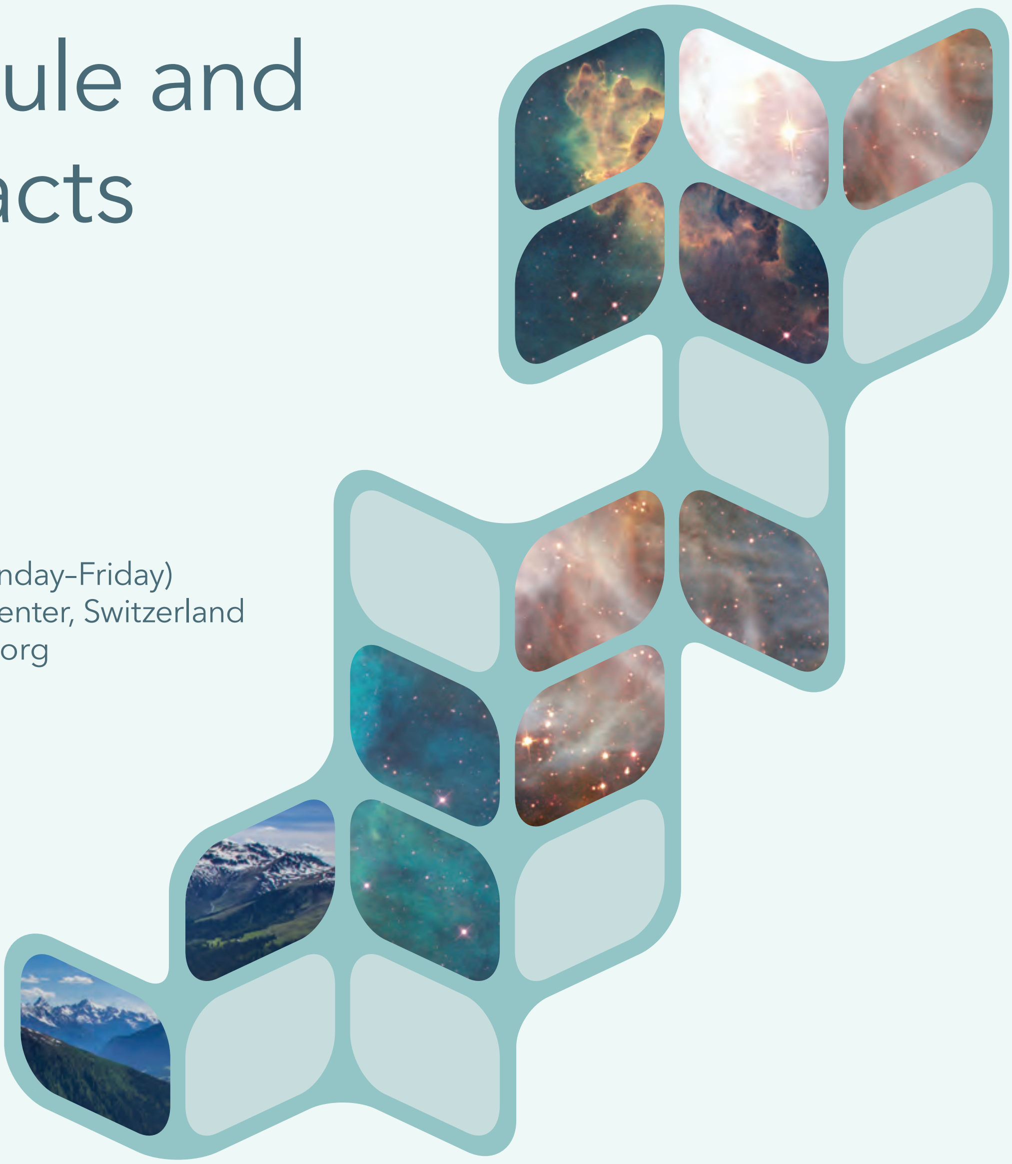
EXOPLANETS I

Schedule and Abstracts



3-8 July 2016 (Sunday–Friday)
Davos Congress Center, Switzerland
exoplanetscience.org

Sunday, July 03, 2016

Welcome

15:00 **Registration**
Welcome reception, networking, hanging up your posters (until 18:00)

Monday, July 04, 2016

Transits

Session Chair: Charbonneau

08:30 **Overcoming stellar variability in planet searches with non-parametric Bayesian methods:**
Suzanne Aigrain (University of Oxford) *Invited*

09:00 **Discovery and Characterization of Exoplanets from the NASA K2 Mission:**
Knicole Colon (NASA Ames Research Center) *Contributor*

09:20 **A hot Jupiter with 70 sec TTV modulation and a period of 3 years: reflex motion induced by a brown dwarf or M-star at 2 AU? :**
Mazeh Tsevi (Tel Aviv University) *Contributor*

09:40 **200 Candidates and Validated Planets from K2's First Year:**
Ian Crossfield (University of Arizona) *Contributor*

10:00 **Coffee break**

10:30 **Invited talk**
Sarah Ballard (University of Washington) *Invited*

11:00 **Detecting & Characterizing Small Planets Orbiting Small Stars: From Kepler to K2 and on to TESS!:**
Courtney Dressing (Caltech) *Contributor*

11:30 **SPECULOOS: searching for exo-Earths at the bottom of the main-sequence:**
Michaël Gillon (University of Liege, Belgium) *Contributor*

11:50 **Surprise talk (10 minutes)**

12:00 **Afternoon break**

Session Chair: Aigrain

15:00	**Invited talk** David Charbonneau (Harvard University) *Invited*
15:30	**Invited talk** Gaspar Bakos (Department of Astrophysical Sciences, Princeton University) *Invited*
16:00	**It's About Time: Exoplanet Evolution from the Pre-Main Sequence to the Red Giant Branch:** Eric Gaidos (University of Hawaii at Manoa) *Contributor*
16:20	**Exploring variations in planet occurrence rates across the Galaxy with K2:** Jessie Christiansen (NASA Exoplanet Science Institute/Caltech) *Contributor*
16:40	**Neptunes and super-Earths from the Next Generation Transit Survey (NGTS):** Peter Wheatley (University of Warwick) *Contributor*
17:00	**Coffee break**
17:30	**Terrestrial Planet Occurrence Rates From The Final Kepler Pipeline Search:** Christopher Burke (SETI / NASA Ames) *Invited*
18:00	**Invited talk** Daniel Foreman-Mackey (University of Washington) *Invited*

Tuesday, July 05, 2016

RV & Stars

Session Chair: Snellen

08:30 **High-precision spectroscopy and velocimetry: new avenues for exoplanet characterization**
Christophe Lovis (University of Geneva) *Invited*

09:00 **A massive rocky planet and an additional non-transiting planet in the Kepler-20 system:**
Lars A. Buchhave (University of Copenhagen) *Contributor*

09:20 **REVISED MASSES AND DENSITIES OF THE PLANETS AROUND KEPLER-10:**
Lauren Weiss (UC Berkeley) *Contributor*

09:40 **Halpha as a Diagnostic of FGKM Stellar Atmospheres:**
Johanna Teske (Carnegie Institution for Science) *Contributor*

10:00 **Coffee break**

10:30 **Kepler Small Planets Follow-up with HARPS-N: The Mass-radius Relation of Rocky Planets:**
Mercedes Lopez-Morales (Harvard-Smithsonian CfA) *Contributor*

11:00 **Rotation and winds of giant exoplanets measured through high-dispersion transmission spectroscopy:**
Matteo Brogi (University of Colorado at Boulder) *Contributor*

11:20 **Overcoming stellar activity radial-velocity noise through solar investigations at HARPS-N:**
Raphaëlle Haywood (Harvard College Observatory) *Contributor*

11:40 **UV and X-ray Irradiance for Atmospheric Characterization of Planets Orbiting M and K Dwarfs:**
Kevin France (University of Colorado) *Contributor*

12:00 **Afternoon break**

Orbital dynamics+TTVs

Session Chair: Queloz

15:00 **Orbital instability and the evolution of planetary systems:**
Katherine Deck (Caltech) *Invited*

15:30 **Low-mass Planets Probed by Transit Timing Variations:**
Daniel Fabrycky (University of Chicago) *Invited*

16:00 **New developments in characterizing the architectures of exoplanet systems:**
Jason Steffen (University of Nevada, Las Vegas) *Contributor*

16:20 **KOINet: reprising Kepler's heritage from the ground:**
Carolina von Essen (Stellar Astrophysics Centre - Aarhus University) *Contributor*

Missions

16:40 **CHEOPS science program outlook:**
Didier Queloz (University of Cambridge) *Contributor*

17:00 **Coffee break**

17:30 **The CHEOPS Mission: Performance and Current Status:**
Christopher Broeg (University of Bern / CSH) *Invited*

18:00 **Invited talk on TESS mission**
Zach Berta-Thompson (MIT) *Contributor*

18:30 **Invited talk on PLATO mission**
Heike Rauer (DLR Berlin)
Invited

Wednesday, Jul 06, 2016

General theory

Session Chair: Murray-Clay

08:30 **Statistical mechanics of exoplanet systems**
Scott Tremaine (Institute for Advanced Study) *Invited*

09:00 **Equations of state of dense matter under planetary interior conditions:**
Gilles Chabrier (CRAL, ENS-Lyon) *Contributor*

09:20 **Exo-Mercury Analogues and the Roche Limit for Close-Orbiting Rocky Planets:**
Leslie Rogers (University of California, Berkeley) *Contributor*

09:40 **A generalized Bayesian inference method to constrain the interiors of super Earths and Sub-Neptunes:**
Caroline Dorn (University of Bern) *Contributor*

10:00 **Coffee break**

10:30 **Invited talk**
Isabelle Baraffe (University of Exeter) *Invited*

11:00 **Dynamical interactions within planetary systems:**
Melvyn Davies (Lund University) *Contributor*

11:20 **Formation and Dynamics of Circumbinary Planets:**
Dong Lai (Cornell Univ.) *Contributor*

11:40 **Warm Jupiters from secular planet-planet interactions:**
Cristobal Petrovich (Canadian Institute for Theoretical Astrophysics) *Contributor*

12:00 **Afternoon break**

Session Chair: Dawson

15:00 **The critical role of residual gas in establishing planetary orbits and compositions**
Rebekah Dawson (Penn State University) *Invited*

15:30 **Forming Super-Earths in Transitional Disks:**
Eugene Chiang (University of California, Berkeley) *Invited*

