Exoplanets & Planet Formation Workshop 2023

Book of Abstracts

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Format for each submission:
Family-Name, Given-Name(s) / Email / Institute
Title
Abstract

Orals (in the sequence of the program):

Dong Ruobing / rbdong@uvic.ca / University of Victoria
Some recent JWST and ALMA observations of protoplanetary disks
ALMA and JWST have been the powerhouse of protoplanetary disk observations. I will introduce two programs in which we use JWST and ALMA to image disks. In one of them, we use JWST to characterize a sample of protoplanetary disks with gaps and spiral arms, and to search for the predicted spiral-driving and gap-opening planets. In the other program, we use ALMA to study the gas kinematics in a protoplanetary disk potentially gravitationally unstable.

Harsono, Daniel / dharsono@gapp.nthu.edu.tw / NTHU
Composition of planet-forming disks from ALMA and JWST
Planets are formed in accretion disks around young stars. Recent results suggest that the planet formation process begins in the earliest stages of star formation. ALMA has unveiled a diversity in the characteristics of planet-forming disks around young stars. Meanwhile, JWST is starting to provide us with the ingredients of these planets by studying the composition of icy dust grains and the hot inner disk. I will present recent results with ALMA and JWST that examine the composition of young planet-forming disks.

Yang, Haifeng / hfyangpku@gmail.com / Peking University
Eccentric dust ring and scattering-induced polarization in the IRS 48 transition disk
Crescent-shaped structures in transition disks hold the key to studying the putative companions to the central stars. The dust dynamics, especially that of different grain sizes, is important to understanding the role of vortices in planet formation. In this work, we present deep polarized dust continuum observation with high resolution towards the Oph IRS 48 system. For the first time, we are able to trace and detect emission along the entire orbit crossing the crescent-shaped structure. The orbit is hightly eccentric with an eccentricity of 0.27. In addition, we detect a compact emission toward the central star with a dust mass of 1.5e-8 solar mass, or 0.005 earth mass. The polarization comes mostly from self-scattering of dust grains, with grain sizes of about 100 micron. We show that the dust scale height has a strong impact on the polarization. We are able to constrain the dust scale height accurately, which gives the turbulent viscosity alpha of about 10^-4~10^-3. Together, our observations reveal a turbulent vortex in a highly eccentric orbit in the transition disk system IRS 48.

Muto, Takayuki / muto@cc.kogakuin.ac.jp / Kogakuin University
Methods to Explore the Disk Asymmetries and its Application to a Young Protoplanetary Disk
Substructures in protoplanetary disks have indications on physical processes at work in disks such as vortex formation, dust accumulation, and planet formation. Disk substructures have also been under active debate observationally since ALMA has enabled to deliver the high

spatial resolution data. Yet, it is still difficult to obtain the structures in the spatial scales comparable to the Solar System (~several au) with standard CLEAN imaging methods. In this presentation, we propose a method to extract non-axisymmetric structures in the disk by direct visibility analyses. We show it is possible to find asymmetric structures with the spatial scale comparable to or less than the beam size of standard CLEAN methods. We also show the application of the methods to a young protoplanetary disk system, which is indicated to have an asymmetric ring-like structure at the deeply embedded phase of its evolution.

Yang, Jun / junyang@pku.edu.cn / Peking University

Cloud behaviour on tidally locked rocky exoplanets

Determining the behaviour of convection and clouds is one of the biggest challenges in our understanding of exoplanetary climates. Given the lack of in situ observations, one of the most preferable approaches is to use cloud-resolving or cloud-permitting models (CPM). Here we present CPM simulations in a quasi-global domain with high spatial resolution (4 × 4 km^2 grid) and explicit convection to study the cloud regime of 1:1 tidally locked rocky planets orbiting around low-mass stars. We show that the substellar region is covered by deep convective clouds and cloud albedo increases with increasing stellar flux. The CPM produces relatively lower cloud liquid water concentration, smaller cloud coverage, lower cloud albedo and deeper H2O spectral features than previous general circulation model simulations using empirical convection and cloud parameterizations. Furthermore, cloud streets—long bands of low-level clouds oriented nearly parallel to the direction of the mean boundary-layer winds—appear in the CPM and substantially affect energy balance and surface precipitation at a local level.

Yan, Fei / yanfei@ustc.edu.cn / University of Science and Technology of China

Characterizing the dayside atmospheres of ultra-hot Jupiters

Characterizing exoplanet atmosphere is a frontier subject in the exoplanet field. By observing the spectra of exoplanet atmospheres, we can probe their chemical compositions as well as physical conditions such as temperature structures, global circulations, and atmospheric escape. In this talk, I will present the recent research on ultra-hot Jupiter, which is a class of giant exoplanets with extremely high temperatures. We have conducted a survey of a dozen ultra-hot Jupiters using ground-based high-resolution spectrographs, such as CRIRES+, CARMENES, HARPS-N. By observing their thermal emission spectra, we detected various chemical species, including Fe, Si, CO, OH. Particularly, we found that temperature inversion layers are common on their dayside hemispheres.

Tan, Xianyu / xianyut@sjtu.edu.cn / Shanghai Jiao Tong University

Meteorology of brown dwarfs

Most brown dwarfs (BDs) and directly imaged exoplanets characterized so far lack significant external stellar irradiation and their atmospheres are sculpted by the internal heat flux. They provide valuable testbeds to understand the climate physics of planetary atmospheres in the self-luminous regime. Recent surveys have revealed that variability is common among these objects with a small fraction having exceptionally large variability amplitudes. Spectroscopic information on the variability has also been obtained from space-based and ground-based facilities. JWST spectroscopic time-series observations of these objects will lead to further breakthrough discoveries. Observations are more than rich to pose critical questions about the climate dynamics of these atmospheres, but theory and modeling are relatively behind. Our recent theoretical development suggested that cloud radiative feedback coupled with atmospheric dynamics could lead to a self-sustained dynamical system, and such a system would generate large-scale turbulence and traveling waves, producing variability with morphology and amplitudes that could broadly explain some of the observed variability. Our general circulation model is further developed to have a nongrey radiative transfer, therefore being able to predict spectroscopic variability and spectrum as a result of such a dynamical system and directly compare to observations.We use VHS1256b, which is the BD with the largest variability amplitude detected so far, as a template to illustrate how we can use spectrum and variability simultaneously to constrain the atmospheric properties.

Wei, Xing / xingwei@bnu.edu.cn / Beijing Normal University

Hot Jupiters' radius anomaly and exomoons' retention

I will talk about the two recent projects, why hot Jupiters' radii are larger than Jupiter's but not too large, and how exomoons can be retained around their host planet.

Chiang, Eugene / echiang@astro.berkeley.edu / UC Berkeley

Accreting protoplanets

The hunt is on for protoplanets in young, gas-rich discs. How bright these planets are, and what they will grow to become, depend on their gas accretion rates, which may be in the runaway regime. We discuss how planet accretion may play out in gas discs, and the prospects of detecting protoplanets via their broadband spectral energy distributions.

Wang, Yu / wang-y21@mails.tsinghua.edu.cn / Tsinghua University

Atmospheric recycling of volatiles by pebble-accreting planets

Planets, embedded in their natal discs, harbour hot envelopes. When pebbles are accreted by these planets, the contained volatile components may sublimate, enriching the envelope and potentially changing its thermodynamical properties. However, the envelopes of embedded planets actively exchange material with the disc, which would limit the buildup of a vapour-rich atmosphere. To properly investigate these processes, we have developed a new phase change module to treat the sublimation process with hydrodynamical simulations. Combined with the recently developed multidust fluid approach, we conduct 2D self-consistent hydrodynamic simulations to study how pebble sublimation influences the water content of super-Earths and sub-Neptunes. We find the extent and the amount of vapour that a planet is able to hold on to is determined by the relative size of the sublimation front and the atmosphere. When the sublimation front lies far inside the atmosphere, vapour tends to be locked deep in the atmosphere and keeps accumulating through a positive feedback mechanism. On the other hand, when the sublimation front exceeds the (bound) atmosphere, the ice component of incoming pebbles can be fully recycled and the vapour content reaches a low, steady value. Low disc temperature, small planet mass, and high pebble flux render the planet atmosphere vapour-rich while the reverse changes render it vapour-poor. The phase change module introduced here can also be employed to model the chemical composition of the gas in the vicinity of accreting planets and solid enhancement around snowlines.

Chen, Kan / kan.chen.21@ucl.ac.uk / University College London

Planet Gap-opening Feedback on Disk Thermal Structure and Composition

(Exo-)planets inherit their budget of chemical elements from a protoplanetary disk. The disk temperature determines the phase of each chemical species, which sets the composition of solids and gas available for planet formation. We investigate how gap structures, which are common in recent disk observations, alter the thermal and chemical structure of a disk. Planet-disk interaction is a leading hypothesis of gap formation and so such changes could present a feedback that planets have on planet-forming material. Both the planet gap-opening process and the disk thermal structure are well studied individually, but how the gap-opening process affects disk thermal structure evolution remains an open question. We develop a new modelling method by iterating hydrodynamical and radiative transfer simulations to explore the gap-opening feedback on disk thermal structure. We carry out parameter studies by considering different planet locations $\rp$ and planet masses $\Mp$. We find that for the same $\rp$ and $\Mp$, our iteration method predicts a wider and deeper gap than the non-iteration method. We also find that the inner disk and gap temperature from the iteration method can vary strongly from the non-iteration or disk without planets, which can further influence dust-trap conditions, iceline locations, and distribution of various ices, such as \ce{H2O}, \ce{CO2}, and CO on large dust grains (“pebbles”). Through that, a gap-opening planet can complicate the canonical picture of the non-planet disk C/O ratio and influence the composition of the next generation of planetesimals and planets.

Hammer, Michael / mhammer44444@gmail.com / ASIAA

How to form compact & other longer-lived planet-induced vortices: VSI, planet migration, or re-triggers, but not feedback

Past computational studies of planet-induced vortices have shown that the dust asymmetries associated with these vortices can be long-lived enough that they should be much more common in mm/sub-mm observations of protoplanetary discs, even though they are quite rare. Observed asymmetries also have a range of azimuthal extents even though computational studies have shown planet-induced vortices should be preferentially elongated. In our recent study, we use 2-D and 3-D hydrodynamic simulations to test whether those dust asymmetries should really be so long-lived or so elongated. With higher resolution (29 cells per scale height) than our previous work, we find that vortices can be more compact by developing compact cores when higher-mass planets cause them to re-form, or if they are seeded by tiny compact vortices from the vertical shear instability (VSI), but not through dust feedback in 3-D as was previously expected in general. Any case with a compact vortex or core(s) also has a longer lifetime. Even elongated vortices can have longer lifetimes with higher-mass planets or if the associated planet is allowed to migrate, the latter of which can prevent the dust asymmetry from decaying as the planet migrates away from the vortex. These longer dust asymmetry lifetimes are even more inconsistent with observations. Our ongoing work suggests this discrepancy is not easy to explain with cooling, perhaps instead suggesting that discs have an intermediate amount of effective viscosity that prevents vortices from being more prevalent in protoplanetary discs.

Liu, Hauyu Baobab / baobabyoo@gmail.com / Sun Yat-sen University, Kaohsiung

A tale of pebble formation

A complete model of planet formation needs to explain the co-existence of water/carbon deficient planets such as Earth and Mars and the icy giants such as Neptune and Uranus. This implies that we need to understand the coagulations of the water-ice-coated and water-ice-free dust grains. I will base on observational case studies to suggest that the water-ice-free dust grains in the innermost part of the protoplanetary disks can grow to larger than 1 mm size without being limited by the classical fragmentation/bouncing barrier. The coagulation of water-ice-coated dust seems to be limited by the fragmentation/bouncing barriers in general, while icy-pebble formation in some localized regions appears possible. While I do not yet have a good idea about the physical mechanism that promotes the formation of the icy-pebble, it seems to me that icy-pebble tends to show azimuthally asymmetric distributions.

Lin, Min-Kai / mklin@asiaa.sinica.edu.tw / ASIAA

Streaming instability: Reborn

The ‘streaming instability’ (SI) between dust and gas in protoplanetary disks is the leading mechanism to form planetesimals — the building blocks of planets. However, the simplicity of the SI is challenged by the complex physics involved in a realistic protoplanetary disk. I describe how turbulence, vertical structure, and thermodynamics can hinder the SI; but also how accretion flows and magnetic fields can help to revive it, albeit in modified forms, which should be investigated in future simulations.

