Laboratory light scattering measurement of planetary regolith analogs.

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The surface regolith of airless bodies is produced by long-term space weathering processes and therefore retains valuable information about the evolutionary history and space environment of the body. Remote identification of surface materials relies heavily on our understanding of the light-scattering properties of densely packed small grains. In this study, we present recent measurement results that address this issue from several perspectives. We first introduce an asymmetry factor (ASF) to characterize the directional scattering properties of particulate surfaces. This metric is based on our extensive reflectance measurements of analog materials spanning a wide range of optical properties. While the concept of the asymmetry parameter is well established for individual particles as a measure of the degree to which light is scattered in the forward or backward direction, it becomes inadequate when particles are densely packed into a layer, such as a planetary regolith. In such cases, the scattering behavior of the surface is more complex, and there remains ongoing debate over whether these surfaces are predominantly backscattering or forward scattering. To address this, we define the asymmetry factor (ASF) as a means to quantify the directional scattering behavior of packed surfaces. We measured the spectral bidirectional reflectance distribution function (BRDF) of various analog materials and fitted the results using Zernike polynomials, producing analytical expressions that closely match the measured data with a maximum fitting error of 5%. This level of accuracy enables reliable parameterization of discrete BRDF data. From the analytical BRDF expressions, we define the asymmetry factor through integration over the viewing zenith angle, within the appropriate angular ranges. Notably, the zeroth-order coefficient of the Zernike polynomial corresponds to the directional-hemispherical reflectance (DHR), also known as the plane albedo. By introducing a Lambertian factor (LF) and defining a ratio of ASF over LF, we found that samples with different grain sizes and optical transparencies exhibit distinct trends in the ASF/LF ratio versus DHR relationship. Using the analytical BRDF models, we also generated disk-integrated spectra (DIS), simulating the reflectance of an asteroid surface covered by such particulate layers. Comparison between DIS and the BRDF of a flat surface reveals that they can differ significantly, especially in spectral slope. For samples exhibiting weak phase reddening effects, DIS spectra closely match their BRDF counterparts, suggesting that the reflectance is relatively insensitive to viewing geometry. In contrast, samples with strong phase reddening effects show pronounced differences between their DIS and BRDF spectra. These results provide a valuable foundation for interpreting planetary remote sensing data, particularly in bridging the gap between laboratory measurements and spacecraft observations.

Comparison of scattering properties of meteorite inclusion analogs

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To better understand protoplanetary disk images obtained with telescopes like ALMA or JWST, it is essential to have a good understanding of the scattering properties of the different objects that compose them. In our Solar System, we can find chondritic meteorites that contain a matrix (fine, sub-micron dust) with millimeter-sized inclusions. These inclusions were formed during the first stages of the protosolar system, and we can imagine finding similar ones in protoplanetary disks where asteroids and planets are yet to form.

Here, we wish to investigate whether the scattering properties of these inclusions are specific enough to leave a signature in young disk images. A non-invasive method known as X-ray computed tomography was performed to retrieve the morphology of actual inclusions. We obtained the shape of three chondrules and one Calcium-Aluminum-rich Inclusion (CAI) found in a carbonaceous chondrite. We then 3D-printed them at centimeter scale using materials whose refractive index is close to that of astronomical silicates. Finally, to measure their scattering properties, we rely on the microwave analogy, using the CCRM facility in Marseille (see [1,2] for details).

For each analog, we obtained the scattering phase function (SPF) and the degree of linear polarization (DLP) from 3 GHz to 18 GHz (size parameters from $\sim$1 to $\sim$15). For the SPF, a comparison with Mie theory shows that the chondrules and the CAI behave roughly like spheres of equivalent mass. However, when looking at the DLP, the CAI differs from Mie theory with a much lower polarization fraction, likely due to its more irregular morphology [3].

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Development of the DESTINY+ Dust Analyzer and future Dust Instruments by the Dust Group of the University of Stuttgart, Osaka, Japan on Tuesday, September 16, 2025 - Saturday, September 20, 2025

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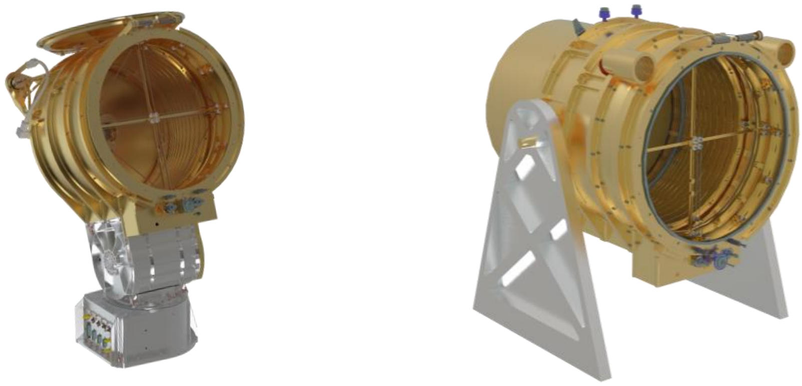
The DESTINY+ Dust Analyzer (DDA) serves as the main scientific instrument on the DESTINY+ mission, focusing on the in-situ analysis of cosmic dust. It examines interplanetary and interstellar dust within 1 AU of the Sun and explores the dust environment surrounding asteroid (3200) Phaethon. By integrating a trajectory sensor with a time-of-flight mass spectrometer, the DDA captures data on the size, velocity, charge, and composition of individual dust grains. Its two-axis pointing system improves sky coverage, establishing DDA as an essential tool for enhancing our knowledge of cosmic dust streams and their composition throughout the DESTINY+ trajectory.



Rendered Image of the DESTINY+ Dust Analyzer Flight Model (left) and possible follow up mission (right)

The development of the DESTINY+ Dust Analyzer is an engaging case study on how to develop a cutting-edge dust science instrument within the confines of a challenging timetable and involving teams spread out all over the globe. This talk aims to give an overview of the design process of the DESTINY+ Dust Analyzer, the challenges encountered along the way and how they were met as well as the most important lessons learned for future projects.

The talk gives a summary of the physical inner workings of the DESTINY+ Dust Analyzer, covering both the in-situ measurement of dust particles as well as the mechanical pointing mechanism which grants the instrument its versatility in what dust streams can be observed. Special focus will be placed on lessons learned during development so other teams working on similar projects know which pitfalls to carefully navigate or avoid. In addition, the DESTINY+ Dust Analyzer serves as an excellent base line for future instruments which can be incorporated into missions orbiting earth, other planets or cruising through interstellar space. With varying constraints placed on the design by the mission parameters, the capabilities of the system can be greatly expanded or refined. Examples of this potential are explored during the talk using specific examples of upcoming projects of the University of Stuttgart Dust Science Group led by Professor Dr. Ing Ralf Srama.

