Exoplanets in the Post-Kepler Era
May 20th & 21st, 2013

ABSTRACTS

Searching for Earth-Twins: A Quest for RV Precision Over the Last Two Decades
Michel Mayor (Geneva Observatory)
Monday, May 20th, 9:05 – 9:40 am

During the eighties, a lot of new instrumental approaches have been proposed to get precise radial velocities. All these efforts were motivated by the challenge of extrasolar planets searches. In parallel to these instruments designed for precision in the range 10-20 m/s, a few teams have been extremely active with spectrographs providing RV with a precision of 250 to 500 m/s. In 1989: strange enough, the first companion with a mass compatible with a giant planet (HD 114762b) was an outstanding discovery made by these "low precision instruments". We will briefly discuss the different steps having allowed the increase of radial velocity precision by a factor 1000 on the last 30 years. Today we have the precision needed to detect earth-type planets in the habitable zone of solar-type stars. On the last decade a rich population of Neptune-mass planets and Super-Earths have been detected by Doppler spectroscopy and more recently by the superb results of the Kepler mission. Already the number of low mass planets is sufficient to provide interesting characteristics of that population.

And what next?

The Once and Future Kepler: Recent Results and News from the Sweet Hereafter
Jon Jenkins (SETI Institute)
Monday, May 20th, 9:40 – 10:05 am

Kepler vaulted into the heavens on March 7, 2009, initiating NASA's search for Earth-size planets orbiting Sun-like stars in the habitable zone, where liquid water could exist on a rocky planetary surface. In the 4 years since Kepler began science operations, a flood of photometric data on upwards of 190,000 stars of unprecedented precision and continuity has provoked a watershed of 120+ confirmed or validated planets, 2700+ planetary candidates (most sub-Neptune in size and many comparable to or smaller than Earth), and a resounding revolution in asteroseismology and astrophysics. The most recent discoveries include Kepler-62 with 5 planets total of which 2 are in the habitable zone with radii of 1.4 and 1.7 Re. The focus of the mission is shifting towards how to rapidly vet the 18,000+ threshold crossing events produced with each transiting planet search, and towards those studies that will allow us to understand what the data are saying about the prevalence of planets in the solar neighborhood and throughout the galaxy.
Statistical Properties of the Small Planets Discovered by Doppler and Transit Surveys
Andrew Howard (University of Hawaii)
Monday, May 20th, 10:05 – 10:30 am

The currently observed architectures of extrasolar planetary systems trace the processes of planetary formation and evolution. Until recently, Jovian-size planets provided nearly all of the observational constraints. From Doppler studies, we detect a steeply rising planet mass distribution down to at least 3 Earth-masses for planets orbiting inside of 0.25 AU. The planet size distribution from Kepler also shows a steep rise with decreasing size, but with a plateau in the occurrence rate for planets 1-2.8 times Earth size. Analyses of the Kepler data support the bottom-up picture of planet formation by core accretion, but also raise new questions about the mechanisms of planet migration, the timing of protoplanetary gas depletion, and the effect of stellar mass on small planet formation. My talk will focus on these occurrence measurements and their interpretation in the context of small planet formation and migration.

New Masses and Radii for 20 Small Planets from Kepler
Geoff Marcy (University of California Berkeley)
Monday, May 20th, 11:00 – 11:25 am

We report multiple RVs spanning four years, of 22 Kepler Objects of Interest (KOIs) that host 42 candidate planets, most being smaller than 4x the size of Earth. We combine the RVs with Kepler photometry to constrain the masses, radii, and orbits of the 42 planets. High-resolution optical spectroscopy of the 22 host stars, combined with asteroseismology analysis for 11 of them, yield accurate stellar and hence planet properties. For 14 planets the RVs provide sound planet masses and for another 10 planets there are 1-2 sigma constraints on mass and density. We assess the probability of false positives by a variety of diagnostics including a spectroscopic search for neighboring stars, adaptive optics, speckle interferometry, light curve analysis, astrometry (centroids), abs. line bisectors, and a statistical model of the Milky Way Galaxy including binary star occurrence. The resulting probability of a false positive is less than 2% for all but three of the planets. The masses, radii, and incident stellar fluxes of the planets are tightly correlated, to be interpreted physically by the following talk by Leslie Rogers. And HD 114762.
Glimpsing the Composition Distribution of Sub-Neptune-Size Exoplanets

