Exoplanet Demographics Conference
November 9-13, 2020
Wednesday Talk Abstracts

Architectures of Systems: Observations

What We Learn from Multi-planet Systems - Wei Zhu (Canadian Institute for Theoretical Astrophysics)

Multi-planet systems contain rich information about the formation and evolution history of planetary systems. For example. The existence and the properties of additional planets can be used to distinguish planet formation theories, and the mutual inclination and the spacing between planets provide constraints on the dynamical evolution of the system as a whole. Multi-planet systems are also the key to link different detection techniques. In this talk, I will first discuss the challenges and current status in taking planet multiplicity into the statistical analysis. I will then review our current understanding about the demographics in terms of the multi-planet system architecture, specifically the correlation between different planet populations and the relative properties (e.g., size & mass) of planets around the same host. A discussion of theoretical implications and open issues will also be provided. Finally, I will briefly discuss the pathways to combine results from ongoing and upcoming missions such as TESS, Gaia, and WFIRST. Results from these different missions (and thus different techniques) can be combined through multi-planet systems to provide much more information than what they can individually.

Demographics of Multi-Planet Systems - Lauren Weiss (University of Hawaii at Manoa)

What can the architectures of planetary systems teach us about the dominant planet formation, migration, and evolution pathways? Multi-planet systems are natural laboratories in which planets form around the same star and within the same protoplanetary disk, offering a controlled environment for studying planet formation. With 400 multi-planet systems hosting at least 1000 planets already discovered, we can study the demographics of multi-planet systems. I will review the demographics of planet orbits, masses, and compositions in multi-planet systems, and more importantly, the demographics of how planets are related to their planetary siblings in each of these properties.

Architecture and Dynamics of Kepler's Multi-Transiting Planet Systems: Comprehensive Investigation Using All Four Years of Kepler Mission Data - Jack Lissauer (NASA Ames)

This talk will report results from a soon to be completed study by our group that expands upon our previous analyses presented in Lissauer et al. (2011, ApJS 197, 8) and Fabrycky et al. (2014, ApJ 790, 146). The Kepler data set now includes ~ 700 multiple-planet systems, far more than were available for our previous two studies, and they provide a powerful means to study the statistical properties of planetary systems. The increased numbers and better information about planetary radii and the properties of stellar hosts allow more statistically-robust analyses of the entire ensemble of Kepler multis and also independent analyses of subsets of the population. Early in the mission it was shown that Kepler was finding very few giant planets in systems with more than one transiting planet (Latham et al. 2011, ApJL 732, 24). With the full data set in hand, it is now apparent that unaccompanied planets (singles) and planets in multi-planet systems (multis) have the same size distributions throughout the range 0.5 - 3 R_{Earth} and also throughout the range 5 - 12 R_{Earth}; however, multis are about three times as abundant relative to singles in the smaller size range as in the larger one. This result argues that low-mass gas-rich planets, which dominate the size range 5 - 8 R_Earth, are more akin to the jovian planets that are tens to hundreds of times as massive than they are to the super-Earths and sub-Neptunes that have masses similar to their own. We reinforce our previous findings that most pairs of planets within the same systems are neither in nor near resonances and that there is a strong excess of planets having period ratios slightly larger than those of first-order mean-motion resonances. However, neglecting a few systems whose planets are locked in 3-body resonances, the deficit of planet pairs with period ratios just narrow of resonance is as large as the excess of planets wide of resonance within root N statistical uncertainties, suggesting that there is no overall excess of planet pairs in the vicinity of resonance. This result contrasts with predictions from planet migration models and radial velocity observations that find orbital resonances among planets (which typically have longer periods and are more massive than the bulk of Kepler planets) are common. We find that three-body resonances among planets are also uncommon, and those that are present are usually associated with two-body resonances or near-resonances.

Cold and Low-mass: Occurrence Rate of Extrasolar Ice Giants - Radek Poleski (Univ. of Warsaw)

Exoplanet analogs of Solar System ice giants, Uranus and Neptune, are extremely hard to discover due to long orbital periods and low intrinsic luminosities. Formation of Uranus and Neptune poses a problem to planet formation models due to the low density of protoplanetary discs at large radii and too short disc lifetimes. We can gain more understanding of Uranus and Neptune formation from their exoplanet analogs. Such exoplanets were already found using the gravitational microlensing technique. The sensitivity of the microlensing technique does depend on the planet-to-star mass ratio and planet position and not on either orbital period or planet luminosity. I will present occurrence rate of the wide-orbit microlensing planets derived based on known planets and planet detection efficiency from most recent microlensing data.