Dust Measurements with the DESTINY$^+$ Spacecraft En Route to the Active Asteroid (3200) Phaethon and beyond

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The DESTINY$^+$ spacecraft will be launched by the Japanese Space Agency JAXA in 2028. The main mission target will be the active asteroid (3200) Phaethon, with a close flyby in 2030. Together with two cameras on board, the DESTINY$^+$ Dust Analyzer (DDA) will perform close observations of the active asteroid to solve essential questions related to the evolution of the inner Solar System, including heating processes and compositional evolution of small solar system objects. Phaethon is believed to be the parent body of the Geminids meteor shower and may be a comet-asteroid transition object. Such objects can likely provide information to better understand the nature and origin of mass accreted on to Earth. The DDA instrument is an upgrade of the Cassini Cosmic Dust Analyzer (CDA) which very successfully investigated the dust environment of the Saturnian system. DDA is an impact ionization time-of-flight mass spectrometer with integrated trajectory sensor, which will analyse sub-micrometer and micrometer sized dust particles. We give an overview of the DESTINY$^+$ mission, the Dust Analyzer DDA and the science goals for the analysis of Phaethon dust as well as interplanetary and interstellar dust to be measured en route to the active asteroid.

The instrument will measure the particle composition (mass resolution $m/\Delta m \approx 100 - 150$), mass, electrical charge, impact velocity (about 10% accuracy), and impact direction (about 10° accuracy). In addition to dust analysis in the vicinity of Phaethon during the close flyby at this small asteroid, DDA will continuously measure dust in interplanetary space in the spatial region between approximately 0.9 and 1.1 AU during the approximately two years spanning cruise phase from Earth to Phaethon.

Cometary dust after Rosetta: A team effort

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Cometary dust is considered one of the best-preserved remnants of the material present during the formation of the solar system. It contains substances that have not undergone significant alteration, offering valuable clues about the origins of comets and the early solar system.

Due to the importance of cometary dust, the *Rosetta Dust Group* was formed during the Rosetta mission. This team included experts in cometary dust, primarily—but not exclusively—from the Rosetta instrument teams. The group's goal was to advance our understanding of cometary dust science by combining results from multiple Rosetta instruments, ground-based observations, and theoretical studies. Several multi-instrument studies have been published as a result of this collaboration (e.g., Tubiana et al. 2019; Güttler et al. 2019).

Since 2015, a series of dust meetings have been organized to share, compare, and discuss cometary dust research, with the aim of deepening our understanding of comets and their dust. These meetings encourage informal discussions and foster potential collaborative activities.

In this meeting, we will present the results discussed during the most recent dust meeting, held in Venice, Italy. The scientific program followed the format of previous workshops, featuring sessions across three main topics: observations, models, and laboratory experiments. The program also included a roundtable discussion on “Current Challenges in Cometary Dust Science.”

A Theoretical Study on Mechanical Properties of Aggregate Dust and Monolithic Dust: Toward a Better Understanding of Ejecta Cloud Formation

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It is natural that small airless bodies in planetary systems are major sources of dust in the zodiacal cloud and debris disks by mutual collisions and volatile sublimation. Conversely, every small airless body in the zodiacal cloud and debris disks is struck on its surface with dust continuously and such a steady bombardment of the airless body results in the formation of a so-called ejecta cloud around it, the presence of which has been identified around Jovian satellites. The formation of an ejecta cloud is directly linked to the mechanical properties of dust in the ejecta cloud, but mesoscopic physics behind the ejecta cloud formation is poorly formulated. Instead, an empirical law of macroscopic impact experiments is commonly applied to previous models of ejecta clouds, whereas there is no justification for the validity of the law in mesoscopic physics. To overcome this situation, we theoretically investigate the mechanical properties of dust in mesoscopic physics, although based on Johnson-Kendall-Roberts theory of contact mechanics, Griffith theory of fracture mechanics, and Weibull theory of flaw statistics. In this presentation, we will provide theoretical formulae for the mechanical properties of dust that are applicable to both aggregates of small grains and monoliths of any porosities. We will demonstrate how well our analytic expressions explain experimental and numerical results of mechanical properties with icy, siliceous, and carbonaceous materials in the size range from nanometers to meters.

The DESTINY$^+$ (Demonstration and Experiment of Space Technology for INterplanetary voYage with Phaethon fLyby and dUst Science) mission will fly by several Near-Earth Asteroids (NEAs), the main target of which is the Geminid parent-body (3200) Phaethon. During their flybys, a dust analyzer named DDA (DESTINY$^+$ Dust Analyser) onboard DESTINY$^+$ will measure the mass, electric charge, velocity, and chemical composition of dust in the ejecta cloud around each NEA. Therefore, the interpretation of DESTINY$^+$/DDA in-situ data on dust in the ejecta clouds will benefit from our theoretical study, which provides a better understanding of ejecta cloud formation.

Inefficient growth of silicate grains and widespread formation of fractal dust

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Gail and Sedlmayr (2013) predicted that silicate grain growth from SiO vapors would be inefficient based on the principle of detailed balance and studies that demonstrated inhibited evaporation of minerals in vacuum (e.g., Nagahara et al., 1994). Kimura *et al.* (2022) measured the vapor-phase growth efficiency of SiO onto $(SiO_x)_n$ clusters in microgravity and found an efficiency between 0.005 to 0.016. Paquette *et al.* (2023) used an SiO growth coefficient of 0.01 in a model of a circumstellar outflow around an AGB star and found that silicate grain coagulation was significant and resulted in the formation of fractal dust aggregates. Compared to a model with efficient growth, grain sizes were approximately 100 times smaller, grain densities were a million higher, and the coagulation rate increased by a factor of a trillion. While the results are somewhat model dependent and are sensitive to the exact SiO growth efficiency used, low growth efficiency always led to higher number density populations of smaller primary condensates that nearly always led to fractal dust aggregates. The traits of the aggregate populations were sensitive to the number density and size of the primary condensates.

The condensation of SiO_x solid/liquid clusters from SiO vapor is a phase change that requires a considerable chemical driving force (supersaturation) to overcome the unstable intermediate SiO dimers, trimers, and larger clusters before reaching a state (the critical cluster) where the addition of the next SiO monomer produces a more stable species that can continue to grow. The concentration of critical clusters depends on the temperature, the chemical characteristics of the condensing species and the concentration of gaseous SiO. As vapor expands and cools the concentration of critical clusters increases exponentially while the monomer population decreases due to both the formation of new critical clusters as well as to cluster growth. If growth is inefficient, then SiO supersaturation remains higher for longer, more SiO is incorporated into cluster creation and less goes into growth. Since the initial quantity of gas-phase SiO is constant, the higher the concentration of critical clusters, the smaller the final size of each of these primary grains. Since the rate of coagulation depends on the square of the grain density, decreasing the SiO growth efficiency results in a significant increase in the number density of grain aggregates.

We will discuss the implications of the formation of fractal aggregates under conditions where condensation is a rapid, dynamic process and note that the result is very different from that obtained under near-constant conditions where thermodynamic equilibrium controls the speciation and morphology of the solids that are formed. We will also discuss the expected evolution of the fractal grains as they leave the circumstellar envelope.

Exploring the Effects of Chemical Composition and Metallic Iron on Amorphous Silicate Dust Spectra

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Amorphous silicate is the dominant form of refractory dust in interstellar and circumstellar environments (Kemper et al. 2004, 2005). Asymptotic giant branch (AGB) stars are the main amorphous silicate dust suppliers, and their infrared spectra show different amorphous silicate features from star to star. However, identifying dust properties from observed spectra is challenging due to the difficulty in distinguishing the spectral change due to chemical composition, size, shape, and temperature. Numerous dust analogs have been synthesized (e.g., Dorschner et al. 1995; Rietmeijer et al. 1986; Mutschke et al. 1998), but it remains unclear which factors (chemical composition, mixtures of different dust components, or physical parameters) are responsible for the observed spectral diversity. Especially, presence and form of iron — whether as metallic inclusions, separate grains, or oxides — remain poorly constrained. Although there are theoretical studies assuming amorphous silicate dust with metallic iron particles (Draine & Lee 1984; Ossenkopf et al. 1992; Speck et al. 2015), laboratory experiments have focused mainly on pure amorphous silicates, and amorphous silicate dust containing metallic iron has not been studied spectroscopically. In this study, we experimentally investigated the effects of metallic iron inclusions and chemical composition on the mid-infrared spectra of amorphous silicate dust.

