Exoplanet Research Program
Abstracts of selected proposals
(NNH14ZDA001N-XRP)

Below are the abstracts of proposals selected for funding for the XRP program. Principal Investigator (PI) name, institution and proposal title are also included. 134 proposals were received in response to this opportunity, 72 of which were reviewed by the Planetary Science Division (PSD). On December 16, 2014, 10 proposals were selected for funding by PSD.

Mate Adamkovics/Regents Of The University Of California, The
The Photochemistry of Gas and Ice in UV and X-ray Irradiated Disk Atmospheres

As we approach the era of JWST and embark on using facilities such as ALMA, which have the capability to produce detailed observations of the material around young stars that form planets, we are still lacking in our understanding of the physical and chemical mechanisms that process and chemically alter this material. We don't yet know how to make the evolutionary connection between the observations of disks of various ages and the thousands of planetary systems observed by Kepler.

We propose here to model the time-dependent chemical evolution of gas and solids in protoplanetary disks, focusing on the distribution of water and organics. We will investigate the heating mechanisms that produce the warm atmosphere that is observed by Spitzer and from ground-based observatories, and will consider the photochemistry and radiative transfer that are critical to establishing and maintaining the inventory of water and organics. We will incorporate and evaluate the implementation of the most recent laboratory data on the complex interactions between solids and gas.

Our aim is to make predictions of the observable properties of disks at various ages, invoking rudimentary approximations for transport and mixing that can inform more detailed and fundamental models of the gas dynamics. By doing so, we will lay the ground work for making the connection between the observable properties of disks, and the distribution of material that ends up on newly forming planets, thereby addressing the likelihood of habitability via the inventory of water and organics present.

L. Deming/University Of Maryland
Optimal Observational Diagnostics for Transiting Exoplanetary Atmospheres

The first detection of a transiting exoplanet atmosphere was made via Hubble observations in 2002, and the first emergent photons were detected using Spitzer in 2005. Since that time, there have been numerous detections and observations of transiting exoplanetary atmospheres using both space-borne and ground-based facilities. Infrared radiation has been detected from planets down to the size of super-Earths. Nevertheless, the number of unequivocal conclusions from the observations is few, and previous results

such as the existence of temperature inversions in hot Jupiter atmospheres are now being questioned. Looking forward, powerful new facilities are expected to be available in the not-too-distant future. In space we will have the James Webb Space Telescope, and a new generation of Extremely Large Telescopes are planned at ground-based observatories. Nevertheless, it is not clear how we can use these new tools to characterize transiting exoplanetary atmospheres in an optimal way. JWST, for example, has more than a dozen observing modes capable of transiting exoplanet measurements. These observing modes could be applied at either/or transit and secondary eclipse, and the large number of possible planetary targets continues to grow almost daily. The community is investing much effort in projecting and simulating the sensitivity of JWST (and to a lesser extent, the ELTs) for exoplanetary science. Nevertheless, the scientific and observational parameter space to be explored is very large, and our current basic knowledge of exoplanetary atmospheres is tentative. To make solid progress, we need to move well beyond mere sensitivity calculations, and we need to focus future observations to go beyond mere detections. To accomplish optimal science, we must model the emergent spectra from exoplanetary atmospheres over a range of plausible physical conditions, determine what observational mode is best suited to those spectra, and thereby narrow the observational parameter space.

We propose a modeling effort that is focused at the interface between theory and observations. We will use flux-constant model atmospheres for exoplanets from hot Jupiters to super-Earths, and calculate their emergent and transmitted spectra, after modifying the models in a manner consistent with a variety of hypotheses that reflect current understanding (temperature inversions, carbon planets, haze layers that mimic blackbodies, etc.). Using a differential-forward approach, and simulations of JWST and ELT observations, we will determine exactly what observational mode is most sensitive to a given physical property of each exoplanet. Then, we will apply an inverse technique to the simulated observations to close the loop and verify that the observations will be conclusive.

We will make the results of this work publically available as a grid of high resolution spectra, with a variety of physical atmospheric perturbations applied to selected key planets, as well as codes to simulate observations of them by all modes available to JWST. Our proposed work is very much in line with the scope of NASA's exoplanet research program as articulated in Appendix E.3 of ROSES 2014.

