospheric lines.

20.12

**Korean-Japanese Planet Search Program: A Jovian-Mass Planet to the Intermediate-Mass Clump Giant Star**

**Masashi Omiya**[1], I. Han[2], H. Izumiura[3], B. Lee[2], B. Sato[1]

*[1]Tokyo Institute of Technology, Japan, [2]Korea Astronomy and Space Science Institute, Korea, Republic of, [3]Okayama Astrophysical Observatory, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

In the framework of a Korean-Japanese planet search program, we have been carrying out a precise Doppler survey of about 190 G or K type giants to search for planets around intermediate-mass giants. The main purpose of this program is to show the properties of planetary systems around intermediate-mass stars by the survey using the 1.8m telescope at Bohyunsan Optical Astronomy Observatory in Korea, and the 1.88m telescope at Okayama Astrophysical Observatory in Japan.
In our presentation, we report a new planetary companion with a minimum mass of 1.8 MJupiter orbiting the giant star with 2.4 $M_\odot$ at a semi-major axis of 0.77 AU. The planet is the lowest-mass planetary companion among those discovered around clump giant stars with masses of >1.9 $M_\odot$. Plotting this system and other known systems on semi-major axis vs. stellar mass diagram, it seems like that the distribution of planetary systems around 1.9−2.5 $M_\odot$ stars may differ from those around other intermediate-mass stars. Almost all the planets orbiting 1.5−1.9 $M_\odot$ stars are normal giant planets (1−6 MJupiter), and are located on orbits with semi-major axes of >1 AU. However, planets orbiting 1.9−2.5 $M_\odot$ stars seem to be classified in two groups: normal giant planets at inner orbits (0.6−1.3 AU) and superplanets (6−13 MJupiter) at outer orbits (1.9−3 AU). Moreover, all planet-mass companions orbiting 2.5−3 $M_\odot$ stars reside at semi-major axes larger than 1.9 AU, while all brown dwarf-mass companions

are orbiting at semi-major axes less than 1.9 AU. In order to verify these properties and examine roles of the Type-II migration and other typical mechanisms on planet formation and evolution around intermediate-mass giant starss, it would be required to evaluate the semi-major axes distribution by further Doppler surveys.

20.13

**Radial Velocities of Low-mass Stars Using Telluric Lines**

**Cullen Blake**[1], M. Shaw[1]

[1]*Princeton University.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The search for companions to the lowest mass stars offers us an exciting pathway toward the detection of Earth-like planets. Low mass-stars are intrinsically small and cool, motivating the development of observational techniques optimized for the deep red (700 to 1000 nm) and infrared wavelengths where these stars are brightest. However, Earth's atmosphere absorbs strongly in these spectral regions, and telluric features due to O2, H2O, CH4, and CO2 dominate significant portions of ground-based spectra at red wavelengths. For the specific application of radial velocity (RV) measurements of low-mass stars, wavelengths where there is significant telluric absorption present a distinct advantage. The telluric lines provide a rich set of absorption features that can readily serve as a simultaneous absorption reference, yielding RV measurements of modest precision using existing instrumentation. We describe the theoretical expectations regarding the fundamental limits of telluric lines as a "zero velocity" wavelength reference and present results from detailed simulations of absorption by Earth's atmosphere as well as the impact of atmospheric variations on RV precision. We present preliminary results from a deep red optical survey of 100 late-M stars that relies on telluric water vapor as a simultaneous reference. We demonstrate that long-term stability of ~10 m/s may be achievable using a typical echelle spectrograph, theoretical models of the composition of Earth's atmosphere, and some basic assumptions about the time variability of the atmosphere. This work has been supported by the National Science Foundation through an Astronomy and Astrophysics Postdoctoral Fellowship.

20.14

**Measuring Radial Velocities in R-band with Telluric Line Calibration**

**Sara Gettel**[1], C. Bender[1], J. Wright[1], A. Wolszczan[1]

[1]*Pennsylvania State Univ..*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The iodine gas cell is replaced by the telluric O2 and water vapor lines to calibrate observations of RV stable M dwarfs made with the High Resolution Spectrograph of the Hobby-Eberly Telescope. Radial velocities are to be measured with the atmospheric lines in the 6000-8800A region and compared to measurements with the iodine cell, as a first step in determining the utility of telluric lines as R-band radial velocity calibrators. Based on other published results, we expect that by modeling atmospheric effects in sufficient detail, a precision of <10 m s-1 is attainable. If feasible, this method will be used to search for Neptune-mass planets around K and M dwarfs.

## 21
### *Planet Detection - Microlensing*
Poster
*Osprey/Grizzly*

21.01

**Exploring Hitherto Uncharted Planet Territory with Lucky-imaging Microlensing Observations**

**Martin Dominik**[1], U. G. Jørgensen[2], F. V. Hessman[3], K. Horne[1], K. Harpsøe[2], J. Skottfelt[2], The MiNDSTEp consortium

*[1]SUPA, University of St Andrews, United Kingdom, [2]Niels Bohr Institute, University of Copenhagen, Denmark, [3]University of Göttingen, Germany.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Leading the agenda for pushing the planet sensitivity limit towards the mass of the Moon, we will report first results from our 2011 MiNDSTEp (Microlensing Network for the Detection of Small Terrestrial Exoplanets) lucky-imaging microlensing follow-up campaign with the Danish 1.54m at ESO La Silla. It serves as a precursor to observations with a global network comprising the LCOGT/SUPAscope, SONG, and MONET 1m-class robotic telescope networks gradually deployed from 2011 to 2014. As for observations from space, the lucky-imaging technique allows us to get around the atmospheric image blurring and to obtain a resolution near the diffraction limit. This enables high-precision photometry on considerably fainter (smaller) stars in the crowded fields towards the Galactic bulge than obtainable from ground-based surveys. Monitoring smaller source stars in turn provides sensitivity to planets with smaller masses orbiting the lens star.

M.D. is supported by a Royal Society University Research Fellowship

21.02

**Implications On The Non-detection Of Brown Dwarfs And Planetary-mass Objects From Sweeps Data Through Microlensing**

**Kailash C. Sahu**[1], SWEEPS Team

*[1]STScI.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The SWEEPS project used the HST/ACS to carry out photometric monitoring of 230,000 F, G, K and M dwarfs in a dense stellar field in the Galactic bulge. During a 7-day monitoring interval we discovered 16 candidate transiting extrasolar planets with periods of 0.45 to 4.2 days. The SWEEPS data are also sensitive to detecting planetary-mass objects through their microlensing signal. No such microlensing event was detected among the 230,000 stars monitored. One implication of this non-detection is that the contribution of planetary-mass objects and brown dwarfs to the total mass budget is small. Details of the procedure, and further implications of this non-detection will be discussed.

21.03

**Completing the Exoplanet Census with the WFIRST Microlensing Survey**

**David P. Bennett**[1], WFIRST Science Definition Team

*[1]Univ. of Notre Dame.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The WFIRST mission is the top rated large space mission from last year's decadal survey. It has three major science programs, a microlensing planet search program, a dark energy program, and a general

observer program. WFIRST's microlensing planet search program will provide a statistical census of exoplanets with masses greater than one tenth of an Earth mass and orbital separations ranging from 0.5AU to infinity. This includes analogs to all the Solar System’s 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, WFIRST's planet search program will provide a complete statistical census of the planets that populate our Galaxy. The current status of the WFIRST mission design will be presented.

## 22

***Planet Detection - Imaging***

Poster

*Osprey/Grizzly*

22.01

**Direct Imaging Constraints on Planet Formation in Extreme Solar Systems**

**Markus Janson**[1]

*[1]University of Toronto, Canada.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

There has been a long-standing discussion in the literature concerning whether planets form by core accretion or disk instabilities. Over the past decade, accumulating evidence has shown that core accretion is most likely the dominant mode of planet formation for close-in planets. However, this does not by itself mean that the majority of the total planet population formed in this manner, since disk instabilities may conceivably form a large numbers of planets farther out in the disk. Here, we present an imaging survey around most massive stars in the Solar neighborhood (B-stars), which should provide very favorable conditions for such planets to form. We find that less than ~30% of the stars form and retain planets through gravitational instability. We also extend this analysis down to lower masses, through Sun-like stars and all the way down to M-stars. The results imply that core accretion is most likely the dominant formation mechanism for the total population of planets.

22.02

**Initial Results From The AO International Deep Planet Search Around Young A Stars**

**Arthur Vigan**[1], J. Patience[1], R. Galicher[2], C. Marois[2], B. Macintosh[3], I. Song[4], R. Doyon[5], B. Zuckerman[6], D. Lafrenière[5], T. Barman[7]

*[1]University of Exeter, United Kingdom, [2]Herzberg Institute of Astrophysics, Canada, [3]Lawrence Livermore National Laboratory, [4]University of Georgia, [5]Université de Montréal, Canada, [6]University of California, [7]Lowell Observatory.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Throughout their evolution, A stars exhibit favorable physical conditions and indirect evidence of planet formation, such as extended protoplanetary disks at the pre-main sequence stage and debris disks in the main sequence phase. Recent breakthrough discoveries of planetary companions around young, dusty A stars have identified the first massive planets at wide orbital separation. In order to understand the frequency of such systems -- an important factor for formation scenarios -- we are conducting a near-infrared adaptive optics search for giant planets around nearby A stars, part the on-going International Deep Planet Search (IDPS). We present the preliminary results of this survey of ~40 stars: 28 of them are nearby (<65 pc) young (<200 Myr) A stars, and the others are star identified as extremely young (<20 Myr) from spectral analysis. The observations were obtained with 8 meter-class telescopes (VLT and Gemini). The Locally Optimized Combination of Images (LOCI) was used to suppress the speckle noise of the central star and reach the detection level of giant planets and low-mass brown dwarfs at wide orbital separation. The median 5-sigma sensitivity of our observations is 9.5 mag at 0.5 arcseconds and 14 mag at separations of a few arcseconds, allowing us to reach limits 1 to 20 Mjup, depending on the target mass and age. We present an overview of the observations, data analysis and performance, followed by a statistical analysis of the survey results, which provide upper limits on the fractions of stars with giant planet and low mass brown dwarf companions.

22.03

**The Gemini NICI Planet-Finding Campaign: Combining Coronagraphy with Angular and Spectral Differencing imaging.**

**Zahed Wahhaj**[1], M. C. Liu[1], B. A. Biller[2], E. L. Nielsen[1], M. Chun[1], L. M. Close[3], C. Ftaclas[1], T. L. Hayward[4], D. W. Toomey[5], Gemini NICI Planet-Finding Campaign Team
*[1]Institute for Astronomy, [2]Max Planck Institute for Astronomy, Germany, [3]Steward Observatory, University of Arizona, [4]Gemini Observatory, Southern Operations Center, Chile, [5]Mauna Kea Infrared.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The Gemini NICI Planet-Finding Campaign is the most ambitious (~300 targets) direct extrasolar planet imaging campaign to date, achieving median contrasts of 12.5 and 15.0 magnitudes at 0.5 and 1.0'' respectively. Starting in December of 2008, we have been looking for both methane-bearing candidates and non-methane-bearing substellar companions around nearby stars chosen on the basis of youth, proximity, spectral type, etc. NICI (Near Infrared Coronagraphic Imager) is the combination of an 85 element adaptive optics system, a Lyot coronagraph, and a dual channel camera capable of simultaneous spectral difference imaging (SDI) on and off the 1.6um methane feature and angular difference imaging (ADI). We have developed a novel method of reducing the data which takes advantage of both SDI and ADI techniques. Speckles with long correlation times are removed by subtracting a static PSF, possible because of ADI. Short-lived speckles are removed by the subtracting the simultaneously imaged channel, possible because of SDI. Here, I present the data reduction techniques optimized for NICI, and compare among alternate techniques. We verify the contrasts achieved, and the photometric and astrometric accuracy by studying the recovery of simulated companions.

22.04

**Young Exoplanets Caught at Formation**

**Adam L. Kraus**[1], M. Ireland[2]
*[1]Univ. of Hawaii-IfA, [2]Macquarie University, Australia.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

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. I will discuss our ongoing survey using adaptive optics and nonredundant mask interferometry to directly image young exoplanets embedded in the gaps of protoplanetary disks. The first major result from our survey was the direct detection of a young exoplanet during its epoch of formation (T~2 Myr). However, followup observations have shown that planet formation is not nearly so clear as we might have expected; our data reveal spatially resolved structures and unusual colors that are difficult to explain with current models of young (proto)planets. I will report the results for our full survey to date, discuss possible explanations for the unusual features we observe, and conclude with by discussing the implications for the process, epoch, and duration of planet formation.

22.05

**Mass Determination Of Directly Imaged Planet Candidates**

**Tobias Schmidt**[1], R. Neuhäuser[1], A. Seifahrt[2]
*[1]Astrophysikalisches Institut und Universitäts-Sternwarte, Jena, Germany, [2]Physics Department, University of California, Davis, USA.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

About 20 sub-stellar companions with large separations (>~ 50 AU) to their young primary stars and brown dwarfs are confirmed by both common proper motion and late-M / early-L type spectra. The origin and early evolution of these objects is still under debate. While often these sub-stellar companions are regarded as brown dwarfs, they could possibly also be massive planets, the mass estimates are very uncertain so far. They are companions to primary stars or brown dwarfs in young associations and star forming regions like Taurus, Upper Scorpius, the TW Hya association, Beta Pic moving group, TucHor association, Lupus, Ophiuchus, and Chamaeleon, hence their ages and distances are well known, in contrast to free-floating brown dwarfs.
Here we present how mass estimates of such young directly imaged companions can be derived, using e.g. evolutionary models, which are however currently almost uncalibrated by direct mass measurements of young objects. An empirical classification by medium-resolution spectroscopy is currently not possible, because a spectral sequence that is taking the lower gravity into account, is not existing. This problem leads to an apparent mismatch between spectra of old field type objects and young low-mass companions at the same effective temperature, hampering a determination of temperature and surface gravity independent from models. We show that from spectra of the objects, using the advantages of light concentration by an AO-assisted integral field spectrograph, temperature, extinction, metallicity and surface gravity can be derived using non-equilibrium radiative transfer atmosphere models as comparison and that this procedure as well allows a mass determination in combination with the luminosities found by the direct observations, as has recently been done by us for several young sub-stellar companions, as e.g. GQ Lup, CT Cha or UScoCTIO 108.

22.06

**Directly Linking Planetary systems to Dusty and Polluted White Dwarfs**

**John H. Debes**[1], C. Stark[2], K. Walsh[3]
*[1]NASA/GSFC, [2]CIW/DTM, [3]Southwest Research Institute.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

It has long been suspected that metal polluted white dwarfs (types DAZ, DBZ, and DZ) and white dwarfs with dusty disks possess planetary systems, but a specific physical mechanism for perturbing a planetesimal within the tidal disruption radius of a white dwarf and that material's subsequent accretion has not yet been fully posited. In this presentation we demonstrate that mass loss from a central star during post-main sequence evolution can sweep planetesimals into mean motion interior resonances with a single giant planet. These planetesimals are slowly removed through chaotic excursions of eccentricity that in time create highly eccentric orbits capable of tidally disrupting the planetesimal. These resonances require giant planets not much more massive than Jupiter, or else relic planetesimals do not survive in sufficient numbers. Numerical simulations of the solar system show that a sufficent number of planetesimals are perturbed to explain a observed white dwarfs with both dust and metal pollution. Finally, we show that once a planetesimal is perturbed into a tidal crossing orbit, it will become disrupted, sometime within the first pass of the white dwarf, where a highly eccentric stream of debris forms the main reservoir for dust producing collisions. These simulations, in concert with observations of white dwarfs, place interesting limits on the frequency of planetary systems around main sequence stars, the frequency of planetesimal belts, and the probability that dust may obscure future terrestrial planet finding missions.

22.07

**The Inner 10 AU of HR 8799**

**Sasha Hinkley**[1], J. M. Carpenter[1], M. J. Ireland[2], A. L. Kraus[3]
*[1]California Institute of Technology, [2]University of Sydney, Australia, [3]University of Hawaii.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
We report the results of Keck L'-band aperture masking interferometry 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. 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.

## 23
### *Planet Detection - Other*
Poster
*Osprey/Grizzly*

23.01

**Towards Astrometric Planet Detection with the VLT**

**JOHANNES SAHLMANN**[1], D. Queloz[1], D. Segransan[1]
[1]*Observatoire de Genève, Switzerland.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Two astrometric planet search programmes are in progress at the Very Large Telescope:
(1) Using FORS2, we are surveying the astrometric motion of twenty close-by L- and M-dwarfs over two years, with the goal of detecting the orbital motion caused by a substellar or planetary companion. The obtained astrometric precision of ~0.1 milli-arcsec per epoch is sufficient to detect a Neptune mass planet in a 1.5-year orbit.
(2) We are commissioning PRIMA at the VLTI and are about to start an large astrometry programme to characterise the masses of known RV-planets and to search for long-period planets around young and main-sequence stars.
I will report on the performances and results obtained with these two new planet search programmes.

23.02

**Timing of Eclipses of Binary Stars from the ASAS Catalog**

**Stanislaw Kozlowski**[1], M. Konacki[1], P. Sybilski[1]
[1]*Nicolaus Copernicus Astronomical Center, Poland.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Light was thought of as something infinite and transcendent till 1676 when Olaus Roemer  carried out precise measurements of the times of eclipses of Jovian moons. Roemer's scrupulous observations led him to a qualitative conclusion that light travels at a finite speed, at the same time providing scientists with the basics of the Light-Time Effect (LTE). LTE is observed whenever the distance between the observer and any kind of periodic event changes in time. The usual cause of this distance change is the reflex motion about the system's barycenter due to the gravitational influence of one or more additional bodies. We present results of the analysis of 5032 eclipsing contact and detached binaries from the All Sky Automated Survey (ASAS) catalogue for variations in the times of eclipses. We use an approach known from the radio pulsar timing where a template radio pulse of a pulsar is used as a reference to measure the times of arrivals of the collected pulses. Most of the variations we detect in O--Cs correspond to a linear period change, but three show evidence of more than one complete LTE-orbit. For these objects we present preliminary orbital solutions. Our results demonstrate that the timing analysis employed in radio pulsar timing can be effectively used to study large data sets from photometric surveys. This is the prelude to the analysis of data gathered by the Solaris Project which aims at the search for circumbinary planets.

23.03

**Eclipses Timing: Detecting Extrasolar Planets with a Network of Robotic Telescopes**

**Piotr Sybilski**[1], M. Konacki[1], S. Kozłowski[1]
[1]*NCAC Polish Academy of Sciences, Poland.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*
The presence of a body in an orbit around an eclipsing binary star manifests itself through the light time effect influencing the observed times of eclipses as both the binary and the circumbinary companions move around the common centre of mass. This fact combined with the periodicity with which the eclipses occur can be used to detect the companions.
The main goal of this work is to investigate the potential of the photometry-based eclipse timing of binary stars from the ground as a method of detecting circumbinary planets. We study the usefulness of our Project Solaris, a new network of 0.5-m robotic telescopes, in detecting circumbinary planets. With the use of the numerical simulations we compare the on-going COROT and Kepler missions with a ground based effort. We study the influence of the white and red photometric noises on the timing precision and provide suggestions for the best targets, observing strategies and instruments for the eclipse timing method.

23.04
**Polarimetry Of Planetary Atmospheres: From The Solar System Gas Giants To Extrasolar Planets**
**Esther Buenzli**[1], A. Bazzon[1], H. M. Schmid[1]
*[1]ETH Zurich, Switzerland.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
The polarization of light reflected from a planet provides unique information on the atmosphere structure and scattering properties of particles in the upper atmosphere. The solar system planets show a large variety of atmospheric polarization properties, from the thick, highly polarizing haze on Titan and the poles of Jupiter, Rayleigh scattering by molecules on Uranus and Neptune, to clouds in the equatorial region of Jupiter or on Venus. Polarimetry is also a promising differential technique to search for and characterize extra-solar planets, e.g. with the future VLT planet finder instrument SPHERE. For the preparation of the SPHERE planet search program we have made a suite of polarimetric observations and models for the solar system gas giants. The phase angles for the outer planets are small for Earth bound observations and the integrated polarization is essentially zero due to the symmetric backscattering situation. However, a second order scattering effect produces a measurable limb polarization for resolved planetary disks. We have made a detailed model for the spectropolarimetric signal of the limb polarization of Uranus between 520 and 935 nm to derive scattering properties of haze and cloud particles and to predict the polarization signal from an extra-solar point of view. We are also investigating imaging polarimetry of the thick haze layers on Titan and the poles of Jupiter. Additionally, we have calculated a large grid of intensity and polarization phase curves for simpler atmosphere models of extrasolar planets.

23.05
**Astrometric Search For Extrasolar Planets In Stellar Multiple Systems**
**Tristan Roell**[1], R. Neuhäuser[1], A. Seifahrt[2]
*[1]Astrophysical Institute (AIU) Jena, Germany, Germany, [2]Physics Department, UC Davis.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
We search for extrasolar planets with high precision relative astrometry (using AO assisted ground based imaging) in nearby stellar multiple systems, especially in binaries with low-mass stars. Using a narrow band-filter located at the near infrared to suppress differential chromatic refraction effects as well as an old globular cluster to monitor the astrometric long-term stability we achieve a final multi-epoch precision down to about 0.1 mas which enables us to find Jovian exoplanets around solar like stars and even less mass exoplanets around nearby low-mass stars. Because of a spatial resolution of

about 0.1 arcsec, we are able to observe nearby binaries with apparent separations down to a few AU, which is less than the expected minimum separation allowing planet formation (about 20 AU), thus to study the conditions for planet formation in binaries. Such close binaries are difficult or even impossible to observe by other techniques like typical radial velocity observations or with PRIMA/VLTI due to the high spatial resolution needed to resolve them.
As a first result of our ongoing astrometric search program, we found a further stellar component in the exoplanet host binary HD19994 A & B. While searching the astrometric signal of the RV exoplanet around the A component (minimum signal about 0.15 mas), we detected the astrometric signal of a low mass star around HD19994B with a mass of about 0.34 solar masses. Looking at the residuals, an additional astrometric signal of more than 1 mas can be excluded and thus an upper mass limit of about 12 Jupiter masses can be given for the RV exoplanet around the primary.
T.R. and R.N thank the German Science Foundation for financial support (NE\,515/23-1, NE\,515/30-1, NE\,515/33-1). A.S. acknowledge support from the National Science Foundation (NSF\,AST-0708074).

## 24
### *Kepler Results*
Poster
*Osprey/Grizzly*

24.01

**Using the Kepler February 2011 Data Release to Estimate the Frequency of Planets**

**Courtney D. Dressing**[1], D. Charbonneau[1]
[1]*Harvard-Smithsonian Center for Astrophysics.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

In February 2011, the *Kepler* team announced the discovery of 1235 planet candidates. The majority of the candidates have radii smaller than Neptune and orbital periods less than fifty days. Although these data are preliminary and some candidates may prove to be astrophysical false positives, this sample of planet candidates is large enough to probe the underlying distribution of planets as a function of planetary radius, semimajor axis, and host star spectral type. We approach this problem by considering a variety of underlying distributions and assigning planets according to those distributions to the stars listed in the Kepler Input Catalog. We simulate the likelihood of detecting a transit of each planet around its assigned host star, accounting for the geometric probability of transit, the transit duration, and the number of transits that would be observed during the first year of the *Kepler* mission assuming square root of N improvement with the number of transits. We require a signal to noise ratio of 7 for detection as required by the *Kepler* team for inclusion in the list of Kepler Objects of Interest in the February data release, and we reject any underlying distribution of planets that differs significantly from the *Kepler* data. CDD acknowledges support from the National Science Foundation Graduate Research Fellowship Program.

24.02

**Measurement of the Spin-Orbit Misalignment of Planet Candidate KOI-13.01 from Gravity Darkening**

**Jason W. Barnes**[1]
[1]*University of Idaho.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Barnes (2009) predicted that objects transiting fast-rotating stars would show unusual, asymmetric lightcurves if the transiter's orbit normal is not aligned with the stellar rotational pole -- i.e. in the case of a spin-orbit misalignment. Recently Gy. Szabo et al. (arXiv:1105.252) showed that KOI-13.01, one of the Kepler planet candidates announced by Borucki et al. (arXiv:1102.0541), rotates with Vsin(i)=65 km/s and shows a pronounced lightcurve asymmetry. Szabo et al. attributed this asymmetry to gravity darkening associated with rapid rotation, but did not measure the implied spin-orbit misalignment. Using the algorithm that I developed for Barnes (2009), I fit the folded transit lightcurve for KOI-13.01. I found that the lightcurve asymmetry indicates a stellar obliquity of 18.5 degrees relative to the plane of the sky (i.e., the stellar north pole is tilted toward the viewer by 18.5 degrees), and that the longitude of the ascending node for the planet is 214.5 degrees (i.e. that the planet transits the south pole of the star first while heading toward the equator at a 34.5 degree angle with respect to the stellar equator). The resulting net spin-orbit misalignment is 40.3 degrees. This technique does not, however, resolve the degeneracy between prograde and retrograde solutions -- hence the spin-orbit misalignment might then be 139.7 degrees if the planet orbits retrograde. The parent star of KOI-13.01 has a binary companion of similar mass with a separation of 1900 AU, which allows that the Kozai mechanism may be responsible

for this system's spin-orbit misalignment. KOI-13.01 thus represents the first system for which the spin-orbit alignment has been measured purely photometrically. The photometric method can complement the Rossiter-McLaughlin effect to constrain spin-orbit alignment for planets orbiting fast-rotating stars.

24.03

**Can We Infer Statistically Valid Masses for the Kepler Planets?**

**Wesley A. Traub**[1]

[1]*Jet Propulsion Laboratory.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We have period-mass diagrams for radial-velocity planets, and period-radius diagrams for the Kepler candidate planets, but no mass information for the majority of the latter. However we can construct a mass-radius diagram for about 100 known planets, albeit with significant scatter, so the question I will address here is, to what extent is it valid to assign masses to the Kepler candidate planets?

24.04

**A New Method For Characterizing The Ensemble Detection Statistics Of The Kepler Pipeline**

**Jessie Christiansen**[1], Kepler Completeness Study Working Group

[1]*NASA Ames Research Center/SETI Institute.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

There are many factors which must be considered in order to address Kepler's primary mission goal - measuring the frequency of Earth-size planets in the habitable zones of solar-like stars. One of these is the detection completeness of the Kepler pipeline, in other words what fraction of the detectable transiting planets are being recovered. However, since Kepler will obtain over 8 billion observations during the nominal mission, characterizing the pipeline detection efficiency in the traditional Monte Carlo manner is computationally infeasible. We describe a new method of measuring the ensemble statistics for completeness, investigating the detection efficiency as a function of stellar and planetary parameters. We present the first results from the study, and the implications for Kepler's ability to measure eta_Earth.

