Exoplanet Demographics Conference
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Thursday Talk Abstracts

Exoplanet Demographics with Stellar Properties

A Review of the Exoplanet-Host Star Composition Connection - Johanna Teske (Carnegie)

For most exoplanets, we will never observe them directly but only infer their properties based on observations of their host stars. High resolution spectroscopy has given us an important window into the compositions of exoplanets through host star chemical abundances. We think host star abundances to some extent are like ``genes'' passed on to their orbiting planets, and thus provide insight into the building blocks that went into forming planets. Host star abundances have also been used to infer likely evolution pathways in different categories of exoplanets. From the first giant exoplanet detections, to the current era of bulk density characterization, and looking toward the upcoming era atmospheric characterization, host star abundances have and will continue to be an important ingredient to understanding exoplanet demographics. In this talk, I will present a brief review of what we have learned thus far about the connection between host star and exoplanet composition, and what new information/techniques in this subfield will help make progress in discerning underlying planet formation pathways.

How Common is Planet Engulfment? - Aida Behmard (Caltech)

Dynamical evolution can cause planets to be engulfed by their host stars. Following engulfment, the stellar photosphere abundance pattern will reflect accretion of rocky material that composes planetary cores by exhibiting refractory enhancements in order of condensation temperature. Multi-star systems are excellent environments to search for such abundance trends because these stars share the same natal gas cloud and primordial chemical compositions to within 0.05 dex. Thus, refractory differences above 0.05 dex that trend with condensation temperature between stellar companions constitute a signpost of planet engulfment. Such observations have been carried out for a few systems, and have occasionally yielded robust engulfment signatures, e.g., Kronos and Krios (Oh et al. 2018), but only a handful targeted systems with known planets. We aim to augment this sample by carrying out a survey using Keck-HIRES of 40 multi-star systems where one star is known to host a planet. The sample of planets hosted by these systems is diverse and includes hot Jupiters, close-in multi-planet systems, and gas giants at a range of orbital periods. Using the Spectroscopy Made Easy tool, we have obtained abundance patterns for each system that can be assessed for possible engulfment signatures. We will present preliminary results from this survey, which will ultimately be used to constrain the prevalence of planet engulfment, examine its role in shaping current planetary system architectures, and investigate possible engulfment-related patterns in stellar and planetary properties.

The California-Kepler Survey: Revisiting the Minimum-Mass Extrasolar Nebula with Precise Stellar Parameters - Fei Dai (Caltech)

We investigate a possible correlation between the solid surface density Σ of the minimum-mass extrasolar nebulae (MMEN) and the host star mass M⋆ and metallicity [Fe/H]. Leveraging on the precise host star properties from the California-{\it Kepler}-Survey (CKS), we found that Σ= 50^{+33}_{-20} \rm{~g~cm}^{-2} (a/1AU)−1.75±0.07 (M⋆/M⊙)1.04±0.22 100.22±0.05[Fe/H] for {\it Kepler}-like systems (1-4R⊕; a<1AU). The strong M⋆ dependence is reminiscent of previous dust continuum results that the solid disk mass scales with M⋆. The weaker [Fe/H] dependence shows that sub-Neptune planets, unlike giant planets, form readily in lower-metallicity environment. The innermost region (a<

0.1AU) of a MMEN maintains a smooth profile despite a steep decline of planet occurrence rate: a result that favors the truncation of disks by co-rotating magnetospheres with a range of rotation periods, rather than the sublimation of dusts. The Σ of {\it Kepler} multi-transiting systems shows a much stronger correlation with M⋆ and [Fe/H] than singles. This suggests that the dynamically hot evolution that produced single systems also partially removed the memory of formation in disks. Radial-velocity planets yielded a MMEN very similar to CKS planets; transit-timing-variation planets' postulated convergent migration history is supported by their poorly constrained MMEN. We found that lower-mass stars have a higher efficiency of forming/retaining planets: for sun-like stars about 20\% of the solid mass within ∼1AU are converted/preserved as sub-Neptunes, compared to 70\% for late-K-early-M stars. This may be due to the lower binary fraction, lower giant-planet occurrence or the longer disk lifetime of lower-mass stars.

