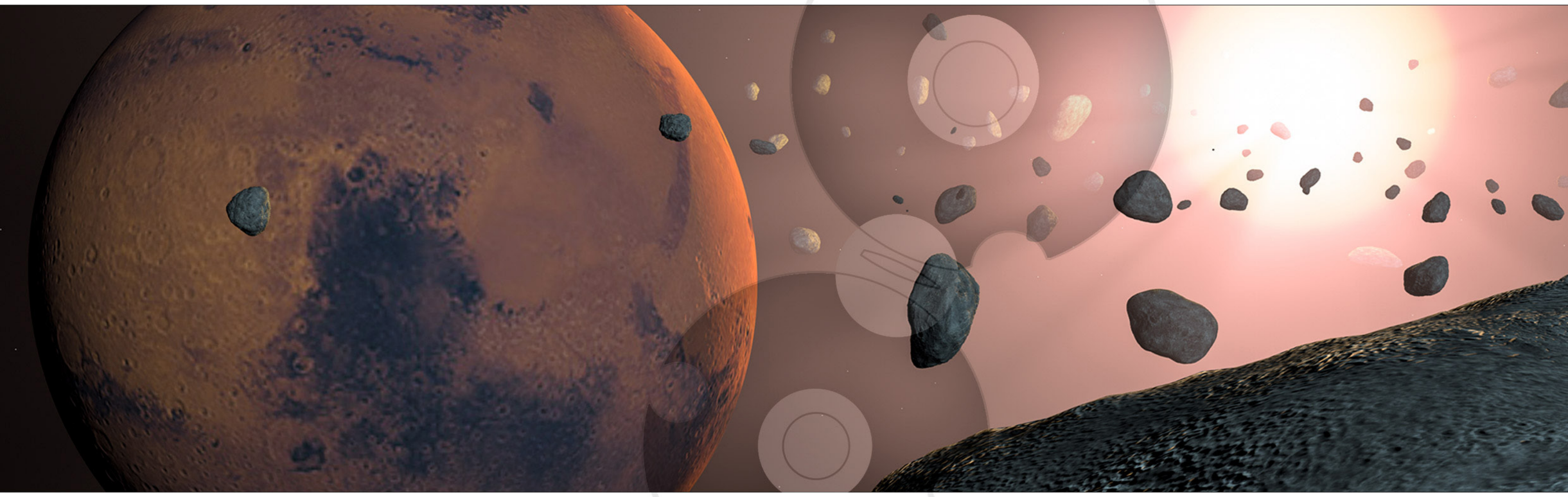
Characterizing Planetary Systems Across the HR Diagram - *Programme & Abstracts*



28 July - 1 August
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UNIVERSITY OF CAMBRIDGE

ioa

Characterizing Planetary Systems Across the HR Diagram
at the Institute of Astronomy, University of Cambridge, UK

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Jay Farihi (chair)
University College London, UK

Mark Wyatt (co chair)
Institute of Astronomy, University of Cambridge, UK

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Space Telescope Science Institute, USA

Orsola DeMarco
Macquarie University, Australia

Michael Endl
McDonald Observatory, USA

Boris Gänsicke
University of Warwick, UK

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Technion, Israel

Kate Su
Steward Observatory, University of Arizona, USA

Alex Wolszczan
Pennsylvania State University, USA

Ed Young
UCLA, USA

Ben Zuckerman
UCLA, USA

Monday, 28 July : Raymond & Beverly Sackler Lecture Theatre, Hoyle Bldg

08:00 • Registration / Coffee

09:00

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9 Melvyn Davies (Lund Observatory)
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10 Roman Rafikov (Princeton University)
Planet Formation Within and Around Binary Stars

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15 Ewa Szuszkiewicz (CASA*, University of Szczecin)
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24 Sasha Hinkley (University of Exeter)
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26 Hervé Beust (Institut de Planétologie et d'Astrophysique de Grenoble)
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29 Alan Jackson (Arizona State University)
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30 Alexander Krivov (AIU, University Jena)
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Chair • Jay Farihi

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Poster Session in the Hoyle Reception Foyer

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08:30 • Coffee

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Chair • Jay Farihi

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38 Angie Wolfgang (University of California, Santa Cruz)
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39 Roberto Raddi (University of Warwick)
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Tea & Coffee
Hoyle Reception Foyer

10:45

39 David Sing (University of Exeter)
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40 Taisiya Kopytova (MPIA)
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40 Nikku Madhusudhan (Institute of Astronomy, Cambridge)
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41 Jayne Birkby (CfA, Harvard)
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Conference End
(Lunch at Churchill College Dining Hall is optional - contact Kristina Bird kbird@ast.cam.ac.uk for details and booking)

Alessandro Morbidelli • OCA
Evolution of Planetary Systems

A planetary system typically does not reach its final structure as soon as its planets are formed. It can significantly evolve, due to processes such as planet migration and planet instabilities. Planet migration mostly happens while there is still gas in the protoplanetary disk, but significant orbital changes are nevertheless possible after the removal of the gas, due to the interaction between planets and planetesimals. Planet instabilities can happen at any time. The study of the Solar System provides an example of how rich the post-formation evolution of a planetary system can be. I will review our current understanding of the Solar System evolution, then discuss which variants could explain the wide diversity observed among extrasolar systems.

Notes:

Melvyn Davies • Lund Observatory
Close Encounters in the Birth Environments of Planetary Systems

The birth environments of planetary systems are crowded places where dynamical encounters between stars are relatively common. We consider the role played by stellar flybys and exchanges into binaries on the formation and evolution of planetary systems. For example, we show how such encounters can destabilise planetary systems, leading to the ejection of some planets whilst leaving others on eccentric orbits. We quantify the frequency of close encounters as a function of initial conditions (i.e. density of star-forming regions, the initial motions of the stars within the region, and the lumpiness of the stellar distribution). We consider the possible role played by free-floating planets within star-forming regions, including encounters between free-floating planets and discs around stars.

Notes:

Roman Rafikov • Princeton University
Planet Formation Within and Around Binary Stars

Planets are known to be able form in hostile environments. Their formation in binary stellar systems, either in a circumstellar or circumbinary configuration, is significantly hampered by enhanced dynamical excitation of planetesimals driven by the companion gravity. This is thought to lead to the destruction, rather than growth of planetesimals and makes emergence of cores, leading to giant planet formation, problematic. Yet, we know more than a dozen of planetary systems either in circumbinary configurations or within tight (<20 AU) binaries. I will address recent advances in understanding the processes affecting planet formation in binaries and show that the gravity of the gaseous protoplanetary disk plays important role in establishing the dynamical state of planetesimal disk. I will demonstrate that disks with high mass (>1% M_Sun) and low eccentricity (e<0.01) provide conditions favorable for planet formation even in the very extreme environments of tight binaries.

Notes:

Lars Bildsten • Kavli Institute for Theoretical Physics
Remaining Stellar Evolution Challenges

I will review our current understanding of the evolution of M<8Msun stars from the pre main sequence to their end results as white dwarfs. Theoretical work on the helium flash may have put to rest one long-standing stellar evolution concern, while recent asteroseismic data from the Kepler and CoRoT satellites have found very slow rotation rates of the stellar helium core during both the red giant phase and those burning helium on the clump. These data challenge our understanding of angular momentum transfer within stars and raise new questions about the role of rotation on the fates of more massive stars.

Notes:

Ruth Angus • University of Oxford
Calibrating Gyrochronology Using Kepler Asteroseismic Targets

Measuring ages for intermediate and low mass stars on the main sequence is challenging, but important for a wide range of studies, from Galactic dynamics to stellar and planetary evolution. The most commonly used dating methods are extremely model dependent and often provide age estimates with uncertainties of order 100% or more. Among the available methods, gyrochronology is a powerful one, because it requires knowledge of only the star's mass (or suitable proxy) and rotation period. However, it is not well calibrated at late ages. The continuous, high precision light curves obtained by Kepler mission are ideally suited to measuring photometric rotation periods and, for a few hundred bright Kepler targets, asteroseismology also provides relatively precise ages. We measured surface rotation periods for 144 Kepler targets with asteroseismic age estimates, which should in principle enable us to test the uniqueness and improve the calibration of the gyrochronology relation at late ages.

Notes:

Eva Villaver • Universidad Autónoma de Madrid
What Can We Learn by Evolving the Host Star?

Evolved planetary systems offer unique opportunities, when compared with their main-sequence counterparts, to understand a wide variety of star-planet interaction processes including orbital evolution, instability, and tidal interactions. As the star evolves off the main sequence, planets are expected to move into new orbital configurations, fall into the stellar envelope, and even evaporate. I will review these stellar-induced changes from a theoretical perspective.