Li, Rixin / rixin@berkeley.edu / UC Berkeley

From Dust to Planetesimals, from Young to Evolved Protoplanetary Disks

The first step in planet formation is to build planetesimals from dust grains in protoplanetary disks. The origin and demographics of planetesimals are crucial to understanding the Solar System, exoplanetary systems, and circumstellar disks. In this talk, I will present our latest works on planetesimal formation via the streaming instability, a mechanism to aerodynamically concentrate dust and produce planetesimals. By contextualizing our models in disks at various evolutionary stages, I will show that planet formation is well underway in massive young disks, and small bodies in the pristine Cold Classical Kuiper Belt formed late in the solar nebula's lifetime. I will then discuss the implications and links between our results and recent disk observations, as well as Solar System explorations.

Huang, Pinghui / phhuang10@gmail.com / University of Victoria

Dust Clumping in Outer Turbulent Protoplanetary Disks

The Vertical Shear Instability (VSI) is a robust hydrodynamic phenomenon that occurs within a range of tens to hundreds of astronomical units (AU) in protoplanetary disks, significantly impacting disk accretion and evolution. The Rossby Wave Instability (RWI) has the capability to generate anticyclonic vortices, effectively trapping dust and thereby promoting dust concentration and growth. Simultaneously, the Streaming Instability (SI) offers a promising mechanism for creating strong dust clumps, which contribute to the formation of planetesimals. In this study, we utilized the newly developed multifluid dust module in Athena++ to conduct 3D global simulations, showcasing the coexistence of VSI, RWI, and SI within protoplanetary disks. Although the weak zonal flows induced by VSI and the subtle dusty vortices arising from RWI may not achieve complete dust trapping, these mild pressure variations do make significant contributions to dust clumping driven by SI. When all three instabilities coexist, they result in more pronounced dust clumping compared to scenarios where only a single instability is active.

Lai, Dong / dong@astro.cornell.edu / Cornell University/TDLI

Hot Jupiters and Super-Earths: Spin-Orbit Dynamics in Exoplanetary Systems

I will discuss two topics on exoplanetary systems. The first concerns hot Jupiters, giant planets with orbital periods of a few days. Observations have revealed that many hot Jupiters have orbits that are highly misaligned with the rotation of their host stars. How did such large stellar obliquities come about? What do they inform about the formation of hot Jupiters? The second topic deals with planetary obliquity, which reflects the planet's dynamical history, and can strongly influence the atmosphere condition and climate of the planet. Many Sun-like stars are observed to host close-in super-Earths (or Earth-like planets) as part of a multi-planetary system. Can such super-Earths (or similar habitable planets around M stars) sustain significant obliquities?

Dai, Fei / fdai@caltech.edu / Caltech

Dynamical Evolution of Near Resonant Planetary Systems

Convergent disk migration has long been suspected to be responsible for forming planetary systems with a chain of mean-motion resonances. Dynamical evolution over time could disrupt the resonant configuration to form the non-resonant Kepler multi-planet systems. We contrast two planetary systems TOI-1136 and TOI-4495. TOI-1136 is a 700-Myr old G star with 6 transiting planets in a chain of mean-motion resonances. The orbital period ratios deviate from exact commensurability by only 1e-4, smaller than the deviations of 1e-2 seen in mature Kepler near-resonant systems. TOI-1136 appears to be a pristine example of the orbital architecture emerging from convergent disk migration before dynamical processes disrupt the resonance. The resonant chain also contains a very delicate 7:5, 2nd order resonance that favors a gentle Type-I migration in a low-density disk with an inner edge at about 0.05AU. On the other hand TOI-4495, ~2Gyr, has two planets that have apparently broken away from mean-motion resonance. We discuss how these two systems could represent snaps of dynamical evolution of hundreds of Kepler-like systems

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Huang, Xiumin / huangxm@pmo.ac.cn / PMO, CAS

The EKL mechanism explains the retrograde orbits and retrograde rotation of the planets around the binary star.

The Eccentric Kozai-Lidov (EKL) mechanism plays an essential role in exploring significant oscillations of the mutual inclination between the planet and the secondary. We perform qualitative analysis and extensive numerical integrations to investigate the flip conditions and timescales of γ Cep Ab's orbit. The timescale for the first orbital flip decreases along with the increase of the perturbation Hamiltonian. The flipping orbits of γ Cep Ab are confirmed to have a large possibility to retain stable based on surfaces of section and the secular stability criterion. For general S-type planetary systems with $a1/a2 \le 0.1$, where the most intense excitation of i occurs when $a1/a2 = 0.1$ and $e2 \sim 0.8$. The planetary obliquity is also a significant factor in determining the physical properties of planetary surfaces and the climate. Secular dynamical theories are helpful to predict the evolution of the planetary obliquity, especially when direct detections are limited by the observation accuracy. The EKL and the equilibrium tide are coupled to investigate the diverse secular evolution paths of planetary obliquity. For close-in S-type terrestrial planets in binary star systems, the planetary obliquity could first undergo the excitation to be retrograde, then enters the quasi-equilibrium state between 40° and 60°. The maximum obliquity can reach 130° when ttide/tkl > 10000. Qualitative simulation results indicate the maximum obliquity increases with the semi-major axis ratio a1/a2 and the perturbing body's eccentricity e2. For general S-type terrestrials with a1~0.1 au and a2<45 au, the retrograde possibility could be 73%. Spin evolution trends of several observed hot-Jupiters in binary star systems are estimated as well.

Wang, Su / wangsu@pmo.ac.cn / Purple Mountain Obervatory, CAS

The Formation of Hot Jupiter and Its Companions

Gas giants in transiting multi-planetary systems are intrinsically much rarer compared to the typical transiting multiple planetary systems only host Super-Earth/Sub-Neptunes discovered by Kepler mission. Compared with the small planet multiple systems, the occurrence rate of multiple planetary systems with gas giants with longer periods increases and there is a pile-up near the 2:1 mean motion resonance. In this work, we investigate the three-dimensional configuration formation of short-period gas giant and its low-mass companions under the influence of the orbital migration of planets in the protoplanetary disk, and the post orbital evolution influenced by the atmospheric mass loss and tidal effect induced by the central star. We find that in the orbital migration phase, the mutual inclination excitation is related to the competition between the eccentricity damping timescale and the migration timescale, and the mass ratio between planets. And the mutual inclinations between the gas giant and its low-mass companions are hard to be excited to larger than six degrees. More planet pairs in near 3:2 MMR have higher opportunities to be in non-coplanar with a mutual inclination of few degrees than they are in 2:1 MMR. After the gas disk vanished, the atmospheric mass loss and tidal effect are two key factors that influence the final orbital configurations. With higher mass loss fraction and hotter jupiter, the mutual inclination can be excited to higher value which is a possible reason of more gas giant multiple planetary system with longer periods have been found. The simulation results is consistent with the observed period ratio obtained from Kepler mission with a mass loss fraction less than 15% of its total mass. Based on the estimation of the expected TTV amplitude of the resulted systems, we predict at least 1-2 systems existed in TESS data with a single transiting super-earth within period of 10 days with TTV amplitude higher than three minutes due to a non-transiting gas giant.

Fang, Min / mfang@pmo.ac.cn / Purple Mountain Observatory

Disk winds from protoplanetary disks

Planet systems are formed from the dust and gas present in protoplanetary disks surrounding young stars. The evolution and eventual dispersal of these protoplanetary disks strongly influence their formation. Among the physical processes that govern the evolution and dispersal of protoplanetary disks, disk winds have been identified as one of the key factors supported by observations and theories. In this talk, I will provide an overview of the advancements in our understanding of disk winds from observational perspective.

Chen, Yuan / ychen@strw.leidenuniv.nl / Leiden Observatory

Tracing complex organic molecules (COMs) from ice to gas in YSOs with JWST and ALMA

How the chemistry in the universe evolves from diffuse interstellar medium to a life-harboring environment on our Earth? Star formation stages from molecular clouds to protostars to circumstellar disk and protoplanets are the key stages in this cosmic chemical evolution. In particular, complex organic molecules (COMs), typically defined as carbon-bearing molecules with at least six atoms, have gained their popularity over the past several decades due to their importance of linking atoms and simple molecules with prebiotic species. So far, more than 80 COMs have been detected in various environments. The emission lines of rotational transitions of gas-phase COMs can be observed in (sub)millimeter wavelengths using radio telescopes, in which the most powerful one is the Atacama Large Millimeter/submillimeter Array (ALMA). With its high sensitivity and resolution (both spatial and spectral), ALMA has detected a rich inventory of COMs in star-forming regions, mostly in Class 0 protostars. The detection of COMs in the solid phase (i.e., in ices) was only confirmed for methanol (CH3OH), the simplest COM, but is now becoming possible for other COMs with the James Webb Space Telescope (JWST) and its Mid-InfraRed Instrument (MIRI). Tracing COMs in both phases in YSOs will help us probe their formation history and shed light on how the chemistry evolves from simple to complex in the universe. This talk will show the results from latest ALMA and JWST observations with a nonexclusive focus on oxygen-bearing COMs (O-COMs), which are the most abundant and therefore detectable for both telescopes. By comparing the ratios between O-COMs and the reference species such as water and methanol, we find that most of the COMs are likely to be formed in ices during the early stages of star formation. However, the gas-phase reprocessing may also act on some species, which needs to be studied more statistically in a larger sample.

Wang, Mutian / mutianwang@smail.nju.edu.cn / Nanjing Univerisity

The Accretion History of EX Lup: A Century of Bursts, Outbursts, and Quiescence

EX Lup is the archetype for the class of young stars that undergoes repeated accretion outbursts of ~ 5 mag at optical wavelengths and that last for months. Despite extensive monitoring that dates back 130 years, the accretion history of EX Lup remains mostly qualitative and has large uncertainties. We assess historical accretion rates of EX Lup by applying correlations between optical brightness and accretion, developed on multi-band magnitude photometry of the ~ 2 mag optical burst in 2022. Two distinct classes of bursts occur: major outbursts (ΔV ~5 mag) have year-long durations, are rare, reach accretion rates of ~ 1e−7 M☉ yr−1 at peak, and have a total accreted mass of around 0.1 Earth masses. The characteristic bursts (ΔV ~ 2 mag) have durations of ~ 2−3 months, are more common, reach accretion rates of ~ 1e−8 M☉ yr−1 at peak, and have a total accreted mass of around 1e−3 Earth masses. The distribution of total accreted mass in the full set of bursts is poorly described by a power law, which suggests different driving causes behind the major outbursts and characteristic bursts. The total mass accreted during two classes of bursts is around two times the masses accreted during quiescence.

Calcino, Josh / josh.calcino@gmail.com / Tsinghua University

Kinematic Signatures of Circumbinary Discs: Spiral arms, Fast Flows, and Doppler Flips

Kinematic studies of protoplanetary discs are becoming a valuable method for uncovering hidden companions. While there exists a subtantial amount of literature on the understanding of planet-disc interactions and their observational implications, little attention has been made towards circumbinary discs. Using 3D hydrodynamical simulations post-processed with Monte Carlo radiative transfer, I found several kinematic and morphological features that can identify circumbinary discs. I will show that Doppler flips, spiral arms, eccentric gas motion, and vortex-like kinematic signatures are commonly seen. These complex kinematic structures may explain some of the observed, and potentially misinterpreted, kinematic signatures seen in the literature.

Wu, Yanqin / wu@astro.utoronto.ca / University of Toronto

Shinning lights on proto-planetary Disks

I will discuss how multiple observational puzzles may be related to the effects of stellar irradiation on disks, and how the planet hypothesis may not be the ultimate answer.

Deng, Hongping / hpdeng353@shao.ac.cn / Shanghai Astronomical Observatory

Are warps in class II circumstellar discs inherited from their formation?

Circumstellar discs, the cradle of planets, are likely formed warped due to the accretion of misaligned infall and streamers. Understanding the evolution of warped circumstellar discs is thus crucial for the planet formation theory. We show via direct hydrodynamic simulations that warps in young circumstellar discs are efficiently damped by spiral density waves within thousands of years. As the disc evolves, when its self-gravity is negligible, a parametric instability takes over to align the disc rapidly. As a result, it is unlikely to pass on any misalignment in the formation stage to the widely observed warped, million-year-old class II discs. One potential solution to this puzzle is the formation of misaligned giant planets via disc fragmentation, which can break up the internal flow for disc alignment and maintain warps.