Planetary and Brown Dwarf Companion Mass Ratio Distribution versus Stellar Mass and Orbital Separation - Michael Meyer (Univ. of Michigan)

Understanding the demographic properties of multiple stars as well as planet populations can provide profound constraints on theories of star and planet formation. Surveys for very low mass companions to stars from M to A types as a function of orbital separation naturally detect very low mass brown dwarfs which are a logical extension of binary star formation as well as exoplanets formed through diverse processes in circumstellar disks in Keplerian rotation. We fit the orbital distribution of planetary mass companions around M, FGK, and A stars with a log-normal distribution that peaks between 3-6 AU (Meyer et al. 2018; Meyer et al. to be submitted). Combining these new results with extrapolations of binary star data, we propose a new parametric model for the companion mass ratio distribution (CMRD) as a function of central host star mass from 0.3-3 MSUN sun that includes very low mass brown dwarf companions formed through "binary-like processes" as well as a "planet-like" mass function. The model predicts binary companions well into the brown dwarf regime as well as exoplanet populations as a function of planet mass and orbital radius. These predictions are found to be consistent with many point estimates of companion fraction as a function of mass ratio and orbital separation ranges for diverse host star samples. We find: a) the brown dwarf "desert" is expected as the natural extension of binary and gas giant planet properties; b) local minima in the CMRD occur between 10-40 Jupiter masses depending on host star mass and orbital separation; and c) in binary companions as well as gas giant planet formation, a key parameter is the ratio of the companion to the host star mass from M to A stellar types.

Spitzer Microlens Parallaxes: Connecting Microlensing Planets to the Broader Planet Distribution - Jennifer Yee (CfA)

It is difficult to incorporate microlensing planets into the broader planet population because of the uncertainties in the physical parameters of microlensing planets (e.g. host mass, planet mass, semi-major axis). However, simultaneous observations from Spitzer and Earth can resolve these uncertainties by measuring the parallax effect. This effect combined with the finite source effect allows measurements of not only the masses of the planets and their stars, but also the distances to the planetary systems. Thus, the Spitzer microlensing planet sample is the best-characterized, statistical sample of microlensing planets. It will provide insight into the broader properties of microlensing planets (e.g., Are the hosts really M dwarfs?) and how to integrate them with results from other techniques, and it will demonstrate the pathway to measuring the distribution of planets as a function of Galactic environment.

A Universal Break in the Planet-to-star Mass Ratio: Implications for Planets around Brown Dwarfs - llaria Pascucci (LPL, U of A)

Following the microlensing approach, we quantify the occurrence of Kepler exoplanets as a function of planet-to-star mass ratio (q) and find that the occurrence rate versus q can be described by the same broken power law with a break that is independent of host type for hosts below 1 Msun. The break in q for the microlensing planet population, which mostly probes the region outside the snowline, is ~3-10 times higher than that inferred from Kepler. We show that these results are expected in the most recent pebble-driven planet formation scenario and discuss what planets may form around very low-mass stars and brown dwarfs.

Full-lifetime Simulations of Planetary Systems - Dimitri Veras (Univ. of Warwick)

Our understanding of exoplanet demographics is aided by the analysis of planetary systems at all stages of stellar evolution. Here I will summarize a series of our recent publications which link together the evolution of planetary systems throughout the main-sequence, giant branch and white dwarf phases of the host star. We have self-consistently modelled a multi-planet system with an exo-Kuiper belt from its birth within a stellar cluster to its death around a white dwarf, and separately have constrained the often-ignored prospects for planet formation around B-type and O-type stars by analyzing the demographics of metal-polluted white dwarfs. I will also set bounds on the formation and main-sequence evolution of the evaporating or disrupted ice giant planet recently reported to orbit white dwarf WD J0914+1914.

Nature vs. Nurture: A Bayesian Framework for Assessing Apparent Correlations Between Planetary Orbital Properties and Stellar Ages - Emily Safsten (Penn State)

As more data on exoplanets have been collected, some apparent correlations between planetary and stellar properties have started to emerge. However, the true nature of such correlations is often unclear as stellar properties are often interrelated. In particular, it is unresolved whether these correlations are due to the age of the system -- pointing to evolution over time being an important factor -- or other parameters to which the age may be related, such as stellar mass or stellar temperature. The situation is complicated further by the possibilities of selection biases, small number statistics, uncertainties in stellar age, and orbital evolution timescales that are typically much shorter than the range of observed ages. Here we develop a Bayesian statistical framework to assess the robustness of such observed correlations and to determine whether they are indeed due to evolutionary processes, are more likely to reflect different formation scenarios, or are merely coincidental. We apply this framework to the case of 2:1 resonances, where it has been proposed that systems with 2:1 resonances tend to be younger than those without, and find nearly equal support for the hypothesis of a correlation with age as for the hypothesis that the apparent trend is coincidental. We also apply this framework to the question of whether stellar obliquities are more correlated with age, more correlated with temperature, or are not related to system properties. The results very strongly favor a relation with temperature, i.e., hot stars have high obliquities and cool stars are aligned with their planetary orbits, which corroborates prior work. Finally, we examine whether the currently available hot Jupiter data truly display a trend of eccentricity due to age, and indeed find very strong support for the hypothesis that the set of known hot Jupiters shows the circularization of orbital eccentricities over time.