16:00 **The Migratory Origin of Hot Jupiters and Super-puffs:**
Eve Lee (UC Berkeley) *Contributor*

16:20 **Hot-Jupiter Inflation and Re-inflation:**
Sivan Ginzburg (Hebrew University Jerusalem) *Contributor*

16:40 **Measuring Stellar Tidal Dissipation Using Extremely Hot Jupiters :**
Kaloyan Penev (Princeton University) *Contributor*

17:00	**Coffee break**

Planet formation

17:30	**On the Origin and Formation of Kepler Planets:** Hilke Schlichting (MIT) *Invited*
18:00	**Planet formation by pebble accretion** Anders Johansen (Lund University) *Invited*
20:00	**Conference dinner** Three-course dinner at Davos Congress Center

extreme-precision radial velocity; detections of exoplanets via transits; exoplanet occurrence rates and statistics; celestial mechanics and transit timing techniques; general theory and nexus of theory and observations; atmospheric characterisation; directly imaged exoplanets and brown dwarfs; synthetic spectra, spectral/chemical modeling and general circulation models; gravitational microlensing; constraints on planet formation; extreme-precision radial velocity; detections of exoplanets via transits; exoplanet occurrence rates and statistics; celestial mechanics and transit timing techniques; space missions and large observatories

Thursday, July 07, 2016

Atmospheres

Session Chair: Kreidberg

08:30	**Invited talk** Jean-Michel Desert (University of Amsterdam) *Contributor*
09:00	**Rethinking the super-Earth exoplanet 55 Cancri e:** Brice-Olivier Demory (Cavendish Laboratory, University of Cambridge) *Contributor*
09:20	**The Nature of the Super-Earth 55 Cancri e:** Diana Dragomir (University of Chicago) *Contributor*
09:40	**Spin of extrasolar planets and the accretion of angular momentum:** Ignas Snellen (Leiden Observatory, Leiden University) *Contributor*
10:00	**Coffee break**
10:30	**Exoplanet Atmospheres:** Nicolas Cowan (McGill University) *Invited*
11:00	**Atmospheric Constraints on Exoplanetary Formation and Migration :** Nikku Madhusudhan (University of Cambridge) *Contributor*
11:20	**A Large Hubble Space Telescope Survey of Low-Mass Exoplanets:** Björn Benneke (Caltech) *Contributor*
11:40	**HELIOS-R, an atmospheric retrieval code for exoplanets:** Baptiste Lavie (University of Bern) *Contributor*
12:00	**Afternoon break**

Session Chair: Heng

15:00	**Exoplanet Atmospheres** Jeff Valenti (STScI) *Invited*
15:30	**New Dimensions of Climate: Exploring Hot Jupiter Atmospheres in 3D with HST and Spitzer:** Laura Kreidberg (Harvard University) *Contributor*
16:00	**The JWST/NIRSpec instrument: capabilities for exoplanet characterisation:** Stephan Birkmann (European Space Agency) *Contributor*
16:20	**Atmospheric Characterization of Exoplanets with NIRISS on JWST :** René Doyon (Université de Montréal - iREx) *Contributor*
16:40	**Tracing the Ingredients of Habitable Worlds:** Edwin Bergin (University of Michigan) *Contributor*

17:00	**Coffee break**
17:30	**Testing Assumptions in Atmospheric Retrieval I: The Pitfalls of "1D" Assumptions:** Michael Line (NASA-Ames) *Invited*
18:00	**Snowlines in Protoplanetary Disks** Karin Öberg (Harvard-Smithsoninan Center for Astrophysics) *Invited*
18:30	**Inhomogeneous exoplanet atmospheric reflection is common:** Avi Shporer (JPL) *Contributor*
18:50	**Transitions in the cloud composition of hot Jupiters:** Vivien Parmentier (Lunar and Planetary Laboratory) *Contributor*

Friday, Jul 08, 2016

Direct imaging and brown dwarfs

Session Chair: Henning

08:30 **Invited talk**
Anne-Marie Lagrange (IPAG, CNRS) *Invited*

09:00 **Discovery of a Faint, Young Analogue to our Solar System:**
Sasha Hinkley (University of Exeter) *Contributor*

09:20 **The GPI Exoplanet Survey I: Mid-course Campaign Update and Improved Analysis Techniques with Application to β Pic b:**
Jason Wang (UC Berkeley) *Contributor*

09:40 **The GPI Exoplanet Survey II: Probing the Diversity of Giant Planet Atmospheres and System Architectures:**
Julien Rameau (iREx, University of Montréal, Canada) *Contributor*

10:00 **Coffee break**

10:30 **Characterization of substellar companions observed during the SPHERE exoplanet survey SHINE:**
Mickaël Bonnefoy (Institut de Planétologie et d'Astrophysique de Grenoble) *Contributor*

11:00 **Exoplanet Demographics versus Host Star Mass: Clues to Formation from Direct Imaging:**
Michael Meyer (ETH Zürich) *Contributor*

11:20 **Debris disk architectures and dust properties discovered with GPI:**
Paul Kalas (UC Berkeley) *Contributor*

11:40 **Direct constraints on planet formation: Young planets embedded in circumstellar disks:**
Sascha P. Quanz (ETH Zurich) *Contributor*

12:00 **Afternoon break**

Session Chair: Quanz

15:00 **Planet Formation in Action**
Adam Kraus (UT-Austin) *Invited*

15:30 **The WFIRST AFTA Coronagraph - Status and Performance Expectations:**
Bijan Nemati (Jet Propulsion Laboratory, California Institute of Technology) *Contributor*

16:00 **Atmospheric C/O Ratios Provide Clues to the Origin of Supermassive Gas Giant Planets at Wide Separations:**
Marta Bryan (Caltech) *Contributor*

16:20 **Substructure in the LkCa 15 planet-forming disk:**
Christian Thalmann (ETH Zürich) *Contributor*

16:40 **The NASA Exoplanet Exploration Program:**
Karl Stapelfeldt (Jet Propulsion Laboratory, California Institute of Technology) *Contributor*

17:00 **Coffee break**

Microlensing

17:30 **Gravitational Microlensing Surveys for Exoplanets: A Watershed:**
Scott Gaudi (OSU) *Invited*

18:00 **Highlights of Microlensing Planet Discoveries:**
Jennifer Yee (Harvard-Smithsonian Center for Astrophysics) *Invited*

18:30 **K2's Campaign 9: The First Microlensing Survey from the Ground and from Space:**
Calen Henderson (NASA Jet Propulsion Laboratory) *Contributor*

extreme-precision radial velocity; detections of exoplanets via transits; exoplanet occurrence rates and statistics; celestial mechanics and transit timing techniques; general theory and nexus of theory and observations; atmospheric characterisation; directly imaged exoplanets and brown dwarfs; synthetic spectra, spectral/chemical modeling and general circulation models; gravitational microlensing; constraints on planet formation; extreme-precision radial velocity; detections of exoplanets via transits; exoplanet occurrence rates and statistics; celestial mechanics and transit timing techniques; space missions and large observatories

Transits

Overcoming stellar variability in planet searches with non-parametric Bayesian methods:

Suzanne Aigrain (University of Oxford) *Invited*

Intrinsic stellar variability has become the limiting factor in our ability to detect and characterise small, cool exoplanets via the transit and radial velocity (RV) methods. This is an obstacle that must be overcome if we are to make the most of current and next-generation transit surveys and RV instruments, whether we seek Earth analogs, or planets orbiting active (low-mass and/or young) stars. It is becoming increasingly important to model variability, instrumental effects and planetary signals jointly, rather than try to filter one after the other. A promising and increasingly popular approach consists in using non-parametric Bayesian methods, such as Gaussian process (GP) regression, to model stochastic processes such as variability, while simultaneously fitting for the planetary signal and any well-understood instrumental effects. This provides a flexible framework into which we can fold new information as our understanding of the physical origin of the variability improves, and enables robust propagation of uncertainties. I will outline the principles behind these new methods and illustrate their potential through representative examples.

Transits

Discovery and Characterization of Exoplanets from the NASA K2 Mission:

Knicole Colon (NASA Ames Research Center) *Contributor*

I will provide an overview of exoplanet discoveries from the NASA K2 mission and highlight some of the particularly unique and exciting discoveries made so far. K2 is a community-driven mission that uses the Kepler spacecraft to observe different fields along the ecliptic in ~80 day campaigns. Over K2's lifetime (~18 campaigns or ~4 years), K2 will discover a significant number of transiting exoplanets, extending the legacy of the Kepler mission. Indeed, K2 has already discovered ~50 exoplanets with a couple hundred more candidates awaiting confirmation, just from the first few campaigns alone. I will also present a catalog of well-vetted K2 exoplanet candidates that is being produced by members of the Kepler/K2 Project Office. Lessons learned during the Kepler mission for identifying and vetting exoplanet candidates are being applied to the K2 data in the development of this catalog. Such a catalog will minimize the number of false positives and increase the efficiency of follow-up efforts by the community. Finally, I will present new results from our program for transit follow-up of K2 exoplanet candidates using near-infrared imagers on the 4m Mayall Telescope and the 3.5m WIYN Telescope at Kitt Peak National Observatory (the latter which had time allocated through the NN-EXPLORE program). These observations aid the confirmation and characterization of these new exoplanets, many which are smaller than Neptune, orbit cool, nearby stars, and are amenable to detailed atmospheric characterization with NASA's James Webb Space Telescope.

Transits

A hot Jupiter with 70 sec TTV modulation and a period of 3 years: reflex motion induced by a brown dwarf or M-star at 2 AU? :

Mazeh Tsevi (Tel Aviv University) *Contributor*

After analyzing the TTVs of all Kepler KOIs, we have found one KOI with small TTV modulation, of about 70 sec amplitude and a period of 3 years. The significant modulation is of KOI-760, a star with a temperature of 6100 +/- 200 deg, orbited by a 5 d hot Jupiter. The modulation is consistent with the LITE effect, reflecting the reflex motion of KOI-760, induced by a massive brown dwarf or a small M star at an orbit of 2 AUs. IF confirmed, this is probably the first time such a companion to a star with hot Jupiter is detected at a distance of 2 AU. Such a system might question the appropriateness of one of the hot Jupiter common paradigms, which assumes a planetary formation at a distance larger than 5 AU followed by disk migration.

