New Horizons in Planetary Systems

13-17 May, 2019 | Victoria, BC

Oral Presentation Abstracts

New Horizons in Planetary Systems

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Monday, 13 May 2019

Start	End	Title	Speaker (* student talk)
7:30 AM	5:00 PM	Registration	
8:45 AM	9:00 AM	Welcome	
		Session 1, Chair: Kate Su	
9:00 AM	9:40 AM	Invited Review: Protoplanetary Disk Theory	Zhaohuan Zhu
9:40 AM	10:00 AM	New Horizons in Protoplanetary Disk Modeling	Joanna Drazkowska
10:00 AM	10:20 AM	Poster Highlights	
10:20 AM	11:00 AM	Coffee and Posters	
11:00 AM	11:20 AM	Dust Evolution & Planet Traps	Matthew Alessi*
11:20 AM	11:40 AM	The Outer Edge of Planet Formation	Nathanial Hendler*
11:40 AM	1:30 PM	Lunch	
		Session 2, Chair: Al Wootten	
1:30 PM	2:10 PM	Invited Review: mm Observations of Solar System Objects	Emmanuel Lellouch
2:10 PM	2:30 PM	Resonant TNO Populations with OSSOS	Samantha Lawler
2:30 PM	2:50 PM	Titan's Atmospheric CH3D Measured in the Submillimeter with ALMA	Alexander Thelen
2:50 PM	3:10 PM	Constraining Neptune's Migration: Cold Classicals in the 2:1 Resonance	Rosemary Pike
3:10 PM	3:30 PM	Poster Highlights	
3:30 PM	4:00 PM	Coffee and Posters	
4:00 PM	4:20 PM	Placing New Horizons' Next Flyby Target in a Solar System & Exosystem Context	C. M. Lisse
4:20 PM	4:40 PM	Substructures in Protoplanetary Disks: Are They Produced by Planets Or Not	Ruobing Dong
4:40 PM	5:00 PM	Dust Unveils the Presence of a Migrating Mini-Neptune in a Protoplanetary Ring	Sebastian Perez
5:00 PM	5:20 PM	Multiple Stars, Multiple Rings	Jiaqing Bi*
5:20 PM	7:20 PM	Poster Session	

Zhaohuan Zhu (University of Nevada, Las Vegas)

Topic: Protoplanetary Disk Theory

Review on Protoplanetary Disk Structure

Recent high spatial resolution near-IR (e.g. Subaru, Gemini, Keck, and VLT) and radio (e.g. ALMA and VLA) observations have provided us unprecedented details of protoplanetary disks across the electromagnetic spectrum. These features not only provide stringent constraints on disk dynamics and planet formation theory, but also reveal rich physical processes which we haven't studied before. First, I will review the detected disk features and their implications on disk dynamics and planet formation theory. Then, I will discuss the progress on first-principle protoplanetary disk modeling and how future observations can help to advance our knowledge on disk dynamics and planet formation.

Joanna Drążkowska (Ludwig Maximilian University of Munich)

Shengtai Li (Los Alamos National Laboratory)
Sebastian Stammler (Ludwig Maximilian University of Munich)
Til Birnstiel (Ludwig Maximilian University of Munich)
Hui Li (Los Alamos National Laboratory)

Topic: Protoplanetary Disks

New Horizons in Protoplanetary Disk Modelling

Models of dust evolution are an important ingredient of our understanding of protoplanetary disk observations. Dust evolution is governed by the underlying gas disk structure. However, due to their computational expense, hydrodynamical models of protoplanetary disks usually stick to oversimplified fixed dust size approach. On the other hand, details of dust coagulation are typically studied in azimuthally and vertically averaged setups. For the first time, we incorporated a complete dust coagulation solver in the state-of-the-art hydrodynamic code LA-COMPASS, which includes full coupling between gas and dust. With this new method, we are able to study the interplay between gas evolution and dust coagulation in full-disk setups, for example including gap-opening planets. We find that dust evolution differs significantly in models that incorporate dust coagulation, proving the importance of introducing more realistic dust size distribution prescriptions, particularly in models performed in the context of interpreting the ALMA observations.

Matthew Alessi (McMaster University)

Ralph Pudritz (McMaster University)

Dust Evolution & Planet Traps: Effects on Planet Populations

The wealth of recently discovered exoplanets has revealed the existence of planet populations on the mass-period diagram. Our work aims to understand the factors in planet formation processes that shape this distribution. We combine an evolving physical and chemical disk model and the core accretion model of planet formation in a population synthesis approach. A key feature of our model is the inclusion of planet traps – barriers that prevent rapid type-I migration. The traps we include are the water ice line, heat transition, and the dead zone outer edge. We explore the effects of radial dust drift, an effect indicated by ALMA disk observations, by comparing planet populations that include its effects to those in which a constant disk dust-to-gas ratio has been assumed. When considering a constant dust-to-gas ratio, our model produces many super Earths and Neptunes, with the majority having orbital radii outside of 1 AU. Including dust evolution has a large affect on our planet populations, and many more super Earths orbiting between 0.1-1 AU are produced. Additionally, efficient radial drift leads to an enhancement of solids at the ice line, and a large number of gas giants near 1 AU are formed as a consequence. Comparing these two treatments of the dust, we are able to identify the degree to which radial drift needs to be slowed to better agree with the observed planet distribution.

Nathanial Hendler (LPL/University of Arizona)

Ilaria Pascucci (LPL/University of Arizona)
Paola Pinilla (Steward/University of Arizona)

Topic: Protoplanetary Disks

The Outer Edge of Planet Formation

We present the results of radial profile fitting in the visibility plane of 64 protoplanetary disk observations made by ALMA in the Chamaeleon I (1-3 Myr) and Upper-Sco (5-11 Myr) star-forming regions. Because these regions probe different disk evolutionary epochs, we are able to search for trends in the evolution of the dust-disk outer radius through time and investigate how processes like grain growth and inward migration constrain the outer edge of planet formation. Comparison of disks' radial size as a function of age and stellar mass have until now not been performed in a homogenous way, leading to reported trends that may not reflect true spreads in disk sizes. By adding to our sample disks modeled in a similar manner in Lupus, Taurus and Ophiucus, we find star-forming regions with 1-3~Myr ages have disks of similar size while the older disks of Upper-Sco are smaller in size. We additionally discuss the results in the context of debris disks and of the Solar System's Kuiper Belt.

Emmanuel Lellouch (Observatoire de Paris)

Topic: Solar System

The Solar System in the ALMA Era

Spectroscopy and radiometry at mm/submm wavelengths has for a long time proven to be a powerful means to study the diversity of Solar System objects (planetary and satellite atmospheres, comets, airless bodies). The operation of ALMA as well as the upgrade of other facilities have provided many new observational results in recent years, addressing a wide range of topics related to either the origin/evolution of these bodies or to the physics of their environments. Submm spectroscopy of comets is an invaluable tool to study the molecular inventory and diversity of comets, their isotopic composition, the nature of cometary activity, the coma physics, and the asteroid/comet relationships. Spectroscopy of planetary atmospheres aims at determining the coupled fields of composition, thermal structure and dynamics, with implication on their energy budgets, and to characterize exogenous input to these atmospheres. Radiometry of satellites and airless small bodies (asteroids and trans-neptunian objects) constrains their surface thermal and emissivity properties, albedo, size, density, with implications for formation mechanisms (e.g. for binary systems). Recent results from ALMA and other mm/submm facilities, including synergies with other approaches, will be discussed.

Sam Lawler (NRC-Herzberg)

and the OSSOS Team

Topic: Solar System

Resonant TNO Populations as Measured by OSSOS

The Outer Solar System Origins Survey (OSSOS) was a large program over 5 years carried out on the Canada-France-Hawaii Telescope, with the goal of detecting and tracking hundreds of trans-Neptunian objects (TNOs) while carefully measuring all survey biases. OSSOS and three affiliated surveys detected over 1100 trans-Neptunian objects (TNOs) with precise orbits, over 400 of which are securely measured to be in mean-motion resonances with Neptune. Because all of the biases are tracked in OSSOS, we can use the OSSOS Survey Simulator to construct unbiased orbital models of each TNO subpopulation. Here we present the orbital distributions of all the Neptune mean-motion resonances that have significant detections in the OSSOS ensemble of surveys. The population ratios and orbital distributions provide constraints on Neptune's migration mode and timescale, as well as the makeup of the proto-Kuiper belt.

Alexander E. Thelen (NASA Goddard Space Flight Center/Catholic University of America)

Conor A. Nixon (NASA GSFC), Martin A. Cordiner (NASA GSFC/CUA), Steven B. Charnley (NASA GSFC), Patrick G. J. Irwin (University of Oxford)

Topic: Solar System

Titan's Atmospheric CH3D Measured in the Submillimeter with ALMA

The complex chemistry and wealth of organic molecules found in Titan's atmosphere is largely dependent on the photodissociation of methane (CH_4), the moon's second most abundant atmospheric constituent (following N_2). The abundance and distribution of Titan's CH_4 is also important for the formation of clouds, surface liquid features, and Titan's methane-based hydrological cycle. However, the source of Titan's atmospheric CH_4 is still poorly understood. Here, we report the first definitive measurement of monodeuterated methane (CH_3D) in the submillimeter, detected in Titan's atmosphere using archival flux calibration data from the Atacama Large Millimeter/submillimeter Array (ALMA). The $J_K=2_1$—1_1 and $J_K=2_0$—1_0 transitions at 465.235 and 465.250 GHz (~0.644 mm) were measured at significance levels of 4.6σ and 5.7σ, respectively. We modeled the disk-averaged spectrum of CH_3D to determine the abundance and D/H in Titan's stratosphere using measurements of CH_4 from the *Cassini-Huygens* mission. Our measurements are consistent with previous ground- and space-based measurements of CH_3D and Titan's D/H, though subsequent observations are required to provide better constraints and investigate possible latitudinal variation of CH_3D. As ALMA provides the capability to map CH_3D and many additional trace species, we can continue to explore the fascinating chemistry and meteorology of Titan's atmosphere in the post-*Cassini* era.

Rosemary E. Pike (ASIAA)

Kathryn Volk (LPL, University of Arizona), Ruth Murray-Clay (UCSC), Wesley Fraser (NRC Herzberg), Michael Marsset (MIT), Megan Schwamb (Gemini Observatory), Michele Bannister (Queen's University Belfast), Nuno Pexinho (CITEUC Portugal), Mike Alexandersen (ASIAA), Ying-Tung Chen (ASIAA), Brett Gladman (UBC), Stephen Gwyn (NRC Herzberg), JJ Kavelaars (NRC Herzberg)

Topic: Solar System

Constraining Neptune's Migration: Cold Classicals in the 2:1 Resonance?

