Pebbles in Planet Formation
Abstract Book

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Format:

ID / schedule (K: Keynote talk, C: Contributed talk, P: Poster)
Name
Affiliation
Title
Abstract

Oral Presentation

Day 1 (Feb. 10)

K1 / 9:30-10:15
Misako Tatsuuma
RIKEN
From Dust to Planetesimals: A Theoretical Review of Dust Aggregation and Pebble Formation in Planet Formation
In this talk, I will review the growth theory of solid bodies from sub-micrometer-sized dust grains to kilometer-sized planetesimals, including pebbles, based on simulations of dust aggregates. Pebbles are a central theme of this workshop, and there are inconsistencies within the current theories of pebble formation and dust aggregation. To address challenges in dust aggregation theory, I will discuss how dust grains undergo growth, fragmentation, bouncing, and structural evolution to ultimately form planetesimals. I will also connect theoretical perspectives on dust aggregation with insights from observations of protoplanetary disks, explorations of small solar system bodies, laboratory dust experiments, and streaming instability, which contribute the formation of planetesimals.

C1 / 10:15-10:30
Yukun Huang
CfCA, NAOJ
From Planetesimals to Dwarf Planets by Pebble Accretion
The size distribution of trans-Neptunian objects (TNOs) in the Kuiper Belt provides crucial insights into the formation and evolution of the outer Solar System. Recent observational surveys, including OSSOS++, have revealed that dynamically cold and hot TNO populations exhibit similar size distributions for dimmer objects (Hr > 5), which are consistent with planetesimal formation by streaming instability. However, the hot population contains a significantly larger number of massive bodies, including several dwarf planets. In this study, we investigate the role of pebble accretion in shaping the size distribution of hot TNOs, after their formation in the primordial disk between 20 and 30 au and before these bodies were dynamically implanted into their current orbits by a migrating Neptune. We find that pebble accretion grows the most massive bodies only, consistent with the flattening of the distribution brightwards of Hr = 5. All results point to a correlation (degeneracy) between the pebble aerodynamical size and the intensity of the gas motions. Nevertheless, we find that accretion from an inward-drifting stream of pebbles is unlikely, as it puts extreme demands on the mass budget of pebbles. Accretion in an environment where pebbles are entrained, as believed to be the case in ALMA rings, is preferable and we can accordingly constrain the conditions during this primordial accretion phase.

C2 / 10:30-10:45
Wladimir Lyra
New Mexico State University
Polydisperse Pebble Accretion: Doing away with planetesimal accretion
Pebble accretion is recognized as a significant accelerator of planet formation. Yet only formulae for single-sized (monodisperse) distribution have been derived in the literature. These can lead to significant underestimates for Bondi accretion, for which the best accreted

pebble size may not be the one that dominates the mass distribution. In this talk I will go through the theory of polydisperse theory of pebble accretion, considering a power-law distribution in pebble radius, and showing analytical solutions to the polydisperse 2D Hill and 3D Bondi limits. In the Bondi limit of low masses, we find accretion rates 1-2 orders of magnitude higher compared to monodisperse, also extending the onset of pebble accretion to 1-2 orders of magnitude lower in mass. We find megayear timescales, within the disk lifetime, for Bondi accretion on top of planetary seeds of masses 1e-6 to 1e-4 Earth masses, over a significant range of the parameter space. This mass range overlaps with the high-mass end of the planetesimal initial mass function, and thus pebble accretion is possible directly following formation by streaming instability. This result removes the need for mutual planetesimal collisions as a major contribution to planetary growth.

C3 / 10:45-11:00

Mengrui Pan
Rice University

Dependence of Planet populations on Stellar Mass and Metallicity: A Pebble Accretion-based Planet Population Synthesis

The formation and evolution of planet systems are linked to their host stellar environment. In this study, we employ a pebble accretion-based planet population synthesis model to explore the correlation between planets and stellar mass/metallicity. Our numerical results reproduce several main aspects of exoplanetary observations. Firstly, we find that the occurrence rate of super-Earths $\eta_{\rm SE}$ follows an inverted V-shape in relation to stellar mass: it increases with stellar mass among lower-mass dwarfs, peaks at early-M dwarfs, and subsequently declines toward higher-mass GK stars. Secondly, super-Earths grow ubiquitously around stars with various metallicities, exhibiting a flat or weak $\eta_{\rm SE}$ dependency on $Z_{\star}$. Thirdly, giant planets, in contrast, form more frequently around stars with higher-mass/metallicity. Lastly, we extend a subset of simulations to 10^3 Myr to investigate the long-term evolution of the systems' architecture. After converting our simulated systems into synthetic observations, we find that the eccentricities and inclinations of single-transit systems increase with stellar metallicity, whereas these dependencies in multi-planet systems remains relatively weak. Our results align well with observations, providing a comprehensive understanding of the relationship between planet populations and stellar characteristics.

C4 / 11:15-11:30

Linn Eriksson
Stony Brook University

Particle fragmentation inside planet-induced spiral waves

Growing planets launch spiral waves in the protoplanetary disk. In a recently submitted paper, we have studied how planet-induced spiral waves affect the motion and collisional evolution of particles in the disk. We found that particle trajectories bend at the location of the spiral wave, and collisions occurring within the spiral exhibit significantly enhanced collisional velocities compared to elsewhere. To quantify this effect, we ran simulations with varying planetary masses and particle sizes. The resulting collisional velocities within the spiral far exceed the typical fragmentation threshold, even for collisions between particles of relatively similar sizes and for planetary masses below the pebble isolation mass. If collisions within the spiral are frequent, this effect could lead to progressively smaller particle sizes as the radial distance from the planet decreases, impacting processes such as gap filtering, pebble accretion, and planetesimal formation.

C5 / 11:30-11:45

Haruto Oshiro
Institute of Science Tokyo

Investigation of the Bouncing Barrier with Collision Simulations of Compressed Dust Aggregates

Coagulation of dust grains is the first step of planet formation in protoplanetary disks. Recent millimeter-wave polarimetric observations suggest the existence of relatively compact dust aggregates (Zhang et al. 2023). Compact dust aggregates not only stick or fragment upon collision but also bounce (Güttler et al. 2010). Some previous simulations have been shown that bouncing has a significant effect on dust growth in protoplanetary disks (Zsom et al. 2010). However, the conditions for bouncing are not well understood. Previous experiments have shown that larger dust aggregates are more likely to bounce at lower velocities (Kothe et al. 2013), On the other hand previous simulations of dust collisions have shown that larger aggregates are more likely to bounce, but do not show a significant velocity dependence (Arakawa et al. 2023). One possible explanation for this discrepancy is that the aggregates used in the experiments and simulations had significantly different internal structures. To test this hypothesis, we performed collision simulations with compressed dust aggregates for various impact velocities, aggregate sizes, and aggregate filling factors. We use compressed BCCA spheres, which are produced through the static compression of fluffy aggregates known as ballistic cluster-cluster aggregates (BCCAs). Dust aggregates consist of icy particles treated as adhesive elastic spheres, and we solve the equations of motion for all constituent particles (Wada et al. 2007). As a result, we confirm that for compressed BCCA aggregates, the mass threshold for bouncing depends on impact velocity for all calculated filling factors. This dependence is in agreement with the experimental results when the impact velocity is less than about 10 m/s. On the other hand, the threshold mass required for bouncing depends strongly on the filling factor. We conjecture that this strong dependence is due to the difference in the static compressive strength of dust aggregates.

C6 / 11:45-12:00

Sin-iti Sirono
Nagoya University

Thermal evolution of icy dust aggregates through the growth of ice particles

The main component of dust aggregates is ice at large distances from the central star. Because ice is a volatile material, it diffuses and sublimates when the temperature is sufficiently high. I will summarize the thermal evolution of icy dust aggregates through the growth of ice particles due to diffusion and sublimation of H_2O ice. A heating event, including FU Orionis outburst, likely happens in a protoplanetary disk. The temperature rises during an event and can cause sublimation of H_2O ice. After the heating event, temperature declines, and H_2O vapor recondenses again to form ice particles. The size of the particles larger than the commonly assumed value of 0.1 microns (Sirono and Furuta 2024). The icy aggregate reformed from the grown particles has a lower mechanical strength than an aggregate of 0.1 micron-sized particles. Then, the collisional growth of the aggregate stops before the planetesimal formation. Sintering can proceed through diffusion even if the temperature is not high enough to sublimate H_2O ice. Because the diffusion constant of low-density amorphous ice is large (Ghesquière et al. 2015), sintering induces the growth of ice particles

by self-diffusion of H_2O molecules. The typical size of the particle after one Keplarian time sintering is 10 microns (Sirono 2025a). The growth of the particle significantly reduces the mechanical strength of the icy aggregates composed of the grown particles. Therefore, it is highly likely that the size of the ice particles is larger than 0.1 micron. It cannot grow to the size of a planetesimal, and growth stops when it reaches the size of a pebble.

K2 / 13:30-14:15

Carsten Güttler
University of Münster

Implications of Rosetta observations on pebble formation

The ESA Rosetta spacecraft visited comet 67P/Churyumov-Gerasimenko between 2014 and 2016. Orbiting the comet at a close distance, eleven instruments studied different aspects of comet 67P and the lander Philae studied the surface from close by in November 2014. Comets are the possibly most pristine objects in the solar system, which provides a chance to learn about comet formation from Rosetta. Several macroscopic parameters measured by Rosetta provide constraints on 67P's formation. Among these are the low bulk density, density homogeneity, very low tensile strength, or the observation of global layering. On a microscopic level the dust in the coma was studied by many of Rosetta's instrument from a level of sub-micrometre topology to light-microscopic imagery, atomic ratios, and its size distribution and global dynamics in the coma. Dust morphology gives hints on the growth processes, which still need to be unravelled. The keynote talk will provide a broad summary of the Rosetta mission and its results, with a strong focus on the cometary dust, potentially the descendants of pebbles in the early protoplanetary disk.