Transits

200 Candidates and Validated Planets from K2's First Year:

Ian Crossfield (University of Arizona) *Contributor*

We present over one hundred validated planets, discovered using data from the first year of the NASA K2 mission (Campaigns 0–4), along with the results of an intensive program of photometric analyses, stellar spectroscopy, high-resolution imaging, and statistical validation. Of the validated planets, 46 are in multi-planet systems. Of the rest, 24 are false positives, and 68 remain candidates. Our validated systems span a range of properties, having median values of R_P = 2.4 Re, P = 9.0 d, Teff = 5300 K, and Kp = 12.7 mag. Stellar spectroscopy provides precise stellar and planetary parameters for most of these systems. We show that K2 has increased by 50% the number of small planets known to orbit moderately bright stars (1–4 Re, J = 8–12 mag). Of particular interest are 37 planets smaller than 2 Re , and 15 orbiting stars brighter than V = 12 mag, and several with Earth-like irradiation levels. We demonstrate that our candidate sample has an overall false positive rate of 20%, with rates substantially lower for small candidates (< 2Re) and larger for candidates with radii > 8 Re and/or with P < 3 d. Extrapolation of the current planetary yield suggests that K2 will discover between 500 – 1000 planets in its planned four-year mission -- assuming sufficient follow-up resources are available. Efficient observing and analysis, together with an organized and coherent follow-up strategy, is essential to maximize the efficacy of planet-validation efforts for K2 , TESS , and future large-scale surveys.

Transits

Detecting & Characterizing Small Planets Orbiting Small Stars: From Kepler to K2 and on to TESS!:

Courtney Dressing (Caltech) *Contributor*

Using the full four-year Kepler dataset, we estimated an occurrence rate of 0.24 (+0.18/-0.08) Earth-size planets and 0.21 (+0.11/-0.06) super-Earths per small star habitable zone and predicted that the nearest, potentially habitable transiting planet orbits an M dwarf within 11 pc. We are now searching for these nearby, potentially habitable worlds by obtaining near-infrared spectra with IRTF/SpeX and Palomar/TripleSpec to characterize the population of K2 planet candidates orbiting low-mass stars. Many K2 targets are poorly characterized, so follow-up observations are crucial for identifying false positives and determining accurate planet radii. As of March 2016, we have observed 103 K2 candidate planetary systems, 48 of which include candidates with initial radius estimates < 2 Earth radii. I will present our resulting catalog of refined system properties and compare the population of K2 planetary systems orbiting low-mass stars to those detected by the original Kepler mission. Finally, I will address the implications for the expected yield of M dwarf planetary systems from the Transiting Exoplanet Survey Satellite and the prospects for detailed follow-up investigations with Hubble, Spitzer, JWST, and the next generation of extremely large ground-based telescopes.

Transits

SPECULOOS: searching for exo-Earths at the bottom of the main-sequence:

Michaël Gillon (University of Liege, Belgium) *Contributor*

The first detailed atmospheric characterizations of exoplanets similar in size and temperature to Earth are eagerly awaited. Theoretically, transit techniques represent a possible path to this breakthrough. Still, the extreme size- and brightness-ratios between an exo-Earth and its stellar host make virtually impossible its atmospheric characterization with existing and next-generation astronomical facilities ... except if the planet transits a very nearby "ultracool dwarf" star, i.e. a Jupiter-sized star at the extreme bottom of the main-sequence. Unfortunately, these mini-stars, despite being very frequent in the Galaxy, have been mostly unexplored for planets so far. In this context, we present here the SPECULOOS project, a new transit survey targeting the ~500 brightest southern ultracool dwarfs based on four dedicated 1m robotic telescopes to be installed this year at ESO Paranal Observatory, Chile. We describe the concept and status of SPECULOOS, some results of its prototype ongoing since 2011 in Chile, and our current efforts to extend the project to the Northern hemisphere.

Transits

It's About Time: Exoplanet Evolution from the Pre-Main Sequence to the Red Giant Branch:

Eric Gaidos (University of Hawaii at Manoa) *Contributor*

Time is one of the least explored dimensions of exoplanet research; most stars targeted by large surveys are middle-aged by necessity or statistics. Yet the first few hundred million years of a planetary system are the most formative and include accretion, migration, and escape of atmospheres. While the Kepler prime field included a small number of young stars by chance, the K2 mission is deliberately selecting some target stars by age, and previews the potential of TESS and PLATO. The Zodical Exoplanets in Time (ZEIT) project is studying K2 systems in stellar clusters of established ages. Transiting planets as small as Earth-size have been detected in the Upper Scorpius, Pleiades, Hyades, and Praesepe clusters. Mysterious aperiodic signals related to circumstellar disks, and possibly connected to planet formation (i.e. planetesimal "clumps") have been found in Upper Scorpius. We are also investigating planets around evolved stars and report a Jupiter-mass planet inflated by irradiation from its host star. This study benefits from the precise asteroseismic parameters available for oscillating red giant branch stars. These systems will be observed at other wavelengths, e.g. with ALMA to measure disk gas and dust content, Spitzer for more accurate lightcurves, and HSt to detect atmospheres. Gaia distances, proper motions, and spectra can identify large numbers of young stars for observation by the TESS and PLATO missions, enabling robust comparisons across a range of ages to understand evolutionary trends, and select propitious targets for follow-up by ELTs and space observatories such as JWST.

Transits

Exploring variations in planet occurrence rates across the Galaxy with K2:

Jessie Christiansen (NASA Exoplanet Science Institute/Caltech) *Contributor*

The repurposed NASA Kepler mission – K2 – and its ecliptic plane transit survey present an early opportunity to investigate how the occurrence rates of planets varies throughout the Galaxy. I will discuss the lessons learned from the Kepler occurrence rate calculations, and begin to lay out the path forward for K2. This includes surmounting new difficulties, such as the target selection variations from campaign to campaign, generating a uniform master list of candidates from the extant lists, and characterising the completeness and reliability of such a sample.

Transits

Neptunes and super-Earths from the Next Generation Transit Survey (NGTS):

Peter Wheatley (University of Warwick) *Contributor*

The Next Generation Transit Survey (NGTS) has been operating since mid-2015 and is designed to detect transiting Neptunes and super-Earths around bright stars. The survey routinely delivers sub-mmag photometry across a wide field, thanks to precise autoguiding and the exceptional observing conditions at the ESO Paranal observatory (the site of the VLT). Exoplanet candidates have already been identified in NGTS data and follow up observations are underway.

In this talk I will explain the science goals of NGTS and describe the current status of the survey. This will include presenting exoplanet candidates and summarizing the status of our follow up observations. I will also show how NGTS will add value to the TESS mission, in particular by detecting long-period planets that have only single transits in the TESS survey data. The NGTS facility is perfectly suited to efficient follow up of TESS candidates because the twelve telescopes are independently steerable and optimized for high-precision measurements of bright stars.

This abstract has been submitted on behalf of the NGTS consortium (including researchers from the universities of Warwick, Leicester, Geneva, Cambridge, Belfast and DLR Berlin).

Transits

Terrestrial Planet Occurrence Rates From The Final Kepler Pipeline Search:

Christopher Burke (SETI / NASA Ames) *Invited*

I discuss latest results in measuring terrestrial planet occurrence rates using the planet candidates discovered by the Kepler pipeline. The final Kepler pipeline search results have become publicly available. I will present preliminary measurements of the sensitivity and reliability of the final search and subsequent automated planet candidate assessments which are critical for an accurate measurement of habitable zone planet population statistics. The Kepler data points to a sharp contrast between the planets hosted by G and M dwarfs with potential implications for understanding the planet formation process.

RV & Stars

A massive rocky planet and an additional non-transiting planet in the Kepler-20 system:

Lars A. Buchhave (University of Copenhagen) *Contributor*

Kepler-20 is a solar type star (V = 12.5) hosting a compact system of five transiting planets, all packed within the orbital distance of Mercury in our own Solar System. A transition from rocky to gaseous planets with a planetary transition radius of ~1.6 R⊕ has recently been proposed by several publications in the literature. Kepler-20b (Rp ~ 1.9 R⊕) has a size beyond this transition radius, however previous mass measurements of were not sufficiently precise to allow definite conclusions to be drawn regarding its composition. We present new mass measurements of three of the planets in the Kepler-20 system from the HARPS-N spectrograph, as well as an updated photometric analysis of the Kepler data and an asteroseismic analysis of the host star. Kepler-20b is a 1.859 +- 0.048 R⊕ planet in a 3.7 day period with a mass of 9.27 +1.25 -1.49 M⊕ resulting in a mean density of 8.0 +1.2 -1.4 g cm-3 indicating a rocky composition with an iron to silicate ratio consistent with that of the Earth. Furthermore, we report the discovery of an additional non-transiting planet with a mass of ~ 20 M⊕ in the gap between Kepler-20f and Kepler-20d with an orbital period of ~ 34.3 days. I will put this result into a more general context and discuss what we have learned about the mass and radius of small planets over the past few years primarily focused on the precise mass measurements of small transiting planets from the HARPS-N consortium.

RV & Stars

REVISED MASSES AND DENSITIES OF THE PLANETS AROUND KEPLER-10:

Lauren Weiss (UC Berkeley) *Contributor*

Determining which small exoplanets have stony-iron compositions is necessary for quantifying the occurrence of such planets and for understanding the physics of planet formation. Kepler-10 hosts the stony-iron world Kepler-10b, and also contains what has been reported to be the largest solid silicate-ice planet, Kepler-10c. Using 220 radial velocities (RVs), including 72 precise RVs from Keck-HIRES of which 20 are new from 2014-2015, and 17 quarters of Kepler photometry, we obtain the most complete picture of the Kepler-10 system to date. We find that Kepler-10b (Rp = 1.47 R⊕) has mass 3.72 ± 0.42 M⊕ and density 6.46 ± 0.73 g cm−3. Modeling the interior of Kepler-10b as an iron core overlaid with a silicate mantle, we find that the iron core constitutes 0.17 ± 0.11 of the planet mass. For Kepler-10c (Rp = 2.35 R⊕) we measure mass 13.98 ± 1.79 M⊕ and density 5.94 ± 0.76 g cm−3, significantly lower than the mass computed in Dumusque et al. (2014, 17.2 ± 1.9 M⊕). Our mass measurement of Kepler-10c rules out a pure stony-iron composition. Internal compositional modeling reveals that at least 10% of the radius of Kepler-10c is a volatile envelope composed of hydrogen-helium (0.2% of the mass, 16% of the radius) or super-ionic water (28% of the mass, 29% of the radius). However, we note that analysis of only HIRES data yields a higher mass for planet b and a lower mass for planet c than does analysis of the HARPS-N data alone, with the mass estimates for Kepler-10 c being formally inconsistent at the 3σ level. Moreover, dividing the data for each instrument into two parts also leads to somewhat inconsistent measurements for the mass of planet c derived from each observatory. Together, this suggests that time-correlated noise is present and that the uncertainties in the masses of the planets (especially planet c) likely exceed our formal estimates. Transit timing variations (TTVs) of Kepler-10c indicate the likely presence of a third planet in the system, KOI- 72.X. The TTVs and RVs are consistent with KOI-72.X having an orbital period of 24, 71, or 101 days, and a mass from 1-7 M⊕.