The cold classical Trans-Neptunian Objects (TNOs) have different albedos, binary fraction, and surface colors from other TNO populations, and are thought to have formed in situ. The surfaces of cold classical and dynamically excited TNOs can be robustly categorized into three surface types based on their *g*, *r*, and *z* band photometry [Pike et al. 2017]. Because of the unique surface reflectance of cold classicals, it is possible to identify objects with cold classical surfaces that are no longer on cold classical orbits. These objects would have been implanted into other TNO dynamical populations as a result of Neptune's migration. As Neptune migrated outward to its current location, its 2:1 resonance swept, jittered, or jumped across the current cold classical region of the Kuiper belt. A smooth, sweeping migration would trap objects from the cold classical region into the 2:1 resonance. The fraction of trapped cold classicals in the 2:1 provides a robust constraint on the distance and speed with which Neptune's resonance smoothly swept over the cold classical Kuiper belt. We combine migration simulations with photometry of a sample with known discovery biases (from OSSOS, CFEPS, HiLat, and Alexandersen 2016) to measure the intrinsic fraction of cold classical objects trapped in the 2:1 resonance. We have acquired *g*, *r*, and *z* band photometry of 17 of our 34 targets on the Large Binocular Telescope (LBT), and our results already exclude the most efficient sweeping scenario: a slow sweeping migration across the entire cold classical region.

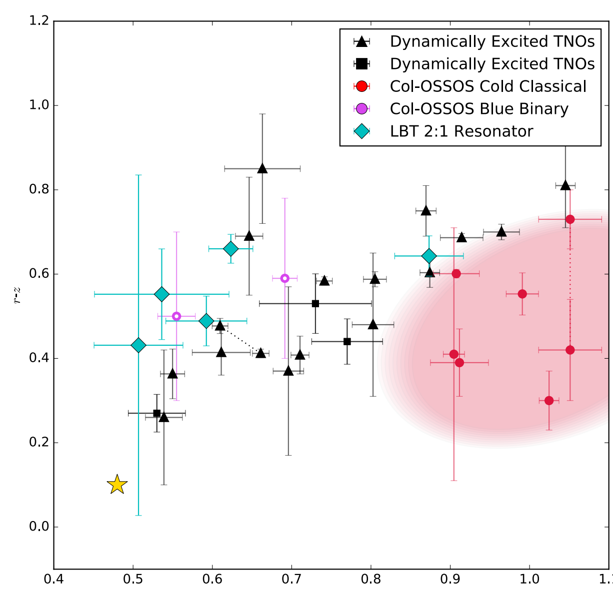

Figure: Colors of dynamically excited TNOs (black triangles and squares), cold classical TNOs (solid red circles), and blue binary cold classical objects (pink circles) which were implanted into the cold belt. Figure is adapted from Pike et al. 2017, with additional data from the 2:1s from LBT (cyan diamonds). Solar colors are indicated by the star. The cold classical objects clearly occupy a separate clump, and can be identified using *grz* photometry. The shaded red area represents the approximate region of cold classical surfaces.

Carey M. Lisse (Johns Hopkins University Applied Physics Laboratory)

Alan Stern, Catherine Olkin, Alex Parker, Joel Parker, John Spencer, Leslie Young (SWrI)
Susan Benecchi (PSI)
Richard Binzel (MIT)
Pontus Brandt, Andrew Cheng, Ralph McNutt, Kirby Runyon, Harold Weaver (Johns Hopkins University Applied Physics Laboratory)
Bonnie Buratti (JPL)
Dale Cruikshank, Jeffrey Moore (NASA Ames Research Center)
Mihaly Horanyi (Univ of Colorado)
William McKinnon (Washington University)
Andrew Poppe (UCB Space Sciences Laboratory)
Michael Summers (George Mason Univ.)
Orkan Umurhan (SETI Institute)
Anne Verbiscer (Univ. of Virginia)

Topic: Solar System – Exosystem Connection

Placing New Horizons' Next Flyby Target in a Solar System & Exosystem Context

Kuiper Belts, thought to be the edge of a star's original proto-planetary disk, are common, perhaps ubiquitous processes of planetary systems - at least 30% of all stars have them according to Spitzer and Herschel surveys. New Horizons is the first spacecraft to ever survey our Kuiper Belt, making measurements on its smallest dust particles up to its largest body, Pluto, and on a number of bodies in between. For example, the New Horizons encounter with Ultima Thule on 1 January 2019 will be the first time a spacecraft has ever closely observed one of the small free-orbiting denizens of the Kuiper Belt. Related, via inward scattering from the Kuiper Belt through the Centaur region and into the inner solar system, to the short period comets explored by spacecraft such as Giotto, Deep Impact, Stardust, and ROSETTA, Ultima Thule will also be the largest, most distant, and most primitive body yet visited by spacecraft.

In this paper we attempt to put the results from these measurements in a planetary system formation and evolution context. We argue that while the Kuiper Belt may have some dynamical similarities to our inner relic planetesimal asteroid belt (e.g., pronounced resonances with a giant planet and scattered disk objects), stable massive inner Gyr-old asteroid belts may be rare. By contrast, all stellar systems must form from edge-truncated disks which produce Kuiper Belts with a unique history at the outer edge of their solar systems. This unique history may or may not involve systems that are in slow, frustrated collisional equilibrium interrupted by planetary perturbations, judging from the reported frequency of our system's KBO binaries and bilobate inner system cometary nuclei and the distribution of mass in the known KBO population.

Ruobing Dong (University of Victoria)

Topic: Protoplanetary Disks

Substructures in Protoplanetary Disks: Are They Produced by Planets Or Not

Recent imaging observations of protoplanetary disks at near-infrared and mm/cm wavelengths have found that substructures, such as spiral arms, gaps, and asymmetries, are common. One major question in planet formation today is the origin of these structures – are they produced by planets? or by non-planetary mechanisms? The answer to this question is of fundamental importance to our understanding of planet formation and disk evolution. I will discuss our current effort in addressing this question with today's observational and modeling capabilities, and a plan forward to better understand the origin of substructures in disks in the future.

Sebastian Perez (Universidad de Santiago de Chile)

Simon Casassus (DAS, U. de Chile), Clement Baruteau (IRAP, Toulouse), Ruobing Dong (Victoria University), Antonio Hales (NRAO/ALMA) and Lucas Cieza (UDP)

Topic: Protoplanetary Disks, Exoplanets

Dust Unveils the Presence of a Migrating Mini-Neptune in a Protoplanetary Ring

Rings and radial gaps seem ubiquitous in protoplanetary disks. Their possible connection to planet formation is subject to intense debate. In theory, giant planet formation leads to wide gaps that separate the mass reservoir in the outer disk, while lower mass planets lead to shallower gaps. I will present ALMA observations of a disk known to harbor several giant protoplanet candidates in its inner regions. We were puzzled to find that the outer ring, expected to be smooth if due to giant planet formation only, instead shows an intricate system of fine rings and narrow gaps. Using hydrodynamical modeling we found that the simplest explanation, involving a single and migrating low mass planet (of a mini-Neptune size), entirely accounts for such an apparently complex phenomenon. The connection was made possible thanks to the isolation of this protoplanetary outer region. I will finish the talk discussing what these observation may be telling us about the planet formation process.

Start	End	Title	Speaker (* student talk)
		Tuesday, 14 May 2019	
		Session 3, Chair: Wladimir Lyra	
9:00 AM	9:40 AM	Invited Review: Planet Formation Theory	Brett Gladman
9:40 AM	10:00 AM	GPIES and Beyond: Status, Results and Upgrades	Benjamin Gerard*
10:00 AM	10:20 AM	Poster Highlights	
10:20 AM	11:00 AM	Coffee and Posters	
11:00 AM	11:20 AM	Small-Scale Substructures in Protoplanetary Disks	Sean Andrews
11:20 AM	11:40 AM	Gaps and Rings in ALMA Large Program DSHARP: Implications for the Young Planet Population	Shangjia Zhang*
11:40 AM	1:30 PM	Lunch	
		Session 4, Chair: Virginie Faramaz	
1:30 PM	2:10 PM	Invited Review: Debris Disk Constraints on Planet Formation	Grant Kennedy
2:10 PM	2:30 PM	Probing Planetesimal Formation Mechanisms	Alexander Krivov
2:30 PM	2:50 PM	Weighing Planetary Systems	Meredith Hughes
2:50 PM	3:10 PM	Connecting Structure in Edge-on Debris Disks to Planetary Systems	Meredith MacGregor
3:10 PM	3:30 PM	Poster Highlights	
3:30 PM	4:00 PM	Coffee and Posters	
4:00 PM	4:20 PM	Depleting Annular Regions in Debris Disks by Secular Resonance with a Two-Planet System	Ben Yelverton*
4:20 PM	4:40 PM	ALMA Reveals Two Populations of Planetesimal Inclinations in the beta Pictoris Debris Disk	David Wilner
4:40 PM	5:00 PM	Characterizing the Low-Frequency Radio Environment in Nearby Stellar Systems	Jason Ling*
5:00 PM	5:20 PM	Comparing the Disk-Bearing and Non-Disk-Bearing Stars of Upper Scorpius	Alycia Weinberger
8:00 PM	9:00 PM	Public Lecture	Kelsi Singer

Brett Gladman (University of British Columbia)

Topic: Hmnnn...I will touch on all of: Protoplanetary disks, Debris disks, Exoplanets, Solar System in this invited review talk….I cannot pick!

Embarrassing Uncles: Things That Don't Fit into Planetary Formation `Theory'

Unlike, say, cosmology, there is no single coherent `theory' of platetary formation. Instead, planet formation `theory' is a complicated set of physical processes that are thought to fit together in a particular way to yield a chain of events that goes from collapsing interstellar gas clouds to mature planetary systems. This review talk will discuss a sequence of observational results from the last decade which cause either `tension' or outright panic when interpreted in the previous paradigm of planetary formation. In some of the examples, this conflict has already clearly pointed the way to a new understanding of the processes involved; in other cases the inappropriate behavior is still there (like an embarrassing uncle at a family gathering) and must but tolerated until it becomes clear how our understanding of these processes is incorrect/incomplete. These topics include: the edges of planetary disks, the time scale and basic processes for planetestimal formation, and the extent of planetary migration in gas-rich and gas poor disks.

Benjamin L. Gerard (University of Victoria)

Christian Marois (National Research Council of Canada, Herzberg Astronomy and Astrophysics)
GPIES collaboration
Raphaël Galicher (Lesia, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universities, Univ. Paris Diderot)
Jean-Pierre Veran (National Research Council of Canada, Herzberg Astronomy and Astrophysics)
Pierre Baudoz (Lesia, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universities, Univ. Paris Diderot)

Topic: Planet Formation Theory

The Gemini Planet Imager Exoplanet Survey and Beyond: Status, Results, and Upgrades

The Gemini Planet Imager (GPI) is an instrument designed for exoplanet imaging, combining an adaptive optics system, coronagraphic masks, and an integral field spectrograph. Its primary scientific focus since first light in 2013 has been the GPI Exoplanet Survey (GPIES), a systematic survey of young nearby stars to detect and characterize self-luminous giant exoplanets and circumstellar debris disks. The GPIES program is now completed, with over 500 stars surveyed. We will summarize preliminary statistical results from the survey, highlighting the occurrence rate of giant planets in wide orbits. We will also discuss the key science cases for potential upgrades to the GPI instrument, and finally provide more details about the possible GPI upgrades currently being developed and tested at NRC-HAA in Victoria.