Eric Ford/Pennsylvania State University
Bulk Properties of Small Transiting Planets and Implications for their Formation

We propose to characterize the masses and eccentricities of Kepler-identified planets, as a function of planet size and incident stellar flux using transit timing variations (TTVs) measured from Kepler data. Characterizing the mass-radius relationship for small planets is one of this decade's most important goals in the field of exoplanets. Recently, NASA's Kepler mission has identified thousands of high probability small transiting planet candidates, providing precise measurements of their size and orbital periods, which are

well measured in the transit light curves. However, for most of planets, Kepler can not measure planet mass. We will focus on planets in systems with multiple transiting planets that have orbital periods near a mean-motion resonance. These are particularly information-rich systems, as they often result in measurable transit timing variations (TTVs) due to planet-planet interactions that enable the characterization of planet masses and orbital eccentricities.

First, we will analyze TTVs in individual planetary systems (i.e., those with multiple transiting planets near mean-motion resonances) to provide constraints on individual planet masses and eccentricities. Second, we will combine our results to statistically characterize the mass-radius-eccentricity distribution of this important population of planets. Our proposed research will dramatically improve on previous analyses by: 1) analyzing the complete Kepler time series, 2) using Kepler's “Short Cadence” data when available, 3) overcoming selection biases by analyzing a uniform sample of systems (including those with no significant TTV detections), 4) applying a hierarchical Bayesian model (HBM) to rigorously characterize the mass-radius distribution (including potential correlations with eccentricity and incident flux), and 5) generalizing the HBM to incorporate results of detailed TTV modeling of systems with more complex TTV signatures. This proposal would result in: 1) significantly improved characterization of masses, compositions and eccentricities of many small planets, 2) characterizing the eccentricity distribution of planets near mean-motion resonances, 3) a much improved characterization of the mass-radius relationship, particularly for small planets, and 4) empirical constraints of the frequency of planet compositions (e.g., rocky, rock+ice).

Based on an analysis of simulated planet mass-radius data, we expect that our results will: 1) constrain the relationship between planet core and envelope masses (e.g., power-law exponent to ~10%), 2) quantify the amount of scatter among planet compositions at a given mass (~10%), and 3) identify sub-populations of planet classes and measure their relative occurrence rates (~10%). An improved mass-radius relation for small planets, would have important implications for the frequency of rocky planets and planet formation.

Wade Henning/University Of Maryland
Tidal Dynamics and Orbital Evolution of Terrestrial Class Exoplanets with Time Varying Internal Melt Fractions

There is a strong need in the orbital modeling of extrasolar planetary systems to incorporate the role of partial melting in rocky and icy exoplanets during orbital migration, especially in cases where high levels of tidal heat production are expected. In this proposal we will present a detailed plan to address orbital evolution with time varying melt fractions, based on a team with extensive experience in tidal and orbital modeling.

Application of typical tidal parameters for Earth analog planets in short orbital periods (e.g., 1âˆ’50 days) around a solar mass host stars leads to orbital circularization times on the order of only 1âˆ’10 million years, suggesting that such planets can reasonably be expected to have fully circular orbits in the absence of other disturbances. In strong contrast, when melting due to tidal heating is considered, the circularization time, even for such close-in objects, may either extend up to and beyond several billion years (and thus well past the age of many stellar hosts), or decrease by up to a factor of 100 (helping small planets to recover even faster from orbital scattering events). The key to distinguishing these two outcomes is the magnitude of heating, melting, and melt extraction to the surface that each planet experiences, with moderate heating leading to the fastest circularization times. The possibility of such dramatically altered tidal damping further implies in multibody systems with scattering, secular perturbations, and mean motion resonances, that the equilibrium eccentricities and survival rates of terrestrial planets against ejection or solar capture will each be significantly modified from present models with constant interior properties.

We propose to use multibody simulations of orbital dynamics to test, against the observed exoplanet population, a sequence of increasingly detailed internal models of tidally driven melt production in terrestrial class planets. The proposed research includes the following core objectives: 1). Quantify melt production and melt extraction rates in silicate, and ice-silicate hybrid exoplanets by developing self-consistent interior thermal models based on the distribution of tidal heat production in multilayer systems. 2). Determine how tidal properties of initially solid planets vary realistically in time in cases of strong tidal forcing. 3). Constrain exoplanet evolution theories by comparing orbital models with time variable melt fractions to the observed exoplanet population.