RV & Stars

Halpha as a Diagnostic of FGKM Stellar Atmospheres :

Johanna Teske (Carnegie Institution for Science) *Contributor*

The detection of exoplanets via radial velocity (RV) has become increasingly dependent on a deep understanding of the behavior of stellar atmospheres. Periodic variations due to stellar activity, rotation, and/or pulsation can be, and have been, confused with signals of orbiting planets, but are also diagnostic of fundamental properties of stars, like age or interior structure. Studying such variation diagnostics across a wide sample of stars is thus important to tease out different dependencies, including planet-induced RV variations, particularly for small planets. I will present, for the first time, measures of the stellar activity as reckoned from the Halpha Balmer line of hydrogen at 6563A in ~43,000 HIRES spectra of ~1500 FGKM stars being monitored for planets, many for over ten years. The motivation to use an additional activity index, besides the S value, comes from the low flux of M dwarf stars in the Ca H&K wavelength region; these stars are the most promising candidates for habitable planets. However, I will show that the variation in Halpha flux is also diagnostic of higher mass star properties, proving its utility across a wide SpT space for both RV planet detection and stellar atmosphere characterization.

RV & Stars

Kepler Small Planets Follow-up with HARPS-N: The Mass-radius Relation of Rocky Planets:

Mercedes Lopez-Morales (Harvard-Smithsonian CfA) *Contributor*

One of the main findings of NASA's Kepler Mission has been an abundance of planets with radii between that of Neptune and Earth around solar type stars, the so-called mini-Neptunes and super-Earths. There is no equivalent of those planets in our Solar System, but about 80 percent of the candidates in the Kepler catalog are in this size range. In spite of their large numbers, we still know very little about the masses of mini-Neptunes and super-Earths, and their densities. In this presentation I will summarize the on-going efforts by the HARPS-N Consortium Team to measure precise, 20% or better, masses of a large set of mini-Neptunes and super-Earths discovered by Kepler, with radii between 1 and 2.5 Earths. Using HARPS-N on the Telescopio Nazionale Galileo, where we have 80 nights per year of guaranteed time, we have already published precise masses for eight planets in that radius range, and found that all observed planets smaller than 1.6 Earth radii and with masses less than about 6 Earth masses are rocky, bare cores, and have interior compositions similar to Earth's. The current hypothesis is that we are observing an insolation effect, since all the rocky planets we have measured so far are in very short orbits. However, a larger sample of small planets with a wider range of insolation levels, and other parameters needs to be observed before we can conclude a cause. We expect our survey results will improve understanding of the origins and evolution of small planets.

RV & Stars

Rotation and winds of giant exoplanets measured through high-dispersion transmission spectroscopy:

Matteo Brogi (University of Colorado at Boulder) *Contributor*

Giant exoplanets orbiting their parent stars in a few days (hot Jupiters) are expected to have equal rotational and orbital periods (tidal locking). In addition, models predict two main regimes of atmospheric circulation, namely equatorial jet streams and global day-to-night side winds.

In this talk I present high-dispersion observations with VLT/CRIRES used to validate these theoretical predictions. We observed a transit of HD189733b, a Jupiter-size planet orbiting a K-dwarf in 2.2 days, at 2.3 micron. We detected the combined absorption of CO and H2O at 7.6 sigma of significance after cross correlating with a range of model spectra. We also measured the distortion of the planet spectral lines caused by rotation and winds. We derived a rotational period consistent with the orbital period and therefore with tidal locking. Although we were unable to constrain the equatorial jet-stream velocity, we detected a small day-to-night side wind. The latter can be compared with sodium absorption measured in the optical and used to infer the vertical wind shear.

These observations reinforce the pivotal role of high-resolution spectroscopy in constraining fundamental properties of exoplanets. The measurements conducted today on hot Jupiters are the foundation of future characterization of terrestrial exoplanets.

RV & Stars

Overcoming stellar activity radial-velocity noise through solar investigations at HARPS-N:

Raphaëlle Haywood (Harvard College Observatory) *Contributor*

Raphaëlle D. Haywood and the HARPS-N science team

Planet-hunter by night and Sun-chaser by day, the HARPS-N spectrograph has been operating with a new solar telescope feed since 2015 July. I will present results from the first 11 months of observations, which show 7 to 8 m/s variations in the solar radial velocity. The solar 27-day rotation signal is found in both the radial velocity and the higher moments of the cross-correlation function. These higher moments are proxies for activity-driven RV variations.

Since we can resolve the surface of the Sun directly, we can explore the origin of these higher moments in magnetically active regions on the photosphere. I use simultaneous, high spatial resolution images from the Solar Dynamics Observatory to reconstruct the line profile shape resulting from individual solar surface features, such as faculae/plage, sunspots and granulation. By comparing these reconstructed line profiles with the cross-correlation functions obtained by HARPS-N, I aim to identify a new proxy for facular radial-velocity signatures. These are known to be the main source of activity variations through suppression of convective blueshift.

This investigation is an essential step to determining precise and accurate masses of Neptune- and super-Earth-mass planets targeted by HARPS-N at nighttime, in readiness for the TESS, CHEOPS and PLATO missions.

RV & Stars

UV and X-ray Irradiance for Atmospheric Characterization of Planets Orbiting M and K Dwarfs:

Kevin France (University of Colorado) *Contributor*

High-energy photons (X-ray to NUV; 5 – 3200 Ang) from exoplanet host stars regulate the atmospheric temperature profiles and photochemistry on orbiting planets, influencing the production of potential "biomarker" gases. However, few observational and theoretical constraints exist on the high-energy irradiance from typical (i.e., weakly active) M and K dwarf exoplanet host stars. Towards the development of an empirical database of stellar spectra to support exoplanet atmosphere modeling, we present results from a panchromatic survey (Hubble/Chandra/XMM/optical) of M and K dwarf exoplanet hosts. The MUSCLES Treasury Survey (Measurements of the Ultraviolet Spectral Characteristics of Low-mass Exoplanetary Systems) combines UV and X-ray observations with reconstructed Lyman-alpha and EUV (100-900 Ang) radiation to create 5 Angstrom to 5 micron stellar irradiance spectra. These data are now publically available as a High-Level Science Product on MAST. We find that all low-mass exoplanet host stars exhibit significant chromospheric/transition region/coronal emission — no "UV/X-ray inactive" M or K dwarfs are observed. The F(FUV)/F(NUV) flux ratio, a driver for possible abiotic production of the suggested biomarkers O_2 and O_3, increases by ~3 orders of magnitude as the star's habitable zone moves inward from 1 to 0.1 AU, while the incident FUV (912 – 1700 Ang) and XUV (5 – 900 Ang) radiation field strengths are approximately constant across this range. Far-UV flare activity is common in 'optically inactive' M dwarfs, and we present tentative evidence for the interaction of massive planets with the upper atmospheres of their cool host stars.

Orbital dynamics+TTVs

Orbital instability and the evolution of planetary systems:

Katherine Deck (Caltech) *Invited*

The Solar System is chaotic but long-lived: orbital instability is thought to have played a role in the past, but the Solar System in many Gyr will likely appear very much as it does today. Similarly, systems of exoplanets orbiting main sequence stars are long-lived (given that we observe them in their current states), yet they too may have been shaped by past orbital instability. I will discuss observational evidence for this, discuss current research results, and highlight open questions remaining, focusing on both systems of giant planets and those with small planets orbiting close to their host stars.

Orbital dynamics+TTVs

Low-mass Planets Probed by Transit Timing Variations:

Daniel Fabrycky (University of Chicago) *Invited*

(Preliminary) The transit timing method is not so easy to apply when we cannot measure individual transit times. Here we discuss recent approaches to photodynamic detection and interpretation of both individual systems and statistical results for many systems. This provides our first look at the eccentricities of rocky planets with masses approaching that of the Earth, and hence gives us new constraints on planet formation.

Orbital dynamics+TTVs

New developments in characterizing the architectures of exoplanet systems:

Jason Steffen (University of Nevada, Las Vegas) *Contributor*

The architecture of planetary systems is key information that connects the formation and dynamical evolution of planetary systems to current observations. I present an analysis of results from the Kepler mission, identifying statistically significant features in system architecture, the understanding of which will shed light on the processes at work in the past. In particular, there is a significant excess of planet pairs with an orbital period ratio near 2.2---a quantity not predicted by standard theoretical models, yet sufficiently close to the 2:1 mean-motion resonance as to be difficult to distinguish from eccentric single planets using RV observations. I present a preliminary study of a sample of RV systems that strongly motivates careful scrutiny of systems with low-mass eccentric planets. In addition, an analysis of single, Earth-sized planets with one-day orbital periods indicates the presence of a new population of planetary system with an architecture that is distinctly different from the typical system seen by Kepler.

Orbital dynamics+TTVs

KOINet: reprising Kepler's heritage from the ground:

Carolina von Essen (Stellar Astrophysics Centre - Aarhus University) *Contributor*

During its four years of photometric observations the Kepler space telescope has detected thousands of exoplanet candidates. One of Kepler's most intriguing tools has been the confirmation and characterization of multiplanet systems via Transit Timing Variations (TTV). Unfortunately there are many interesting multiplanet candidate systems displaying TTVs on such long time scales that the existing Kepler observations are insufficiently long to confirm or characterize them. Therefore we have organized KOINet, a near-global photometric follow-up network consisting of ~20 middle-sized telescopes distributed in longitude between the United States and China, allowing almost 24 hours of continuous monitoring. Over the last years we have used KOINet to follow-up long period TTV systems to confirm and characterize 60 Kepler Object of Interest. Here we present the current status of KOInet and our first results over Kepler-9b,c and KOI-0410.