Sean Andrews (Center for Astrophysics | Harvard & Smithsonian)

Topic: Protoplanetary Disks

Small-Scale Substructures in Protoplanetary Disks

The Disk Substructures at High Angular Resolution Project (DSHARP) observed 20 nearby protoplanetary disks in the 240 GHz continuum and 12CO J=2-1 spectral line with the Atacama Large Millimeter/submillimeter Array (ALMA) at a resolution of 35 milli-arcseconds (5 au). This talk will describe the motivation for this project and highlight the initial DSHARP results. We find that small-scale substructures in the dust continuum emission are ubiquitous in this sample, manifesting primarily as axisymmetric, narrow rings and gaps, with a small subset showing azimuthal deviations or spiral wave patterns. These features will be compared with current models for potential origins of disk substructures, and used to highlight some important follow-up work

Shangjia Zhang (University of Nevada, Las Vegas)

Zhaohuan Zhu (University of Nevada, Las Vegas)
Jane Huang (Harvard-Smithsonian Center for Astrophysics)
Viviana Guzmán (Pontificia Universidad Católica de Chile)
Sean Andrews (Harvard-Smithsonian Center for Astrophysics)
Tilman Birnstiel (Ludwig-Maximilians-Universität München)
Cornelis Dullemond (Heidelberg University)
John Carpenter (Joint ALMA Observatory)
Andrea Isella (Rice University)
Laura Pérez (Universidad de Chile)
Myriam Benisty (Universidad de Chile / Univ. Grenoble Alpes)
Clément Baruteau (CNRS / Institut de Recherche en Astrophysique et Planétologie)
Xue-Ning Bai (Tsinghua University)
Luca Ricci (California State University, Northridge)

Topic: Protoplanetary Disks

Gaps and Rings in ALMA Large Program DSHARP: Implications for the Young Planet Population

Discoveries over the past few decades show that planets are common. However, most discovered exoplanets are mature, so their orbital properties have gone through dynamics alteration. To test planet formation theory, it is crucial to constrain the young planet population right after they are born in protoplanetary disks. Recent high-resolution imaging in millimeter interferometry reveal a variety of disk features, some of which may be imprinted by young protoplanets. Our recent ALMA Large Program, “The Disk Substructures at High Angular Resolution Project” (DSHARP), provides the first homogeneous overview of disk substructures.

In this work, we explore the possibility that these gaps/rings are induced by young planets, by carrying out a grid of hydrodynamics simulations with different values for viscosity, scale height and planet mass. I will first introduce our simulations including dust particles with drift and explain how they are scaled to the dust emission at DSHARP observation wavelength. Then I will highlight our simulation demonstrating that the intricate series of gaps in the AS 209 disk can be explained by a single planet. I will also demonstrate that the angular resolution and sensitivity of DSHARP observations are able to reveal disk structures induced by giant planets in the young solar system and HR 8799 analogs. Finally, I will explore the potential young planet population on the planet mass-semimajor axis diagram. We find the occurrence rate of giant planet $> 5\ M_J$ is consistent with direct imaging constraints. We also probe a new parameter space of Neptune to Jupiter mass planets beyond 10 au, which are not accessible to other planet searching techniques.

Grant Kennedy (University of Warwick, UK)

Topic: Debris Disks

Debris Disk Constraints on Planet Formation

Debris disks are the rubble left over from the planet construction process. While we *visit* the largest constituents of the Solar system's debris disk, around other stars we are limited to observing the dust produced when larger bodies collide. Nevertheless, as has been successfully demonstrated in the Solar system, debris disks have the potential to reveal the compositions, architectures, and histories of other planetary systems. Indeed, much of this work is essentially the application of ideas rooted in the Solar system to other stars. This talk aims to partially cover the 35-year history of debris disk exploration, and by analogies with Solar system formation, structure, and dynamics, illustrate how this work provides valuable information about planetary system formation and evolution.

Alexander V. Krivov (AIU Jena)

Mark Booth (AIU Jena)
Aljoscha Ide (AIU Jena)
Torsten Löhne (AIU Jena)
Anders Johansen (Lund University)
Jürgen Blum (TU Braunschweig)

Topic: Debris Disks, Protoplanetary Disks

Probing Planetesimal Formation Mechanisms with Debris Disks

Two basic routes for planetesimal formation have been proposed in the last few decades. One is a classical 'slow-growth' scenario. Another one is 'particle concentration', where small pebbles are concentrated locally and then collapse gravitationally to form planetesimals. We look into possibilities to distinguish between the two scenarios from debris disk data. Both types of models make certain predictions for the timescales of planetesimal formation, as well as the size distribution and internal structure of newly born planetesimals. We use these predictions as input to simulate both initial stirring of debris disks left after the gas dispersal and their subsequent collisional evolution. The results are compared to various samples of debris disks.

We find that disks of planetesimals formed by pebble concentration get self-stirred more rapidly than in the slow-growth scenario. In that case, nearly all of the debris disks detected so far would be compatible with being self-stirred. Yet we identify a few young debris disk systems that probably cannot be self-stirred and so may require planets as stirrers, which makes them promising candidates for planet searches.

The observed debris disk brightness as a function of a system's age is found to be consistent with both planetesimal formation scenarios. However, regardless of the assumed planetesimal formation mechanism, explaining bright debris disks in the samples uncovers an intriguing 'disk mass problem.' To reproduce such disks by collisional simulations, a total mass of planetesimals of up to ~1000 Earth masses is required, which exceeds the total mass of solids available in the protoplanetary progenitors of debris disks. Interestingly, a similar problem has recently been identified for the protoplanetary disks themselves: they do not appear to be massive enough to produce the observed exoplanet populations. Is something wrong with our understanding of disks? Possible solutions to the conundrum are discussed.

This research was conducted in the framework of the Research Unit FOR 2285 “Debris Disks in Planetary Systems” established by the German Research Foundation (DFG), grants Kr 2164/13-1, Lo 1715/2-1, and Bl 298/24-1.

A. Meredith Hughes (Wesleyan University)

Cail Daley (U. Illinois), Evan Carter (Wesleyan), Kevin Flaherty (Williams), Zachary Lambros (Wesleyan), Margaret Pan (MIT), Hilke Schlichting (UCLA), Eugene Chiang (UC Berkeley), Mark Wyatt (Cambridge), David Wilner (CfA), Sean Andrews (CfA), John Carpenter (JAO)

Topic: Debris Disks

Weighing Planetary Systems: Mass of Stirring Bodies in the AU Mic Debris Disk Inferred from Resolved Vertical Structure

The vertical distribution of dust in debris disks is sensitive to the number and size of large planetesimals dynamically stirring the disk, and is therefore well-suited for constraining the prevalence of otherwise unobservable Uranus and Neptune analogs. Information regarding stirring bodies has previously been inferred from infrared and optical observations of debris disk vertical structure, but theory predicts that the small particles traced by short-wavelength observations will be ‘puffed up’ by radiation pressure, yielding only upper limits. The large grains that dominate the disk emission at millimeter wavelengths are much less sensitive to the effects of stellar radiation or stellar winds, and therefore trace the underlying mass distribution more directly. Here we present ALMA 1.3 mm dust continuum observations of the debris disk around the nearby M star AU Mic from Daley et al. (submitted). The 3au spatial resolution of the observations, combined with the favorable edge-on geometry of the system, allows us to measure the vertical thickness of the disk. We report a scale height-to-radius aspect ratio of h = 0.031+/-0.005 between radii of 23au and 41au. Comparing this aspect ratio to a theoretical model of size-dependent velocity distributions in the collisional cascade (Pan & Schlichting 2012), we find that the perturbing bodies embedded in the local disk must be larger than about 400 km, and the largest perturbing body must be smaller than roughly 1.8 $M_\oplus$. These measurements rule out the presence of a gas giant or Neptune analog near the $\sim$ 40 au outer edge of the debris ring, but are suggestive of large planetesimals or an Earth-sized planet stirring the dust distribution. We also present initial results from a simultaneous analysis of ALMA 450um observations of the AU Mic system (Carter et al. in prep). By combining the two widely separated millimeter bands that trace two different grain sizes, we can place constraints on the tensile strength of bodies in the collisional cascade for the first time outside our Solar System.

Meredith MacGregor (Carnegie DTM)

Alycia Weinberger (Carnegie DTM), Meredith Hughes (Wesleyan University), David Wilner (Center for Astrophysics | Harvard & Smithsonian), Thayne Currie (NAOJ), John Debes (STScI), Jessica Donaldson (Carnegie DTM), Seth Redfield (Wesleyan Univeristy), Aki Roberge (NASA Goddard), Glenn Schneider (Steward Observatory), Erika Nesvold (Carnegie DTM),

Topic: Debris Disks

Connecting Structure in Edge-On Debris Disks to Planetary Systems

Debris disks are the end stage of circumstellar evolution, surrounding mature planetary systems that interact with the dusty material in these disks, sculpting it through gravitational perturbations. HD 15115, an Ftype star, hosts a nearly edge-on debris disk (originally dubbed the 'Blue Needle') that shows an extreme asymmetry in optical scattered light with an extent almost two times larger to the west of the star than to the east. HD 61005 (G-type star, “The Moth") and HD 32297 (A-type star) both host iconic, edge-on debris disks with dramatic swept-back wings of dust. We present new observations from the Atacama Large Millimeter/submillimeter Array (ALMA) at 1.3 mm of dust continuum and 12CO J=2-1 gas (when present) emission that capture all three of these intriguing systems with the highest resolution at millimeter wavelengths to date. By fitting models directly to the observed visibilities within a Markov Chain Monte Carlo (MCMC) framework, we are able to characterize the millimeter continuum emission and place robust constraints on the structure and geometry of all three disks. The new ALMA image of HD 15115 shows no evidence for the dramatic east-west scattered light asymmetry, but instead reveals two rings in the disk separated by a depleted gap. We use dynamical modeling to infer the properties of a planet that could be sculpting this gap from the best-fit model gap properties. In contrast, our ALMA images of HD 32297 and HD 61005 show for the first time that the scattered light wing structures are also traced by millimeter emission, requiring large grains to populate these extended halos. Since the mechanism responsible for creating the observed wing structures must operate on both small and large grains, this disfavors an ISM interaction and favors sculpting by eccentric interior planets.