Li, Jiaru / jiaru.li@northwestern.edu / CIERA - Northwestern University

Resonant Excitation of Planetary Eccentricity due to a Dispersing Eccentric Protoplanetary Disk: a New Mechanism of Generating Large Planetary Eccentricities

I will present a new mechanism of generating large planetary eccentricities. This mechanism applies to planets within the inner cavities of their companion protoplanetary disks. A massive disk with an inner truncation may become eccentric due to non-adiabatic effects associated with gas cooling, and can retain its eccentricity in long-lived coherently-precessing eccentric modes; as the disk disperses, the inner planet will encounter a secular resonance with the eccentric disk when the planet and the disk have the same apsidal precession rates; the eccentricity of the planet is then excited to a large value as the system goes through the resonance. We solve the eccentric modes of a model disk for a wide range of masses. We then adopt an approximate secular dynamics model to calculate the long-term evolution of the "planet + dispersing disk" system. The planet attains a large eccentricity (up to 0.6) in our calculations, even though the disk eccentricity is quite small (~0.05).

Lee, Man Hoi / mhlee@hku.hk / The University of Hong Kong

Resonant Chains and the Convergent Migration of Planets in Protoplanetary Disks

An increasing number of compact planetary systems with multiple planets in a resonant chain have been detected. The resonant chain must be maintained by convergent migration of the planets due to planet-disk interactions, if it is formed before the dispersal of the protoplanetary gas disk. For type I migration in an adiabatic disk, we show that an analytic criterion for convergent migration can be developed by requiring that any part of the resonant chain should be convergently migrating toward the remaining part. The criterion depends primarily on the logarithmic gradients of the surface density and temperature profiles of the disk, and it is independent of the absolute values of the surface density and temperature. The analytic criterion is applied to the Kepler-60, Kepler-80, Kepler-223, TOI-178, and TRAPPIST-1 systems. Due to the variation of planetary masses within the resonant chains, we find that convergent migration typically requires rather extreme values of the logarithmic gradients that have little or no overlap with common disk models. Finally, we show that there is a empirical relationship between the distance of the innermost planet from the central star and the stellar mass for the observed resonant chain systems, which supports the idea that the resonant chains are formed and maintained by stalling the migration of the innermost planet near the inner edge of the disk truncated by the magnetic fields of the protostar.

Fujii, Yuri / fujii.yuri.2z@kyoto-u.ac.jp / Kyoto University

Reexamination of Cosmic-Ray Ionization Rate in Protoplanetary Disks with Sheared Magnetic Fields

The magnetic fields in protoplanetary disk are stretched to the azimuthal directions due to the velocity shear. Thus, the cosmic rays entering into the disk need to detour while propagating to the midplane. However, most of the previous studies assume that cosmic rays travel to the midplane straightly from the vertical direction. We investigate the effects of magnetic-field configurations on the ionization rate by cosmic rays in protoplanetary disks. First, we consider cosmic-ray propagation from the interstellar medium (ISM) to the protoplanetary disks in the case that magnetic fields threading the protoplanetary disk are connected to its parent molecular cloud, and show that the cosmic-ray density around the disk should be 4

times lower than the isotropic ISM value. Then, we compute the attenuation of cosmic rays in protoplanetary disks. Our result show that the detouring effectively enhances the column density by about two orders of magnitude. We employ a typical ionization rate by cosmic rays in diffuse ISM, which is considered too high to be consistent with observations of protoplanetary disks, and find that the cosmic rays are significantly shielded at the midplane. In the case of the disk around IM Lup, the midplane ionization rate is very low for inner to ~100 au, while the value is as large as a diffuse ISM in the outer radii. Our results are consistent with the recent ALMA observation that indicates the radial gradient in the cosmic-ray ionization rate. The high ionization rate in the outer radii of disks may activate the magnetorotational instability that was thought to be suppressed due to ambipolar diffusion. These results will have a strong influence on the dynamical and chemical evolutions of protoplanetary disks.

Okuzumi, Satoshi / okuzumi@eps.sci.titech.ac.jp / Tokyo Institute of Technology

Thermal evolution of protoplanetary disks

Understanding how the thermal structure of protoplanetary disks evolves is essential for addressing the fundamental question of how and where planets of varying compositions form. Classical solar system formation theory assumed that the solar nebula's snow line resided at the current position of the asteroid belt. However, models of disk evolution show that the snow line's location is, in fact, highly uncertain and depends on the disk's heating and cooling processes. In this presentation, I will discuss our recent efforts to model the thermal evolution of protoplanetary disks, with a specific focus on MHD-induced Joule heating, planet-induced shock heating, and self-shadowing caused by dust pileups.

Lee, Yueh-Ning / ynlee@ntnu.edu.tw National / Taiwan Normal University

Non-ideal MHD and the size of early protoplanetary disks

Many mechanisms have been proposed to alleviate the magnetic catastrophe, that prevents the Keplerian disk from forming inside a collapsing magnetized core. Such propositions include inclined field and non-ideal magnetohydrodynamics effects, and have been supported with numerical experiments. Models have been proposed for typical disk sizes when a field threads the rotating disk, parallel to the rotation axis, while observations at the core scales do not seem to show any correlation between the directions of angular momentum and the magnetic field. In this talk, I will present a new model that considers vertical and horizontal fields and discuss their effects on the protoplanetary disk size.

Zhang, Shangjia / shangjia.zhang@unlv.edu / University of Nevada, Las Vegas

Vertical Shear Instability in Stellar-Irradiated Protoplanetary Disks

Vertical Shear Instability (VSI) is a promising candidate for the source of turbulence in protoplanetary disks. We use Athena++ radiation module to study VSI in full and transition disks, considering radiation transport and stellar irradiation. With stellar irradiation, the location of the inner rim is crucial for the disk thermal structure. The thermal structure has a strong impact on velocity components and turbulence levels. With a temperature gradient in the vertical direction, the typical n=1 corrugation mode disappears in realistic disk setups. The shear can be the strongest near the tau=1 surface for the star, which leads to a strong accretion. At several gas scale heights, radial-azimuthal turbulence stress is stronger than that in the vertically isothermal simulations, closer to the vertical-azimuthal stress (~1e-2). In the midplane, the stresses can be weak (~1e-4-1e-3). The weak turbulence in the midplane and the closer-to-isotropic turbulence levels are consistent with highly settled dust layers from dust continuum observations.

Hirano, Teruyuki / hd17156b@gmail.com / Astrobiology Center / National Astronomical Observatory of Japan

Exoplanet Detection and Characterization by the InfraRed Doppler (IRD) Instrument on Subaru

IRD is a fiber-fed near-infrared spectrograph covering 950-1730 nm with a spectral resolution of R~70000. It is designed to achieve an exceptional radial-velocity (RV) precision (1-2 m/s) in the near infrared for mid-to-late M dwarf stars, which are generally faint in the visible. With IRD, we have conducted 1) a blind Doppler survey for mid-to-late M dwarfs, 2) validations/confirmations of transiting-planet candidates identified by K2/TESS, and 3) orbital and atmospheric characterizations of transiting planets. In this talk, I will summarize the latest progress in these projects with an emphasis on the characterization of transiting planets. I will also present the future prospect of exoplanet observations by IRD.

Teng, Huanyu / hyteng@bao.ac.cn / National Astronomical Observatories, Chinese Academy of Sciences

The Progress of East Asian Planet Search Network

East Asian Planet Search Network (EAPS-Net) surveys late-G (including early-K) giant stars with precise radial velocities, aiming to search for planets around intermediate-mass stars in their evolved stages. The EAPS-Net began 20 years ago, with 48 exoplanetary systems discovered by telescopes in east Asia. In this presentation, we report the latest discoveries from the EAPS-Net and statistical information from planet survey around evolved stars.

Hu, Qingru / huqr20@mails.tsinghua.edu.cn / Tsinghua University

TOI-677 b: A spin-orbit aligned yet eccentric warm Jupiter in a dynamically hot system

With the development of high-resolution spectroscopic observations, the Rossiter-McLaughlin (RM) measurement for wide-orbiting warm Jupiters becomes feasible. The RM measurement can tell us the sky-projected angle between the stellar spin and the planet orbit norm, which encodes valuable information about angular momentum transfer of the system. From a combined fit of observations from the PFS/Magellan spectrograph and the ESPRESSO/VLT spectrograph, we derived a low sky-projected stellar obliquity of $\lambda\sim3.2\degree$ and a moderately high eccentricity of $e\sim0.460$ for TOI-677 b, making it part of an emerging puzzling class of wide-orbiting giant planets that exhibit large orbital eccentricities and yet low stellar obliquities. We suggest that TOI-677 b may have had its orbital eccentricity excited through either disk-planet interactions or ZLK oscillations with a mutually inclined companion.

Wu, Zexuan / wuzexuan@pku.edu.cn / Department of Astronomy, School of Physics, Peking University

Gaia22dkvLb: A Microlensing Planet Potentially Accessible to Radial-Velocity Characterization

Microlensing is sensitive to “cold” planets extended to a few AUs and provides complementary probes of unexplored parameter space for exoplanets. However, microlensing reveals little about planet dynamics and the system architecture, which are routinely recovered using Radial-Velocity (RV) techniques. The majority of microlensing planets are discovered in bulge field, where the host stars are typically low-mass stars located far away, thus challenging for RV follow-ups. Here we report the newly discovered microlensing planetary system Gaia22dkv. Our analysis yields a Jovian planet with a turn-off host at r'~14, and it is far brighter than any previously discovered microlensing planet host. With the exceptional brightness and the Jovian mass ratio, this system is potentially accessible to high-precision RV facilities, e.g., VLT ESPRESSO, enabling dynamic characterization of the microlensing planet. Additionally, RV data would allow for the search of inner planets of the cold jupiter, as suggested by the “inner-outer correlation” inferred from Kepler and RV discoveries.

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3D Global Simulations of Accretion onto Gap-opening Planets: Implications for Circumplanetary Disc Structures and Accretion Rates

We perform a series of 3D simulations to study the accretion of giant planet embedded in protoplanetary discs (PPDs) over gap-opening timescales. We find that the accretion mass flux mainly comes from the intermediate latitude above the disc midplane. The circumplanetary disc (CPD) for a super-thermal planet is rotation-supported up to $\sim$20-30\% of the planet Hill radius. While both mass inflow and outflow exists in the CPD midplane, overall trend is an outflow that forms a meridional circulation with high-latitude inflows. We confirm the absence of accretion outburst from disc eccentricity excited by massive planets in our 3D simulations, contrary to the consensus of previous 2D simulations. This suggests the necessity of 3D simulations of accretion even for super-Jupiters. The accretion rates of planets measured in steady-state can be decomposed into the ``geometric" and ``density depletion" factors. Through extensive parameter survey, we identify a power-law scaling for the geometric factor $\propto q_{\rm th}^{2/3}$ for super-thermal planets ($q_{\rm th}$ being the thermal mass ratio), which transforms to $\propto q_{\rm th}^{2}$ for less massive cases. The density depletion factor is limited by the disc accretion rate for mildly super-thermal planets, and by gap-opening for highly super-thermal ones.Moderate planetary eccentricities can enhance the accretion rates by a factor of $2-3$ through making the gap shallower, but does not impact the flow geometry. We have applied our simulations results to accreting protoplanet system PDS 70 and can satisfactorily explain the accretion rate and CPD size in observations.

Chen, Yixian / yc9993@princeton.edu / Princeton University

Twists and Turns in the Circumplanetary Flow Pattern

Extensive studies have shown that when a planet is embedded within a protoplanetary disk, the azimuthal flow in its close vicinity would be prograde, or in other words, aligned with the global orbital angular momentum. However, this is not trivial as the background Keplerian shear is effectively retrograde, and the tidal gravity field must significantly influence the flow to maintain its prograde nature. Using 3D global hydrodynamic simulations with adaptive mesh refinement, we show that when the planet eccentricity is large enough the circumplanetary flow becomes retrograde due to impact velocity relative to the background flow, affecting planetary spin evolution and satellite formation; Likewise, the presence of strong turbulence also introduces constantly fluctuating impact velocities, leading to the randomization of the circumplanetary flow pattern as well as migration torque in the Type I regime.