Missions

CHEOPS science program outlook:

Didier Queloz (University of Cambridge) *Contributor*

CHEOPS is a S mission class space mission planned to be launched early 2018. A first outlook of the comprehensive science program jointly established by the CHEOPS Science Team will be described in this talk in views of the expected performance of this mission.

Missions

The CHEOPS Mission: Performance and Current Status:
Christopher Broeg (University of Bern / CSH) *Invited*

The CHaracterising ExOPlanet Satellite (CHEOPS) is a joint ESA-Switzerland space mission dedicated to search for exoplanet transits by means of ultra-high precision photometry. It is expected to be flight-ready at the end of 2017.

CHEOPS will be the first space observatory dedicated to search for transits on bright stars already known to host planets. It will have access to more than 70% of the sky. This will provide the unique capability of determining accurate radii for planets for which the mass has already been estimated from ground-based radial velocity surveys and for new planets discovered by the next generation ground-based transits surveys (Neptune-size and smaller). The measurement of the radius of a planet from its transit combined with the determination of its mass through radial velocity techniques gives the bulk density of the planet, which provides direct insights into the structure and/or composition of the body. In order to meet the scientific objectives, a number of requirements have been derived that drive the design of CHEOPS. For the detection of Earth and super-Earth planets orbiting G5 dwarf stars with V-band magnitudes in the range $6 \leq V \leq 9$ mag, a photometric precision of 20 ppm in 6 hours of integration time must be reached. This time corresponds to the transit duration of a planet with a revolution period of 50 days. In the case of Neptune-size planets orbiting K-type dwarf with magnitudes as faint as V=12 mag, a photometric precision of 85 ppm in 3 hours of integration time must be reached. To achieve this performance, the CHEOPS mission payload consists of only one instrument, a space telescope of 30 cm clear aperture, which has a single CCD focal plane detector. CHEOPS will be inserted in a low Earth orbit and the total duration of the CHEOPS mission is 3.5 years (goal: 5 years).

The talk will describe the mission rationale of CHEOPS and present the payload and mission design. Furthermore it will show the development status, and the expected performances.

General theory

Equations of state of dense matter under planetary interior conditions:
Gilles Chabrier (CRAL, ENS-Lyon) *Contributor*

In this talk, I will present recent calculations of new equations of state and transport and optical properties for various elements under conditions characteristic of planetary interiors. These new equations of state will now supplement the present generations of semi-analytical models and enable us to solve the uncertainties in planetary models due to the limited reliability of the old models. Furthermore, I will highlight the possibility to now test the validity of these eos models with the high power laser facilities (LMJ in France, NIF in the USA) which now allow for the first time to genuinely probe astrophysical and planetary conditions in laboratories.

General theory

Exo-Mercury Analogues and the Roche Limit for Close-Orbiting Rocky Planets:

Leslie Rogers (University of California, Berkeley) *Contributor*

The origin of Mercury's enhanced iron content is a matter of ongoing debate. The characterization of rocky exoplanets promises to provide new independent insights on this topic, by constraining the occurrence rate and physical and orbital properties of iron-enhanced planets orbiting distant stars. The ultra-short-period transiting planet candidate KOI-1843.03 (0.6 Earth-radius, 4.245 hour orbital period, 0.46 Solar-mass host star) represents the first exo-Mercury planet candidate ever identified. For KOI-1843.03 to have avoided tidal disruption on such a short orbit, Rappaport et al. (2013) estimate that it must have a mean density of at least 7g/cc and be at least as iron rich as Mercury. This density lower-limit, however, relies upon interpolating the Roche limits of single-component polytrope models, which do not accurately capture the density profiles of >1000 km differentiated rocky bodies. A more exact calculation of the Roche limit for the case of rocky planets of arbitrary composition and central concentration is needed. We present 3D interior structure simulations of ultra-short-period tidally distorted rocky exoplanets, calculated using a modified version of Hachisu's self-consistent field method and realistic equations of state for silicates and iron. We derive the Roche limits of rocky planets as a function of mass and composition, and refine the composition constraints on KOI-1843.03. We conclude by discussing the implications of our simulations for the eventual characterization of short-period transiting planets discovered by K2, TESS, CHEOPS and PLATO.

General theory

A generalized Bayesian inference method to constrain the interiors of super Earths and Sub-Neptunes:

Caroline Dorn (University of Bern) *Contributor*

Characterization of exoplanet interiors is key for understanding planet diversity. We present a generalized Bayesian inference method for rigorously characterizing the interiors of super Earths and Sub-Neptunes, including atmospheres, high-pressure ices, and rocky cores. We employ a full probabilistic Bayesian inference analysis that formally accounts for observational and model uncertainties. Using a Markov chain Monte Carlo technique, we compute how strong constraints on composition and layer thicknesses are based on observations of mass, radius, and bulk abundance constraints on refractory elements (Fe, Mg, Si). The latter can be assumed to be correlated to stellar abundances. We include state-of-the-art structural models that use self-consistent thermodynamics of core, mantle, high-pressure ice and liquid water and compute irradiated atmospheres.

Our method is able to predict interior structures of Neptune that agree with independent geophysical estimates. Furthermore, we apply our method on six exoplanets for which not only mass and radius are known but also additional bulk abundance proxies from their host stars. These exoplanets are HD 219134b, Kepler-10b, Kepler 93b, CoRoT-7b, 55Cnc e, and HD 97658 b. We are able to determine their ranges of possible interior structures as well as the correlations between structural parameters, which highly depend on data and data uncertainties. For example, we generally find strong correlations between mass of waterice and the mantle size. To first order, (1) structural parameters of core, mantle, and water envelope are sensitive to planetary mass, (2) parameters of gaseous and water envelope are sensitive to planetary radius, and (3) parameters of core and mantle are coupled through the stellar abundance proxy. The probability for the tested exoplanets to be Earth-like is generally very low.

Our provided general methodology of analyzing interior structures of exoplanets may help to better understand planet diversity and hence planet formation.

General theory

Dynamical interactions within planetary systems:

Melvyn Davies (Lund University) *Contributor*

I will discuss how dynamical interactions within planetary systems can shape their architectures. In particular, I will focus on what happens to planetary systems when the outer planets within a system become unstable, either through planet-planet interactions or Kozai perturbations from an inclined stellar companion. Both processes may lead to the scattering of planets towards the inner regions of the planetary system. Building on our published work (Mustill, Davies & Johansen, 2015, ApJ, 808, id. 14), I will show how such scattering can explain at least some hot jupiters, as well the observed absence of close-in companions to hot jupiters. Thus we will connect the outer worlds (observed typically through radial-velocity surveys) with those inner worlds (found in transit surveys).

General theory

Formation and Dynamics of Circumbinary Planets:

Dong Lai (Cornell Univ.) *Contributor*

The discovery of more than a dozen transiting circumbinary planets provides new constraints on the planet formation and migration processes in circumbinary disks and also raises a number of puzzles. I will discuss several recent works related to circumbinary planets and disks. (1) New long-duration hydro simulations of circumbinary disks (Miranda, Lai and Munoz 2016). The simulations reveal that the inner circumbinary disk may develop appreciable eccentricity and precesseses coherently – these features are bound to have a strong impact on planet-disk interaction. (2) The disruption of planetary orbits through evection resonances with an external companion (Xu and Lai 2016a). This may help explain the lack of transiting planets around very compact stellar binaries (Munoz and Lai 2015). (3) The stability of mean-motion resonance capture as planets migrate inwards in a circumbinary disk. This relates to the pile-up of planets near the stability limit as observed in the sample of transiting circumbinary planets (Xu and Lai 2016b in prep).

General theory

Warm Jupiters from secular planet-planet interactions:

Cristobal Petrovich (Canadian Institute for Theoretical Astrophysics) *Contributor*

Most warm Jupiters (gas-giant planets with a~0.1-1 AU) have pericenter distances that are too large for significant orbital migration by tidal friction. We study the possibility that the warm Jupiters are undergoing secular eccentricity oscillations excited by an outer companion (a planet or star) in an eccentric and/or mutually inclined orbit. In this model the warm Jupiters migrate periodically, in the high-eccentricity phase of the oscillation when the pericenter distance is small, but are typically observed at much lower eccentricities. We show that the expected eccentricity distribution of the warm Jupiters migrating by this mechanism is approximately flat, which is consistent with the observed distribution of the warm Jupiters that have outer companions detected by radial-velocity surveys. Based on these findings and a population synthesis study, we argue that high-eccentricity migration produces ~20% of the warm Jupiters and most of the warm Jupiters with e>~0.4, a population that it is difficult to account for by other mechanisms (e.g., disk migration or in-situ formation). Finally, we provide predictions for the expected mutual inclinations and spin-orbit angles of the planetary systems with hot and warm Jupiters produced by high-eccentricity migration.

General theory

Forming Super-Earths in Transitional Disks:

Eugene Chiang (University of California, Berkeley) *Invited*

We review our understanding of transitional disks — those with central cavities that may host nascent planetary systems. New simulations of gap opening by planets will be presented. We show how super-Earths (a.k.a. mini-Neptunes), discovered in abundance by Kepler, may have acquired their voluminous atmospheres within transitional disks. In particular, we extend the theory of core nucleation — how cores accrete gas from the ambient nebula — to optically thin environments.

General theory

The Migratory Origin of Hot Jupiters and Super-puffs:

Eve Lee (UC Berkeley) *Contributor*

We discuss the origin of two rare classes of close-in exoplanets: hot Jupiters and super-puffs. Hot Jupiters are gas giants with orbital periods less than ~10 days. We review theoretical and observational reasons why we believe they migrated to their current locations. Through N-body calculations, we show that if hot Jupiters migrated by Lidov-Kozai oscillations driven by external planetary perturbers, close-in super-Earth companions would have been perturbed onto their host stars. This naturally explains why most hot Jupiters have no close-in transiting neighbour. Super-puffs are sub-Saturns with large radii (> 4 Rearth) and small masses (~2–6 Mearth), typically found between 0.3–0.5 AU. We show how super-puffs must have formed as dust-free worlds outside 1 AU, and then migrated to their current orbits; they are expected to form the outer links of mean-motion resonant chains, and to exhibit greater water content.