K3 / 14:15-15:00

Ryota Fukai
JAXA

Curation of Ryugu and Bennu samples

The study compares asteroid Bennu and Ryugu samples to understand the origin and evolution of the small bodies in the Solar System. Both asteroids share similar origins based on isotopic, elemental, and mineralogical data. Bennu samples allocated to JAXA and processed in clean chambers underwent spectroscopy and mineralogical analyses. Results show that Bennu samples' visible and infrared spectral properties closely align with OSIRIS-REx remote-sensing data, though slight differences are attributed to space weathering and grain structure. These samples are consistent with Ryugu data, particularly in Mg-rich phyllosilicates' presence, but differ slightly in spectral sharpness and Christiansen feature positions. These variations highlight the need for further comparative studies to assess asteroid evolution, thermal history, and the representativity of collected samples.

C7 / 15:00-15:15

Marie-Anne Carpine
CEA/DRF/DAp - AIM

From cosmic dust to planet formation : Building new dust models.

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The characterisation of cosmic dust properties is key for understanding, among other things, planet formation processes. Astronomical observations provide us information from which it is possible, but not trivial, to deduce physical properties of cosmic dust. For instance, recent observations of 12 young protostars found dust emissivity indices with values $\beta < 1$ [Maury et al. 2019, Galametz et al. 2019], which would imply that dust coagulated into grains over 100µm in size [Ysard et al. 2019], much larger than what predicts actual paradigms of planet formation at this stage of stellar evolution. However, relating the grain sizes to their opacity measured in the millimetre bands is not straightforward and rely heavily on the validity of current dust models used as astrophysical analogs in the community. For example, the optical properties of large dust aggregates in cold environments, as observed in millimetre wavelengths were not explored in a systematic way, limiting the astrophysical interpretation that can be done from the measurements, especially for the dense ISM. Our work addresses this blind spot, building new physically-motivated dust models to interpret the dust signatures in protostellar environments. Our study concentrates on the optical properties of a few examples of dust grains. Using laboratory-measured material properties from the THEMIS 2 dust model [Ysard et al. 2024], we derive various grain shapes in the scope of picturing the evolution from small compact grains to potentially large fluffy aggregates. We used the Discrete Dipole approximation (DDA) code ADDA [Yurkin et al. 2011] to compute our grains' optical properties. First results show a heavy dependence of these optical properties on the shape, but also on the composition of dust grains. Building reliable dust models is decisive in the interpretation of observations of the dense ISM, in our understanding of dust evolution towards planet formation. We hope to build a robust model of dust grains population, challenge fiducial dust models, and permit to make progress in these fields.

C8 / 15:45-16:00
Vardan Elbakyan
University of Duisburg-Essen
Pebbles vs. Turbulence: A Delicate Balance in Protoplanetary Disk Evolution
We present results from simulations of self-gravitating protoplanetary disks that incorporate dust evolution, including growth, fragmentation, and gas-dust dynamics, over 0.5 Myr of disk evolution. We explore the impact of turbulent viscosity (α), dust fragmentation velocity (u_{frag}), and gravitoturbulence (α_{GI}) on pebble formation and distribution. Our findings reveal that the $\alpha = 10^{-2}$ model is viscosity-dominated, with dust-to-gas mass ratios deviating by no more than 30% from the canonical 1:100 value. In this regime, pebbles are absent, and dust is limited to sub-millimeter sizes. In contrast, disks with $\alpha = 10^{-3}$ and 10^{-4} are shaped by gravitational instability. For $\alpha = 10^{-4}$, radially varying gravitational torques create a bottleneck effect, concentrating gas and dust into a narrow ring at approximately 1 AU. This results in abundant pebbles and elevated dust-to-gas mass ratios exceeding 1:100 in specific regions. Lower u_{frag} values suppress pebble formation, confining them to sub-AU regions, while higher u_{frag} supports widespread pebble growth. Gravitoturbulence further reduces pebble masses and spatial coverage by increasing turbulent velocities, lowering the fragmentation barrier. Despite these effects, the integrated pebble mass in low-turbulence disks is sufficient to form Earth-like and giant planets under suitable conditions ($u_{\text{frag}} \geq 1.0 \, \text{m/s}$, $\alpha < 10^{-3}$). We also show that using the standard 1:100 dust-to-gas mass conversion criterion can lead to substantial errors in the pebble mass estimates. Our findings highlight

the critical role of turbulence and gravitational instability in shaping the spatial distribution of pebbles and their contribution to planetesimal formation and early planetary core growth.

C9 / 16:00-16:15

Eduard Vorobyov

University of Vienna

Dust growth and pebble formation in the initial stages of protoplanetary disk evolution

I will present the results of three-dimensional numerical hydrodynamics modeling of a protoplanetary disk with the focus on the initial stages of dust growth and pebble formation. The spatial distribution of pebbles in the disk midplane exhibits a highly nonhomogeneous and patchy character. The total mass of pebbles in the disk increases with time and reaches a few tens of Earth masses after a few tens of thousand years of disk evolution. The simulations suggest that protoplanetary disks with an age ≤20 kyr can possess notable amounts of pebbles and feature dust-to-gas density enhancements in the disk midplane. Hence, these young disks can already be ripe for the planet formation process to start.

C10 / 16:15-16:30

Yinhao Wu

University of Leicester

Dust Dynamics in Hall-effected Protoplanetary Disks

Recent studies have shown that the large-scale gas dynamics of protoplanetary disks (PPDs) are controlled by nonideal magnetohydrodynamics (MHD), but how this influences dust dynamics is not fully understood. To this end, we investigate the stability of dusty, magnetized disks subject to the Hall effect, which applies to planet-forming regions of PPDs. We find a novel background drift Hall instability (BDHI) that may facilitate planetesimal formation in Hall-effected disk regions. Through a combination of linear analysis and nonlinear simulations, we demonstrate the viability and characteristics of BDHI. We find it can potentially dominate over the classical streaming instability (SI) and standard MHD instabilities at low dust-to-gas ratios and weak magnetic fields. We also identify magnetized versions of the classic SI, but these are usually subdominant. We highlight the complex interplay between magnetic fields and dust-gas dynamics in PPDs, underscoring the need to consider nonideal MHD like the Hall effect in the broader narrative of planet formation.

Day 2 (Feb. 12)

K4 / 9:30-10:15

Bastian Gundlach

Institut für Planetologie, Universität Münster

Experimental aspects of planetesimal and comet formation

The formation of planetesimals and comets is a crucial aspect of planetary system evolution, yet many of the processes involved remain poorly understood. This talk will explore the experimental efforts to simulate and investigate the conditions that lead to the formation of these celestial bodies. We will examine laboratory experiments designed to replicate the conditions of the early solar system, focusing on key aspects such as dust aggregation, collisional growth, and the role of water ice. Additionally, we will discuss the formation of icy bodies in the outer solar system and the potential for cometary building blocks to preserve primordial material from the protoplanetary disk. By combining experimental data with astrophysical observations and computer models, we aim to provide vital insights into the planetesimal and comet formation processes.

C11 / 10:15-10:30

Tomomi Omura
Osaka Sangyo University

Experimental Study on Compaction Behavior and Structural Evolution in Pebble Layers

Planetesimals formed by self-gravitational instability are thought to be aggregates of pebbles (agglomerates of dust particles). In this study, we focus on the effect of compaction due to self-gravity on the physical properties of the pebble layer. Before compaction, the pebble particle layer exhibits physical properties as an aggregate of pebble particles. On the other hand, after considerable compaction, the layer likely demonstrates the physical properties of a homogeneous grain layer due to deformation, fracturing, and merging of the pebbles within the layer. We investigated the consolidation behavior and particle structural changes of the pebble particle layer between these two phases. In this presentation, we report the results of compaction experiments on a pebble particle layer and a homogeneous particle layer. We discuss the influence of the physical properties of the pebbles on the compaction process by comparing the two. We also report the changes in the internal particle structure associated with compaction. The pebbles used in the compaction experiments consisted of glass beads with a diameter of 4.2 μm (Potters-Ballotini, EMB-10). The pebbles were formed by adding water to the sample powder. We used agglomerates with diameters of 1–2 mm as the pebbles. In our experiments, the pebbles were poured into a cylindrical container and compacted with a piston attached to a universal testing machine (Shimadzu, AG-X). The piston applied pressure to the pebble sample (pebble particle layer) until it reached 6x10^6 Pa. For comparison, the same experiment was carried out with powder sample (homogeneous particle layer) as well. For some pebble samples, the maximum pressure was adjusted in the range from 1x10^4 to 6x10^6 Pa. For these experiments, the interiors of the samples were observed using a CT scanner (NAOMi-CT 3D-M) after the experiments. The compaction curves of the pebble and powder samples indicate that the pebble sample required more pressure to compact than the powder sample with the same filling factor during the initial stages of compaction. This required pressure increased with pebble strength. As compaction of the samples progressed, the pebble and powder samples showed similar compaction curves after a certain pressure. This pressure also increased with pebble strength. In the range where pebble properties influence the compaction behavior, the compaction curves of the pebble samples normalized by the pebble strength collapsed into a single line. This suggests that in this range, compaction progresses due to the fracture of the pebbles. The CT scan results also showed that the pebbles' outlines inside the sample were lost in this range. These results confirm that the pebble particles inside pressure-exposed pebble layers undergo fracturing and merging, and finally, the physical properties of the original pebble particles are almost lost.