Aoyama, Yuhiko / yaoyama@pku.edu.cn / Peking University

Planet-disk interaction in windy disks

Young giant planets in protoplanetary disks (PPDs) can open disk gaps and drive planet migration, which are of key to understanding planet formation. However, planet-disk interaction has been nearly exclusively studied in the viscous disk framework, despite the emerging new paradigm that disk evolution is primarily driven by magnetized disk winds. We conduct 3D non-ideal magnetohydrodynamic (MHD) simulations of planet-disk interaction in the presence of MHD winds applicable to the outer disks. Our results show that the planet draws the magnetic flux into its orbit, enhancing the radial accretion flow within the planet-induced density gap. This faster accretion deepens the gap, disrupts the horseshoe turn flow, and alters the accretion pathway to the planet. Implications to planet migration, kinematic signatures, and circumplanetary disks will also be discussed.

Chen, Zhuo / chenzhuo_astro@tsinghua.edu.cn / Tsinghua University

Circumplanetary disks around gas giants

During the final stages of its formation, a gas giant will typically develop a circumplanetary disk (CPD) around the planet, which can accrete some of the surrounding material. Meanwhile, satellites can grow and evolve within the CPD. Currently, there are few observational constraints on the temperature, density, and state of CPDs. In the hope of uncovering the interior of the CPDs, we conduct axis-symmetric 2D radiation hydrodynamic simulations. Our simulations suggest that the CPD of a gas giant may have temperatures as high as 1400K, which can sublimate high-temperature-resistant dust such as silicates. In addition, the spin of the gas giant can affect the transfer of mass and angular momentum in CPD-gas giant interactions. In this report, I will show the process of gas giant accretion through CPDs and discuss the formation and evolution of gas giants and their satellites under more realistic conditions.

YU, Cong / yucong@mail.sysu.edu.cn / Sun Yat-sen University

Boundary Layers of Circumplanetary Disks with Azimuthal Magnetic Field around Spinning Planets

The accretion of material from disks onto weakly magnetized objects invariably involves its traverse through a material surface, known as the boundary layer (BL). Our prior studies have revealed that two distinct global wave modes for circumplanetary disks (CPDs) with BLs exhibit opposite behaviors in spin modulation. We perform a detailed analysis about the effect of magnetic fields on these global modes, highlighting how the magnetic resonances and turning points could complicate the wave dynamics. It is found that the angular momentum flux oscillates near the corotation resonance with increasing magnetic field strength. We also examine the perturbation profile to demonstrate the amplification of magnetic fields within the BL. The dependence of growth rates on the width of the BL, the Mach number, the magnetic field strength, and the spin rate are systematically investigated. We find that stronger magnetic fields tend to result in lower terminal spin rates. We stress the potential possibility of magnetized CPDs for the formation of primordial rings, moons, and angular momentum belts. The implications for the spin evolution and quasi-period oscillations observed in compact objects are also briefly discussed. Our calculations advance the comprehension of magnetohydrodynamical (MHD) accretion processes and lay a foundation for observational studies and numerical simulations.

Ormel, Chris / chrisormel@tsinghua.edu.cn / Tsinghua University

Origin of the TRAPPIST-1 planet system

The exoplanet system around the low-mass star (0.09 solar) TRAPPIST-1 is perhaps the most iconic example of a compact, multi-planet system. The planets are found at close distances from the star (but some at moderate irradiation levels) and are all in mean motion resonances. Modelling of transit timings variations and photometry have resulted in, for astronomical standards, unprecedented constraints on the planets masses, compositions, and their dynamical states. These constraints allow us to reconstruct how the system assembled. I will present numerical simulations that reproduce the physical and dynamical properties of the TRAPPIST planets. It is found that the latter is only possible in a formation context, that is, the present dynamical state of the TRAPPIST-1 system has been determined in its first few million years and seen little change thereafter.

Pan, Mengrui / panmr@zju.edu.cn / Zhejiang University (ZJU)

Planet formation around M dwarfs

The study of planets around stars with differing masses reveals significant variations in the types of planets and the architectures of planetary systems. To unravel the planet formation around low-mass stars and provide insights into the observed planetary populations, we perform N-body simulations to identify differences in the statistical distribution of synthetic planets in different models. We also explore the optimal disk conditions for giant planet formation in the framework of pebble-driven core accretion. Our research contributes to a better understanding of the diversity of planets and the configuration of planetary systems around M dwarfs, shedding light on the intricacies of planetary formation in such environments.

Ogihara, Masahiro / ogihara@sjtu.edu.cn / TDLI

Formation of diverse planetary systems from a ring in a disk with peaked gas density profile

It is known that the orbital characteristics of the terrestrial planets of the solar system can be well explained by considering a ring-like distribution of material at a distance of about 1 au from the star. Such localized material distribution can be achieved by dust concentration and local planetesimal/protoplanet formation in a protoplanetary disk with a density peak at about 1 au. In such peaked disks, inward migration of protoplanets can be avoided and the localized orbital distribution is maintained after type I migration. If such peaked disks are common, then the orbital distribution of low-mass planets in other exoplanet systems should also be explained by the same model. In this study, we perform N-body simulations of planet formation to investigate whether the orbital distributions of various planetary systems can be reproduced from a ring considering the peaked gas disk profile. Our simulation results show that the characteristics of the solar system terrestrial planets can be well reproduced. In addition, depending on the setting of the simulations, it is also possible to explain the origin of the orbital characteristics of super-Earths in close-in orbits in the same model.

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Chicken or Eggs? Formation of Planets from Pebble Rings

Rings are a prevalent feature observed in both protoplanetary and debris disks, hinting at an intrinsic connection between them. In the protoplanetary disk phase, these rings serve as accumulation sites for pebbles, fostering planetesimal formation and subsequent planet assembly. We investigate the viability of planet formation inside ALMA rings, where pebbles are trapped either by a Gaussian-shaped pressure bump or through strong dust backreaction. Planetesimals are assumed to form at the mid-plane of the ring via the streaming instability. Through N-body simulations, we explore the growth of these planetesimals via collisional mergers and pebble accretion. The concentrated pebbles and the reduced headwind within the ring enhance the efficiency of planetesimal growth by pebble accretion as soon as they are born, ultimately yielding the ring as an efficient planetary core factory. A broad and massive planetesimal belt is left at the planet-forming ring's location. Remarkably, the majority of directly imaged planets coexist with debris disks, exemplified by the four giants residing in HR 8799. The presence of a mean motion resonance chain and an ALMA-resolved debris ring beyond these four planets renders HR 8799 an ideal candidate for the application of our model. We will also present a dedicated model that the cores of these four giants originated within a planetesimal-forming pebble ring and evolved to their current state.

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Planetary Census Through Time and Space aided by LAMOST-Gaia-Kepler

Since the discovery of the first exoplanet (51 Peg b) orbiting a solar star in 1995, the study of exoplanets has been one of the most active frontiers. To date, over 5000 exoplanets have been discovered and thousands of candidates are yet to be confirmed. The map of known exoplanets has expanded significantly from the solar neighborhood (100-200 pc) to a much larger area (orders of 1000 pc) in the Galaxy thanks to the improvement of observational technology. We are therefore entering a new era of exoplanet census in the Milky Way Galaxy. In the Galactic context, one of fundamental questions in studying exoplanets is: what are the differences in the properties of planetary systems at different positions in the Galaxy with different ages? The answer to this question will provide insights on the formation and evolution of the ubiquitous and diverse exoplanets in different Galactic environments. In this presentation, I will introduce our recent work aiming to address this question, which has been aided by the LAMOST, Gaia and Kepler surveys.

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The evolution of hot Jupiters revealed by the age distribution of their host stars

The unexpected discovery of hot Jupiters challenged the classical theory of planet formation inspired by our solar system. Until now, the origin and evolution of hot Jupiters are still uncertain. Determining their age distribution and temporal evolution can provide more clues into the mechanism of their formation and subsequent evolution. Using a sample of giant planets around Sun-like stars collected from the kinematic catalogs of the Planets Across Space and Time (PAST) project, we find that hot Jupiters are preferentially hosted by relatively younger stars in the Galactic thin disk. We subsequently find that the frequency of hot Jupiters declines with age. In contrast, the frequency of warm/cold Jupiters shows no significant dependence on age. Such a trend is expected from the tidal evolution of hot Jupiters' orbits, and our result offers supporting evidence using a large sample. We also perform a joint analysis on the planet frequencies in the stellar age-metallicity plane. The result suggests that the frequencies of hot Jupiters and warm/cold Jupiters, after removing the age dependence are both correlated with stellar metallicities. Moreover, we show that the above correlations can explain the bulk of the discrepancy in hot Jupiter frequencies inferred from the transit and radial velocity (RV) surveys, given that RV targets tend to be more metal-rich and younger than transits.

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Deciphering Origins of Hot Jupiters through Stellar Obliquity Distribution

Recently, multiple lines of observational evidence suggest that high-eccentricity tidal migration is an inevitable pathway for forming hot Jupiters. However, the mechanism that excites the highly elliptical orbits of proto-Hot Jupiters remains unclear. Several candidate mechanisms have been proposed, including the von Zeipel-Lidov-Kozai effect, secular chaos, planet-planet scattering, among others. We leverage the stellar obliquity information of hot Jupiters to identify the dominant mechanism responsible for eccentricity excitation.

First, we demonstrate that the population-level stellar obliquity distribution can be inferred purely from projected obliquities, as measured by the Rossiter-McLaughlin effect, even in the absence of stellar inclination information. This is because the projected stellar obliquity provides a more significant constraint on the true stellar obliquity compared to stellar inclination. Next, we introduce a hierarchical Bayesian framework capable of inferring stellar obliquity at the population level. When applied to exoplanetary systems with RM-effect measurements, it reveals that misaligned systems are nearly isotropically distributed, with no pronounced clustering near 90 degrees. We find that the deviation from Albrecht+21 results stems from biases in their sample selection. Lastly, we interpret the stellar obliquity distribution to shed light on the origins of hot Jupiters. Our findings highlight planet-planet interactions as a significant mechanism in the formation of hot Jupiters.

Feng, Fabo / ffeng@sjtu.edu.cn / Tsung-Dao Lee Institute, Shanghai Jiao Tong University

A population of mutually inclined multi-planet systems

Our solar system is home to an intriguing population of multiple cold giants, which are gas giant planets characterized by their long orbital periods. Detecting these cold giants has proven to be a challenging task, given their extended orbits and elusive nature. However, recent advancements in high-precision astrometry, facilitated by Gaia's mission and the 24-year gap between the Hipparcos and Gaia missions, have enabled us to identify dozens of these systems with multiple giant planets. We have identified a subset of these systems with high mutual inclinations, indicating a dynamically hot history probably induced by planet-planet or planet-disk interactions. These findings raise questions about the uniqueness of our solar system, as it appears to possess an exceptional level of coplanarity when compared to these newly discovered, more dynamically active systems.

Ida, Shigeru / ida@elsi.jp / ELSI, Tokyo Tech

The origin of significant carbon depletion in the inner Solar system

Tamami Okamoto (1,2) & Shigeru Ida (1) / presented by Ida

1. ELSI, Tokyo Institute of Technology
2. Cote d’Azur Observatory

The Earth and asteroid parent bodies in the inner Solar System are depleted in carbon by a few orders of magnitude compared to the Sun and the ISM dust. This is a big puzzle, because observations suggest that a half of carbon materials in molecular clouds are in refractory forms such as amorphous hydrocarbon grains and complex organics, which can become building blocks of rocky bodies. We have investigated the carbon depletion processes through 3D Lagrangian simulation of dust particles in turbulent disks and found that two orders of magnitude carbon depletion robustly occurs inside the snow line if silicate dust grains ejected from icy pebbles at the snow line are much smaller than the icy pebbles due to the difference in the collisional fragmentation limit between silicate and ice, while the depletion by the variations of the refractory carbon carriers or temporal strong disk heating events such as FU Orionis bursts are uncertain.

Wang, Lile / lilew@pku.edu.cn / Peking University

Computational Microscopic Foundations of Planets and their Formation

Planets and their formation processes are complicated and require detailed treatments of various coupled microphysical mechanisms for convincing results of theoretical studies. We will discuss the methods of constructing the microscopic foundations for the studies of protoplanetary disks and planet atmospheres computationally, as well as their applications in connecting theories to observations directly.