Notes:

Kevin Schlaufman • MIT

Observational Insight into the Effect of Stellar Evolution on Exoplanet Systems

Planets around stars on the red giant branch differ from planets around main-sequence stars in two ways: they are much more likely to be on circular orbits, and much less likely to be found with orbital periods less than 100 days. Previously, these differences have been attributed to stellar mass, as it was thought that the evolved stars that were searched for planets were systematically more massive than the main-sequence stars. I will show that the Galactic space motions of the evolved host stars demand that on average they be similar in mass to main-sequence FG type planet-hosts. Therefore, the two samples differ only in age, and provide a glimpse of the same exoplanet population both before and after the host star begins to evolve into a giant. Consequently, the lack of hot Jupiters around stars at the base of the red giant branch is clear evidence that such planets are tidally destroyed. Questions remain, though, about the interpretation of other reported differences between the planet populations around evolved stars and main-sequence stars, such as their period and eccentricity distributions and overall occurrence rates.

Notes:

Jan Staff • Macquarie University

Hydrodynamic Simulations of the Interaction Between Giant Stars and Planets

We show the results of 3 dimensional hydrodynamic simulations of the interaction between AGB or RGB stars with one or two massive planets or a brown dwarf. We aim at understanding the degree of disruption of the star during and after the interaction. The planet is initially at a separation such that the giant fills its Roche lobe, causing mass transfer and soon thereafter, inspiral. Very little gas is unbound in the process, as expected. However, the planet can stir up the outer layers of the star increasing the photospheric radius, before the final plunge at which point the planet can be disrupted. Finally, we show the calculated light curves for these events and comment on the likelihood of observing them.

Notes:

Gilles Fontaine • Université de Montréal

An Overview of White Dwarf Stars

I will present a brief summary of what is currently known about white dwarf stars, with an emphasis on their evolutionary and internal properties. As is well known, white dwarfs represent the end products of stellar evolution for the vast majority of stars and, as such, bear the signatures of past events (such as mass loss, mixing phases, loss and redistribution of angular momentum, and thermonuclear burning) that are of essential importance in the evolution of stars in general. In addition, white dwarf stars represent unique environments for inferring the bulk composition of planetary debris that, more or less periodically, crash down on them during their long lifetimes orbiting about in the Galaxy. I will discuss the basic physics and provide an updated view of the so-called accretion-diffusion model needed to interpret the observed abundances of planetary elements in the atmospheres of white dwarfs.

Notes:

Dimitri Veras • University of Warwick

Comparing Asteroids, Moons, Planets and Comets as Possible Progenitors of the Pollution Observed in White Dwarf Atmospheres

Abundant metal pollution in white dwarf atmospheres primarily arises from circumstellar material and not the interstellar medium. Although well-characterised on an element-by-element basis, this rocky and sometimes watery material has largely unknown origins, and may be consistent with asteroids, moons, planets or comets. Here I interpret each alternative from a dynamical context, illustrating the resulting types of orbits we may expect from late-stage dynamical instabilities, and the frequency of collisions or near-collisions with white dwarfs. I identify the sometimes significant challenges in modeling each case analytically and numerically, and conclude by detailing the constraints each case can place on the formation and early evolution of planetary systems through full-lifetime simulations across all phases of stellar evolution.

Notes:

Alexander Mustill • Lund Observatory, Lunds Universitet

The Stability of Multiplanet Systems on the Main Sequence and Post-Main Sequence

When stars leave the main sequence they lose a significant fraction of their mass: around 50% for a Solar-mass star, and greater fractions for more massive stars. This mass loss has significant effects on the orbits of planets: in particular, in multi-planet systems, dynamical interactions become stronger, and previously stable systems can be destabilised. We study the stability of multi-planet systems through the lifetimes of their host stars, from the zero-age main sequence to an old white dwarf, with numerical integrations incorporating the changes to the star's mass and radius as it evolves. We show that orbital instability occurs following mass loss in many systems, both those that already experienced instability on the main sequence and those that were stable. We discuss implications for the orbits and detectability of giant planets orbiting WDs, the prospects for the delivery of terrestrial planets to the WD "habitable zone", and the efficiency of WD atmospheric pollution by destabilised planetesimals.

Notes:

Nader Haghighipour • Institute for Astronomy, University of Hawaii

Planet Formation in Evolved Binary Star Systems

The discovery of planets in close binary systems (i.e., stellar separations $\leq$ 50 AU) has lent strong support to the fact that planet formation around a star of a binary is robust, and these systems (known as S-type binaries) can host a variety of planets. At present, there are six close S-type systems that host planetary bodies: GJ86, γ-Cephei, HD41004, HD196885, HD176051, and α-Centauri. While in the last four, the components of the binary are main sequence stars, the primary of γ-Cephei (which is also the planet-hosting star) is a K1-IV sub-giant, and in GJ86 system, the secondary is a white dwarf (suggesting that the planet orbits the originally less massive star). The discovery of planets in such evolved binaries has raised questions regarding their formation and orbital evolution. It is possible that planets did not form in their current orbits and around their current stars. For instance, in the case of GJ86, the initial binary separation was smaller, making this systems a challenging environment for planets to form. We have developed a comprehensive model for the formation of planets around a star of a binary that takes into account stellar evolution, in particular the changes in the binary separation and stellar mass loss. Our model indicates that in binaries similar to GJ86, planet might have formed while the binary separation was increasing and reached its current orbit through interactions with the binary and/or possibly other planets in the system. We will present our model and discuss its applications and results.

Notes:

Stefan Driezler • Georg August University

Planets in Post-Common Envelope Binaries - A Second Phase of Planet Formation?

Among the thousands of confirmed or candidate extrasolar planets the majority is found in solar-type single stars. Planets in wide binaries orbiting one of the binary components, however, have been found since the first exoplanet detections. In contrast, planets orbiting both stars in close binary systems, i.e. circum-binary planets, are a rather recent discovery. On the one hand the Kepler-satellite has provided several planets orbiting MS+MS binaries. Circum-binary planets have also been claimed to be detected in post-common envelope binaries. In those systems, the variation of the eclipse times of the close binary is used as indication for the presence of additional bodies in the system. Since the host binary has undergone a drastic evolution loosing about 75% of its mass, the detection of planets raises the question whether or not these planets survived the common envelope evolution or if they are formed during the common envelope ejection. In the talk I will present the status of our current knowledge about planets in post-common envelope systems and discuss the results in the context of planet and planetary system evolution.

Notes:

Ewa Szuszkiewicz • CASA*, University of Szczecin

On the Role of Orbital Migration in the Formation of the Planetary System Around the Pulsar PSR B1257+12

The long-term stability of the PSR B1257+12 system has been demonstrated by Gozdziewski, Konacki and Wolszczan (2005) by means of 1 Gyr direct integrations. Their result gives a strong prediction about the future of the system, but to determine its past remains still an open problem. In this paper we investigate possible scenarios leading to the presently observed characteristics of the system. The central feature of our study is an intriguing configuration close to the 3:2 resonance of the two bigger planets with masses 4.3 and 3.9 Earth masses respectively. The orbital migration of the planets at the early phases of the evolution plays an important role in the successful reconstruction of the dynamics of this system.

Notes:

Suzanne Aigrain • University of Oxford

The Demographics of Exoplanets Orbiting Main-Sequence Stars: Recent Results, Challenges and Future Prospects

The past few years have seem something of an explosion in the rate of discovery exoplanet around main-sequence stars, driven in large part by the Kepler transit-search mission, but also by a steady improvement in the sensitivity of radial velocity, microlensing, direct imaging and ground-based transit surveys. These larger samples, together with careful evaluation of observational biases, allow for an increasingly detailed investigation of the demographics of the exoplanet population, over a wide range of host star spectral type (A to M) and planet types (Jupiters to Earths). The first order result is that planets are very common: the average number of planets per star (integrated across the full parameter space accessible to current studies) ranges from ~25% (for Sun-like stars) to 50% or more (for M-stars). Small planets (R<2.5 R_earth, M<10 M_earth) in short-period orbits (a<0.5 AU) make up the bulk of this population, and tend to be found in compact, multi-planet systems. Several recent studies have estimated eta_earth -- the frequency of Earth-size planets in the habitable zone of their host star -- though for Sun-like stars this still involves extrapolation.

I will give an overview of recent population studies based on Kepler and other datasets, highlighting the most important trends, discussing the main methodological differences and challenges along the way. I will also compare the results of different surveys to each other and discuss, in very broad terms, their implications for planet formation and evolution models. Finally, I will highlight areas of parameter space where we may expect interesting developments over the next few years.