## 25
### *Transit Timing*
Poster
*Osprey/Grizzly*

25.01

**Fast Inversion Method for Determination of Planetary Parameters from Transit Timing Variations**

**David Nesvorny**[1], C. Beauge[2]
*[1]SWRI, [2]National University at Cordoba, Argentina.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The Transit Timing Variation (TTV) method relies on monitoring changes in timing of transits of known exoplanets. Non-transiting planets in the system can be inferred from TTVs by their gravitational interaction with the transiting planet. The TTV method is sensitive to low-mass companions and can be used to validate planetary candidates from Kepler. We developed a fast algorithm that can be used to determine the mass and orbit of planets from TTVs. We applied our code, known as TTVIM, to a wide variety of planetary systems to test the uniqueness of the TTV inversion problem, and its dependence on S/N of TTV measurements. We found that planetary parameters, including the mass and mutual orbital inclination of planets, can be determined for most systems where the amplitude of short-period TTVs exceeds noise. In principle, the TTV method can therefore be used to characterize the inclination distribution of multi-planet systems. We are applying the code to the available Kepler data and will discuss the interesting systems at the meeting.

This research was supported by the NSF Award AST 1008890.

25.02

**Frequency of Second Planet Occurrence in Mean Motion Resonances with Hot Jupiters**

**Akihiko Fukui**[1], M. J. Holman[2], N. Narita[3], T. Sumi[4]
*[1]Nagoya University, Japan, [2]Harvard-Smithsonian CfA, [3]National Astronomical Observatory of Japan, Japan, [4]Osaka University, Japan.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Measuring transit timings (TTs) of hot Jupiters provides us information about the existence or absence of additional planets around these migrated giant planets. TTs of a hot Jupiter can significantly vary from a linear ephemeris when additional planets exist near mean motion resonances (MMRs) with the hot Jupiter. The existence of such planets may be a consequence of their convergent migration with the hot Jupiter.

To date, TTs of about 15 transiting hot Jupiters have been measured to see whether they show variations or not. None show conclusive variations due to additional planets, although some preliminary indications of variations have been reported. Using the published TT data, we calculated the efficiency with which we could detect a second planet in MMRs for each hot Jupiter, as a function of the second planet's mass. We then converted these results to the frequency of occurrence of additional planets in MMRs with hot Jupiters. As a result, we found that second planets in MMRs with hot Jupiters are, even if some exist, not common. We discuss the implications of this result on theories of the migration of hot Jupiters.

25.03

**A Survey of Transit Timing Variations of M Stars Among Kepler's Targets: Evidence for Possible New Companions**

**Mahmoudreza Oshagh**[1], G. Boué[1], N. Haghighipour[2], M. Montalto[1], N. Santos[1]
*[1]Centro De Astrofisica Da Universidade Do Porto, Portugal, [2]Institute for Astronomy and NASA Astrobiology Institute, University of Hawaii-Manoa.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
As the least massive stars, M stars have the greatest reflex acceleration due to an orbiting planet. The transit depths and transit times of planets around M stars are large and well-matched to the temporal resolution of ground-based telescopes as well as that of Kepler. As a result, M stars have been of particular interest for searching for planets in both radial velocity and transit photometry surveys. In continuation of our project to search for planetary companions around M stars, we have monitored the light curves of over 100 M stars in Kepler’s publicly available data sets Q0 to Q2. We used four criteria, namely, the magnitude, proper motion, H-Ks and J-H colors, and identified around 100 M stars in these data sets. A study of the light curves of these stars shows evidence of possible transiting systems as well as transit timing variations. Using a model-independent method, we analyzed these TTVs and determined the possibility that they might be due to planetary companions. We have found that the observed TTV signals in some of these systems cannot be explained by a constant period. However, they can be explained assuming that companions, with masses in the planet-mass domain, may be present in the system. We present the results of our survey and discuss the possibility of the new planetary candidate(s).

## 26
### *Rossiter-McLaughlin Measurements*
Poster
*Osprey/Grizzly*

26.01

**The Rossiter-McLaughlin Effect: Improved Model and New Data**

**TERUYUKI HIRANO**[1], J. N. Winn[2], N. Narita[3], Y. Suto[4], B. Sato[5], A. Shporer[6], S. Albrecht[2]
*[1]MIT / The University of Tokyo, [2]MIT, [3]NAOJ, Japan, [4]The University of Tokyo, Japan, [5]Tokyo Institute of Technology, Japan, [6]UCSB / Las Cumbres Observatory Global Telescope Network.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The Rossiter-McLaughlin (RM) effect is a distortion in spectral lines during a planetary transit caused by a partial occultation of the rotating stellar disk. A measurement of the RM effect reveals the relation between the orbital axis of planet and the spin axis of the planet hosting star. Although the RM effect is a promising tool to observationally distinguish among planetary migration theories, the relation between the observed anomalous radial velocity and the position of the planet has been unclear. We have recently derived a new analytic formula to describe the RM effect, and shown that the analytic formula is in good agreement with numerical simulations. As an application of our new analytic formula, we present new results of RM measurements for several selected systems and also report on the reanalysis of the previously published RM measurements using our new improved modeling. Finally, we discuss the revised statistic of the RM results.

26.02

**In the Shadows of Giants: Tomographic Rossiter-McLaughlin Analyses of Wasp Planets**

**Grant Miller**[1], A. Collier Cameron[1]
*[1]University of St Andrews, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The spin-orbit alignment of a transiting planetary system can be measured via the radial velocity anomaly caused when the planet partially obscures light from the stellar disc during transit (the Rossiter-McLaughlin effect). We present a tomographic method for analysing this effect. By modelling the time-variable asymmetry of the average stellar line profile during transit we can determine the projected spin-orbit alignment and stellar rotation rate. We present results for multiple known planets from the WASP survey and discuss the importance of this method in confirming planets around Main Sequence stars of earlier spectral type, which have been previously inaccessible to transiting-planet hunters.

## 27
### *Statistical Properties of Orbits and Masses*
Poster
*Osprey/Grizzly*

27.01

**On The Nature Of Small Planets Around K And M Stars**

**Eric Gaidos**[1], D. A. Fischer[2], S. Lepine[3], A. W. Mann[1]

[1]*University of Hawaii,* [2]*Yale University,* [3]*American Museum of Natural History.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We compare 1406 Keck/HIRES radial velocity measurements of 172 late K and early M stars to a model based on Kepler candidate planet radii and a planetary mass-radius relation. The observed distribution of radial velocity variation can be closely reproduced by the model, but only if Kepler observations are ~50% complete for these spectral types. Stellar noise on orbital timescales may partly explain this discrepancy. Alternatively, the distribution of stars hosting candidate Kepler planets with visible and near-infrared colors and log g suggests that many K-type Kepler targets are subgiants or giants, around which small planets are very difficult to detect. Our comparison of observed and predicted radial velocity variations constrains the mass-radius relation of planets much smaller than Neptune (<3 Earth radii). The index alpha of a power-law relation is highly correlated with systematic noise, but for a noise level of 3 m/s, alpha ~ 4. Alternatively, a uniform density mass-radius relation requires a density beta (relative to Earth) ~2. These findings indicate that rocky planets dominate the planet population on close orbits around late K and early M dwarfs. This work has been funded by the NSF Astronomy & Astrophysics program, the NASA Astrobiology program, and the NASA Origins of Solar Systems program.

27.02

**Homogeneous Studies of Transiting Extrasolar Planets: Current Status and Future Plans**

**John Taylor**[1]

[1]*Keele University, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We now know of over 500 planets orbiting stars other than our Sun. The jewels in the crown are the transiting planets, for these are the only ones whose masses and radii are measurable. They are fundamental for our understanding of the formation, evolution, structure and atmospheric properties of extrasolar planets. However, their characterization is not straightforward, requiring extremely high-precision photometry and spectroscopy as well as input from theoretical stellar models. I summarize the motivation and current status of a project to measure the physical properties of *all* known transiting planetary systems using homogeneous techniques (Southworth 2008, 2009, 2010, 2011 in preparation). Careful attention is paid to the treatment of limb darkening, contaminating light, correlated noise, numerical integration, orbital eccentricity and orientation, systematic errors from theoretical stellar models, and empirical constraints. Complete error budgets are calculated for each system and can be used to determine which type of observation would be most useful for improving the parameter measurements. Known correlations between the orbital periods, masses, surface gravities, and equilibrium temperatures of transiting planets can be explored more safely due to the homogeneity of the properties. I give a sneak preview of *Homogeneous Studies Paper 4*, which includes the properties of thirty transiting planetary systems observed by the CoRoT, Kepler and Deep Impact space missions.

Future opportunities are discussed, plus remaining problems with our understanding of transiting planets. I acknowledge funding from the UK STFC in the form of an Advanced Fellowship.

27.03

**Combining Kepler and HARPS Occurrence Rates to Infer the Super-Earth Period-Mass-Radius Distribution**

**Angie Wolfgang**[1], G. Laughlin[1]
[1]*University of California, Santa Cruz.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The ongoing High Accuracy Radial velocity Planet Search (HARPS) has found that 30-50% of FGK stars in the solar neighborhood host planets with $M_{pl} \le M_{Neptune}$ in orbits of $P \le 50$ days. At first glance, this high overall occurrence rate seems at best to be marginally consistent with the planet frequency measured during Q0-Q2 of the *Kepler Mission*, whose 1235 detected planetary candidates imply that ~15% of main sequence dwarfs harbor a short-period planet with $R_{pl} < 4 R_\oplus$. A rigorous comparison between the two surveys is difficult, however, as they observe different stellar populations, measure different planetary physical properties, and are subject to radically different sampling plans. Here we report the results of a Monte Carlo study which seeks to partially overcome this discrepancy by identifying plausible planetary population distributions that jointly conform to the results of the two surveys. We find that a population concurrently consisting of (1) dense silicate-iron planets and (2) low-density gas-dominated worlds provides a natural fit to the current data. In this scenario, the fraction of dense planets decreases with increasing mass, from $f_{rocky} = 90\%$ at $M = M_\oplus$ to $f_{rocky} = 10\%$ at $M = M_{Neptune}$. Our best fit population has a total occurrence rate of 40% for $2 \le P \le 50$ days and $1 \le M \le 17 M_\oplus$, and is characterized by simple power-law indices of the form $N(M)dM \sim M^\alpha dM$ and $N(P)dP \sim P^\beta dP$ with $\alpha = -1.0$ and $\beta = 0.0$. Our model population therefore contains four free parameters and is readily testable with future observations. Furthermore, our model's insistence that at least two distinct types of planets must exist in the survey data indicates that multiple formation mechanisms are at work to produce the population of planets commonly referred to as "super-Earths".

27.04

**"Extremely Low Mass: The Circumstellar Envelope of a Potential Proto-Brown Dwarf**

**Jennifer J. Wiseman**[1], M. Barsony[2], R. Sahai[3]
[1]*NASA / GSFC,* [2]*Space Studies Institute,* [3]*NASA Jet Propulsion Laboratory.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

What is the environment for planet formation around extremely low mass stars? Is the environment around brown dwarfs and extremely low mass stars conducive and sufficiently massive for planet production? The determining conditions may be set very early in the process of the host object's formation. IRAS 16253-2429, the source of the Wasp-Waist Nebula seen in Spitzer IRAC images, is an isolated, very low luminosity ("VeLLO") Class 0 protostar in the nearby rho Ophiuchi cloud. We present VLA ammonia mapping observations of the dense gas envelope feeding the central core accreting system. We find a flattened envelope perpendicular to the outflow axis, and gas cavities that appear to cradle the outflow lobes as though carved out by the flow and associated (apparently precessing) jet, indicating environmental disruption. Based on the NH3 (1,1) and (2,2) emission distribution, we derive the mass, velocity fields and temperature distribution for the envelope. We discuss the combined evidence for this source to be one of the youngest and lowest mass sources in formation yet known, and discuss the ramifications for planet formation potential in this extremely low mass system.

## 28
### *Multiple-Planet Systems*
Poster
*Osprey/Grizzly*

28.01

**Enhancing Multiple-Transiting Planet System Validation with Transit Duration Ratios**

**Robert C. Morehead**[1], E. B. Ford[1], A. Prša[2], D. Ragozzine[3]
[1]*University of Florida,* [2]*Villanova University,* [3]*Harvard-Smithsonian Center for Astrophysics.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The recent discoveries of three planets transiting Kepler-9 (Holman et al. 2010; Torres et al. 2011), six densely packed planets transiting Kepler-11 (Lissauer et al. 2011), and a total of 170 stars with multiple transiting planet candidates (Borucki et al. 2011; Steffen et al. 2010) bode well for the future of multiple-transiting planet systems (MTPSs). For many faint (Kp>14) Kepler targets, traditional confirmation by radial velocities is not practical. Fortunately, detailed light curve analysis can eliminate the vast majority of false-positive scenarios and statistically validate such systems (Torres et al. 2011; Fressin et al. 2011). We explore the utility of the ratio of the observed transit durations in MTPSs for validating candidate MTPSs. After normalizing by a function of orbital periods, we obtain a parameter with a distribution centered on unity for multiple planets around the same star, but markedly different for certain blend scenarios. Using the *Kepler* Input Catalog and galactic stellar population models, we investigate these distributions through Monte Carlo simulations of four scenarios: 1) one star with two planets, 2) one star with one planet blended with an eclipsing binary, 3) two eclipsing binaries, and 4) two stars each with one planet. We discuss the utility of this statistics for in planet validation and estimating the false alarm probabilities for candidate systems identified by *Kepler*.
*Kepler* was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA, Science Mission Directorate. R.C.M. is supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-0802270.

28.02

**A New Look At HD128311 With Data From The Het And Hst: Planets, Masses And Resonance**

**Barbara McArthur**[1], F. Benedict[1], T. Harrison[2]
[1]*Univ. of Texas,* [2]*new mexico state.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

We use HST astrometric data along with new radial velocity data from the HET combined with existing radial velocity data to place new observational constrains on the HD128311 system. We find mass limits from the astrometry, uncover another signal in the radial velocity data and find system parameters that do not indicate mean motion resonance in a dynamical exploration of the system.

28.03

**On the Dynamical State of the HD 82943 Planetary System**

**Man Hoi Lee**[1], X. Tan[1], E. B. Ford[2], M. J. Payne[2], A. W. Howard[3], G. W. Marcy[3], J. A. Johnson[4], J. T. Wright[5]
[1]*The Univ. of Hong Kong, Hong Kong,* [2]*Univ. of Florida,* [3]*UC Berkeley,* [4]*Caltech,* [5]*Pennsylvania State Univ..*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Previous analysis of radial velocity data of the star HD 82943 has shown that it hosts a pair of planets that are likely in 2:1 mean-motion resonance, with the orbital periods about 220 and 440 days (Lee et al.

2006). However, alternative fits that are qualitatively different have also been suggested, with the two planets in 1:1 resonance or the addition of a third planet possibly in a Laplace resonance with the other two (Gozdziewski & Konacki 2006; Beaugé et al. 2008). We present a new analysis of the HD 82943 system based on 10 years of radial velocity measurements obtained with the Keck telescope. An efficient and reliable method to explore the parameter space is needed because of the large number of model parameters and the cost of orbital integrations. We compare the results obtained using different approaches: multiple-Keplerian or N-body fitting, combined with the least-squares method on parameter grids or the Markov chain Monte Carlo method. A systematic exploration of the parameter space that combines statistical and dynamical analysis is performed to assess the viability of the different types of fits for the HD 82943 system.

This work is supported in part by Hong Kong RGC grant HKU 7034/09P.

28.04

**Astrometry of Nearby Exoplanet Host Stars - Why and How**

**G. Fritz Benedict**[1], B. E. McArthur[1]

*[1]Univ. of Texas, Austin.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

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. Possible future contributions are outlined.

28.05

**The Orbital Architecture of 55 Cnc: An Orbital Resonance, Jupiter Analog, and Transiting Super-Earth**

**Benjamin E. Nelson**[1], M. Payne[1], E. Ford[1], J. Wright[2]

*[1]University of Florida, [2]Pennsylvania State University.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

55 Cnc is the only naked eye star with a known transiting planet (Winn et al. 2011) and one of a few systems with five known planets characterized via Doppler methods. The planets span a wide range of masses and orbital periods. We investigate the orbital architecture, focusing on two of the giant planets near 3:1 mean-motion resonance and the potential impact on the dynamical effects on the other planets. To quantify the uncertainty in the orbital parameters of the 55 Cnc system requires exploring a high-dimensional (~35) parameter space and using self-consistent N-body integrations, both of which are computationally demanding. To surmount these challenges, we apply a differential evolution Markov chain Monte Carlo algorithm to characterize the orbital properties and masses. We present these results and discuss the implications on the dynamical evolution of the 55 Cnc system.

## 29

## *Earths and Super-Earths*

Poster

*Osprey/Grizzly*

29.01

**Slitless Spectroscopy Of GJ 1214b In K-band**

**Johanna Teske**[1], C. Griffith[1], M. Swain[2], P. Deroo[2], D. McCarthy[1], C. Kulesa[1]

*[1]University of Arizona, [2]JPL.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Extreme in the sense that it is one of the only observable 'super-Earth' exoplanets, GJ 1214b has shown disparate evidence for an atmosphere composed primarily of H/He, and one having a significant H2O component. Recent observation and modelling efforts (Croll et al. 2011; Miller-Ricci Kempton et al. 2011; Crossfield et al. 2011) have suggested that the flat spectral signature in the optical and very-NIR (Bean et al. 2010) may indicate GJ 1214b's atmosphere is indeed water-rich, and/or that there may be a short-wavelength cloud layer blocking some of GJ 1214b's flux in these regions. This latter prediction is in conjunction with a more varying/peaked spectrum indicated by J- and K-band photometry (Croll et al. 2011). To help deduce the detailed shape and/or variability in the NIR spectrum of GJ 1214b, we present preliminary results of May 2010 observations at the MMT using the ARIES NIR spectrograph in K band. We used 'slitless-spectroscopy' at a resolution of ~200 and the Adaptive Optics (AO) system as a guider to observe the primary transit of GJ 1214b. Using only simple detrending fits to remove airmass and instrumental signatures, we find agreement with previous single-point photometric K-band measurements, but also (may) see spectroscopic variation in eclipse depth across K-band (~2-2.4 microns).

29.02

**Mantle Convection In Super-earths: An Effect Of Adiabatic Compression**

**Chihiro Tachinami**[1], M. Ogawa[2], H. Senshu[3], S. Ida[1]

*[1]Tokyo Institute of Technology, Japan, [2]Tokyo University, Japan, [3]Chiba Institute of Technology, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We have studied solid mantle convection in massive terrestrial planets, so-called super-Earths, by using numerical simulation for compressible thermal convection. The mantle convection of terrestrial planets highly affects on their surface environment driving plate tectonics and degassing. On the other hand, the thermal transfer of mantle convection is also very important for core dynamo and magnetic shielding of surface from hazardous stellar wind.

The main differences between mantle convection in both of Earth and super-Earths are gravity acceleration and mantle thickness.

Increase in these quantities results in sufficient adiabatic compression, and it highly affects on the stability of mantle convection.

The magnitude of adiabatic compression is represented by a non-dimensional number, dissipation number that is proportional to gravity acceleration and mantle thickness.

In the case of the Earth, the dissipation number is about 0.5. On the other hand, the dissipation number of super-Earth with 10 Earth mass is about 5. Thus, an order of magnitude larger adiabatic compression can be affected to mantle convection for the case of super Earths.

We have investigated mantle convection with varying the dissipation number that corresponding to

planetary mass to show how it affects on style and thermal transfer efficiency of mantle convection. We will show some simulation results and how different the mantle convection of super-Earths is from that in Earth.

29.03

**Global Mapping of Earth-like Exoplanets from Scattered Light Curves as a Probe of the Habitat**

**Yuka Fujii**[1], H. Kawahara[2]

[1]*The Univ. of Tokyo, Japan,* [2]*Tokyo Metropolitan University, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

As the next step after the recent discoveries of exoplanets in habitable zones, it is desirable to develop techniques to investigate them farther to determine whether or not they really harbor life. In this context, it is valuable to consider a well-defined question how we would know about the habitat if we were to observe an Earth-twin at an astronomical distance.

In principle, the scattered light of planets contains rich information of planetary surface and the atmosphere, and indeed the new instruments for direct imaging in optical/near-IR are actively proposed. However, interpretation of the spatially unresolved light from the planets can be complicated especially in the case of highly inhomogeneous planets like our own Earth.

Here we demonstrate the 2-dimensional mapping of the surface from the scattered light variation assuming a continuous observation for 1 year (Kawahara and Fujii, 2010, 2011). We create mock light curves of the Earth including the realistic cloud cover and the seasonal variation, and invert them to the surface inhomogeneity by making the most of the spin rotation and orbital motion of the planet and using the technique of tomography. The recovered map successfully traces the actual cloud distribution, continents, and even the localized red-edge feature of vegetation. Therefore, such long observations of scattered light will give us the access to the landscape of exoplanets with diverse surface components.

Another consequence of this tomography is the measurement of the planetary obliquity, which is a key parameter both for habitability and to constrain the formation scenario. We discuss the detectability of obliquity assuming a realistic instrumental design.

29.04

**The Nitrogen Constraint on the Habitability of Planets around Low Mass M-stars**

**Feng Tian**[1]

[1]*University of Colorado at Boulder.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The traditional habitable zones around stars are defined based on the stability of liquid water over geological timescales. Being too far away from the stars, the planet would be incapable of maintaining a warm surface and thus no liquid water. Being too close to the star, the planet would experience a 'runaway' greenhouse phase, during which its oceans could be lost quickly, and end up similar to our sister planet, Venus.

The definition of tranditional habitable zones does not consider the availability of other elements important for life. All life as we know it needs nitrogen. Our calculations of upper planetary atmospheres show that nitrogen could be lost rapidly from planetary atmospheres with CO2 concentrations lower than certain threshold. This suggests that life on planets around low mass M-stars may be self-limiting, and planets of low mass M-stars are less favorable places to search for life than G- or K-type stars.

29.05

**Near Earth Astrometric Telescope**

**Alain LÃ©ger**[1]
*[1]IAS, France.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
The main scientific goal of the NEAT (Nearby Earth Astrometric Telescope) mission proposal is to detect and characterize planetary systems *in an exhaustive way down to 1 Earth mass in the HZ* and further away, *around nearby F, G, and K stars*. This survey would provide the actual planetary masses, *the full characterization of the orbits* including their inclination, for all the components of the planetary system (located within or further than the HZ) down to that mass limit.
Only extremely-high-precision astrometry, in space, can detect the dynamical effect due to low mass orbiting planets on their central star. NEAT will continue the work performed by Hipparcos (1 mili-as precision) and Gaia (7 micro-as aimed) by reaching a (0.05 micro-as, 1sigma) precision. The mission profile is driven by the fact that the two main modules of the payload, the telescope and the focal plane, are placed 40m away leading to a *formation flying* option. The NEAT satellites are foreseen to operate at L2 for 5 years.
The principle is to measure the angles between the target star, usually bright (R < 6), and fainter reference stars (R < 11) using a metrology system that projects *dynamical* Young's fringes onto the focal plane. The proposed mission architecture relies on the use of two satellites of about 700 kg each in formation flying, offering a capability of more than 20,000 reconfigurations.

29.06
**Characterising Super Earths With The EChO Spacemission Concept**
**Marcell Tessenyi**[1], M. Ollivier[2], G. Tinetti[1], J. P. Beaulieu[3], V. Coudé du Foresto[4], T. Encrenaz[4], G. Micela[5], B. Swinyard[1], I. Ribas[6], A. Aylward[1], J. Tennyson[1], M. R. Swain[7], A. Sozzetti[8], G. Vasisht[7], P. Deroo[7]
*[1]University College London, United Kingdom, [2]Université Paris Sud, IAS, France, [3]IAP, CNRS, France, [4]Observatoire de Paris-Meudon, France, [5]INAF - Osservatorio Astronomico di Palermo, Italy, [6]Institut de Ciencies de l'Espai (CSIC-IEEC), Spain, [7]Jet Propulsion Laboratory, California Institute of Technology, [8]INAF - Osservatorio Astronomico di Torino, Italy.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Transiting Super Earths orbiting M dwarfs are excellent targets for the prospect of studying potentially habitable extrasolar planets. While most of the currently known Exoplanets are of the Hot Jupiter and Neptune type, attention is now turning to these Super Earths. Two recent examples are GJ 1214b, found by Charbonneau et al. in 2009, and Cancri 55 e, found by Winn et al. in 2011. These candidates offer the opportunity of obtaining spectral signatures of their atmospheres in transiting scenarios, via data obtained by ground based and space observatories, compared to simulated climate scenarios.
With the recent selection of the Exoplanet Characterisation Observatory (EChO) mission by ESA for further studies, I present observational strategies and time requirements for a range of targets characterisable by EChO, with a view to Super Earths orbiting M dwarfs.

29.07
**The Photometric Light Curves Of Earth As A Planet Along Its History**
**Enric Palle**[1], E. Sanroma[1]
*[1]IAC, Spain.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
By making use of real information about the continental and oceanic surface distribution of the Earth, and cloudiness data from the International Satellite Cloud Climatology Project (ISCCP), we have studied

the large-scale cloudiness behavior according to latitude and surface types (ice, water, vegetation and desert). These empirical relationships are used here to reconstruct the possible cloud distribution of historical epochs of the Earth history such as the Late Cretaceous (90 Ma ago), the Late Triassic (230 Ma ago), the Mississippian (340 Ma ago), and the Late Cambrian (500 Ma ago), when the landmass distributions were di®erent from today's. This information is used here to simulate the photometric variability of these planets according to their different geographical distribution.

29.08

**The Occultation and Phase Variations of 55 Cnc e**

**Jason Rowe**[1], J. N. Winn[2], J. M. Matthews[3], R. I. Dawson[4], D. Fabrycky[5], M. J. Holman[4], T. Kallinger[3], R. Kuschnig[6], D. Sasselov[4], D. Dragomir[3], D. B. Guenther[7], A. F. J. Moffat[8], S. Rucinski[9], W. W. Weiss[6]
*[1]NASA Ames/ SETI Institute, [2]Massachusetts Institute of Technology, [3]University of British Columbia, Canada, [4]Harvard-Smithsonian Center for Astrophysics, [5]UCO/Lick Observatory, [6]University of Vienna, Institute for Astronomy, Austria, [7]SaintMary's University, Canada, [8]Université de Montréal, Canada, [9]University of Toronto, Canada.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We have detected transits of the innermost planet "e" orbiting 55 Cnc (V = 6.0), based on two weeks of precise nearly continuous photometric monitoring with the MOST space telescope. The planet orbits with a period of only 17 hours and 41 minutes. The host star is far brighter than that of any other known transiting planet, which makes possible follow-up investigations which are challenging for other exoplanetary systems. Both the mass and radius of 55 Cnc e are now known to within 10%, making it an excellent test of theoretical models of super-Earth structure. The small planet-star separation (0.016 AU) provides a special opportunity to search for signals of reflected light and thermal emission from a super-Earth. We report on the analysis of the MOST data to determine the planet's size, and to search for signatures of its atmosphere as well as any star-planet interactions.