Unearthing the Earths: Using TESS and Kepler to Reveal the Primordial Population of Short-Period Planets - Rachel Fernandes (LPL, Univ. of Arizona)

Over the past decade, the Kepler mission was instrumental in the discovery of thousands of Gyr-old exoplanets. A large number of these are short-period planets, most of whose orbits are closer in to their host star than Mercury is to our Sun, whereas only one Earth-size planet has been found in the habitable zone of a solar analogue. Prominent features in this Gyr-old population of short-period planets suggest that planets have evolved with time and that the population of small (<1.8 Rearth) short-period planets, which is extrapolated to the habitable zone to estimate the frequency of habitable zone Earth-size planets (hereafter EtaEarth), is contaminated by the bare cores of once sub-Neptune planets. This begs the question: What was the primordial population of short-period planets and how did it evolve with time? One way to answer this question and quantify the contamination of once sub-Neptune planets to EtaEarth is by measuring the occurrence of these planets in young clusters (~10-500 Myr), before their envelope is stripped away. We will discuss our ongoing effort to discover primordial sub-Neptunes in young (<500 Myr) clusters using TESS FFIs and preliminary results on an improved EtaEarth. Our investigation will provide unique constraints to planet formation models, clarify how planetary atmospheres and radii evolve with time, and lend a more reliable EtaEarth estimate - a key parameter to evaluate the yield of nearby Earth analogs that can be detected and characterized by future missions.

Planetary Archaeology: Exploring the Planet Population of Evolved Stars with TESS - Samuel Grunblatt (AMNH)

Most planet searches to date have focused largely on solar-like stars. However, with the advent of large all-sky surveys like TESS and Gaia, comprehensive planet searches are extending from the often targeted FGK and M dwarf stars to more extreme stellar hosts, such as red giants. The long, eventful lives of these systems gives us unique insights into the inflation, evolution and longevity of planets, and the intrinsic brightness of giant stars allows us to robustly characterize planet demographics on larger scales within our Galaxy. Previous studies with Kepler and K2 have revealed that these systems do exist, but our knowledge about them has been seriously limited by the paucity of targets. This issue has now been resolved thanks to the abundance of full frame image data from TESS. Here, I will present the newest discoveries of planets and planet candidates orbiting evolved stars with data from TESS and Gaia. Through a combination of ground- and space-based observation, we are using these systems to test theories of planet inflation and engulfment, explore giant planet occurrence as a function of stellar mass, and investigate properties of planet populations on kiloparsec scales for the first time.

Exoplanet Demographics with White Dwarfs

Observations of Post-Main-Sequence Planetary Debris Disks - Erik Dennihy (Gemini Observatory)

Frequently detected across a wide range of stellar classes, debris disks provide more than just a snapshot of the stages of planetary formation. Features such as gaps, rings, and the ongoing evolution that these disks exhibit shine light on complex, hierarchical planetary systems that will someday become difficult to observe once the planetary system is formed. Beyond the main-sequence, a different kind of debris disk around stellar remnants can likewise provide insight into planetary systems that escape direct detection, but in this case through a process of planetary destruction as opposed to planetary formation. In this review talk, I will discuss the state of observations of debris disks around white dwarf stars, remnant of solar-type stars with circumstellar disks populated by the remnants of now unstable planetary systems. This class of debris disks offers an independent view of the frequency of hierarchical planetary formation, and observations of variability on timescales of hours, days, and years inform the same physical process that govern the evolution of their main-sequence counterparts.

Cold Gas Giant Planets Evaporated by Hot White Dwarfs - Matthias Schrieber (Universidad de Valparaiso)

All known exo-planet host stars will eventually evolve into white dwarfs, their burnt-out cores left behind after the end of the fusion of hydrogen and helium. It is observationally well established that many white dwarfs are accreting small planetary bodies, including asteroids and comets. Gravitationally scattering such planetesimals towards the white dwarf requires the presence of more massive bodies, yet no planet has so far been detected at a white dwarf. We have discovered a moderately hot white dwarf that is accreting from a circumstellar gaseous disc composed of hydrogen, oxygen, and sulfur. The composition of the disc is unlike all previously detected gaseous disks around white dwarfs but resembles predictions for deeper atmospheric layers of icy gas giants, with H2O and H2S being major constituents. We therefore suggest that a gas giant orbiting the white dwarf with a semi-major axis of approximately 15 solar radii is evaporated by the strong extreme-ultraviolet irradiation from the white dwarf. This discovery represents the so far clearest evidence for the expected existence of gas giant planets around white dwarfs and was recently published in Nature.