Frequency and Properties of Free-floating Planets - Przemek Mroz (Caltech)

Thousands of extrasolar planets have been discovered up to date. Although many of the known exoplanets do not resemble those in our Solar System, they have one thing in common - they all orbit a star. However, theories of planet formation and evolution predict the existence of free-floating planets, gravitationally unattached to any star. They may form as a result of dynamical processes in young planetary systems or during late stages of host star evolution.

Gravitational microlensing is uniquely suited for finding free-floating planets. I will present the current constraints on the frequency and properties of rogue planets in the Milky Way based on long-term observations of microlensing events in the Galactic bulge by the OGLE sky survey. I will also present several of the most promising candidate free-floating planets discovered to date. Finally, I will briefly discuss the future prospects for determining the frequency and mass function of rogue planets by the planned microlensing experiments.

Architectures of Systems: Theory

Using Radius-dependent Occurrence Rate Profile to Reveal Formation Pathways - Eve Lee (McGill University)

One of the long-standing issues in exoplanet science is identifying the formation location of planets; in particular, whether most planets have undergone a long-range migration or a largely in situ formation. In this talk, I will review how the distributions of orbital periods (planet occurrence rate vs. orbital period) and period ratios can be analyzed to reveal the formation pathways of exoplanets. Why is the occurrence rate of sub-Neptunes flat in log orbital period (unlike their larger counterparts)? How do we understand its fall-off inside ~10 days? How much migration is required to account for the excess of planet pairs just outside of first order mean motion resonances? I will also discuss how the shape of the period distribution changes with planet radii, and how we may leverage this radius-dependent difference to probe potentially diverse arrays of formation pathways that shape the observed diversity of exoplanets.

A Compositional Link Between Warm Super-Earths and Cold Jupiters - Martin Schlecker (MPIA)

Recent demographic studies have suggested a positive correlation between the occurrence rates of inner super-Earths and outer giant planets, challenging some established planet formation theories. Using global simulations that model the evolution of a protoplanetary disk and planetary growth via core accretion, we have produced a synthetic population of 1000 multi-planet systems that qualitatively confirms this observation.

A peculiar trend emerges when we associate the disk initial conditions with the bulk composition of the resulting planets: in disks of moderate solid content (~100 Mearth), super-Earths form from icy material beyond the water ice line and migrate to observable distances. No giant planets are formed. On the other hand, in massive disks (~>200 Mearth), dry super-Earths form on close orbits and are frequently accompanied by an outer gas giant. This results in the testable hypothesis that high-density inner super-Earths are proxies for cold Jupiters in the same system. I will discuss how a confirmation of this prediction would constrain central open questions in contemporary planet formation theory, ranging from efficiency of pebble accretion to planet migration behavior.

Can Large-Scale Migration Explain the Giant Planet Occurrence Rate? - Tim Hallat (McGill)

Jupiters and sub-Saturns share a similar shape of distributions in orbital periods, which may hint at a common formation pathway. In this work we assess whether the observed occurrence rate vs. orbital period can be explained by large-scale migration using self-consistent calculations of planetary envelope growth and planet-disk interaction. We demonstrate that disk-induced migration cannot simultaneously explain the observed distribution of orbital periods and masses of gas giants inside ~300 days. While the overall rise in the number of giants at longer orbital periods requires systematically more massive giants farther from the star, such a trend is not observed. We further show that the migration paradigm predicts the sub-Saturn occurrence rate to be flat in log orbital period, inconsistent with that observed. Our results suggest that large-scale migration is not the general origin of Jupiters and sub-Saturns.

Sub-Neptune Formation: The View from Resonant Planets - Nick Choksi (UC Berkeley)

While most pairs of sub-Neptunes are not in mean-motion resonance, some are. We examine the non-resonant and 3:2 and 2:1 resonant populations and show how their orbital period distributions faithfully record how sub-Neptunes interacted with each other, their parent circumstellar disk, and their host star. Orbits are sculpted mainly by disk dynamical friction which damps eccentricities and drives migration. The interplay between dynamical friction and resonant forcing decides conclusively how sub-Neptunes completed their formation: whether in a gas-rich disk (e.g., by pebble accretion) or in a gas-poor disk (e.g., by giant impacts). We also show that the resonances established during the last doublings in planet mass are stable, contrary to an earlier claim.

The Origins of Multi-Planet Systems with Misaligned, Nearby Companions - Juliette Becker (Caltech)

Ultra-short period planets provide a look at the inner edge of the allowed parameter space for planetary orbits. One particularly intriguing geometry of system containing ultra-short period planets is high multiplicity systems where the ultra-short period planet and the outer planets exist in two different dynamical states. This has manifested in the observational data as a small number of stars hosting systems of tightly packed coplanar inner planets as well as an ultra-short period planet, where the orbit of the latter is misaligned relative to the mutual plane of the former. We describe two different mechanisms that can produce an ultra-short period planet that is misaligned with the rest of its compact planetary system: natural decoupling between the inner and outer system via the stellar quadrupole moment, and decoupling forced by an external companion with fine-tuned orbital parameters. These two processes operate at different timescales, and can thus occur simultaneously or independently within a single system. We use the K2-266 system as an example to illustrate the dynamics of these two processes. We will also discuss the possibility of placing constraints on when ultra-short period planets in multi-planet systems arrive at their final orbital locations using the results of this work.