Notes:

Andrew Howard • University of Hawaii

Earth-Sized Exoplanets

The Kepler Mission has taught us that Earth-sized planets in the Habitable Zones of Sun-like stars are common and that most Earth-sized planets have rocky compositions. Three recent results highlight these remarkable properties of Earth-size planets. First, our team measured the mass of the planet Kepler-78b, the only Earth-sized planet with a measured mass and radius outside of the Solar System. The bulk density of 5 grams per cubic centimeter suggests a rocky composition with an insubstantial atmosphere, similar to Earth. In a separate project, we showed that high densities are common for small exoplanets. Based on three years of Doppler measurements of the masses of dozens of Kepler planets, we showed that planets smaller than about 1.5 times Earth size are mostly rocky, while thick gas atmospheres envelop larger planets. Finally, we re-analyzed the Kepler photometry to determine an independent, calibrated catalog of planets, including Earth-sized planets in the Habitable Zones of Sun-like stars (GK dwarfs). We calibrated the survey completeness using injection-and-recovery tests of transit signals into Kepler photometry using our custom-built TERRA pipeline. Combining our planet catalog and completeness estimate we find that 22 percent of Sun-like stars have a planet that is 1-2 times the size of Earth orbiting in the Habitable Zone. Warm, Earth-sized planets appear to be common.

Notes:

Eric Gaidos • University of Hawaii at Manoa
Giants and Dwarfs: Do M Dwarfs Really Host Fewer Giant Planets?

Stellar mass may be an important parameter in giant planet formation: If more massive stars are born with more massive disks, the prevailing "core-first" scenario of giant planet formation predicts a higher (lower) occurrence of giant planets around more (less) massive stars. Johnson et al. (2010) found that giant planet occurrence in Doppler surveys is proportional to stellar mass and that M dwarf stars have about half as many giant planets as solar-mass stars. However, the occurrence of giant planets is also a rapidly increasing function of host star metallicity such that a difference of only 0.1-0.2 dex in mean [Fe/H] between samples equates to a factor of two in occurrence (Neves et al. 2013). Until recently, the metallicities of M dwarfs have not been determined to this precision. We have developed a precise (+/- 0.07 dex) method of measuring the metallicities of M dwarfs using features in their infrared spectra (Mann et al. 2012). We present the metallicity distribution of nearly all of the ~150 M dwarfs used by the analysis of Johnson et al. We rigorously compare these to the SPOCS catalog of solar-mass Doppler target stars (Valenti & Fischer 2005), control for metallicity, and constrain the dependence of giant planet occurrence on stellar mass, a potential test of the giant planet formation scenarios. Finally, we predict the number of giant planets we expect to detect in our ongoing MERMAIDS Doppler survey of metal-rich M dwarfs.

Notes:

Artie Hatzes • Thueringer Landessternwarte
Giant Planets Around Giant Stars

Over the past 20 years approximately 1000 exoplanets have been discovered. More than 80% of these exoplanets orbit host stars with masses less than about 1.2 M_sun. The reason for this is that the Doppler method, the most successful detection method, has insufficient precision to detect planets around more massive main sequence stars. These stars are hot and thus have few spectral lines that are often broadened by large rotation rates. We thus know little about the process of planet formation as a function of the most fundamental property of a star its mass.

Evolved giant stars offer us a way to detect planets around intermediate mass stars. As massive stars evolve up the giant branch their effective temperatures decrease and their rotation rates slow. They thus have a plethora of narrow spectral lines amenable to Doppler measurements. A number of programs have been surveying giant stars for exoplanets. So far about 50 exoplanets have been discovered around stars with stellar masses greater than about 1.2 M_sun. Although far fewer than the number of planets around solar like stars, these planets around evolved intermediate planets show differences in properties to their main sequence counterparts. Few have been discovered in short period orbits and most are in long period orbits of several hundred days. There is also a tendency for giant planets around more massive stars to be more frequent, and with higher masses (~ 5 M_Jupiter) than for those around solar mass stars. I will review the results from these various programs as well as address such issues as determination of the stellar mass, which is more problematic than for main sequence stars, and the possibility that rotational modulation by surface features may be responsible for some of the long period radial velocity signals that have been detected.

Notes:

Andreas Quirrenbach • LSW Heidelberg
Planets Around Giant Stars: Results from the Lick Survey

We present results from a radial-velocity survey of 373 giant stars at Lick Observatory, which started in 1999. We have detected planets around 15 of these stars; an additional 20 stars host planet candidates. Companions with up to 25 Jupiter masses are rather commonly found around stars with about 2 Solar masses. The frequency of detected planetary companions appears to increase with metallicity. No planets or planet candidates are found around stars with more than 2.7 Solar masses, although our sample contains 113 such stars. We conclude that the occurrence rate of giant planets as a function of Stellar mass peaks around 2 Solar masses. This has important consequences for our understanding of giant planet formation.

The stars 91 Aqr and tau Gem have companions with orbits that are among those with the lowest eccentricities of all known exoplanets, perhaps due to tidal circularization during the RGB phase. If confirmed, this would be the first evidence of planetary orbits modified through stellar evolution.

We have discovered several multiple systems in our sample. An extensive dynamical analysis of the eta Cet system indicates that it contains two massive planets in a 2:1 orbital resonance. The star nu Oph is orbited by two brown dwarf companions in a 6:1 resonance. It is likely that they arrived in this resonance through migration in a circumstellar disk, arguing strongly that objects with more than 20 Jupiter masses can be formed in disks around Herbig Ae stars.

Notes:

Roberto Silvotti • INAF-OATo
SdB Planets

I will summarize the field of sdB planetary systems comparing theoretical expectations with the known planetary systems. I will review the various detection methods and describe the current status of the sdB planet detections.

Notes:

JJ Hermes • University of Warwick

The Tug of White Dwarf Planets or Something Else Entirely? The Cautionary Tale of GD 66

A subset of pulsating white dwarfs serve as exceptionally stable optical clocks, which can be monitored for reflex orbital motion caused by planetary companions. The hot subdwarf B star CS 1246 demonstrates that the pulse-timing technique is a reliable way to detect unseen companions to stellar remnants, which were confirmed by follow-up, radial-velocity observations. Periodic timing variations of the pulsating white dwarf GD 66 garnered attention as evidence of a planetary companion. I will present complications to this planetary hypothesis, and show that this white dwarf offers a cautionary tales in the quest for claiming the detection of planets around evolved stars. I will also discuss the useful limits we can now place on a lack of close-in planets to evolved extrasolar systems: After more than a decade of monitoring a sample of pulsating white dwarfs from the McDonald Observatory, we can now exclude Jupiter-mass planets out to 10 AU for at least six stars in this sample.

Notes:

Tom Marsh • University of Warwick

Planets Around Post Common-Envelope Binaries

Binary stars with one or more white dwarf or subdwarf components can make good timing sources through eclipses and pulsations. In the best cases, times can be established to better than 0.1 seconds precision, making them sensitive to perturbations from Neptune-like companions on circumbinary orbits. The best current examples are survivors of the "common envelope" phase during which both stars orbited within a single envelope formed from the evolved objects which severely constrains the planetary orbits prior to the common envelope, and may in some cases require the planets to form from the envelope itself. In turn, if the existence of the planets can be established beyond all doubt, these systems may offer provide a new handle upon the common envelope phase itself. I will review the observational evidence for planetary companions to evolved binary stars, and discuss the dynamical stability of the systems which appear to have more than one companion. I will show results from a survey of a large number of such systems, including first results on double white dwarf binaries in which interaction within the binary is expected to be negligible.

Notes:

Matthias Schreiber • Universidad de Valparaiso
Caught in the Act: Direct Detection of Forming Planets

Although more than 1000 exoplanets have been detected to date, the precise mechanisms through which planets form remain largely unknown. The situation is particularly troubling for giant planets, for which two very dissimilar formation theories exist, namely core accretion and gravitational instability. The direct detection of forming giant planets still embedded in a protoplanetary disk is the most promising pathway towards a better understanding of planet formation and it is within reach of current observing techniques. Based on measurements of disk masses, multiplicity, accretion rates, and SED morphology of a large sample of protoplanetary disks we selected the best candidate systems for ongoing giant planet formation. Using NaCo Sparse Aperture Masking we potentially directly detected forming planets in some of our candidates and modeling complementary ALMA observations of these systems allowed us to characterize the surrounding planet forming disks. I will present the observational results of this project, discuss the reliability of NaCo/SAM detections, and relate our findings to current theories of giant planet formation.