## 30
### *Planets Around Evolved Stars and Compact Objects*
Poster
*Osprey/Grizzly*

30.01

**Red Giants from the Penn State - Torun Planet Search**

**Pawel Zielinski**[1], A. Niedzielski[1], G. Nowak[1], A. Wolszczan[2]
[1]*Nicolaus Copernicus University, Poland,* [2]*Pennsylvania State University.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The Penn State - Torun Planet Search (PTPS) performed with the Hobby-Eberly Telescope is devoted to search and characterization of extrasolar planetary systems around evolved stars. For complete description of these systems detailed knowledge of their suns is essential. Therefore, in parallel to the planet search we perform a complete spectroscopic analysis of ~1000 PTPS targets using existing photometric/astrometric data and our high resolution, high SNR HET/HRS template spectra. Here we present detailed description of ~350 PTPS stars from the Red Giant Clump sample. For these stars both atmospheric (Teff, log g, [Fe/H]) and fundamental (log L/Lsun, M/Msun, R/Rsun, age) parameters were determined. For stars with unknown trigonometric parallaxes spectrophotometric parallaxes were determined. We also obtained absolute radial velocities and performed cross-correlation analysis in search for spectroscopic binaries. The sample galactic distribution and complete kinematical characteristic is presented as well.

30.02

**Lithium Abundances For a Sample Of ~1000 PTPS Stars.**

**Monika Adamow**[1], A. Niedzielski[1], A. Wolszczan[2]
[1]*Torun Centre for Astronomy, Nicolaus Copernicus University, Poland,* [2]*The Pennsylvania State University.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Lithium is a very intriguing element. It was created during the Big Bang nucleosynthesis but its primordial abundance is still uncertain. While built into the stars it may be easily destroyed at temperatures of only 2.5 mln. K. It may also be created in late stages of stellar evolution enriching the interstellar medium and next generations of stars. Its appearance in stars is also enigmatic. To much surprise it appears to be present or even overabundant in evolved giant stars (Kumar et al. 2011). Its presence in stellar atmospheres of dwarfs is possibly related with appearance of planetary systems around them (Israelian et al. 2009, Ghezzi et al. 2010). The PennState - Torun Planet Search (PTPS) with ~1000 evolved stars is in a very good position to test hypotheses concerning lithium abundance in giants as well as relations between lithium abundance and planets. We found in our sample 8 giants with strong lithium overabundance, 5 of them in the Red Giant Clump sample. Here we present results of lithium abundance analysis in ~350 PTPS Red Clump Giants. We compare lithium abundance with binarity, planet presence and stellar parameters like mass, metallicity or age.

30.03

**Non-LTE Analysis of Gaseous Planetary Debris Disks around White Dwarfs**

**Stephan Hartmann**[1], T. Nagel[1], T. Rauch[1], K. Werner[1]
[1]*Institute for Astronomy and Astrophysics Tuebingen, Germany.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

About two dozen white dwarfs (WD) exhibit an IR excess that most likely originates from a circumstellar debris disk formed from ground planetary material. Some of these objects also have gaseous disk components which were discovered by CaII IR triplet emission. Potentially, a quantitative spectral analysis of the gas disk reveals the chemical composition of extrasolar planetary material around WDs directly. This method is in contrast to the hitherto employed method that uses the WD atmosphere as a "detector" of accreted material. The latter method may suffer from uncertainties in our knowledge of gravitational settling of heavy elements in WD atmospheres. We have constructed models for metallic gas disks with detailed non-LTE radiation transfer and successfully apply them to fit optical and UV spectra of a particular object.

30.04

**ALICE - a New Code for Simultaneous Radial Velocity and Stellar Activity Measurements**

**Grzegorz Nowak**[1], A. Niedzielski[1], A. Wolszczan[2]
*[1]Torun Centre for Astronomy of the Nicolaus Copernicus University, Poland, [2]Department of Astronomy and Astrophysics of the Penn State University.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Evolved stars observed within the Penn State - Torun Center for Astronomy Planet Search (PTPS) conducted with the Hobby-Eberly Telescope are supposed to present various effects of activity. In addition to chromospheric activity and/or pulsations one may expect spots temporarily appearing on their surfaces and rotating with stars that mimic planetary companions in precise radial velocities (RV) by altering line profiles. Proper interpretation of the observed radial velocity variations in these stars requires therefore simultaneous to RV measurements monitoring of line profile variations at the precision level comparable to that in RV. The most efficient way of such a monitoring is bisector velocity span (BVS) and/or bisector curvature variation (BC) monitoring using exactly the same spectra as used in measurements of RV.
To achieve maximum possible atomization in simultaneous RV and BVS/BC measurement we developed an independent code. The main point in our approach is the combination of the iodine cell method (Marcy & Butler 1992) for RVs and the cross-correlation technique for BVS/BC (Queloz et al. 2001). Using the iodine cell method to measure RVs independently in 96-pixel long segments of our HET/HRS spectra we obtain information about imperfection in the initial Th-Ar dispersion curve and determine the instrumental profile. With these informations at hand we clean-up our spectra from the iodine lines and construct the cross-correlation function (CCF) from exactly the same parts of the spectra from which we measure RVs.
Here we present examples of application of our code. We show BVS variations in HD 166435, present new spectroscopic binaries detected within PTPS with the CCF technique, and demonstrate precision of the RV code for stars of various spectral types. We also present the calibration of the vsin(i) of our stars based on the width of the CCFs obtained from our template spectra.

30.05

**Planet Engulfment by ~1.5-3 Msun Red Giants**

**Masanobu KUNITOMO**[1], M. Ikoma[1], B. Sato[1], Y. Katsuta[2], S. Ida[1]
*[1]Tokyo Institute of Technology, Japan, [2]Hokkaido University, Japan.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Recent radial-velocity surveys for GK clump giants have revealed that planets also exist around ~1.5 - 3 Msun stars. However, no planets have been found inside 0.6 AU around clump giants, in contrast to solar-type main-sequence stars.

In this study we examine the possibility that planets were engulfed by host stars evolving on the red-giant branch (RGB).
We integrate the orbital evolution of planets in the RGB and helium burning (HeB) phases of host stars, including the effects of stellar tide and stellar mass loss. Then we derive the critical semimajor axis (or the survival limit) inside which planets are eventually engulfed by their host stars after tidal decay of their orbits.
Especially, we investigate the impact of stellar mass and other stellar parameters on the survival limit in more detail than previous studies. In addition, we make detailed comparison with measured semimajor axes of planets detected so far, which no previous study did.
We find that the critical semimajor axis is quite sensitive to stellar mass in the range between 1.7 and 2.1 Msun. Our comparison between theoretical and observational limits of existence of planets demonstrates that all those planets are beyond the survival limit, which is consistent with the planet-engulfment hypothesis. However, on the high-mass side (> 2.1 Msun), the detected planets are orbiting significantly far from the survival limit, which suggests that engulfment by host stars may not be the main reason for the observed lack of short-period giant planets.
To confirm our conclusion, the detection of more planets around clump giants, especially with masses > 2.5 Msun, is required.

30.06
**Archaeology of Extrasolar Rocky Minor Planets**
**Jay Farihi**[1]
[1]*University of Leicester, United Kingdom.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Recent and ongoing work has demonstrated that empirical constraints on the frequency and chemistry of rocky planet formation around other stars, and signatures of water therein, can be found via the asteroidal debris orbiting and polluting white dwarf stars. These stellar remnants yield observable information that can be acquired no other way: the frequency, bulk chemical composition, and minimum mass of rocky minor planets around other stars. Asteroids are ancient planetesimals, the building blocks of the terrestrial planets. In the Solar System, we indirectly measure the composition of asteroids by studying meteorites. Analogously, we can obtain a picture of terrestrial planet formation at A- and F-type stars by studying the composition of extant asteroids as they fall onto and chemically pollute their white dwarf remnants. Critically, it is possible to identify significant amounts of water in these asteroidal systems, providing an indication of (current or prior) habitable environments as well as extrasolar testing grounds for models of water delivery to the Earth.
I will present the latest and new developments in this area of research. I hope to include some results of an ongoing HST COS effort to study asteroidal debris as a function of post-main sequence age and main-sequence progenitor mass. Other highlights are two stars polluted by the debris of rocky planetary bodies sufficiently large to have been differentiated, and thus at least as large as Vesta or Ceres, the two largest asteroids in the Solar System. Currently, there is at least one compelling case for the accretion of water-rich, asteroidal debris, while the totality of known polluted white dwarfs hints at a significant population of water-rich asteroid analogs orbiting other stars.

**31**
***Planets in Star Clusters***
Poster
*Osprey/Grizzly*

31.01
**Young Stars and Their Companions in NGC 2362**
**Lauren M. Weiss**[1], S. T. Hodgkin[2], M. Irwin[2], J. Irwin[3], J. L. Birkby[4], R. Jackson[5], R. Jeffries[5]
*[1]U. C. Berkeley, [2]Institute of Astronomy, U. of Cambridge, United Kingdom, [3]Harvard University, [4]U. of Leiden, Netherlands, [5]U. of Keele, United Kingdom.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
The mass-radius relation of young, low-mass ($M < M_\odot$) stars is poorly understood due to a dearth of observations. Better measurements of the masses and radii of these stars would enable a fuller understanding of how low-mass stars form and better characterization of planets orbiting such stars. We investigate velocities of 116 cool (K-type and later), small ($0.1 < M/M_\odot < 1.2$) stars with magnitude $14 < I < 19$ in the $\sim$ 5 Myr open cluster NGC 2362 with the aims of:
(1) Identifying cluster members by finding the velocity and velocity dispersion of the cluster.
(2) Constraining the masses and radii of candidate occulting systems by examining their radial velocities at multiple epochs.
We obtained time-series photometry of 1180 candidate cluster members at the CTIO 4-m Blanco telescope with the Mosaic-II detector between January and December 2006. Multi- epoch spectra of 116 stars were obtained from the ESO/VLT using the GIRAFFE/FLAMES multi-fibre spectrograph in December 2007. We measured radial velocities of 93 cluster can- didates, 81 of which are within 3σ of the cluster velocity (39.7±1.58 km/s). One M dwarf displays eclipse depths of 5%, although the double-lined spectrum of this object suggest that it is an M dwarf binary. We calculate upper and lower limits on the masses and radii of the primary star and its companion: $0.34 < M1/M_\odot < 0.53$; $1.0 < R1/R_\odot < 1.25$; $0.035 < M2/M_\odot < 0.34$; $0.28 < R2/R_\odot < 1.0$. This system is ideal for follow-up with high cadence photometry and high resolution spectroscopy at quadrature. These measurements would allow the solution of the primary and secondary masses and radii and adding to the sparse existing measurements of the masses and radii of young, low-mass stars.

## 32
### *Planets in Binary Stars*
Poster
*Osprey/Grizzly*

32.01

**Debris Discs in Binaries**

**Philippe Thebault**[1]
[1] *Observatoire de Paris, France.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Following the preliminary results of Thebault et al.(2010), we present new simulations of the evolution of debris discs in binaries using a new, specifically developed code that can handle both the dynamical and collisional evolution of the system. We show how the radial extension of the disc and its shape crucially depend on the companion star's orbit. The complex interplay between gravitational perturbations and collisional production of small grains leads to the development of periodic and short-lived (for very eccentric binaries) or long-lived-but-precessing (for circular orbits) spiral structures. We also find that the disc morphology strongly depends on the companion star's position on its orbit. We compare these results to known debris discs in order to assert to what extent binarity can be the source of observed spatial structures.

32.02

**Dynamical Evidence For A Sub-stellar Companion To By Draconis**

**Krzysztof Helminiak**[1], M. Konacki[2], M. W. Muterspaugh[3], S. E. Browne[4], A. W. Howard[4], S. R. Kulkarni[5]
[1] *Pontificia Universidad Catolica, Chile,* [2] *Nicolaus Copernicus Astronomical Center, Poland,* [3] *Tennessee State University,* [4] *University of California Berkeley,* [5] *California Institute of Technology.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

We present the results of our analysis of the famous double-lined spectroscopic binary BY Draconis, a prototype of a whole class of active variables. We combine our high-precision RV measurements (orbital fit rms ~ 160 m/s) with the archival visibility measurements from the PTI instrument. For the firs time we were able to derive its physical and orbital parameters with precision sufficient to securely estimate the evolutionary status of the system. We conclude that BY Dra is a main-sequence system with components rotating pseudo-synchronously, but the high eccentricity (e=0.3) is puzzling. Our analysis shows that this may be caused by a planetary-mass companion on a dynamically stable orbit with the period of few tenths to few hundred days, which induces Kozai cycles in the inner binary.

## 33
### *Planet Formation Theory*
Poster
*Osprey/Grizzly*

33.01

**Evolution of Protoplanetary Disks in Binary Stars**

**Tobias MÃ¼ller**[1], W. Kley[1]
[1]*Institute for Astronomy & Astrophysics Tuebingen, Germany.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

About 50 planets have been detected in binary star systems. Among those, several binaries have a close separation of about 20 AU only. To study the conditions under which planets might form in such an environment, we investigate the evolution of a circumstellar disk in an eccentric binary star system. For that purpose we performed two-dimensional simulations for non-isothermal, radiative disks which are assumed to be coplanar with the binary. The disks are geometrically thin and are primarily governed by gas pressure and (turbulent) viscosity (described by the α model). We studied the influence of several physical parameters such as disk mass, α value and opacity on the evolution on the disk eccentricity, disk periastron and mass. For our standard model in the simulations we chose the γ Cephei system with a 0.01 solar mass disk. We find that the evolution of radiative disks differs significantly from the purely isothermal evolution. In particular, the magnitude of the disk's eccentricity is reduced.

33.02

**Growth of Gas-giant Cores in Protoplanetary Discs**

**Michiel Lambrechts**[1]
[1]*Lund University, Sweden.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The core accretion scenario is the most successful theoretical model for gas-giant formation. However, the initial growth of the core depends on arbitrary assumptions on planetesimal sizes. Growing the solid core before gas dissipation is problematic due to the long time-scale for run-away accretion, especially in the outer distant regions of a protoplanetary disc.
We have studied the dynamics of gas-coupled cm-sized pebbles, gravitationally interacting with larger than km-sized cores. The Pencil Code is used to correctly model the gas drag hydrodynamics. Interestingly, the presence of pebbles in the gaseous disc influences both the dynamics (through dynamical friction) and growth rate of the gas-giant core. Under favourable conditions, i.e. unity mid-plane dust-to-gas ratio and particle growth to mm and cm sizes, pebble accretion turns out to be significantly faster than run-away accretion of planetesimals.

33.03

**Carbon and Oxygen in Nearby Stars: Keys to Protoplanetary Disk Chemistry**

**Erik Petigura**[1], G. Marcy[1]
[1]*UC Berkeley.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

We present carbon and oxygen abundances for 941 FGK stars--the largest such catalog to date. We find that planet-bearing systems are enriched in these elements. We self-consistently measure $N_C/N_O$, which is thought to play a key role in planet formation. We identify 46 stars with $N_C/N_O \geq 1.00$ as potential hosts of carbon-dominated exoplanets. We measure a downward trend in [O/Fe] versus [Fe/H] and find distinct trends in the thin and thick disk, supporting the work of Bensby et al. (2004). Finally, we measure sub-solar $N_C/N_O = 0.40^{+0.11}_{-0.07}$ for WASP-12, a surprising result as this star is host to a transiting hot Jupiter whose dayside atmosphere was recently reported to have $N_C/N_O \geq 1$ by Madhusudhan et al. (2011). Our measurements are based on 15,000 high signal-to-noise spectra taken with the Keck 1 telescope as part of the California Planet Search. We derive abundances from the [OI] and CI absorption lines at λ = 630.0 and 658.7 nm using the SME spectral synthesizer.

33.04

**Gas Giants Formation With Small Cores Triggered By Envelope Pollution By Icy Planetesimals**

**Yasunori Hori**[1], M. Ikoma[2]

*[1]National Astronomical Observatory of Japan, Japan, [2]Tokyo Institute of Technology, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We have investigated how envelope pollution by icy planetesimals affects the critical core mass for gas giant formation and the gas accretion time-scales. In the core-accretion model, runaway gas accretion is triggered after a core reaches a critical core mass. All the previous studies on the core-accretion model assumed that the envelope has the solar composition uniformly. In fact, the envelope is likely polluted by evaporated materials of icy planetesimals because icy planetesimals going through the envelope experience mass loss via strong ablation and most of their masses are deposited in the deep envelope. In this paper, we have demonstrated that envelope pollution in general lowers the critical core masses and hastens gas accretion on to the protoplanet because of the increase in the molecular weight and reduction of adiabatic temperature gradient. Widely- and highly-polluted envelopes allow smaller cores to form massive envelopes before disc dissipation. Our results suggest that envelope pollution in the course of planetary accretion has the potential to trigger gas giant formation with small cores. We propose that it is necessary to take into account envelope pollution by icy planetesimals when we discuss gas giant formation based on the-core accretion model.

33.05

**The Metallicity Planet Correlation In The Harps Volume Limited Sample**

**SÃ©rgio Sousa**[1], N. C. Santos[1], G. Israelian[2], C. Lovis[3], M. Mayor[3], G. Lo Curto[4], S. Udry[3]

*[1]Centro De Astrofisica Da U. Porto, Portugal, [2]IAC, Spain, [3]Geneva Observatory, Switzerland, [4]ESO, Germany.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

To understand the formation and evolution of solar-type stars and planets in the solar neighborhood, we need to obtain their stellar parameters with high precision. We present a catalog of precise stellar parameters for the FGK stars in a volume limited sample followed by the HARPS spectrograph in the quest for extra solar planets. The spectroscopic analysis was completed assuming LTE with a grid of Kurucz atmosphere models and using the ARES code for an automatic measurement of the line equivalent widths. The results are compared against different independent methods and also with other values

that are found in the literature for common stars. Both comparisons are consistent and show the homogeneity of the parameters derived by our team.

The derived metallicities in this sample reveal a somewhat different distribution for the present planet hosts, but still indicates the already know higher frequency of planets observed for the more metal rich stars. We combine the results derived in this sample with the one from CORALIE survey to present the largest homogeneous spectroscopic study of the metallicity-giant planet relation.

33.06

**3D Simulations of the Collapse of Protoplanetary Clumps in Disk Instability Using a New Equation of State.**

**Marina Galvagni**[1], L. Mayer[1], P. Saha[1]
[1]*University of Zurich, Switzerland.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We present the first realistic study of the evolution of protoplanetary clumps formed in disk instability, in order to assess whether or not they can collapse into gas giant planets.

As a first step, we derive a new equation of state for a mixture of atomic and molecular hydrogen which takes into account para-ortho ratio for molecular hydrogen, freezing of degrees of freedom at low temperatures and the dissociation of molecular hydrogen. We run our simulations with a new version of Gasoline implementing this new equation of state, and taking our initial condition for the clumps from global 3D simulations of accreting protoplanetary disks by T. Hayfield and L. Mayer (see eg Boley et al. 2010). Our results show that the code is able to resolve the collapse through dissociation, covering several orders of magnitude in density.

As a second step, we study how the internal angular momentum and the non-axisymmetry of a self-gravitating clump affect its evolution.

Preliminary results show that rotating clumps collapse into a slowly rotating, dense core surrounded by a fast rotating envelope/circumplanetary disk, due to the redistribution of angular momentum and mass induced by bar-like and spiral instabilities. We then determine the collapse time of clumps of a variety of masses including radiative cooling, and we compare with published semi-analytical work assuming spherical, quasi-static collapse.

By being able to determine the collpase time and the configuration of the clump after it contracts dynamically following dissociation we also lay out a scheme for implementing a sub-grid model of clump evolution and collapse in global disk simulations.

33.07

**Formation of Close-in Super-Earths: The Effect of Eccentricity Trap**

**Masahiro Ogihara**[1], S. Ida[2], M. J. Duncan[3]
[1]*Nagoya University, Japan,* [2]*Tokyo Institute of Technology, Japan,* [3]*Queen's University, Canada.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We have investigated planetary accretion from planetesimals in the vicinity of central star through N-body simulations including gravitational interactions with disk gas. The increasing number of discovered extrasolar planets opens an opportunity for studies of new planet formation scenarios. Recent observations suggest that discovered super-Earths are generally not in resonant orbits and the averaged orbital radius is about 0.1 AU, well beyond the disk inner edge. Through a series of N-body simulations, we find that, in the case where the type I migration speed is reduced by a factor of ~ 100 from that predicted by the linear theory, non-resonant solid planets are formed beyond ~ 0.05 AU.

Using orbital integration and analytical arguments, we also find a new mechanism (an "eccentricity trap") to halt type I migration of planets near the disk inner edge. In this mechanism, asymmetric eccentricity damping due to disk-planet interaction on the innermost planet at the disk edge plays a crucial role in the trap. This trap is so strong that the edge torque exerted on the innermost planet can completely halt type I migrations of many outer planets through mutual resonant perturbations. Consequently, the convoy stays outside the disk edge, as a whole. We derive semi-analytical formula for the condition for the eccentricity trap and predict how many planets are likely to be trapped. It can be responsible for the formation of non-resonant, multiple, close-in super-Earths.

33.08

**Coevolution of Dust and Magnetorotational Turbulence in Protoplanetary Disks**

**Satoshi Okuzumi**[1], S. Hirose[2]

*[1]Nagoya University, Japan, [2]JAMSTEC, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Turbulence driven by magnetorotational instability (MRI) crucially affects the evolution of solid bodies in protoplanetary disks. On the other hand, small dust particles stabilize MRI by capturing ionized particles needed for the coupling of gas and magnetic fields. To provide an empirical basis for modeling the coevolution of dust and MRI, we perform three-dimensional, ohmic resistive MHD simulations of a vertically stratified shearing box with an MRI-inactive "dead zone" of various sizes and with a net vertical magnetic flux of various strengths. We find that the vertical structure of turbulence is well characterized by the vertical magnetic flux and three critical heights derived from the linear analysis of MRI in a stratified disk. In particular, the turbulent structure depends on the resistivity profile only through the critical heights and is insensitive to the details of the resistivity profile. We discover scaling relations between the amplitudes of various turbulent quantities (velocity dispersion, density fluctuation, vertical diffusion coefficient, and outflow mass flux) and vertically integrated accretion stresses. We also obtain empirical formulae for the integrated accretion stresses as a function of the vertical magnetic flux and the critical heights. These empirical relations allow to predict the vertical turbulent structure of a protoplanetary disk for a given strength of the magnetic flux and a given resistivity profile. Using the empirical relations, we show that a dead zone created by a small amount of dust particles enables icy dust aggregates to grow beyond the meter-size fragmentation barrier keeping the gas disk accreting onto the central star on a timescale of 10^6 yr.

33.09

**Ionization State in Circumplanetary Disks**

**Yuri I. Fujii**[1], S. Okuzumi[1], S. Inutsuka[1]

*[1]Nagoya University, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We calculate the ionization degree of circumplanetary disks including dust grains. It is important to understand the structure and evolution of circumplanetary disks since they are thought to be the sites of satellite formation. The turbulence that causes gas accretion is supposed to be driven by magnetorotational instability (MRI), that occurs only when the ionization degree is high enough for magnetic field to be coupled to gas. We calculate the ionization degrees in circumplanetary disks to estimate the sizes of MRI-inactive regions so-called, “dead zones.” We properly include the effect of dust grains because they efficiently capture charged particles and make ionization degree lower. Inclusion of dust grains complicates the reaction equations and requires expensive computation. In order to accelerate the calculation of ionization reactions, we develop a semianalytic method based on the charge distribution model of Okuzumi (2009). This method enables us to study the ionization state of disks for a wide range of model parameters. For a previous model of circum-Jovian disk, we find that a dead zone covers almost all inner regions even without dust grains. This suggests that the gas accretion rates in are much smaller than previously thought.

33.10

**Streaming Instability In The Global Protoplanetary Disks**

**Kacper Kowalik**[1], M. Hanasz[1], D. Woltanski[1]
[1]*Torun Centre for Astronomy, Poland.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
We investigate streaming instability using two-fluid approximation (neutral gas and dust) in global, stratified protoplanetary disk, with the help of PIERNIK code. We compare amplification rate of the eigen-mode in numerical simulations, with the corresponding growth resulting from the linear stability analysis of full system of Euler's equation in cylindrical coordinates, including aerodynamical drag. We find that the growth rate of streaming instability excited modes coincides with the growth rate resulting from linear stability analysis.

33.11
**Circumplanetary Discs: Truncation and Outbursts**
**Rebecca G. Martin**[1], S. H. Lubow[1]
[1]*STScI.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
After a planet with a mass greater than that of Nepture forms it opens a gap in the circumstellar disc. Material continues to flow on to the planet and a circumplanetary disc forms. We model circumplanetary discs as accretion discs subject to the tidal forces of the central star. The tidal torques remove the disc angular momentum near the disc outer edge and permit the accreting disc gas to lose angular momentum at the rate appropriate for steady accretion. Circumplanetary discs are truncated near the radius where periodic ballistic orbits cross, where tidal forces on the disc are strong. This radius occurs at approximately 0.4 times the planet Hill radius. During the T Tauri stage of disc accretion, the disc is fairly thick with aspect ratio H/r>0.2. We model the disc structure using one-dimensional time-dependent and steady-state models and also two-dimensional SPH simulations. The circumplanetary disc structure depends on the variation of the disc turbulent viscosity with radius and is insensitive to the angular distribution of the accreting gas. If the disc is turbulent throughout, the predicted disc structure near the location of the regular Jovian and Saturnian satellites is smooth with no obvious feature that would favor formation at their current locations. Dead zones form in accretion discs where the temperature is too low for the disc to be fully thermally ionised. They are even more favorable in circumplanetary discs than in circumstellar discs because the surface densities are high while the temperature remains low enough to avoid thermal ionisation. We consider the conditions under which dead zones form and the resulting unsteady accretion on to the planet. Outbursts in the accretion rate on to the planet have observational implications for planet detection.