Architecture of Systems: The Role of Giant Planet Migration on the Formation of Systems with Multiple Rocky Planets and Super-Earths - Nader Haghighipour (IfA, Univ. of Hawaii)

We report the results of a major initiative on understanding the role of giant planet migration on the formation and orbital architecture of systems with super-Earths and terrestrial-class bodies. The goal of our project is to determine the connection between the type, number, and rate of the migration of giant planet(s) and the mass, frequency, size distribution, and orbital assembly of the final super-Earths and rocky bodies. We have carried out several hundred simulations for different values of the mass and migration rates of giant planet(s), different mass distribution and surface density profile of the protoplanetary disk, and different masses of the central star. Results indicate that, as expected, multiple rocky planets and small super-Earths form in systems where giant planet migration terminates at distances away from the central star interior to which the protoplanetary disk can maintain its material to accommodate planet formation. Capture into resonance of migrating giant planets does not play a significant role as long as the increased influence zones of these planets still allows the protoplanetaty disk to maintain planet forming material. Our simulations indicate that chain-resonance small, rocky bodies are results of the migration of planetary embryos, and close-in large super-Earths (mini-Neptunes) are the failed cores of giant planets that migrated out of their birthplaces. We discuss details of our simulations and present an analysis of the frequency of rocky planets and super-Earths in multi-planet systems in comparison to the outcome of planet formation models in our solar system and some of the extrasolar planets.

Self-Consistent Planet Populations for Direct Imaging Space Missions - Shannon Dulz (Univ. of Notre Dame)

We have developed a suite of numerical models to determine the extent to which ground-based observing programs could improve the planet characterization efficiency of flagship direct imaging missions. As a first step in the process, we have developed tools that may be used to synthesize exoplanet populations based on the occurrence rates from multiple detection methods (transit, RV, imaging). We find that naive extrapolation of planet occurrence from small to large semimajor axes (tens of astronomical units) leads to an unrealistically high number of cold planets, particularly Neptune-mass planets that result in unstable orbits. As a solution, we impose stability criteria based on mutual Hill radii. In this presentation, we show that dynamically packed systems may be used as a limiting case to assess the occurrence rates of imageable planets on the outskirts of their solar systems. Through these synthetic populations, our research quantifies the gains in mission efficiency due to a precursor RV survey. The results will have important implications for planned space missions such as the Roman Space Telescope, LUVOIR, and HabEx.

The Intrinsic Architectures of Planetary Systems: Correlations of AMD-Stable Systems - Matthias He (Penn State)

Kepler's multi-transiting planet systems provide valuable insights into the correlations within planetary systems and their architectures if the detection biases are properly accounted for. In He, Ford, & Ragozzine (2019, 2020), we used SysSim to forward model the Kepler catalog and showed that planets in the same system are more similar in period and in size than if they were drawn independently, the fraction of stars with planets (with Rp>0.5R_Earth and 3d<P<300d) increases towards later type (cooler) stars, and the observed multiplicity distribution can be well matched by two populations consisting of a low and a high mutual inclination component (a Kepler dichotomy). Here, I will present a new model to show that a broad, multiplicity-dependent distribution of eccentricities and mutual inclinations arising from systems at the angular momentum deficit (AMD) stability limit can also reproduce the observed population. Systems with intrinsically more planets have lower eccentricities and mutual inclinations. For each intrinsic multiplicity count, the distributions of eccentricities and mutual inclinations are close to lognormal, instead of the previously assumed Rayleigh distributions. This trend with multiplicity arises from the dependence of the critical AMD on the minimum period ratio in the system, as systems with tightly-spaced planets must have low AMD in order to remain stable. We also find that intrinsic single planets have higher eccentricities than multi-planet systems. I will show that there is evidence for these trends with multiplicity in the Kepler distributions of circular-normalized transit durations and transit duration ratios. Altogether, our new model demonstrates that a single population of AMD-stable planetary systems can match the observed population, eliminating the need for a dichotomy in either multiplicity or mutual inclinations. I will also revisit the observed "peas in a pod" trends and show that the preferences for the ordering of planets in increasing size and for their uniform spacings cannot be explained by detection biases, and are even more extreme than our simple clustering in periods and planet sizes. Finally, I will discuss how our simulated planet catalogs can be used to inform RV follow-up efforts in the search for additional non-transiting companions in systems with transiting planets (such as those observed from the TESS mission).