Condensation experiments in the system including Na, Al, Ca, Mg, Fe, Ni, Si, and O were carried out using the induction thermal plasma (ITP) system (JEOL TP-40020NPS, Kim et al. 2021) and produced dust analogs with Fe, Ni-free CI chondritic composition, metallic Fe, Ni-containing CI chondritic composition, systematically changing Al/Si, Ca/Mg ratios from the CI chondritic composition. The products were analyzed by XRD (Rigaku RINT-2100), EPMA (JEOL JXA-8530F), and TEM (JEOL JEM-2800). In addition to infrared transmittance measurements (JASCO FT/IR-4200), reflectance spectra of the condensates were measured (Thermo NICOLET6700) using pressed pellets of the particles with and without Au coating. We determined the optical constants of products from transmittance and reflectance spectra, assuming the Lorentz oscillator model. We also try to calculate multi component dust spectra using the program DUSTY (Ivezic & Elitzur 1995; Nenkova et al. 2000).

The products were amorphous silicate nanoparticles ($\phi 10-200\,\mathrm{nm}$). In the system with Fe-Ni, silicate grains contained kamacite ($Fe_{0.9}Ni_{0.1}$) particles. The size proportion of metallic cores ranged from 0 to 0.87, and the average was 0.50. Despite a high Fe abundance (Fe/Si$\sim$0.83), close to the Solar value (Fe/Si$\sim$0.85),the spectral peak positions of samples with Fe cores showed no significant shift compared to those without. This suggests that the infrared spectra are primarily governed by the size distribution and number density of metallic cores. If metallic iron condenses into relatively large cores but most grains contain only small inclusions, the cores may remain undetectable in MIR observations. In the Mg-Ca-Al-Si-O system, peak positions shifted from 9.4 to 9.6 μm as Al/Si increased from 0.07 to 0.53, and from 9.4 to 9.7 μm and 17.7 to 19.1 μm as Ca/Mg increased from 0 to 1. The observed dust emission features of certain AGB stars were reproduced by modeled spectra based on the optical constants of our samples, under varying assumptions of grain size and dust temperature, indicating compositional diversity in AGB silicate dust.

Dust destruction in supernova remnants and in the ISM

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Supernova remnants (SNRs) are pivotal players in the galactic dust cycle - producing dust in their ejecta while simultaneously destroying it through powerful shocks. Understanding how much dust survives these environments is critical for explaining dust enrichment in galaxies across cosmic time. This is particularly relevant for high-redshift galaxies, where SNe are thought to dominate dust production due to the short lifetimes of massive stars and the limited contribution from evolved stars. However, the survival fraction of dust grains remains highly uncertain, with predictions ranging from near-complete destruction to substantial preservation.

In this talk, I will present recent results from dust destruction simulations in both clumpy supernova ejecta and the turbulent, magnetized ISM. Using our dust post-processing code *Paperboats*, we analyze high-resolution MHD simulations to study dust grain evolution across a wide range of physical conditions. Our model includes an unprecedented number of physical processes, making it uniquely comprehensive in the field. Notably, grain-grain collisions - often neglected in previous studies - are found to play a critical role in dust destruction, both in SNRs and in the ISM. This expanded physical treatment allows for significantly improved estimates of dust survival rates. In addition, we generate synthetic dust density maps from our simulations, providing a novel tool for connecting theoretical predictions with observational data.

We find that dust destruction in SNRs depends sensitively on the density contrast between ejecta clumps and the surrounding gas. In addition to dust-specific factors such as grain size and composition, the magnetic field strength and orientation influence destruction by shaping shock dynamics and grain trajectories. Accurate estimates of dust survival therefore require detailed knowledge of grain properties, clump structures, magnetic fields, and the ejecta evolution. Furthermore, grain-grain collisions act synergistically with sputtering to enhance overall destruction. In a turbulent, magnetized ISM, dust destruction by forward shocks is significantly reduced compared to a homogeneous medium. However, the total dust mass destroyed under these conditions still far exceeds the amount expected to form in SNR ejecta.

Whether we aim to model dust destruction in the subgrid physics of galaxy simulations, interpret observations of SNRs, or gain a deeper understanding of the dust lifecycle, it is essential to accurately determine how dust responds to shocks under a range of astrophysical conditions. This work contributes to a more unified and predictive framework for dust evolution. The insights are critical for interpreting current and future observations and for developing consistent models of cosmic dust evolution across diverse astrophysical environments.

Dust Survival after Shock Processing in Bipolar Circumstellar Environments

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Dust formed in stellar ejecta is a major contributor to the cosmic dust budget, yet its long-term survival remains uncertain. Massive stars can produce important amounts of dust during eruptive mass-loss events, such as those that formed the bipolar nebula around η Carinae, which contains an estimated 0.25–0.4 $M_\odot$ of dust. However, the intense radiation and mechanical feedback from the star itself, especially a potential subsequent supernova (SN), could efficiently destroy this dust. Understanding the balance between dust formation and destruction is critical for determining the net contribution of massive stars to cosmic dust.

We present 3D hydrodynamical simulations, performed with the FLASH code and the CINDER dust module, to study dust survival in the ejecta of bipolar stellar remnants. Our models follow the interaction of stellar winds, eruptive outflows, and supernova feedback for both spherical and bipolar geometries. The simulations include on-the-fly dust physics, including grain growth, sputtering, and gas–dust cooling.

Our results show that dense, asymmetric circumstellar environments created by pre-supernova eruptions promote efficient radiative cooling, which weakens the impact of the SN shock and allows a significant fraction of dust to survive. For short time delays between eruption and explosion, up to 75% of the dust mass can persist. Conversely, longer delays allow the circumstellar medium to expand. This decreases the circumstellar gas density, and thus reduces dust survival to $\lesssim$ 10%. These findings show the importance of large eruptive mass loss events in shielding dust from SN feedback and suggest that massive stars, under the right conditions, can be significant net contributors to the cosmic dust budget.

Dr Tim Pearce

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Title: What is hot dust doing so close to main-sequence stars?

Abstract: Excess near-infrared emission is detected around one fifth of main-sequence stars, but its nature is a mystery. These excesses are interpreted as populations of small, hot dust very close to their stars, but such grains should rapidly sublimate or blow out of the system. Many models have been put forward to explain this phenomenon, but to date, none has successfully explained the nature of hot dust, nor its ubiquity around such a diverse range of star types and ages. The fundamental problem is that it is unclear how to deliver and sustain these dust populations, which comprise grains small enough and hot enough for their near-infrared emission to significantly exceed their mid-infrared emission. I summarise the current status of the field, including what we do and do not know from observations and recent theoretical work. I give an overview of the diverse range of models seeking to explain hot dust, and particularly focus on how upcoming observations with VLTI/MATISSE should significantly improve our understanding. I also discuss areas where further progress must be made if we are to explain the phenomenon. My aim is to motivate input from the broader dust community, to identify any physics that we may have overlooked, and identify promising new directions in our attempts to explain hot dust.