General theory

Hot-Jupiter Inflation and Re-inflation:

Sivan Ginzburg (Hebrew University Jerusalem) *Contributor*

Many hot Jupiters have observed radii that significantly exceed theoretical predictions. One suggested explanation for this discrepancy is deep heat deposition inside these planets that keeps them hot and inflated. We present an analytical model for the evolution of such irradiated, and internally heated gas giants. We show that cooling and contraction halt when the internal luminosity of the planet drops below the heat deposited in its convective region, with a slowdown in the evolutionary cooling prior to equilibrium possible only for heat sources that do not extend to the planet's center. As a quantitative example, we estimate the Ohmic heat dissipation resulting from the interaction of the atmospheric winds with the planet's magnetic field. We calculate the Ohmic inflation of planets as a function of their distance from the star, accounting for the radius excess of most inflated planets. We also argue that Ohmically inflated planets have already reached their equilibrium phase, and no longer contract. In addition, we argue that while it is possible to re-inflate (reheat) cold planets, the re-inflation timescales are longer than their age.

General theory

Measuring Stellar Tidal Dissipation Using Extremely Hot Jupiters :

Kaloyan Penev (Princeton University) *Contributor*

I will present preliminary results of measuring the stellar tidal quality factor (Q*) in the very shortest period exoplanetary systems with surface convective zone host stars. In particular I will consider two main methods of constraining Q*:

1. As stellar tidal dissipation causes the planet to migrate inward, the star gets spun up. Combining this with an empirically motivated prescription on how stars lose angular momentum, the present spin of the star can be predicted and compared to the observed value. Using just a single system (HATS-18) this constrains Q* to within an order of magnitude, with other short period systems providing less tight constraints.

2. The stellar tidal dissipation efficiency determines the amount of time it would take for the planet to spiral all the way in and be engulfed by the star, as well as the amount of time planets spend at different orbital periods on their way in. This, combined with estimates of how easy it is to detect a given planet at a given orbital period predicts the expected distribution of planetary orbits. At extremely short periods this expected distribution will be sensitive to the value of Q* and thus can be used to measure its value.

The results of both comparisons above will be discussed in the context of the recently claimed measurement of tidal decay in the WASP-12 system (Maciejewski et. al. 2016).

Planet formation

On the Origin and Formation of Kepler Planets:

Hilke Schlichting (MIT) *Invited*

Recent observations by the Kepler space telescope have led to the discovery of more than 4000 exoplanet candidates consisting of many systems with Earth- to Neptune-sized objects that reside well inside the orbit of Mercury around their respective host stars. How and where this new class of planets formed is one of the major unanswered questions in planet formation. I will present new results that self-consistently treat the nebular gas accretion onto rocky cores and the subsequent evolution of gas envelopes due to cooling and photo-evaporation following the dispersal of the protoplanetary disk. I will demonstrate that planets shed their outer layers (dozens of percent in mass) following the disk's dispersal (even without photo-evaporation), and that their atmospheres shrink in a few Myr to a thickness comparable to the radius of the underlying rocky core. In addition, I will show that the large diversity in exoplanet mean densities can be achieved by one or two late giant impacts, which are frequently needed to establish long-term orbital stability in multiple planet systems once the gas disk has disappeared. I will conclude with discussing the implications of these new results for the origin and formation of Kepler planets.

Atmospheres

Rethinking the super-Earth exoplanet 55 Cancri e:

Brice-Olivier Demory (Cavendish Laboratory, University of Cambridge) *Contributor*

Numerous efforts to observe the spectra of super-Earth exoplanets have so far proven extremely challenging by revealing only featureless spectra. I will present the first longitudinal thermal brightness map of a super-Earth, built from Spitzer observations obtained on the nearby 55 Cancri e. These observations reveal highly asymmetric dayside thermal emission and a strong day–night temperature contrast, which indicates inefficient heat redistribution from the dayside to the nightside. Our observations are consistent with either an optically thick atmosphere with heat recirculation confined to the planetary dayside, or a planet devoid of atmosphere with low-viscosity magma flows at the surface. I will present how the picture of this planet evolved along the years, what the implications of our results are, and how current and future efforts will allow us to solve the outstanding questions surrounding one of the most enigmatic exoplanet.

Atmospheres

The Nature of the Super-Earth 55 Cancri e:

Diana Dragomir (University of Chicago) *Contributor*

Recent surveys have revealed an extraordinary and unexplained diversity of low-mass exoplanets. The main frontier for constraining the nature and origins of these planets is atmospheric characterization to reveal their detailed physical properties. The transiting super-Earth 55 Cnc e orbits its bright, G type host star with an extremely short period of just under 18 hours. These characteristics make 55 Cnc e a good candidate for transmission spectroscopy, and an ideal target for dayside emission spectroscopy. We will present continuing evidence of a phase variation at the period of the planet seen in MOST photometry, first observed in the MOST 2011 transit discovery data for 55 Cnc e. We will show results from newly acquired Spitzer and HST WFC3 transits and eclipses of this planet (most of which will have been observed by the end of April 2016). From these data, we will generate the first dayside emission spectrum of a super-Earth. We will discuss our results in light of the recently announced variable eclipse depth and phase variations of this planet as observed with the Spitzer telescope. This multi-pronged data set for 55 Cnc e will guide JWST spectroscopy of a much larger sample of close-in low-mass transiting exoplanets.

Atmospheres

Spin of extrasolar planets and the accretion of angular momentum:

Ignas Snellen (Leiden Observatory, Leiden University) *Contributor*

Last year we detected for the first time the spin rotation of an extrasolar planet. Beta Pictoris was found to rotate with an equatorial velocity of 25 km/sec, significantly faster than Jupiter – in line with the mass-rotation relation found for Solar System planets. We now measured the rotation of several other planets (yet unpublished). What can it tell us about the process of angular momentum accretion?

Atmospheres

Exoplanet Atmospheres:

Nicolas Cowan (McGill University) *Invited*

Why? Because there are a lot of them and they are more varied than Solar System examples: they provide the leverage to uncover general trends, and the numbers to discover rare outliers.

How? By studying the light they reflect (NUV-NIR) and the light they radiate (NIR-FIR). For transiting exoplanets, it is also possible to study starlight filtered through the planet's upper atmosphere.

What? Highlights from the past 15 years include: detecting atoms, molecules, and clouds in the atmospheres of planets orbiting distant stars; measuring atmospheric temperature as a function of height, longitude, and latitude; seeing reflected light from patchy clouds; monitoring the rotation of planets, and observing their seasons.

Atmospheres

Atmospheric Constraints on Exoplanetary Formation and Migration:

Nikku Madhusudhan (University of Cambridge) *Contributor*

Chemical abundances in planetary atmospheres provide critical constraints not only on their atmospheric processes but also on their interiors and formation conditions. In the solar system the observed abundances of C, S, N, and nobel gases in Jupiter's atmosphere support its significant accretion of planetesimals during formation and constrain their origins in the disk. Recent advancements in spectroscopic observations of exoplanets are for the first time allowing precise estimations of their atmospheric chemical abundances. Such abundance measurements have the potential to possibly constrain the chemical conditions in exoplanetary formation environments and their migration pathways. In this talk we will present some of the latest results in this emerging area. Our results follow from a combination of detailed theoretical models spanning a wide range of formation/migration scenarios as well as precise observational constraints from state-of-the-art atmospheric abundances of a sizable sample of exoplanets. On the modeling side, we expand upon previous studies that used semi-analytic population synthesis models to presently using more rigorous hydrodynamic models that self-consistently take into account the accretion and migration. On the observational front, our atmospheric abundance measurements are obtained from the latest high-precision spectra and photometry from HST, Spitzer, and ground-based facilities. We will show how these data and models are providing the first insights into the formation/migration processes of exoplanets that have hitherto been hard to constrain using dynamical observables alone. Finally, we will discuss the future prospects and challenges on this new frontier.

Atmospheres

A Large Hubble Space Telescope Survey of Low-Mass Exoplanets:

Björn Benneke (Caltech) *Contributor*

The discovery of short-period planets with masses and radii between Earth and Neptune was one of the biggest surprises in the brief history of exoplanet science. From the Kepler mission, we know that these "super-Earths" or "sub-Neptunes" orbit at least 40% of stars, likely representing the most common outcome of planet formation. Despite this ubiquity, we know little about their typical compositions and formation histories. In this talk, we will shed new light on these worlds by presenting the main results from our 124-orbit HST transit spectroscopy survey to probe the chemical compositions of low-mass exoplanets. We will report on multiple molecular detections. Our unprecedented HST survey provides the first comprehensive look at this intriguing new class of planets by covering seven planets ranging from 1 Neptune mass and temperatures close to 2000K to a 1 Earth-mass planet near the habitable zone of its host star.

Atmospheres

HELIOS-R, an atmospheric retrieval code for exoplanets:

Baptiste Lavie (University of Bern) *Contributor*

Atmospheric retrieval is a growing, new approach in the theory of exoplanet atmosphere characterization. Unlike self-consistent forward modeling it allows us to fully explore the parameter space, as well as the degeneracies between the parameters using a Bayesian framework. I will discuss the difference between those two methods and I will present HELIOS-R, a very fast retrieving code written in Python and optimized for GPU computation. As the new generation of direct imaging instruments (SPHERE, GPI) have started to gather data, the first version of HELIOS-R focuses on emission spectra. We use a 1D two-stream forward model for computing fluxes and couple it to an analytical temperature-pressure profile that is constructed to be in radiative equilibrium. Different assumptions can be made in terms of number of molecules, number of parameters for the TP profile and molecules abundances treatment. Indeed, we introduce a new model to derive molecules abundances using equilibrium chemistry analytical solution developed by Heng & Lyons (2015). We use our ultra-fast opacity calculator HELIOS-K (open-source) to compute the opacities of CO2, H2O, CO and CH4 from the HITEMP database. We test both opacity sampling (which is typically used by other workers) and the method of k-distributions. Using this setup, we first focus on model selection by coupling our different forward models to a nested sampling algorithm. By focusing on model selection (Occam's razor) through the explicit computation of the Bayesian evidence, nested sampling allows us to deal with current sparse data as well as upcoming high-resolution observations. Once the best model is selected, HELIOS-R provides posterior distributions of the parameters. As a test for our code we studied HR8799 system and compared our results with the previous analysis of Lee, Heng & Irwin (2013), which used the proprietary NEMESIS retrieval code.