We will meet these goals by combining analytical and numerical techniques on existing computing facilities. We will combine existing codes for multilayer tidal heating, parametrized convection, and planetary thermal evolution, with published models for melting and melt transport, to create modules for the widely utilized N-Body orbital simulation code Mercury. We will then distribute such modules, along with instructions and tutorials, for community utilization. This work is directly relevant to the goals of the NASA Exoplanet Research Program to improve our understanding of extrasolar planetary systems and to facilitate the interpretation of data from missions such as the Kepler Space Telescope, as well as by leading to predictions for the orbital evolution of Earth and super-Earth class worlds that can be tested with NASA observatories.

Hiroshi Imanaka/SETI Institute

Laboratory investigation of plausible photochemical haze particles in hot exoplanetary atmospheres: Towards understanding of the coupled silicon and CHNO photochemistry

Recent transit observations of exoplanets have demonstrated the possibility of a wide prevalence of haze/cloud layers at high altitudes, obscuring the detection of major gaseous compositions. As a result, we must understand plausible formation mechanisms

of haze/cloud particles and their optical properties to interpret the observational data. We proposed to investigate EUV-VUV photochemistry of H2/CO with CH4 or SiO to understand plausible photochemical haze formations in warm/hot (temperature 500-1400 K) exoplanetary atmospheres. A coupled Si-CHO disequilibrium could result in very refractory dust materials. Thus, the goal of this proposed laboratory investigation is to constrain the onset of haze formations and their chemical/optical properties. We will conduct a series of VUV photochemical experiments of nominal H2/CO/(CH4) gas mixture at 500 - 800 K, and H2/CO/SiO gas mixture at 1400 K. This is possible by modification to our existing VUV photochemical chamber by implementing a high-temperature furnace. The plausible haze compositions and their optical constants from this laboratory investigation would help interpretation of the current and near-future observations of exoplanetary atmospheres.

Hannah Jang-Condell/University Of Wyoming
Structure, Dynamics, and Evolution of Planet-Forming Disks: Modeling the Inner Walls of Transitional Disks

Transitional disks are disks of material around young stars that may be the seed beds of planet formation. They are rich in gas and appear to have cleared out inner regions or holes in their centers. We would like to understand whether or not these inner holes are evidence of active planet formation by creating detailed models of their structure. A particularly interesting phenomenon observed in these disks is rapid variability in their infrared thermal emission. This may be caused by material within the inner hole shadowing and cooling the outer disk. As this material moves around, the shadows cast on the outer disk also move, leading to cooling in different regions. This may manifest as infrared variability. Some questions we will address in this study include: Are inner holes caused by planets? Does infrared variability indicate the presence of planets inside the inner holes? How do we differentiate between signatures of planet formation and other disk evolution processes in transitional disks?

We propose to address these questions by upgrading our existing codes for modeling the effects of shadowing and illumination in disks around young stars. The changes we propose will allow us to (1) model transitional disks with shadowing material inside their inner holes, (2) model the extent of shadowing on the rest of the disk, (3) accurately predict the thermal effects at the disk surface, and (4) examine how the whole system varies over time. These new models will allow us to explore different geometries of disks and the material in their inner holes. We will generate models of transitional disks with and without planets to predict what observable features might be attributed to planets and which ones cannot. This research will give us a better understanding of the planet formation process overall.

This project promotes NASA's Strategic Goal 2.2: “Discover how the universe works, explore how it began and evolved, and search for Earth-like planets” (2011 NASA Strategic Plan). This project falls under the scope of the Exoplanet Research program because it is “basic research & to advance our knowledge and understanding of

exoplanetary systems." The theory and modeling studies proposed here will "improve understanding of the origins of exoplanetary systems."