Ben Yelverton (University of Cambridge)

Grant Kennedy (University of Warwick)

Topic: Debris disks

Empty gaps? Depleting Annular Regions in Debris Disks by Secular Resonance with a Two-Planet System

We present the results of a theoretical study of the secular evolution of an extended debris disk interacting with a system of two inner planets. In particular, we show how such a system can clear a gap in the disk from a distance via secular resonance. Using Laplace-Lagrange theory, we quantify the location, width and formation timescale of the resulting gap. We apply these considerations to the systems HD 107146 and HD 92945, both of which host broad debris disks with gaps, with the aim of identifying configurations of planets which could be responsible for the observed disk structure. By performing N-body simulations of some of these configurations and constructing synthetic observations, we find that a gap does indeed form at the expected location, along with characteristic asymmetries in the disk: an offset inner ring and spiral structure in the outer ring.

David Wilner (Center for Astrophysics | Harvard & Smithsonian)

L. Matra (Center for Astrophysics | Harvard & Smithsonian), M.C. Wyatt (IoA Cambridge), W.R.F. Dent (ALMA), S. Marino (MPIA), G.M. Kennedy (U. Warwick), J. Milli (ESO)

Topic: Debris Disks

ALMA Reveals Two Populations of Planetesimal Inclinations in the β Pictoris Debris Disk

We present new high resolution ALMA observations of millimeter emission from the nearly edge-planetesimal belt in the debris disk surrounding the nearby star beta Pictoris. These data show that the vertical distribution of emission can be described well by the sum of two Gaussian components, a narrow one and wide one, corresponding to scale heights of about 2 au and 16 au at radius 150 au. This two component structure suggests a bimodal distribution of planetesimal inclinations, analogous to the "hot" and "cold" populations of our Kuiper Belt. For the beta Pictoris system, the rms inclinations are 8.9 degrees for the hot population and 1.1 degrees for the cold population, with the hot population containing 80% of the observed mass. Secular perturbations from the directly imaged giant planet beta Pictoris b (with semi-major axis 9 au) are unlikely to provide sufficient dynamical heating throughout the full radial extent of the belt to explain the hot population, and viscous stirring from large bodies within the belt alone cannot produce both populations. This argues for an alternative or additional scenario, such as the birth of planetesimals on high inclination orbits, or resonance sweeping and scattering by the outward-migration of an additional, unseen planet, similar to Neptune's migration through our Kuiper Belt.

Jason Ling (Rice University)

Andrea Isella (Rice University), Christopher Johns-Krull (Rice University), Joseph Lazio (JPL/Caltech)

Topic: Low-Frequency Radio, Exoplanets, Young Stars

Characterizing the Low-Frequency Radio Environment in Nearby Stellar Systems

Detections of low-frequency (< 10 GHz) radio emissions can help characterize the radiation environments around nearby stellar systems. Planetary origins of the emission, produced primarily through charged particles radiating via the electron cyclotron maser [ECM] instability, correlate directly with the local magnetic field strength of the emitting body. Recent radio detections of active brown dwarfs have begun to constrain the observational and magnetic properties of extrasolar, near planetary-mass emitters of ECM. Additional non-detections of lower mass objects of interest continue to refine the upper limits on the typical emission from exoplanetary systems. In our own Solar System, stellar radio emission is enhanced during episodic flaring events and coronal mass ejections, which contribute to the notion of space weather. Stellar radiation environments, as well as exoplanetary magnetic fields, would play important roles in the ongoing question of planetary habitability.

In our study, we analyze a variety of sample populations of interest using data from 3 low-frequency radio sky surveys to look for evidence of stellar and/or planetary emissions. We utilize archival data from the 74 MHz VLA Low-frequency Sky Survey redux [VLSSr], the 150 MHz TIFR GMRT Sky Survey [TGSS], and the 1.4 GHz NRAO VLA Sky Survey [NVSS] to look at the positions of exoplanetary systems within 300 parsecs, young stellar objects in the Taurus and Upper Sco starforming regions, and stars within a few tens of parsecs in distance from the Earth. We investigated direct, positional detections as well as stacked averages of the imaged data, deriving their statistical significance relative to their respective sky survey. Evidence of 14 tentative direct detections were made, which will require follow-up observations, and we also present upper limits on the emission fluxes from the ensemble-averaged samples for each surveyed frequency for consideration by the community.

Alycia Weinberger (Carnegie DTM)

Topic: Protoplanetary Disks / Debris Disks

Comparing the Disk-Bearing and Non-Disk-Bearing Stars of Upper Scorpius

I am conducting a survey of the Upper Scorpius region with APOGEE-South. Upper Sco is an interesting region in which to study disk evolution, because at an age of ~10 Myr, it still has protoplanetary disks, debris disks, and many disk-less stars. So, a large homogeneous survey can study how disk evolution depends on stellar parameters. APOGEE-South, part of the instrument complement of the Sloan Digital Sky Survey IV, is a near-infrared (H-band) spectrograph that obtains up to 300 high resolution (~20,000) spectra over a one degree field of view. These data enable measurements of intrinsic stellar properties -- luminosity, effective temperature, and surface gravity, now known only coarsely, that flow into our understanding of the fundamental properties of mass and age. In addition, we get radial velocities for every star. By cross-matching our targets with Gaia for distances, we can measure the detailed properties of disk-bearing and disk-less populations. Although presumably coeval, existing HR diagrams exhibit apparent spreads in age, which may be explained by stochastic accretion histories that temporarily change or reset some of the stellar parameters, or as due to varying magnetic field levels across otherwise coeval stars.

I began by targeting all the Upper Sco stars previously studied by Kepler's K2 mission; these targets were selected based on kinematics and/or spectral signatures of youth. I recently expanded the program with a Gaia-distance based, but kinematics-blind survey. All of these data will be made public as part of the SDSS data releases.

So far, 944 putative Upper Sco members have been observed, of which 210 have detected disks via infrared excess. I have also observed another 1200 probably main sequence stars, some of which have turned out to be association members via their similar kinematics to known members. By the time of the meeting, another few hundred members should have been observed, along with 1000 Gaia-selected potential members.

I will present comparisons of the properties of the disk-bearing and disk-less populations -- their kinematics and spatial distribution, ages as inferred from pre-main sequence models, and their surface gravities.

New Horizons in Planetary Systems

13-17 May , 2019 | Victoria, BC

Wednesday, 15 May 2019

Start	End	Title	Speaker (* student talk)
		Session 5, Chair: Antonio Hales	
9:00 AM	9:40 AM	Invited Review: First Results from TESS	Diana Dragomir
9:40 AM	10:00 AM	Understanding the Radius Valley as a By-product of Planet Formation	Akash Gupta*
10:00 AM	10:20 AM	The LEECH Exoplanet Imaging Survey: Limits on Planet Occurrence Rates	Jordan Stone
10:20 AM	10:40 AM	Imprints of the Disk Dispersal Phase on Mature Exoplanet Systems	Cristobal Petrovich
10:40 AM	11:00 AM	A Young Planetary System Modified by a Coplanar Stellar Flyby	Paul Kalas
11:00 AM	11:40 AM	Coffee and Posters	
		Session 6, Chair: Hannah Jang-Connell	
11:40 AM	12:20 PM	Invited Review: Cometary Chemistry and Early Planet Formation	Geromino Villanueva
12:20 PM	12:40 PM	Modeling the Solar System's Debris Disk: The View from Inside and Out	Andrew Poppe
12:40 PM	1:00 PM	In-Situ Observations of the Solar System's Debris Disk from Earth to the Kuiper Belt	Marcus Piquette*
		Free afternoon	

Diana Dragomir (MIT)

Topic: Exoplanets

First Results and the Bright Future of the TESS Mission

Ten months into its primary mission, TESS has already brought about the discovery of exciting new exoplanet systems. I will give an overview of TESS early results and I will describe the vibrant community process that leads from the discovery to the confirmation of TESS planets.

The most conspicuous legacy of TESS will be the discovery of individual systems suitable for detailed atmospheric characterization. But I will argue that the survey can also revolutionize the exoplanet field by dramatically increasing the number of small exoplanets known to transit nearby stars, enabling a wide variety of statistical studies for a much larger sample than is available today. This enhanced ensemble of exoplanets can then be leveraged to uncover new trends and gain deeper insights into the composition, system architecture, and ultimately the formation of small exoplanets.

Finally, I will discuss TESS' growing impact on solar system and stellar science as well.

Akash Gupta (University of California, Los Angeles)

Hilke Schlichting, (University of California, Los Angeles; Massachusetts Institute of Technology)

Topic: Exoplanets

Understanding the Radius Valley as a by-product of Planet Formation: Relevance of Core-Powered Mass-Loss Mechanism and its Dependence on Stellar Properties

Recent observations have revealed a ‘valley’ in the radius distribution of small, short-period exoplanets. I will discuss the effect of a planet's own cooling luminosity on its thermal evolution and atmospheric mass-loss (core-powered mass-loss), and its observational consequences for the distribution of small, close-in exoplanets. Using simple analytical descriptions and numerical simulations, we can demonstrate that planetary evolution based on the core-powered mass-loss mechanism alone (i.e., without any photoevaporation) can produce the observed valley in the radius distribution. I will present our results which show that we can reproduce the valley's location, shape and slope in planet radius-orbital period parameter space, and the relative magnitudes of the planet occurrence rate above and below the valley. We find that the slope of the valley is, to first order, dictated by the atmospheric mass-loss timescale at the Bondi radius and get an estimate of -0.11 for the slope in a logarithmic planet size-orbital period space. This indirectly attests to the significance of internal compression for planetary cores more massive than Earth. We further find that the location of the valley depends on the core composition and that the observed planet population must have predominantly rocky cores with typical water-ice fractions of less than ~ 20%. Furthermore, we find that the relative magnitude of the planet occurrence rate above and below the valley is sensitive to the details of the planet-mass distribution but that the location of the valley is not. At last, I will discuss the dependence of the planet distribution on stellar properties like mass, metallicity and age. I will show, for instance, that we can even reproduce the observed trend between planet size and stellar mass.

In conclusion, radius valley seems an inevitable by-product of planet formation via core-powered mass-loss mechanism, even without photoevaporation. However, it is likely that both core-powered mass-loss and photoevaporation have been active in sculpting the radius valley observed today but more work needs to be done to understand their individual contributions.

Jordan Stone (University of Arizona)

Andy Skemer (UCSC), Phil Hinz (University of Arizona/UCSC), the LEECH team (various)

Topic: Exoplanet Demographics

The LEECH Exoplanet Imaging Survey: Limits on Planet Occurrence Rates under Conservative Assumptions

We present results from the largest L′ (3.8 μm) direct imaging survey for exoplanets —the Large Binocular Telescope Interferometer (LBTI) Exozodi Exoplanet Common Hunt (LEECH). We observed 98 stars with spectral types from B to M. Cool planets emit a larger share of their flux in L′ compared to shorter wavelengths, affording LEECH an advantage in detecting low-mass, old, and cold-start giant planets. We emphasize proximity over youth in our target selection, probing physical separations smaller than other direct imaging surveys. For FGK stars, LEECH outperforms many previous studies, placing tighter constraints on the hot-start planet occurrence frequency interior to ∼ 20 au. For less luminous, cold-start planets, LEECH provides the best constraints on giant-planet frequency interior to ∼ 20 au around FGK stars. Direct imaging survey results depend sensitively on both the choice of evolutionary model (e.g., hot or cold-start) and assumptions (explicit or implicit) about the shape of the underlying planet distribution, in particular its radial extent. Artificially low limits on the planet occurrence frequency can be derived when hot-start models are used exclusively, and when the shape of the planet distribution is assumed to extend to very large separations, well beyond typical protoplanetary dust-disk radii (~50 au). We place a conservative upper limit on the planet occurrence frequency using cold-start models and planetary population distributions that do not extend beyond typical protoplanetary dust-disk radii. We find that ~90% of FGK systems can host a 7 to 10 M Jup planet from 5 to 50 au. This limit leaves open the possibility that planets in this range are common.