Notes:

Leslie Rogers • California Institute of Technology
Characterizing the Hot Kepler Objects of Interest

Thousands of exoplanets have been discovered to date; most orbit stars that are similar to our Sun (FGK dwarfs) or cooler (M dwarfs). Detecting planets orbiting hotter stars (A dwarfs) is a challenge because hot stars have rotationally-broadened spectral features and large radii. Accumulating a statistical sample of well-characterized planets orbiting A stars is important to constrain trends in planet occurrence and orbital properties as a function of stellar mass. Throughout its four years of operation, the Kepler mission monitored a few thousand hot stars (T_eff>7000K) with sufficient photometric precision to detect the transits of Jupiter-size planets. We characterize the main sequence A stars with transiting planet candidates detected by Kepler. We identify likely A stars in the Kepler Input Catalog (KIC) by their stellar effective temperatures, derived from KIC grizJHK photometry using the empirical relations from Boyajian et al. (2013). To verify the classification of a subset of these stars, we measure their spectra using Palomar DBSP and collect high-resolution images with Keck NIRC2. We determine the physical parameters of the transiting planets' orbits by fitting the Kepler transit light curves with Markov Chain Monte Carlo methods. By constraining the semi-major axis and eccentricity distributions of planets orbiting A stars, we gain insights into the formation and tidal evolution of planets in a relatively uncharted region of the H-R diagram.

Notes:

Courtney Dressing • Harvard-Smithsonian Center for Astrophysics
Prospects for Detecting Planets Around Stars Across the Main Sequence Based on Updated Planet Occurrence Rates from Kepler

In anticipation of the next generation of planet surveys, we would like to know the distances and apparent magnitudes of the stars hosting the nearest planets. We will present the most likely properties of these stars and the population of planets that might be detected by upcoming surveys given the planet occurrence rates found from Kepler. For M dwarf targets, we will use an updated estimate of the planet occurrence rate based on running our planet injection and detection pipeline on Kepler data. For larger stars, we will adopt previously published values. We will then compile a mock catalog of possible target stars and populate them with planets. We will present estimates of the brightnesses, distances, and spectral types of the stars hosting the nearest transiting planets and discuss the potential planet yield from surveys such as TESS, PLATO, K2, MEarth, CARMENES, CHEOPS, ExoplanetSat, ExTrA, HPF, SPECULOOS, and SPIROU. We will also address the requirements for ground-based follow-up observations with extremely large ground-based telescopes like the GMT, TMT, and E-ELT.

Notes:

Brice-Olivier Demory • University of Cambridge, Physics
Space-Based Characterization of Super-Earth Exoplanets

Very little is known about those super-Earths that have been discovered so far. Their interiors are largely unconstrained due to compositional degeneracies while no super-Earth's atmosphere has been detected to date. I will present the results of a new program employing both Kepler and Spitzer space telescopes to better understand super-Earths properties, by combining observations obtained in different wavelength regimes. We find that close-in super-Earths have large geometric albedos in the Kepler bandpass, possibly due to clouds or reflective surfaces. We also find that some super-Earths initially thought to be volatile-rich exhibit circulation patterns matching a rocky composition, requiring new developments regarding our knowledge of super-Earth interiors.

Notes:

Yossi Shvartzvald • Tel Aviv University
The Frequency of Snowline Planets from a Second-Generation Microlensing Survey

Among the techniques currently used to discover extrasolar planets, microlensing has a unique sensitivity to planets beyond the "snowline", where gas and ice giants are likely to form. Starting April 2011, we have begun a "second generation" microlensing survey, combining OGLE, MOA, and the Wise observatory, in which 8 deg^2 of the Galactic Bulge are monitored round the clock, for several months each year. I will present a statistical analysis for the first three seasons of the survey. Over 10% of the events that were observed by all three sites showed a deviation from a single-lens microlensing, and for almost 1/3 of those the anomaly might be explained by a planetary companion. By accounting for our detection efficiency, we find a ~20% planetary system abundance. Moreover, our results suggests that massive planets around low-mass stars are common, which may be in conflict with planetary formation scenarios. The data also can set constraints on the multiplicity fraction and on the binary mass ratio distribution.

Notes:

Marshall Johnson • University of Texas at Austin
Investigating Short-Period Planets Around A Stars

Planet searches (except for direct imaging programs) have traditionally avoided main sequence A stars as these stars are not amenable to precise radial velocity measurements due to their wide, rotationally broadened stellar lines. Some A stars were observed by Kepler, providing the first opportunity to investigate the short-period planetary population of these stars. We are pursuing a program to validate Kepler planet candidates around rapidly rotating A stars using Doppler tomography, where we spectroscopically resolve the distortion in the stellar line profile during transit due to the Rossiter-McLaughlin effect. This also allows us to measure the spin-orbit misalignments of these planets. We present results from this program, as well as an estimate of the planet occurrence rate for short-period planets around main sequence A stars.

Notes:

Luca Ricci • Caltec

Highlighting the Dynamical Interaction Between Planets and Planetesimal Belts with ALMA

Debris disks surrounding Main Sequence stars trace dust that is produced when planets gravitationally stir a population of kilometer-sized planetesimals, which subsequently collide and are ground down to micron-sized particles. Mapping the structure of debris disks is important since the spatial distribution of dust and larger bodies is a powerful diagnostic to investigate the interaction between planetary systems and a belt of planetesimals.

I will present the results of recent ALMA observations of the debris disk surrounding HD 107146, a young ~ 100 Myr old nearby Solar analog. The large sub-mm flux and face-on geometry make this object an ideal candidate to look for signposts of planets-disk dynamical interaction around a young Solar-like star.

I will use this example to show how ALMA already in Cycle 2 can highlight structures, such as radial gaps, azimuthal asymmetries, extrasolar Trojans, which will shed light on the physical processes which shape the architecture of planetary systems, including our own.

Notes:

Brenda Matthews • NRC Herzberg

Debris Discs from the Pre-Main Sequence Through the Giant Branch

Debris discs are observed around main sequence stars of all ages and around evolved stars as well. The onset of the debris phenomenon, collisional grinding of large bodies to smaller dust, likely begins very early, potentially even in the pre-main sequence phase. In this review, I will focus on resolved imaging and the characterization of debris discs across this age range, including what we know about the solar system's debris disc and how it can be linked to studies of debris discs around other stars.

One of the great promises of debris disc imaging is that evidence of unseen planets could be detected within the system. Indeed, both Fomalhaut and Beta Pictoris were singled out as potential planet hosts due to asymmetries in their debris discs. The increasing number of debris discs with multiple discrete belts of dust are highly suggestive of the presence of planets. I will highlight these results in particular as well as more generally presenting evidence of the interconnection between debris discs and exoplanetary systems.

Notes:

Sasha Hinkley • University of Exeter

Connecting Planet and Debris Populations: A New Survey for Planetary Mass Companions at Keck and VLT

Circumstellar debris disks are the signposts of planet formation. I will present our progress on the largest Adaptive Optics (AO) survey to date dedicated to imaging planetary mass companions orbiting stars with newly identified debris disks. The NASA WISE mission has discovered hundreds of new stars bearing debris disks, and we have obtained deep AO imaging of over 250 of these on the Keck and VLT telescopes. Importantly, nearly all of our targets have not been targeted by other comparable-sized surveys (e.g. IDPS, SEEDS, NICI, etc.). Further, the debris disks we target in our survey tend to be younger than the more evolved debris disk systems traditionally observed with AO. As such, our sample serves as a particularly important connection between the study of evolved planetary systems, and those objects in young moving group systems. Our survey will give the strongest constraints on the connection between planet and debris populations, and will pave the way for future spectroscopic follow-up of these planetary mass companions.

Notes:

Tiffany Meshkat • Leiden University
Searching for Planets in "Holey Disks"

We present the results from a survey of stars with "holey disks" obtained at VLT/NACO and the apodized phase plate coronagraph. We demonstrate that these disks with holes are good targets for directly detecting planets with the recent discovery of a planet around two of our targets, HD 95086 and HD 106906, at L'-band. For HD 95086, the non-detection in H-band demonstrates the importance of thermal infrared observations. The detected planets shepherd the outer cool debris belt. The relatively dust-free gap in these disks implies the presence of one or more closer-in planets. We discuss our new constraints on planets around other targets in our survey as well as disk properties of these targets and describe how future instruments such as METIS will find the inner planets.

Notes:

Paul Kalas • University of California, Berkeley
New Observations of Fomalhaut, Beta Pic and HR 4796A with HST and GPI

High contrast imaging observations with HST show that the nearby star Fomalhaut is surrounded by a dusty debris belt and a candidate planet Fomalhaut b. Among the directly imaged exoplanets, Fomalhaut b has unexpected characteristics, such as a relatively blue spectrum and a highly eccentric orbit, leading to hypotheses that it is a gravitationally scattered, low-mass planet hosting a giant planetary dust ring or cloud seen in reflected light. Here we present new HST/STIS observations made in 2013 that authenticate the existence of Fomalhaut b at a fifth epoch. We discuss progress on several fronts, including the possible variability and spatial extent of Fomalhaut b, the existence of an azimuthal belt gap, and the probability that Fomalhaut b will physically intersect the belt over the next two decades. Also in 2013-2014, the Gemini Planet Imager (GPI) was successfully commissioned. I will review our new findings with GPI concerning the orbit of beta Pic b and its relationship to the warped debris disk, and present our analysis of belt structure and dust grain properties for HR 4796A.