C12 / 10:30-10:45

Satoshi Ohashi
National Astronomical Observatory of Japan

Experiment of micro-particles adhesion: initial results

The first step in planet formation is thought to be the attachment and growth of interstellar dust of size 0.1 μm to each other in the protoplanetary disk. However, this process has pointed out various problems, such as central star drift, collisional destruction, and bounce problems. Therefore, how interstellar dust grows remains unresolved. To improve our understanding of these issues, it is important to actually "observe" the deposition of micron-sized particles. Therefore, by introducing aerosol technology into our experimental apparatus, we created an environment in a gas cell where microparticles can freely float in the gas (nitrogen). We started an experiment to observe and monitor their adhesion and growth process with a high-speed camera. We have so far conducted experiments using spherical amorphous SiO2 particles with a diameter of 5 μm. As a result, we succeeded in capturing the motion of SiO2 particles at about 1 - 100 cm s-1. In addition, by taking instantaneous images of collisions between particles, we observed that when particles collided head-on, they tended to adhere to each other, whereas when one particle collided with the other at a certain angle, they did not adhere and bounced off each other. At this stage, the number of times the particles were observed to collide with each other is still insufficient, and further experiments are needed to confirm this. Suppose such a process is occurring in protoplanetary disks. In that case, the key to head-on collisions is the relative velocity of the dust in rotational motion, and dust collisions of different sizes may play a crucial role. In this talk, I will give an overview of our experiments on dust particle attachment and initial results, and plans for future experiments.

C13 / 10:45-11:00

Yukari Toyoda
Kobe University

Low-velocity impact experiments of porous ice balls: Porosity dependence of restitution coefficients

We investigated the porosity dependence of the restitution coefficient (COR) of porous ice balls with porosities of 49.6%, 53.8%, and 60.8% colliding with granite and porous ice plates at a low impact velocity (vi = 0.93–96.9 cm/s) and temperature of − 13.8 °C. The relationship between vi and COR was divided into two regions by the critical velocity vc: In the quasi-elastic region (vi ≤ vc), COR had a constant value regardless of vi and could be explained by using Dilley's viscous dissipation model. In the inelastic region (vi ≥ vc), COR decreased with vi and could be explained by using the improved Andrews' plastic deformation model. We then determined empirically porosity dependence of the relationships between vi and COR. It was found that COR decreased with increasing porosity of the porous ice, and was strongly dependent on the porosity of the porous ice.

C14 / 11:15-11:30

Jakob Penner
University of Duisburg-Essen

Ionizing protoplanetary disks in pebble collisions

Ionization of protoplanetary disks is important for turbulence and chemistry. In recent years, experiments showed that collisions can provide charges on grains by tribocharging. However, charges might not be restricted to the solids. Collision experiments with glass grains conducted by Jungmann et al. demonstrated that charges are not conserved on grain surfaces [1]. To investigate this phenomenon further, we conducted experiments using a basalt grain ensemble in a vacuum chamber at a low-pressure regime of approximately 1 mbar. Our aim was to verify whether grain collisions ionize the surrounding air, thereby explaining the missing charges on the grain surfaces. In these experiments, the sample ensemble was agitated to induce frequent collisions. Subsequently, the ambient gas was transported convectively to a capacitor using a fan. This setup allowed us to detect ions generated stochastically by grain collisions. The detection was achieved by measuring the voltage across a resistor connected in series with the capacitor. While this approach confirmed ion generation, it did not allow for the quantification of single-grain ionization events due to the ensemble nature of the experiments. To address this limitation, we conducted collision experiments with carefully defined, single-digit quantities of grains. This setup enabled us to determine the charges generated by individual grain collisions, allowing us to quantify ionization events with a specific numerical value. In general, ionization of the protoplanetary disk by pebble collisions can be significant. Reference: 1. F. Jungmann, H. van Unen, J. Teiser und G. Wurm, Physical Review E 104, l022601 (2021)

C15 / 11:30-11:45

Jens Teiser

University of Duisburg-Essen

Charge driven growth: The end of the bouncing barrier?

Pebbles - dust agglomerates of a certain size range - play a crucial role in planet formation. The critical size range is defined by the gas-particle interaction, given by a Stokes number of St = 1. Hydrodynamic models describe, how pebbles can be concentrated until a critical particle concentration is reached to form planetesimals by gravitational collapse of the pebble cloud. Other models describe how planetary cores can grow efficiently by accreting pebbles. All models have in common that a critical Stokes number - meaning particle size - is needed. The formation starts with the coagulation of (sub-) micrometer dust grains by surface (van der Waals) forces as the dominant force. Starting with fractal dust agglomerates, subsequent collisions lead to compaction, bringing the growth process to a natural halt before the particle sizes reach pebble size (bouncing barrier). Mutual collisions of particles lead to charge transfer between the colliding particles. This tribocharging process holds for solid grains (such as chondrules), as well as dust agglomerates. Experiments show that charged particles in the sub-millimeter range grow efficiently to centimeter sizes, bridging two orders of magnitude easily. Such agglomerates are by far more stable than agglomerates of non-charged particles, with a fragmentation threshold at 0.5 m/s. Experiments with (sub-) millimeter dust agglomerates show that tribocharging works as well for agglomerates as for solid particles.

C16 / 11:45-12:00

Tetsushi Sakurai

Graduate School of Science, Kobe University

Consolidated porous material: Experimental study of elastic-wave velocity and thermal conductivity using sintered glass particles

Planetesimals, the parent bodies of boulders found on the surfaces of asteroids and chondrites, were formed through the accumulation of dust aggregates or pebbles (e.g., Blum, 2017). Initially, planetesimals were porous and granular in nature, and the presence of boulders and chondrites suggests that planetesimals underwent consolidation processes during their evolution. Such processes may involve hot pressing (sintering) (e.g., Henke et al., 2012) and cementation through mineral dissolution and reprecipitation (Sakatani et al., 2021). We experimentally investigated the elastic-wave velocities and thermal conductivities of sintered materials composed of glass particles with a particle size of approximately 30 μm.

The porosities of these sintered materials are ≲0.65, with nearly homogeneous particle arrangements. However, initial planetesimals are thought to have had higher porosities (Omura and Nakamura, 2021). Highly porous boulders (porosity ≳ 0.7) have been observed on the surface of asteroid (162173) Ryugu (Sakatani et al., 2021). Furthermore, interiors of initial planetesimals are thought to have exhibited heterogeneous particle arrangements due to the accumulation of dust aggregates or pebbles. We are currently preparing sintered materials composed of glass particles with diameters of 1-10 μm. These sintered materials exhibit higher porosities, reaching up to ≲0.87. Additionally, sintered materials made from dust agglomerates (diameters 500-1000 μm) that remained on the sieve have also been prepared. Their porosities are ≲0.65, and they possess hierarchical structures. We will present the results of the relationship between porosity, porosity structure, and longitudinal wave velocity.

C17 / 12:00-12:15

Yuuya Nagaashi
Tohoku University

Evaluation of surface energy of insoluble organic matter simulants from adhesive force measurements

The organic matter on the surface of rocky dust in protoplanetary disks may promote its collisional sticking. However, the surface energy that determines the collisional sticking is not well constrained. Therefore, we evaluated the surface energy from adhesive force measurements of insoluble organic matter simulants synthesized by a formose-type reaction. The measurements were performed mainly in atmosphere using centrifugal and impact separation methods, but also in vacuum after heating to reduce the effect of adsorbed water. As a result, the adsorbed water had little effect on the adhesive force, and the surface energy was evaluated to be ~10 mJ m^{-2}. This value is of the same order or lower than that of silica, depending on the disk conditions. Thus, the surface energy of insoluble organic matter cannot promote collisional sticking.

K5 / 13:30-14:15

Min-Kai Lin
ASIAA

Bitter and sweet flavors of the streaming instability

Forming 1-100 km-size planetesimals is a critical step in building planets. However, the collisional growth of solids in protoplanetary disks ceases to be effective beyond mm-cm or pebble sizes. This is due to various growth barriers that emerge at this scale, such as fragmentation and radial drift. Overcoming these obstacles is the heart of modern planet formation theory. To this end, the `streaming instability', arising from the mutual interaction between dust and gas, has been proposed to bypass intermediate scales, allowing planetesimals to be formed directly from pebbles. I will review the fundamental physics of the streaming instability, recent developments, and discuss future directions to better understand where and when it can produce planetesimals.

C18 / 14:15-14:30

Konstantin Gerbig
Yale University

Planetesimal Formation Instigated by Diffusive Instabilities

The hydrodynamic behavior of dust in protoplanetary disks, key during the initial stages of planet formation, remains riddled with questions. In particular, there is ambiguity regarding the physical processes that can concentrate dust to densities sufficient for planetesimal formation. Drawing upon the analogy of underwater sand ripples, I will introduce a new linear, axisymmetric instability that may resolve this question. The diffusive instability can reorganize a turbulent dust patch in the mid-plane of a protoplanetary disk into azimuthally elongated, high density filaments, provided diffusivity decreases sufficiently fast with increasing dust loading — a premise supported by our numerical simulations of protoplanetary disks where dust-gas interactions self-generate turbulent diffusion during the nonlinear saturation of streaming instability. I will conclude by discussing the diffusive instability's role in broader planetesimal formation theory, including its relationship to the streaming instability.