Cristobal Petrovich (CITA)

Yanqin Wu (University of Toronto)
Mohamad Ali-Dib (Université de Montréal)

Topic: Exoplanets

Imprints of the Disk Dispersal Phase on Mature Exoplanet Systems

Observations of protoplanetary disks and exoplanets provide with snapshots of planetary systems at two very different stages of their evolution. I will discuss the imprints that a transition phase between these two stages, i.e. the disk dispersal phase, has on the orbital architectures of exoplanet systems, including its effect of their orbital eccentricities and inclinations. As a proof of concept, I will argue that the disk dispersal phase has shaped the intriguing 3-D orbits of the Kepler-419 multi-planet system and our model argues for a depletion of the disk starting from a large cavity inside a few AU. Finally, I will discuss how TESS and Gaia together will provide more systems like Kepler-419 with 3-D information to study the link between mature exoplanet systems and their early stages evolution during the dispersal of their birth protoplanetary disks.

Paul Kalas (UC Berkeley)

Robert De Rosa (Stanford University)

Topic: Exoplanets, Debris Disks, Solar System

A Young Planetary System Modified by a Coplanar Stellar Flyby

Close stellar encounters have the potential to significantly alter the architecture of planetary systems. Stars passing close to our solar system have been invoked to explain the formation of the Oort cloud, comet showers, the disruption of the Kuiper Belt, and the distant detached orbits of dwarf planets such as 90377 Sedna, as well as the hypothetical Planet Nine. Such stellar flybys have also been invoked to explain the orbital properties of extrasolar planets. However, direct empirical evidence for these hypothetical encounters is lacking.

Here we show that the 15 Myr-old planet-hosting binary star HD 106906 underwent a close stellar encounter that can explain the system's current architecture. Using the exquisite precision of ESA's Gaia satellite for measuring stellar motions we have discovered a pair of external stellar perturbers that approached within 1 pc of the HD 106906 system in a flyby geometry that is coplanar with the observed, highly asymmetric circumbinary disk. This flyby is consistent with the scenario that the massive planet HD 106906 b formed in a disk near the binary star, was ejected from the inner system through interactions with the eccentric binary, and was subsequently stabilized onto its current wide orbit (~740 au) by the perturbations of the passing stars.

Geronimo Villanueva (NASA Goddard Space Flight Center)

Topic: Exoplanets

New Frontiers in the Exploration of Comets and the Origin of the Solar System

Comets are some of the best cryogenically preserved relics from the early solar system. Exploring their composition is therefore directly relevant to understanding the origins of our planetary system and to testing the hypothesis that small icy bodies have delivered prebiotic matter to early Earth. Ices are most sensitive to temperature and to radiation processing, and preserve key information of the processes (thermo/ion-molecule/photo-chemistry, radial-mixing, UV and X-ray processing) acting during the formation and evolution of our Solar System. By measuring molecular and element abundances and isotopic ratios in these primordial ices and by relating these to the stability regions of ices in the solar nebula (e.g., snow lines of H2O, CO2 and CO), we can better understand how our solar system formed.

In the last decades, we have seen a revolution in our understanding of comets, thanks to several in-situ missions (e.g., Rosetta, Deep-Impact, EPOXI) and astronomical studies of these bodies employing space (e.g., Herschel, HST) and ground-based observatories. High-resolution infrared spectrometers with broad spectral coverage at ground-based observatories (e.g., Keck, IRTF, VLT) and arrays of radio telescopes with state of the art receivers (e.g., ALMA) now permit the exploration of the kinematics, composition and thermal structure of a broad range of these bodies with unprecedented precision. These, combined with the advent of comprehensive spectroscopic databases containing billions of lines, accurate radiative transfer models, and unprecedented available computational power, are transforming the way we investigate comets.

In this talk, I will present a review of our current understanding of these primordial bodies, and how new capabilities will provide unprecedented exploration opportunities for exploring the origins of our Solar system.

A.R. Poppe (Space Sciences Laboratory, Univ. of California at Berkeley)

C.M. Lisse (Johns Hopkins University / Applied Physics Lab.)
M. Zemcov (Rochester Institute of Technology)
C. Beichman (California Institute of Technology)
M. Piquette (Univ. of Colorado at Boulder)
J.R. Szalay (Princeton Univ.)
M. Horányi (Univ. of Colorado at Boulder)

Topic: Debris Disks; Edgeworth-Kuiper Belt

Modeling the Solar System's Debris Disk: The View from Inside and Out

Our solar system is known to harbor several reservoirs of small bodies, including the asteroid belt, Jupiter family comets, the Edgeworth-Kuiper Belt (EKB), and the Oort Cloud. Together, the collisional grinding and/or cometary outgassing of these bodies generate a vast, yet relatively tenuous cloud of debris throughout the solar system. This debris, typically in the sub-millimeter size range, is subject to several forces (including gravity, solar radiation pressure, Poynting-Robertson drag, and electromagnetism) and subsequently migrates throughout the solar system. Remote sensing using optical scattering (i.e., 'zodiacal light') and/or thermal emission signatures and in-situ dust measurements have defined many aspects of the inner interplanetary dust complex; however, a complete picture – especially in the outer solar system – is limited, mainly due to the challenge of making such measurements. Such a picture is necessary to both fully understand the distribution of dust in our own solar system but also to compare our debris disk with the plethora of debris disks that have been observed around other stars ('exozodiacal disks').

Here, we have used a model of the interplanetary dust density from Poppe [2016] constrained by in-situ measurements from Pioneer 10 and the New Horizons Student Dust Counter – currently transiting through the EKB dust dusk – to predict both the optical scattering and thermal emission signatures of interplanetary dust in the solar system. The dust model provides the spatial distribution of dust grains generated from Jupiter-family comets, Oort Cloud comets, and Edgeworth-Kuiper Belt objects for sizes between 0.5 – 500 μm. By assuming a representative compositional mix of olivine (25%), enstatite (25%), and amorphous carbon (50%) for the interplanetary dust grains, we have calculated the optical scattering characteristics, equilibrium temperatures, and thermal emission fluxes as a function of position and composition. Modeled brightnesses agree well with Pioneer 10 photopolarimeter measurements in the inner solar system, and here, we present here the modeled scattered light profile for wavelengths from 0.1 – 5.0 μm and the thermal emission spectrum from 1 – 103 μm for the entire solar system. We also present spatially resolved images of the interplanetary dust cloud at various wavelengths as seen from an outside observer as a connection to currently surveyed exodisks and as a prediction for what optical and/or IR imagers may see on-board a mission such as the proposed Interstellar Probe Explorer.

M. Piquette (University of Colorado at Boulder)

A.R. Poppe (Space Sciences Laboratory, University of California at Berkeley)
E. Bernardoni (University of Colorado at Boulder)
J.R. Szalay (Princeton University)
D. James (University of Colorado at Boulder)
M. Horányi (University of Colorado at Boulder)

Topic: Debris Disks

In-situ Observations of the Solar System’s Debris Disk from Earth to the Kuiper Belt

Information on the distribution of interplanetary dust particles (IDPs) provides constraints on the origin and evolution of planetary bodies. The distribution of IDPs depends on the sources, sinks, and dynamics of dust grains permeating the solar system. IDPs are subject to gravity, radiation pressure, EM forces, and Poynting-Robertson drag. Under these forces, IDPs migrate throughout the solar system, often getting trapped in resonances with or scattered by the giant planets. Being able to accurately map the distribution of IDPs will provide insight into the parent bodies of the particles as well as the overall evolution of the solar system. The Student Dust Counter (SDC) is an in-situ dust detector aboard the New Horizons spacecraft observing the distribution of IDPs of mass > 10-12 g, or approximately 0.5 µm in radius. New Horizons was launched on January 19th, 2006 and performed fly-bys of the Pluto and Ultima-Thule systems in 2015 and 2019, respectively and continues to explore the Kuiper Belt. SDC has nearly continuously mapped the dust density distribution along the trajectory of New Horizons from Earth to the Kuiper Belt.

A recent model, Poppe [2016], has detailed the sources, sinks, and transport of dust particles in the outer solar system allowing direct comparisons with SDC observations. The model used a test particle approach, with collisional schemes introduced, integrating the motion of individual grains under the influence of gravity due to the Sun and the giant planets, radiation pressure, Poynting Robertson drag, electromagnetic perturbation due to the interplanetary magnetic fields, and grain-grain collisions. Relative densities and production rates of particles between 0.5 µm and 100 µm were constrained with in-situ observations from Pioneer 10 and SDC. We present the interplanetary dust density and size distribution measured by SDC and how it compares to the model, showing an overall lack of larger particles (> 2 µm) in the SDC data set compared to the model’s predictions. We discuss these discrepancies as well as possible solutions.