33.12
**Collisional Growth of Dust aggregates in Protoplanetary Disks**
**Hidekazu Tanaka**[1]
[1]*Hokkaido Univ., Japan.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Dust growth by aggregation is an important process as the first step of planet formation in protoplanetary disks. Dust growth also influences the radiation field and/or the temperature structure in protoplanetary disks. However, we still have a large uncertainty in dust growth process. This uncertainty is mainly originated from unknown factors in the structure of growing dust aggregates and their collisional outcomes. It is still unclear what kind of structure dust aggregates have during their growth and how small impact velocity is required for their collisional sticking without major fragmentation.

Furthermore, the collisional outcomes would be strongly dependent on the aggregate structure (the porosity, the number of connections among particles in the aggregate, charging, etc.). In recent years, many theoretical studies on aggregate collisions have been done (i.e., evolution of dust porosity or charging, the maximun impact velocity for dust growth, etc.). I will introduce remarkable results in these studies, focusing on results by our group.

33.13

**Distribution of Accreting Gas and Angular Momentum onto Circumplanetary Disks**

**Takayuki Tanigawa**[1], K. Ohtsuki[2], M. N. Machida[3]

[1]*Hokkaido University / Center for Planetary Science, Japan,* [2]*Kobe University / Center for Planetary Science, Japan,* [3]*Kyushu University, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We investigate gas accretion flow onto a circum-planetary disk from a protoplanetary disk in detail by using high-resolution three-dimensional nested-grid hydrodynamic simulations, in order to provide a basis of satellite forming processes around giant planets. We show that most of gas accretion onto circum-planetary disks occurs nearly vertically toward the disk surface from high altitude, whereas gas in the midplane moves radially outward and escapes from the Hill sphere simultaneously. We obtain distribution of mass flux of the gas accretion onto circum-planetary disks and find that large fraction of of gas accretion occurs at the outer region of the disk, i.e., at about 0.1 times the Hill radius.

33.14

**Nbody Simulation Of Planetary Spin In Runaway/oligarchic Stages**

**Daishi Matsukura**[1], E. Kokubo[2], S. Ida[1]

[1]*Tokyo Institute of Technology, Japan,* [2]*National Astronomical Observatory of Japan, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

In our planetary system, all planets are rotating with wide varieties of obliquities and spin rates. Especially current spin properties of terrestrial planets give us much useful information to constrain the scenario of planetary formation. Ohtsuki and Ida(1998) have investigated the spin of protoplanet which accreted in a disk of planetesimals with non uniform spatial distribution. Their three-body calculations show that the current spin values of the Earth-Moon system is achieved by planetesimal accretion only in the case planetesimals are initially existing around the feeding zones of the protoplanet. In our study, we calculate the whole process of planetary spin by Nbody simulations during their growth stage. Our results show that the distribution of runaway bodies' obliquities are nearly isotropic after runaway growth stage. Additionally, planetesimals acquire their spin angular velocity up to their break-up speed but afterward runaway bodies begin to lose their spin angular velocity as they eat other small bodies. According to our results, runaway bodies statistically have rotation periods between 1-10 hours.

33.15

**Save the Planet: Recycle the Pre-planetesimals!**

**Farzana Meru**[1], R. J. Geretshauser[1], R. Speith[1], W. Kley[1]

[1]*Universitat Tuebingen, Germany.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We carry out three-dimensional Smoothed Particle Hydrodynamics simulations to determine the outcome of pre-planetesimal collisions of approximately 1-10 centimetre-sized silica dust aggregates. Previous laboratory results have investigated the threshold velocity above which dust aggregates shatter (e.g. Blum & Münch 1993; Teiser & Wurm 2009). However, detailed parameter studies are not possible

in the laboratory. We perform a comprehensive study into the outcomes by considering the collision velocity, impact parameter, mass ratio and porosity of the aggregates to determine the conditions that allow them to grow into planetesimals. We also determine the properties of the largest and second largest fragments, as well as the fragmented population as done so in the four-population model introduced by Geretshauser et al. (2011). While previous studies often assume a threshold velocity of approximately 1m/s, recent experimental results suggest that higher threshold velocities (approximately 55m/s) may be possible.
Using high resolution SPH simulations, we find that the aggregate and collision properties significantly affect this value. We find that compact and highly porous objects are more prone to destruction as they are too fragile and too brittle, respectively, while intermediate porosity (approximately 65%) objects are more resistant to fragmentation. In addition, collisions between very different sized objects allow growth at larger velocities, at least as high as 20m/s. While collisions between medium porosity, unequal-sized aggregates is optimum for growth, all is not lost if destructive collisions occur: such collisions produce large and small fragments which may then collide and be recycled into aggregates that grow. Furthermore, the destruction of highly porous and compact aggregates in a series of collisions may produce medium porosity objects that can then be recycled into growing aggregates. This may have profound implications on planetesimal formation as the destructive collisions may counter-intuitively aid the growth of planetary cores.
This research is DFG funded.

33.16

**Origin of Earth's Water: Delivery by Planetary Embryos or Local Adsorption from Primordial Nebula?**

**AndrÃ© Izidoro**[1], N. Haghighipour[1], O. Cabo Winter[2]
*[1]Institute for Astronomy - University of Hawaii, [2]UNESP, Brazil.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The origin of Earth's water is one of the most outstanding unanswered questions in planetary science. It is generally believed that the Earth's local environment during its formation was sufficiently hot to prevent the hydration of planetesimals and protoplanets. That is, the Earth's nearby building blocks were likely devoid of water and water must have been delivered to Earth from large distances. The two paradigms for the delivery of water, namely, the cometary impacts and delivery through planetesimals and planetary embryos have their own uncertainties. The measured values of the D/H ratio in some comets are approximately twice the terrestrial value which may preclude comets as a source of Earth's water. Also, the Os isotopes in Earth's mantle play against water delivery by means of planetesimals and protoplanets. A third scenario suggests that Earth might have formed wet and its water could have its origin in the water vapor that was adsorbed on dust grains (which later contributed to its formation) in the primordial nebula. We have carried out extensive simulations of the formation of Earth in a disk where the distribution of water follows the adsorbtion model. Results of our simulations indicate that, when compared with the current value of Earth's water budget, the scenario of the wet formation of Earth introduces too much water to the inner part of the solar system. However, when this scenario is limited to a small region and is combined with the model based on the delivery of water through planetesimals and planetary embryos, the accumulated amount of water on Earth will become more realistic. In other words, a more viable scenario for the origin of Earth's water seems to be a combination of these two models. We present the results of our study and discuss their implications for water on terrestrial planets.

## 34

### *Dynamical Evolution and Interactions*

Poster

*Osprey/Grizzly*

34.01

**Thefluid Equilibrium Tide In Stars And Giant Planets**

**FranÃ§oise Remus**[1], S. Mathis[1], J. Zahn[2]

*[1]CEA/DSM/IRFU/SAp, France, [2]Observatoire de Paris - LUTh, France.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Many extrasolar planets orbit very close to their parent star, so that they experience strong tidal interactions; by converting mechanical energy into heat, these tides contribute to the dynamical evolution of such systems. This motivates us to acquire a deeper understanding of the processes that cause tidal dissipation, which depend both on the structure and the physical properties of the considered body.

Here we examine the equilibrium tide, i.e. the hydrostatic adjustment to the tidal potential, in a rotating fluid planet or star. We first present the equations governing the problem, and show how to rigorously separate the equilibrium tide from the dynamical tide, which is due to the excited eigenmodes. We discuss in particular how the quality factor Q is linked whith the turbulent viscosity of the convection zone. Finally we show how the results may be implemented to describe the dynamical evolution of the system.

34.02

**The Dependence of Orbital Stability of Planets Trapped in the Mean-Motion Resonance**

**Yuji Matsumoto**[1], M. Nagasawa[1], S. Ida[1]

*[1]Tokyo Institute of Technology, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We study the stability of planets in the mean-motion resonances with numerical simulations.

Nowadays, about 550 planets and 1235 KOI candidates are observed. There are 8 systems and 158 candidate systems that are composed of multi super-Earths or Neptunes.

Most of systems are not in mean-motion resonances.

Numerical works suggest protoplanets migrate toward their central stars due to the interaction with the gas disk. Migration is stopped when a protoplanet arrives at the inner edge of the gas disk.

Protoplanets are captured at the locations of mean-motion resonances near the inner edge (Terquem & Papaloizou 2007). Normally, the resonant systems are stable longer than the system age.

Ogihara & Ida (2009) performed N-body simulations of planetary accretion in the case of weaker type I migration than the linear value. In such a case, planets become unstable after the gas depletion. Then final configure of planets are in large orbital separations and not in the mean-motion resonances.

There are differences in the configuration of planetary systems. A question arises which parameter is most responsible to make systems offset from the resonances. So we calculate the stability time of resonant systems changing parameters. We put on innermost planet at 0.1AU and put the other planets on m+1:m resonant orbits.

We find that when the number of planets becomes some value, the stability time of resonant system decreases rapidly.

With a fixed mass of planets, this critical number is smaller as the orbital separation, which is normalized

by Hill radius becomes narrower. With fixed orbital separation, the critical number is smaller as the planetary mass gets smaller.
Exopanet systems whose planets are not in resonances is thought to be formed by the scenario that planets over critical number are trapped in resonances and these planets cause orbital instability after gas depletion.

34.03

**Internal Gravity Waves and Tidal Dissipation in Solar-Type Stars**

**Adrian Barker**[1], G. Ogilvie[1]
[1]*DAMTP, University of Cambridge, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Internal gravity waves are excited at the interface of convection and radiation zones of a solar-type star by the tidal forcing of a short-period planet. The fate of these waves as they approach the centre of the star depends on their amplitude. We present the results of numerical simulations of these waves approaching the centre of a star, and the resulting evolution of the spin of the central regions of the star, and the orbit of the planet. We complement this by also describing the results of a stability analysis of a tidally excited gravity wave. Our main result is that if the waves have large enough amplitudes to break, we find efficient tidal dissipation, which can threaten the survival of sufficiently massive short-period planets. If these waves have insufficient amplitude to break, they are gradually damped by parametric instabilities, which are, however, estimated to result in much weaker tidal dissipation. Our main conclusion is that the absence of wave breaking near the centre of a host star could provide an explanation for the survival of all short-period extrasolar planets observed around FGK stars. Additionally, this mechanism predicts the destruction of more massive planets, for which wave breaking is expected. This hypothesis will be tested by ongoing and future observations of transiting planets, such as WASP and Kepler.

34.04

**The Formation and Maintenance of Laplace Resonances in Multiple Exoplanet Systems**

**Yuanyuan Chen**[1], J. Zhou[1], J. Yang[1], H. Zhang[1], Y. Sun[1]
[1]*Astronomy Department, Nanjing University, China.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Laplace resonance was first discovered among the inner Galilean moons of Jupiter, which is characterized with three bodies' period radio close to 4:2:1 and the Laplace angle librating, and often companied with a double 2:1 mean-motion resonance. Similar to other resonances, Laplace resonance also results from bodies' differential migration due to non-conservative forces. As the differential migration of the Galilean satellites due to interactions with a circumjovian disk leading to the primordial formation of the Laplace resonance, tidal interaction with circumstellar gas disc can also drive protoplanets into Laplace resonance under some circumstances.
We investigated two multi-exoplanet systems, HD40307 and GJ876 systems, in which both period radios of three nearest planets are close to 4:2:1. Considering the planets' large masses relative to their close orbits, orbital migrations are supposed to be inevitable. So it is very probable that they are or have been in Laplace resonance. By N-body simulation and some analyses, we constricted the conditions for disks and bodies' masses in which Laplace resonance could be trapped, and made a discussion how different parameters affect the trapping probability. We also discussed the possible multiple exoplanet systems that might be in 4:2:1 resonances detected in Kepler mission.

34.05

**Constraining the Size of the Protosolar Nebula**
**Katherine A. Kretke**[1]
*[1]Southwest Research Institute.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Observations indicate that the circumstellar gaseous disks around young stars vary significantly in size, ranging from 10s to 1000s of AU. As we try to unravel the events leading to the formation of our own solar system, we would like to understand the properties of our own primordial disk. Fortunately, the dynamics of objects in the Kuiper belt provide interesting constraints. After Jupiter formed, it must have scattered a significant number of planetesimals into eccentric orbits. If there had been a massive, extended protoplanetary disk at that time, then the disk would have excited Kozai oscillations in the scattered objects, driving some into high-inclination, low-eccentricity orbits. The dissipation of the gaseous disk would strand some objects in these high-inclination orbits; orbits that are stable on Gyr timescales. The fact that we have yet to observe Kuiper belt objects on these orbits therefore places strict limits size of the disk at the time of planet formation, revealing important information about the environment from which our solar system emerged.

34.06
**A Dynamical Analysis of the HU Aquarii Planetary System**
**Robert A. Wittenmyer**[1], J. Horner[1], J. Marshall[2], C. Tinney[1]
*[1]University of New South Wales, Australia, [2]Universidad Autonoma de Madrid, Spain.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
In early 2011, the surprising discovery of two giant planets orbiting the eclipsing polar HU Aquarii was announced. We present a detailed dynamical study of the orbital stability of the HU Aquarii planetary system, revealing that the proposed planetary orbits are highly dynamically unstable. In order for the planets to be dynamically stable on timescales greater than ~10000 years, they must move on significantly different orbits than were suggested in the discovery work. In fact, unless the orbit of the outer planet is retrograde relative to the inner, we find that it must instead orbit well beyond the 1-sigma uncertainties stated in that work if the system is to remain stable over even moderate timescales. This suggests that the HU Aquarii planetary system is either more complicated or significantly different to that proposed, or that it is currently undergoing a significant dynamical destabilisation. We also re-analyse the discovery data and present alternative and more physically plausible system configurations.

34.07
**The Kozai Mechanism and Angular Momentum Conservation**
**Frederic A. Rasio**[1], S. Naoz[1], W. M. Farr[1], Y. Lithwick[1], J. Teyssandier[1]
*[1]Northwestern Univ..*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
The theory of secular perturbations between two orbits in a hierarchical triple configuration has many astrophysical applications, from planetary dynamics to triple star systems. In the secular approximation the orbits may change their shape and orientation, but the semi-major axes remain constant. For sufficiently inclined systems, the Kozai mechanism can produce large-amplitude oscillations in the orbital eccentricities and relative inclination. We have re-derived the full set of secular evolution equations including both quadrupole and octupole orders using Hamiltonian perturbation theory. Our new derivation corrects an error in several previous treatments of the problem. We discuss various

interesting implications of using the correct formalism for systems containing two coupled planets, including the possibility of forming retrograde planets.

34.08

**Effects of Stellar Evolution on Test Particle Stability**

**Shane Frewen**[1], B. Hansen[1]

[1]*UCLA.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

A large fraction of white dwarfs appear to be contaminated with metals despite their high surface gravities and short diffusion times. The current theoretical model for this contamination is accretion of rocky bodies, perturbed inwards toward the white dwarf by planets via instabilities caused by mass loss. We examine the stability of test particles in a single-planet system during the main sequence and white dwarf stages within 10 and 20 AU, respectively. In particular, we compare the instabilities that develop before and after the star loses mass to form a white dwarf, a process which causes the semi-major axes of the planet to expand adiabatically. We repeat this process for a range of planetary masses and eccentricities, focusing on the number of particles that become unstable and the fraction of those that impact the central body. These results are compared to the observed white dwarf accretion rates and duration of accretion.

34.09

**Exploring the Parameter Space of Retrograde Planets in the Secular Hierarchical 3-body Problem**

**Jean Teyssandier**[1]

[1]*Northwestern University*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Recent observations using the Rossiter-McLaughlin effect have revealed the existence of Hot Jupiters in highly inclined and even retrograde orbits. At the same time, distant planets have been discovered using direct imaging methods. Motivated by these observations, we explore the possibility of forming retrograde orbits in hierarchical triple configurations with two giant planets, or one giant planet and a brown-dwarf binary companion. We survey a large set of orbital parameters, highlighting the range of initial conditions that allow for the formation of retrograde Hot Jupiters. We use the formalism developed in Naoz et al. 2011 \footnote{Naoz et al. ArXiv e-prints 1107.2414}, which gives a correct treatment of the secular evolution of hierarchical triple systems to octupole order. With this new formalism, a complete numerical study can be done. Based on our new survey, we show how and when an eccentric planetary or brown-dwarf companion can perturb the inner planet into a retrograde orbit, as long as the mutual inclination is high. Constraints on the outer body can be used to guide future observations.

## 35

### *Stellar Surface Deposition of Material*

Poster

*Osprey/Grizzly*

35.01

**A Dozen Red Giant Stars That May Have Accreted Planets**

**Joleen K. Carlberg**[1], K. Cunha[2], V. V. Smith[3], S. R. Majewski[4]

[1]*University of Virginia/Carnegie Institution of Washington,* [2]*Steward Observatory/NOAO,* [3]*NOAO,* [4]*University of Virginia.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We have identified twelve red giant stars as candidates for having accreted a former planetary companion in a previous study aimed at understanding the role of planet accretion in creating the unusual red giant rapid rotators. Their planet accretion candidacy is based on the apparent replenishment of lithium in their atmospheres and (in some cases) enhanced rotation speeds, coupled with the difficulty of alternative Li-enhancement mechanisms working at these stars' evolutionary stages. The stellar mass estimates, however, are not precise enough to unambiguously describe the mass-dependent chemical processing (e.g., the degree of light element dilution) expected in these stars. In this study, we explore additional chemical signatures expected to be unique to planet accretion. For example, one hallmark of a planetary composition is a trend of increased abundance with condensation temperature, i.e., relative enhancement of refractory elements over volatiles. In main sequence stars, a relative enhancement of refractory elements in stellar atmospheres has been explored as a signature of the accretion of planetary material (e.g., Smith et al. 2001) while the opposite trend (depleted refractories in the Sun) has been suggested as a possible indicator that a star hosts terrestrial planets (Melendez et al. 2009). Here we explore whether condensation temperature dependent abundance patterns exist in our red giant planet-accretion candidates and the implications of the presence or absence of such a trend. Finally, we briefly highlight future experiments to further test our hypothesis that these stars have accreted planets, such as looking for changes in specific abundance ratios and the feasibility of radial velocity monitoring to look for unaccreted planets.

## 36
### *Disks and Migration Theory*
Poster
*Osprey/Grizzly*

36.01
**Outward Migration in Radiative Discs**
**Bertram Bitsch**[1], W. Kley[1]
[1]*Computational Physics, Germany.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Influences on planetary migration in 3D fully radiative discs
Recent studies have shown that low mass planets can migrate outwards in fully radiative discs at a distance of about 5 AU from the star. In order to sustain the outward migration of these planets, the disc has to meet certain criteria (temperature profile, entropy gradient, etc.). With increasing distance to the central star, the disc's temperature and density reduce. This reduction, however, has a dramatic effect on the torque acting on the planet (the torque determines the speed and direction of motion for planets on circular orbits). We find that for larger radi, the torque becomes negative and the planet would migrate inwards again. The planets therefore stop their outward migration at a point in the disc, while a planet moving inwards from further out stops its inward migration. This region in the disc can act as a feeding zone for planetary embryos.
The zero-torque radius for planets is dependent of the disc structure. The structure of our 3D fully radiative discs is determined by viscous heating and radiative transport/cooling to the surface. Therefore, the viscosity, the disc mass and the adiabatic index change the structure of the disc. A change in these parameters influences the zero-torque radius for low mass planets quite dramatically. I will present these changes in the disc structure for fully radiative discs and show the effect on the migration properties of planets in such discs.

36.02
**Disc-Planet Interactions for Planets on Extreme Orbits**
**Hanno Rein**[1], T. Muto[2]
[1]*Institute for Advanced Study,* [2]*Department of Earth and Planetary Sciences, Tokyo Institute of Technology, Japan.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
The discovered extrasolar planets exhibit a huge variety of orbital parameters whereas all planets in our own solar system are on nearly circular orbits with low eccentricities and mutual inclinations.
We present new results on the interaction of proto-planetary discs and planets on extreme orbits (i.e. high inclination and high eccentricity). Both analytic calculations and three dimensional hydrodynamic simulations show interesting effects in an area of the parameter space which hasn't been studied before.
For highly inclined planets ($i>H/r$), the interaction with the disc is much weaker than for embedded planets and is dominated by dynamical friction. The relevant timescales become comparable to the disc lifetime. Furthermore, the migration timescale might be faster than the inclination damping timescale for low planet masses. This allows the formation of inclined planets even in the presence of a gas disc, as planets will not re-align with the disc.
For embedded, highly eccentric planets ($e>H/r$) the evolution is also dominated by dynamical friction.

The timescales are also long, but depend on the global disc structure in this case. It is possible that eccentric planets created by gravitational instability or planet-planet scattering remain in their orbits even when they are embedded in the disc.

36.03

**Non-ideal MHD Effects in Protoplanetary Disks**

**Xue-Ning Bai**[1], J. M. Stone[1]

*[1]Princeton University.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Non-ideal MHD effects play a significant role on the dynamics of protoplanetary disks (PPDs), hence affect the processes of planet formation and migration. In particular, the onset and saturation level of the magnetorotational instability (MRI) depend critically on non-ideal MHD processes including Ohmic resistivity, Hall effect and ambipolar diffusion (AD), with the latter two effects poorly explored in the literature. We perform 3D unstratified shearing-box simulations of the MRI with AD using a variety of magnetic configurations and AD coefficients. We find that the MRI becomes inefficient when the neutral-ion collision frequency falls below the orbital frequency, and sustained MRI turbulence requires weak magnetic field in the AD dominated regime. We further show preliminary results on the non-linear evolution of the MRI in the Hall-dominated regime. Incorporating all the constraints obtained from the simulations, we present a general framework to estimate the level of turbulence, the MRI-driven accretion rate and the corresponding magnetic field strength in PPDs. We find that the entire outer disk with radius larger than 10-20 AU is likely to be MRI-active, while MRI proceeds through the surface layer in the inner disk. Tiny grains such as polycyclic aromatic hydrocarbons promote accretion compared with sub-micron grains due to their own conductivity. Our predicted accretion rate in the inner disk, however, is insufficient to account for the observed accretion rate in a large fraction of T-Tauri stars, calling for additional mechanisms such as magnetized wind for angular momentum transport, or stronger sources of ionization. On the other hand, the predicted accretion rate at larger disk radii is consistent with the observed range in transitional disks.

36.04

**Planetary Migration in Weakly Magnetized Turbulent Disks**

**Clement Baruteau**[1], S. Fromang[2], R. P. Nelson[3], F. Masset[4]

*[1]DAMTP, University of Cambridge, United Kingdom, [2]AIM, CEA Saclay, France, [3]Queen Mary, University of London, United Kingdom, [4]ICF, Universidad Nacional Autonoma de Mexico, Mexico.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The migration of low-mass planets in their nascent protoplanetary disks has recently received detailed attention. It may be directed inwards or outwards, depending on the magnitude of the corotation torque, the torque exerted on the planet by its coorbital region. The long-term evolution of the corotation torque is intimately related to viscous and thermal diffusion processes in the planet's coorbital region. However, its behavior in the presence of realistic turbulence is so far unknown. I will present the results of the first 3D MHD simulations investigating the properties of the corotation torque experienced by planets embedded in weakly magnetized turbulent disks. The impact of the new corotation torque our simulations have uncovered will be discussed.

36.05

**Heating and Cooling Protoplanetary Disks**

**Neal J. Turner**[1], S. Hirose[2]

*[1]Jet Propulsion Laboratory, California Institute of Technology, [2]JAMSTEC, Japan.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Planets form in the disks of gas and dust orbiting young stars. Much of the material spirals inward, and is observed in many cases falling onto the growing star. The gravitational energy released during the inspiral powers the turbulent stirring and heating of the planet-forming flow, governing temperatures, densities and velocity fields. The nature of the energy release process has been a mystery, and thus a major uncertainty in planet formation models for decades. I will discuss the possibility that magnetic activity is the driver.
Any picture of the energy release must account for these issues:
(1) The near-infrared emission from carbon monoxide molecules in the atmospheres of some disks shows transonic velocities.
(2) Thermal-chemical modeling indicates the emission cannot be powered by the starlight or stellar X-rays, but can be powered by the inflow if the atmospheric turbulence reaches the sound speed.
(3) Mid-infrared emission lines of water and several carbon-bearing molecules are widespread among young solar-mass stars with disks, as found recently with the Spitzer Space Telescope. The lines probe conditions in the disk atmospheres. The water lines originate in gas about 1 AU from the star, with temperatures around 600 K, substantially hotter than the disk photosphere.
I will outline how magnetic activity can lead to each of these properties, using results from the first 3-D numerical radiation-MHD calculations of the energy release to treat the stellar X-ray ionization coupling the gas to the magnetic fields. Matching such models against the molecular spectra will enable us to infer the conditions in the disk interior where the planets form.

36.06
**Planet Traps and the Origin of Planetary System Architectures**
**Yasuhiro Hasegawa**[1], R. E. Pudritz[1]
*[1]McMaster University, Canada.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Massive planets likely form as a consequence of rapid migration of planetesimals and low mass cores into specific trapping sites in protoplanetary discs. We show that a complete analysis of how planet traps arise and move during disk evolution coupled with an analysis of how planets "drop-out" of such traps to undergo Type II migration, provides deep insight into architecture of planetary systems as represented in the observed mass-period relation. We present analytical modeling of inhomogeneities in Protoplanetary discs around a variety of young stars and show how they give rise to planet traps. We investigate both corotation and Lindblad torques, and show that a new trap arises from the (entropy-related) corotation torque. This arises at that disc radius where disc heating changes from viscous to stellar irradiation dominated processes. We demonstrate that up to three traps (heat transitions, ice lines and dead zones) can exist in a single disc. The radial positions of these traps are sensitive to stellar masses and accretion rates. These traps move differently as disc accretion rates decrease with time as a consequence of viscous evolution of disks. We can predict when planets become massive enough that they cease to follow the motion of their traps and undergo slower type II migration. In a number of systems, the planets in their traps converge upon one another during the later phases of disk evolution - to the point that planet-planet interaction occurs. We have combined all of these physical effects together with photoevaporation of disks, and find that planet traps together with trap-induced planet-planet interaction are crucial ingredients for understanding the mass-period relation. We demonstrate that the structure of the mass-period relations also depends on the mass of the host stars which ultimately regulate the positions of planet traps as well as the efficiency of photoevaporation.