Atmospheres

New Dimensions of Climate: Exploring Hot Jupiter Atmospheres in 3D with HST and Spitzer:

Laura Kreidberg (Harvard University) *Contributor*

Measurements of exoplanet thermal structure constrain the physics of atmospheric heat circulation and reveal planetary climate. In this talk, I will present results from an intensive space-based observational campaign exploring the thermal structure of two hot Jupiters, WASP-103b and WASP-18b. This program combines the new technique of phase-resolved HST/WFC3 spectroscopy with Spitzer eclipse mapping, to yield the first constraints on temperature structure as a function of latitude, longitude, and altitude. I will discuss how these detailed measurements shed new light on several currently debated features of hot Jupiter atmospheres, including blackbody dayside spectra and carbon-rich compositions.

Atmospheres

The JWST/NIRSpec instrument: capabilities for exoplanet characterisation:

Stephan Birkmann (European Space Agency) *Contributor*

The Near Infrared Spectrograph (NIRSpec) is one of the science instruments on the James Webb Space Telescope that is on schedule for launch in 2018. NIRSpec has a dedicated mode for exoplanet transit spectroscopy, offering a wide wavelength coverage from 0.6 to 5.3 micron and a spectral resolution of up to ~3000. We present the instrument's characteristics and features relevant for exoplanet transit, eclipse and phase curve observations, and provide an update on expected source brightness limits and instrument performances.

Atmospheres

Atmospheric Characterization of Exoplanets with NIRISS on JWST:

René Doyon (Université de Montréal - iREx) *Contributor*

The Near-Infrared Imager and Slitless Spectrograph (NIRISS) onboard the James Webb Space Telescope features a grism mode specialized for high-precision transit spectroscopy of relatively bright stars. NIRISS provides simultaneous wavelength coverage between 0.6 and 2.8 um at a resolving power of 1500-1400, a unique capability for atmospheric characterization of existing transiting exoplanets – from hot Jupiters to super-Earths – as well as new systems unveiled by K2, CHEOPS, TESS and other ground-based observatories. This talk will present a brief overview of JWST's capabilities for exoplanet studies and highlight the NIRISS Guaranteed Time Observation program dedicated to exoplanet spectroscopy, including transits, eclipses and phases of several hot Jupiters and super-Earths.

Atmospheres

Tracing the Ingredients of Habitable Worlds:

Edwin Bergin (University of Michigan) *Contributor*

In this talk I trace the ingredients of habitable worlds, specifically compounds bearing carbon and nitrogen from their implantation into icy rocks in the early stages of planet formation to the fate of these carriers during planetary assembly. This work combines experts in astrochemistry, geophysics, and planetary science to use the C/N ratio to explore the origin of life's key ingredients to nascent terrestrial worlds. Thus I will outline our knowledge about carbon and nitrogen in the Earth and discuss the potential reservoirs available to supply needed volatile C and N to a forming planet. We will use this information to outline key relevant processes that lead to volatile gain or loss including: early stage kinetic chemistry within a gas-rich protoplanetary disk, thermal metamorphism in growing planetesimals, along with core formation and atmospheric loss during planetary assembly.

These loss processes must be accounted for in terrestrial planetary synthesis modeling along with a subsequent potential gain of these elements in the gas dominated atmospheres of giant planets. Where possible I will highlight how new instruments such as ALMA can set useful contraints. The stochastic nature of these processes hints that the surface/atmospheric abundances of biosphere-essential materials of terrestrial planets will likely be variable.

Atmospheres

Testing Assumptions in Atmospheric Retrieval I: The Pitfalls of "1D" Assumptions:

Michael Line (NASA-Ames) *Invited*

Transiting exoplanet spectra have the potential to provide a wealth of knowledge about atmospheric properties. However, the information we glean from such spectra are as of now, highly model dependent. Therefore any inferences about molecular/elemental abundances, cloud properties, and thermal properties will be largely influenced by our model assumptions. One, perhaps overlooked, assumption is the "1D" approximation. Most transit transmission and occultation spectra assume uniform terminators or emitting hemispheres, respectively. Real planets, however, need not be homogenous and assuming so could potentially bias our inference of thermal structure and composition. I will explore the biases incurred by the assumption of 1D on both transmission and emission spectra. First I will discuss the role of non-uniform cloud cover along the planetary limb and how cloud patchiness is degenerate with composition in the transit geometry along with implications. Second, I will discuss the role of hemispheric thermal inhomogeneities (e.g., multiple temperature-pressure profiles) on emission spectra and implications for the interpretation of phase curve spectra. These two examples illustrate how even the simplest 2- or 3-D effects can significantly skew spectral interpretations when not considered.

Atmospheres

Inhomogeneous exoplanet atmospheric reflection is common:

Avi Shporer (JPL) *Contributor*

We identify three transiting planets whose orbital phase-folded light curves are dominated by atmospheric processes including thermal emission and reflected light, while the impact of other processes, beaming (aka Doppler boosting) and tidal ellipsoidal distortion, is negligible. Therefore, these planets allow a direct view of their atmospheres, in visible light, without being hampered by the approximations used in the inclusion of both atmospheric and non-atmospheric processes in the phase curve modeling. We model Kepler-12b and Kepler-41b atmosphere based on their Kepler phase curve, while the modeling of Kepler-7b was already presented elsewhere. We confirm Kepler-12b and Kepler-41b show a westward phase shift between the brightest region on the planetary surface and the substellar point, similar to Kepler-7b. We find that reflective clouds located on the west side of the substellar point can best explain the phase shift. This observational identification of a bright-spot shift in all three systems we identify as having an atmospheric-dominated Kepler phase curve serves as empirical evidence that it is a common feature, affecting many other phase curves where both atmospheric and non-atmospheric effects are present, and where accounting for a bright-spot shift introduces model degeneracies. In addition, we identify a few chemical species that can be responsible for the shifted bright-spot, showing that phase curves can be used to study the atmospheric composition. Finally, the large optical geometric albedos of these three planets suggests that the photometric modulations induced by reflected light of non-transiting but otherwise similar planets can be used to detect them.

Atmospheres

Transitions in the cloud composition of hot Jupiters:

Vivien Parmentier (Lunar and Planetary Laboratory) *Contributor*

Over a large range of equilibrium temperatures clouds seem to dominate the transmission spectrum of hot Jupiters atmospheres but no trend allowing the classification of these objects have yet emerged. Here I will combine the latest observations with insights gained from a grid of global circulation models covering the whole equilibrium temperature range span by hot Jupiters to understand the physical and chemical properties of clouds together with their spatial distribution.

First I will show how the formation of a small particle haze and a large particle cloud deck are naturally produced by the atmospheric circulation of tidally locked planets, in agreement with current observations of the transit spectrum of HD189733b.

Then I will discuss how the large temperature contrast on hot Jupiters shapes the cloud distribution and why it is a telltale sign of the cloud composition. I will show that current observations by Kepler suggest that a transition similar to the L/T transition happens in hot Jupiters. Silicate clouds are present in planets with equilibrium temperatures hotter than 1600K but should disappear in cooler planets, where other type of clouds become important. Other transitions are expected and might be confirmed by future observations.

Direct imaging and brown dwarfs

Discovery of a Faint, Young Analogue to our Solar System:

Sasha Hinkley (University of Exeter) *Contributor*

I will announce the discovery of a new, edge-on circumstellar debris disc associated with a very young, nearby, solar type star. We successfully gathered scattered light images of the disc using Keck high contrast imaging over multiple epochs, representing the faintest scattered light disk observations for a K-type star. Unlike the majority of all other debris disc images, this target is a solar-type star, as well as a previously unrecognized member of the Beta Pictoris Moving Group stellar association with age 10-20 Myr. As such, this system is an analogue of our own solar system, but viewed shortly after the formation of massive planets has ceased. Further, we have obtained millimeter imaging at the SMA, IRAM and JCMT validating the extent of the cold dust component responsible for the millimeter emission. Importantly, our images show a striking non-linearity between the two edge-on disc lobes, and a lack of WISE infrared excess at 12 microns suggests clearing of very warm dust close to the star. This signature of inner disc clearing, as well as clear dynamical perturbations, strongly suggests this star hosts a newly formed exoplanetary system. Ongoing high contrast observations may be able to identify the exoplanet perturber.

Direct imaging and brown dwarfs

The GPI Exoplanet Survey I: Mid-course Campaign Update and Improved Analysis Techniques with Application to β Pic b:

Jason Wang (UC Berkeley) *Contributor*

The Gemini Planet Imager Exoplanet Survey has observed over 250 stars searching for young Jupiter-mass planets on Solar System scales. Combining the advanced instrumentation of the Gemini Planet Imager with an automated data reduction system, the survey has imaged 51 Eridani b, two previously-known exoplanets, and a new brown dwarf companion. Almost halfway through the survey, we are able to place the strongest constraints yet on the occurrence of medium-separation giant planets and can compare them with radial velocity results for closer-in planets. To further improve our survey performance, we have developed a new technique to analytically forward model the signal of a planet through our data reduction pipeline. Using this forward modelling technique, we can better distinguish a planet from residual speckle noise from the star, improving the survey's sensitivity to fainter planets closer in to the star. Additionally, this technique can also obtain accurate and precise astrometry and spectroscopy of exoplanets, and we will demonstrate its advantages in characterizing β Pictoris b, including reassessing its transit probability.

Direct imaging and brown dwarfs

The GPI Exoplanet Survey II: Probing the Diversity of Giant Planet Atmospheres and System Architectures:

Julien Rameau (iREx, University of Montréal, Canada) *Contributor*

After one and a half year, the Gemini Planet Imager (GPI) Exoplanet Survey has provided constraints on the diversity of directly-imaged giant planets in the Sun's neighborhood. Owing to the high-contrast and high-angular resolution offered by GPI and advanced data processing techniques, we achieved high astrometric precision and broad spectral coverage necessary to study the architecture of extrasolar planetary systems as well as the processes at play in the atmospheres of young giant planets which are not strongly illuminated. These observations are essential to test models of atmospheres, dynamical stability simulations, and planet-disk interactions. Based on GPIES observations of the systems of HD 95086, the recent 51 Eridani and one with a new brown-dwarf companion – the two latter discovered within the campaign – we can study the diversity of giant planet atmospheres, orbital configurations and interactions with circumstellar debris disks systematically present around these systems.