Thursday, 16 May 2019			
Start	End	Title	Speaker (* student talk)
		Session 7, Chair: Emmanuel Lellouch	
9:00 AM	9:40 AM	Invited Review: New Horizons Flyby	John Spencer
9:40 AM	10:00 AM	New Horizons and ALMA Observations of Kuiper Belt Object (15810) Arawn	Anne Verbiscer
10:00 AM	10:20 AM	A Pathway to Form Objects like Ultime Thule via the Streaming Instability	Rixin Li*
10:20 AM	11:00 AM	Coffee and Posters	
11:00 AM	11:20 AM	Size-Distribution of Objects in the Outer Solar System	Kelsi Singer
11:20 AM	11:40 AM	Ultime Thule: Formation via the Streaming Instability and Binary Hardening with Gas Drag	Wladimir Lyra
11:40 AM	1:30 PM	Lunch	
		Session 8, Chair: Diana Dragomir	
1:30 PM	2:10 PM	Invited Review: Disk Composition and Chemistry	Karin Öberg
2:10 PM	2:30 PM	Tracing Chemical Inheritance in Protoplanetary Disks	Ryan Loomis
2:30 PM	2:50 PM	CO Depletion in Protoplanetary Disks	Sebastiaan Krijt
2:50 PM	3:10 PM	Midplane CO Depletion in PPDs: Primordial C/H Predictions Inside the CO Snowline	Kamber Schwarz
3:10 PM	3:30 PM	Giant Planet Formation Sweet Spot - Discs around Herbig Ae Stars	Olja Panic
3:30 PM	4:00 PM	Coffee and Posters	
4:00 PM	4:20 PM	Catching Planet Formation in the Act: Signatures of Planets in Disks	Hannah Jang-Condell
4:20 PM	4:40 PM	Revealing the General Properties and the Origins of Disk Substructures	Feng Long*
4:40 PM	5:00 PM	Characterization of Ring Substructures in Protoplanetary Disks	Enrique Macias
5:00 PM	5:20 PM	PDS 70b: Disentangling Disk Structures	Valentin Christiaens
7:00 PM	10:00 PM	Banquet	

John R. Spencer (Southwest Research Institute)

S. Alan Stern (Southwest Research Institute), Harold A. Weaver (Johns Hopkins Applied Physics Laboratory), Catherine B. Olkin (Southwest Research Institute), Jeffrey M. Moore (NASA-Ames Research Center), William M. Grundy (Lowell Observatory), Randy Gladstone (Southwest Research Institute), and the New Horizons Science Team

Topic: New Horizons

The New Horizons Flyby of Cold Classical Kuiper Belt Object 2014 MU69

On January 1st 2019, the New Horizons spacecraft successfully obtained the first close-up observations of a small object in the Kuiper Belt, 2014 MU69. Based on its orbit and color, MU69 is almost certainly a member of the Cold Classical Kuiper Belt (CCKB), the least disturbed known trans-Neptunian population, and is thus likely to be the most primordial object yet visited by spacecraft. It is likely to be representative of many of the > 100,000 objects of similar or larger size in the CCKB. New Horizons revealed MU69 to be a contact binary, composed of two flattened components roughly 20 and 14 km across, which appear to have merged very gently. The larger component, and possibly the smaller component too, appear to consist of sub-units which may represent earlier stages of the accretion process. MU69 thus provides an unprecedented window into accretionary process in the outer solar system, and perhaps more generally throughout this and other solar systems. I will describe what New Horizons has told us about the morphology, composition, and environment of this remarkable object.

Anne Verbiscer (University of Virginia)

Arielle Moullet (SOFIA)
Mark Gurwell (Harvard-Smithsonian Center for Astrophysics)
Simon Porter (Southwest Research Institute)
New Horizons Science Team

Topic: Solar System

New Horizons and ALMA Observations of Kuiper Belt Object (15810) Arawn

In addition to the reconnaissance of the Pluto system in July 2015, NASA's *New Horizons* mission is exploiting its unique capabilities as a spacecraft traversing the outer Solar System by making observations of Kuiper Belt objects (KBOs) at viewing geometries unattainable from Earth. Although the sizes and albedos of the largest of these distant KBO targets are well-known from thermal measurements and/or occultations, the albedos, and therefore the sizes, of the smaller targets are constrained only loosely by knowledge of the average albedo of their dynamical classes. These fundamental physical quantities are now within reach of ALMA when combined with optical observations. Here we report the measurement of the size and thus the geometric albedo of (15810) Arawn (1994 JR_1) inferred from ALMA continuum observations at 350 GHz (0.86 mm) combined with Earth-based observations at visible wavelengths. Arawn is classified as a plutino since it, like Pluto, is in a 2:3 mean-motion resonance with Neptune. *New Horizons* has sampled Arawn's solar phase curve at optical wavelengths (0.55 μm) at phase angles of 27, 59, and 131 degrees, enabling the determination of its visible phase integral. When combined with the geometric albedo inferred by ALMA, the phase integral from *New Horizons* yields the spherical albedo. The spherical albedo is the ratio of the total flux reflected in all directions from a planetary surface to the total solar incident flux; therefore, its measurement enables an evaluation of the thermal energy budget of a Solar System surface. This combination of ALMA and *New Horizons* results enables the comparison between the surface scattering properties of a plutino to those of other well-studied Solar System objects.

Rixin Li (University of Arizona)

David Nesvorný, (Southwest Research Institute)
Andrew Youdin (University of Arizona)
Jacob Simon (Southwest Research Institute & University of Colorado)
William Grundy (Lowell Observatory)

Topic: Planetesimal Formation & Minor Objects in the Solar System

A Pathway to Form Objects like Ultima Thule: Planetesimal Formation by the Streaming Instability

The New Horizons’ flyby of the contact binary Ultima Thule ((486958) 2014 MU69) provides invaluable clues to planetesimal formation in the early Solar system. We explore a pathway to form objects like Ultima Thule, one of the pristine trans-Neptunian binaries in the Cold Classical Kuiper Belt Objects (CCKBO), by the Streaming Instability (SI). The SI is an aerodynamical mechanism to concentrate solids in protoplanetary disks and facilitate the formation of planetesimals. We analyze new high-resolution SI simulations that include particle self-gravity, with a newly developed clump-finding code (PLAN). We find that the SI clumps possess excess angular momenta that might explain why all planetesimals formed as binaries/multiples and the high binary fraction among CCKBOs. Furthermore, the predicted binary orbits show a broad inclination distribution with 80% of prograde orbits, excellently matching the observations of trans-Neptunian binaries. Our results provide insights for future observations and modeling for planetesimal formation.

Kelsi N. Singer (Southwest Research Institute)

William B. McKinnon (Washington University in St. Louis),
Brett Gladman (University of British Columbia),
Sarah Greenstreet (B612 Asteroid Inst. and DIRAC Center at U. Washington),
J. J. Kavelaars (National Research Council of Canada),
The New Horizons Geology, Geophysics and Imaging Science Theme Team, and
The New Horizons Ralph and LORRI Teams

Topic: Solar System

What Can the Sze-distribution of Objects in the Outer Solar System Tell Us About Their Formation and Evolution? Results from the New Horizons Mission to Pluto and the Kuiper Belt

The New Horizons flyby of the Pluto-system on 14 July 2015 provided the first high resolution images of planetary surfaces embedded in the Kuiper belt. Impact craters observed on Pluto and Charon were formed by other Kuiper belt objects (KBOs) ranging in diameter from ~40 km down to ~300 m, smaller than most KBOs observed directly by telescopes. We find a relative paucity of small craters (≲ 13 km in diameter). This observation cannot be explained solely by geological resurfacing, and implies a corresponding deficit of small KBOs (≲ 1-2 km in diameter). Some surfaces on Pluto and Charon are likely ~4 billion or more years old, thus the crater record provides key information on the size-frequency distribution of KBOs at the end of the accretionary and rearrangement epochs of the early solar system (*1*). On 1 January 2019, New Horizons made the first close flyby of a small bilobate KBO: (486958) 2014 MU69, nicknamed Ultima Thule (*2*). Other KBOs less than ~1-2 km in diameter are also the sizes primarily impacting MU69 (*3*). From the initial images, there does not appear to be a large number of craters, which may be consistent with the crater data from the Pluto-system and also indicates a deficit of small KBOs (*1*). The size-frequency distribution slopes and general paucity of smaller KBOs is not consistent with traditional collisional evolution models. If the shallower slope for small KBOs is primordial, it may be more consistent with dynamical models of gravitational instabilities causing rapid growth to larger objects (*4-7*). These models produce fewer small bodies, which could also result in fewer collisions overall, leading to a lower production rate of collisional fragments. Gravitational collapse should become less efficient for smaller-mass clumped regions at some characteristic scale or scales, which could potentially explain the shallow SFD slopes (*q* values) we observe (*8*) though higher-resolution studies are likely needed to fully address this issue. There may be more than one combination of processes that can produce the observed KBO SFD.

(1) K N. Singer et al., Science, (2019). doi: 10.1126/science.aap8628 (2) S.A. Stern, Science Submitted, (2019). (3) S. Greenstreet, et al., ApJ-L, (2019), Accepted. (4) E. Chiang & A.N. Youdin, Annu. Rev. Earth Planet Sci. 38, 493-522 (2010). doi: 10.1146/annurev-earth-040809-152513 (5) B. J. R. Davidsson et al., A&A 592, (2016). doi: 10.1051/0004-6361/201526968 (6) A. Johansen, et al., Science Advances 1, (2015). doi: 10.1126/sciadv.1500109 (7) D. Nesvorný, et al., Astron. J. 140, 785-793 (2010). doi: 10.1088/0004-6256/140/3/785 (8) C.P. Abod et al., http://adsabs.harvard.edu/abs/2018arXiv181010018A.

Wladimir Lyra (California State University, Northridge / Jet Propulsion Laboratory)

Anders Johansen (Lund University)
Andrew Youdin (University of Arizona)
Orkan Umurhan (SETI institute)
Rixin Li (University of Arizona)

Topic: Solar System/Protoplanetary Disks

Ultime Thule: Formation via Streaming Instability and Binary Hardening with Gas Drag

A full theoretical understanding of the formation of planetesimals, i.e., the ~100 km sized building blocks of planets, still remains a conundrum for planet formation theory. NASA's recent mission past the informally named Ultima Thule, a cold Kuiper Belt Object (CKBO) located at 42 AU, may offer some clues to this age-old question. Post gaseous global dynamical stability models of the solar system suggest that the Cold Kuiper Belt region of the solar system is relatively stable against the disruptive effect of giant planet migration, implying that CKBO bodies are likely bona fide, relatively unaltered, remnants of the planetesimal formation era Recent analysis of non-carbonaceous chondrites show that they are composed of 1mm sized individual chondrules or their 1cm sized aggregates. Grains in this size range orbiting a young star in a gaseous protoplanetary disk will experience a headwind since the disk gas has some pressure support causing it orbit little slower. This headwind causes the dust to drift radially inwards. The relative drift between the grains and gas results in a momentum exchanging resonance called the Streaming Instability, which develops grain overdensities strong enough to reach Roche density and collapse the ensemble into gravitationally bound objects. Also, radiogenic dating of chondrites suggests that 100 km bodies were formed within the first 0.5 – 2.0 Ma after Calcium Aluminum inclusions, nominally the starting point of solar system evolution. Taken together, these lines of evidence give strong support to the streaming instability as one of the main leading hypothesis for planetesimal formation. Another, complementary hypothesis, is concentration in anticyclonic vortices. The lines of evidence in support of it are: (i) such systems have recently been observed in circumstellar disks around young stars with ALMA; (ii) theoretical models of turbulence in disks predict their emergence and (iii) they are very efficient in trapping the same grains. Provided these vortices intrinsically survive long enough, then they become a possible setting to investigate planetesimal formation. NASA's New Horizons spacecraft imaging of 2014 MU_{69} on January 1, 2019 revealed a 15-hr rotating bi-lobed object whose constituents, informally referred to as Ultima (U) and Thule (T), appear nearly spherical with 9.5 km and 7.1 km radii. U and T have similar colors and their measured albedos are approximately 0.1, indicating that UT is a typical member of the CKBO class. On the assumption that U and T are indeed slowly rotating osculating spheres, at the time of observation the long axis of UT appears to be tilted 23^o away from the spacecraft's approach vector which, taken together with its orbital orientation, suggests that its obliquity is nearly 92^o with respect to the ecliptic. These observations of UT suggest that these bodies formed in close proximity to one another, and subsequently the binary gradually lost angular momentum. In this talk we will present simulations of the formation of U and T via the different proposed scenarios, and show that it is possible to harden the binary from formation to contact via gas drag alone within the lifetime of the disk gas (<~ 10 Myr).