36.07

**Planet Destruction Rate of Occurrence and Observability: Has Planet Accretion Been Recently Found?**

**Stuart F. Taylor**[1], I. Jiang[1], P. Thakur[1]
*[1]National Tsing Hua University, Taiwan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Planet accretion and destruction will release more energy and material than any other planet-related event. When it happens fast enough, the release of matter and energy can produce stronger observational signals than any other planet-related event. But Roche lobe overflow can lead to outward migration that prolong Roche lobe overflow for so long that perhaps only the matter release might be an observable indicator of planet accretion. We present some plausible lifetimes of this overflow phase that support the interpretation of Spezzi et al. (2011) who suggest that "planet ingestion" may explain their finding of nine high luminosity/low temperature objects. We suggest that the planets may not have quickly released most of their material. Our results indicate that the overflowing planets may still be present, and still undergoing overflow. The length of time of the overflow phase depends on several factors, including the tidal quality factor (the rate of tidal friction), and what fraction of the angular momentum goes into the orbit versus spinning up the star. Finally, we present work on the rates that observers may be able to find different types of planet destruction. Planet accretion is proving to be a rich area of study itself, which will also reveal much about stars and planets, especially as it will be possible to observe planets come apart layer by layer.

36.08

**Stripping a Debris Disk by Gravitational Interaction with an Inner Planet**

**Etienne MOREY**[1], J. Lestrade[1]
*[1]Observatoire De Paris, France.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Debris disks are detected through scattered light or thermal emission of their dust, produced by collisions or erosion of planetesimals. The rate of collisions depends on the number density of planetesimals and on the dynamical excitation and geometry of the whole disk. We have studied a debris disk gravitationally perturbed by a single inner planet, by using a numerical integration over a large parameter space for both the orbital elements of the planet and the disk geometry. We discuss our findings in the context of observed orbital elements for exoplanets and plausible disk geometries.
We have studied whether or not a disk can be significantly stripped of its planetesimals because of this interaction, and quantified its final dynamical excitation. We estimate the resulting dust production given that stripping would impede dust production while higher dynamical excitation would enhance it.

36.09

**Kepler Photometry Of HAT-P-11: Starspots And Spin-orbit Misalignment**

**Roberto Sanchis Ojeda**[1], J. Winn[1]
*[1]MIT.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

I will present the analysis of 26 light curves of HAT-P-11 obtained with the Kepler satellite over 4 months. The light curves show spot-crossing anomalies, which are used to demonstrate that the stellar rotation and planetary orbit are misaligned by 90 +/- 23 degrees. This method of measuring spin-orbit alignment is purely photometric and is therefore complementary to the spectroscopic Rossiter-McLaughlin effect. Furthermore this new technique delivers the three-dimensional spin-orbit angle

rather than the sky projection.

For HAT-P-11 the analysis also shows that star spots occur at certain preferred latitudes on the star, as is the case for the Sun. We expect that these preferred latitudes will migrate toward the stellar equator over the years, in analogy with the "butterfly diagram" observed for sunspots. Thus, data from an extended Kepler mission will allow for a new and powerful probe of starspot activity cycles.

## 37
### *Interior Structure*
Poster
*Osprey/Grizzly*

37.01

**The Impact of Semi-convection on (Extrasolar) Giant Planet Interior Structure and Evolution.**

**Jeremy Leconte**[1], G. Chabrier[1]
[1]*CRAL/ENS Lyon, France.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

While conventional interior models for giant (exo)planets are based on the simplistic assumption of a solid core surrounded by a homogeneous gaseous envelope, we derive new models with an inhomogeneous distribution of heavy elements, i.e. a gradient of composition within these planets. Because such a continuous heavy element gradient impedes large-scale convection, the inner thermal profile of these «semi-convective» planets departs from the traditionally assumed adiabatic one. This yields a slower cooling, thus contraction, than in the fully convective, adiabatic case, possibly providing the missing piece to the puzzle of anomalously inflated Hot Jupiters.
In order to test the viability of this hypothesis, we derive semi-convective, inhomogeneous structure models for Jupiter and Saturn which satisfy all observational constraints (gravitational moments, surface abundances), while being substantially super adiabatic. The larger internal temperature in the semi-convective planet, which implies a larger fraction of heavy elements to counteract the radius increase, leads to metal enrichments up to 30 to 60% larger than previously thought for our gas giants. However, as the heavy elements tend to be redistributed within the gaseous envelope, the models predict smaller than usual central cores inside Saturn and Jupiter, with possibly no core for this latter.
As these new structural and cooling properties directly apply to extrasolar planets, we also examine the efficiency of this «bloating mechanism» by quantifying the impact of the reduced heat flux due to semi-convection on the contraction/cooling of Hot Jupiters. Such a possibility of semi-convective planetary interiors opens a new window on our understanding of giant planet formation, structure and evolution, inside and outside our Solar System.

37.02

**Combining Stellar And Exoplanetary Models: Uncertainties And Constraints On Planetary Compositions**

**Mathieu Havel**[1], T. Guillot[1]
[1]*Observatoire de La Cote D'Azur, France.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

With well over 100 transiting planets and thousands of candidates, we now have access to a statistically significant ensemble of planets. In order to take the most out of these statistics and reveal any correlations that could shed light on planetary/stellar formation and evolution models, we need to model the systems as accurately and homogeneously as possible. Relying on a database of stellar and planetary evolution models, we present SET, a tool to model both the host star and the planet in a consistent way, by keeping tracks of the correlations between the inferred parameters.
First we compare wildly used stellar evolution models in order to estimate the magnitude of intrinsic errors. When fixing mass and age we find that errors on the stellar effective temperature are relatively small (less than 1.5%), but that those on the mean stellar density are about 7%. For transiting systems,

this translates into a 1-2% error on the planetary radius. In reality errors accumulate over that value. For example systems modelled with solar composition tracks can have planetary radii that systematically underestimated by up to 10% for very metal-rich stars ([Fe/H]~0.4).
We then apply our method to known transiting exoplanets,whit the aim to accurately derive their bulk composition. As shown for the CoRoT star-planet systems modelled with SET (CoRoT-8 to 18), the uncertainties remain numerous. Stellar ages are particularly difficult to constrain. We show that PMS solutions always complement the traditional MS solutions. Furthermore we stress that the non-gaussian solutions have to be properly accounted for in statistical studies of
exoplanetary systems.
Finally we present results of the Kepler-9 system, the first multiple transiting planetary systems. We show that the relative composition of the two Saturn-mass planets -- Kepler-9b and 9c -- can be much better constrained than with individual composition studies.

## 38
### *Protoplanetary Disk Observations*
Poster
*Osprey/Grizzly*

38.01

**The Gas Content Of Protoplanetary Herbig Ae/be Discs As Seen With Herschel**

**Gwendolyn Meeus**[1], GASPS (Herschel OTKP, PI B. Dent)
[1]*UAM, Spain.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The mechanisms determining planet formation are not (yet) well-understood. Primordial protoplanetary discs consist 99% out of gas, and only 1% out of dust. With time, those discs are believed to evolve from a flaring geometry into a flat geometry, as the initially small dust grains grow to larger sizes and settle towards the mid-plane. In the mean time, the gas will disperse, until so little is left that giant planets no longer can form. As an important piece of the puzzle of planet formation, it is important to understand the influence of the gas heating/cooling processes on the young disc structure, its chemical composition and finally how fast gas gets dispersed.
In this talk, we study the protoplanetary discs around Herbig Ae/Be stars, young objects of intermediate mass, in the context of its gas content. We present Herschel PACS spectroscopic observations for a sample that was obtained within the GASPS (Gas in Protoplanetary Systems) Open Time Key Project, concentrating on the detection and characterisation of emission lines of the [OI], [CII], and CO, tracing the disc between 5 and 500 AU. We look for correlations between the observed line fluxes and stellar properties such as effective temperature, Halpha emission, accretion rates and UV flux, as well as the disc properties: degree of flaring, presence and strength of PAH emission and disc mass. We will present a few cases to show how simultaneous modeling (using the thermo-chemical disc code ProDiMo) of the atomic fine structure lines and both molecular lines can constrain the disc gas mass, once the disc structure is derived. Finally, we compare our gas line observations with those of young debris disc stars, for which the HAEBE stars are thought to be progenitors.

38.02

**Herschel Reveals A Low C / O Ratio In The Disk Around Beta Pictoris**

**Alexis Brandeker**[1], Herschel GT KP "Stellar Disk Evolution", PI Olofsson
[1]*Stockholm University, Sweden.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The young star beta Pictoris is well-known for its dusty debris disk, produced through collisions by planetesimals, kilometer-sized bodies in orbit around the star. In addition to dust, small amounts of gas are also known to orbit the star, likely the result from vaporisation of violently colliding dust grains. Since the disk is seen edge on, we know from previous absorption spectroscopy that the gas is very rich in carbon, relative to metallic species. The oxygen content was more difficult to assess, with early estimates finding very little oxygen in the gas at a C / O ratio 20 times higher than the cosmic value. A C / O ratio that high would have far-reaching consequences for planet formation. Here we report on new observations by the far-infrared space telescope Herschel, that show strong emission lines from ionised carbon and neutral oxygen. The emission lines reveal a much larger reservoir of oxygen than previously estimated, pushing the C / O ratio down to close to the cosmic ratio. With the gas originating from vaporised grains, this gives us an indirect measurement of the C / O ratio of the planetesimals, the building blocks of planets.

38.03

**A Spitzer Study of Dusty Disks in the Scorpius-Centaurus OB Association**

**Christine Chen**[1], E. E. Mamajek[2], M. A. Bitner[1], M. Pecaut[2], K. Y. L. Su[3], A. J. Weinberger[4]
*[1]STScI, [2]University of Rochester, [3]University of Arizona, [4]Carnegie Institution of Washington.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

We obtained Spitzer Space Telescope Multiband Imaging Photometer for
Spitzer (MIPS) 24 micron and 70 micron observations of 183 nearby, Hipparcos F- and G-type common proper motion single and binary systems in the nearest OB association, Scorpius-Centaurus. We also obtained Magellan/MIKE R~50,000 visual spectra at 3500 - 10500 Angstrom for 181 candidate ScoCen stars in single and binary systems. Combining our MIPS observations with those of other ScoCen stars in the literature, we estimate 24 micron F+G-type disk fractions of 9/27 (33% ± 11%), 23/68 (34% ± 7%), and 22/71 (31% ± 7%) for Upper Scorpius (~10 Myr), Upper Centaurus Lupus (~15 Myr), and Lower Centaurus Crux (~17 Myr), respectively. We confirm previous IRAS and MIPS excess detections and present new discoveries of 41 proto-planetary and debris disk systems, with fractional infrared luminosities ranging from $L_{IR}/L_* = 10^{-5} - 10^{-2}$ and grain temperatures ranging from $T_{gr}$ = 40 - 300 K. We searched for an increase in 24 micron excess at an age of 15-20 Myr, consistent with the onset of debris production predicted by coagulation N-body simulations of outer planetary systems. We found such an increase around 1.5 $M_{sun}$ stars but discovered a decrease in the 24 micron excess around 1.0 $M_{sun}$stars. We additionally discovered that the 24 micron excess around 1.0 $M_{sun}$ stars is larger than predicted by self-stirred models. Finally, we found a weak anti-correlation between fractional infrared luminosity ($L_{IR}/L_*$) and chromospheric activity ($R'_{HK}$), that may be the result of differences in stellar luminosity and/or activity.

38.04

**Circumplanetary Disks Around Wide-Orbit Planets: Formation Theory, Observations, And Moon Systems**

**Megan Shabram**[1], A. Boley[1], E. Ford[1]
*[1]University of Florida.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Using radiation hydrodynamics simulations, we explore the evolution of circumplanetary disks around wide-orbit substellar companions. At large distances from the star (r ~ 100 AU), gravitational instability followed by disk fragmentation can form gas giants and/or brown dwarfs that are likely to host large, circumplanetary disks. These subdisks are not only affected by the tidal potential of the primary, but can also be gravitationally unstable, leading to nonaxisymmetric spiral structure. These spiral waves redistribute circumplanetary disk mass and can cause repeated heating events in the otherwise cold subdisk. We examine the evolutionary timescales for these circumplanetary disks, as well as the role that they play in regulating the growth of the substellar companions. In addition, we explore the effects that the resulting shock structures have on the thermal history of the gas, with application to ice grain physics, disk chemistry, and moon composition. Finally, the time scale for disk evolution affects the observability of these objects, increasing flux densities to be well within ALMA capabilities. The evolution of circumplanetary disks is fundamental to formation theories for massive planets and brown dwarfs. Moreover, large circumplanetary disks leave open the possibility for the formation of extensive moon systems, potentially including moons sufficiently massive to retain an atmosphere.

38.05

**Submm Images of the HR 8799 Debris Disk and Taurus Protoplanetary Disks**

**Jenny Patience**[1], J. Bulger[1], R. King[1], B. Ayliffe[1], M. Bate[1], I. Song[2], C. Pinte[3], J. Koda[4], D. Dowell[5], A. Kovacs[6], J. Carpenter[5], J. Monin[3]
*[1]University of Exeter, United Kingdom, [2]University of Georgia, [3]IPAG, France, [4]Stony Brook University, [5]Caltech, [6]University of Minnesota.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

With 350µm observations from the CSO, we are pursuing programs to investigate the debris disk encircling the HR 8799 planetary system and the protoplanetary disks around low mass members of Taurus, spanning the stellar/substellar limit. For the HR 8799 disk, we have measured the first spatially resolved map at 350um. The 350um map exhibits an arc of emission with a bright clump at a distance consistent with that expected from simulations of dust trapped in a 2:1 resonance with the outermost planet. The distribution and location of the dust is a powerful tool to understand the migration and eccentricity history of the planets. The submm map suggests that the planets migrated to their current locations and that the eccentricity is low, if the dust is trapped in a resonance. For the Taurus study, our sample spans the M2-M9 range. The submm data reveals the presence of outer disk material and enables an estimate of key parameters such as mass and grain growth, important parameters for assessing the viability of planet formation around these low mass objects.

38.06

**New Warm Debris Disks from WISE and Herschel**

**Deborah Padgett**[1]
*[1]Caltech and GSFC.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The Wide Field Infrared Survey Explorer (WISE) has just completed a sensitive all-sky survey in photometric bands at 3.4, 4.6, 12, and 22 microns. We report on an initial investigation of main sequence Hipparcos and Tycho catalog stars with 22 micron emission in excess of photospheric levels. This warm excess emission traces material in the circumstellar region likely to host terrestrial planets and is preferentially found in young systems with ages < 1 Gyr. Several hundred warm debris disk candidates, most of which are new,are detected among A-M stars within 120 pc. We are in the process of obtaining spectra to determine spectral types and activity level of these stars and have initiated observations with Keck, Herschel, and HST to characterize the dust, multiplicity, and substellar companions of these systems. In this contribution, we will discuss source selection methods and individual examples from among the WISE debris disk candidates, as well as the latest results from followup observations.

## 39
### *Planets Around Young Stars*
Poster
*Osprey/Grizzly*

39.01

**The Young Planet Hosting Triple System TYC 2627-638-1**

**Heidi Korhonen**[1], K. Olah[2], K. Vida[2], A. Moor[2], S. P. Jarvinen[3], A. A. Djupvik[4], I. V. Ilyin[3]
*[1]Niels Bohr Institute, Denmark, [2]Konkoly Observatory, Hungary, [3]Leibniz Institute for Astrophysics, Germany, [4]Nordic Optical Telescope, Spain.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The more than 500 currently known exoplanets have shown that planetary systems are many and varied. Still, most of these planets are found around older single stars. TYC 2627-638-1 appears to be very young, approximately 25 Myr, multiple system with a planet. The primary component of this wide binary likely hosts a substellar companion of less than five Jupiter masses, and our new observations also show that the primary has an additional red object orbiting it with about two year period, making TYC 2627-638-1 a triple system. Here, we will discuss the properties of this complex young stellar system hosting a substellar body, and present new optical and infrared observations.

39.02

**Hot Jupiters in Young Open Clusters**

**Anne Eggenberger**[1], J. Bouvier[1], I. Boisse[2], A. Lagrange[1], X. Bonfils[1], E. Moraux[1], S. Randich[3], N. Meunier[1], X. Delfosse[1]
*[1]Institut De Planétologie Et D'Astrophysique De Grenoble, France, [2]Centro de Astrofisica da Universidade do Porto, Portugal, [3]INAF - Osservatorio Astronomico di Arcetri, Italy.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

We are carrying out a Doppler search for short-period giant planets around ~100 solar-type stars in nearby open clusters aged 30-150 Myr. Finding planets around such young stars will provide unique constraints on the formation and early dynamical evolution of planetary systems. As the properties of our targets are precisely known, we can subtract the large-amplitude radial velocity signal induced by rotating spots to recover the lower-amplitude Doppler signal produced by a close-in giant planet. We present here the results of a pilot study conducted with
ESO/HARPS and OHP/SOPHIE. These results illustrate our methodology and demonstrate our ability to detect hot Jupiters around a subsample of representative targets.

39.03

**Reanalysis Of The PZ Tel System: Arguments For The Reality Of PZ Tel B To Be PZ Tel b**

**James Jenkins**[1]
*[1]Universidad De Chile, Chile.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

I will present some new analysis of the PZ Tel system, which has recently been shown to host a young companion with a mass of around 30 Jupiter-masses, along with a debris disk of around 0.3 Lunar-masses. We have reanalyzed the iron abundance of the host star using our new spectral synthesis method, and contrary to previous results, we find the star to be super metal-rich, with a metallicity ([Fe/H]) of 0.2 dex. We also find the age of the system from chromospheric activities and pre-main

sequence evolutionary models to be around 25Myrs. I will show some comparisons between the companion's bulk properties, such as broadband colours, and some of the latest evolutionary models as a function of metallicity. Finally, I will use these results to show how the companion to PZ Tel could be the first directly imaged extreme-Jovian extrasolar planet and not a low-mass brown dwarf.
I acknowledge funding by Fondecyt through grant 3110004 and partial support from Centro de Astrofisica FONDAP 15010003, the GEMINI-CONICYT FUND and from the Comite Mixto ESO-GOBIERNO DE CHILE.

## 40
### *Planetary Atmospheres*
Poster
*Osprey/Grizzly*

40.01

**Electrification Events In Mineral Clouds Of Planetary Atmospheres**

**Christiane Helling**[1], M. Jardine[1], D. Diver[2], S. Witte[3]
*[1]University of St Andrews, United Kingdom, [2]University of Glasgow, United Kingdom, [3]University Observatory Hamburg, Germany.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Planets and brown dwarfs are the only objects which habour clouds inside their atmosphere where they determine the spectral energy distribution by their feedback into the chemistry and the temperature structure, and potentially also into the atmospheric electrification. The warmer these objects are, the less likely is the formation of solar-system-like liquid clouds, instead, solid cloud particles made of silicates and oxides will form preferentially. These cloud particles are rich in chemistry and diverse in size (Helling, Woitke, Thi 2008). A convection-powered turbulent fluid field amplifies their relative velocities, and it initiates the formation of dust in elsewhere hostile parts of the atmosphere. Based on our detailed model of dust formation, we recently suggested that turbulent, mineral clouds are a source of ionisation in brown dwarf and planetary atmospheres where temperatures are too low for thermal ionisation (Helling, Jardine & Mokler 2011). This work is part of the LEAP project which studies charge processes in extrasolar planetary atmospheres.

40.02

**Ground-based Spectroscopy Of Extrasolar Planets**

**Ingo Waldmann**[1]
*[1]University College London, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

In recent years, spectroscopy of exoplanetary atmospheres has proven to be very successful. When in the past discoveries were made using space-born observatories such as Hubble and Spitzer, the observational focus continues to shift to ground-based facilities. This is especially true since the end of the Spitzer cold-phase, depleting us of a space-borne eye in the infrared. With projects like E-ELT and TMT on the horizon, this trend will only intensify.
So far several observational strategies have been employed for ground-based spectroscopy. All of which are trying to solve the problems incurred by high systematic and telluric noise and are distinct in their advantages and dis-advantages. Using time-resolved spectroscopy, we obtain an individual lightcurve per spectral channel of the instrument. The benefits of such an approach are multifold since it allows us to utilize a broad spectrum of statistical methods.
Using new IRTF data, in the K and L-bands, we will illustrate the intricacies of two spectral retrieval approaches: 1) the self-filtering and signal amplification achieved by consecutive convolutions in the frequency domain, 2) the blind de-convolution of signal from noise using non-parametric machine learning algorithms.
These novel techniques allow us to present new results on the hot-Jupiter HD189733b, showing strong methane emissions in both, K and L-bands at spectral resolutions of R ~ 170. Using data from the

IRTF/SpeX instrument, we will discuss the implications and possible theoretical models of strong methane emissions on this planet.

40.03

**Optical Transmission Photometry of Large Scale Height Planets WASP-15b and WASP-17b**

**Joao Bento**[1], P. Wheatley[1]

[1]*University of Warwick, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We present transit observations of planets with large atmospheric scale heights (WASP-15b and WASP-17b) using the high-speed multi-band photometer ULTRACAM. We used several filter combinations (both broad and narrow band) to accurately measure transit depths in the optical regime. The ongoing analysis of these data allows us to perform transmission photometry to probe the opacity sources in the atmospheres of these planets. Our choice of filter combinations is designed to detect features arising from TiO, Na or Rayleigh scattering.

40.04

**Possible Large C/O Ratio on Several Transiting Exoplanets: Photochemical Consequences and Conceivable Origin**

**Julianne I. Moses**[1], C. Visscher[2]

[1]*Space Science Institute,* [2]*Lunar and Planetary Institute.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Detailed analyses of transit and eclipse observations of extrasolar giant planets often suggest atmospheric compositions that are out of equilibrium and/or that contain a non-solar abundance of heavy elements. The departures from equilibrium are not surprising given the likely influence of transport-induced quenching of disequilibrium species on giant planets and given the large, photochemistry-inducing, ultraviolet flux incident on these close-in transiting exoplanets. What is surprising, however, is the nature of the departures from solar composition: CO typically appears to be more abundant than $H_2O$ on a wide variety of transiting exoplanets, ranging from the relatively cool GJ 436b to the warmer HD 189733b to the very hot WASP-12b. Large $CO/H_2O$ ratios are not expected from either thermochemical equilibrium or from disequilibrium chemistry in atmospheres with solar-like elemental ratios; however, they are expected for atmospheric C/O ratios that are close to 1. We use a photochemical and thermochemical kinetics and transport model to examine the influence of the atmospheric C/O ratio on the disequilibrium (and equilibrium) chemistry of the three aforementioned exoplanets. We find that the observable composition is extremely sensitive to the C/O ratio, which has some interesting consequences in relation to photochemistry and transit/eclipse observations. We discuss the implications for atmospheric composition and suggest ways in which the planets could have developed an enhanced C/O ratio during their formation and evolution. This work has been supported by the NASA Planetary Atmospheres program.

40.05

**New Chemical Models for Extrasolar Giant Planet Atmospheres, and Implications for Observations**

**Channon W. Visscher**[1], J. I. Moses[2]

[1]*Southwest Research Institute,* [2]*Space Science Institute.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We have developed one-dimensional photochemical and thermochemical kinetics and diffusion models to study the effects of disequilibrium processes such as photochemistry and transport-induced

quenching in extrasolar giant planet (EGP) atmospheres. These models transition smoothly between each chemical regime (thermochemical, transport-quench, and photochemical) and allow us to explore the effects of photochemistry and/or atmospheric transport on the vertical abundance profiles of individual atmospheric constituents. Here we will present model results for neutral H-C-N-O chemistry in the atmospheres of GJ 436b, HD 189733b, HD 209458b, and WASP-12b. We will examine the sensitivity of the model results to thermal and eddy diffusion profiles, and identify the major chemical processes affecting the abundance of potentially observable carbon, nitrogen, and oxygen species. Particular attention will be given to transport-induced quenching mechanisms, including updates to a timescale approach that can be used to estimate the abundance of quenched species in EGP atmospheres. A comparison of model results with primary transit and secondary eclipse observations will be used to discuss implications for the observational properties of EGPs. In general, our results indicate that disequilibrium processes such as photochemistry and transport-induced quenching play a larger role on cooler exoplanets than on warmer exoplanets. Disequilibrium processes are also likely to enhance the abundances of various atmospheric constituents (e.g., CH4, HCN, NH3, and C2H2) that are expected to affect the spectral and photometric behavior of extrasolar giant planets. This work is supported by the NASA Planetary Atmospheres Program.

40.06

**Atmospheric Dynamics of Wasp-12b**

**Ian Dobbs-Dixon**[1]

[1]*University of Washington.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Of all the planetary systems, Wasp-12b ranks as one of the more extreme. Orbiting its host star in just over a day and being heated to temperatures of 3600 it has been suggested that this planet is actively overflowing its Hill sphere, spilling onto its host star. I will present three-dimensional radiative hydrodynamical simulations of Wasp-12b. In particular I will discuss how including the full Roche potential (star and planet), something not necessary for most of the other known hot-Jupiter planets, significantly influences the overall dynamics of the atmosphere. The stellar gravitational force provides a counter to the well-known day-night potential difference caused by differential irradiation. This ultimately changes the flow patterns and impacts the delivery of mass to the L1 point, necessary for overflow.

40.07

**Direct Detection of Exoplanets with Polarimetry**

**Sloane Wiktorowicz**[1]

[1]*University of California, Santa Cruz.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

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 by 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. Orbital inclination, mean number of scattering events, and scattering particle index of refraction and size are

potentially discernable with polarimetry. I will report on the search for scattered light from known exoplanets using the POLISH2 polarimeter on the Lick 3-m telescope. This instrument has recently been upgraded with simultaneous full-Stokes capability and UBV filters. This polarimeter has achieved nightly precisions at the part per million level on V < 9 stars, and systematic effects have been suppressed to this level as well. The POLISH2 polarimeter is therefore ideally suited for direct detection of close-in exoplanets. This work was supported by a UC Lab Fees Research Grant, UCO/Lick Observatory, and a NExScI Sagan Fellowship.

40.08

**A Ground-based, Near-infrared, Emission Spectrum Of WASP-12b**

**Ian J. M. Crossfield**[1], B. M. S. Hansen[1], T. Barman[2]
*[1]UC Los Angeles, [2]Lowell Observatory.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

We report our measurement of the emission spectrum of the Hot Jupiter WASP-12b. We observed two secondary eclipses with SpeX on the NASA IRTF (covering the H and K bands at low resolution) and recover consistent planetary spectra from both events. We discuss our results, which are consistent with recent CFHT/WIRCam ground-based photometry but suggest a somewhat different spectral slope than inferred from those and Spitzer/IRAC data. In general, we find the ability of single-slit spectrographs to characterize exoplanet atmospheres is ultimately limited by our inability to sufficiently characterize temporal evolution of telluric and instrumental systematics. We discuss our possibilities and limitations in the context of our ongoing efforts to perform ground-based exoplanet spectroscopy, and reiterate the exciting, transformative potential of near-infrared multi-object spectrographs to revolutionize this field.