C19 / 14:30-14:45

Teng Ee Yap

California Institute of Technology (CalTech)

Dust-gas coupling in turbulence- and MHD wind-driven protoplanetary disks: Implications for rocky planet formation

The size and spatial distributions of dust particles in protoplanetary disks depend on the coupling of these particles with their surrounding H2-He gas, and govern both the efficiency of planetesimal formation as well as the favored mode of planetary accretion (i.e., classical, pairwise planetesimal collisions vs. pebble accretion) in different disk regions. The degree of such coupling is quantified by the dimensionless Stokes number (St), which is intrinsically tied to particle size. Here, we self-consistently model the characteristic St of particles across time in disks evolving under both turbulent viscosity and magnetohydrodynamic (MHD) disk winds. In both turbulence- and wind-dominated disks, we find that fragmentation is the limiting mechanism for particle growth by hit-and-stick collisions, thus setting their St. Moreover, the water-ice sublimation line constitutes a critical transition point in particle settling, drift, and size regimes, reflecting the higher fragmentation threshold velocity of icy particles relative to their rocky counterparts. In particular, icy particles are characterized by greater settling, faster drift velocities, and larger sizes. The extent of dust settling at the disk midplane holds significant bearing on the rate of pebble accretion (PA; i.e., whether it operates in the 2D or less efficient 3D regime). Through simulations of rocky planet growth, we evaluate the competition between PA and pairwise planetesimal collisions. We find that the dominance of the former can only be realized in slow-evolving, wind-dominated, and hence quiescent disks characterized by Shakura-Sunyaev turbulence parameters $\alpha\nu$ ≤ 10-4. These disks must also be devoid of pressure maxima that could lead to the formation of planetesimal rings, in which collisional growth is enhanced. We conclude that for most of parameter space corresponding to astronomically observed values of $\alpha\nu$ (>10-4), pairwise planetesimal collisions serves as the dominant pathway of rocky planet growth. Our results are discussed in the context of super-Earth origins, and argue against a significant (> 10%) of carbonaceous, outer disk material to the terrestrial planets in the form of pebbles, in agreement with inferences drawn from multi-element analyses of nucleosynthetic isotope anomalies as well as chemical considerations (e.g., Mg/Si) of Earth's building blocks.

C20 / 14:45-15:00

Satoshi Okuzumi

Institute of Science Tokyo

Retaining small pebbles with MHD-driven surface accretion flows in protoplanetary disks

Planetesimal formation via streaming and gravitational instabilities of pebbles in protoplanetary disks requires a local dust-to-gas mass ratio exceeding unity. Radial drift of large grains toward pressure bumps is a plausible mechanism for achieving such high dust concentrations. However, recent submillimeter polarimetric observations reveal that icy pebbles in the outer regions of protoplanetary disks are significantly smaller than predicted by conventional dust evolution models. This raises the critical question of how small pebbles, strongly coupled to disk gas, can accumulate radially to form planetesimals. In this talk, I propose a novel dust retention mechanism that enhances the disk's dust-to-gas mass ratio by retaining slowly drifting grains. This mechanism assumes that a gas accretion flow near the disk surface, driven by magnetohydrodynamic winds, removes disk gas while trapping grains below the flow. Using a global dust–gas evolution model that incorporates grain growth, fragmentation, and radial transport, I demonstrate that the midplane dust-to-gas mass ratio in surface-accreting disks can exceed unity within the first few million years of disk evolution. This new mechanism may thus enable planetesimal formation even with the observed small pebbles. If time permits, I will also discuss the compatibility of this pebble retention scenario with multi-wavelength observations of protoplanetary disks. ALMA surveys of large, least-biased disk populations have revealed correlations among dust (sub)millimeter emission radii, luminosities, and spectral slopes. Previous models attribute these trends to dust trapping at pressure bumps. In this talk, I will briefly review the key statistical properties of (sub)millimeter dust emission for disks in the Lupus star-forming region. I will then demonstrate that pebble retention in surface-accreting disks naturally sustains optically thick (sub)millimeter dust emission over a few million years, yielding correlations consistent with observations. These findings suggest that pressure bumps are not essential for explaining the statistical properties of dusty disks.

Reference: Okuzumi, S. 2024, Surface accretion as a dust retention mechanism in protoplanetary disks. I. Formulation and proof-of-concept simulations, PASJ, in press (arXiv:2411.09934)

C21 / 15:00-15:15

Daniel Carrera

New Mexico State University

Dust Growth and Planetesimal Formation in Class 0/I Disks Subject to Infall

Planetesimals are 1-1,000 km bodies that are the building blocks of planets. There is growing evidence that planet formation begins early, within the first ~1 Myr Class 0/I phase, at a time when infall dominates the disk dynamics. Our goal is to determine if Class 0/I disks can reach the conditions needed to form planetesimals by the streaming instability (SI). We focus on a recent suggestion that early infall causes an "inflationary" disk phase in which dust grains are advected outward. We modified DustPy to build a 1D disk with a sophisticated treatment of dust growth, along with infall and the thermal evolution of the disk. We explore different infall scenarios and the role of shock heating. Our results conflict with previous work that suggested that this inflationary stage can form planetesimals by the SI. We find a large increase in dust-to-gas ratio at the edge of the expanding disk. However, neither this nor any of the other concentration mechanisms that we explored led to conditions under which the SI could form planetesimals. In every run, the the SI impeded by small grain sizes rather than insufficient dust-to-gas ratio. Grains are mostly fragmentation-limited and their small sizes are due to viscous heating and the link between temperature and turbulence in the alpha model. Future work should explore models with less viscous heating (e.g. disk winds) and the link between temperature and turbulence.

K6 / 15:30-16:15

Takahiro Ueda
Center for Astrophysics | Harvard & Smithsonian

Characterization of Protoplanetary Dust by Radio Observations

Characterizing dust in protoplanetary disks through observations is crucial for understanding planet formation. Dust sizes and masses have been measured by observing dust thermal emission at (sub-)millimeter wavelengths. Photometric surveys of various star-forming regions have revealed that most protoplanetary disks exhibit low spectral slopes at millimeter wavelengths, indicating the presence of large (>mm) pebbles. However, ALMA polarimetric observations have highlighted the ubiquity of scattering-induced polarization, which is more consistent with smaller dust grains. High-resolution ALMA polarization images have further advanced our understanding of dust shapes, in addition to sizes, by disentangling alignment polarization from scattering polarization. In this presentation, I will review recent (sub-)millimeter observations of dust in protoplanetary disks, discuss their implications for dust growth in these environments, and outline future observational plans.

C22 / 16:15-16:30

Kiyoaki Doi
MPIA

Dust size distribution revealed from the dust spatial distribution from high-resolution multi-wavelength ALMA observations

Planet formation begins with the growth of dust grains in protoplanetary disks, so observational constraints on dust size distribution are crucial for understanding the planet formation process. Previous studies have estimated dust size from the spectral index derived from multi-wavelength observations, but they still have significant uncertainties. In this study, we propose a new method to constrain the dust size distribution from the dust spatial distribution observed at multiple wavelengths. Larger dust grains are efficiently accumulated in narrower regions, and larger dust grains are more sensitive at longer wavelengths, so the spatial distribution can differ depending on the observed wavelength. We applied this method to high-resolution ALMA observations of HD 163296, and we successfully constrained both the maximum dust size and the power-law index of the dust size distribution. Based on these results, we discuss how evolved the dust grains are and what limits the maximum dust size. This study demonstrates that the spatial distribution of dust emission provides new insights into the characterization of protoplanetary disks.

C23 / 16:30-16:45

Yangfan Shi
Kavli Institute for Astronomy and Astrophysics, Peking University

Testing the Trapping of Large Dust Grains in the Outer Ring of MWC 480 by ALMA and VLA Observations

Concentric rings and gaps in protoplanetary disks have been frequently seen in high resolution observations at millimeter wavelength by ALMA. These features are thought to be generally associated with gas pressure bumps that trap mm-sized grains. Larger grains should also be trapped at the pressure maxima, while centimeter emission of these

substructures is not always consistently detected as those at shorter wavelength. In this work we present new observations of the disk around MWC 480 using the VLA at Ka Band (9mm), with an angular resolution of ~0.1'' and a very deep sensitivity of ~1 μJy/beam. The source hosts a central blob and an outer ring at ~100 au at millimeter wavelengths. We detect the outer ring substructure at 9mm, consistent with the ring present at shorter millimeter wavelength, which provides strong evidence of dust particle trapping in pressure bump. By combining with previous ALMA observations at Band 7, 6 and 3, we characterize the difference of the ring morphology at different wavelengths and measure the spectral index of the ring. We fit the spectral energy distribution at different radius with a physical model (including dust scattering) to constrain the dust growth and dust trapping in the ring.

C24 / 16:45-17:00

Chiara Eleonora Scardoni
Università degli Studi di Milano

Seeing the invisible: indirect methods to detect the action of streaming instability in protoplanetary discs

In the core accretion scenario, planets form by growing the initial µm-sized dust grains present in protoplanetary discs up to the size of a planet; the dust-gas interaction, however, causes cm-sized grains to rapidly drift towards the central star, thus hindering planet formation ('radial drift barrier'). The streaming instability (SI) is a popular solution to the radial drift barrier, promoting rapid dust concentration in clumps that can later collapse under self-gravity. However, probing the action of SI is challenging due to the small (sub-au) size of SI-induced dusty filaments. This work aims at investigating the emission of systems undergoing SI, searching for detectable signatures. We first analyse the global emission of simulated systems undergoing SI, focusing on the optically thick fraction (ff) and the spectral index (α). By comparing the simulations' distribution before/after the action of SI to the distribution data (available in the Lupus star-forming region) in the ff-α plane, we demonstrate that the action of SI drives the simulations towards the area of the plane occupied by the data. This suggests that dusty filaments formation via SI has a detectable impact on the two observables and is consistent with the data. We further analyse the azimuthal brightness asymmetries produced when systems undergoing streaming instability are observed at an inclination angle. Our analysis reveals that the inclined disc emission exhibits a maximum (minimum) emission along the minor (major) axis. We characterise such emission both qualitatively and quantitatively via a simplified analytical model, showing that the model can be used to detect the presence of SI. Finally, we argue that both the global emission and the azimuthal brightness asymmetries have broad applicability, offering valuable tools to detect and probe the presence of unresolved, optically thick substructures in protoplanetary discs.