Nomura, Hideko / hideko.nomura@nao.ac.jp / National Astronomical Observatory of Japan

Carbon Isotope Chemistry: From Protoplanetary Disks to Asteroid Ryugu

Origin of materials in our solar system is one of our ultimate questions. Thanks to recent ALMA observations with high sensitivity, some complex organic molecules as well as many rare isotopologues have been detected towards protoplanetary disks. Looking for chemical similarities/differences between pristine materials in our solar system and materials in protoplanetary disks is one of the possible approaches to tackle the question. In particular, the isotope ratios provide a powerful tool. Recent ALMA observations suggest bimodal fractionation of carbon isotopes in CO and HCN molecules; 12CO/13CO ratio shows a lower value (~20) while H12CN/H13CN does higher value (~ 86) inside ~100 au of the TW Hya disk, compared with the local interstellar value (~69), which could be caused by thermal isotope exchange reaction under a low temperature environment with C/O > 1 (Yoshida et al. 2022). Such bimodal fractionation can be transported in more complex molecules found in our solar system. I will discuss a possible connection to the materials in the Japanese Hayabusa 2 sample return mission exploring to the asteroid Ryugu.

Tatsuuma, Misako / misako.tatsuuma@gmail.com / RIKEN iTHEMS

Formation process of small solar system bodies and pebbles via self-gravitational compression of dust aggregates

Constraining the formation process of comets and asteroids in the solar system is crucial for understanding the size growth and porosity evolution of planetesimals. One widely accepted scenario for planetesimal formation is the pebble accretion scenario, but the formation process of pebbles from submicrometer-sized dust grains remains unknown. In this work, we investigate the formation process of comets, asteroids, and pebbles by calculating the internal density of planetesimals made from dust aggregates. We calculate the bulk density and diameter of dust aggregates by equating their compressive strength with their self-gravity and compare them with the observational and explorational results of asteroids, comets, and trans-Neptunian objects. As a result, we numerically obtain the relation between the bulk density and diameter depending on material parameters such as monomer radius, material density, and surface energy, and also succeed in deriving an analytical formula. By comparing our results with the bulk density and diameter of asteroids and comets and the porosity of observed pebbles, we find a unified formation scenario of planetesimals including pebbles. First, 0.1-μm-sized dust grains coagulate and grow into dust aggregates, and then the first-generation planetesimals composed of dust aggregates form. The first-generation planetesimals include Ryugu's parent body and possibly include comets' parent bodies. Second, the first-generation planetesimals fragment into pebbles, they coagulate and grow into pebble aggregates, and then the second-generation planetesimals composed of pebble aggregates form. The second-generation planetesimals can be comets.

Dong, Chuanfei / dcfy@bu.edu / Boston University

Atmospheric escape from M-dwarf exoplanets and implications for habitability

In the last two decades, the field of exoplanets has witnessed a tremendous creative surge. Research in exoplanets now encompasses a wide range of fields ranging from astrophysics to heliophysics and climate science. One of the primary objectives of studying exoplanets is to determine the criteria for habitability, and whether certain exoplanets meet these requirements. The classical definition of the Habitable Zone (HZ) is the region around a star where liquid water can exist on the planetary surface given sufficient atmospheric pressure. However, this definition largely ignores the impact of the stellar wind and stellar magnetic activity on the erosion of an exoplanet's atmosphere. Amongst the many factors that determine habitability, understanding the mechanisms of atmospheric loss is of paramount importance. We will discuss the impact of exoplanetary space weather on atmospheric loss and long-term climate evolution, which offers fresh insights concerning the habitability of exoplanets, especially those orbiting M-dwarfs, such as Proxima b, TOI-700 d, and the TRAPPIST-1 planets. We will address a wide range of planetary parameters, including atmospheric composition, magnetization, size, and obliquity. For each of these cases, we will demonstrate the importance of the exoplanetary space weather on atmospheric ion loss and habitability.

Liu, Pengyu / pengyu.liu@ed.ac.uk / University of Edinburgh, Leiden University

Direct imaging and atmosphere structures of giant exoplanets and brown dwarfs

Direct imaging is a promising technique to detect and characterise earth-like planets directly in the future. A dozen of exoplanets have been detected by direct imaging. Unlike the majority of exoplanets detected by radial velocity and transiting, they are wide-separation planets with a few Jupiter mass. In this talk, I will present recent direct imaging surveys and results. Then I will present a near-infrared variability survey of young planetary-mass objects. These free-floating objects are analogues to directly imaged planets but are easier to characterise. From L to T spectral types, brown dwarfs expierience drastic atmosphere changes, from clear to cloudy and to clear. Photometric monitoring of brown dwarfs show that variability is common in brown dwarfs. As young planetary-mass objects, they have a lower surface gravity than their field dwarf counterparts. Surface gravity plays an important role in the atmospheric structure of L- and T-type objects. We conduct continuous monitoring for 18 objects with spectral types from L5 to T8 and detect four new variables and two variable candidates. Combining with previous variability surveys of field and young L and T objects, we find that young objects tend to be more variable than field objects within peak-to-peak variability amplitude ranges of 0.5%–10% and period ranges of 1.5–20 hr. For the first time, we constrain the variability rate of young T dwarfs to be 56% compared to 25% for field T dwarfs. This work supports the critical role of surface gravity on the atmospheric structure from L to T spectral types. I will also discuss variability monitoring of directly imaged exoplanets in the end.

Guo, Jianheng / guojh@ynao.ac.cn / Yunnan Observatories, CAS

Characterizing regimes of hydrodynamic escape of low mass exoplanets by the upgraded Jeans parameter

Distinguishing between the driving mechanisms responsible for the hydrodynamic escape of hydrogen-rich atmospheres of low-mass, close-in exoplanets is complicated due to the involvement of many physical factors. Characterizing hydrodynamic escape using essential physical parameters can provide deep insights into the driving mechanisms and patterns of escape. My simulations show that the hydrodynamic escape can be driven by thermal energy deposited in the lower layers of the atmosphere due to the own core luminosity of the planet or bolometric heating from the star even in the absence of other energy sources, as long as the planet's Jeans parameter is below 3. If the Jeans parameter exceeds 3, three distinct regimes can be identified by introducing an upgraded Jeans parameter that takes into account tidal forces. When the upgraded Jeans parameter is less than 3 or greater than 6, the main driver of the atmospheric escape is tidal forces or XUV radiation of the host star, respectively. In the range of 3 to 6, both factors can trigger the escape of the atmosphere. Planets with high gravitational potential and low stellar irradiation are more likely to undergo subsonic escape, although transonic escape is common among most planets. Moreover, the ionization status is significantly dependent on both upgraded Jeans parameter and the gravitational potential. The calculation results are applied to fit the uncertain parameters of the energy-limited equation.

Huang, Chenliang / huangcl@shao.ac.cn / Shanghai Astronomical Observatory

A hydrodynamic study of the atmospheric escape of the hot Jupiter WASP-121b

The escape of the atmosphere plays a crucial role in planetary evolution. Recent advancements in high spectral resolution transmission spectrum observation have provided an exceptional opportunity to investigate the structure of exoplanet upper atmospheres and their escape processes. In this talk, I will introduce a sophisticated forward model by expanding the capability of a one-dimensional model of the upper atmosphere and hydrodynamic escape, to include important processes of atomic metal species.

Using this model, we can interpret the detected atomic features in the transmission spectrum of WASP-121b, which originate from material outside the planet's Roche lobe. By studying these atomic signatures, we can explore the impact of metals and excited hydrogen on the upper atmosphere, gain insights into the mechanisms of atmospheric escape, and emphasize the significance of the high mass-loss rate caused by Roche lobe overflow.

Posters, Disk & Planet Formation

Chung, Chia-Ying / sharon0311chung@gmail.com / ASIAA

Constraining dust masses and grain growth in Class II protoplanetary disks by the (sub)millimeter broadband Taurus-Auriga survey

We have performed a new SMA 200–400 GHz survey of 47 Class II sources in the Taurus-Auriga region. The improved precision tightens the constraints on the (sub)millimeter spectral indices. Intriguingly, we found that the observed spectral indices are mostly populated in an extremely narrow range of 2.1 ± 0.2; only a handful of spatially resolved (e.g., diameter >250 au) disks present larger spectral indices. Using population synthesis, we argue that the most probable interpretation for the observational results is that the (sub)millimeter luminosities are dominated by very optically thick (e.g., $\tau \gtrsim 10$) dust thermal emission. This immediately implies that the previous dust mass estimates, assuming optically thin, may be underestimated by at least one order of magnitude. The largely retained dust mass budget in the Class II disks may be the consequence that dust coagulation outside of the water snowline is still limited by the classical bouncing/fragmentation barrier. Indeed, our population synthesis indicates that the maximum grain sizes in our sample may be a few times smaller than 100 microns. These results may be essential to developing theories of planet formation.

Doi, Kiyoaki / doi.kiyoaki.astro@gmail.com / NAOJ

Constraints on the dust size distributions in the HD 163296 disk from wavelength-dependent spatial distribution of ALMA continuum images

Planet formation begins with dust coagulation in protoplanetary disks. Therefore, observational constraints on the dust size distribution in the disks can be a clue for understanding planet formation. While previous studies estimated the dust size from the spectral index derived from multi-wavelength observations or dust polarization observations, they still have large uncertainties. In this study, we present a new method to constrain the dust size distribution from the dust spatial distribution. High-resolution observations with ALMA revealed ring-like structures. These rings are thought to be formed by the dust trapping at gas pressure maxima. Since larger dust grains are trapped more effectively in the gas pressure bump, they form narrower rings. As a result, the dust rings appear narrower at longer wavelength observations since observations are sensitive to the dust grains whose size is comparable to the observed wavelength. Since the difference of the apparent ring widths on the observed wavelengths depends on the dust size distribution, we can constrain the dust size from the ratio of the dust ring widths between two wavelengths. We analyze high-resolution Band 4 (2.1 mm) and Band 6 (1.3 mm) images of the HD 163296 disk and find that the widths of the inner dust ring are similar between the two wavelengths, but the outer dust ring is 1.2 times narrower in Band 4 than in Band 6. Using simple dust ring models that assume size-dependent dust trapping, we derive constraints on the dust size distribution, such as maximum dust size and dust size power law. We constrain that 0.9 mm $< a_{max} <$ 5 mm and $p < 3.3$ in the inner ring, and $a_{max} > 3\times10^{1}$ mm and $3.4 < p < 3.7$ in the outer ring. The larger maximum dust size in the outer ring implies a spatial dependency in dust growth, potentially influencing the formation location of the planetesimals, and the exponent of the size distribution suggests that dust growth is inhibited by dust fragmentation.

Hu, Ying-Chi / yingchihu@asiaa.sinica.edu.tw / National Tsinghua University (NTHU)

Dust Grain Growth in Early Disk? A Multi-Wavelength study of the HH 212 Disk

The growth of dust grains during the initial stages of star formation is an important process in planet formation. However, various properties of dust particles in young protostellar disks, such as their composition, grain sizes, and porosity, remain uncertain. Recent studies of dust polarization detection in the Class 0 HH 212 disk in ALMA Band 7 (Lee et al. 2018a, 2021) have suggested the importance of self-scattering from growing dust grains. Here, we aim to investigate this possible grain growth by modeling the continuum maps of the disk obtained at multiple wavelengths, ranging from 0.85 (ALMA Band 7) to 9 mm (VLA Band Ka). We have derived the opacity and albedo of the dust in this disk. The low opacity index suggests the presence of mm/cm-sized grains, while the low albedos indicate grain sizes smaller than 100 μm. We propose a possible vertical grain size distribution to explain this contradiction. We note that the possibility of uniformly distributed porous dust grains cannot be ruled out.

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Radiative Transfer Model of Embedded Gravitational Unstable Disks

The previous observational studies may have systematically underestimated the dust and gas masses in the embedded and naked protoplanetary disks. The evolution of (embedded) protoplanetary disks may be regulated by gravitational instability instead of viscosity. To testify these possibilities, it is becoming important to seek observational signatures in the models of gravitationally unstable disks, which is relatively less explored at this moment as compared to the viscous disk models. We use the publicly available radiative transfer simulation code, RADMC-3D, to produce mock observations for the 1D parameterized model of gravitationally unstable disks published by Xu and Kunz (2021). The major assumptions in this model include marginal gravitational instability, vertical hydrostatic equilibrium, and local thermodynamic equilibrium (LTE). The advantage of the model we adopted is that it permits self-consistently constructing the 3D density and temperature distributions using a small number of free parameters. This poster makes a demonstration of our present achievement.