Leslie Rogers (California Institute of Technology)

Monday, May 20th, 11:25 – 11:50 am

The Kepler Mission, combined with ground based RV follow-up and TTV dynamical analyses, has revolutionized the observational constraints on sub-Neptune-size planet compositions. We present an updated planet mass-radius distribution including the 42 small Kepler planet candidates with Keck RV-measured masses (or mass upper limits) unveiled by Geoff Marcy in the previous talk. From the observed planet mass-radius distribution, we theorize about why parts of the distribution are unpopulated and about whether this could be a signature of planet formation and evolution. We focus on the intriguing transition between rocky exoplanets and planets with voluminous gas layers, and explore how the current census of sub-Neptune-size exoplanets constrains the maximum radii of rocky planets.

A Framework for Atmospheric Escape from Low-Mass Planets

Ruth Murray-Clay (Harvard-Smithsonian Center for Astrophysics)

Monday, May 20th, 11:50 am – 12:15 pm

The atmospheres of sub-Neptune-mass planets can evolve substantially due to atmospheric escape, particularly when those planets are located close to their host stars. As we begin to measure the properties of low-mass planetary atmospheres, a clear understanding of the physics driving atmospheric escape will become increasingly important. Escape processes can alter not only the masses of planetary atmospheres but also their compositions, as fractionation occurs due to the preferential loss of lighter molecules. In this talk, I will present a framework for understanding atmospheric escape from low-mass planets. A range of physical processes must be considered as sources of atmospheric loss. I will highlight thermal escape of atmospheric gas, including both Jeans escape and hydrodynamic blow-off. When is "energy-limited" escape driven by UV and X-ray radiation appropriate? The answer depends on atmospheric photochemistry. I will present results for hydrogen atmospheres, and explain how analogous calculations may be done for atmospheres with more complicated chemistries.
Probing the Metallicity of the Kepler Exoplanet Host Stars
Lars A. Buchhave (University of Copenhagen)
Monday, May 20\(^{th}\), 2:00 – 2:25 pm

The abundance of heavy elements (metallicity) in the photospheres of stars similar to the Sun provides a fossil record of the chemical composition of the initial protoplanetary disc. Metal-rich stars are much more likely to harbor gas giant planets thereby supporting that planets form by accumulation of dust and ice particles. Recent ground-based surveys suggest that this correlation is weakened for Neptunian-sized planets. However, how the exoplanet-metallicity relationship extends into the terrestrial planet regime is unknown. Here we report spectroscopic metallicities of the host stars of a statistically significant number of small exoplanet candidates (226) discovered by the Kepler mission, including objects that are comparable in size to the terrestrial planets in our Solar System. We find that, contrary to gas giants, the detection of small planets does not depend as strongly on the metallicity of the host star: Planets smaller than 4 Earth radii form around host stars with a wide range of metallicities – on average close to that of the Sun – whereas large planets preferentially form around stars with higher metallicities. This observation suggests that terrestrial-like planets may be widespread in the disk of our Galaxy.

TESS: Discovering New Earths and Super-Earths in the Solar Neighborhood
George Ricker (Massachusetts Institute of Technology)
Monday, May 20\(^{th}\), 2:25 – 2:50 pm

In a two-year survey of the solar neighborhood, TESS will monitor more than 500,000 stars for temporary drops in brightness caused by planetary transits. This first-ever spaceborne all-sky transit survey will identify planets ranging from Earth-sized to gas giants, around a wide range of stellar types and orbital distances.

TESS stars will be 30-100 times brighter than those surveyed by the Kepler satellite; thus, TESS planets should be far easier to characterize with follow-up observations. All of the half-million plus TESS targets will be observed at a rapid cadence (1 minute or less). Hence, the brighter TESS stars will potentially yield valuable asteroseismic information. TESS will provide prime exoplanet targets for characterization with the James Webb Space Telescope (JWST), as well as other large ground-based and space-based telescopes of the future.