Day 3 (Feb. 13)

C25 / 9:30-9:45

Luca Cacciapuoti
European Southern Observatory

Assemble of the earliest pebbles: dust growth in protostellar envelopes?

The importance of the early stages of star and planet formation is becoming more and more evident thanks to efforts such as the ALMA programs "FAUST" (PI: Yamamoto, S.) and "eDisk" (PI: Ohashi, N.), in which the properties of Class 0/I young stellar objects are investigated in detail. In these stages, star and planet formation advances while an infalling envelope replenishes the disk of dust and gas. The dust properties of such envelopes have been at the centre of a debate that has not yet found answer: "are dust grains growing in protostellar envelopes to pebble sizes?" (Kwon et al. 2009, Miotello et al. 2014, Galametz et al. 2019). I will present a new and refined multi-scale, multi-wavelength approach to measure dust emission spectral indices in the envelopes of Class 0/I objects (Cacciapuoti et al., 2023; in prep), and show its results when applied to the ALMA "FAUST" Large Program. This work represents an effort to finally aim to a statistical understanding of dust evolution in envelopes with future, focused surveys. Finally, I will discuss whether the constraints I derived on dusty envelopes are consistent with in-situ grain growth or grain transport along protostellar outflows (Cacciapuoti et al., 2024).

C26 / 9:45-10:00

Simin Tong
University of Leicester

Compact protoplanetary discs can be produced by dead zones

Radially compact protoplanetary discs (≲ 50 au) are typically interpreted as the result of rapid dust loss in the absence of effective dust traps, but high-resolution observations by the ALMA demonstrate that substructures are common in these discs. We propose that fragmentation of fragile pebbles beyond the dead zone provides an effective alternative mechanism to form compact discs. We study dust coagulation and fragmentation in discs formed by this mechanism using DustPy and generate synthetic observations. We find that these discs have sizes determined by the extent of their dead zones. Accounting for dust porosity and less fragile pebbles does not change the disc sizes significantly. The smooth dust morphology can be altered only when pressure bumps are present in the dead zone. However, pressure bumps at small radii (≲ 10 au) are ineffective traps, which can replenish inner discs with small grains, effectively hiding the traps in the optically thick inner disc. This proposed mechanism can also form structures that strikingly resemble those seen in recent high-resolution observations of compact discs, such as Sz 66 and MP Mus.

C27 / 10:00-10:15

Ryo Tazaki
University of Tokyo

JWST observations of edge-on protoplanetary disks

Protoplanetary disks are the sites of ongoing planet formation. The crucial initial step in this process is the vertical settling of dust grains, leading to the formation of a dense pebble layer in the midplane of the disk. The formation of this pebble layer is a prerequisite for efficient planetesimal formation. However, our understanding of this phenomenon has been limited by insufficient information from disk observations. Observationally studying the vertical structure of disks is best achieved through edge-on protoplanetary disks. These disks, when observed edge-on, provide a direct insight into the disk's vertical structure. In this presentation, we will present our cycle 1 observation (#2562) of the HH30 disk, a renowned edge-on protoplanetary disk. We obtained the disk image at five different wavelengths ranging from 2 μm to 21 μm, utilizing NIRCam and MIRI instruments. We combine these observations with archival optical/near-IR scattered light images obtained with the Hubble Space Telescope (HST) and a millimeter-wavelength dust continuum image obtained with the Atacama Large Millimeter/submillimeter Array (ALMA) with the highest spatial resolution ever obtained for this target. Our multiwavelength images clearly reveal the vertical and radial segregation of micron-sized and sub-mm-sized grains in the disk. By performing radiative transfer simulations, we show that grains of about 3 microns in radius or larger are fully vertically mixed to explain the observed mid-IR scattered light flux and its morphology, whereas millimeter-sized grains are settled into a layer with a scale height of >~1 au at 100 au from the central star. We also discuss the diversity of the observational appearance of edge-on disks revealed by JWST.

C28 / 10:15-10:30

Linhan Yang

Shanghai Astronomical Observatory, Chinese Academy of Sciences

Multi-Wavelength ALMA Rings with Dust Coagulation/Fragmentation: Simulations, Analytical Fits and a case-study of HD163296

We studied the dust-trapping rings with both dust drift/diffusion and coagulation/fragmentation effects in consideration, developed an analytical fit for such dust rings based on theoretical models. As an example, we applied the analytical model to the HD163296. The ring widths and the spectra energy distribution were fitted simultaneously to better extract information from the ALMA multi-wavelength data. We found the turbulence/fragmentation velocities/maximum size can be well constrained.

C29 / 10:30-10:45

Elena Viscardi

European Southern Observatory (Garching)

A guide to multi-wavelength analyses of protoplanetary discs and application to GM Aurigae

Multi-wavelength dust continuum observations of protoplanetary discs are essential for accurately measuring two key ingredients of planet formation theories: the dust mass and grain size. Unfortunately, they are also extremely time-expensive. Thus, it is fundamental to investigate the most economic way of performing this analysis. In my talk, I will present the benchmarking of the dust characterization analysis on synthetic multi-wavelength observations. I will comment on how optically thick and thin observations aid the reconstruction of the dust properties in three different dust mass regimes. For each regime, I will discuss on the total dust mass that we derive from the SED analyses and compare it with the traditional method of deriving dust masses from millimeter fluxes. I will also show how different spatial resolutions affect the results and how we can improve the spatial resolution of the measured dust properties. Lastly, I will present new high-resolution (0.07”) high-sensitivity 9mm VLA observations of GM Aurigae (from the V-SHARDS large program; P.I. Macias) and discuss how they improve our constraints of the dust properties in this very famous disc.

C30 / 10:45-11:00

Xiaoyi Ma

Peking University

Testing the vortex hypothesis in a protoplanetary disk HD34282

The HD34282 is a protoplanetary disk that hosts an azimuthal asymmetry in the mm dust continuum observed by ALMA. The asymmetry coincides with a one-arm spiral and shadow on the outer disk in near-infrared scattered light, which is coherent with signatures of a vortex shown in simulations. HD34282 thus one of few disks with solid evidence for the

presence of a vortex in both NIR and mm observations. The presence of vortices is key to planet formation since they are prime sites to form planetesimals and the potential birthplace of the planets. In our work, we aim to further test the vortex hypothesis for HD34282 by examining three additional theoretical predictions for vortices: i) smaller dust traced at shorter wavelengths is less concentrated azimuthally than larger dust traced at longer wavelengths; ii) dust at the vortex center can reach a maximum dust size of several mm, one order of magnitude or larger than that in the background rings; iii) Larger dust trapped ahead of the vortex while smaller dust trapped at the center of the vortex. This is done by carrying out high-resolution multi-wavelength dust continuum observations. We compare the azimuthal extent and location of the structure at multiple wavelengths and constrain the dust properties via multi-wavelength spectral energy distribution modelling. Once three predictions are verified, this project will have the potential to provide the most definitive verification of a vortex in a protoplanetary disk and associate the azimuthal asymmetries mm continuum observation with vortices. On the other hand, the negative result would challenge the current theory and motivate alternative explanations for both azimuthal asymmetries in the mm continuum and one-arm spirals in NIR.

C31 / 11:30-11:45
Jean-François Gonzalez
Centre de Recherche Astrophysique de Lyon
Porosity is crucial for the evolution of dust grains in protoplanetary disks
In protoplanetary disks, pebble-sized solids form easily from micron-sized dust grains, but their subsequent growth to planetesimals is hindered by several barriers, such as radial drift or fragmentation. Grain porosity has been identified as a possible solution to help overcome these barriers. We present an improved model of the evolution of the porosity of dust aggregates as they grow, fragment, drift and settle, and apply it to numerical simulations of protoplanetary disks. We find that compaction during their fragmentation is crucial to obtain sizes and porosities comparable to those in observed disks. Finally, we show that the evolution of porous grains can produce large sections in the disks where the triggering conditions of the streaming instability, currently considered to be the best candidate mechanism to form planetesimals, are met.

C32 / 11:45-12:00
Thomas Pfeil
Flatiron Institute
The Semi-analytic Dust Coagulation Model TriPoD and its Applications
TriPoD is a simple and accurate dust coagulation sub-grid model that can easily be implemented in most multi-fluid-capable hydrodynamics codes. The local model evolves a power-law dust size distribution under the influence of coagulation and fragmentation. This allows for a more detailed description of the dust properties than with other simplified dust coagulation prescriptions at similarly low computational cost. TriPoD's applications reach from studies of planet-disk interactions, over modeling of infall and vortices, to more realistic synthetic continuum observations of protoplanetary disks, and more. In my talk, I will introduce the method and some of the applications we are pursuing at CCA and LMU.