40.09

**Optical To Near-infrared Transit Observations Of Super-Earth GJ1214b: Water-world Or Mini-Neptune?**

**Matteo Brogi**[1], E. J. W. de Mooij[1], R. J. de Kok[2], J. Koppenhoefer[3], B. V. Nefs[1], I. A. G. Snellen[1], J. Greiner[3], J. Hanse[1], R. C. Heinsbroek[1], C. H. Lee[4], P. van der Werf[1]
*[1]Leiden Observatory, Netherlands, [2]SRON, Netherlands, [3]Max-Planck-Institute fur extraterrestrische Physik, Germany, [4]Universitats-Sternwarte Munchen, Germany.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

In late 2009, the discovery of the transiting 6.5 Earth-mass planet GJ1214b was announced by the MEarth team. With a mean density ~35% of that of the Earth, this planet could either be a ''mini-Neptune'', consisting of a rocky core and a thick, hydrogen-dominated atmosphere, or a water-dominated planet: in the first case, the large atmospheric scale-height may result in a detectable transmission spectrum.

We obtained ground-based observations during several transits of GJ1214b, using a range of instruments and photometric filters, and spanning from the visible to the near-infrared. By comparing the transit depth between these bands, we investigated the properties of the atmosphere.

The resulting transmission spectrum is essentially flat, except for a ~ 2 sigma positive deviation in *g*-band and a lower increase in $K_s$-band. Our data are globally consistent with the water-world scenario, although a model with a hydrogen atmosphere of sub-solar metallicity and a cloud deck - suppressing most of the spectral features - seems to be in better agreement with our measurements.

When including results from different authors, this intermediate model fits even better the transmission spectrum of GJ1214b. We recently observed two additional transits of the planet in $K_c$- and *g*-band, in

order to better assess the significance of the deviation from a flat transmission spectrum.
We finally show that a variable spot level on the surface of the parent star can significantly alter not only the average value of the transit depth, but also the slope of the transmission spectrum.

40.10
**Secondary Eclipses of Kepler Planet Candidates**
**Mercedes Lopez-Morales**[1], J. L. Coughlin[2]
*[1]CSIC-IEEC, Spain, [2]New Mexico State University.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
We present here the results of a search for optical planetary emission among the 1235 Kepler mission planet candidates reported by Borucki et al. (2011). We detect the secondary eclipses of over 15 candidates with confidence levels up to about 7-8 sigma. We summarize the parameters of the detections and derive the basic parameters of the planetary atmospheres, i.e. albedo, temperatures and energy redistribution factors based on the observed eclipse depths. We also present additional follow-up observations of some of these candidates to establish whether they are truly planetary objects or false positives.

40.11
**The Interaction of Thermal Tides with Equatorial Winds on Tidally Locked Hot Jupiters**
**Pin-Gao Gu**[1], S. Tsai[1]
*[1]Institute of Astronomy & Astrophysics, Academia Sinica, Taiwan.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
The large majority of exoplanets are gas planets exposed to strong stellar irradiation, and are likely to be tidally locked by their parent stars. Both 3D models and observations of the tidally locked gas giants have suggested the phenomena of equatorial superrotation in the atmosphere; i.e. the equatorial winds blow faster than self rotation of the planets. The phenomena have exhibited in several slow rotating planets such as Venus and Titan. Some mechanisms have been proposed to explain the equatorial superrotation. In our work, we adopt the theory first suggested by Fels and Lindzen (1974), that the equatorial superroatation on Venus results from the thermal tides pumping the momentum via vertical transport. Thermal tides are oscillations in temperature, density, pressure, and wind velocity driven by the stellar heating. The vertical structure of thermal tides is basically internal gravity waves with the phase speed equal to the apparent motion of the parent star. Thermal tides or waves generated in the stellar heating region have the effect of acceleration to the direction opposite to the stellar motion, leading to the maintenance of superrotational winds. A linear analysis is applied to HD209458b to demonstrate the superrotation formation and maintenance. Our model suggests that when the stellar heating is absorbed near the center of the equatorial jet, the superrotation can be in part explained by thermal tides, which provide the momentum redistribution between different altitudes of the atmosphere. This work is supported by the NSC grant in Taiwan through NSC 98-2112-M-001-011-MY2.

40.12
**Application of the VSTAR Code for Modeling of Spectra and Polarization Curves of Hot Jupiters**
**Lucyna Kedziora-Chudczer**[1], J. Bailey[1]
*[1]University of New South Wales, Australia.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
The Versatile Software for Transfer of Atmospheric Radiation (VSTAR) code is a portable and versatile package, which solves the radiative transfer problem for a plane-parallel atmosphere with the line-by-

line treatment of molecular and atomic absorption. The code has a modular structure, which allows treatment of spectral line absorption using a database of more than 1.6 billion spectral lines. It includes full treatment of scattering processes and radiative transfer solvers. VSTAR package can be used to model hot and cool atmospheres of planets, brown dwarfs and cool stars.
We present examples of the application of VSTAR to model spectra and polarization curves as a function of phase angle for hot-Jupiter type exoplanets.

40.13

**Temperature-Pressure Profile In The Upper Atmosphere Of HD 189733b: Detection Of The Thermosphere**

**Catherine Huitson**[1], D. K. Sing[1], A. Vidal-Madjar[2], A. Lecavelier des Etangs[2], G. E. Ballester[3], J. Desert[4], F. Pont[1]
*[1]University of Exeter, United Kingdom, [2]CNRS, Institut d'Astrophysique de Paris, France, [3]University of Arizona, [4]Harvard-Smithsonian Center for Astrophysics.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

We present transmission spectra of the hot-Jupiter HD 189733b taken with STIS aboard the Hubble Space Telescope. The spectra cover the wavelength range 5808 - 6300 Å with resolving power R = 5000. We detect the Na I line within the exoplanet's atmosphere at the 10 σ confidence level with a 5 Å band of absorption (0.094 ± 0.0095 %) and use the data to measure the line absorption profile. We see only the narrow core of the line, with width < 45 Å, which could be due either to an obscuring high-altitude haze or a significantly sub-solar sodium abundance. We also observe that the effects of starspots on the absorption depths and profile are within errors in the sodium feature.
We use the absorption profile to probe the vertical structure of the upper atmosphere over approximately 7 scale heights. By comparing with model absorption profiles, we constrain the temperature at each atmospheric scale height, thus allowing us to construct a vertical temperature profile. We identify three temperature regimes clearly above the broadband Rayleigh signature; an 800±200 K region at 475-700 km, a 1300±300 K region at 700-925 km and a 2500±500 K region at 925-2215 km. We measure a white light radius of Rp/Rstar (z=0) = 0.15628. The temperature rises with higher altitudes, indicating an inversion characteristic of a thermosphere.
The absolute pressure scale depends on the species responsible for the Rayleigh signature and its abundance. We discuss plausible scenarios for this species and the atmospheric T-P profiles that result. We compare the sodium absorption depth with a solar abundance model and a feature at 8 microns, assuming this is water, and find that we cannot constrain the sodium abundance. However, a higher than solar sodium to water abundance ratio suggests that a super-solar abundance is likely.

40.14

**Evaporation of Extrasolar Planets**

**Alain Lecavelier**[1]
*[1]IAP-CNRS, France.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Among the five hundreds extrasolar planets known, almost 30% orbit closer than 0.1 AU from their parent star. We will review the observations and the corresponding models of the evaporation of these "Hot-exoplanets".
The observations started with the discovery made with HST that the planet orbiting HD209458 has an extended atmosphere of escaping hydrogen. Subsequent observations obtained with STIS and ACS and most recently with COS confirm the escape of the gas. And, even more, atomic oxygen, ionized carbon

and silicon have been shown to be present at very high altitude in the upper atmosphere. Observations of other targets like HD189733b and Wasp-12 show that evaporation is a general phenomenon which could contribute to the evolution of planets orbiting close to their parent stars.
To interpret these observations, we developed models to quantify the escape rate from the measured occultation depths. Numerous models have also been published to investigate mechanisms which can lead to the estimated escape rate. In general, the high temperature of the upper atmosphere heated by the far and extreme UV combined with the tidal forces allow a very efficient evaporation of the upper atmosphere.
We will review the different models and their implications, in particular in the light of the new Kepler results.
Finally we will also present the latest observations of the gas escaping HD189833b. These observations have been obtained with the repaired HST/STIS.

40.15

**Characterising the WASP Planets with Infrared Occultation Measurements: Latest Results**

**Alexis Smith**[1], WASP consortium
*[1]Keele University, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

When a transiting planet is occulted by its host star, we are able to detect the emergent flux from the planet. Combining the timing of such occultations 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 the efficiency of the heat redistribution 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.
We have recently published Spitzer occultations of WASP-17b, which enabled the orbital eccentricity to be precisely determined, in turn allowing us to confirm the anomalously large planetary radius of 2.0 Jupiter radii. Another recently published result is a ground-based occultation of WASP-33b, which revealed it to be the hottest known exoplanet, with a brightness temperature of 3620 ± 225 K. I will present the latest results from our ongoing programme to measure the occultations of the WASP planets from both the ground and from space.

40.16

**The Atmospheres and Evolution of Young Brown Dwarf/Planetary-Mass Companions**

**Robert King**[1], J. Patience[1], R. De Rosa[1], S. Witte[2], C. Helling[3], E. Rice[4], T. Barman[5], C. Marois[6]
*[1]University of Exeter, United Kingdom, [2]Hamburger Sternwarte, Germany, [3]University of St Andrews, United Kingdom, [4]American Museum of Natural History, [5]Lowell Observatory, [6]Herzberg Institute of Astrophysics, Canada.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

We present VLT\SINFONI JHK spectra of a set of young, low-mass brown dwarf and planetary-mass companions and a comparison with more evolved substellar companions and several theoretical model atmospheres. In the study of cool atmospheres, these low-mass companions to nearby young stars are particularly valuable since the primary provides constraints on the distance to and age of these low-mass objects, breaking the mass-age-luminosity degeneracy. Our sample consists of the lowest mass imaged companions with ages of 2-30 Myr and estimated masses of 5-25 MJup. These companions represent the lowest mass objects in the 2-30 Myr age range for which it is possible to obtain high

quality infrared spectra. A particularly interesting member of the sample is 2M1207b, a young L dwarf with an anomalously low luminosity. We explore possible scenarios to explain its observed spectrum.

40.17

**Spitzer Spectroscopy of Exoplanets Re-visited**

**Kamen 0. Todorov**[1], D. Deming[2], C. Grillmair[3]

*[1]Pennsylvania State University, [2]University of Maryland, [3]Spitzer Science Center/California Institute of Technology.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

In recent years, the Spitzer Space telescope observed thermal emission spectra of two hot Jupiter exoplanets, HD189733b and HD209458b, at wavelengths from 5 to approximately 14 microns. Those spectra were acquired using the IRS instrument, at a spectral resolving power of approximately 100. We report progress on a re-analysis of all the Spitzer IRS data for both planets, including some data not previously published. Our analysis exploits the recently improved understanding of instrument and detector effects, such as using a double-exponential function to account for the ramp effect at the longest wavelengths. There is much recent interest in future exoplanet spectroscopy using JWST, and our work is aimed at improving extant methodology for transit and eclipse spectroscopy of extrasolar planets in the thermal infrared.

40.18

**Search For Molecules In The Atmospheres Of Non-transiting Planets**

**Florian Rodler**[1]

*[1]IEEC-CSIC, Barcelona, Spain.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The study of exoplanets is one of the most vibrant and exciting fields in modern astronomy. In the past decade-and-a-half, over 550 exoplanets have been discovered. This has led to an increasing interest in the physical characterization of these objects. As result of those characterization efforts, several chemicals have thus far been detected in the atmospheres of a few planets by means of high-precision photometry and spectroscopy. However, those detections have been only made in transiting planets so far.

In our project which we present here, we go a step further: We are interested to measure the molecules CO and K in the atmosphere of non-transiting hot Jupiters by means of high resolution spectroscopy at near infrared wavelengths. The detection of these molecules in the planetary atmosphere does not only allow us to test theoretical models, but also enables us to directly measure the orbital inclination of the planetary system, and therefore the exact mass of the planet.

In this contribution, we will outline the strategy of our project and present preliminary results of the data analysis.

40.19

**Developments in Transmission Spectroscopy**

**Patricia Wood**[1], P. Maxted[1]

*[1]Keele University, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Transmission spectroscopy is a comparison of spectra taken during transit to spectra outside of transit. Light from the star passes through the atmosphere of the planet during transit, and some wavelengths are reduced in flux due to opacity

sources in the atmosphere. These measurements contain information about the structure and composition of the atmosphere; measurements at the narrowest bandwidths probe the highest parts of the
atmosphere, and measurements at wider bandwidths probe the lower atmosphere. Atmospheres of hot Jupiter exoplanets strongly absorb sodium (Na) at 589.0 and 589.6 nm.
The interpretation of transmission spectroscopy for very narrow bandwidths must account for Doppler shifts due to the orbit of the planet and the
rotation of the star. We have developed a numerical model using IDL which predicts the changing shape of the Na absorption lines during the transit,
due to the rotation of the star - the Rossiter-McLaughlin (RM) effect. The model is called Sodium WASP (Wide Angle Search for Planets) Atmospheric Rossiter Model - SWARM. Parameters are input, and SWARM calculates orbital elements and the RM effect for the times of a set of proposed observations including a transit, and the corresponding change in shape of the Na lines. The output of SWARM is a set of synthetic spectra which include the effects of the planetary absorption signal.
These can be used in various ways. For each planetary system, the Na transit depth can be measured; the planet's orbit, and the planetary absorption signal can be plotted; and the radial velocity shifts of the altered spectra can also be measured, and the RM curve calculated and plotted. A greyscale plot clearly shows the planetary Na absorption in WASP-17b, and the calculated RM curve reproduces that obtained from observations.
PLW is supported by a Science and Technology Facilities Council postgraduate studentship.

40.20

**The Major Role of Minor Condensates in Metal-Rich Exoplanetary Atmospheres**

**Caroline Morley**[1], J. Fortney[1], M. Marley[2]
*[1]UC Santa Cruz, [2]NASA Ames Research Center.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

The formation of clouds in exoplanet atmospheres significantly changes their observable properties. Published models of warm planetary atmospheres have included the most important condensates expected to be found in observed exoplanets, which are iron clouds and silicate clouds. However, these are not the only condensates expected to form at these temperatures and pressures. I will present results from a series of 1D models of planetary atmospheres that include not only iron and silicate clouds, but also collections of condensates that have previously been ignored. These clouds will include condensates such as potassium chloride, chromium, manganese sulfide, sodium sulfide, and zinc sulfide. These clouds should be most prominent at low surface gravity, strongly super-solar atmospheric abundances, and at the slant viewing geometry appropriate for transits. Observational implications for transmission spectra of transiting planets and direct imaging observations of young Jupiters will be presented.

40.21

**Studying Atmospheres Of Exoplanets With The VLT: Near IR Eclipses Of WASP-17b And WASP-18b**

**Leslie Hebb**[1], Y. Gomez Maqueo Chew[2], M. Gillon[3]
*[1]Vanderbilt University, [2]Queen's University, Belfast, United Kingdom, [3]University of Liege, Belgium.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Secondary eclipse measurements of a transiting planet obtained when the planet is occulted by its host star provide important information about the thermal emission of the planet itself. Studies of the planet's atmosphere is possible when such eclipse observations are made over a range of wavelengths.

In addition, the eclipse timing is useful for determining the orbital eccentricity of the system which is a key parameter in understanding the tidal history and internal energy budget of the planet. Here, we present new H and K-band observations of the secondary eclipses of two unique transiting planets, WASP-17b and WASP-18b. These data were obtained with the HAWK-1 instrument on the VLT and are part of a larger program to obtain ground based, near IR eclipses of a large number of transiting planets.

40.22

**Atmospheric Chemistry in Extrasolar Giant Planets or The Cosmic Shoreline**

**Kevin Zahnle**[1]

[1]*NASA Ames Research Center.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Title: Atmospheric Chemistry in Extrasolar Giant Planets.

Metallicity and C/O ratio are potential observables in spectra of EGPs. Both address the mode of planetary formation. Metallicity reveals itself best in molecules composed of more than one “metal” atom, such as CO2. C/O ratio is more complicated.

There are parallels between the chemistry generated by 1994’s SL9 impacts on Jupiter and the chemistry of EGPs. In both, a hot gas quenches by cooling and rarefaction. In SL9, the impact-heated gas exploded, expanded, and cooled. In EGPs, quenching is a consequence of vertical mixing. Products of SL9 included S2, CS2, HCN, C2H4, CO, CO2, and carbonaceous hazes. All of these might be expected in EGPs. Close-in planets differ from SL9 in the photochemical consequences of stellar UV. Primary photolysis of H2S, NH3, and H2O creates free radicals that react with H2 to make atomic H. Abundant H attacks CH4 and promotes formation of C2H2 and HCN, which readily polymerize to make hazes. It is likely that such a haze is observed in HD 189733b.

Title: Cosmic Shoreline.

Volatile escape is the classic existential problem of planetary atmospheres. The problem has gained new currency now that we can begin to study escape, or the cumulative effects of escape, from extrasolar planets seen in transit. Already some intriguing patterns have emerged. In particular, transiting EGPs appear to fit a pattern seen in our own Solar System. The data show that atmospheres are found where escape velocity is high and (i) solar heating is low or (ii) impact velocities are low. In either case, the boundary between planets with and without atmospheres --- the cosmic shoreline, as it were --- is a simple power law that extends from Pluto to Jupiters and beyond.

40.23

**Hot Jupiter Magnetospheres**

**George Trammell**[1], P. Arras[1], Z. Li[1]

[1]*University of Virginia.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Transmission spectra from ground and space-based observations are probing several close-in gas giant exoplanet upper atmospheres. Due to strong heating and high expected ionization levels, the planetary magnetic field plays a fundamental role in the gas dynamics. We present numerical MHD simulations of upper atmosphere structure, including the intrinsic planetary magnetic field and the stellar tide. In addition to a magnetically-confined region near the equator and an outflow at mid-latitudes, magnetically-dominated region that supports an outflow, there is a third region near the poles where an outflow can be quenched by a sufficiently strong stellar tide. We demonstrate the effects of the magnetic field and stellar tide on the optical depth and velocity structure, as well as the resulting mass and angular momentum loss rates. Model Lyman α transmission spectra are computed from the simulations and compared with the Hubble observations, in order to provide constraints on the atmospheric structure.

40.24

**A Comparative Study of the Atmospheres of Transiting Exoplanets**

**Kaspar von Braun**[1], J. E. Krick[1], J. Ingalls[1], S. Carey[1], S. R. Kane[1], D. R. Ciardi[1], H. Knutson[2], C. J. Grillmair[1], P. Plavchan[1], H. Schlichting[3], D. M. Gelino[1], C. Gelino[1], G. T. van Belle[4], A. Burrows[5]

*[1]Caltech, [2]UC Berkeley, [3]UCLA, [4]Lowell Observatory, [5]Princeton University.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Spitzer's extended warm mission gives us the opportunity to perform comparative studies of exoplanets' atmospheres. We describe the techniques and methods involved in our recently accepted Spitzer Exploration Science Proposal (Proposal ID 80016; PI: J. Krick; 619 hours) to obtain high-precision 4.5 micron phase curves for 22 transiting hot Jupiter systems, along with observations of secondary eclipses of 7 of these systems. The principal goal of this study, which will quadruple the number of phase curve observations to date, is to map longitudinal temperature distribution of the planetary atmospheres and to assess the following questions: (1) What is the contrast between exoplanetary day− and nightside temperatures, i. e., how efficiently is the incident energy redistributed? (2) Are the weather phenomena in the exoplanetary atmospheres stable over long periods of time? (3) How do the temperature distributions on the planetary surfaces correlate with astrophysical properties of the star−planet systems? To answer these questions with our proposed Spitzer observations, we will employ a novel observing technique involving snapshot observing to reduce telescope time requirements, and PCRS peak−up to IRAC to increase the pointing accuracy and thus minimize the photometric error due to intrapixel sensitivity variation.

40.25

**Observations of Heterogeneous Clouds and Weather in Substellar Atmospheres**

**Jacqueline Radigan**[1], R. Jayawardhana[1], D. Lafreniere[2], E. Artigau[2]

*[1]University of Toronto, Canada, [2]Universite de Montreal, Canada.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Atmospheres of cool brown dwarfs and gas giant planets share important similarities such as low temperatures, a rich molecular chemistry, condensate clouds, and rapid rotation. The combination of condensate clouds and rapid rotation has long motivated searches for weather phenomena on cool brown dwarfs. However, until recently, observations have failed to show compelling evidence for heterogeneous cloud features or giant storms that are commonplace within our own Solar System. Here we describe the most comprehensive variability survey of cool brown dwarfs to date. Our J-band search has targeted ~50 isolated brown dwarfs over 60 nights at the DuPont 2.5-m telescope at Las Campanas with high cadence, high-precision photometric sequences, and is complemented by follow-up observations in additional bands in order to characterize the nature of the variations. Our data suggest that heterogeneous cloud features are responsible for variability (in one case as large as 30%) in a subset of partially cloudy brown dwarfs. Our results highlight the limitations of current 1D model atmospheres for brown dwarfs and extrasolar giant planets, and can be used to inform higher-dimensional modeling. In addition, variable brown dwarfs may provide a means of mapping winds and weather in ultracool atmospheres, thereby providing an empirical anchor for atmospheric circulation models in a new (non-irradiated, higher mass, rapidly rotating) physical regime.

40.26

**Revisiting HST/COS Transit Observations in the FUV of Hot Jupiters**

**Gilda E. Ballester**[1], L. Ben-Jaffel[2]
*[1]Univ. Of Arizona, [2]Institute d'Astrophysique de Paris, France.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
One transit of the hot Jupiter HD 209458b was observed in the FUV with the COS instrument using the G130M grating by Linsky et al. (Ap. J., 717, 1291, 2010). The data were averaged over the single HST orbit, and then contrasted against an average spectrum of the star obtained at different dates (with the planet off-transit). A positive detection of absorption (7.8% +/- 1.3%) by extended CII ions (at 1335 Ang) was reported confirming that from previous HST/STIS observations (7.8% +/- 3.5%; Vidal-Madjar et al., Ap. J. 604, L69, 2004; 7.4% +/- 4.7% Ben-Jaffel and Hosseini (Ap. J., 709, 1289, 2010) and showing absorption excess in the blue line-wings, indicative of a tail of escaping C+ ions. Linsky et al. also reported a positive detection of Si III ions (8.2% +/- 1.4% at 1206 Ang). In contrast, the previous STIS observations did not show a transit absorption signature in Si III (1206 Ang), and, furthermore, they showed variations at the few percent level in both the C II and Si III stellar emissions. The transit results of Linsky et al. could thus be associated with stellar variation. Here, we will use the time-tagging of the COS data to determine the true transit absorption signature by resolving mid-transit against egress behavior (transit light curves) sampled during the HST orbit. We will also evaluate a COS G130M observations of HD 189733 which, unfortunately, only covered the egress portion of its hot Jupiter transit (as well as consecutive HST orbits off-transit). We will search for any egress signature, and we will evaluate the COS capability to measure exoplanet transit signatures in OI 1304 Ang against the geocoronal 1304 Ang background that varies along the HST orbit.
GEB is funded by StScI thru HST-GO-11673-01.A

40.27

**A Bayesian Approach to Quantify Molecular Abundances in Atmospheres of Transiting Super-Earths**

**Bjoern Benneke**[1], S. Seager[1]
*[1]MIT.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
With the first spectral observations of potentially terrestrial planets, a need has arisen for methods to rigorously analyze such observations to characterize the planets' atmospheres. Due to the complexity of the formation and evolution of super-Earth atmospheres, their compositions cannot be constrained a priori, suggesting that self-consistent modeling of super-Earth atmospheres for observational analysis is impractical. Here we present a novel retrieval method based on Bayesian inference that enables us to quantify molecular abundances in the atmosphere of transiting terrestrial exoplanets solely based on observations. We demonstrate the capability of the retrieval method for future observations by applying it to virtual observations of plausible scenarios for planets transiting nearby M-stars. By using the method in this way we obtain a predictive tool to assess the scientific potential for future observations. For representative scenarios, we show which atmospheric properties and quantitative constraints on molecular abundances can be found from spectral transit observations.

## 41
### *Future Missions and Instrumentation*
Poster
*Osprey/Grizzly*

41.01

**The Gaia Astrometric Survey of Nearby M Dwarfs: A Treasure Trove for Exoplanet Astrophysics**

**Alessandro Sozzetti**[1], P. Giacobbe[2], M. G. Lattanzi[1], G. Micela[3], G. Tinetti[4]
*[1]INAF - Osservatorio Astronomico di Torino, Italy, [2]University of Trieste, Italy, [3]INAF - Osservatorio Astronomico di Palermo, Italy, [4]University College London, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

Cool, nearby M dwarfs within a few tens of parsecs from the Sun are becoming the focus of dedicated experiments in the realm of exoplanets astrophysics. This is due to the shift in theoretical paradigms in light of new observations, and to the improved understanding of the observational opportunities for planet detection and characterization provided by this sample.
Gaia, in its all-sky survey, will deliver precision astrometry for a magnitude-limited (V=20) sample of M dwarfs, providing an inventory of cool nearby stars with a much higher degree of completeness (particularly for late sub-types) with respect to currently available catalogs.
We gauge the Gaia potential for precision astrometry of exoplanets orbiting a sample of already known dM stars within 30 pc from the Sun, carefully selected based on cross-correlation among catalogs in the literature (e.g., Lepine, PMSU). We express Gaia sensitivity thresholds as a function of system parameters and in view of the latest mission profile, including the most up-to-date astrometric error model. The simulations also provide insight on the capability of high-precision astrometry to reconstruct the underlying orbital elements and mass distributions of the generated companions. These results will help in evaluating the complete expected Gaia planet population around late-type stars.
We investigate the synergy between the Gaia data on nearby M dwarfs and other ground-based and space-borne programs for planet detection and characterization, with a particular focus on: a) the improvements in the determination of transiting planet parameters thanks to the exquisitely precise stellar distances determined by Gaia; b) the betterment in orbit modeling when Gaia astrometry and precision radial-velocities are available for the same targets; and c) the ability of Gaia to carefully predict the ephemerides of (transiting and non-transiting) planets around M stars, for spectroscopic characterization of their atmospheres with dedicated observatories in space, such as EChO.