TESS will serve as the “People’s Telescope,” with data releases every 4 months, inviting immediate community-wide efforts to study the new planets. The TESS legacy will be a catalog of the nearest and brightest main-sequence stars hosting transiting exoplanets, which will comprise the most favorable targets for detailed investigations.

TESS has been selected by NASA for launch in 2017 as an Astrophysics Explorer mission.
TESS Science: Learning from Kepler  
*David Latham (Harvard-Smithsonian Center for Astrophysics)*  
Monday, May 20th, 2:50 – 3:15 pm

Lessons learned from Kepler are having an enormous impact on the science we will do with TESS. An obvious example is the high occurrence rate for small planets found by the mission, which has been fed into the simulations of planet yields expected from TESS. The numbers are impressive. Another example is the experience brought to the TESS Science Team by the several veterans from the Kepler team. Especially important is the experience and expertise brought to the development of the TESS pipeline by Jon Jenkins and his team. Much of the TESS science will be carried out by working groups, following a model that has worked well for Kepler. In November the Kepler mission transitioned into the extended mission, and there is no longer a proprietary period for the mission data. Kepler is leading the way in a social experiment for how its science will be carried out by the community. We will be watching the results of this experiment with interest, since TESS has promised a similar open policy.

The Cool Kepler Objects of Interest (KOIs) and Beyond  
*John Johnson (California Institute of Technology)*  
Monday, May 20th, 3:45 – 4:10 pm

Just three years ago the prospect of finding temperate, rocky worlds around other stars was still the subject of science fiction: none had been found and reasonable estimates put us years or decades away from such a momentous discovery. All of that has changed very recently on the heels of the extraordinarily successful NASA Kepler mission. By searching for the tiny diminutions of starlight indicative of an eclipsing planet, Kepler has produced thousands of new planet candidates orbiting distant stars. Careful statistical analyses have shown that the majority of these candidates are bona fide planets, and the number of planets increases sharply toward Earth-sized bodies. Even more remarkably, many of these planets are orbiting right “next door,” around tiny red dwarf stars. I will describe our multi-telescope campaign to validate and characterize these tiny planetary systems, and present some early, exciting results that point the way to the first detection of the first Earth-sized planet in the habitable zone of a star.
Precise Radial Velocities in the NIR: Challenges and Opportunities  
_Suvrath Mahadevan (Pennsylvania State University)  
Monday, May 20th, 4:10 – 4:35 pm_

The NSF MRI funded Habitable Zone Planet Finder (HPF) spectrograph for the 10m Hobby Eberly Telescope will target M dwarfs in a radial survey aimed at finding low mass planets in Habitable Zones. I shall discuss instrumental challenges peculiar to the infrared and ways we are overcoming these challenges: NIR detectors, instrument stability, calibration sources, and fiber modal noise in particular. The development of precision NIR RV capability will be highly complementary to ongoing (MEARTH) and future (TESS) precision photometric surveys that will survey M dwarfs.

MEarth: Making the Most of the (Nearby) Small Star Opportunity  
_Jonathan Irwin (Harvard-Smithsonian Center for Astrophysics)  
Monday, May 20th, 4:35 – 5:00 pm_

The diversity and ubiquity of exoplanetary systems found in nature continues to exceed our wildest expectations. Recent results from the Kepler mission indicate that this may continue down to the very bottom of the main sequence. The high planet occurrence rates and favorable observational characteristics of these stars present us with the opportunity to characterize the atmosphere of an extrasolar Earth-like body residing in the habitable zone of its parent star in detail using current or near-future facilities. But first we must find it. I will describe the MEarth survey, which has now been in operation for 4.5 years, searching for transiting planets around many of the closest, brightest examples of these stars, and how we have modified it based on the Kepler results to improve the expected survey yield by searching for smaller planets out to longer orbital periods.