C33 / 12:00-12:15
Maxime Lombart
CEA/DAp-AIM

How to treat dust coagulation/fragmentation in 3D hydro simulations ?
Particles coagulation and fragmentation are ubiquitous in nature and industrial proccesses (raindrop formation, air pollution, combustion, crystallization, astrophysics), and mathematically described by the Smoluchowski coagulation and the fragmentation equations. Solving these equations accurately while preserving tractable computational costs is a tremendous numerical challenge, yet critical for understanding the formation of the planets. In particular, low-order schemes do strongly overestimate the formation of large particles. We present a novel high-order discontinuous Galerkin algorithm (Lombart+,2021,2022,2024) that addresses all these issues. The algorithm is designed in a modular way to be coupled to other codes. In particular, we aim to perform the first 3D simulations of dusty protostellar collapses and protoplanetary discs that include realistic coagulation/fragmentation.

C34 / 13:45-14:00
Nicolas Kaufmann
University of Bern
Bridging the Gap, From Planetesimals Formation to the Onset of Pebble Accretion: Investigating the Early Growth of Locally Formed Planetesimals
One of the most promising formation pathways for planetesimals is the concentration of dust via Streaming instability (SI) and the subsequent gravitational collapse into planetesimals. Due to the enhanced dust-to-gas ratio required to trigger the formation via gravitational collapse, the localized formation of a narrow ring of planetesimals is considered in multiple previous studies. These planetesimals then grow via mutual collisions and pebble accretion, understanding this early growth is essential for determining the timing of giant planet formation. To investigate this scenario, we simulate the formation of the seed of pebble accretion from a filament of planetesimals formed via gravitational collapse. To consistently simulate this early stage of planet formation, we utilize an adapted version of the “Bern model”. We track the growth of the largest planetesimal whose initial size is dictated by the initial mass function from Streaming instability simulations from a filament of planetesimals described by a 1D Eulerian disk. We both consider the accretion of planetesimals and pebbles in tandem. We find that, the formation of a body large enough to accrete pebbles efficiently from a Ring of locally formed planetesimals proves challenging at large separations and is very sensitive to multiple parameters like the stellar mass and the diffusive widening of the planetesimal ring due to mutual gravitational stirring.

C35 / 14:00-14:15
Kundan Kadam
Space Research Institute (IWF, ÖAW), Graz, Austria
Planetesimal Formation in Rossby Vortices Originating at Snow Regions
How sub-micrometer-sized dust in a protoplanetary disk grows to form planetesimals and eventually planetary systems, constitutes one of the major uncertainties in the theory of planet formation. Streaming instability (SI) is an important mechanism for formation of gravitationally bound planetesimals, which can further grow via pebble accretion. Snow lines in a protoplanetary disk can assist this process, as they can form pressure maxima and dust drifts towards a positive pressure gradient. Due to the latent heat of the volatile species, a snow line in a protoplanetary disk is in fact a “snow region” of constant temperature, at the corresponding sublimation temperature. In this talk, I will present the results of our latest global, gas-dust coupled hydrodynamic simulations, which investigate the possibility of

vortex excitation at temperature substructures associated with the snow regions. Our hydrodynamic models are based on a recently postulated scenario, wherein the recombination of charged particles on the surface of dust grains results in reduced ionization fraction and in turn the turbulence via magnetorotational instability (MRI). The simulations suggest that with this dust-dependent viscosity, the temperature substructures give rise to axisymmetric rings, which quickly become Rossby unstable. A series of small-scale vortices are formed, which are long-lived and give rise to successive generations of vortices throughout the inner disk. The conditions within the vortices are particularly suitable for dust growth, SI and formation of gravitationally bound planetesimals or larger objects. Thus, the Rossby vortices origination at snow regions can potentially play a key role in the process of planet formation.

C36 / 14:15-14:30

Hui Li
Los Alamos National Laboratory

Dust Dynamics and Evolution in Multi-Dimensional Protoplanetary Disks

To understand the dust dynamics and their size evolution in protoplanetary disks (PPDs), we have carried out both 2D and 3D global gas+dust two-fluid simulations of PPDs with and without the embedded massive planets to study how the dust coagulation, fragmentation and bouncing processes will determine the dust size distribution in different regions of the PPDs and their evolution. Dust size evolution is self-consistently included together with the global hydrodynamic disk evolution. Specifically, we will present results on two studies: one is a set of 2D global PPD studies with multiple dust rings and gaps (generated by multiple planets), focusing on how coagulation, fragmentation, and bouncing regulate the dust size distribution and evolution over ~ million-year timescale. These results are applicable to a number of observed multiple ring/gap sources such as HD163296. The other is a set of 3D global PPD studies of dust evolution in the presence of streaming instability, vertical shear instability and Rossby-wave instability operating in 3D PPDs. These extensive numerical studies are providing valuable understanding on how dust might behave in 3D realistic disks and offer critical insights on interpreting implications for observations.

C37 / 14:30-14:45

Pinghui Huang
University of Victoria

Dust Clumping In Turbulent Protoplanetary Disks: The coexistence of Vertical Shear Instability, Streaming Instability and Rossby Wave Instability

Planetesimal formation is a critical stage in the bottom-up model of planet formation. The first step in this process is the concentration of dust. Dust can be trapped in pressure maxima through aerodynamic drag from the gas or clumped by Streaming Instability (SI), a promising mechanism for forming dense dust clumps during radial drift. On the other hand, protoplanetary disks are turbulent. Vertical Shear Instability (VSI), a hydrodynamic instability, typically occurs in the outer regions of protoplanetary disks, where magnetic coupling is weak. VSI generates anisotropic turbulence that stirs up dust. Moreover, 3D VSI turbulence can be saturated by Rossby Wave Instability (RWI), which generates anticyclonic vortices that facilitate further dust trapping and promote dust concentration and growth. In this study, we use the newly developed multifluid dust module in Athena++ to perform a 3D global simulation with adaptive mesh refinement, demonstrating the coexistence of VSI, SI, and RWI within protoplanetary disks. Although the weak zonal flows induced by VSI and the small dusty vortices generated by RWI may not fully trap dust, these mild pressure perturbations significantly contribute to dust clumping driven by SI. The simultaneous presence of all three instabilities leads to more substantial dust clumping compared to cases where only one instability is present.

C38 / 15:15-15:30

Jiahan Shi
MPIA/ITA, Heidelberg University

Streaming Instability vs. Forced Turbulence: Identifying the physics of strong clustering.

Numerical simulations of streaming instability (SI) can show the generations of high particle concentrations, provided the application of the proper particle sizes and mean dust to gas ratios. Once these particle concentrations reach a critical value in mass, planetesimal formation in a gravitational collapse can be triggered. Whereas the linear phase of SI is well understood we have a lack of studies explaining the strong particle clustering in the fully developed turbulent SI phase. In this paper we investigate in how much this strong clustering is either a non-linear SI effect or alternatively a general property of any turbulence in a disk, provided the general level of this turbulence is as low as produced by SI. To this end we perform simulations of externally driven turbulence in a shearing box at a forcing level leading to comparable turbulent Mach numbers as for SI simulations. We then study the concentration of passive (no feedback) particles in this turbulence and find equally strong clustering as in the SI simulations with particle feedback. We conclude that SI strong clustering is a general feature of disk turbulence with SI having the benefit over other mechanisms to automatically force the right spatial scales with optimal correlation times.

C39 / 15:30-15:45

Jip Matthijsse
Technical University Delft

Polydisperse Formation of Planetesimals: The dust size distribution in clumps

The streaming instability is an efficient method for overcoming the barriers to planet formation in protoplanetary discs. The streaming instability has been extensively modelled by hydrodynamic simulations of gas and a single dust size. However, more recent studies considering a more realistic case of a particle size distribution show that this will significantly decrease the growth rate of the instability. This talk will cover the submitted paper that follows up on these studies by evaluating the polydisperse streaming instability, looking at the non-linear phase of the instability at the highest density regions, and investigating the dust size distribution in the densest dust structures. The polydisperse streaming instability is less efficient than its monodisperse counterpart in generating dense clumps that could collapse into planetesimals. In the densest dust structure, the larger dust sizes are more abundant because they are less coupled to the gas and, therefore, can clump together more than the smaller dust grains. This trend is broken at the largest dust size due to size-dependent spatial segregation of the highest-density regions, where particles with the largest Stokes numbers are located just outside the densest areas of the combined dust species. This is observed as a peak in the size distribution at the densest regions, which could relate to the size distribution that ends up in the planetesimal after collapse and can mimic the size distribution of dust growth.

C40 / 15:45-16:00

Timmy Delage
Imperial College London
Spontaneous formation of long-lived dust traps during the secular evolution of magnetized protoplanetary disks
Understanding the properties of the planet-forming environments -- the protoplanetary disks (PPDs) -- is critical, as they provide the initial conditions for the planet formation process. However, one of the main challenges is the elusive role of detailed microphysics on the complex and interdependent physico-chemical processes that control their dynamics and evolution. In particular, an outstanding gap in the current planet formation theory is about the first steps of the planet formation process; namely how, when and where the initially ISM-like dust particles grow into millimeter- to centimeter-sized pebbles and planetesimals, the building blocks of planetary cores. In this talk, I will propose a new way to alleviate this outstanding problem. PPDs are weakly magnetized accretion disks that are subject to the magnetorotational instability (MRI), one of the main magnetized processes responsible for their angular momentum transport and their gas turbulence. The nonideal magnetohydrodynamic (MHD) effects prevent the MRI from operating everywhere in PPDs, leading to a complex dichotomy between MRI active regions with higher MRI-driven turbulence and non-MRI regions with lower MRI-driven turbulence. I will present the first numerical framework that describes the evolution of PPDs over millions of years powered by the MRI. It captures the MRI-driven gas evolution via sophisticated nonideal MHD calculations that accounts for the effect of the dynamics and growth of the solid dust particles on the MRI-driven turbulence. An exciting MRI-powered mechanism that can spontaneously generate short- and long-lived pressure maxima in the "effective" MRI-active layer of PPDs in unveiled. Within the long-lived pressure maxima, I will show that dust particles can be efficiently trapped and grow into pebbles, as well as reach high enough dust-to-gas mass ratios to trigger the formation of planetesimals via the streaming instability.