Silicate features in Debris Disks

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Debris disks are faint dust disks around main sequence stars. Some warm debris disks exhibit silicate features in their spectral energy distributions (SEDs), which may contain important clues about the process of planet formation. Radiation pressure from host stars blow out small dust grains $\lesssim 10\,\mu$m, while silicate features are not explained by the thermal emission from large grains. Consequently, these features are often attributed to the recent production of small grains through stochastic collisions, such as giant impacts, potentially linked to planet formation. However, previous discussions have lacked quantitative estimates of small dust production rates. If production is sufficiently high, the abundance of small grains may exceed the level inferred from silicate feature observations.

In this study, we perform simulations for collisional evolution of bodies in warm debris disks, explicitly account both the production of small grain and their removal by blow-out. We obtain the time evolution of the size distribution of bodies, which reaches a quasi-steady state on short timescales. Our results show that in young, massive disks, the production rate of small dust is sufficient to maintain a population capable of producing observable silicate features. As collisional evolution reduces the total disk mass over time, the production rate of small dust also decreases, eventually suppressing silicate features. Thus, we conclude that silicate features are more likely to be observed in young, massive, warm debris disks.

Dust as a Key to Understanding the Molecular Evolution of the Low-Metallicity Universe

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Understanding the chemistry of the interstellar medium in environments with low dust abundance (i.e., low metallicity) is essential for unveiling the physical and chemical processes that occurred in the early Galactic environment or in high-redshift galaxies, where the metallicity was significantly lower compared to the present-day solar neighborhood. Over the past decade, there has been significant progress in astrochemical studies of interstellar molecules in low-metallicity star-forming regions, such as those in the Large and Small Magellanic Clouds (LMC/SMC), other dwarf galaxies in the Local Group, and the outskirts of our Galaxy (see Shimonishi 2025, IAU Proc., in press; arXiv:2411.04451, and references therein).

Observations with single-dish telescopes have revealed enhanced photochemistry in low-metallicity molecular clouds, likely due to reduced shielding of the interstellar radiation field in such environments. Infrared telescopes have unveiled the chemical compositions of ices in deeply embedded protostars in the LMC and SMC. These ice compositions cannot be explained solely by differences in elemental abundances; instead, grain surface chemistry under relatively warmer conditions—compared to solar-metallicity clouds—must be considered. Observations with ALMA have detected a variety of molecular species, including complex organic molecules (COMs), toward dense and high-temperature protostellar envelopes in low-metallicity environments. Interestingly, the abundance of organic molecules exhibits substantial source-to-source variation: in some cases, it aligns with a metallicity-scaled abundance relative to Galactic counterparts, while in others, it is markedly lower than what would be expected from metallicity differences alone. The origin of this chemical diversity among low-metallicity protostellar sources remains under debate, but it may be linked to grain surface chemistry, as most COMs are thought to form as ices during the early stages of star formation.

These observations suggest that dust grains are crucial for understanding the molecular complexity of the metal-poor universe. This presentation will summarize recent advances in the observation of interstellar molecules in low-metallicity environments, from molecular-cloud scales (~1–10 pc) to protostellar-core scales (<0.1 pc). I will then discuss the key processes that govern molecular evolution in low-metallicity star-forming regions.

Refining Dust Properties in Protostellar Envelopes and Disks: Insights from ALMA, NOEMA, and NIKA2 Observations (PEBBLES/ENYGMA)

Asako Sato [1], Anaëlle Maury [1,2,3], Josep-Miquel Girart [1], Andrés Zuleta [1], Leonardo Testi [4,5], Ilseung Han [1]

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Dust is one of the key elements in the physical processes regulating the formation of stars and their planetary systems, but recent observations are overturning the models used until now to describe its evolution from submicron grains to pebbles. Observing and modelling the properties of dust grains during the earliest phases of disk formation promises to provide important insights into the conditions leading to the formation of solar systems such as our own. The PEBBLES project seeks to develop a methodology for characterizing dust properties in protostars. By combining size-sensitive dust observations and new astrophysical models, the project aims to enhance our understanding of dust in protoplanetary disks, a key factor in early planetary system formation. It will explore the evolution of dust during star formation and its role in linking the magnetic field to surrounding matter, influencing both the star and its disk. In addition, the ENYGMA large program (PI: A. Maury, L. Testi) addresses unprecedented constraints on dust properties and processes at work for its evolution, using the first NOEMA dust polarization observations of embedded 52 protostars resolving down to envelope scales (~1000au). In this talk, I will present our recent progress of ALMA polarization and NIKA2 observations from the PEBBLES project and NOEMA polarization observations from the ENYGMA project (Maury et al., in prep).

First, I will present our ALMA polarization program towards unique Class 0/I protostellar twins embedded within B213 in Taurus, IRAS 04166+2706 (hereafter K66) and IRAS 04169+2702 (K69) with unprecedented spatial resolutions from ~20 au to 1000 au, resolving for the first time both the protoplanetary disks and the surrounding envelopes (**Sato et al., in prep**). Our data reveals striking differences between the two sources, despite them being embedded and born in the same environment. In particular, the polarized emission of K66 likely traces both the B-fields and self-scattering around the disk, implying that dust growth occurs not in the disk but also in the inner envelopes. (Fig.1). K69 has more compact polarized emission with a low polarization fraction <3%, implying that self-scattering could be dominant at the 20au scale. In this talk, I will discuss the implications of these differences between the twins, focusing on dust evolution and the role of magnetic fields in shaping the star formation there.

I will also present preliminary results of dust properties of clumps in Perseus, including L1448C, L1448N, and L1448-2A, obtained from NIKA2 1mm and 2mm continuum data at a resolution of ~0.02 pc, resolving the molecular cloud cores (**Zuleta et al. in prep**). Fig.2 presents the decrease of alpha towards the protostellar cores in the high-density filament, which may trace a change of dust emissivity. Finally, I will briefly introduce an overview obtained from the ENYGMA data.

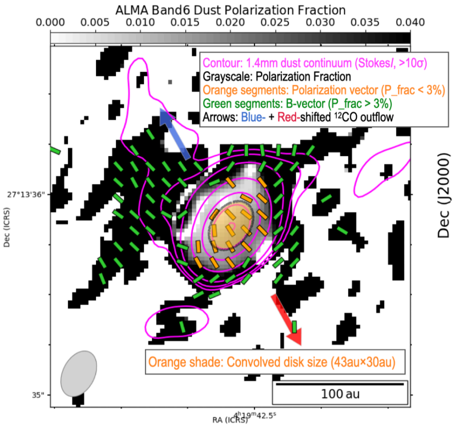

Fig.1: ALMA Band6 polarization map around a Class 0 disk of one of our targets (K66), implying that large grains may grow in the inner envelope, where the polarization fraction is lower than 3% outside the disk (Sato et al. in prep)