Karin Öberg (Harvard University)

Topic: Protoplanetary Disks

Protoplanetary Disk Composition and Chemistry

Planets form in disks around young stars, and the outcome of planet formation is therefore regulated by structures and processes active in these disks. The chemical disk composition and how molecules are distributed throughout the disk affect all stages and aspects of planet formation, from initial grain sticking probabilities to the acquisition of hydrospheres and atmospheres. In the age of ALMA we can directly observe some of the key chemical structures in disks, including snowlines, signs of non-uniform C/O/N ratios, and non-uniform distributions of organics implicated in origins of life scenarios. Together these results imply that both the composition and chemical habitability of a nascent planet will depend sensitively on where in the disk it acquires its volatile inventory. I will review these observations, as well as the frameworks that have developed to interpret them. I will also suggest some paths going forward, to better connect the compositions and chemistry we observe in disks with the compositions and chemistry we observe on planets.

Ryan Loomis (National Radio Astronomy Observatory)

Jennifer Bergner (Harvard University), L. Ilsedore Cleeves (University of Virginia), Karin Oberg (Harvard University)

Topic: Protoplanetary Disks, Astrochemistry

Tracing Chemical Inheritance in Protoplanetary Disks

The chemical composition of nascent planets is set by the molecular inventories of the dust and gas rich protoplanetary disks in which they form. Understanding these environments is therefore crucial to predicting potential habitability, as well as uncovering the origin of Earth's organic reservoir. Recent gains in the sensitivity and resolution of (sub)mm observations have revolutionized our understanding of disk chemistry, enabling the detection of prebiotic precursors such as CH3CN, CH3OH, and HCOOH. Major challenges remain, however, including how to connect ALMA observations of gas-phase disk organics with the bulk icy reservoir responsible for comet and planet formation. Such extrapolations require both (1) complete disk molecular inventories and (2) detailed characterization of molecular abundance distributions. In this talk I discuss recent observational progress toward these two goals, enabling better constraint of disk chemical models and comparisons to Solar System cometary measurements.

First, I present a new analysis technique for detecting weak spectral lines and highlight results from its application to an unbiased ALMA spectral line survey of two disks. Five new molecular species are detected for the first time in disks, a ~20% increase in the number of known disk species. Second, I present new observations of the complex organics CH3CN and CH3OH toward a small sample of disks and interpret these results in the context of protostellar inheritance vs. disk chemical reset. Comparing chemical model predictions of CH3CN abundances with Solar System cometary measurements, I show that inheritance of nitriles from interstellar ices likely occurred in the Solar Nebula, in agreement with recent results from the Rosetta mission.

Sebastiaan Krijt (The University of Arizona)

Arthur Bosman (Leiden University)
Ke Zhang (University of Michigan)
Fred J. Ciesla (The University of Chicago)
Daniel Apai (The University of Arizona)

Topic: Protoplanetary Disks

CO Depletion in Protoplanetary Disks: Coupling Physical and Chemical Processes

Understanding the behavior of CO molecules in protoplanetary disks is important for several reasons. First, CO and its isotopologues are commonly used as a disk mass tracer. Second, carbon and oxygen play an important role in the formation of habitable planets and understanding how they are delivered to planetary bodies is essential. With several observational works finding CO to be under-abundant relative to HD (e.g., Bergin et al. 2013; McClure et al. 2016), recent theoretical works have studied the removal of CO using exclusively astrochemical modeling (Schwarz et al. 2018; Bosman et al. 2018) or a combination of physical processes like dust growth, settling and CO condensation (Krijt et al. 2018). These studies find that CO indeed becomes less abundant on ~Myr timescales, but struggle to reach the levels of depletion inferred observationally. Moreover, high angular resolution ALMA observations of C18O and and 13CO in a handful of nearby disks suggest that both chemical processing and dust evolution are needed to explain the radial distribution of CO in these objects (Zhang et al. in prep).

We present new simulations that, for the first time, combine all relevant physical and chemical processes, showing how the CO abundance changes on a disk-wide scale as the result of cosmic ray and X-ray induced gas-phase and grain-surface reactions, dust evolution (coagulation, settling, and radial drift), and turbulent diffusion. These models allow us to create time-dependent and two-dimensional (R+z) maps of the CO/H2 ratio, showing that the CO abundance (in regions probed by ALMA) indeed declines faster and more dramatically when physical and chemical processes are combined. In addition, our calculations provide information on the ice composition of migrating pebbles (e.g., do they carry carbon in the form of CO, CO2, CH4, or CH3OH?), as a function of time and location in the disk. By varying key parameters such as the turbulence strength and the cosmic ray ionization rate, we study how the appearance of disks (as seen in CO and mm continuum) and the delivery of carbon and oxygen to the planet formation region are impacted as the underlying physical and chemical timescales change.

Kamber Schwarz (University of Arizona)

Edwin Bergin (University of Michigan)
Ilse Cleeves (University of Virginia)
Ke Zhang (University of Michigan)
Karin Öberg (Harvard University)
Geoff Blake (California Institute of Technology)
Dana Anderson (California Institute of Technology)

Topic: Protoplanetary disks

Unlocking Midplane CO Depletion in Protoplanetary Disks: Primordial C/H Predictions Inside the CO Snowline

CO is the dominate reservoir of volatile carbon in the ISM. Recent observations of numerous protoplanetary disks reveal low CO abundances relative to dust, suggesting either a low total gas mass or reprocessing of volatile carbon. Alternative tracers of the gas mass in three systems reveal that it is the CO, not the total gas, which is missing, which has implications for the initial atmospheric composition of giant planets. One possibility is that carbon is removed from CO via chemical processing. However, the full range of physical conditions conducive to chemical reprocessing is not well constrained. Further, current observations primarily probe the upper layers of the disk, as opposed to the planet-forming midplane. I will discuss the results of my systematic survey of the time dependent midplane chemistry in protoplanetary disks for 198 chemical models with a range of physical conditions. I show that substantial chemical reprocessing of volatile carbon in the midplane is possible, though highly dependent on the local flux of UV photons and cosmic rays. I will also discuss the conditions under which CO reprocessing in the observable warm molecular layer can be linked to CO reprocessing in the midplane as well as how this reprocessing influences the likely starting composition of planets.

Olja Panić (University of Leeds, UK)

Co-authors: Ilaria Pascucci (University of Arizona, USA), Thomas Haworth (Imperial College London, UK), Mark Wyatt (IoA Cambridge, UK), Inga Kamp (University of Groningen, NL), Cathie Clarke (IoA Cambridge, UK), Robin Upham (University of Manchester, UK), Chunhua Qi (Harvard CfA, USA), Thorsten Ratzka (University of Graz, Austria), Nathanial Hendler (University of Arizona, USA)

Topic: Protoplanetary Disks

Giant Planet Formation Sweet Spot - Discs Around Herbig Ae Stars

Giant planets are most frequently found around stars around 2Msun. In the narrow range from 1.5-3.5Msun, these, typically A-type stars, are markedly distinct from all other types of stars in terms of the pre-main sequence evolution of their interior, their emission and consequently of the evolution of their protoplanetary discs. This is possibly one of the most prominent links between disc evolution, planet formation and exoplanet studies. Investigating this link is especially facilitated by the fact that the bright pre-main sequence (<10Myr old) A-type stars and their discs by far outrank all others as ideal observing targets as planet-formation laboratories.

In this talk I will examine the existing observational and theoretical evidence arguing that the high giant planet incidence lies in the propensity of these discs to form giant planets. In particular, I will focus on the results from our recent ALMA survey which reveals that large gas masses and therefore giant planet formation around A-type stars can persist up to the main sequence, much longer than we would expect based on the studies of lower mass stars.

Hannah Jang-Condell (University of Wyoming)

Topic: Protoplanetary Disks

Catching Planet Formation in the Act: Signatures of Planets in Disks

Interactions between forming planets and the young circumstellar disks from which they develop can result in large-scale structural changes to disks that are potentially observable. The observation of these signatures promises to be a direct probe of the planet formation process, provided that those signatures can be properly interpreted. In this talk, I will discuss theoretical predictions of planet formation signatures, with a particular focus on gap formation, as well as some possible false positives. Gaps have been observed across a wide range of wavelengths, from the optical to millimeter. I will discuss how the appearance of these gaps changes across these wavelengths and how models can be applied to interpret the structure of the gaps. With the recent discovery that many protoplanetary disks show gapped structure when observed with ALMA, we have the potential to solve long-standing questions about how and when planets form.

Feng Long (Peking University)

Gregory Herczeg (Peking University), ALMA-Taurus Team

Topic: Protoplanetary Disks

Revealing the General Properties and the Origin of Disk Substructures: An ALMA Disk Structure Survey in Taurus

The remarkable disk substructures revealed from recent high-spatial resolution observations have transformed our view of disks. While their origin is still hotly debated, they already offer much-needed new constraints on planet formation models. We have performed a high resolution (~0.1 arcsec, 15 au) ALMA observation at 1.3 mm for an unbiased sample of 32 disks in Taurus, and detect dust substructures in more than 1/3 of them. These substructures are preferentially detected in larger disks but we find no trend with either stellar mass or disk brightness (Long et al. 2018). Axisymmetric rings and gaps are the most common type of substructures. We rule out ice lines as the universal mechanism for their formation based on the inferred gap and ring properties. If disk gaps are carved by planets, low-mass (Neptunes) planets are preferred. Interestingly enough most other disks in our sample are compact (radii less than 40 au) and do not show substructures at our current resolution limits. Some of these disks may be tidally truncated by companions. Others may have different initial conditions or evolution and different planet formation pathways.

Enrique Macias (Boston University)

Catherine Espaillat (Boston University)
Mayra Osorio, Guillem Anglada (Instituto de Astrofisica de Andalucia-CSIC)
Hendrik Linz, Thomas Henning, Mario Flock (Max Planck Institut fur Astronomie)
Carlos Carrasco-Gonzalez (Instituto de Radioastronomia y Astrofisica-UNAM)

Topic: Protoplanetary Disks

Characterization of Ring Substructures in Protoplanetary Disks Using Multiwavelength ALMA Observations

The recent discovery of multiple rings and gaps in protoplanetary disks has sparked significant interest since these substructures could work as dust traps, accumulating grains, increasing their growth, and possibly enhancing planet formation. In this talk I will present a detailed characterization of the multi-ring disk of HD 169142, showing strong evidence that the ring substructures are efficiently trapping large dust particles. We analyzed ALMA data at 0.88 mm, 1.3 mm, and 3 mm with a simple physical model, estimating the radial distribution of dust optical depth, temperature, and particle size distribution. Our results indicate that the disk is composed of three ring-like features. The two most prominent rings are working as strong and narrow radial traps of pebbles, displaying narrower widths at longer wavelengths. This confirms the suspicion that rings are likely associated with local maxima in the gas pressure distribution of the disk. The deep brightness contrast between the rings and the gaps points toward planet-disk interactions as the most likely origin for the pressure maxima, adding to the evidence that disk substructures are signposts of early planet formation.