Poster Presentation

P1
Yasir Abdul Qadir
University of Turku
Broadband linear polarimetry of exoplanet Upsilon Andromedae b: Constraints on the orbital and physical parameters
Recent advancements in astronomical polarimetry have enabled the detection and characterization of exoplanets, providing insights into their orbital parameters, atmospheric composition, and reflective properties. By combining polarimetric studies with spectroscopy and photometry, a comprehensive understanding of exoplanets, including non-transiting hot Jupiters like υ And b, can be achieved.   The polarimetric observations of the υ And star system were conducted over a period of nearly three years, capturing data at different orbital phases of υ And b. We used T60 telescope in combination with high-precision DiPol-2 polarimeter, which provided an exceptionally high accuracy. To identify periodic signals in our unevenly sampled polarimetric data, we employed the Lomb-Scargle periodogram method. Our findings revealed a polarimetric signal precisely at half of the known orbital period of υ And b, as expected from the polarimetric data of an exoplanet. By applying the Rayleigh-Lambert scattering model, we derived constraints on the exoplanet's orbital

parameters, including inclination angle, longitude of periastron, and longitude of the ascending node. Combining these results with previous spectroscopic studies, we determined the planetary mass, mean density, and surface gravity of υ And b. Additionally, our analysis of TESS photometric data for υ And provided further evidence suggesting the presence of starspots, which likely affected the observed polarimetric signal of the exoplanets. Consequently, accurately quantifying the scattering atmosphere radius and planetary albedo of υ And b proved to be elusive.   In conclusion, high-precision polarimetry serves as a powerful tool for studying exoplanets, allowing for the deduction of their orbital parameters and atmospheric properties. This study highlights the significant potential of astronomical polarimetry in characterizing various types of exoplanets. By incorporating multiple observational techniques, we can enhance our understanding of the complex nature of explanatory systems.

P2

Simon Anghel

Astronomical Institute of the Romanian Academy / Paris Observatory

How to measure the meteoroids impacting the Earth's atmosphere?

Many small meteoroids enter the atmosphere unnoticed due to their short luminous trajectories, low energy output, and limited geographic coverage of observation networks. Thus, in order to constrain the size of centimeter-size material, a set of various energy estimation techniques we compared and analyzed for well-know meteoroids observed via multiple instruments. These include dynamic mass calculations, photometric analysis, empirical relations based on infrasound or seismic signal. We show that the optical energy proves to be the most reliable predictor of entry mass for centimeter-size objects. Ultimately, by constraining the size and frequency of small meteoroids, we can make inferences about the formation, evolution, and distribution of material around other stars, furthering our understanding of cosmic processes.

P3

Irina San Sebastián

Politecnico di Milano

Compressibility and strength of pebble piles

Pebbles play a crucial role in planetary and planetesimal formation, as planetesimals and their remnants form from the gravitational collapse of a pebble cloud. Understanding the compressibility and strength of pebble piles is essential not only for elucidating these processes, but also for collisional evolution studies. In this work, we generated different sized silica pebbles to assemble pebble pile samples in the laboratory. We compressed them to obtain their crush curves and then determined the tensile strengths of the compressed samples using the Brazilian Disk Test. Additionally, we calculated the tensile strength through Discrete Element Method simulations and compared these results with the experimental findings. Furthermore, we compare our correlation between the tensile strength and the volume filling factor with previous works. Finally, we present a new relationship for the tensile strength as a function of compression for pebble piles, incorporating previous results for low pressures.

P4

Akiko Nakamura

Kobe University

Measurement of Static and Dynamic Strengths of Chondrules

Chondrules, one of the main components of chondrites, are submillimeter- to millimeter-sized spherical objects that are believed to have formed through rapid cooling from molten or partially molten droplets. While various physical properties of meteorites—such as porosity, elastic properties, strength, and thermal conductivity—have been studied, the physical properties of chondrules, which may help us understand the formation processes and environments that chondrules underwent, remain underexplored in comparison. A study on chondrules from the Allende meteorite reported that 75% of the chondrules fractured at impact velocities below 30 m/s upon collision with a stainless steel target (Ueda et al., 2021). Research on Saratov chondrules showed that the maximum void size was 300 μm, with porosity ranging from 1–2% (Lewis et al., 2018). We investigated the physical properties of chondrules by measuring the crush strength and impact fracture strength of chondrules extracted from the Allende and Saratov meteorites (Shigaki and Nakamura, 2015, NIPR symp.). We re-examined the data, and estimated their Young's modulus based on the crush strength measurements. This presentation compares these results with those obtained from rock samples.

P5

Gretha Völke
Universität Duisburg-Essen

Tribocharged Solids in Protoplanetary Disks

Triboelctricity is an important factor for pebble growth in protoplanetary disks. Electrically charged pebbles can form stable agglomerates beyond the bouncing barrier, if the lifetime of the electrically charges is long enough in comparison to the timescale between particle collisions. Triboelectric charges on dust particles in protoplanetary disks can last from minutes to years, depending on environmental conditions. The discharge is influenced by external ions or internal conductivity, with water on the surfaces playing a central role. Experiments show that the resistance of dust particles increases with decreasing pressure, which allows charge to persist for weeks to years under the conditions in a protoplanetary disk.

P6

Holly Capelo
University of Bern

Experimental Insights into Dust-Gas Interactions and Instabilities in Protoplanetary Discs

Understanding the formation of macroscopic bodies in protoplanetary discs requires an interplay of mechanisms that enhance local dust concentrations and overcome barriers to growth at intermediate sizes. Aerodynamic instabilities, such as the streaming instability (SI) and shear-flow phenomena, play a critical role in facilitating these processes by coupling dust and gas dynamics. This study presents complementary experimental results addressing key aspects of dust-gas interactions under conditions analogous to those in circumstellar discs. We conduct laboratory experiments to observe particle dynamics in a laminar, low-pressure gas flow with dust-to-gas mass density ratios approaching unity. Using three-dimensional particle tracking, we reveal small-scale clumping, density enhancements, and collective drag reduction effects consistent with SI. Parallel experiments in a microgravity environment employ particle image velocimetry to explore granular shear flow instability in stratified dust-gas mixtures with high Knudsen numbers. These observations provide the first direct evidence of a shear-driven instability analogous to the Kelvin-Helmholtz mechanism in planet-forming discs. Together, these experiments bridge the gap between theoretical models and natural phenomena, advancing our understanding of how instabilities mediate the early stages of planet formation in protoplanetary environments.

P7

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Pebble evolution assisted by streaming instability in protoplanetary disks

Collisional growth of dust grains and pebbles into planetesimals is the key step in planet formation. There are several obstacles that limit collisional growth, including fragmentation and rapid depletion due to radial drift (e.g., Weidenschilling 1977; Blum & Wurm 2008). The streaming instability (SI) has been proposed to bridge the gap to planetesimal formation (e.g., Youdin & Goodman 2005). According to previous studies, the instability drives efficient clumping of pebbles and creates massive clumps from which planetesimals form by gravitational collapse. Although it is promising, massive clump formation is only efficient if the pebbles are sufficiently large (e.g., Lim et al. 2024). The required pebble sizes are larger than the fragmentation-limited size. Thus, there is still a gap between initial collisional growth and planetesimal formation. To bridge this gap, we examine pebble growth through moderate-level clumping due to the SI, which should occur prior to the massive clump formation. It is suggested that once the SI operates, turbulent motion of pebbles will be dominated by the SI rather than larger-scale gas turbulence (Klahr & Schreiber2020). We perform numerical simulations of the SI to measure typical coagulation timescales in moderate clumping as well as characteristic collision velocities. We find that the coagulation timescale is a few to ten Keplerian periods, which is shortest for St~0.03-0.1. We also find that the characteristic collision velocities are on the order of 0.1 percent of the sound speed and below the critical velocities for water ice and CO_2 ice. This suggests that the SI allows further pebble growth beyond the fragmentation barrier. Based on these results, we develop a simple model of pebble evolution and show that such SI-assisted coagulation greatly relaxes the conditions for planetesimal formation.

P9

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Thermally Induced Dust Concentration and Rocky Planetesimal Formation in the Inner Region of Protoplanetary Disks

The formation of planetesimals from dust grains in protoplanetary disks is the first step of planet formation. Leading scenarios for planetesimal formation invoke streaming and/or gravitational instabilities of dust over-densities, with a dust-to-gas ratio at the mid-plane exceeding unity. Such dust over-densities can be produced by pressure maxima associated with gas surface density bumps. However, the disk’s pressure structure depends not only on the gas density but also on the temperature structure, which is influenced by dust distribution. In the inner disk region where accretion heating is efficient, the mid-plane temperature is primarily determined by the balance between accretion heating and radiative cooling. In such a region, one can expect that a local enhancement of dust surface density makes radiative cooling inefficient, potentially producing a temperature maximum and a pressure maximum. We investigate whether a temperature maximum formed by the above-mentioned mechanism can lead to a runaway concentration of dust grains. To this end, we calculate the evolution of dust and disk temperature simultaneously, by incorporating the advection, diffusion, coagulation, and fragmentation of dust grains, as well as viscous heating, radiative cooling, and radial thermal diffusion. Our results demonstrate that the pressure maximum formed by a dust surface density perturbation can indeed lead to spontaneous dust concentration even without a gas surface density maximum. In this self-sustained dust trap, the dust-to-gas density ratio at the mid-plane can exceed unity, thus potentially causing planetesimal formation via streaming/gravitational instabilities. This spontaneous dust concentration requires viscous heating to dominate disk heating, and typically occurs inside of the snow line. The total dust mass in the self-sustained dust trap reaches approximately one Earth mass. Our results suggest that the dust concentration mechanism presented in this study could drive the formation of rocky planetesimals, building blocks of terrestrial planets in the solar system.