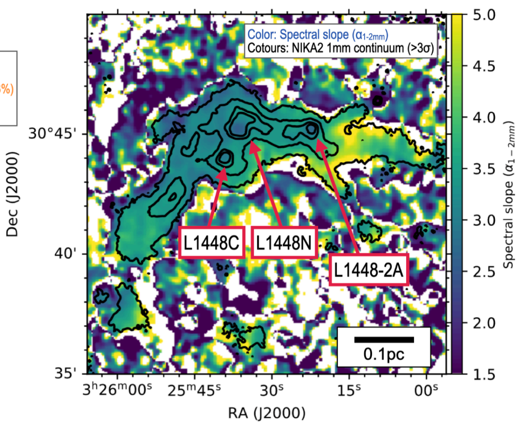

Fig.2: The preliminary map of the spectral index alpha, obtained from NIKA observations of the Perseus L1448 clump, between 1mm and 2mm. (Zuleta et al. in prep)

Simulating Early Dust Evolution in Protostellar Systems: A Radiation-MHD Framework

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Dust grains are essential to the star- and planet-forming processes, influencing their evolution by regulating gas cooling, enabling molecular chemistry, and seeding planet formation. They are well known to grow to millimeter or even centimeter sizes in Class II protoplanetary disks. Moreover, protoplanets have been directly detected in this phase, providing compelling evidence that planet formation may begin earlier than previously thought. While previous (sub)millimeter interferometric observations have revealed tentative signs of grain growth even in Class 0/I protostellar envelopes, the timing, location, and physical environments in which growth occurs during the earliest evolutionary phase remain uncertain.

To better understand the conditions under which grain growth proceeds during protostellar collapse and how this growth manifests in observations, we combine magnetohydrodynamic (MHD) simulations and radiative transfer modeling. We perform MHD core collapse simulations using the RAMSES code, forming an embedded protostar and a surrounding envelope in a magnetized core. Since the physical conditions evolve during the collapse, we also track grain growth using a new dust evolution model COALA, which includes both coagulation and fragmentation and computes time-dependent grain size distributions across the simulation domain. We then post-process these simulation outputs using the radiative transfer codes RADMC-3D and POLARIS to generate synthetic continuum maps and polarization signatures at (sub)millimeter wavelengths. In addition, we implement various dust populations, such as compact silicate grains, aggregates, and icy mantles, to explore how different grain properties affect the resulting observables.

This comprehensive modeling framework helps reveal how grain properties, shaped during the initial evolutionary phases, translate into observable features, enabling better constraints on grain growth in protostellar environments. In this presentation, we will introduce our modeling framework and present preliminary results, highlighting their implications for early dust evolution.

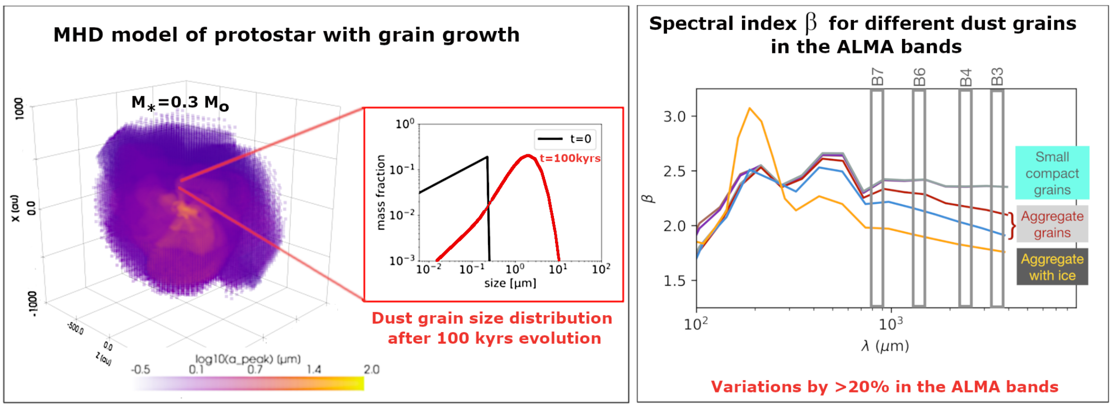

Figure 1: *(Left)* MHD simulation of a protostellar system. Color shows the peak grain size, with warmer colors indicating larger grains. *(Right)* Dust emissivity index β as a function of wavelength for various dust grain models. Shaded regions indicate ALMA Bands, where differences between the models exceed 20%.

Dust characterization in planet-forming disks

Ryo Tazaki[1]

[1] *The University of Tokyo*

Dust coagulation is the first step in planet formation. Constraining the chemical, mineralogical, and physical properties of dust particles in planet-forming disks is a key objective in planetary science. Over the past decade, dust observations of protoplanetary disks have made remarkable progress across a wide range of wavelengths—from optical and near-infrared to millimeter—using facilities such as Subaru, VLT, JWST, and ALMA. These multi-wavelength observations have enabled us to probe various dust properties, including size distribution, porosity, and even chemical composition and mineralogy. In particular, polarimetric observations provide unique constraints on the morphology of dust grains, including their shape, porosity, and fractal structure.

Parallel advances in theoretical modeling have greatly enhanced our ability to interpret these observations. Although simulating the optical properties of more realistic particles—such as irregular and aggregated grains—usually requires considerable time and resources, it is now increasingly feasible. These results have been incorporated into radiative transfer simulations to model observational results of planet-forming disks.

In this review, I will summarize the current understanding of dust properties in planet-forming disks as inferred from recent observational and modeling efforts. I will also discuss the implications for grain growth and the early stages of planet formation, and outline future directions in the observational modeling of protoplanetary dust particles.

3D-Printed Dust Analogs for Protoplanetary Disk Studies

François Ménard[1], and the "Dust2Planets" group

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Astrophysical Context: Small dust particles in planet-forming circumstellar disks must grow by several orders of magnitude to form planetary embryos. The exact processes by which this happens remain unclear today. Information is known about the dust sizes and their rough chemical composition in disks, as measured via, e.g., spectral energy distribution measurements and fitting and near- and mid-infrared spectroscopy. However, particle shapes also hold important clues to the elusive dust-growth mechanisms, a better understanding of which is needed to advance our knowledge of the first stages of planet formation. Although rarely studied, particle shapes can be investigated via high resolution imaging of disks and the measurements of scattering phase functions in intensity and linear polarisation, from the optical to the millimeter wavelength range. To reveal the meaning of these phase functions, a comparison is necessary with a database of "measured" or "calculated" scattering properties of complex dust particles of known shapes, sizes, and composition. I will present our recent efforts to measure such scattering properties of complex dust particles from Laboratory Experiments.

Microwave analogy and additive manufacturing: Taking profit of the recent improvements of 3D printers, we built cm-sized analogs of small circumstellar dust particles with a variety of complex shapes and refractive index. The shapes include fractal aggregates with fractal dimensions, Df , in the range 1.5-2.8, particles with rough surfaces, CAI inclusions and chondrules from meteorites, random Gaussian spheres, etc... See Figure 1. The scattering properties of these analogs were measured in the frequency range 3-18 GHz (size parameters in the range 0.5-35) to mimic their behavior in the visible and/or millimeter range [1,2]. The refractive indices of various printing materials were measured and carefully selected to mimic the properties of relevant astronomical silicates and carbonaceous compounds at near-infrared and mm wavelengths.