Direct imaging and brown dwarfs

Characterization of substellar companions observed during the SPHERE exoplanet survey SHINE:

Mickaël Bonnefoy (Institut de Planétologie et d'Astrophysique de Grenoble) *Contributor*

The SPHERE high-contrast imager has entered operation in May 2014 at the VLT. The SHINE survey conducted on the instrument aims to characterize the giant planet population beyond 5 AU around 400-500 nearby stars. Once a companion is resolved, the collection of sub-instrument of SPHERE can uniquely provide spectra and photometry of known exoplanet and brown-dwarf companions from 0.5 to 2.5 μm. Those spectro-photometric informations are used to better understand their orbital, physical, and chemical properties of the objects, and in turn to access the formation modes and dynamical evolution of planetary systems.

During the past two years, we have achieved with SPHERE a complete characterization of all known bona-fide planets discovered so far (HR8799 bcde, Beta Pic b, etc), as well as some benchmark brown dwarf companions. We will present our results and detail how they change our view of the architecture and formation history of those systems. We will also highlight how some key properties of those companions are currently exploited to distinguish them from background contaminants in the field of view of the instrument.

Direct imaging and brown dwarfs

Exoplanet Demographics versus Host Star Mass: Clues to Formation from Direct Imaging :

Michael Meyer (ETH Zürich) *Contributor*

The distribution of planetary companion masses, as well as the integrated surface density of companions over fixed mass ranges provide a wealth of information concerning planet formation processes as well as the subsequent dynamical evolution of planetary systems. However decoding this information requires an extra degree of freedom in experimental design: namely large samples of host stars of differing mass. Here we review recent direct imaging results from the ESO NACO Large Program (Chauvin et al. 2015; Desidera et al. 2015) undertaken as a precursor to the SPHERE SHINE survey) to constrain the frequency of gas giants at large orbital radii (Reggiani et al. 2016). This work combines predictions for planetary mass distributions as well as very low mass brown dwarf binaries suggesting a local minimum in the companion mass ratio distribution. We also summarise predictions of these models for the on-going SPHERE SHINE survey and what we hope to achieve with the survey results. Next we introduce a new model fitting all constraints on the surface density distribution of gas giant planets surrounding M dwarfs combining results from radial velocity, microlensing, and imaging surveys (Meyer et al. submitted). Finally, we discuss the implications of these results (the local minima in the companion mass ratio and the local maxima in derived surface density distribution of gas giant companions) as a function of stellar mass. We show how some model degeneracies can be broken if observations include large samples over a wide range in host star mass. We hope to inspire new direct imaging surveys, with ground- and space-based facilities.

Direct imaging and brown dwarfs

Debris disk architectures and dust properties discovered with GPI:

Paul Kalas (UC Berkeley) *Contributor*

The direct imaging of debris disks on solar system scales has recently made major progress using a new generation of high-contrast instrumentation. Here we will review more than 12 debris disks detected with the Gemini Planet Imager Exoplanet Survey in the first two years of operation. The findings include several belt-like structures that provide indirect evidence for yet-to-be-detected planets within approximately 50 AU of each star. Stellocentric offsets and other distinct asymmetries suggest that the dynamical architecture includes planets on eccentric and inclined orbits. Complementary, wider-field images with the Hubble Space Telescope exhibit cases of highly disturbed morphologies that point to dynamical upheavals originating from within the planetary system or by external perturbers. A diversity of polarization signals detected with GPI reveals that the physical properties of scattering grains can also vary significantly within the sample. These unexpected results suggest a heterogeneous co-evolution of exoplanets with their debris disks.

Direct imaging and brown dwarfs

Direct constraints on planet formation: Young planets embedded in circumstellar disks:

Sascha P. Quanz (ETH Zurich) *Contributor*

Where, when and how do (gas giant) planets form? Up to now the formation process of planets was mostly a subject of theroretical studies and computer simulations. Empirical data were only used to constrain the initial conditions (e.g., the physical and chemical conditions in circumstellar disks) or the outcome of the planet formation process (e.g., by comparing bulk density and atmopsheric composition from simulations to observed exoplanets or by comparing simulated planet populations to the observed population of exoplanets). Recently, however, high-contrast and high-spatial resolution observations revealed a few objects that are best explained with young planets that are still embedded in the circumstellar disks of their host stars. For the first time, these objects may allow us to derive empirical constraints on the immediate formation process of gas giant planets. In this talk, I will summarize the current knowledge of these systems, highlight the challenges that remain in interpreting the existing data and how they can be overcome, and illustrate why empirical constraints on the planet formation process are crucial for exoplanet research in general.

Direct imaging and brown dwarfs

The WFIRST AFTA Coronagraph — Status and Performance Expectations:

Bijan Nemati (Jet Propulsion Laboratory, California Institute of Technology) *Contributor*

WFIRST AFTA is a 2.4 meter space-qualified telescope awaiting completion of its wide field imager (WFI) and Coronagraph (CGI) instruments. The WFI enables constraints on the nature of dark energy from gravitational weak lensing measurements. The CGI, being designed and developed at NASA's Jet Propulsion Laboratory, is a visible-band coronagraph, designed for imaging and spectroscopy of planets and disks. With an inner working angle of 150 mas, this instrument will be sensitive to Jupiter class planets as close in as 3 AU at 20 pc. The Integral Field Spectrograph (IFS) instrument will provide characterization of exoplanetary atmospheres in three bands spanning the visible to near-IR. Technology demonstration of high contrast imaging with this instrument is expected to be completed in 2016. An integrated model of the instrument, including orbital, thermal, structural, optical and controls aspects is being used to assess its performance under various observing scenarios. Modeling shows the telescope and instrument design to be sufficiently robust as to allow 1e-10 contrast imaging with relatively straightforward applications of reference differential imaging, and more sophisticated techniques are being explored which promise further improvements. In this presentation we describe the coronagraph and its expected performance in detection and characterization of exoplanetary systems.

Direct imaging and brown dwarfs

Atmospheric C/O Ratios Provide Clues to the Origin of Supermassive Gas Giant Planets at Wide Separations:

Marta Bryan (Caltech) *Contributor*

Over the past decade, direct imaging searches for young gas giant planets have revealed a new population of companions with orbital separations of over 100 AU and masses near or at the deuterium burning limit. Thus far, 15 wide-separation planetary-mass companions have been confirmed, most of which are less than 10 Myr old. These wide-separation planetary-mass companions pose significant challenges to all three possible formation mechanisms, including core accretion, disk instability, and turbulent fragmentation. We directly test these three competing formation mechanisms by obtaining high-resolution K-band spectra of two directly imaged wide-separation planetary mass companions, ROXs 42B b and GSC 6214-210 b, using NIRSPEC-AO at Keck. We use these spectra to obtain the first measurements of the atmospheric C/O ratios of these two planets, and compare these ratios to those of their host stars and a sample of two free-floating planetary-mass objects from the same star forming region.

Direct imaging and brown dwarfs

Substructure in the LkCa 15 planet-forming disk:

Christian Thalmann (ETH Zürich) *Contributor*

Within the exciting field of protoplanetary disk studies, LkCa 15 is among the most exciting targets, featuring a young solar analog as its star, a pre-transitional disk with a gap large enough to fit all solar system planets, ongoing stellar accretion, and claims of protoplanets caught in the act of formation. We present our newest results from high-contrast imaging, including J-band imaging polarimetry with SPHERE IRDIS at unprecedented sensitivity, which finally allows us to reveal substructure in the disk.

Direct imaging and brown dwarfs

The NASA Exoplanet Exploration Program:

Karl Stapelfeldt (Jet Propulsion Laboratory, California Institute of Technology) *Contributor*

The Exoplanet Exploration Program (ExEP) is responsible for implementing NASA's plans for the discovery and understanding of planetary systems around nearby stars. ExEP plays an important function in U.S. exoplanet research, by laying out a long-term view of the entire field and charting out a strategic timeline of NASA missions and instruments. Major program elements include the Kepler/K2 mission; the LBTI instrument for measuring exozodiacal light; an upcoming precision RV instrument for the 3.5m WIYN telescope; the flagship WFIRST mission for dark energy, exoplanet microlensing, and coronagraphy; technology development for space-based high contrast imaging; and studies of future space missions that can realize the goal of detecting and charactizing habitable Earth-like exoplanets.

Microlensing

Gravitational Microlensing Surveys for Exoplanets: A Watershed:

Scott Gaudi (OSU) *Invited*

Measurements of the demographics of exoplanets over a range of planet and host star properties provide fundamental empirical constraints on theories of planet formation and evolution. Because of its unique sensitivity to low-mass, long-period, and free-floating planets, microlensing is an essential complement to our arsenal of planet detection methods. Although microlensing has already produced several important results regarding exoplanet demographics, it has yet to reach its full potential. I will demonstrate that this will soon change. With current and near-future next-generation ground and space-based surveys, microlensing is poised to revolutionize our understanding of the demographics of planets beyond the snow line, the abundance of free-floating planets, and the Galactic distribution of planets. Ultimately, a microlensing survey with WFIRST will complete the census of planets begun by Kepler, and yield a nearly complete picture of the demographics of planetary systems throughout the Galaxy.

Microlensing

Highlights of Microlensing Planet Discoveries:

Jennifer Yee (Harvard-Smithsonian Center for Astrophysics) *Invited*

With over 30 planet detections, microlensing is transitioning from an era of individual planet discoveries to an era of mass planet detections that will enable the characterization of planet populations. As a planet-finding technique, microlensing will soon be competitive with radial velocity and transit surveys. I will review recent microlensing planet discoveries and discuss how these pave the way for completing the census of exoplanets by probing planets beyond the snow line ranging from Jupiters to Earths and smaller.

Microlensing

K2's Campaign 9: The First Microlensing Survey from the Ground and from Space:

Calen Henderson (NASA Jet Propulsion Laboratory) *Contributor*

K2's Campaign 9 (K2C9) will conduct the first microlensing survey from the ground and from space from 7/April through 1/July this year. The spatial baseline between K2 and the Earth during C9, which ranges from ~0.1 to ~0.8 AU, will provide satellite parallax measurements for over 100 microlensing events, ultimately facilitating mass and distance determinations for the lens systems. K2C9 will cover ~3.7 square degrees and will allow us to address several demographic questions, including the frequency of cold exoplanets, the Galactic distribution of planets, and the abundance of free-floating exoplanets. I will give an overview of the parameters of K2C9, including the vast array of ground-based resources that will accompany the survey, and will detail these scientific drivers. Finally, given that the campaign will have ended 2 days before this conference starts, I will highlight events with particular scientific promise.