P10

Michael Hammer
ASIAA

An MHD-based model for wind-driven disc-planet interactions

Hydrodynamic simulations of protoplanetary discs with planets typically assume the disc is viscously-driven, even though magnetic disc winds are now considered to be the main driver of angular momentum transport through the disc. Magnetic disc winds are typically left out of hydro simulations because they require full MHD and a complex 3-D domain that is computationally expensive and difficult to set up. A few studies have attempted to incorporate disc winds in disc-planet simulations without full MHD by adding in a torque to mimic the effects of a disc wind. However, these studies all predate any actual 3-D MHD simulations of planets in the presence of a disc wind. In light of recent MHD simulations of disc winds beginning to include a planet, we use these new studies to design a new disc wind prescription and test its efficacy. With three main components – namely (i) excess torque in the planetary gap region, (ii) an MHD-based radial profile for the background torque, and (iii) a moderate level of viscosity – we find that we can largely reproduce planetary gap profiles for more-massive planets above the thermal mass. With lower-mass planets, however, we find it's more difficult to reproduce their gap structure. Lastly, we explore the planet’s migration track and find that the planet rapidly migrates inwards due to the excess torque in the gap.

P11

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Effects of refractory condensates deposited outside the Jovian gap in the protosolar disk on the isotopic dichotomy of the solar system

Isotopic analyses of meteorites have revealed that they can be classified into non-carbonaceous (NC) and carbonaceous (CC) meteorites (e.g., Warren, 2011). One scenario to explain this dichotomy is that a proto-Jupiter formed and created a gap in the primordial solar nebula during the early stages of solar system formation. Homma et al. (2024) recently showed numerically that the collisional growth/fragmentation and radial transport (radial drift and diffusion) of dust aggregates around the Jovian gap can indeed reproduce the observed time variation of the ^{54}Cr isotopic anomalies of NC and CC meteorites. In this study, we expand the work by Homme et al. (2024) and investigate if the

same scenario can also reproduce the Cr–Ti isotopic dichotomy observed in meteorites. Our model assumes that refractory condensates like calcium–aluminium-rich inclusions (CAIs) found in CC meteorites were the dominant carriers of ^{50}Ti anomalies. Dust aggregates, corresponding to meteorite matrices, experience coagulation and fragmentation, whereas refractory condensates do not owing to their coarse-grained nature. We calculate the mixing ratios of these solids inside and outside the Jovian gap and examine how the inclusion of refractory condensates affects the ^{54}Cr–^{50}Ti isotopic anomalies of the mixtures. Our results show that the Cr–Ti isotopic compositions inside and outside the gap can partially reproduce the NC and CC meteorite trends, respectively, if we assume poorly sticky dust (with a fragmentation threshold velocity of 1 m/s) and refractory condensates with size distributions similar to those in CV and CK meteorites.

P12

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Constraining Properties of Gas Accreting Planets through Pebbles in Circumplanetary Disks

Pebbles in protoplanetary disks form by collisional growth of dust particles and play important roles in the planet formation. Recently, the growing particles have been observed by Atacama Large Millimeter/submillimeter Array (ALMA) and have provided immense contributions to the understanding of the planet formation. During the gas accretion process of gas giants, small gas disks called circumplanetary disks (CPDs) form around the planets. We found that pebbles in CPDs could also provide constraints on the gas accretion process of the host planets. In this talk, we show the constraints on three gas accreting planets/planet-candidates, PDS 70 b, c, and AB Aurigae b, obtained from the comparisons with our model predictions considering the growth and thermal emission of the dust particles in their CPDs and previous (sub)millimeter continuum observations by ALMA.

P13

Masashi Minehira
Kyoto University

Jovian and Saturnian Satellite Formation Incorporating Pebble Accretion and Cavity Evolution

It is generally accepted that the Galilean satellites and Titan formed within circumplanetary discs surrounding their host planets. However, these satellite systems exhibit differences, and no widely accepted scenario currently explains their formations in a unified way. Here we propose a new scenario that could account for their differences by incorporating the evolution of disc inner cavities and pebble accretion. As a step toward future research, we calculate the temporal evolution of the inner edge positions of the Jovian and Saturnian discs.

P14

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Central Star and Nearby Massive Star Influence on UV Synthesis of Organics in Protoplanetary Disks

Planets are thought to form in protoplanetary disks from micron-sized dust grains that coagulate and grow into full-sized planets. The beginning stage of planet formation is inefficient in the outer parts of the disk, where the grains are often mantled by an ice layer that can contain simple molecules. When exposed to UV radiation, radicals are formed within the ice mantle. Once the grains drift inside the snow line, the warming and sublimation of ices can trigger organic synthesis on the grains. In addition to radiation from the interstellar medium (ISM), two other sources, irradiation from the disk's central star, and nearby massive stars, play an important role in facilitating organic synthesis. We perform a vertical dust size evolution simulation and calculate the abundance of radicals inside icy grains produced by UV irradiation. We consider the effects of the central star's FUV continuum emission and Lyman-alpha emission separately, each characterized by different transport mechanisms in the disk. We find that, due to the enhancement in flux via the additional radiation sources, radicals are formed both at a higher quantity, and at a faster rate. Additionally, we find that the Lyman-alpha emission of the central star plays a significant role in forming radicals in the disk due to its scattering by the atomic hydrogen layer on the disk surface, allowing photons to penetrate deeper into the disk interior. Our results suggest that there could be more organics formed once grains drift inward than previously thought, contributing to rapid growth in the inner disk.

P15

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Water supply to terrestrial embryos through pebble accretion in magnetized protoplanetary disks

The terrestrial planets in the solar system are characterized by their depletion of water. Such planets are thought to form inside the snow line, the boundary orbit where water ice sublimates. In our previous study, we investigated the impact of snow line migration on dust growth in magnetized protoplanetary disks. However, we assumed the steady accretion and did not solve dust motion. To discuss the formation of the water-depleted terrestrial planet, it is important not only to consider the timing of snow line passage but also how much water ice pebble the terrestrial embryos capture after the snow line passes through. Therefore, we calculated the water content evolution of embryos by icy pebble accretion in magnetized protoplanetary disks. We considered dust radial drift, diffusion, and collisional coagulation and fragmentation. We assumed the formation position of embryos and the fragmentation velocity of dust particles as parameters. As a result, we found that obtaining a water content consistent with proto-Earth (~1 wt%) requires the embryo to form closer to the Sun than the current Earth orbit (~0.5 au) and a low fragmentation velocity (~0.1 m/s).

P16

Yuya Fukuhara

Institute of Science Tokyo

Hydrodynamical simulations of the vertical shear instability with dynamic dust and cooling rates in protoplanetary disks

Turbulence in protoplanetary disks affects dust evolution and planetesimal formation. The vertical shear instability (VSI) is one of the candidate turbulence-driving mechanisms in the outer part of the disks. Since the VSI requires rapid gas cooling, dust particles in disks can influence and potentially control VSI-driven turbulence. However, VSI-driven turbulence has strong vertical motion, causing vertical diffusion of dust particles. We perform global two-dimensional hydrodynamical simulations of an axisymmetric protoplanetary disk to investigate how the VSI drives turbulence and maintains a balance between dust settling and diffusion. These simulations account for the dynamic interplay between dust distribution, cooling rates, and VSI-driven turbulence. We find that small dust particles can achieve equilibrium in a turbulent state, forming a thick dust layer with a dimensionless vertical diffusion coefficient of approximately 10^{-3}. The ability of VSI to sustain this equilibrium depends on dust size and dust-to-gas mass ratio. Larger grains or lower mass ratios weaken the turbulence, leading to dust settling. Our results suggest that in VSI-dominated disks, dust grows under turbulence with intensity varying by dust size.

P17

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Strong Clumping in global Streaming Instability simulations with a dusty fluid

Two big questions need to be answered in planet formation: How do we prevent dust from being accreted, and how can dust form planetary seeds? For the first question, we already have a variety of theoretical mechanisms and observations like rings, vortices, or, in general, dust traps that can efficiently prevent dust from migrating inwards. To answer the second question, we need a mechanism that allows dust to clump together until gravitational collapse becomes relevant and additional material can be collected. One promising candidate is Streaming instability, which is usually studied using lagrangian particles in local shearing box simulations. This time, I will present global axisymmetric simulations of this instability, in which dust is modeled as a pressureless fluid with a Stokes number of 0.01. Strong clumping sets in once the total dust-to-gas mass ratio is large enough. We investigate the maximum density in these clumps over 160 orbits and compare it to the Hill density to determine if the clumps become gravitationally unstable. In addition, we try to estimate the optical depth of these clumps to see which ALMA band is most suitable for observations.

P18

Jun Hashimoto
ABC

Dust Trapping in the Ring around Class I Protostar WL 17 with JVLA

We investigated the width of dust ring surrounding the class I object WL 17 using the Karl G. Jansky Very Large Array. Observations were conducted at 33 GHz, corresponding to wavelengths of 9.1 mm, with a spatial resolution of approximately 7 au. By analyzing visibility data, we found that the ring width was less than 5 au, which is narrower than that of 13 au reported by ALMA band 3 observations at 3 mm. This result suggests that dust trapping takes place in the class I phase.