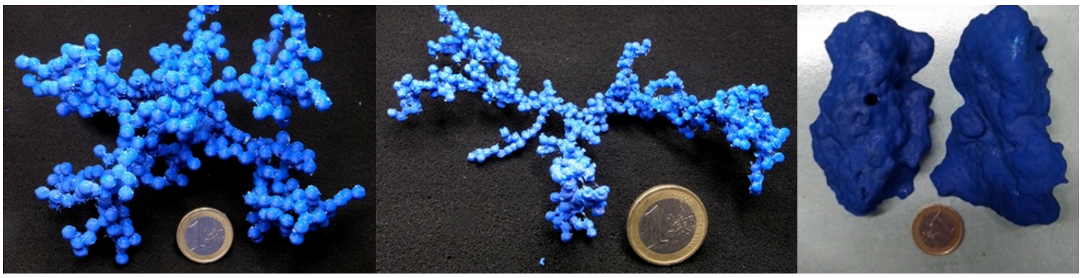

Figure 1: Printed analogs: (left) Fractal aggregate with 500 monomers, Df = 2.0. (Middle) Fractal aggregate with 500 monomers, Df = 1,7. (Right) Copy of a Calcium-Aluminum Rich inclusion. Exact geometry obtained via X-ray tomography. Real size of CAI inclusion = 0.77mm.

Results: The measurement protocol is described in [3, 4] who presented results for small fractal aggregates and rough spheres. New measurements are available for larger aggregates, Random Gaussian Spheres, and aggregates made of irregular monomers recently printed. Their relevance to understand the evolution of dust in protoplanetary disks will be discussed.

Acknowledgments: This project has received funding from the European Research Council (ERC) under the European Union's Horizon Europe research and innovation program (grant No. 101053020, Dust2Planets).

References: [1] Saleh et al, IEEE Transactions on Antennas and Propagation, Volume 69, Issue 2, February (2021); [2] Vaillon and Geffrin, Journal of Quantitative Spectroscopy and Radiative Transfer, Vol. 146, Oct. (2014); [3] Tobon-Valencia et al., Astronomy & Astrophysics, 666, A68 (2022); [4]Tobon-Valencia et al., Astronomy & Astrophysics, 688, A70 (2024)

Dust composition and sub-structures in the inner regions of planet forming disks

Young stars are surrounded by circumstellar disks, in which planets are forming. Rocky planets acquire most of their mass from disk material originally in the form of sub-micron sized dust grains, composed mostly of silicates, iron, and carbon. Circumstellar silicate grains can be easily detected at mid-infrared wavelengths, by their characteristic spectral features. Spectral analysis can uncover the mineral buildup of the dust, and thus we can estimate the composition of the planets forming from that material, and make valuable comparisons with our Solar System.

Planet-forming disks are relatively short-lived (<10 Myr) and in continuous change. Circumstellar dust is being processed, and forming planets also leave their imprints in the disk structure and material composition. With spatially resolved observations at milliarcsecond resolution, we can study these processes in the inner disk region ($r < 5$ au) where terrestrial planets form. This is made possible with infrared interferometric observations at the Very Large Telescope Interferometer (VLTI). VLTI's MATISSE instrument is uniquely suited for that job, because it is able to spatially resolve the inner disk, and spectrally resolve the relevant dust emission features in the N band at the same time.

The VLTI/MATISSE Guaranteed Time Observations team, which I am part of, is conducting a multi-year large survey of about a hundred planet-forming disks, with the aim to create a systematic overview of inner disk sub-structures and dust composition. The majority of our objects are Class II Herbig AeBe and T Tauri disks. In my talk, I will present science highlights from the first five years of our survey, focusing on the results on dust.

A spectacular case is the disk of HD 144432 where VLTI's sub-au angular resolution allowed us to detect a three-ringed structure in the inner 5 au. We were able to constrain the dust composition in each ring, and we confirmed that the disk region within 1 au has a high fraction of crystalline silicates, suggesting thermal annealing taking place there. We also found evidence for solid iron grains in the disk.

Finally, in the last part of my talk, I will present a novel project to study T Tauri disks by combining JWST/MIRI and MATISSE observations. MIRI data is used for compositional analysis of both dust and gas, while MATISSE data constrains the radial distribution of the disk material. The cooperation of the two instruments allows us to extend the discovery space of MATISSE to disk studies in the faint flux regime.

József Varga
Konkoly Observatory, RCAES, HUN-REN
Budapest, Hungary

From disk to dust : The new DRAGyS tool for extracting scattering phase function through disk observation

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The early phase of planet formation, involving the birth of planetesimals through grain growth, remains one of the most enigmatic chapters in the story of planetary systems. Estimating the dust grain properties in these young disks is a key requirement for studying dust evolution. Recent studies of the scattering phase function (SPF) measured in the disks surrounding young stars may reveal crucial insights on dust grain properties. However, with the growing number of high-resolution disk images, there is a pressing need for a fast and scalable analysis tool.

This is the starting point for `DRAGyS` (Disk Ring Adjusted Geometry yields Scattering phase function). `DRAGyS` is a new tool designed for fast, model-free estimation of disk geometry and extraction of the total and polarized SPF in protoplanetary disks with rings and gaps. `DRAGyS` directly estimates key parameters — inclination, position angle, and scattering height — by fitting ellipses to surface brightness peaks, assuming circular disks and without the need for time-consuming radiative transfer modeling. We tested and validated our method both on synthetic disk images and on a sample of nine archival VLT/SPHERE images of polarized scattered light from six protoplanetary disks. Beyond its time-saving method, `DRAGyS` stands out for its ability to extract the SPF separately from each side of the disk, making it particularly suited to the study of asymmetries. More importantly, it incorporates a correction for limb brightening, a geometric effect largely neglected in previous studies but which significantly alters the SPF, particularly at smaller scattering angles. `DRAGyS` accurately recovers geometric parameters from synthetic data and provides SPFs in excellent agreement with the results of previous published research. Its key advantages lie in its quick, purely geometric approach to estimating the disk geometry and extracting the SPF, either globally or by disk side, making it a powerful tool for the analysis of ring-shaped protoplanetary disks.

Furthermore, we apply DRAGyS to a promising sample: a set of protoplanetary disk images from the large program DESTINYS, observed with VLT/SPHERE in the J, H, and K bands. Among these observations, a dozen disks reveal well-marked ring structures, perfectly suited to analysis with `DRAGyS`. This panel represents a new application for our tool, both in terms of statistical analysis of SPFs over the whole set of disks, and in terms of specific studies of remarkable cases, some of which have several rings or have been observed at different wavelengths. We will present the preliminary results and trends on dust properties provided by the SPFs from this large sample. This represents a key step forward in constraining dust evolution.

JWST and PAHs in Protoplanetary Disks: Placing Constraints on the PAH Properties and Disk Structures

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1. University of Missouri 2. Korea Astronomy and Space Science Institute

The 3.3, 6.2, 7.7, 8.6 and 11.3 μm emission features of polycyclic aromatic hydrocarbon (PAH) molecules have been detected in protoplanetary disks (PPDs) around Herbig Ae/Be stars and T Tauri stars. PAHs are present at the disk surfaces and even in the cavity or gaps from which large grains are missing. They play an important role in the thermal budget and chemistry of the gas in PPDs, by providing photoelectrons for heating the gas and large surface areas for chemical reactions. Stochastically heated by a single UV/visible photon, PAH emission is spatially more extended than large grains and therefore, PAH emission can resolve PPDs more easily and is a powerful tracer of the disk structure.