We extend on this result by calculating the orbital separation at which gas giant planets will be evaporated by hot white dwarfs. We find that the hottest white dwarfs (60.000-100.000K) are bright enough at EUV wavelengths to generate hydrodynamic escape in gas giants located at separations up to 100 au. Even somewhat cooler white dwarfs may still evaporate giant planets at separations of 10-30 au. A fraction of the evaporated material will be accreted by the white dwarf and generate detectable absorption features. Hot white dwarfs can therefore be used to constrain the fraction of gas giant planets around white dwarfs and their progenitor stars. We find that the observed volatile accretion onto hot white dwarfs can be fully explained if at least 50 per cent of hot white dwarfs (and therefore also their main sequence progenitor stars) host gas giant planets beyond a few au.

Doppler Imaging of a Second Planetary Debris Discs Around a White Dwarf - Christopher Manser (Imperial College London)

There is considerable evidence of the survival of planetary material around white dwarfs, the remnant stellar end-points for the majority of planet-hosting stars. One such piece of evidence is the debris discs that orbit within ~1 solar radius of the white dwarf produced by the tidal disruption of a planetesimal. A rare subset of these discs reveal emission from a gaseous component, which can be used to study the dynamical and physical properties of these discs.

In this talk I will present the second image of a gaseous debris disc around a white dwarf produced using Doppler tomography - a technique analogous to CT scanning in hospitals. I will discuss the importance of these images in enhancing our understanding of both the physics of planetary accretion discs as well as the process of the tidal disruption of planetary bodies around white dwarfs. I will conclude with the open questions surrounding debris discs around white dwarfs, and the future prospects for these exciting systems.

Exoplanet Demographics with Stellar Environment

The Impact of Binary Stars on Exoplanet Demographics and Survey Statistics - Maxwell Moe (University of Arizona)

The majority of solar-type stars are born in binaries. Close binaries (a < 50 AU) in particular truncate the mass and longevity of protostellar disks and therefore significantly sculpt planet formation. Indeed, multiple surveys of various types of planet hosts all demonstrate that close binaries suppress planet formation. In this review, I will discuss these surveys and highlight how binary stars affect the observed exoplanet demographics. For example, ~40% of solar-type stars do not host close planets due to suppression by close binaries. The close binary fraction increases with stellar mass and decreases with metallicity, which significantly biases the inferred exoplanet trends with host star parameters. I will also demonstrate how selection effects due to close binaries account for previously unexplained exoplanet anomalies, such as the discrepancy in hot Jupiter occurrence rates measured from radial velocity versus transit techniques and the apparent enhancement of wide stellar companions to hot Jupiter hosts. In the end, I will show how a vetted planet population from the all sky view of TESS can further leverage the true planet occurrence rates with respect to stellar mass and metallicity. I will also emphasize eta_Earth within the context of binary stars and suggest strategies for finding the nearest Earth analogs.

The Demographics of Circumbinary Planets to Help Understand Planet Formation and Migratory Processes - Amaury Triaud (University of Birmingham)

Circumbinary planets orbit around both stars of a binary system. The presence of a binary is thought to affect the accumulation of dust and planetesimals into planets close to the binary. Yet most planets detected thus far are close to their binary. As such the existence of circumbinary planets demonstrates that disc-migration is an effective form of transport within a disc, for super-Earths and for gas-giants.
I will report on preliminary results of the only radial velocity survey dedicated to circumbinary planets currently in operation. We are monitoring 100 single-line eclipsing binaries, north and south seeking planetary candidates. The first stage of our southern survey ended recently, with the identification of 15 candidate signals. One of our systems was also found to host a transiting planet by the TESS mission. Our goal is to compare one to one, the population properties of planets orbiting single stars, to planets orbiting binaries. Our early results confirm that circumbinary planets are quite frequent, as well as confirm a suspicion that circumbinary planets with masses in excess of 1 Mjup are rare. Combining our results to Kepler detections of circumbinary planets, we can draw conclusions on the mutual inclination distribution between planetary and binary orbital planes.

Highly Inclined Planets Around Eccentric Orbit Binaries - Steve Lubow (STScI)

One of the key discoveries of the Kepler mission was the detection of transiting circumbinary planets. By the nature of the detection technique, these planets are preferentially found on nearly coplanar orbits with the binary. We (Martin and Lubow 2017; Lubow and Martin 2018) have shown through analytic modeling and hydrodynamical simulations that a mildly inclined gaseous circumbinary protoplanetary disk around an eccentric orbit binary can naturally evolve to a highly inclined polar orbit that is perpendicular to the binary orbital plane. Planets formed in such a disk would orbit around the semimajor axis of the binary, instead of the binary angular momentum vector. Such a disk was recently discovered in HD98800 by Kennedy et al. (2019) using ALMA. In our model, the coplanarity of the Kepler detected planets is a natural outcome of the generally low eccentricities of the central binaries. The low eccentricities are in turn a consequence of the fairly short binary orbital periods in these systems. We predict that there should exist a significant population of highly inclined planets around eccentric orbit binaries at longer orbital periods than studied by Kepler. New missions such as TESS are in a good position to search for such planets using eclipse timing variations of the binary.