Notes:

Andrew Shannon • Institute of Astronomy, Cambridge
Stellar and Debris Disk Dynamics of the Fomalhaut Triple System

Fomalhaut is a triple system, with all components widely separated (~100000 au). Unusually, Fomalhaut A has a bright debris disk with coherent eccentricity ~0.1, and Fomalhaut C is also know to have a debris disk. Widely separated binaries are thought to form during cluster dissolution, but that process is unlikely to form a triple system. We explore an alternative scenario, where A and C form as a tighter binary from a single molecular cloud core, and B is captured during cluster dispersal. We use N-body simulations augmented with the Galactic tidal forces to show that such a system naturally evolves into a Fomalhaut-like system in about half of cases, on a timescale compatible with the age of Fomalhaut. From non-interacting orbits, Galactic tides drive cycles in B's eccentricity that lead to a close encounter with C. After several close encounters, typically lasting tens of millions of years, one of the stars is ejected. The Fomalhaut-like case with both components at large separations is almost invariably a precursor to the ejection of one component, most commonly Fomalhaut C. By including circumstellar debris in a subset of the simulations, we also show that such an evolution usually does not disrupt the coherently eccentric debris disk around Fomalhaut A, and in some cases can even produce a coherently disk. We also find that the final eccentricity of the disk around A and the disk around C are correlated, which may point to the origin of the unusual debris disk around C.

Notes:

Hervé Beust • Institut de Planétologie et d'Astrophysique de Grenoble
An Independent Determination of Fomalhaut b's Orbit and the Dynamical Effects on the Outer Dust Belt

Fomalhaut harbours a cold, moderately eccentric dust belt with a planet candidate (Fom b) imaged near its inner edge. Based on available astrometric data, we perform a new orbital determination of Fom b using MCMC. We show that the orbit is highly eccentric (e~0.9), nearly apsidally aligned with the belt and subject to cross it.

We study the secular interaction between the planet and the dust ring. We show that unless Fom b is a small mass object (Super-Earth sized at most), close encounters rapidly destroy the dust belt. Conversely, if Fom b is very small (sub-Earth regime), the belt's self-gravity prevents the planet from dynamically affecting it. In the intermediate mass regime, Fom b actually perturbs the belt without destroying it. But it inevitably drives it to high eccentricity. Moreover the belt turns out not to be apsidally aligned with Fom b. We show that this behaviour is due to the planet's high eccentricity.

This contradicts both observations and orbital determination. We conclude that Fom b cannot account itself for the dust ring sculpting, and that its present orbital configuration may be recent. Consequently, another, more massive and less eccentric planet (Fom c) is required to dynamically control the belt. We present various scenarios involving two planets. We show that Fom b is likely to have been formerly trapped in mean-motion resonance with Fom c and that subsequent eccentricity increase caused it to cross Fom c's orbit and to jump on its present day orbit via a scattering event.

Notes:

Grant Kennedy • Institute of Astronomy, Cambridge
The Impact of Exo-Zodi on Exo-Earth Imaging

To directly image habitable Earth-like planets around other stars, a future New Worlds Mission will need to overcome background noise from warm "exo-Zodi" around the target stars. The occurrence rate of exo-Zodi of a given brightness (a.k.a the luminosity function) is unknown, and therefore so is the potential impact of exo-Zodi on future Earth-imaging attempts. With this motivation, I will present the first characterisation of the 12um exo-Zodi luminosity function around Sun-like stars. The dustiest old (>Gyr) systems are 1 in 10,000 occurrences, but warm dust is much more common around young (<120Myr) systems, with a 5% occurrence rate. These very different occurrence rates can be explained by two different models: in situ collisional evolution with a stochastic component, or comet delivery from exterior regions by planet scattering. Using the collision model, I will show predictions for the fraction of stars with exo-Zodi bright enough to cause problems for future exo-Earth imaging attempts. The prediction should be strongly tested by the Large Binocular Telescope Interferometer, for which I will present some initial results. The comet delivery model cannot yet make predictions, but I will present results from a study of two-temperature debris disks that test which of the collision or comet delivery scenarios is more likely.

Notes:

John Debes • Space Telescope Science Institute
The Origin and Dynamics of Dusty Disks Around White Dwarfs

As the final endpoint of stellar evolution, at first glance white dwarfs don't appear to be fertile grounds for the study of exoplanetary systems. Over the past twenty-seven years however, evidence has mounted that a significant fraction of white dwarfs might be hosts to relic planetary systems. The observable signatures planets are most easily detected as either an infrared excess due to dust orbiting a few tens of white dwarf radii away or through the presence of photospheric metal lines--both signatures of tidally disrupted minor bodies perturbed by larger planets into highly eccentric orbits. In this talk I will review the various observations of the dust component around WDs and link them to our understanding of the late stages of planetary system evolution. Firmly establishing this link is crucial for interpreting the composition of WD dust.

Notes:

Stephan Hartmann • Institute for Astronomy and Astrophysics
Spectral Modeling of Gaseous, Planetary Debris Disks Around White Dwarfs

Planetary systems may survive their host star's final evolution stages. The numerous dusty debris disks orbiting single white dwarfs can be seen as evidence for remnant planets after the formation of the compact object. A handful of these systems host an additional gaseous debris disk, offering us the unique possibility to directly analyze the metal-rich debris content.

Here we present our latest models of such metal-rich, gas disks around single white dwarfs. Using the Tübingen accretion disk code AcDc, we calculated synthetic spectra for different chemical compositions, surface densities, effective temperatures, and various radial extent. Tailoring the models to fit the hallmarking Ca II infrared triplet (at 8498, 8542, 8662 angstrom) of the observational data, we found the disks to be rather warm (about 6000 K) and low on density (below 0.3 g/cm^2). The total gas mass and the chemical composition are similar to those of average solar planetesimals, supporting the picture of remnant planetary material orbiting the white dwarf.

Notes:

A. Meredith Hughes • Wesleyan University
49 Ceti and the Mystery of Gas-Rich Debris Disks

The dispersal of primordial gas and dust from debris disks sets the timescale for giant planet formation and is closely intertwined with our understanding of the physical processes that shape planetary systems. While it is generally assumed that molecular gas dissipates before the debris disk stage, the nearby A star 49 Ceti is one of only a handful of systems known to host a tenuous, second-generation debris disk while still retaining a substantial molecular gas reservoir. It is the closest, best-studied, and oldest of the group of objects, with the most recent estimates placing its age at 40 Myr. We present ALMA observations that spatially resolve the outer dusty debris belt for the first time, and improve upon previous molecular gas observations by an order of magnitude in both sensitivity and spectral resolution. A combined analysis of the two CO transitions probed by ALMA and SMA provide new measurements of the gas temperature and mass, which allows us to infer the lifetime of the molecular gas. We also examine the disk kinematics in exquisite detail, following up on deviations from Keplerian rotation hinted at by previous SMA observations. We place the 49 Ceti system in context by comparing it with the other known gas-rich debris disks. We discuss the implications of the new ALMA observations for the origins of the gas in these systems, in particular whether they imply a primordial or second-generation (i.e. cometary) source.

Notes:

Huan Meng • University of Arizona

Extraterrestrial Collisions in the Era of Terrestrial Planet Formation

We present a detailed analysis of the first real-time detection of a planetary collision outside the solar system, observed with Spitzer at 3.6 and 4.5 microns around a 38-Myr-old solar analog star. The very bright, warm debris disk was originally only moderately variable. The collision is indicated by a substantial brightening, after which the output showed significant quasi-periodic variations on monthly timescales, on top of a decay over a year. This event may correspond to a secondary collision triggered by an original giant impact at least a decade ago and leading to the production and loss of tiny dust particles around the blowout size due to the stellar radiation. An overview of the infrared monitoring of similar systems, most of which are in the age range of terrestrial planet formation, suggests that such variations may be common in extreme debris disks around solar-like stars.

Notes:

Alan Jackson • Arizona State University

Debris from Giant Impacts, at Home and Abroad

We have direct evidence for at least 6 massive, planetary scale, collisions in the solar system, spanning the entire range of orbital distances from Mercury to the Kuiper belt, and there are likely to have been many more. A generic feature of such collisions is the production of large quantities of debris. The fate of this debris is an important aspect of the early history of our solar system. Meanwhile, in other planetary systems, we might observe the aftermath of similar impacts as debris discs. I will discuss the characteristics of these debris discs, and what debris produced by giant impacts can tell us about planet formation, both in the solar system, and further afield.