41.02

**Status of the Integral Field Spectrograph for the Gemini Planet Imager**

**Jeffrey K. Chilcote**[1], J. E. Larkin[1], R. Doyon[2], M. P. Fitzgerald[1], J. R. Graham[3], B. A. Macintosh[4], D. W. Palmer[4], M. D. Perrin[5], L. Saddlemyer[6]
*[1]UC Los Angeles, [2]Universite de Montreal, Canada, [3]University of Toronto, Canada, [4]Lawrence Livermore National Laboratory, [5]Space Telescope Science Institute, [6]Herzberg Institute of Astrophysics, Canada.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*

We present the status of the construction, testing and characterization of the Integral Field Spectrograph (IFS) for the Gemini Planet Imager (GPI). GPI is a facility class instrument for the Gemini Observatory led by Bruce Macintosh at LLNL and involving eight institutions. The UCLA Infrared Lab is currently involved with the construction and testing of the IFS. 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. 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. A cryogenic Wollaston prism can be inserted into the reimaging optic path to produce two images of orthogonal polarization states. We present the most current results from in-lab system tests of performance and characterization.

41.03

**A Portable Ultra-Stable Calibration Source for Precision RV Measurements in NIR**

**Ji Wang**[1], J. Ge[1], X. Wan[1], A. Delgado[1], H. Jakeman[1]
[1]*University of Florida.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

In the next decade, astronomers are aiming at reaching ~0.1 m/s RV precision, which will enable discoveries of Earth-like planets around solar-type stars. However, the RV precision is currently limited by stellar activity, the stability and bandwidth of RV calibration sources. We proposed to use an ultra-stable monolithic Michelson interferometer as an RV calibration source. This monolithic interferometer source has several advantages over the conventional RV calibration sources: (1), it produces sinusoidal spectral features which can be easily processed, unlike gas absorption cells or emission lamps, which spectral line distributions are extremely nonuniform; (2), it has a wide spectral coverage from visible to near infrared (NIR); (3), it is designed to be thermal-stable (thermally compensated) so that the thermal induced RV drift is very small; (4), it is also field compensated to ensure a high optical efficiency so that a spatially incoherent continuum light source is suitable for producing bright calibration light (unlike the faint ThAr emission lamp); (5). it is extremely compact (~10x10x10 cm3) and low cost compared to the bulky (more than 1x1x1 m3) and extremely high cost laser frequency combs. With the help of the proposed RV calibration source, the search of exoplanets around M dwarfs or even L, T dwarfs can be extended to the NIR band. The predicted sub m/s RV calibration precision will enable the discovery of Earth-like planets in the habitable zone around M dwarfs. The proposed calibration source may be quite useful for calibrating future space instruments for possible space RV exoplanet searches in the IR region where RV measurements are free of contamination of the Earth's telluric lines, which is a serious issue for ground-based IR RV observations. We will present our latest results of the calibration source on its application for both Echelle spectrograph and the instrument adopting DFDI method.

41.04

**Fiber Scrambling for Extreme Doppler Precision**

**Julien Spronck**[1], Z. Kaplan[1], D. Fischer[1]
[1]*Yale University.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The detection of Earth-like exoplanets with the radial velocity method requires extreme Doppler precision and long-term stability in order to measure tiny reflex velocities in the host star. Recent planet searches have led to the detection of so called “super-Earths” (up to a few Earth masses) that induce radial velocity changes of about 1 m/s. However, the detection of true Earth analogs requires a precision of 10 cm/s. One of the factors limiting Doppler precision is variation in the Point Spread Function (PSF) from observation to observation due to changes in the illumination of the slit and spectrograph optics. Thus, this stability has become a focus of current instrumentation work. Fiber optics have been used since the 1980’s to couple telescopes to high-precision spectrographs, initially for simpler mechanical design and control. However, fiber optics are also naturally efficient scramblers. Scrambling refers to a fiber’s ability to produce an output beam independent of input. Our research is focused on understanding the scrambling properties of fibers with different geometries (circular, square,

octagonal), different lengths and fiber sizes. Another important parameter when it comes to fibers is the so-called focal ratio degradation (FRD), which accounts for a different (faster) focal ratio after the fiber than the one sent into the fiber. In this paper, we will present new insight on fiber scrambling, FRD and what we call fiber personality, which describes differing behaviors for supposedly identical fiber.

41.05

**EChO - the Exoplanet Characterisation Observatory**

**Giovanna Tinetti**[1], EChO team

[1]*University College London, United Kingdom.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The science of extra-solar planets is one of the most rapidly changing areas of astrophysics and since 1995 the number of planets known has increased by almost two orders of magnitude. A combination of ground-based surveys and ded-icated space missions has resulted in 540-plus planets being detected, and over 1200 that await confirmation. NASA’s Kepler mission has opened up the possibility of discovering Earth-like planets in the habitable zone around some of the 100,000 stars it is surveying during its 3 to 4-year lifetime. The new Gaia mission is expected to discover thousands of new planets around stars within 200 parsecs of the Sun. Yet among the exoplanets detected or proposed, so far there is actually little resemblance to the morphology of the Solar System.

The key challenge now is moving on from discovery, important though that remains, to characterisation: what are these planets actually like, and why are they as they are?

In the past ten years, we have learned how to obtain the first spectra of exoplanets using transit transmission and emission spectroscopy. With the high stability of Spitzer, Hubble, and large ground-based telescopes the spectra of bright close-in massive planets can be obtained and species like water vapour, methane, carbon monoxide and dioxide have been detected.

The Exoplanet Characterisation Observatory, EChO, will be a dedicated mission to investigate the physics and chemistry of exoplanetary atmospheres. EChO has been selected by the European Space Agency to be assessed as one of four M3 mission candidates. By characterising spectroscopically more bodies in different environments we will take detailed planetology out of the Solar System and into the Galaxy as a whole.

41.06

**Detectability of Earth-mass planets with RV and astrometric technics around Sun-like stars**

**Katrien De Bondt**[1]

[1]*IPAG, France.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We present the results of detailed simulations of the RV and astrometric signals expected from the Sun, when taking into account its activity (spots, plages, convection). To do so, we considered all structures (2,000,000) identified on the Sun surface over a full cycle. We show that the Sun activity would prevent the detection of the Earth (and Earth-mass planets in the Habitable Zone) with RV technics with today or forthcoming instruments, mainly because of convection. Concerning the astrometric technic, though, the detectability around Sun-like stars is governed by the instrumental precision rather than the activity. Therefore, he activity-induced astrometric signal is much less important than the RV one for an Earth-like planet detection.

## 42
### *Habitability*
Poster
*Osprey/Grizzly*

42.01

**Habitable Zone of Land Planets; 1-D EBM with t Transportation of Surface Liquid Water**

**Yuya Takao**[1], H. Genda[1], T. Kodama[1], Y. Abe[1]
[1]*University of Tokyo, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Abe et al. (2011) investigated climates on planets with a very small amount of water on their surface (called 'land planets'). The notable feature of land planets is local balance between precipitation and evaporation. They, using GCM (General Circulation Model), have shown that liquid water is localized on high latitudes, while low latitudes are dried up. As a result, the value for incoming radiation by which liquid water on a land planet is completely evaporated (called the 'complete evaporation limit') corresponds to 170% of the incident solar flux that the present earth receives, which is substantially larger than that of a planet that is globally covered with ocean (122%, Nakajima et al. (1992)).
The key for land planets to have large value for complete evaporation limit is the localization of liquid water on high latitudes. Their GCM, however, does not include transportation of liquid water on surface, which may disturb water localization.
In order to investigate the influence of transportation of surface water on the complete evaporation limit for land planets, we develop the 1-D EBM (Energy Balance Model) including transportation of surface liquid water, which is given in forms of diffusion. As a result, we find that the complete evaporation limit is 122% of the incident solar flux when liquid water on planetary surface is transported very efficiently (one tenth as efficient as water vapor transportation in the atmosphere). This value is the same one as the complete evaporation limit for planets globally covered with ocean. On the other hand, when liquid water on the surface is not transported so efficiently (one five hundreds as efficient as water vapor transportation), water localization takes place and the complete evaporation limit of our model is about 140-150% of the incident solar flux, depending on the water content of the planet.

42.02

**Inner Edge of Habitable Zone; Evolution from Aqua Planets to Land Planets by Water Loss**

**Takanori Kodama**[1], H. Genda[1], Y. Abe[1], K. J. Zahnle[2]
[1]*The University of Tokyo, Japan,* [2]*NASA Ames Research Center.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Habitable zone (HZ) has been defined as the region from the central star where liquid water is stable in the planetary surface. Kasting et al. (1993) has estimated the width of HZ around various types of the main sequence stars for the Earth-like planets (called 'aqua planet'). In the results, they estimated HZ; 90% - 110% of the present solar radiation at 1 AU.
Abe et al. (2011) has considered a hypothetical planet with very small amount of water (called 'land planet'). Using the GCM (General Circulation Model), they found that HZ for a land planet is located between 77% and 170% of the present solar radiation at 1AU, which means that HZ for a land planet is about three times wider than that for an aqua planet.
Therefore, the amount of water on the planetary surface is important for the width of HZ. We focus on long term processes of water escape. If the water is efficiently lost during stellar age, there is a

possibility that an aqua planet changes to a land planet which means that the HZ becomes wider. In this case, the aqua planet inside or outside of HZ would become habitable planets as a land planet.
On a hypothetical planet with various initial water contents and distances from central star, we calculate the evolution of water content on the planet and discuss planetary states by considering the hydrodynamic escape of water and star evolutions. In our results, in case of solar type stellar and a planet that initially possesses about 0.1ocean masses, planets change from the mode of aqua planet to the mode of land planet at about 0.7 AU. Our study demonstrates the possibility of the various types of habitable planets, which will be observed in the future.

42.03

**Carbon Cycle and Long-Term Evolution of Climate for a Globally Ocean-Covered Planet**

**Hidenori Genda**[1], R. Kimura[1], Y. Abe[1], E. Tajika[1]
[1]*The University of Tokyo, Japan.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

Carbon cycle is important for considering the long-term stability of climate of a planet. For the Earth, as the surface temperature rises, continental weathering is enhanced, which causes consumption of atmospheric CO2 and then results in decrease of the surface temperature. This negative feedback called Walker feedback works on a planet with plate techtonics and continents, and stabilizes its climate over the long term.
There may be wide variety of the amount of the ocean on extrasolar terrestrial planets. If the amount of water on the Earth increased by five times, the Earth's surface would be completely covered by the ocean. Since the mass of the ocean on the present Earth is tiny (0.023wt%) compared to the Earth's mass, a lot of exoplanets with globally covered ocean will be found.
According to the preliminary carbon cycle model, the surface temperature of the planet with very small fraction of continental area (1%) is maintained to be much higher (about 80 degrees Celsius) than that of the Earth, because surface weathering is suppressed and effective burial of carbonate does not work. In order to consider a globally ocean-covered planet, we further develop a carbon cycle model with weathering of oceanic crust in the hydrothermal system and thermal evolution of the planet. We discuss the long-term stability and habitability of the globally ocean-covered planet with various sizes from mini Earths to super Earths.

42.04

**Seeding of Life on Moons of the Outer Planets**

**Rachel Worth**[1], S. Sigurdsson[1], C. House[1]
[1]*The Pennsylvania State University.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

We explore the possibility that life on the potentially habitable moons in the outer Solar System could have been seeded by transfer of meteorite ejecta from Earth or Mars. It has been shown that bacterial spores can remain viable for some time in the vacuum of space, and it is hypothesized that if embedded in rock, they may survive long enough to reach other parts of the Solar System through orbital perturbations. We use numerical N-body simulations to study the ejection of low mass bodies from the inner planets. We follow the orbits of the ejecta for long times to determine the probability that they may arrive at, and impact, the outer moons most interesting from a habitability standpoint, such as Europa.

## 43
### *Theory*
Poster
*Osprey/Grizzly*

43.01
**Extremely Inflated Hot Jupiters Could Be Extremely Young**
**Eduardo L. Martin**[1], Henk Spruit, Ramarao Tata
[1]*INTA-CSIC Centro de Astrobiologia, Spain.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Extremely inflated hot Jupiters could have formed recently from the merger of two low-mass stars. The frequency of W~UMa stars is not enough to account for many inflated hot Jupiters, so low mass detached binaries could also contribute to the progenitor population. We find that the degree of inflation of the transiting hot Jupiters correlates with their expected spiral-in life time by tidal dissipation, and this could be an indication of youth if the Q dissipation parameter is sufficiently low, as suggested by the studies of the Jupiter-Io system. There is also a correlation between radius anomaly and host star rotational velocity as expected in the merger scenario. The distribution of rotational velocities among the host stars is statistically similar to that of blue stragglers in the globular cluster 47 Tuc. A significant challenge to the binary merger hypothesis is the efficient angular momentum loss required to explain the slow rotation of some inflated hot Jupiter host stars. As observational tests we point out that if hot Jupiters are mainly formed as a result of binary mergers, the frequency of this kind of planets should be higher around blue stragglers than around T Tauri stars. The presenter is supported by funding from the Spanish Ministry of Science and Technology and the ROPACS European training network.

**44**
***Observational***
Poster
*Osprey/Grizzly*

44.01
**A Comparative Test of Metallicity Calibrations for M dwarfs**
**Vasco Neves**[1], X. Bonfils[2], N. C. Santos[1]
*[1]CAUP, Portugal, [2]IPAG, France.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
The determination of the stellar parameters of M dwarfs is of prime importance in the fields of galactic, stellar and planetary astronomy. M stars are the least studied galactic component regarding their fundamental parameters. Yet, they are the most numerous stars in the galaxy and contribute to more than half of its total (baryonic) mass. In particular, we are interested in their metallicity in order to study the star-planet connection and to refine the planetary parameters. Here we present a comparative test of five metallicity calibrations of M dwarfs proposed in the literature. Our test sample is made of 22 M dwarfs, companion of widely separated (> 5 arcsec) F-, G- or K- dwarfs with known or newly measured metallicity. We included M dwarfs with reliable V photometry only by restricting our sample to stars with V uncertainty lower than ~0.02 dex. Among all calibrations, we find that Schlaufman & Laughlin (2010) provides a lower offset and residuals against our sample and, ultimately, we used that larger sample to update and marginally improve their calibration. Despite better V photometry than used in previous studies the dispersion remains largely in excess given [Fe/H] and photometric uncertainties, suggesting it has physical roots. Finally, we also present preliminary work on a new, high-precision spectroscopic calibration involving the direct measurement of high-resolution spectra of M dwarfs.
This work is supported by the European Research Council/European Community under the FP7 through Starting Grant agreement number 239953. NCS also acknowledges the support from Fundacão para a Ciência e a Tecnologia (FCT) through program Ciência 2007 funded by FCT/MCTES (Portugal) and POPH/FSE (EC), and in the form of grant reference PTDC/CTE-AST/098528/2008. VN would also like to acknowledge the support from FCT in the form of the fellowship SFRH/BD/60688/2009.

44.02
**Spitzer Lightcurves of WASP-18**
**Pierre Maxted**[1], N. Iro[1], D. R. Anderson[1], J. Harrington[2], A. Collier-Cameron[3]
*[1]Keele University, United Kingdom, [2]University of Central Florida, [3]St Andrews University, United Kingdom.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
WASP-18b is a massive hot Jupiter exoplanet (10 MJup) which orbits an F6V star with an orbital period of only 0.94 days. The energy deposition and redistribution in hot Jupiter atmospheres is not well understood currently, but is a major factor for their evolution and survival. We present new results from a Spitzer campaign to observe lightcurves at 3.6-micron and 4.5-micron The minimum flux of the phase variation compared to the eclipse depth shows that the unheated hemisphere of WASP-18b is extremely dark at 3.6-micron and 4.5-micron. This suggests that the efficiency of heat distribution from the day-side to the night-side of the planet is extremely inefficient. We have also measured the amplitude, phase and shape of the phase variation in WASP-18b. We will report the results of comparing these parameters to the results of time dependent radiative models for the atmosphere of WASP-18b. This

enables us to put strong constraints on the efficiency of heat redistribution in this extreme planetary system and to determine the pressure level at which the heat distribution occurs.

44.03

**The Relation Between Metallicity and Rotation Period for M-dwarfs in the MEarth Sample.**

**Elisabeth Rose Newton**[1], J. Irwin[1], D. Charbonneau[1], B. Rojas-Ayala[2], Z. K. Berta[1], C. J. Burke[3], J. Dittmann[1], E. E. Falco[4], P. Nutzman[5]

*[1]Harvard University, [2]Cornell University, [3]NASA Ames, [4]Whipple Observatory, [5]UC Santa Cruz.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

M dwarfs are the most promising candidates around which to find habitable, Earth-sized planets amenable to detailed spectroscopic study of their atmospheres by transmission or occultation methods. This is possible using instrumentation available presently and in the near future. A correlation between stellar metallicity and planet occurrence has been demonstrated for F, G and K stars, with exoplanet detections rising sharply above solar metallicity. Recent results indicate that this relation may also hold for M-type stars; if correct, we would be able to increase the yield of planet surveys by targeting metal-rich stars. The MEarth Project is a transiting planet survey that is photometrically monitoring 2000 of the nearest M dwarfs in the northern sky and which will expand in the next year to include an additional 2000 stars in the southern hemisphere. We aim to measure the metallicities of this sample using a new method pioneered by Rojas-Ayala et al. (2010) that uses moderate resolution near-infrared spectra. Here, we present a study of 140 mid to late M dwarfs observed with IRTF, including 60 for which we have measured rotation periods. Included in this sample is a subset of the 850 stars around which MEarth has searched for planets. We will discuss the physical properties of stars observed to date and prospects for front-loading the MEarth target list with metal-rich stars.

44.04

**Resolved DEBRIS Discs**

**Mark Booth**[1], DEBRIS Team

*[1]University of Victoria, Canada.*

8:30 AM Monday - 3:00 PM Friday

*Osprey/Grizzly*

The Herschel DEBRIS survey is a volume-limited survey of 446 of the closest stars at wavelengths of 100 and 160 microns. Excesses at these wavelengths imply the presence of debris discs. Many of these discs were previously imaged with Spitzer but the superior angular resolution of Herschel has allowed us to resolve more than 20 of the largest of these discs. Although similar to the Kuiper belt in our own Solar System, these discs are much more massive and extend much further from their host stars.

I will present images for a selection of these systems and discuss what extra information the resolved data can provide about these systems. For instance, the radii measured from the resolved images are shown to be different from that predicted by a black-body fit to the SEDs. This information allows us to infer properties about the size and composition of the dust. Resolved images can also tell us about the planetary system as a whole as the inner edges of these discs are likely to be the result of sculpting by planets.

This research is funded through a Space Science Enhancement Program grant from the Canadian Space Agency.

44.05

**An Improvement of the Radial Velocity Measurement Method for Subaru/HDS**

**Hiroki Harakawa**[1], B. Sato[1]

*[1]Tokyo Institute of Technology, Japan.*

8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
Now extra solar planet surveys have been transitioning to the next stage: to clarify the correlation between planet parameters and stellar parameters such as stellar metallicity, mass and age, or occurrence frequency of the habitable Super-Earths with high accuracy RV observations. In such a trend, an improvement of the RV measurement accuracy is crucial for the detection of exoplanets.
It requires that a high dispersion spectrograph and excellent wavelength scaling for stellar templates to measure radial velocities (RV) precisely. And such a good wavelength scale is provided by $I_2$ spectrum for the HDS at the Subaru telescope.
Previously, we obtained stellar templates by deconvolution of IP from the observed star+$I_2$ spectra described in Sato et al. (2002). However, for HDS, it have been reported that the long-term precision of RV measurements was higher than $10ms^{-1}$.
En route to improvement trials, we found that the method of obtaining the intrinsic stellar spectrum (a stellar template) can be one of the main sources of uncertainty. Compared with the intrinsic stellar spectrum, because of its low resolution, the deconvolved spectra tend to be noisy.
In order to avoid the calculation of deconvolution, we took the target star's spectrum of extremely high resolution of R=160,000 without the $I_2$ spectrum as the stellar template. Those templates would not be affected by IP, and its wavelength scale is approximately collected. By using our new stellar template, we have achieved the long-term precision of about $3ms^{-1}$ for over four years.
The precision we have achieved indicates that the Subaru/HDS have been extended detection levels into the range of planets with masses about 6 $M_{Earth}$ around 7 days orbit to M-dwarfs with the mass of $0.5M_{SUN}$. Suppressing internal errors of RVs would be our near future work.

44.06
**X-ray Irradiation And Evaporation Of Close-in Exoplanets**
**Peter Wheatley**[1]
[1]*University of Warwick, United Kingdom.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
I will present a series of X-ray observations of exoplanet systems designed to determine the role of stellar activity in the evolution of close-in planets. In particular, I will present the first detection of an exoplanet transit in X-rays, and show how the X-ray absorption spectrum places new and powerful limits on the evaporation rates of irradiated exoplanets. I will also present new X-ray monitoring observations designed to test the suggestion that the presence of a hot Jupiter can amplify stellar activity and then feedback to enhance mass-loss in close-in systems. Data analysis is currently underway, but the results of this analysis will be available in time for the meeting.

44.07
**Cryptographic Protocol for Comparing Sets without Leaking Them: Applications in Astronomy**
**Peter R. McCullough**[1]
[1]*STScI.*
8:30 AM Monday - 3:00 PM Friday
*Osprey/Grizzly*
We describe a cryptographic protocol for two or more persons to compare individual lists of astronomical objects of interest without leaking them. Cryptographers have long known such protocols; astronomers and other scientists may benefit from them also. We describe some latent opportunities that would be enabled by this protocol. Consider the following scenario: Alice has a set of stars that are candidate hosts of transiting planets. Bob has a similar set. Alice and Bob have a mutual desire to know

the intersection of their two lists without revealing them to each other. Alice and Bob can recruit a trusted third party, Josephine, to make the comparison, report the results, and then destroy each list. Limitations of that approach are that 1) Josephine must devote time to make each comparison, 2) Alice and Bob may not know a Josephine that they both can trust, especially if Alice and Bob are from different communities, 3) Josephine may not indeed be trustworthy, 4) a fourth person may wittingly or unwittingly intercept one or both of the lists in Josephine's care, and 5) anticipating those limitations, Alice and Bob may elect not to recruit a Josephine and hence not compare their lists. We describe a variant that overcomes those limitations by A) encrypting the lists prior to transmitting them to Josephine, and B) replacing a human Josephine with a computer website.

# Author Index

Abe, Y. : 42.01, 42.02, 42.03
Adamow, M. : **30.02**
Adams, F. C. : **10.04**
Agol, E. : 12.01, 12.06, 14.06, **15.06**
Aigrain, S. : **11.05**, 11.06, 19.06
Albrecht, S. : **06.02**, 12.03, 26.01
Alsubai, K. A. : 19.08
Amado, P. J. : 10.01
and the Kepler Team, : 04.03
Anderson, D. R. : 06.04, 44.02
Anglada, G. : 20.01
Argabright, V. S. : 19.14
Arras, P. : **10.06**, 40.23
Arriagada, P. : 20.06
Artigau, E. : 40.25
Augereau, J.-C. : 16.04
Ayliffe, B. : 38.05
Aylward, A. : 29.06
Bai, X.-N. : **36.03**
Bailey, J. : 40.12
Balan, S. : 20.07
Ballard, S. : **03.03**, 04.03
Ballester, G. : 12.02
Ballester, G. E. : 40.13
Ballester, G. E. : **40.26**
Barbieri, C. : 19.11
Barbieri, M. : **19.11**
Barker, A. : **34.03**
Barman, T. : 07.05, 12.04, 22.02, 40.08, 40.16
Barnes, J. : **20.06**
Barnes, J. W. : **24.02**
Barsony, M. : 27.04
Baruteau, C. : **36.04**
Basri, G. : 19.14
Batalha, N. M. : **01.01**
Bate, M. : 38.05
Batygin, K. : **13.02**
Bazzon, A. : 23.04
Bean, J. : **11.01**
Beatty, T. : 19.01
Beauge, C. : 25.01
Beaulieu, J. P. : 29.06
Ben-Jaffel, L. : 40.26
Bender, C. : 02.05, 02.06, 20.14
Benedict, F. : 28.02

Benedict, G. F. : **28.04**
Benneke, B. : **40.27**
Bennett, D. P. : **21.03**
Bento, J. : **40.03**
Benz, W. : 01.02
Berdyugin, A. : 14.07
Berdyugina, S. : **14.07**
Berta, Z. K. : **11.03**
Berta, Z. K. : 44.03
Bertaux, J.-L. : 01.02
Biller, B. A. : 07.02, 22.03
Birkby, J. : **12.03**
Birkby, J. L. : 31.01
Bitner, M. A. : 38.03
Bitsch, B. : **36.01**
Blake, C. : **20.13**
Bochanski, J. : 15.03
Bodenheimer, P. H. : 13.02
Boisse, I. : 06.04, **20.09**, 39.02
Boley, A. : 38.04
Boley, A. C. : 06.07
Boley, A. C. : **08.06**
Bonavita, M. : 07.04
Bonfils, X. : 20.09, 39.02, 44.01
Bonsor, A. : 15.01, **15.05**
Booth, M. : **44.04**
Borucki, W. J. : 03.04, **04.02**, 19.14
Botzer, B. : 02.05, 02.06
Bouchy, F. : 01.02
Bouchy, F. : 06.04, 14.03
Boue, G. : 10.03
Boué, G. : 25.03
Bouvier, J. : 39.02
Brandeker, A. : **38.02**
Brinkworth, C. : 15.04
Brogi, M. : **40.09**
Bromley, B. : **08.01**
Brown, D. : **06.04**
Browne, S. E. : 32.02
Buchhave, L. A. : 19.03, **19.17**
Buenzli, E. : **23.04**
Bulger, J. : 38.05
Burgasser, A. : 15.03
Burkart, J. : 10.06
Burke, C. : 19.18
Burke, C. J. : 11.03, **19.16**
Burke, C. J. : 44.03
Burrows, A. : 12.01, 12.03, 12.06, 14.02, 14.06, 40.24