Dynamics and Architecture: It’s about Time.  
_Daniel Fabrycky (University of Chicago)  
Tuesday, May 21st, 9:15 – 9:40 am_

Transit timing variations were highly anticipated since the early days of transiting planets. After observing many transits of hot Jupiters through 2010, the exoplanet community had no clear detections. This situation changed instantly when Kepler began its long-timescale, continuous coverage. It discovered hundreds of multi-transiting systems with longer periods, several dozens of which show timing variations due to their mutual gravitational interactions. I will discuss why Kepler’s continuous-viewing strategy was so important, and review the scientific results we have gleaned from these systems. Their current-day dynamics reveals insight into their orbital architectures, which in turn speaks to their formation. We will learn much more as we track the phases and durations of these transiting planets into the future.
**The Legacy of Giant Planet Dynamical Histories**
*Rebekah Dawson (Harvard-Smithsonian Center for Astrophysics)*
Tuesday, May 21st, 9:40 – 10:05 am

As we enter the era of discovering and characterizing nearby Earth-like planets, the likely dynamical histories of the giant planets in the system will provide crucial context (for example, how much planetary system upheaval an Earth-like planet likely endured). I will present results from our search for super-eccentric hot Jupiter progenitors in the Kepler sample, and evidence that giant planets orbiting metal-rich stars show signatures of planet-planet gravitational interactions. These two studies suggest that both disk migration and planet-planet interactions may be widespread in shaping the architectures of planetary systems, with the latter occurring primarily in metal-rich planetary systems where multiple giant planets can form. I will conclude by discussing implications for TESS target selection and follow-up.

**BEER analysis of Kepler and CoRoT light curves: I. Discovery of Kepler-76b: A hot Jupiter with evidence for superrotation**
*Tsevi Mazeh (University of Tel Aviv), Simchon Faigler, Lev Tal-Or, Dave Latham, and Lars Buchhave*
Tuesday, May 21st, 10:05 – 10:30 am

We present the first case in which the BEER algorithm identified a hot Jupiter in the Kepler light curve, confirmed by follow-up spectroscopy. Kepler-76b was identified by the BEER algorithm, which detected the BEaming (sometimes called Doppler boosting) effect together with the Ellipsoidal and Reflection/emission modulations (BEER), at an orbital period of 1.54 days, suggesting a planetary companion orbiting the 13.3 mag F star. Radial-velocity with TRES and SOPHIE confirmed Kepler-76b as a transiting planet with 2.0+/−0.26 Mjup. We found evidence for the superrotation phenomenon, which involves eastward displacement of the hottest atmospheric spot of a tidally-locked planet by an equatorial super-rotating jet stream. This phenomenon was previously observed only in the infrared by Spitzer. Kepler-76b is the first to show superrotation evidence in the Kepler band. Its discovery illustrates for the first time the ability of the BEER algorithm to detect short-period planets and brown dwarfs.

**The Role of Radial Velocities in the Quest for New Earths**
*Stéphane Udry (Geneva Observatory)*
Tuesday, May 21st, 11:00 – 11:25 am

After the detection and first characterization by radial-velocity surveys of the unforeseen population of super-Earths and Neptunes close to solar-type stars, the radial-velocity planet-searches are targeting even lighter planets with the longer-term goal of detecting a planet similar to the Earth. I will discuss some of the astrophysical limitations associated with the measurements of radial velocities at the few cm/s level, and give updates on the status of the HARPS-N and ESPRESSO projects.
Combining Multiple Activity Diagnostics to Improve RV Precision  
*Suzanne Aigrain (University of Oxford)*  
Tuesday, May 21st, 11:25 – 11:50 am

Stellar activity is now the single most important factor limiting radial velocity searches for planets around bright stars. It also has a significant impact on our ability to measure masses for the Kepler objects of interest. Chromospheric activity indices, line asymmetry diagnostics, and (in the case of Kepler) precise photometry, which are measured simultaneously with the radial velocities, all contain potentially valuable information about activity, and increasingly sophisticated methods are being developed to make use of this information. In my talk I will discuss such an approach, where the rotational and convective signatures of starspots are modelled as latent (not directly observed) processes, which are present in different proportions in the different time-series available. I will show preliminary applications of this method to two example cases with widely different characteristics: Kepler + HIRES data of the KOI-82 system of 5 candidate planets, and HARPS data of Alpha Cen B.