Kim, Seongjoong / kimseongjoong@mail.tsinghua.edu.cn / Tsinghua University

The application of 2D parametric disk model to multiple CO line data

The temperature and density structures of protoplanetary disks are fundamental components for understanding the planet formations and disk evolutions. Recent molecular line observations done by ALMA have opened a new window to examine the disk vertical structure with the estimation of line-emitting surfaces. In this study, we establish a comprehensive parametric disk model including temperature, density, and CO isotopic abundances. We do the fitting of model parameters with the Markov chain Monte-Carlo method by comparing the model image to the observed CO isotopologue lines (12CO, 13CO, and C18O lines) in the RU Lup disk. Although the model result is limited by the poor angular resolution, this case study provides another possible way to estimate the disk physical conditions from the observations.

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Vortex-induced rings and gaps in a protoplanetary disk

The co-existence of crescents and rings has been observed in protoplanetary disks in dust continuum emission. The crescents in continuum emission have been proposed to be the dust-trapping vortices generated by Rossby Wave Instability (RWI). We hypothesize that the RWI vortices could produce rings and gaps by driving density waves, analogous to planets. We study the properties of density waves and substructures induced by a vortex in 2D hydrodynamic simulations for both global disks and shearing boxes performed by Athena++. In this work, we aim to find rings and gaps induced by vortices in disks comparable to observations.

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Temperature structure of magnetized protoplanetary disks

Understanding the thermal structure of protoplanetary disks (PPDs) is crucial for elucidating the formation of rocky planets. We present 2D global radiative magnetohydrodynamic (MHD) simulations of the inner region of PPDs, taking into account all three non-ideal MHD effects, irradiation and Joule heating due to the global magnetic structure. The thermal structure consistent with the disk dynamics is calculated using a simplified radiative transfer method that is computationally efficient. Our simulations show that strong Joule heating occurs primarily in the strong current layer at the disk surface, where the global magnetic fields bend, which does not significantly heat the disk midplane. This is the case whether the poloidal magnetic field is aligned or anti-aligned. As a result, the temperature structure of PPDs, even at a few au, is mainly determined by irradiation heating. In addition, the structure of the irradiated surface is affected by the high-density disk wind, and the intensity of irradiation heating depends on the MHD disk wind structure. This suggests the need to construct a disk temperature model that takes into account the MHD behavior of the disk.

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Gravitational Instability of the Irradiated Protoplanetary Disk via Meshless Methods

Planet formation in young protoplanetary disks (PPDs) may proceed via the gravitational instability (GI) followed by disk fragmentation. While disk fragmentation requires relatively rapid radiative cooling, the subsequent evolution of these fragmented clumps remains enigmatic, primarily due to the lack of proper treatment of radiation transport. In this work, we successfully apply the two-moment radiation transport scheme with the M1 closure using the meshless finite mass (MFM) method in the Lagrangian code GIZMO and enable a second-order M1 radiation hydrodynamics scheme. We have extensively tested the code including the thermal equilibrium of PPDs under stellar irradiation in local and global settings, and will present preliminary results of our GI simulations.

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The evolution misaligned protoplanetary disks around binary star systems

The majority of stars born in dense stellar clusters are part of binary star systems. Circumbinary discs of gas and dust commonly surround binary star systems and are responsible for accreting material onto the binary. The gas flow dynamics from the circumbinary disc onto the binary components have significant implications for planet formation scenarios in binary systems. Misalignments between the circumbinary disc and the binary orbital plane are commonly observed. A misaligned circumbinary disc undergoes nodal precession. For a low initial inclination, the precession is around the binary angular momentum vector, while for a sufficiently high initial inclination, the precession is around the eccentricity vector. Dissipation causes the disc to evolve to align coplanar to the binary orbital plane or perpendicular (i.e., polar) to the binary orbital plane. I present 3-dimensional hydrodynamical simulations and linear theory on the evolution of highly misaligned circumbinary discs. I show that polar-aligned circumbinary discs are favorable environments for forming polar circumbinary (P-type) planets. Moreover, misaligned and polar circumbinary material flows around each binary component, forming misaligned and polar circumstellar discs. These circumstellar discs undergo long-lived Kozai-Lidov oscillations that may prompt the formation of giant circumstellar (S-type) planets in binary star systems. The evolution of protoplanetary discs in and around binary star systems bears important implications for planet formation.

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(1) Self-gravity Protoplanetary Disk with Cooling: Linear Perturbation Analysis

Self-gravity and thermodynamics are both important in protoplanetary disks. Their combined effects have been studied in many hydrodynamic simulations. We investigate the most unstable modes in disks with a wide range of star-mass ratios and dimensionless cooling timescales using linear perturbation analysis. We find that the dominance of the most unstable modes change from small-scale ones (those with high azimuthal wave number 'm') which are mostly suppressed when β is around 1, to large-scale ones (those with small azimuthal wave number 'm') which are mostly suppressed when β is larger than 1 as the disk-star mass ratio increases. Implications for disk evolution and planet formation will be discussed.

(2) Dynamical Consequence of Shadows Cast to the Outer Protoplanetary Disks

Many protoplanetary disks (PPD) show evidence of shadows in ourter disks observed in scattered lights that are cast from the disk inner region, while in the meantime present substructures of various kinds in the submillimeter. As stellar irradiation is the primary heating source for outer PPDs, the presence of such shadows thus suggest inhomogeneous heating of the outer disk in azimuth. We study the dynamical consequence of shadows cast to the outer protoplanetary disks as potential cause of disk substructure formation. We run idealized 2D disk simulations of the outer disk with azimuthally-varying cooling prescription. We find that shadows can potentially lead to the formation of a variety of types of substructure including rings, spirals and crecents, depending on the viscosity, cooling time, etc. Implications for disk observations and future perspectives will be discussed.

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Gas dynamics of innermost protoplanetary disk

The innermost region of protoplanetary disks (PPDs, <1AU) is characterized by the complex

interplay of various physical processes, including radiation transport, thermal and non-thermal ionization chemistry, and non-ideal magnetohydrodynamics (MHD). It is the region where most exoplanets have been discovered, yet its physics remains poorly understood. We have implemented radiation transport by M1 closure in the Athena++ MHD code. By conducting local shearing-box simulations at representative disk radii that fully incorporate the relevant microphysics, we present preliminary results indicating that the bulk disk can become magneto-rotational instability (MRI) active and "dead" dependent on the thermal history of disk evolution.

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A two-component dust model to model the vertical structure of protoplanetary disks

Protoplanetary disk contains a large amount of gas and dust. These disks host dust particles of varying sizes, ranging from micrometers to (sub-)millimeters. Particles will settle and diffuse in the disk under the effect of gravity and turbulent motion. At millimeter (mm) wavelength, dust emission is concentrated at the midplane, while at near-IR wavelengths, the disk becomes very extended. The simultaneous thinness at mm-wavelength, but the thickness of disks in near-IR/scattered light defies an explanation. In this study, we construct a two component model of small grains and large pebbles to simulate the vertical distribution of micrometer-sized dust grains and (sub-)mm-sized pebbles within a protoplanetary disk. We consider that two components will exchange mass due to collisions. In this model, in the region near the midplane, small grains population decreases because of sweep-up by pebbles, while in the upper regions, the small grains population increase due to high velocity erosive collisions.With this model we attempt to meet observation constraints from near-IR to sub mm-wavelength given by VLT/SPHERE and ALMA. By adjusting parameters such as particle sizes and turbulent properties, we attempt to match the two-component transport model with observational data.

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Ionization of the innermost protoplanetary disks

Ionization plays a critical role in the gas dynamics of protoplanetary disks (PPDs), which is further related with disk evolution and planet formation. While non-thermal ionization mechanisms, such as X-rays and cosmic rays, dominate the bulk regions of PPDs, the innermost regions (<0.1AU) are characterized by high temperatures (>1000K) with thermal ionization of alkali species, ion emission and thermionic emission from the dust. Such processes are expected to dramatically enhance the disk ionization fraction, leading to a revival of the magneto-rotational instability. To better understand the complex ionization processes in this region, we develop a comprehensive ionization chemical network that accounts for both non-thermal ionization and high-temperature effects. Using this model, we calculate the ionization fraction and the resulting magnetic diffusivities throughout the full range of physical conditions present in PPDs and discuss the implications on the gas dynamics of the innermost disk regions. Our findings provide a robust microphysical basis for future magnetohydrodynamical simulations.

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Observational signatures of dust clumping in protoplanetary disks

The prevalence of substructures in protoplanetary disks (PPDs) suggests dust trapping in such substructures, which is expected to further trigger dust clumping and potentially planetesimal formation. However, such clumping is expected to occur on spatial scales much smaller than the observational resolution, thus dust clumping is not directly detectable. We post-process non-ideal magnetohydrodynamic simulations of dust trapping and clumping under weakly MRI-turbulent dust rings with multi-species dust through radiative transfer calculations using the RADMC-3D code. We compare calculation results using simulation data versus a model without dust clumping. While the two results are morphologically similar, the spatial map of spectral indices holds promise to distinguish dust clumping from a smooth dust profile.

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The dusty Rossby wave instability (DRWI): linear analysis and simulations of turbulent dust-trapping rings in protoplanetary disks

Recent numerical simulations have revealed that dust clumping and planetesimal formation likely proceed in ring-like disc substructures, where dust gets trapped in weakly turbulent pressure maxima. The streaming instability has difficulty operating in such rings with external turbulence and no pressure gradient. To explore potential paths to planetesimal formation in this context,we analyse the stability of turbulent dust-trapping rings under the shearing sheet framework. We self-consistently establish the pressure maximum and the dust ring in equilibrium, the former via a balance of external forcing versus viscosity and the latter via dust drift versus turbulent diffusion. We find two types of >~H-scale instabilities (H being the pressure scale height), whichwe term the dusty Rossby wave instability (DRWI). Type I is generalised from the standard RWI, which is stationary at the pressure maximum and dominates in relatively sharp pressure bumps. Type II is a newly identified travelling mode that requires the presence of dust. It can operate in relatively mild bumps, including many that are stable to the standard RWI, and its growth rate is largely determined by the equilibrium gas and dust density gradients. We further conduct two-fluid simulations that verify the two types of the DRWI. While Type I leads strong to dust concentration into a large gas vortex similar to the standard RWI, the dust ring is preserved in Type II, and meanwhile exhibiting additional clumping within the ring. The DRWI suggests apromising path towards formation of planetesimals/planetary embryos and azimuthally asymmetric dust structure from turbulent dust-trapping rings.

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Disc evolution and planet formation under the impacts of stellar cluster environments

Most stars (and their protoplanetary discs) form in large stellar clusters with high stellar density, and there has been growing attention on how these dense cluster environments can influence disc evolution, planet formation and possibly the final planetary system. The “external” UV radiation field emitted by the massive stars in such clusters can affect protoplanetary discs via external photoevaporation, where UV radiation heats and disperses material from disc surfaces, depleting disc mass and truncate the disc radius. In a dynamically evolving stelar cluster, discs are exposed to time varying FUV radiation. Discs initially embedded in the cloud can be shielded for some time before stellar feedback processes disperse the cloud, exposing discs to strong FUV radiation. Recent studies shown shielding can protect discs from high mass loss rates at least for early stage disc evolution, but how this affect planet formation and diversity is still largely unknown. We have investigated how planet core formation via pebble accretion is affected by external photoevaporation, and how its effects can be mitigated by disc shielding time, and we also extend our investigations of these effects on forming multiple planetary systems.

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Effects of Thermodynamics On the Accretion of Gas Giants

The runaway process is a crucial stage in the formation of planets, as it is during this phase that the gas giants acquire majority of their masses. Accretion onto the planet is dependent on the circumplanetary disk(CPD) and is influenced by spiral density waves induced by planets whose intensity and structure are strongly impacted by the thermodynamics of the protoplanetary disk(PPD). We carry out a series of 2D and 3D simulations with FARGO3D and Athena++ to test the impact of thermodynamics in the runaway stage. Our research focuses on investigating the accretion rates, structures of CPDs and the mechanisms of accretion in different cooling time scales. This analysis aids in our understanding of the accretion process in CPD and the growth of gas giants.

Liu, Huigen / huigen@nju.edu.cn / Nanjing University

Title: Understanding the Planetary formation and evolution in Clusters

Abstract: Stars form in cluster environments, and the clusters can provide homogeneous and accurate parameters of cluster members, to investigate the correlation between planetary systems and hosts. In this talk, I will briefly introduce the UPiC program to explore the planet formation and evolution correlated with the open clusters and associations, via simulations and statistics based on Kepler-TESS-Gaia sample. The simulations reveal the stability of cold planets in OCs, as well as the disk lifetime in cluster environment due to external photoevaporation. Combining Kepler and Gaia data, we provide observational evidences of the influence on Kepler's planet occurrence rate due to dynamical history. We also collect a largest exoplanet catalogues in clusters and associations to do statistics, and constrain the mechanism of formation of HJs and Hot-Neptune desert.