Due to their limited sensitivities, it was not possible for ISO or Spitzer to spatially resolve PAH emission in PPDs. Indeed, so far almost all spatially-resolved observations of PAH emission were made by ground-based telescopes. Also, the low detection rate of PAH emission in T Tauri disks is probably related to their faintness. With its unprecedented sensitivity, JWST is expected to detect and spatially resolve PAH emission at all the major bands in a much larger sample of Herbig Ae/Be and T Tauri disks. This will enable far more detailed band analysis than previously possible.

To facilitate the analysis, interpretation and modeling of the incoming JWST data of PAH emission in PPDs, we develop a PAH spectral and band-ratio (i.e., $I_{6.2}/I_{7.7}$, $I_{11.3}/I_{7.7}$) library. This library will serve as a quantitative diagnostic tool for determining the PAH size and ionization fraction from the observed band ratios of the PAH emission features at 6.2, 7.7 and 11.3 μm.

We calculate the IR emission spectra of both neutral and ionized PAHs of various sizes, located at various radial distances (from the central star) in PPDs around stars of a wide range of spectral types and of several representative luminosities. We create a library of PAH model emission spectra and model band ratios and generate a series of diagrams of $I_{6.2}/I_{7.7}$ vs. $I_{11.3}/I_{7.7}$. To demonstrate the effectiveness of this diagnostic tool, we apply the model $I_{6.2}/I_{7.7}$ vs. $I_{11.3}/I_{7.7}$ diagrams to infer the PAH size and ionization fractions of a number of PPDs of representative properties (for all of which PAH emission has been detected and spatially resolved).

Collision Simulations of Compressed Icy Dust Aggregates: Probing the Sticking-Bouncing Boundary

Haruto Oshiro[1], Misako Tatsuuma[2], Satoshi Okuzumi[1], and Hidekazu Tanaka[3]

[1]*Department of Earth and Planetary Sciences, Institute of Science Tokyo, Japan,* [2]*Divisions of Fundamental Mathematical Sciences, RIKEN Center for Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS), Japan,* [3]*Astronomical Institute, Graduate School of Science, Tohoku University, Japan*

Understanding the collisional evolution of dust aggregates is crucial for unravelling planetesimal formation. Recent millimeter-wave polarimetric observations suggest the existence of relatively compact icy dust aggregates (e.g., Zhang et al. 2023). Compact dust aggregates not only stick or fragment upon collision but also bounce (e.g., Güttler et al. 2010). Some previous simulations have shown that the bouncing collisions have a significant effect on dust growth in protoplanetary disks (e.g., Zsom et al. 2010; Dominik & Dullemond 2024).

However, the conditions under which bouncing occurs are not well understood. Previous experiments with SiO_2 aggregates (e.g., Kothe et al. 2013) or icy aggregates (e.g., Schräpler et al. 2022) have shown that larger aggregates are more likely to bounce at lower velocities. In contrast, previous collision simulations of icy dust aggregates have indicated that larger aggregates are more likely to bounce, but do not show a significant velocity dependence (Arakawa et al. 2023).

In this study, we performed a suite of collision simulations of moderately compact icy dust aggregates with various impact velocities, aggregate radii, and filling factors between 0.4–0.5 (Oshiro et al. 2025). Unlike previous simulations, we generate compact aggregates by compressing fluffy aggregates — known as ballistic cluster-cluster aggregates (BCCAs) — mimicking the natural process through which compact aggregates form. Icy particles in the aggregates are 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 the impact velocity for all tested filling factors, in qualitative agreement with previous experiments. We also find that the threshold aggregate mass for bouncing decreases sharply with increasing the aggregate filling factor. An energy analysis reveals that approximately 90% of the initial impact energy is dissipated during the collision, resulting in a restitution coefficient of about 0.1.

Using our results from collision simulations, we estimate the effect of the bouncing barrier on dust growth in protoplanetary disks. Dust aggregates stop growing at sizes of the order of 100 μm, almost independently of other factors such as radial distance from the central star or gas surface density. This value is in agreement with millimeter-wave polarimetric observations (Kataoka et al. 2015). Although bouncing-limited aggregates are too small to trigger the streaming instability (Lim et al. 2025), their concentration within the smallest turbulent eddies can still lead to planetesimal formation (Cuzzi et al. 2001).

Dust Entrainment in External Photoevaporative Winds: Theory and Observation

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[1]*Queen Mary University of London, U.K.*

The environment in which circumstellar discs evolve plays a crucial role in their evolution, and the eventual formation of planets. Stars commonly form in stellar clusters, so most discs and planets form in environments with at least some external radiation, which irradiates the gas and dust in these discs. An important, but under-studied aspect of this is what sizes of dust get entrained in the disc wind. This affects the amount and position of planet-forming solids, as well as having a feedback-loop effect by shielding the disc from further UV radiation. We hence need to understand the grain sizes and amounts that are entrained in winds to understand gas and dust mass loss rates from these discs.

We have developed a particle solver to track the entrainment of dust in multi-dimensional simulations of photo-evaporating discs. This code was benchmarked against Weidenschilling (1977) and we validated an existing analytic estimate in 1D by Facchini et al. (2016). However, we found the situation more complex for 2D axisymmetric models, with significant angular variation in entrained dust sizes between the midplane and above the disc surface. From the disc surface, only sub-micron dust was entrained, while up to 100μm dust grains could be entrained from near the midplane of the disc outer edge. Interestingly, however, as the opacity to UV radiation is dominated by smaller dust (on the order of 0.1μm), our models predict that the shielding should be uniform in all directions, even if the dust size distribution is not. This has implications for the structure of gas mass loss and observational characteristics of proplyds. For example, HST has observed dark lanes emanating from the outer edge of silhouette discs in Orion (e.g. Ricci et al. (2008)), but not from above the discs, consistent with the outcomes of our models.

Here, we present synthetic observations of these evaporated disc models at various wavelengths, including IR, optical and mm and discuss what can be learned from them. We will focus on recovering dust grain sizes from optical and IR images, as well as what can be learned about the dust composition and disc structure from spectra and mm images.

A systematic study of dust in the harsh environments of AGNs with AKARI, Spitzer, and JWST infrared spectroscopy

Hidehiro Kaneda[1], Risako Katayama[1], Tsubasa Kondo[1], Takuro Tsuchikawa[1], Shinki Oyabu[2], and Takuma Kokusho[1]

[1]Nagoya University, Japan, [2]Tokushima University, Japan

In general, active galactic nuclei (AGNs) in their early evolutionary phases are surrounded by dense clouds in the circumnuclear regions. In such early phases, the activity of AGNs is usually quite high, and thus expected to significantly influence the physical and chemical properties of the dust in the clouds surrounding AGNs through mechanical shocks by energetic jets and irradiation by high-energy photons. Indeed, it is observationally known from past studies that, for instance, the crystallinity of silicate grains in AGNs tends to be high, while the abundance of polycyclic aromatic hydrocarbons (PAHs) is considerably low, as compared to the properties of interstellar dust typical of the diffuse ISM in our Galaxy or usually observed in star-forming galaxies.