Valentin Christiaens (Monash University)

Simon Casassus (Universidad de Chile), Olivier Absil (Université de Liege), Carlos Gomez Gonzalez (Université Grenoble Alpes), Ricardo Ramirez (Universidad of Chile), Julien Girard (Space Telescope Science Institute), Christophe Pinte (Monash University), Benoit Pairet (Université Libre de Bruxelles), Faustine Cantalloube (Max Planck Institute for Astronomy), Sascha P. Quanz (ETH Zurich), Andres Jordan (Pontificia Universdidad de Chile), Dimitri Mawet (Caltech/JPL), Zahed Wahhaj (ESO-Santiago), and Daniel J. Price (Monash University)

Topic: Protoplanets - Protoplanetary disks - High-contrast and high-angular resolution imaging

PDS 70 b: Disentangling the Protoplanet from Extended Disc Structures, and Spectral Characterization

Planet formation models require critical input from direct observations of forming planets. Protoplanetary discs with large inner clearings (transition discs) are prime targets to look for protoplanets and study their interaction with the disc. A large number of transition discs have been scrutinized with NIR high-contrast imaging instruments, and several tentative detections have been claimed over the past few years. Nonetheless, in most cases later evidence have suggested that the image processing algorithms applied on extended disc signals could lead to spurious point-source detections. Recently though, more robust multi-epoch and multi-instrument evidence for an embedded protoplanet in transition disc PDS 70 was presented by the VLT/SPHERE team.

Here, I will firstly briefly describe the techniques we used to process VLT/SINFONI observations in order to reach an optimal contrast and evaluate possible biases induced on either extended disc signals or point sources. We apply them to a VLT/SINFONI dataset of PDS 70 and confirm the protoplanet. We also present observational evidence for extended disc structures, some of which possibly related to the planet. We extract a spectrum for the companion between 2.0-2.45 μm (K band), and use both the published SPHERE spectrum and our new SINFONI spectrum for a combined fit to synthetic spectral models. Our results provide new constraints on the effective temperature, surface gravity, mass, and radius of the protoplanet, and hence on its formation process. Finally, we also set independent constraints on the accretion rate of the companion.

Friday, 17 May 2019			
Start	End	Title	Speaker (* student talk)
		Session 9, Chair: Olja Panić	
9:00 AM	9:40 AM	Invited Review: Exoplanet Atmospheres	Heather Knutson
9:40 AM	10:00 AM	Exoplanet Clouds and How to Characterize Them	Thomas Beatty
10:00 AM	10:20 AM	Detection of Potassium in the Atmosphere of HD 189733b	Engin Keles*
10:20 AM	11:00 AM	Coffee and Posters	
11:00 AM	11:20 AM	How to Detect Forming Planets?	Judit Szulagyi
11:20 AM	11:40 AM	Extreme Debris Disk Variability -- Tracers for the Impacts of Large Asteroids	Kate Su
11:40 AM	12:00 PM	Seeds of Dust and Planets: Forming the First Benzene Ring	Brett McGuire
12:00 PM	12:30 AM	Student Awards and Conference Conclusion	

Heather Knutson (Caltech)

Topic: Exoplanet Atmospheres

Exoplanet Archaeology: Can We Use Composition to Constrain Planet Formation Histories?

The present-day properties of exoplanetary systems can provide us with invaluable clues to their past formation and migration histories. In my talk I will focus on current efforts to characterize the bulk and atmospheric compositions of short-period transiting planets in an effort to determine whether they formed in situ or migrated in from a more distant formation location. I will also discuss how the architectures of planetary systems can provide much-needed context for these composition measurements.

Thomas G. Beatty (University of Arizona)

Topic: Exoplanets

Exoplanet Clouds and How to Characterize Them

Clouds have long been known to be present in the atmospheres of hot exoplanets, as evidenced by their strong signatures in transmission spectra. Theory predicts that the presence of clouds and the resulting cloud-feedback should have a noticeable effect on the dynamics and thermal properties of these atmospheres, though the precise nature of these effects should depend upon both the cloud composition and grain size. Therefore, understanding cloud properties and their effects is crucial in our understanding of planetary atmospheres, and hence planetary compositions and formation pathways.

Unfortunately, it has proven difficult to constrain cloud properties based on transmission spectra, which probe high in an exoplanetary atmosphere. However, recently it has become possible to use emission spectroscopy measurements to place direct observational constraints on exoplanets' cloud properties. I will discuss how we have used HST and LBT to make an estimate of the average cloud grain sizes (Beatty+2017), Spitzer to determine the prevalence and rough composition of nightside clouds on hot Jupiters and their average longitudinal extent (Beatty+2018), and very recent HST/WFC3 spectroscopic phase curve observations that have yielded the first direct spectrum of an exoplanet's nightside emission. This last result allows us to spectroscopically constrain the composition of the nightside clouds, and I will discuss how this fits into the previous HST, LBT, and Spitzer results.

Combined, the multiple atmospheric vantage points afforded by these observations allow us to assemble a holistic view of the formation and composition of clouds on hot exoplanets. By comparing these results to recent 3D atmospheric models with clouds, we can understand the role clouds play in setting the observed dynamics and thermal structure of exoplanetary atmospheres. This, in turn, gives us a better understanding of the underlying atmospheric compositions necessary to support these cloud systems.

Finally, I will highlight what we expect to see with the upcoming, joint, JWST/NIRCam+MIRI guaranteed time observations program. These observations will focus on exploring how the bulk composition of exoplanets changes with planet mass, from Jupiter- to Neptune-masses, and they will also provide exquisite spectroscopic data to see how cloud compositions and grain sizes change over this same mass range.

Engin Keles (Leibniz-Institut für Astrophysik Potsdam)

Matthias Mallonn (Leibniz-Institut für Astrophysik Potsdam)
Thorsten Carroll (Leibniz-Institut für Astrophysik Potsdam)
Carolina von Essen (Aarhus University)
Ilya Ilin (Leibniz-Institut für Astrophysik Potsdam)
Xanthippi Alexoudi (Leibniz-Institut für Astrophysik Potsdam)
Lorenzo Pino (University of Amsterdam)
Jake Turner (Cornell University)
Klaus Strassmeier (Leibniz-Institut für Astrophysik Potsdam)

Topic: Exoplanetary Atmospheres

Detection of Potassium in the Exoplanet Atmosphere of HD189733b Using High Resolution Spectroscopy

To characterize exoplanetary atmospheres, transmission spectroscopy is one of the most successfully used techniques. This technique provides the possibility of investigating the presence of constituents within the atmospheres of hot Jupiters. Several works presented the detection of specific alkali atoms in exoplanetary atmospheres creating excess absorption curves i.e. where in- and out- of- transit data are used to show an increased absorption in the line during transit. In this work we present high resolution transit observations of the exoplanet HD189733b, using the 2 x 8.4m Large Binocular Telescope and the Potsdam Échelle Polarimetric and Spectroscopic Instrument (PEPSI). We investigate the potassium excess absorption at 7698.98Å after correcting for telluric line contamination and center-to-limb variation and show the first high-resolution potassium detection in the atmosphere of HD189733b.

Judit Szulagyi (University of Zurich)

Topic: Circumplanetary Disks & Forming Planets

How to Detect Forming Planets?

To understand better planet formation, we need to detect planets during their formation, even though this is an extremely challenging task. During the formation phase, nascent giant planets are surrounded with their own disk, the circumplanetary disk. To detect forming planets, therefore, the characteristics of these disks need to be known. I show my radiative hydrodynamic simulations on the subject, which then I turned to synthetic observations with wavelength-dependent radiative transfer. I examined the detections of these young planets and their circumplanetary disks in various wavelengths: sub-mm/radio, near/mid infrared, near infrared scattered light with polarization, as well as I created their SEDs. I will explain what informations can/cannot be extracted at the various wavelength observations and why currently sub-mm seems to be the best to observe forming planets. I will also show, what integration times, what resolution requirements are needed to carry out such observations for forming planets. The planet-disk interactions reveal different information at different wavelengths, whether we can see the circumstellar disk midplane, or its surface. Therefore, I will also explain what structures we can see at which wavelength-range and what imprints forming planets leave in the circumstellar disk.

Kate Su (University of Arizona)

George Rieke (University of Arizona), Alan Jackson (University of Toronto), Andras Gaspar (University of Arizona), Robin Dong (University of Victoria), Grant Kennedy (University of Warwick), & Paul Smith (University of Arizona)

Topic: Exoplanets

Extreme Debris Disk Variability – Tracers for the Impacts of Large Asteroids

Terrestrial plant formation is a violent and messy process with roughly half of the impact-body mass contributing to net growth, leading to diverse compositions in the solar system's terrestrial bodies. Variable disk emission by the dust produced in the aftermaths of large asteroid impacts provides critical diagnostic information on the violent collisions that are needed to build terrestrial planets. Through our dedicated Spitzer monitoring program, we have identified multiple violent impacts in the 35-Myr-old NGC 2547-ID8 system, involving large (>100 km) asteroid-sized bodies. Our high-quality infrared light curves reveal the amount of fresh dust generated during the post-impact evolution. Additionally, we have identified other extremely dusty systems with infrared variability of similar amplitude and timescales as that of the NGC 2547-ID8 system. When the viewing geometry of such systems is nearly edge-on, the passing of impact-produced dust clumps in front of the star also produces optical dips and variation in the polarized light. In this talk, I will summarize the results from our dedicated Spitzer monitoring program, and showcase how much we can learn about these dynamically active systems from their detailed infrared light curves and simultaneous polarimetric observations.

Brett A. McGuire (NRAO)

Kin Long Kelvin Lee (CfA)
Michael C. McCarthy (CfA)

Topic: Exoplanets

Seeds of Dust and Planets: Forming the First Benzene Ring From the Ground Up

Five and six membered aromatic rings are ubiquitous in life and chemistry on Earth, and in the polycyclic aromatic hydrocarbons (PAHs) in the ISM that may contain up to 25% of interstellar carbon and be the seeds for carbonaceous dust. The formation of the first ring, benzene (C_6H_6) is a bottleneck in the bottom-up generation of PAHs both on Earth and in the ISM, and has led many to speculate that PAHs are instead formed by the degradation of macroscopic carbonaceous soot expelled from late-stage AGB stars. Our recent detection of cyanobenzene (C_6H_5CN) in TMC-1, a cold dark cloud at the earliest stages of star formation radically alters this perspective. I will present a combined laboratory and observational investigation demonstrating that the first aromatic benzene ring can indeed be synthesized from small, abundant precursors in the gas phase and in the absence of any star. This in turn would indicate that this important reservoir of both carbon and the potential seeds of dust and planet formation already exist at the earliest stages of the process.