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Exploring radius valley formation from collisions between super-Earths and planetary embryos using N-body simulations

From detailed analysis of observed exoplanets, low-mass planets have a bimodal size distribution, with peaks at about 1.3 and 2.4 Earth radii, and a valley at about 2 Earth radii. The origin of this radius valley can be explained by the dissipation of H/He atmospheres from super-Earths. Recent N-body simulations of super-Earth/sub-Neptune formation suggest that eccentric planetary embryos may remain after the dissipation of protoplanetary disks. When these embryos collide with super-Earths, impact erosion of the super-Earth’s atmosphere can occur. In this study, we investigate whether the origin of the radius gap can be explained by impact erosion due to collision between embryos and super-Earths. We perform N-body simulations to simulate the long-term orbital evolution of super-Earths and embryos, and analyze the size evolution due to impacts. We find that high-eccentricity embryos can collide with super-Earths, resulting in atmospheric dissipation and a decrease in the size of super-Earths. On the other hand, the presence of embryos can cause collisions between super-Earths, which can increase the size of super-Earths due to core growth. Whether the observed radius valley can be explained by this mechanism depends on the properties (e.g., distribution, number, eccentricity) of the remaining embryos after the disk dissipation.

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Planet formation from planetesimal rings

In the standard scenario of planet formation, it is assumed that planetesimals form throughout the protoplanetary disk and are smoothly distributed. Recently, however, a number of models have been proposed in which planetesimals form only at limited locations, such as gas pressure bumps, snow lines, and so on, and planetesimals are concentrated and distributed in a ring-like structure. Moreover, simulations have shown that the mass distribution of terrestrial planets in the solar system can be reproduced by arranging protoplanets in a narrow ring. In the observations, it is revealed that ring structures are universal in protoplanetary disks. These results support the existence of ring-like structures during planet formation. If planetesimals are distributed in a ring-like structure, the distribution of resulting protoplanets and planets would be different from ones in the standard scenario that assumes a smooth disk. However, the evolution of planetesimal rings has not been investigated in detail. In this study, we aim to illustrate the accretion process of ring-distributed planetesimals and the structure of the resulting planetary systems. We are performing a series of high-resolution N-body simulations and calculated the evolution of ring-distributed planetesimals. In the poster, we will report the results of our current calculations and discuss the evolution of planetary systems and the dependence of their structure on the initial distribution.

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Stellar outbursts and chondrite composition

The temperatures of observed protoplanetary disks are not sufficiently high to produce the accretion rate needed to form stars, nor are they sufficient to explain the volatile depletion patterns in CM, CO, and CV chondrites and terrestrial planets. We revisit the role that stellar outbursts, caused by high accretion episodes, play in resolving these two issues. These outbursts provide the necessary mass to form the star during the disk lifetime, and provide enough heat to vaporize planet-forming materials. We show that these outbursts can reproduce the observed chondrite abundances at distances near one AU. These outbursts would also affect the growth of calcium-aluminum-rich inclusions (CAIs) and the isotopic compositions of carbonaceous and non-carbonaceous chondrites.

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On the Dynamical History of Kepler-221 Planet System

Kepler-221 is a G-type star hosting four planets. In this planet system, planet b, c and e are in (or near) a 6:3:1 three-body resonance while the intermediate planet d is not part of the resonance chain. This configuration cannot naturally be explained by traditional migration theory. To reach this resonance configuration, we propose a scenario in which there were originally five planets in the system which started out in a chain of first-order resonances. After disk dispersal, the resonance chain became unstable and two planets quickly merged to become the current planet d. In addition, the b/c/e three-body resonance was re-established because of effective damping from stellar (obliquity) tides. We run N-body simulations using REBOUND to investigate the parameter space under which this scenario can operate. We find that the re-establishing of the 3-body resonance is the key step, which puts strong constraint on the mass of planets and their effective tidal Q parameters. In particular, we find that the planets in the system have a similar mass of around $9M_\oplus$, with tidal damping preferentially operating on planet c. Such methods can also be applied to other planet systems in resonance, such as K2-138.

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Wave propagation and transmission in a rotating polytropic spherical shell

Wave propagation can simultaneously transport momentum and energy, therefore it may have important effects on stellar or planetary interior structures and evolutions. It is quite common for a star or planet to have a multi-layer structure, and yet propagation and transmission of internal waves in these layers have not been fully explored. In this work, we study the wave propagation and transmission by solving the linearized equations of a compressible, self-gravitating, uniformly rotating polytropic spherical shell. We use a 2D pseudo-spectral method which allow us to calculate the adiabatic and inviscid oscillation modes. The influence of Coriolis force in the equation of motion is fully taken into account but the centrifugal force and rotation distortion of the equilibrium state is neglected for simplicity. We consider interior models with polytropic index n = 1.5 (convective), n = 2.5, 3, 4 (radiative), and n transiting from 4 to 1.5 at the RCB. We characterize the energy flux and kinetic energy of these waves and find that energy flux carried by high-frequency acoustic wave (p mode) but kinetic energy carried by low-frequency gravity wave (g mode), inertial wave (r mode) or mixed gravito-inertial wave (GIWs). It is also shown that rotation can facilitate wave propagation and enhance wave transmission.

Posters, Exoplanets

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The Eccentricity–Metallicity Trend for Small Planets Revealed by the LAMOST–Gaia–Kepler Sample

Orbital eccentricity is one of the basic planetary properties, whose distribution may shed light on the history of planet formation and evolution. Here, in a series of works on Planetary Orbit Eccentricity Trends (dubbed POET), we study the distribution of planetary eccentricities and their dependence on stellar/planetary properties. In the first work of the POET series, we investigate whether and how the eccentricities of small planets depend on stellar metallicities (e.g., [Fe/H]). Previous studies on giant planets have found a significant correlation between planetary eccentricities and their host metallicities. Nevertheless, whether such a correlation exists for small planets (e.g., super-Earths and sub-Neptunes) remains unclear. Here, benefiting from the large and homogeneous LAMOST–Gaia–Kepler sample, we characterize the eccentricity distributions of 244 (286) small planets in single (multiple) transiting systems with the TDR method. We confirm the eccentricity–metallicity trend whereby the eccentricities of single small planets increase with stellar metallicities. Interestingly, a similar trend between eccentricity and metallicity is also found in the radial velocity sample. We also found that the mutual inclination of multiple transiting systems increases with metallicity, which predicts a moderate eccentricity–metallicity rising trend. Our results of the correlation between eccentricity (inclination) and metallicity for small planets support the core accretion model for planet formation, and they could be footprints of self (and/or external) excitation processes during the history of planet formation and evolution.

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Understanding the Planetary Formation and Evolution in Star Clusters(UPiC)-I: Evidence of Hot Giant Exoplanets Formation Timescales

Planets in young star clusters could shed light on planet formation and evolution since star clusters can provide accurate age estimation. However, the number of transiting planets detected in clusters was only ~30, too small for statistical analysis. Thanks to the unprecedented high-precision astrometric data provided by Gaia DR2 and Gaia DR3, many new Open Clusters(OCs) and comoving groups have been identified. The UPiC project aims to find observational evidence and interpret how planets form and evolve in cluster environments. In this work, we cross-match the stellar catalogs of new OCs and comoving groups with confirmed planets and candidates. We carefully remove false positives and obtain the biggest catalog of planets in star clusters up to now, which consists of 73 confirmed planets and 84 planet candidates. After age validation, we obtain the radius--age diagram of these planets/candidates. We find an increment of the fraction of Hot Jupiters(HJs) around 100 Myr and attribute the increment to the flyby-induced high-e migration in star clusters. An additional small bump of the fraction of HJs after 1 Gyr is detected, which indicates the formation timescale of HJ around field stars is much larger than that in star clusters. Thus, stellar environments play important roles in the formation of HJs. The Hot-Neptune desert occurs around 100 Myr in our sample. Combining photoevaporation and high-e migration may sculpt the Hot-Neptune desert in clusters.

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Moist convective variability on mini-Neptunes with a 1D model

Hydrogen has a significantly smaller molecular weight than most condensable gases. This can lead to convective inhibition, in which the presence of a heavy condensable gas (like H2O vapor) suppresses convection inside a light H2-dominated atmosphere. Convective inhibition is believed to play an essential part in explaining the Great White Spots on Saturn and could similarly lead to variable convection phenomena on gas giants or mini-Neptunes with high amounts of condensables. However, the dynamics of convective inhibition are still poorly understood. Here we investigate the variability of moist convection in H2-H2O atmospheres with a 1D time-stepping model. We have developed a flexible moist convection code based on Ding & Pierrehumbert (2016). Even this very simple model shows cyclic variations in convection. By making some simplifications, we are able to categorize moist H2-atmospheres into several categories, including convective oscillations with different periods and possible multiple equilibria. We will discuss how these vertical and temporal characteristics are affected by parameters such as incoming solar radiation, total optical thickness, surface pressure, etc.

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OGLE-2015-BLG-0845: A Bulge M dwarf From Combination of Xallarap and Parallax Effect

We report a precise determination of both the mass and distance of the single-lens microlensing event OGLE-2015-BLG-0845, achieved through a combined analysis modeling both xallarap and parallax effects. Our analysis indicates that the lensing object is likely an M-dwarf situated in the Galactic Bulge. The measured mass of the lens is 0.13 +- 0.05 M_sun, and its distance is 7.4 +/- 1.0 kpc. We demonstrate that the xallarap effect serves to effectively break the inherent mass-distance degeneracy commonly encountered in microlensing events, together with the parallax effect. Furthermore, we estimate that approximately 4% of such microlensing events present the xallarap effect amenable to characterization through future joint observations employing both radial velocity techniques and continued microlensing studies.

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A fast cloud model for exoplanet atmosphere retrieval

Exoplanet atmosphere has been investigated by a number of ground-based and space-based telescopes. With the launch of JWST, we are embracing an era of precise measurement of exoplanet atmosphere’s transition and emission spectrum. The potential presence of cloud poses major uncertainty to the retrieval of atmosphere properties, as it can smooth out the spectral features. We proposed a new cloud model to be used in the retrieval of exoplanet. The model follows the transport of cloud particles, composed of various condensates, the condensation of which is calculated from supersaturation ratio. A relaxation

method is utilized to find a steady state solution with computational speed fast enough to be used in atmospheric retrieval. Our model is robust again a wide range of parameters, flexible to be used in different kinds of planets and versatile to include a variety of cloud species.

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Radial Velocity Precision of CHORUS with Different Pupil Slicing Designs

Precise radial velocity (RV) surveys are trying to find Earth 2.0 in the next decade, which requires extremely high resolution spectrographs. We carry out simulations to compare two instrumental designs of CHORUS. The Canarian Hybrid Optical high-Resolution Ultra-stable Spectrograph, which will be installed on the Gran Telescopio de Canarias in 2027. CHORUS is under construction by NAOC and NIAOT in China, and it is expected to reach a RV precision of lower than 10cm/s in visible band. The two different designs differ primarily in the number of pupil slicing (3 vs. 2) and spectral resolution (120,000 vs. 90,000). We found that the RV precision obtained under the 3-slice setting is better than the 2-slice setting, as expected, and the 3-slice setup would reach the instrument target of 10 cm/s precision at a more reasonable SNR. We used Kurucz's solar template to synthesize observational spectra with input Doppler shift and various SNRs. Then we extracted RVs using the cross-correlation method. We will carry out further simulations to test other aspects in the instrumental designs of CHORUS, and our work could help assessing the photon-limited RV precision and performances of other similar instruments.

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Adaptive Parallel Tempering Markov Chain Monte Carlo with Nii-C

This talk introduces an adaptive parallel tempering Markov Chain Monte Carlo (APT-MCMC) code Nii-C that enables rapid convergence in the sampling of complex distributions. The Nii-C code has two outstanding features. First, an efficient control system is implemented that can adaptively adjust the step sizes of the proposal distributions for all model parameters across all parallel tempering chains. This can ensure that the real-time sampling acceptance rates are within an ideal range. Second, it is a pure C language implementation using the Message-Passing Interface (MPI) protocol, which guarantees its fast execution speed. To facilitate the adaptation of the Nii-C code to different posterior distributions faced by various Bayesian analysis models, the user-defined prior and likelihood functions were designed to be as independent as possible and isolated into two separate source files. Tracking of the samplers in a linear regression model and a hierarchical statistical model demonstrates the advantages of Nii-C in terms of speed and convergence capability.