Notes:

Alexander Krivov • AIU, University Jena
Statistics of Herschel-Resolved Debris Disks Across the Main Sequence

We consider a representative sample of more than thirty debris disks around AFGKM stars well resolved in various Herschel Space Observatory programs, which is probably the largest set of resolved disks ever analyzed. For each target, the disk radius is inferred from the resolved PACS images, and the spectral energy distribution is modeled with two different methods to determine the amount of dust, its temperature, and the size distribution. The results are used to investigate how various disk parameters (dust fractional luminosity, disk radius, typical dust grain size, dust opacity) depend on the stellar parameters (spectral type, luminosity, age, and metallicity). For instance, we find no significant trend of disk radii with the stellar luminosity. The dust temperature systematically increases towards earlier spectral types, yet the ratio of the dust temperature to the blackbody temperature at the disk radius decreases with the stellar luminosity. We find a clear trend of typical sizes increasing towards more luminous stars, with a larger scatter towards higher stellar luminosities. Possible explanations for these and other findings are proposed and their implications are discussed.

Notes:

Christine Chen • STScI
The IRS Debris Disk Catalog

During the Spitzer Space Telescope cryogenic mission, Guaranteed Time Observers, Legacy Teams, and General Observers obtained Infrared Spectrograph (IRS) observations of hundreds of debris disk candidates. We calibrated the spectra of 571 candidates, including 64 new IRAS and MIPS debris disks candidates, modeled their stellar photospheres, and produced a catalog of excess spectra for unresolved debris disks. We carried out two separate SED analyses. (1) For all targets, we modeled the IRS and MIPS 70 micron data (where available) assuming that the SEDs were well-described using, zero, one or two temperature black bodies. We calculated the probability for each model and computed the average probability to select among models. (2) For a subset of 120 targets with 10 and/or 20 micron silicate features, we modeled the data using spherical silicate (olivine, pyroxene, forsterite, and enstatite) grains located either in a continuous disk with power-law size and surface density distributions or two thin rings that are well-characterized using two separate dust grain temperatures. We present a demographic analysis of the disk properties. For example, we find that the majority of debris disks are better fit using two dust components, suggesting that planetary systems are common in debris disks and that the size distribution of dust grains is consistent with a collisional cascade.

Notes:

Inga Kamp • Kapteyn Astronomical Institute
Chemistry of Protoplanetary Disks Across the HR Diagram

Protoplanetary disks are observed around a wide variety of young stars, Herbig AeBe stars, T Tauri stars and also around Brown Dwarfs. At the same time, surveys for exoplanets indicate that - at least for solar-type stars - these protoplanetary disks are very efficient in forming planets. Various studies have indicated that the chemical signatures may depend on the spectral type of the central star. This has consequences for the type of planets that can form and their bulk composition as well as their atmospheres.

I will review chemical surveys in various wavelengths bands and the possible conclusions for differences in disk structure and chemical composition. In addition, I will present radiation thermo-chemical models for disks around Herbig AeBe stars, T Tauri stars and Brown Dwarfs. The main pathways of chemistry in various disk regions will be discussed and also the "chemical appearance" of these disks as a function of the spectral type of the central star.

Notes:

Jonathan Williams • Institute of Astronomy
Protoplanetary Disk Demographics

The remarkable abundance of exoplanets tells us that the natural end state of a circumstellar disk is a planetary system. Moreover, disk evolution is known to be varied and stellar mass dependent and this is likely a key factor in the great diversity of exoplanet properties.

Millimeter wavelength observations provide the best means for measuring disk masses, both of the dust and gas, and for following the growth of dust grains. I will discuss the results from SMA, IRAM and JCMT millimeter surveys of disks over a range of ages and infrared evolutionary states that provide important demographic information for comparing to exoplanet statistics. Disk dust masses decrease within time such that most of the solid mass resides in millimeter and larger sized particles within about 3 Myr. Isotopologue CO line fluxes are lower than expected for an ISM gas-to-dust ratio of 100. Either gas masses are very low (Jupiter masses or less) in Class II disks or there are new chemical pathways not seen in clouds or cores that lock carbon up in the solid component.

Although disk luminosities rapidly decrease with time, the future is bright with ALMA. I will end by presenting new ALMA results on photo evaporating disks in Orion which demonstrate the promise of this facility for strengthening the connection between protoplanetary disk evolution and exoplanet diversity.

Notes:

Steven Desch • Arizona State University
Snow Lines in Photoevaporated Protoplanetary Disks

Water content is one of the most fundamental properties of a terrestrial planet. Most moons and Kuiper belt objects in our Solar System have the solar composition of half ice, half rock. The Earth is extraordinarily dry in comparison, ~ 0.05% water by weight. Proximity to the Sun is not the sole cause. While high temperatures are possible in young, actively accreting disks, radiative transfer models (including my own I will present) routinely show temperatures were cold enough to let ice condense, well inside 1 AU, by the time Earth's building blocks were forming. The distribution of water in the disk was also affected by radial transport within the disk.

Here I argue that the radial transport of water is sensitive to the star-forming environment in which the disk is born. Planets born in high-mass star-forming regions will be dry. Nearby massive OB stars photoevaporate disks and drive outward transport in them. This transport enhances outward diffusion of water vapor and frustrates inward migration of ice. The inner portions of these disks are dehydrated early in their evolution. In contrast, planets born in low-mass star-forming regions, I predict, are ice-rich. Without photoevaporation-driven outward transport, ice migrates into the inner portions of disks as accretional heating vanishes, before planets form.

I will present model calculations of ice/rock fractions in planets formed in either type of star-forming region. Roughly equal fractions of planets should form in either region, possibly explaining the fraction of terrestrial exoplanets with low densities < 2 g/cc.

Notes:

Bertram Bitsch • University of Lund
Formation of Planetesimals in Evolving Accretion Discs

Planetesimals are the seeds in the core accretion model to form terrestrial planets and the cores of gas giants. The formation of planetesimals can be triggered by the streaming instability (Johansen & Youdin, 2007). This process depends on the relation between the mean gas flow and a pure Keplerian orbit, which strongly depends on the underlying disc structure. In the simple power-law assumptions made in the Minimum-Mass-Solar-Nebula (MMSN), it is much harder to form planetesimals further away from the star.

Recent simulations of accretion discs which include stellar heating and radiative cooling have shown that accretion discs are not uniform power laws, but show some bumps and dips (Bitsch et al, 2013a, 2014). These changes in the disc structure then alter the location of the regions in the disc where planetesimals can be formed by the streaming instability. We present studies of accretion discs with different accretion rates and their influence on the formation of planetesimals. We also investigate the influence of viscosity transitions in the disc and their role in the formation of planetesimals. Additionally we present a more accurate model of the structure of accretion discs that allows for detailed predictions for the formation of planetesimals, pebble accretion and the migration of planets, than the MMSN model.

Notes:

Simon Casassus • Universidad de Chile
Rocky Clumps in the Dust Trap of HD142527

Recent progress suggests that the accretion of rocky cores could occur efficiently in the outer regions of protoplanetary disks hosting large gaps, at stellocentric radii comparable to the Kuiper belt in the solar system. Such annular cavities are thought to be sculpted by massive giant planets, in a transition phase when gas reservoirs are exhausted or dissipated. During this dynamical clearing, azimuthal overdensities at the outer edge of the gaps trap dust grains, and segregate the gas. The dust concentrations show azimuthal asymmetry, resembling a horseshoe as seen in recent sub-mm images. The aerodynamic coupling of dust grains with pressure gradients predicts that larger grains are trapped more efficiently in such horseshoes, leading to grain growth, formation of planetesimals, and eventually rocky cores. Here we bring observational support for efficient grain growth in a dust trap at large stellocentric radii. Opaque clumps at 1.2mm in the outer disk of HD142527 display the flattest opacity laws, as expected for the larger grains. At the observable extreme of the size distribution, we find cm-wavelength clumps coincident with the 1.2mm opacity maxima. Interestingly the temperature in these rocky clumps are <25K, and they also coincide with decrements in the molecular emission of volatile species. These cm-wavelength emission maxima probably correspond to clumps of large grains with icy mantles, as expected in the context of rocky core accretion in outer disks.

Notes:

Francesco Pignatale • CRAL Centre De Recherche Astrophysique De Lyon Observatoire De Lyon
A 2D Dust Chemistry on the inner Solar Nebula

Infrared spectroscopy provides details of the chemistry of the surface layers of protoplanetary disks but provides no information about the dust composition of the midplane and layers deep inside the disk. Thus, information from the bulk chemistry of the disk, where the process of planet formation takes place, are missing. Radial theoretical condensation sequences returns a good agreement with the chemical gradient found in the Solar System when applied to the midplane of the Solar Nebula. However, they cannot reproduce the complex chemistry of meteorites such as carbonaceous chondrites and the rare enstatite chondrites.
In this work, we utilise a 2D disk model to derive, for the first time, the 2D condensates distribution within the inner Solar Nebula from the surface to the midplane. The resulting distribution is compared with observations of protoplanetary disks and then combined with analytical calculations of dynamical processes (radial migration and vertical settling of dust and the dead zone). As an extension of this work, preliminary simulations using Smoothed Particle Hydrodynamics to study the motion of grains with different chemistry will be presented.