Burrows, A. S. : **13.01**
Buzasi, D. L. : 19.14
Cabo Winter, O. : 33.16
Cahoy, K. : 17.05
Caldwell, D. A. : 19.14
Cameron, A. : **10.01**
Carey, S. : 40.24
Carlberg, J. K. : **35.01**
Carpenter, J. : 38.05
Carpenter, J. M. : 22.07
Carter, J. A. : 03.04, **05.01**, 19.03, 19.17
Chabrier, G. : **13.04**, 37.01
Chambers, J. E. : 16.02
Chang, P. : 09.06
Chaplin, W. J. : 19.14
Charbonneau, D. : 03.03, 04.03, 11.03, 12.01, 12.06, 14.06, 24.01, 44.03
Chatterjee, S. : **05.06**
Chauvin, G. : **05.04**
Chen, C. : **38.03**
Chen, Y.-Y. : 19.04
Chen, Y. : **34.04**
Chilcote, J. K. : **41.02**
Christiansen, J. : **24.04**
Christiansen, J. L. : 19.14
Chun, M. : 07.02, 22.03
Ciardi, D. : 19.15
Ciardi, D. R. : 40.24
Clampin, M. : 12.06
Close, L. M. : 07.02, 22.03
Cochran, W. D. : 12.04
Cohen, O. : **18.06**
Collier Cameron, A. : 06.04, 19.08, 26.02
Collier-Cameron, A. : 44.02
Colon, K. : **19.05**
Correia, A. : 10.03
Coudé du Foresto, V. : 29.06
Coughlin, J. L. : 40.10
Cowan, N. : 12.01
Cowan, N. B. : **14.02**, 14.06
Croll, B. : **11.04**, 14.02
Crossfield, I. J. : **40.08**
Crouzet, N. : **19.18**
Cunha, K. : 35.01
D'esert, J.-M. : 19.17
Dawson, R. I. : **09.04**
Dawson, R. I. : 29.08
De Bondt, K. : **41.06**
de Kok, R. J. : 40.09

de Mooij, E. : 12.03
de Mooij, E. J. W. : 40.09
De Rosa, R. : 40.16
Debes, J. H. : **22.06**
DEBRIS Team, : 44.04
Deeg, H. : 19.13
Delfosse, X. : 39.02
Delgado, A. : 41.03
Deming, D. : 03.06, 12.01, 12.06, 14.02, 14.04, 14.06, **17.03**, 17.04, 40.17
Demory, B. : 17.03
Demory, B.-O. : **17.04**
Deroo, P. : 29.01, 29.06
Desert, J.-M. : 03.03, **04.03**, 11.03, 12.01, 12.02, 12.06, 14.06, 40.13
Diddams, S. : 02.05, 02.06
Dittmann, J. : 44.03
Diver, D. : 40.01
Djupvik, A. A. : 39.01
Dobbs-Dixon, I. : **40.06**
Dominik, M. : **21.01**
Dowell, D. : 38.05
Doyle, L. : 05.01
Doyon, R. : 22.02
Doyon, R. : 41.02
Dragomir, D. : **17.07**, 19.15, 29.08
Drake, J. : 18.06
Dressing, C. D. : **24.01**
Dumusque, X. : 02.02, **20.04**
Duncan, M. J. : 33.07
DUNES consortium, : 16.04
Dunham, E. W. : 19.14
Eastman, J. : 19.01
EChO team, : 41.05
Eggenberger, A. : **39.02**
Ehrenreich, D. : 12.02
Eiroa, C. : 16.04
Eldridge, J. J. : 15.01
Elser, S. : **18.04**
Encrenaz, T. : 29.06
Endl, M. : 12.04
Enoch, B. : 06.04
Ertel, S. : 16.04
et al., Harvard-Smithsonian Center for Astrophysic, s. : 19.17
Evans, T. : 11.05, 11.06, **19.06**
Fabrycky, D. : 03.01
Fabrycky, D. : 07.05, 14.03, 29.08
Fabrycky, D. C. : **03.04**
Falco, E. E. : 44.03
Farihi, J. : 15.04, **30.06**

Farr, W. : 06.05
Farr, W. M. : 34.07
Fegley, B. : 17.05
Figueira, P. : 10.03, **20.11**
Fischer, D. : 19.15, 41.04
Fischer, D. A. : 19.03
Fischer, D. A. : 27.01
Fitzgerald, M. P. : **07.06**
Fitzgerald, M. P. : 41.02
Ford, E. : 28.05, 38.04
Ford, E. B. : **03.01**, 05.06
Ford, E. B. : 06.07
Ford, E. B. : 18.02, 19.05
Ford, E. B. : 28.01, 28.03
Forgan, D. : 08.05
Fortney, J. : 11.03, 12.01, 12.02, 40.20
Fortney, J. J. : 13.06, 14.05, 14.06, 17.06
Fraine, J. : 17.03
Freedman, R. S. : 14.05
Fressin, F. : 03.03, 04.03, **04.04**
Frewen, S. : **34.08**
Fromang, S. : 36.04
Ftaclas, C. : 07.02, 22.03
Fujii, Y. : **29.03**
Fujii, Y. I. : **33.09**
Fukui, A. : **25.02**
Gaensicke, B. : **15.04**
Gaidos, E. : **27.01**
Galicher, R. : 22.02
Galvagni, M. : **33.06**
Garraffo, C. : 18.06
GASPS (Herschel OTKP, PI B. Dent), : 38.01
Gaudi, B. : 19.01
Gautier, T. N. : 19.14
Ge, J. : 41.03
Gelino, C. : 40.24
Gelino, D. M. : 40.24
Gemini NICI Planet-Finding Campaign Team, : 07.02, 22.03
Genda, H. : 42.01, 42.02, **42.03**
Geretshauser, R. J. : 33.15
Gettel, S. : **20.14**
Giacobbe, P. : 41.01
Gibson, N. : 11.05, **11.06**, 19.06
Gilliland, R. : 12.06
Gilliland, R. L. : 19.14
Gillon, M. : 06.04, 17.03, 17.04, 40.21
Girven, J. : 15.04
Gombosi, T. : 18.06

Gomez Maqueo Chew, Y. : 40.21
Graham, J. : **07.01**
Graham, J. R. : 07.06
Graham, J. R. : 41.02
Greaves, J. : **08.05**
Greene, T. : 14.02
Gregory, P. C. : **20.05**
Greiner, J. : 40.09
Griffith, C. : 29.01
Grillmair, C. : 40.17
Grillmair, C. J. : 40.24
Gu, P.-G. : **40.11**
Guenther, D. B. : 29.08
Guenther, E. : 10.01
Guillot, T. : **12.07**, 37.02
HÃ©brard, G. : **20.10**
Haas, M. R. : 19.14
Haghighipour, N. : **18.05**, 25.03, 33.16
Hamilton, D. : 09.05
Han, I. : 20.12
Hanasz, M. : 33.10
Hanse, J. : 40.09
Hansen, B. : 34.08
Hansen, B. M. : **08.03**
Hansen, B. M. S. : 40.08
Harakawa, H. : **44.05**
HARPS Team, : 17.07
Harpsøe, K. : 21.01
Harrington, J. : 44.02
Harrison, T. : 28.02
Hartmann, S. : **30.03**
Hasegawa, Y. : **36.06**
Havel, M. : **37.02**
Hawkins, K. : 04.06
Hayward, T. L. : 07.02
Hayward, T. L. : 22.03
Hebb, L. : **40.21**
Hebrard, G. : 06.04, 14.03
Heinsbroek, R. C. : 40.09
Hellier, C. : **04.01**, 06.04
Helling, C. : **40.01**, 40.16
Helminiak, K. : 20.02, **32.02**
Heng, K. : **11.07**
Henk Spruit, : 43.01
Henry, G. : 19.15
Herschel GT KP "Stellar Disk Evolution", PI Olofss, o. : 38.02
Hessman, F. V. : 21.01
Hinkley, S. : **22.07**

HIRANO, T. : **26.01**
Hirose, S. : 33.08, 36.05
Hodgkin, S. : 19.09, 19.10
Hodgkin, S. T. : 31.01
Hollis, M. : **20.07**
Holman, M. J. : 03.04, 19.03, 25.02
Holman, M. J. : 29.08
Homeier, D. : 11.03
Hora, J. : 14.02
Hori, Y. : **33.04**
Horne, K. : 19.08, 21.01
Horner, J. : 34.06
House, C. : 42.04
Howard, A. : **02.01**, 04.06, 19.15
Howard, A. W. : 03.05, 28.03, 32.02
Howell, S. B. : 19.14
Huitson, C. : **40.13**
Husnoo, N. : **14.03**
Ida, S. : 06.06, **16.05**, 29.02, 30.05, 33.07, 33.14, 34.02
Ikoma, M. : 30.05, 33.04
Ilyin, I. V. : 39.01
Ingalls, J. : 40.24
Inutsuka, S.-I. : 33.09
Ireland, M. : 22.04
Ireland, M. J. : 22.07
Iro, N. : 44.02
Irwin, J. : 11.03, 31.01, 44.03
Irwin, M. : 31.01
Isaacson, H. : 04.06
Israelian, G. : 33.05
Izidoro, A. : **33.16**
Izumiura, H. : 20.12
Jørgensen, U. G. : 21.01
Jackson, B. : **03.06**
Jackson, R. : 31.01
Jakeman, H. : 41.03
Jang-Condell, H. : **16.07**
Janson, M. : 07.04, **22.01**
Jardine, M. : 40.01
Jarvinen, S. P. : 39.01
Jayawardhana, R. : **07.04**, 40.25
Jeffries, R. : 31.01
Jenkins, J. : 20.06, **39.03**
Jenkins, J. M. : **19.14**
Jensen, A. G. : 12.04
Jensen, E. : 19.15
Jiang, I.-G. : 36.07
Johnson, J. : 04.06

Johnson, J. A. : **03.05**
Johnson, J. A. : 28.03
Jones, H. R. A. : 20.06
Jordán, A. : 20.06
Kalas, P. : **01.04**, 07.06
Kallinger, T. : 29.08
Kane, S. R. : **19.15**, 40.24
Kaplan, Z. : 41.04
Kashyap, V. : 18.06
Kasting, J. F. : 18.01
Kataria, T. : **14.05**
Katsuta, Y. : 30.05
Katz, B. : **09.03**
Kawahara, H. : 29.03
Kedziora-Chudczer, L. : **40.12**
Kempton, E. : 11.03, **14.01**, 17.06
Kenyon, S. : 15.07
Kenyon, S. J. : 08.01
Kepler Completeness Study Working Group, : 24.04
Kepler Science Team, : 03.01, 04.05
Kepler Team, : 03.03, 03.04, 04.04, 05.02, 16.02
Kimura, R. : 42.03
King, R. : 38.05
King, R. : **40.16**
Kinnear, T. : 15.04
Kipping, D. M. : **19.02**
Kite, E. : 12.01
Kley, W. : 33.01, 33.15
Kley, W. : 36.01
Knutson, H. : **12.01**, 12.06, 14.06, 40.24
Koch, D. G. : 03.04
Koch, D. G. : 04.02
Koda, J. : 38.05
Kodama, T. : 42.01, **42.02**
Koester, D. : 15.04
Koesterke, L. : 12.04
Kokubo, E. : 33.14
Kolodziejczak, J. : 19.14
Konacki, M. : **20.02**, 20.03, 23.02, 23.03, 32.02
Konopacky, Q. M. : **07.05**
Kopparapu, R. : **18.01**
Koppenhoefer, J. : 40.09
Koppenhofer, J. : 12.03
Korhonen, H. : **39.01**
Kovacs, A. : 38.05
Kovacs, G. : **19.09**
Kowalik, K. : **33.10**
Kozłowski, S. : 23.03

Kozlowski, S. : 20.02, **23.02**
Kratter, K. : 08.04, 15.07
Kratter, K. M. : **08.07**
Kraus, A. L. : **22.04**, 22.07
Kretke, K. A. : **34.05**
Krick, J. E. : 40.24
Kuhn, R. : 19.01
Kulesa, C. : 29.01
Kulkarni, S. R. : 20.03
Kulkarni, S. R. : 32.02
KUNITOMO, M. : **30.05**
Kuschnig, R. : 29.08
LÃ©ger, A. : **29.05**
Lafreniere, D. : 07.04
Lafrenière, D. : 22.02
Lafreniere, D. : 40.25
Lagrange, A.-M. : 39.02
Lahav, O. : 20.07
Lambrechts, M. : **33.02**
Langton, J. : 12.01, 14.06
Langton, J. S. : **14.04**
Larkin, J. E. : 41.02
Laskar, J. : **09.01**
Latham, D. W. : 19.17
Lattanzi, M. G. : 41.01
Laughlin, G. : 12.01, 14.04, 14.06, 19.15, 27.03
Lecavelier, A. : **40.14**
Lecavelier des Etangs, A. : 12.02, 40.13
Leconte, J. : **37.01**
Lee, B.-C. : 20.12
Lee, C. H. : 40.09
Lee, M. : **28.03**
Legel, L. W. : 18.02
Leinhardt, Z. : **05.05**
Lepine, S. : 27.01
Lestrade, J.-F. : 36.08
Lewis, N. : 12.01, **14.06**
Lewis, N. K. : 13.06, 14.05
Li, M. : 19.04
Li, Z.-Y. : 40.23
Lin, D. N. C. : 16.05
Lissauer, J. J. : **04.05**, 16.02
Lithwick, Y. : 06.05, **09.02**, 34.07
Liu, M. C. : 07.02, 22.03
Livio, M. : 15.02
Lo Curto, G. : **02.03**, 33.05
Lodders, K. : 17.05
Loehne, T. : **16.04**

Long, D. : 19.18
Lopez, E. : **17.06**
Lopez-Morales, M. : 12.02, **40.10**
Lovis, C. : 01.02, **02.02**, 20.04, 33.05
Lubow, S. H. : 33.11
Luhman, K. : **15.03**
MÃ¼ller, T. : **33.01**
Machalek, P. : 14.02, 19.14
Machida, M. N. : 33.13
Macintosh, B. : 07.05, 22.02
Macintosh, B. A. : 41.02
Madhusudhan, N. : **12.05**, 12.06
Mahadevan, S. : 02.05, **02.06**, 19.15
Majewski, S. R. : 35.01
Mamajek, E. E. : 38.03
Mandell, A. : 08.02, 12.06
Mandushev, G. : 19.12
Mann, A. W. : 27.01
Marcy, G. : 04.06
Marcy, G. : 33.03
Marcy, G. W. : 03.05
Marcy, G. W. : 28.03
Markov, H. : 19.12
Marley, M. : 40.20
Marley, M. S. : 14.05, **17.05**
Marmier, M. : 01.02
Marois, C. : 07.05, 22.02, 40.16
Marsh, T. : 15.04
Marshall, J. : 16.04, 34.06
Martin, E. : 19.07
Martin, E. L. : **43.01**
Martin, R. G. : **33.11**
Masset, F. : 36.04
Mathis, S. : 34.01
Matsukura, D. : **33.14**
Matsumoto, Y. : **34.02**
Matsumura, S. : **09.05**
Matthews, J. M. : 10.01
Matthews, J. M. : 17.07
Matthews, J. M. : 29.08
Maxted, P. : 40.19, **44.02**
Maxted, P. F. L. : 06.04
Mayer, L. : 33.06
Mayor, M. : **01.02**, 02.02, 20.04, 33.05
Mazeh, T. : 14.03
McArthur, B. : **28.02**
McArthur, B. E. : 28.04
McCarthy, D. : 29.01

McCullough, P. : 11.03, 19.12
McCullough, P. R. : 19.18
McCullough, P. R. : **44.07**
McDonald, I. : 10.01
McQuillan, A. : 11.05
Meeus, G. : **38.01**
Melo, C. : 20.11
members of the EC funded RoPACS Initial Training N, e. : 19.09, 19.10
Meru, F. : **33.15**
Meunier, N. : 39.02
Micela, G. : 29.06
Micela, G. : 41.01
Mighell, K. : 14.06
Miller, G. : **26.02**
Miller, G. R. M. : 06.04
Miller, N. : 17.06
Minniti, D. : 20.06
MOA and OGLE collaboration, : 01.03
Moffat, A. F. J. : 29.08
Monin, J.-L. : 38.05
Montalto, M. : 25.03
Moor, A. : 39.01
Moore, B. : 18.04
Moorhead, A. V. : 03.01
Moraux, E. : 39.02
Morbidelli, A. : **08.02**
Mordasini, C. : **16.06**
Morehead, R. C. : **28.01**
MOREY, E. : **36.08**
Morishima, R. : 18.04
Morley, C. : **40.20**
Moro-Martin, A. : **16.03**
Morton, T. : **04.06**
Morton, T. D. : 03.05
Moses, J. I. : **40.04**
Moses, J. I. : 40.05
MOST Science Team, : 10.01
Moutou, C. : 14.03
Murray-Clay, R. : **08.04**, 09.04
Mustill, A. : 15.05
Mustill, A. J. : 15.01
Muterspaugh, M. W. : 20.03
Muterspaugh, M. W. : 32.02
Muto, T. : 36.02
Muxlow, T. : 08.05
Nagasawa, M. : **06.06**, 34.02
Nagel, T. : 30.03
Naletto, G. : 19.11

Naoz, S. : **06.05**, 34.07
Narita, N. : **05.03**, 25.02, 26.01
Nayakshin, S. : **10.02**
Nefs, B. : 12.03
Nefs, B. V. : 40.09
Nelson, B. E. : **28.05**
Nelson, R. P. : 36.04
Nesvorny, D. : **25.01**
Neuhäuser, R. : 22.05, 23.05
Neves, V. : **44.01**
Newton, E. R. : **44.03**
Niedzielski, A. : **02.04**, 30.01, 30.02, 30.04
Nielsen, E. L. : **07.02**, 22.03
NIR RV collaboration, : 20.01
Nowak, G. : 30.01, **30.04**
Nutzman, P. : 11.03, 44.03
O'Brien, D. : 08.02
Ogawa, M. : 29.02
Ogihara, M. : **33.07**
Ogilvie, G. : **10.05**, 34.03
Ohtsuki, K. : 33.13
Okuzumi, S. : **33.08**, 33.09
Olah, K. : 39.01
Olling, R. P. : 19.12
Ollivier, M. : 29.06
Omiya, M. : **20.12**
Osborne, M. : 11.05, 11.06
Oshagh, M. : **25.03**
Osterman, S. : **02.05**, 02.06
Paardekooper, S.-J. : 05.05
Padgett, D. : **38.06**
Palle, E. : **29.07**
Palmer, D. W. : 41.02
Parley, N. : **19.08**
Parmentier, V. : 12.07
Parviainen, H. : **19.13**
Patience, J. : 22.02, **38.05**, 40.16
Payne, M. : 28.05
Payne, M. J. : **06.07**
Payne, M. J. : 28.03
Pecaut, M. : 38.03
Pepe, F. : 01.02, 20.04, 20.11
Pepper, J. : **19.01**
Perets, H. : **15.07**
Perrin, M. D. : 41.02
Petigura, E. : **33.03**
Piirola, V. : 14.07
Pilyavsky, G. : 19.15

Pineda, S. : 03.05
Pinfield, D. : 19.10
Pinte, C. : 38.05
Plavchan, P. : **20.01**, 40.24
Pollacco, D. : 06.04
Pont, F. : **11.02**, 11.06, 12.02, 14.03, 40.13
Prša, A. : 28.01
Pudritz, R. E. : 36.06
QES consortium, : 19.08
Quataert, E. : 10.06
Queloz, D. : 01.02, 06.04, 23.01
Quinlan, F. : 02.05
Quinlan, F. : 02.06
Quintana, E. V. : **16.02**
Quirrenbach, A. : **20.08**
Radigan, J. : **40.25**
Ragozzine, D. : 03.04, **06.03**, 28.01
Ramarao Tata, : 43.01
Ramirez, R. : 18.01
Ramsey, L. : 02.05, 02.06
Randich, S. : 39.02
Ranjan, S. : **12.06**
Rasio, F. : 06.05
Rasio, F. A. : 05.06, **34.07**
Ratajczak, M. : 20.02, **20.03**
Rauch, T. : 30.03
Rauscher, E. : **13.05**, 14.01
Raymond, S. : 08.02
Redfield, S. : **12.04**
Redman, S. : 02.05, 02.06
Reece, S. : 11.05
Rein, H. : **36.02**
Remus, F. : **34.01**
Ribas, I. : 29.06
Rice, E. : 40.16
Rice, K. : 08.05
Richards, A. : 08.05
Roberts, S. : 11.05
Roberts, S. : 11.06, 19.06
Rodler, F. : **40.18**
Roell, T. : **23.05**
Rogers, L. : **18.03**
Rojas-Ayala, B. : 44.03
Rojo, P. : 20.06
Rowe, J. : **03.02**, 03.04, **29.08**
Rowe, J. F. : 03.01
Roy, A. : 02.06
Rucinski, S. : 29.08

Saddlemyer, L. : 41.02
Saha, P. : 33.06
Sahai, R. : 27.04
SAHLMANN, J. : **23.01**
Sahu, K. C. : **21.02**
Sanchis Ojeda, R. : **36.09**
Sanroma, E. : 29.07
Santos, N. : **10.03**, 20.09, 20.11
Santos, N. : 25.03
Santos, N. C. : 33.05
Santos, N. C. : 02.02
Santos, N. C. : 20.04
Santos, N. C. : 44.01
Sasselov, D. : 29.08
Sasselov, D. D. : **17.01**
Sato, B. : 20.12, 26.01, 30.05, 44.05
Schaefer, L. : 17.05
Schlichting, H. : **09.06**, 40.24
Schmid, H. M. : 23.04
Schmidt, T. : **22.05**
Seager, S. : 12.06, 17.03, 17.04, 18.03, 40.27
SEEDS/HiCIAO/AO188 teams, : 05.03
Segransan, D. : 01.02, 23.01
Seifahrt, A. : 22.05, 23.05
Senshu, H. : 29.02
Shabram, M. : 13.06, **38.04**
Shaw, M. : 20.13
Shkolnik, E. : 10.01
Showman, A. : 12.01, 12.06, 13.05
Showman, A. P. : **13.06**, 14.05, 14.06
Shporer, A. : 14.03, 26.01
Sibthorpe, B. : 08.05
Sigurdsson, S. : **18.02**, 42.04
Simpson, E. : 06.04
Sing, D. : 11.06, **12.02**
Sing, D. K. : 40.13
Sipocz, B. : **19.10**
Siverd, R. : 19.01
Skillen, I. : 12.03
Skottfelt, J. : 21.01
Smalley, B. : 06.04
Smith, A. : **40.15**
Smith, A. M. S. : 10.01
Smith, V. V. : 35.01
Snellen, I. : 12.03
Snellen, I. A. G. : 40.09
Socrates, A. : **10.07**
Sokolov, I. : 18.06

Song, I. : 22.02, 38.05
Sousa, S. : **33.05**
Sozzetti, A. : 19.03, 29.06, **41.01**
Speith, R. : 33.15
Spronck, J. : **41.04**
Stadel, J. : 18.04
Stapelfeldt, K. R. : **07.03**
Stark, C. : 22.06
Stassun, K. : 19.01
Steffen, J. : 03.01
Steffen, J. H. : **18.07**
Stevenson, D. J. : 13.02
Stewart, S. T. : 05.05
Stone, J. M. : 36.03
Su, K. Y. L. : 38.03
Sumi, T. : **01.03**, 25.02
Sun, Y.-S. : 19.04, 34.04
Suto, Y. : 26.01
Swain, M. : 29.01
Swain, M. R. : 29.06
SWEEPS Team, : 21.02
Swinyard, B. : 29.06
Sybilski, P. : 20.02, 23.02, **23.03**
Tachinami, C. : **29.02**
Tajika, E. : 42.03
Takahashi, Y. H. : 05.03
Takao, Y. : **42.01**
Tan, X. : 28.03
Tanaka, H. : **33.12**
Tanigawa, T. : **33.13**
Tata, R. : **19.07**
Taylor, J. : **27.02**
Taylor, S. F. : **36.07**
Team, K. : 06.03
Telting, J. : 10.01
Tenenbaum, P. : 19.14
Tennyson, J. : 29.06
Terrien, R. : 02.05, 02.06
Teske, J. : **29.01**
Tessenyi, M. : **29.06**
Teyssandier, J. : 06.05, 34.07, 34.09
Thakur, P. : 36.07
The Kepler Science Team, : 05.01
The MiNDSTEp consortium, : 21.01
the SOPHIE Team, : 20.10
Thebault, P. : **32.01**
Tian, F. : **29.04**
Tinetti, G. : **01.05**, 29.06, 41.01, **41.05**

Tinney, C. : 34.06
Todorov, K. O. : **40.17**
Toomey, D. W. : 07.02
Toomey, D. W. : 22.03
Torres, G. : 03.03, 04.04, **19.03**, 19.17
Trammell, G. : **40.23**
Traub, W. A. : **24.03**
Triaud, A. H. M. : 06.04
Tsai, S.-M. : 40.11
Tsvetanov, Z. I. : **19.12**
Turner, N. J. : **36.05**
Udry, S. : 01.02
Udry, S. : 02.02
Udry, S. : 20.04, 33.05
Valencia, D. : **17.02**
van Belle, G. T. : 40.24
Van Cleve, J. : 19.14
van der Werf, P. : 40.09
Vasisht, G. : 29.06
Veras, D. : **15.01**
Vida, K. : 39.01
Vidal-Madjar, A. : 12.02, 40.13
Vigan, A. : **22.02**
Villaver, E. : **15.02**
Visscher, C. : 40.04
Visscher, C. W. : **40.05**
von Braun, K. : 19.15, **40.24**
Wahhaj, Z. : 07.02, **22.03**
Waldmann, I. : **40.02**
Walker, G. A. H. : 10.01
Walkowicz, L. M. : 19.14
Walsh, K. : 08.02, 22.06
Wan, X. : 41.03
Wang, J. : **41.03**
Wang, X. : 19.15
WASP Consortium, : 06.04, 40.15
Weinberg, N. : 10.06
Weinberger, A. J. : 38.03
Weiss, L. M. : **31.01**
Weiss, W. W. : 29.08
Welsh, W. F. : **05.02**, 19.14
Werner, K. : 30.03
WFIRST Science Definition Team, : 21.03
Wheatley, P. : 40.03, **44.06**
Wiktorowicz, S. : **40.07**
Wilson, P. : 12.02
Winn, J. : 36.09
Winn, J. N. : **06.01**, 19.03, 26.01

Winn, J. N. : 29.08
Wiseman, J. J. : **27.04**
Witte, S. : 40.01, 40.16
Wittenmyer, R. A. : **34.06**
Wolfgang, A. : **27.03**
Wolszczan, A. : 02.04
Wolszczan, A. : 20.14
Wolszczan, A. : 30.01
Wolszczan, A. : 30.02, 30.04
Woltanski, D. : 33.10
Wood, P. : **40.19**
Worth, R. : **42.04**
Wright, J. : 19.15, 20.14, 28.05
Wright, J. T. : 28.03
Wu, Y. : **13.03**
Wyatt, M. : 15.05
Wyatt, M. C. : 15.01
Yang, J.-Y. : 19.04, 34.04
Ycas, G. : 02.05, 02.06
Youdin, A. : 08.04, **16.01**
Zahn, J.-P. : 34.01
Zahnle, K. : 17.05, **40.22**
Zahnle, K. J. : 42.02
Zampieri, L. : 19.11
Zhang, H. : 19.04, 34.04
Zhou, J. : **19.04**
Zhou, J.-L. : 34.04
Zielinski, P. : **30.01**
Zuckerman, B. : 22.02