Improving Exoplanet Mass Measurements in the ELT Era  
*Andrew Szentgyorgyi (Harvard-Smithsonian Center for Astrophysics)*  
Tuesday, May 21st, 11:50 am – 12:15 pm

The GMT-Consortium Large Earth Finder (G-CLEF) is a fiber fed, optical echelle spectrograph selected as a first light instrument for the Giant Magellan Telescope (GMT). G-CLEF has been designed to be a general-purpose high-dispersion spectrograph with precision radial velocity (PRV) capability. We have defined the performance envelope of G-CLEF to address several of the highest science priorities in the US Astronomical Decadal Survey. Particular focus is on the search for and characterization of exoearths & the most metal poor stars, as well as several tests of fundamental physics and cosmology. A central design objective for G-CLEF is to achieve <10 cm/sec radial velocity precision. We will describe on-going efforts to exploit laser frequency combs and other calibrators to achieve this goal. We will also present preliminary results of a study modeling the impact of the GMT adaptive optics system on PRV.

Beyond Hot Jupiters: Planetary Atmospheres across the Mass and Temperature Spectrum  
*Heather Knutson (California Institute of Technology)*  
Tuesday, May 21st, 2:00 – 2:25 pm

Although Kepler has dominated discussions of exoplanet statistics in recent years, ground-based transit surveys have been undergoing a quiet renaissance of their own that has resulted in the discovery of an ever-growing sample of lower-mass and longer-period planets around bright, nearby stars. This has created a unique opportunity to extend the current statistical studies of hot Jupiter atmospheres down to smaller and cooler planets that are still favorable for detailed characterization studies. The best-studied planets in
this regime (GJ 436, GJ 1214) have puzzling properties that have yet to be adequately explained; in my talk I will present new measurements obtained with the Spitzer and Hubble Space Telescopes that aim to place these planets in a larger statistical context and to illuminate the major transitions that take place in planetary atmospheres across the mass and temperature spectrum. These studies serve as a precursor for the amazingly rich and diverse atmospheric science that will be possible in the upcoming era of TESS and JWST.

**Finding extraterrestrial life using ground-based high-dispersion spectroscopy**  
_Ignas Snellen (Leiden Observatory)  
Tuesday, May 21st, 2:25 – 2:50 pm_

Ground-based high-dispersion spectroscopy provides unique information on exoplanet atmospheres, inaccessible from space - even using the James Webb Space Telescope. Recent successes in transmission- and dayside spectroscopy with the Very Large Telescope prelude the enormous discovery potential of high-dispersion spectrographs on the next generation Extremely Large Telescopes (ELTs). This includes the orbital inclination and masses of hundred(s) of non-transiting planets, line-by-line molecular band spectra, planet rotation and global wind patterns, longitudinal spectral variations, and possibly even isotopologue ratios. Thinking beyond the ELTs, I advocate that ultimately a systematic search for oxygen in atmospheres of nearby Earth-like planets can be conducted using large arrays of relatively low-cost flux collector telescopes equipped with high-dispersion spectrographs.

**An Equation to Estimate the Probability of Identifying an Inhabited World Within the Next Decade**  
_Sara Seager (MIT)  
Tuesday, May 21st, 2:50 – 3:15 pm_

The ambitious goal of identifying signs of life via biosignature gases in an exoplanet atmosphere is within reach. The _James Webb Space Telescope_ has a chance to be the first to provide evidence of biosignature gases. But how high is this chance? We need to first discover a pool of super Earths transiting in the “extended” habitable zones of nearby, quiet M stars. Life must not only exist on one of those planets, but the life must produce biosignature gases that are spectroscopically active. Exoplanets with H2-rich atmospheres are the most accessible for transmission spectroscopy due to their inflated scale height. To estimate the probability for biosignature gas detection we can use both quantitative and speculative terms in a “revised Drake equation”.

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_Exoplanets in the Post-Kepler Era Abstracts_