The resulting 2D chemistry provides new insights on the origin of the crystalline grains seen by IR observations and new clues on the bulk composition of planets. Furthermore, we have identified the potential zone in which enstatite chondrites could have formed, supporting recent evidence that these objects and the surface of Mercury shared similar bulk compositions.

Notes:

Nuno Santos • Centro de Astrofísica da Universidade do Porto
Exploring the Planet Frequency and Architecture Across the HR Diagram

It is now widely recognized that the study of the chemical properties of planet host stars provides invaluable information about the processes of planet formation. In this presentation we will review some of the most recent works on this subject. We will start by looking at the results of the most prolific planet search programs concerning solar-type, FGK dwarfs. In this context we will explore how the stellar parameters relate with the planet frequency and architecture. We will then analyze the situation for their lower mass counterparts, M-dwarfs, as well as for evolved stars (giants) with planets. Overall, the presentation will highlight the importance that chemical abundances have on the formation and architecture of planetary systems.

Notes:

Johanna Teske • Carnegie Institution for Science
Constraining Hot Jupiter Exoplanet Compositions via Host Star Abundances of Planet-Building Elements

It is currently unknown how/to what extent the chemical compositions of planetary atmospheres correlate with those of their host stars and/or if different host star compositions influence planet occurrence (beyond the well-known metallicity correlation). The carbon-to-oxygen abundance ratio is one crucial measurement that may be used to better understand a possible connection between star and planet compositions. Currently C and O are the only elements that can potentially be measured in both star and exoplanet atmospheres. Large samples of coupled planet and host star C/O measurements may reveal trends indicative of processes in the protoplanetary disk or planetary interior that shift the planet's elemental composition away from the star's. However, estimating C/O ratios in transiting exoplanet atmospheres is still difficult due to paucity of data and degeneracies between atmospheric model parameters. Moreover, even with high resolution, high S/N spectra, determinations of the stellar C/O ratios can be challenging. I will present a methodologically consistent sample of C/O ratios measured from high-resolution spectra of transiting exoplanet host stars from several different C and O abundance indicators, using classical stellar abundance analysis techniques. Additional elements measured from the transiting HJ host star sample, including other "planet-building" elements like Si and Mg, will also be presented. This talk will consider the difficulties of host star abundance measurements, and what insights into planet formation and composition are possible from such analyses. I will conclude with a preview of a new extension of the investigation of giant exoplanet compositions via comparison of bulk interior models and host star abundances.

Notes:

Boris Gänsicke • University of Warwick
Rocky Planetary Debris Around Young WDs

The strong surface gravity of white dwarfs causes metals to sink out of the atmosphere on time-scales much shorter than their cooling ages, leading to pristine H/He atmospheres. Therefore any metals detected in the atmosphere of a white dwarf imply recent or ongoing accretion of planetary debris. Determining the photospheric abundances of debris-polluted white dwarfs is hence analogue to the use of meteorites for measuring the abundances of planetary material in the solar system.

I will review the results of a large, unbiased HST/COS survey of relatively young (~20-100Myr) white dwarfs. At least 27% of all white dwarfs in our sample are accreting planetary debris, and that fraction may be as high as 50%. The low C/Si ratio found for most polluted WDs confirms the rocky nature of the debris, though some white dwarfs are accreting icy material, and C/O ratios imply that "carbon planets" are not common. Up to 11 elements are detected in the most polluted stars, enabling a detailed comparison between the chemistry of exo-planetary material with that of solar system meteorites. We find a wide spread in the relative abundances of Mg, Fe, Si, and O, a constant Al/Ca ratio, and evidence for differentiation of Fe & Ni. The median progenitor mass is ~2Msun, and about half of the WDs descending from late B and A-type stars are debris-polluted, demonstrating that the formation of rocky material around 2-3Msun stars is common.

Notes:

Elisa Delgado Mena • CAUP
Li Depletion in Solar Analogues with Exoplanets

Light elements can give us important information about the mixing processes inside stellar interiors. However, their depletion mechanisms are not completely understood yet. A wide spread in Li and Be abundances has been observed in clusters like M67 or NGC3960 as well as in field solar type stars but it cannot be explained with standard models. In this work we present new determinations of lithium abundances for 326 main sequence stars with and without planets in the Teff range 5600-5900 K, observed inside HARPS-GTO samples or with other high-resolution spectrographs. We confirm significant differences in the Li distribution of solar twins (solar Teff $\pm$ 80 K, solar log g $\pm$ 0.2 and -0.2 $<$ [Fe/H] $<$ 0.2): the full sample of planet host stars (22) shows Li average values lower than "single" stars with no detected planets (60). If we focus on subsamples with narrower ranges in metallicity and age, we observe indications of a similar result though it is not so clear for some of the subsamples. Moreover, we find indications that the amount of depletion of Li in planet-host solar-type stars is higher when the planets are more massive than Jupiter. We suggest that the presence of planets might cause additional rotationally induced mixing in the external layers of planet host stars and thus an extra Li depletion.

Notes:

Kevin Walsh • Southwest Research Institute

Terrestrial Planet Formation and the Mixing of Planetesimal Populations

Models of terrestrial planet formation in the Solar System face many more constraints than simply their masses and orbits. Rather, our knowledge of the Earth's composition and meteorite samples on Earth provide substantial information on how the terrestrial planets were put together. Similarly, the dynamical shape and compositional gradients of the Main Asteroid belt and other small body populations serve as strict tests for the dynamical evolution of any proposed models.

Recent models have addressed many long-standing problems of terrestrial planet formation using the dramatic migration of the giant planets early in Solar System history. These works simultaneously provide reasonable matches for constraints from both the planetary bodies and the planetesimal populations, in part due to the substantial mixing of small body populations across many AU. While such a system evolution is certainly not generic, the radial mixing of small body populations driven by the location and behavior of a system's giant planets almost certainly is, and will strongly affect the properties of the other planets in the system.

Notes:

Edward Young • UCLA

Inheritance of Solar System Radionuclides from Molecular Clouds: Evidence That We Are Not So Unusual After All

Studies of polluted white dwarf stars indicate that melting of small planetesimals was common outside the solar system. This in turn requires solar-like concentrations of 26Al (mean life = 1 Myr) in other planetary systems and implies that the solar system was not unusual in its complement of short-lived radionuclides. Indeed, apparent excesses in early-solar 26Al, 36Cl, 41Ca, and 60Fe relative to expectations for the ISM disappear if one accounts for ejecta from massive-star winds enriching star-forming regions. The removal of apparent excesses is evident when wind yields from Wolf-Rayet stars are included in the plot of radionuclide abundances normalized by their production vs. mean life. The resulting trend indicates that the solar radionuclides were inherited from parental molecular clouds with a characteristic cloud residence time of 10^8 years. This residence time is of the same order as the present-day timescale for conversion of molecular cloud material into stars. The concentrations of these extinct isotopes in the early solar system need not signify injection from unusual proximal stellar sources, but instead are well explained by normal concentrations in average star-forming clouds. The results imply that the efficiency of capture is greater for stellar winds than for supernova ejecta proximal to star-forming regions. They also suggest that enrichment of short-lived radionuclides is common in large and long-lived star-forming regions such as Cygnus X.

Notes:

Edwin Bergin • University of Michigan

Exploring the Origin of Carbon in Terrestrial Worlds

Given the central role of carbon in the chemistry of life, it is a fundamental question as to how carbon is supplied to the Earth, in what form and when. In this talk I will outline our knowledge about carbon in the Earth and discuss the potential reservoirs available to supply needed carbon to a young-forming planet. An important conundrum lies in the fact that nearly half of the carbon in the interstellar medium is found in some refractory solid state and yet the Earth's surface (and primitive undifferentiated meteorites) are significantly carbon-poor relative to silicon. This problem extends beyond our Solar System as metals in the atmospheres of white dwarfs are suggested to be a result of accretion of asteroids, and these systems often display a marked carbon deficiency. We suggest that chemical kinetics plays a key role in accounting for this carbon deficiency. We will outline models that explore the destruction of carbon grains in the disk and explore the evolution of the molecular carbon reservoir that precedes planet formation. Where possible I will outline the astrophysical observations that can set limits on the potential distribution and evolution of these reservoirs in protoplanetary disks.