Lee, Sanghee / lee.s.ay@m.titech.ac.jp / Tokyo Institute of Technology

Magnetic activity variability of Sun-like stars by intensive H alpha line monitoring

We report intensive monitoring of the activity variability in the H alpha line for 13 Sun-like stars using the 1.88-m reflector at Okayama Branch Office, Subaru Telescope, during the last four years 2019-2022. Our aim was to investigate features of the stellar magnetic activity behaviors from various aspects, including activity cycles, amplitudes of activity variability, and exoplanet detection. We correlated the H alpha line variability of each star with the stellar activity levels derived from the Ca II H&K line, suggesting its efficiency as a magnetic activity indicator. Each target star exhibited distinct magnetic activity, suggesting the possibility of short-term activity cycles in F-type stars and temporal absence/existence of the cycle period. With respect to the stars with a hot Jupiter, we could not find any signature of the star-planet magnetic interaction. It is speculated that the magnetic activity variability in the H alpha observation is related to the stellar intrinsic activity rather than the existence of the hot

Jupiter. We also found the range of the amplitudes of the H alpha variability that may or may not induce a stellar noise to the RV with the precision of few m/s.

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Radio Astronomy of Exoplanets

Radio observations provide a unique avenue to surpass the limitations of optical observations, allowing us to probe the magnetic fields of planets. This report delves into the application of radio astronomy in unveiling the characteristics of exoplanets. We introduce how the radio data is employed to investigate exoplanets. We also discuss ongoing radio observation projects and look forward to the future, where radio observations hold promise in providing valuable data for a deeper understanding of exoplanets and their potential habitable conditions.

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PFS Radial Velocity Survey on Long-period Giant Planets

Understanding cold Jupiters, a population similar to our own Jupiter, is important for studying exoplanet demographics or planet formation. Long-term radial velocity (RV) surveys provide powerful constraints on the occurrence and properties of cold Jupiters. Here we present the initial results from a long-term high-precision RV survey of 468 stars using the Magellan Planet Finder Spectrograph (PFS). We report our sample selection criteria, planet-searching algorithm, the resulting catalog containing confirmed or newly identified exoplanets and substellar companions, and the search completeness of each system. Our data contain around 17000 RV measurements with a median baseline of 12 years. Our survey result stands as an independent, homogeneous dataset, with a relatively low selection bias. This distinctive dataset represents an invaluable resource for diverse statistical investigations. In our following papers, we will delve deeper into the occurrence rate and property distributions of giant planets. These findings will provide reassuring independent and/or new evidence for giant planet formation in tandem with findings from other similar RV surveys.

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Introduction to the SOlar Terrestrial Habitability Explorer (SOTHE)

Among more than 5000 exoplanets discovered up to now, around 60 are believed to be potentially habitable. The Sun-Earth system provides a unique example based on which detailed insights into the properties, formation, evolution, and thus habitability of exoplanets could be gained. However, simultaneously observing the Sun as a star and the Earth as an exoplanet has been rare. In this talk, I will briefly introduce the SOlar Terrestrial Habitability Explorer (SOTHE) to be deployed to the Sun-Earth L1 point. SOTHE will carry 5 payloads to obtain the spectra of the Sun and the Earth at the same time, together with images of the Earth at a number of unique passbands and the local plasma and magnetic field parameters at the L1 point. The core scientific goal of SOTHE is to conduct the first-ever simultaneous spectral observations of the Sun and Earth to explore key characteristics related to the habitability of the Sun-Earth system and provide a unique baseline for habitable exoplanets exploration.

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Convection and Clouds under Different Planetary Gravities

In this study, we employ a cloud-resolving model to investigate how gravity influences convection and clouds in a small-domain (96 × 96 km) radiative–convective equilibrium. Our experiments are performed with a horizontal grid spacing of 1 km, which can resolve large (>1km2) convective cells. We find that under a given stellar flux, sea surface temperature increases with decreasing gravity. This is because a lower-gravity planet has larger water vapor content and more clouds, resulting in a larger clear-sky greenhouse effect and a stronger cloud warming effect in the small domain. By increasing stellar flux under different gravity values, we find that the convection shifts from a quasi-steady state to an oscillatory state. In the oscillatory state, there are convection cycles with a period of several days, comprised of a short wet phase with intense surface precipitation and a dry phase with no surface precipitation. When convection shifts to the oscillatory state, the water vapor content and high-level cloud fraction increase substantially, resulting in rapid warming. After the transition to the oscillatory state, the cloud net positive radiative effect decreases with increasing stellar flux, which indicates a stabilizing climate effect. In the quasi-steady state, the atmospheric absorption features of CO2 are more detectable on lower-gravity planets because of their larger atmospheric heights. While in the oscillatory state, the high-level clouds mute almost all of the absorption features, making the atmospheric components hard to characterize.

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The Feasibility Analysis of Constraining the Shape of a Jupiter Analog with JWST Transit

The shape of a planet can provide massive clues about itself and its system, including the spinning, interior structure, and even its evolutionary history. An oblate planet can cause the transit light curve asymmetric and distortions in the ingress and egress, which is detectable with JWST observation accuracy. We perform oblateness signal injection and recovery in the case of a Jupiter analog, Kepler-167e. We simulate the light curve of a Kepler-167e-like planet with a certain oblateness, with the photometric noise of JWST/NIRSpec and the stellar red noise corresponding to a Kepler-167-like star. The fitting results of light curves in different oblateness show that we can significantly detect the oblateness of a planet in a condition of the Angle between the planet's axis of rotation and the plane of revolution greater than 20 degrees. This enables us to characterize exoplanets more comprehensively.

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Asymmetry and Variability in the Transmission Spectra of Tidally Locked Habitable Planets

Spatial heterogeneity and temporal variability are general features in planetary weather and climate, due to the effects of planetary rotation, uneven stellar flux distribution, fluid motion instability, etc. In this study, we investigate the asymmetry and variability in the transmission spectra of 1:1 spin–orbit tidally locked (or called synchronously rotating) planets around low-mass stars. We find that for rapidly rotating planets, the transit atmospheric thickness of the evening terminator (east of the substellar region) is significantly larger than that of the morning terminator (west of the substellar region). The asymmetry is mainly related to the spatial heterogeneity in ice clouds, as the contributions of liquid clouds and water vapor are smaller. The underlying mechanism is that there are always more ice clouds on the evening terminator, due to the combined effect of coupled Rossby–Kelvin waves and equatorial superrotation that advect vapor and clouds to the east, especially at high levels of the atmosphere. For slowly rotating planets, the asymmetry reverses (the morning terminator has a larger transmission depth than the evening terminator), but the magnitude is small or even negligible. For both rapidly and slowly rotating planets, there is strong variability in the transmission spectra. The asymmetry signal is nearly impossible to be observed by the James Webb Space Telescope (JWST), because the magnitude of the asymmetry (about 10 ppm) is smaller than the instrumental noise and the high variability further increases the challenge.

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RVxTESS I: Modeling Asteroseismic Signals with Simultaneous Photometry and RVs

The Radial Velocity (RV) method, measuring the Doppler Shifts from stellar spectra, is widely used for the detection and characterization of exoplanets. For low-mass planets, RV detection typically requires cm/s precision, whereas the stellar jitter becomes an issue at the m/s level. Thus, it is essential to mitigate such stellar jitter in order to detect Earth-like planets using RVs. Our project focuses on the asteroseismic signals of stellar jitter, including stellar oscillation and granulation. We study HD 5562 with fitting the model of stellar jitter to the observational data from the Transiting Exoplanet Survey Satellite (TESS) and RVs from the Carnegie Planet Finder Spectrograph on the Magellan II Telescope (Magellan/PFS). We perform a Gaussian Process (GP) regression on the star's photometric and RV data to describe its asteroseismic signals. The simultaneous fit model suggests that the primary mode of its oscillation is around 15 minutes or around 1000 muHz. We have reduced the RV scatter from 2.03 m/s to 0.50 m/s by fitting a GP model, which was trained on the TESS light curves, to the RV time series. We also explore multiple ways to model the oscillation in the photometry and how it could be transferred effectively to the RV domain. In addition, we seek to extend the method to test the detectability of Super-Earths around evolved stars. Our project is part of the RVxTESS program (RVxTESS.com), which combines simultaneous TESS photometry with ground-based RV observations to study stellar jitter.

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Modeling the H-alpha and He 10830 transmission spectra of a hot Jupiter

In this talk, I will show our work of modeling of H-alpha and He 10830 transmission spectrum of a hot Jupiter. The work helps to constrain the stellar XUV and Ly-alpha flux, H/He ratio and mass loss rate of the exoplanetary atmosphere, and provides clues to the escaping atmosphere of hydrogen and helium. To do this, we use the XUV driven hydrodynamic simulation to obtain the atmospheric structures, solve the rate equations of non-local thermal equilibrium related to hydrogen and helium to calculate the detailed level population, and then conduct the radiative transfer simulation to model the transmission spectrum of H-alpha and He 10830. The Monte Carlo simulations of Ly-alpha radiative transfer are performed to calculate the Ly-alpha mean intensity distribution inside the planetary atmosphere, necessary in estimating the hydrogen level population.

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Planets Across Space and Time (PAST) IV: The Occurrence and Architecture of Kepler Planetary Systems as a Function of Kinematic Age Revealed by the LAMOST-Gaia-Kepler Sample

One of the fundamental questions in astronomy is how planetary systems form and evolve. Measuring the planetary occurrence and architecture as a function of time directly addresses this question. In the fourth paper of the Planets Across Space and Time (PAST) series, we investigate the occurrence and architecture of Kepler planetary systems as a function of kinematic age by using the LAMOST-Gaia-Kepler sample. To isolate the age effect, other stellar properties (e.g., metallicity) have been controlled. We found the following results. (1) The fraction of stars with Kepler-like planets (Fkep) is about 50% for all stars; no significant trend is found between Fkep and age. (2) The average planet multiplicity (Np) exhibits a decreasing trend (~2σ significance) with age, which decreases from ~3 for stars younger than 1 Gyr to Np~1.8 for stars about 8 Gyr. (3) The number of planets per star (η=Fkep*Np)

also shows a decreasing trend (~2-3σ significance), which decreases from η~1.6-1.7 for young stars to η~1.0 for old stars. (4) The mutual orbital inclination of the planets ($\sigma_{i,k}$) increases from 1.2(+1.4,-0.5) to 3.5(+8.1,-2.3) as stars aging from 0.5 to 8 Gyr with a best fit of $\log(\sigma_{i,k})=0.2+0.4*\log(Age/1Gyr)$, and interestingly, the Solar System also fits such a trend. The nearly independence of Fkep~50% on age implies that planet formation is robust and stable across the Galaxy history. The age dependence of Np and $\sigma_{i,k}$ demonstrates planetary architecture is evolving, and planetary systems generally become dynamically hotter with fewer planets as they age.

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Novel Atmospheric Dynamics Shape Habitable Zone Inner Edge Around White Dwarfs

White dwarf stars offer a unique opportunity to search nearby stellar systems for biosignatures. Due to white dwarfs' small size, planets orbiting these stars are much easier to characterize via transmission spectra than planets orbiting main sequence stars. The potential habitability of white dwarf planets, however, is still poorly understood. Here we use the ExoCAM, a 3D global climate model (GCM), to investigate the inner edge of the habitable zone (HZ) around white dwarfs. Since white dwarfs are low-luminosity and compact, habitable planets orbiting them are most probably tidally locked and rapidly rotating with orbital periods ranging from hours to days. We find that the runaway greenhouse limit for white dwarfs lies in-between that for rapidly rotating non-tidally locked planets and slowly rotating tidally locked planets reported in previous research. The upper atmospheres of white dwarf planets are also much drier than for main sequence stars, which means most white dwarf planets never experience a moist greenhouse state. We explain these features as resulting from a novel atmospheric dynamical regime. When tidally locked planets rotate rapidly (orbital period ~< 1 day), the hottest point on the planetary surface shifts from the equator to the subtropics which leads to the formation of anti-Hadley Cells on the planet's dayside and strongly modifies the dayside cloud cover. The inner edge of the habitable zone around white dwarfs is therefore strongly affected by planetary rotation, the dynamics of which cannot be resolved in 1D models.