Marc Kuchner/NASA Goddard Space Flight Center
Probing the Debris Disk-Planet Connection with Collisional Cascades

Recent observations of circumstellar debris disks indicate particle size distributions inconsistent with standard collisional cascade theory (e.g. Acke et al. 2012, Ertel et al. 2012). In order to properly interpret and fully exploit these and other debris disk data from, for example, Herschel, ALMA, and soon JWST, we propose to advance and refine the theory of collisional size distributions by self-consistently incorporating planetesimal velocities into size distribution calculations. We will use both analytic and numerical techniques to incorporate velocity evolution via viscous stirring, collisional damping, dynamical friction, and radiation pressure into calculations of collision rates and dust production. We will then apply the results to observed disks. In particular, given size distribution, scale height, and/or velocity dispersion measurements for a certain disk, the new theory will allow us to constrain the disk planetesimals' bulk compositions and the mass in any nearby planets interacting gravitationally with the disk.

This work is directly relevant to the Exoplanets program objective "characterization of planets and planetary systems outside of our Solar System, including the determination of their compositions, dynamics, energetics, and chemical behaviors."

Mark Marley/NASA Ames Research Center
Understanding the Directly Imaged Exoplanets

We propose to construct a large grid of model atmospheres that will facilitate the interpretation of observations of young giant planets discovered by the GPI and SPHERE exoplanet surveys. In addition we will construct custom models for specific planets with the highest quality of data. We will use existing computational tools and develop new models in order to constrain the atmospheric composition, thermal and chemical states, and cloud properties of these planets. This work will address NASA and Exoplanet Program goals of understanding the chemical and physical processes of exoplanets and inform future JWST followup observations of these objects.

Thomas Quinn/University of Washington
Cooling and Fragmentation of Protoplanetary Disks

Objectives:

The numbers of giant planets being discovered around other stars leads to the conclusion that the formation of such planets is a very efficient process. The short lifetimes of gaseous disks in star forming regions further implies that this process must also be rapid.

The Gravitational Instability model for giant planet formation where the giant planets form by direct fragmentation of the gas disk is therefore very attractive. Furthermore, recent discoveries of planets far from their host star, where core formation timescales are very long, make alternative models more compelling. However, the growth and fate of such instabilities is strongly controlled by the heating and cooling of the disk which in turn is influenced by external radiation, radiative cooling, viscous heating and shocks, and advection of thermal energy. Hence detailed modeling of these phenomenon are required to determine whether, and in what circumstances, Gravitational Instability is a viable model for planet formation.

Methodology:

Progress in understanding disk fragmentation will require adaptive,high resolution simulations of the gravitational instability process that also incorporate a realistic equation of state coupled to radiative processes. We will improve the radiative transport in our highly scalable Smooth Particle Hydrodynamic code, ChaNGa, and use it to more realistically model the growth (or lack thereof) of protoplanets via fragmentation. By putting strong constraints on this particular scenario for planet formation, such realistic simulations are crucial to answering the more fundamental question of whether planet formation is a ubiquitous or a rare process.

Relevance: As a theoretical investigation of protoplanetary disks and the formation and early evolution of planetary systems, this proposal falls directly with in the scope of the Exoplanet Research program. Furthermore, this research will provide a theoretical framework for the interpretation of data from missions attempting to discover and characterize other planetary systems, such as JWST and Kepler.

Neal Turner/California Institute Of Technology
The Planet-Forming Environment Close to Young Stars

Protostellar disks' inner regions, the central 0.05-1 AU, are crucial for understanding the origins of the large population of planets found by the Kepler mission orbiting close to their stars. New constraints on the inner regions' structure and time evolution are in reach thanks to infrared interferometry with Keck and the VLT, and variability studies using Spitzer, CoRoT, and ground-based spectroscopy. We propose to combine those measurements with first-principles radiation-MHD modeling to determine the disks' density and temperature distributions. We will then find the magnitude and sign of the torques on embedded, migrating planets, properly treating the radiative heading and cooling effects that are now known to modify the migration's rate and even direction. We will examine the masses at which the planets open gaps in the disk, and seek locations where the planets' migration comes to a halt. These are essential ingredients for learning about the close exoplanets' formation and history. We will furthermore use radiative transfer modeling to look at the observable signatures of planets embedded in the disks, considering the planets' effects on images, thermal infrared photometry, and stellar extinction measurements. We will compare the planet signatures with the features

produced by the transport processes intrinsic to the disk, to enable both probing the transport and distinguishing true young planets.