Notes:

Ben Zuckerman • UCLA

The Frequency and Compositions of Rocky Exoplanet Precursors via Polluted White Dwarfs

The 2014 consensus view is that the presence of elements heavier than helium in the atmosphere of an isolated white dwarf is a signpost for a planetary system in orbit about that star. This interpretation was a long time in coming. The first identification of a white dwarf atmosphere "polluted" with heavy elements occurred in 1917; at that time little was understood about the nature and physics of white dwarfs. Subsequently, other polluted white dwarf atmospheres were identified, but until 1983 always of the helium-rich variety. Since the time required for heavy elements to settle out of the atmosphere of a (cool) He-atmosphere white dwarf is quite long, accretion of interstellar matter, perhaps long ago, was the most analyzed and perhaps the most plausible mechanism to explain the pollution.

Because of the short time frame associated with the settling of heavy elements out of hydrogen-rich white dwarf atmospheres, the 1983 discovery of calcium in the atmosphere of one such white dwarf stimulated astronomers to consider seriously alternatives to the interstellar accretion model. But the field advanced slowly, and it was not until 20 years later (2003) that the current consensus model began to take serious shape.

By now the evidence is overwhelming that white dwarf pollution from tidally disrupted planetesimals is common; we can utilize the heavy element abundances in these otherwise-pristine stellar atmospheres to obtain the bulk composition of these erstwhile planetesimals. For the roughly one dozen stars where detailed relative abundances of 8 to 15 heavy elements have been measured, the pattern is unmistakably refractory- rich, volatile-poor, and broadly consistent with Solar System rocky materials (i.e. meteorites and bulk Earth).

I will highlight important results in the journey to the present picture, and will discuss the inferred masses and bulk chemical properties of these large and rocky, extrasolar planetesimals. In particular, using the Solar System as a model, we can deduce a past history of differentiation and collisions for some of these rocky exoplanet precursors.

Notes:

Angie Wolfgang • University of California, Santa Cruz

How Rocky Are They? The Composition Distribution of Kepler's Sub-Neptune Planet Candidates within 0.15 AU

The Kepler Mission has found thousands of planetary candidates with radii between 1 and 4 Rearth. As these planets have no analogues in our own Solar System, they provide an unprecedented opportunity to understand the range and distribution of planetary compositions allowed by planet formation and evolution. Although a mass measurement is usually required to constrain the possible compositions of an individual super-Earth-sized planet, we can address this question for the Kepler sample without them. This is possible with a statistical approach that leverages interior structure models which, by accounting for the thermal evolution of a gaseous envelope around a rocky core, yield radii largely independent of mass. In particular, we apply Hierarchical Bayesian Modeling to a complete subsample of Kepler planet candidates to find the current-day composition distribution, which shows that gaseous envelopes are most likely to be ~ 1% of the planet's total mass. We also address the gaseous/rocky transition and illustrate its sensitivity to the uncertainty in the planets' radii. Finally, we illustrate that this composition distribution does not result in a one-to-one relationship between the population of sub-Neptune masses and radii; accordingly, dynamical studies which wish to use Kepler data must adopt a probabilistic approach to accurately represent the range of possible masses at a given radius.

Notes:

Roberto Raddi • University of Warwick
Is SDSSJ1242+5226 Accreting Water-Rich Debris?

Given the extremely high surface gravity of white dwarfs, their atmospheres are expected to be composed of pure H, He, or a mixture of both. The detection of photospheric metals unambiguously signals recent, or ongoing accretion, and debris from tidally disrupted planetary bodies is the most plausible origin of the polluting circumstellar material. We report the discovery of one of the most metal-polluted white dwarfs, SDSSJ1242+5226. The atmosphere of this star is He-dominated, and our intermediate resolution spectroscopy (3100-8500A) reveals absorption features of H, O, Na, Mg, Si, Ca, and Fe. Photospheric abundances determined our state-of-the-art model atmosphere code show that the circumstellar debris is rich in refractory elements, as typical for heavily polluted white dwarfs. However, our analysis implies a very large mass of H in the white dwarf envelope, reminiscent of two other strongly-polluted white dwarfs, GD362 and GD16. We argue that the common characteristics of GD362, GD16, and SDSSJ1242+5226 may be related to the accretion of large water-rich planetary bodies.

Notes:

David Sing • University of Exeter
A Decade of Hot Exoplanet Atmospheric Investigations

Exoplanetary systems with short orbital periods are now known to be extremely common throughout the galaxy, with now more than one thousand confirmed transiting exoplanets discovered. Through transmission, emission, and phase curve spectroscopy of transiting planets, a great deal of detailed characteristics are now being learned about exoplanet atmospheres. A new opportunity is arising to spectrally type and classify these completely new groups of astrophysical objects, and perform detailed comparative exoplanetology. Such is the challenge facing the extrasolar planets christened hot Jupiters, hot Neptunes, and super Earths an incredibly diverse group of exoplanets now accessible to transit spectroscopy. In this talk, I will review the atmospheric discoveries for these planets over the last decade, as well as present recent results from a large survey on the Hubble Space Telescope targeting hot Jupiter atmospheres.

Notes:

Taisiya Kopytova • MPIA
Chemical Abundance as a Key to Formation Scenario of Exoplanets

We present our spectroscopic study of directly imaged exoplanets and brown dwarf companions using VLT/SINFONI, and their hosts using FEROS at La Silla. We derive [Fe/H] and the C/O ratio for the companions and hosts, which helps us to distinguish between the core accretion and the disk instability scenarios for formation of the companions. Previous studies showed that metal-rich stars have more massive planets. This could be an outcome of the core accretion formation theory. The larger the metallicity of the disk, the faster the core is formed and more gas can be accreted onto it. Lower-mass planets do not accrete large amounts of gas over the timescale of core formation, therefore, they are less sensitive to the disk metallicity. Due to different condensation temperatures of carbon and oxygen, the C/O ratio is different at different parts of a protoplanetary disk and depends on the disk temperature profile. Therefore, the C/O ratio of a companion formed by core accretion can vary and will reflect that of the part of the disk where it formed. Conversely, companions formed by disk gravitational instability are expected to have C/O ratios consistent with their host stars. We present the very first study using this approach and put constraints on the application of this method for testing formation scenarios of exoplanets and brown dwarfs.

Notes:

Nikku Madhusudhan • Institute of Astronomy, Cambridge
Elemental Abundances in Exoplanetary Atmospheres and Lessons Across the HR Diagram

Spectroscopic observations of extrasolar planets in the past few years have led to the possibility of determining elemental abundance ratios in their atmospheres. Nominal constraints on atmospheric C/O ratios have already been reported for a few hot Jupiters. In the present work, we combine existing data from the Spitzer Space Telescope with new data obtained using the Hubble Space Telescope and ground-based facilities to place stringent constraints on the atmospheric elemental abundances for six transiting exoplanets. These planets are representative of the range of the irradiated exoplanet population in sizes and temperatures. We use our estimates of these elemental abundance ratios to place the first rigorous constraints on the formation and evolutionary conditions of close-in exoplanets, and study the correlations of their formation histories with their stellar and orbital parameters. We also compare the elemental abundances we derive for exoplanets around main sequence stars to those derived for young directly-imaged exoplanets and protoplanetary disks, as well as to those inferred from debris disks and pollution signatures in white dwarf spectra. Based on these comparisons, we discuss some insights into planetary compositions across the HR diagram.

Notes:

Jayne Birkby • CfA, Harvard

Constraining the Carbon and Oxygen Abundances of Hot Jupiter Atmospheres Using Ground-Based Very High-Resolution Spectroscopy

The chemical composition of a hot Jupiter atmosphere has the potential to place unique constraints on precisely how and where in the proto-planetary disk the planet formed. This is due to the varying abundances of gaseous carbon- and oxygen-bearing molecules throughout the proto-planetary disk, and requires a robust, reliable determination of the carbon-to-oxygen ratio in the planet's atmosphere. I will present ground-based high-resolution (R~100,000) spectra from CRIRES/VLT at 3.2 and 3.5 microns of several transiting and non-transiting hot Jupiter atmospheres (51 Peg b, tau Boo b, HD 209458 b), in which we have searched for the radial velocity signature of water, methane and carbon dioxide molecules in the planetary spectra. We combine these results with previous high spectral resolution detections of carbon monoxide in these hot Jupiter atmospheres to provide constraints on the temperature-pressure profile of the atmospheres, and to determine the relative abundances of the major carbon- and oxygen-bearing species. Preliminary results for 51 Peg b indicate a non-inverted and oxygen-rich atmosphere. I will also highlight how combining spatial information with high resolution spectra allows a similarly robust determination of the chemical composition of planets at large separations (i.e. directly imaged planets), via the detection of carbon monoxide in beta Pic b (Snellen et al. 2014, Nature, embargoed). This novel technique opens up exoplanet atmosphere characterisation at high spectral resolution to a new regime of younger planets and their evolution.

Notes:

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Characterizing Planetary Systems Across the HR Diagram

at the Institute of Astronomy, University of Cambridge, UK

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