In this presentation, we show the results of our systematic study on the properties of silicate and hydrocarbon dust under the influence of the AGN activity, which are revealed by Spitzer mid-infrared and AKARI near-infrared spectroscopy for about 100 infrared-bright AGNs. We find that the crystalline mass fractions of the total silicate are significantly high, 5.8% on average, for the AGNs, compared to 1.4%, a value along the line of sight toward Sgr A* in our Galaxy, while the amorphous pyroxene mass fractions of the total silicate are significantly low, 5.1% on average, for the AGNs, compared to 17%, a value typical of the diffuse ISM in our Galaxy. We also find that the aliphatic-to-aromatic ratios of hydrocarbons are systematically higher for the AGNs than for star-forming galaxies, which tend to increase with the AGN activity traced by the hot dust emission, with the aliphatic emission features at 3.4 - 3.6 μm showing unusual profiles stronger at longer wavelengths as compared to those of star-forming galaxies. Hence the silicate and hydrocarbon dust in the AGNs both seem to be processed significantly in the circumnuclear regions, their properties changed through the AGN activity.

Based upon those results, we suggest that the crystalline-rich and pyroxene-poor tendencies of the silicate in the AGNs may be attributed to crystallization and differentiation through heating processes related to the AGN activity, while the relatively abundant aliphatic hydrocarbon dust with the unusual spectral emission features may come from a new population created through mechanical processes such as shattering of large carbonaceous grains by AGN outflows. In order to verify the hypothesis, a spatially-resolved study using the JWST data is crucial; several AGNs in our sample have already been observed with JWST. In this presentation, therefore, we also show a tentative result of our analysis on the spatial variations of the silicate and hydrocarbon features utilizing the JWST archival data.

A Framework for Probing Dust Clump Properties in High-Redshift Galaxies Through Dust and Chemical Evolution Modeling

Ryusei Kano[1], Tsutomu T. Takeuchi[1,2]

[1]Nagoya University, Japan, [2]The Institute of Statistical Mathematic, Japan.

In the context of galaxy evolution studies, interstellar dust plays a fundamental role in shaping various physical processes, notably affecting the spectral energy distribution (SED), which characterizes how energy is emitted across different wavelengths, as well as influencing the star formation history. To capture these processes comprehensively, this study employs a theoretical framework that simultaneously models both chemical and dust evolution. Here, chemical evolution refers to the progressive change in elemental abundances due to stellar activity, while dust evolution accounts for the formation, growth, and destruction of dust grains within the interstellar medium.

Based on this framework, we developed a galaxy SED model capable of reproducing the observed SEDs of local (nearby) galaxies. However, when extending this model to galaxies at high redshift (e.g., z~8), modifications become necessary to account for intrinsic differences in their physical properties. This work focuses on refining the theoretical formulation of the SED model to improve its applicability to extremely high-redshift galaxies.

A key refinement involves the treatment of dust-rich molecular clouds—often referred to as "clumps"—surrounding newly formed stars. These clumps are assumed to be spherically symmetric for radiative transfer calculations. Given that high-redshift galaxies are generally more compact in structure, we posit that the dust clumps in these environments possess higher internal densities than those in nearby galaxies. By decoupling the clump radius from the global galactic properties and enhancing the dust number density within these regions, the model more accurately reproduces the elevated dust emission seen in observations of early galaxies.

Furthermore, we have implemented Markov Chain Monte Carlo (MCMC) methods to optimize model parameters more robustly. This statistical approach allows for a more precise exploration of parameter space, enabling tighter constraints on physical properties such as clump density, size, and dust-to-gas ratio. As a result, the improved model yields simulations that align more closely with observed SEDs and supports the interpretation that early galaxies harbor dust clumps with significantly higher number densities than their local counterparts.

Analysis of grain size evolution using an extended two-size approximation model

Ryo Igarashi[1], Ryoichi Nishi[1]

[1]*Niigata University, Japan*

In this presentation, we construct a dust evolution model that extends the two-size approximation [1] to a two-phase medium consisting of hot and cold gas. We then discuss the resulting evolution of dust grain sizes.

Dust is thought to influence galaxy evolution by promoting star formation through processes such as molecule formation on grain surfaces, radiative cooling, and UV shielding. It is also believed to affect the spectral energy distribution of galaxies. Since these effects depend on dust size and composition, developing detailed dust evolution models is crucial not only for theoretical studies but also for interpreting observations. Although a full calculation of the size distribution is ideal for modeling dust evolution, it is computationally expensive. However, the essential characteristics of dust evolution can still be captured by using a simplified two-size approximation model, separating grains into large and small populations. Therefore, we adopt the two-size approximation as a first-order approach in our calculations.This method based on Hirashita(2015) [1].

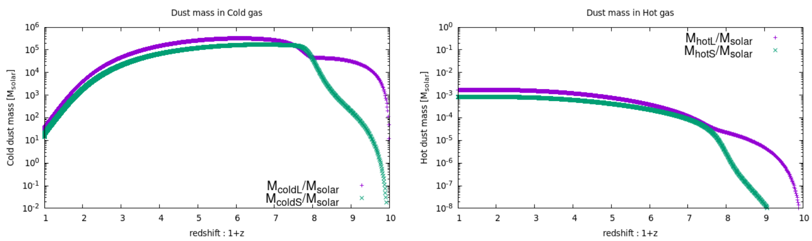

Figure 1: Dust mass evolution in cold gas (left) and hot gas (right) as a function of redshift.The purple and green solid lines correspond to large grains and small grains, respectively.

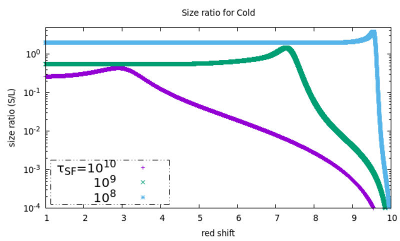

Figure 2: Variation in the small-to-large dust mass ratio for different star formation timescales.

The results of our calculations are shown in Figures 1, and 2. Figure 1 presents the evolution of dust mass in cold gas as a function of redshift. Initially, large grains dominate the dust population, but around redshift $z \sim 8$, the masses of small and large grains become comparable. Eventually, the dust masses of both size populations reach similar values.

Figure 2 shows the evolution of the small-to-large dust mass ratio as a function of redshift for different star formation timescales. The fiducial model corresponds to a star formation timescale of $\tau_{\rm SF} = 5 \times 10^9$ [year]. In the case of a shorter timescale ($\tau_{\rm SF} = 5 \times 10^8$ [year]), the ratio of small dust grains was found to increase sharply in the early stages, and small grains remained dominant thereafter. This behavior is expected to occur in environments with intense starburst activity, such as in early galaxies, and may have a significant impact on our understanding of galaxy evolution.

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Polycyclic aromatic hydrocarbon and the ultraviolet extinction bump at the cosmic dawn

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First detected in 1965, the mysterious ultraviolet (UV) extinction bump at 2175 Å is the most prominent spectroscopic feature superimposed on the interstellar extinction curve. Its carrier has remained unidentified over the six decades since its first detection, although many candidate materials have been proposed. Widely seen in the interstellar medium of the Milky Way as well as several nearby galaxies, this bump was recently also detected by the James Webb Space Telescope (JWST) at the cosmic dawn in JADES-GS-z6-0, a distant galaxy at redshift z ≈ 6.71, corresponding to a cosmic age of just 800 million years after the big bang. Differing from that of the known Galactic and extragalactic interstellar sightlines, which always peak at ~2175Å, the bump seen at z ≈ 6.71 peaks at an appreciably longer wavelength of ~2263 Å and is the narrowest among all known Galactic and extragalactic extinction bumps. Here we show that the combined electronic absorption spectra quantum chemically computed for a number of polycyclic aromatic hydrocarbon (PAH) molecules closely reproduce the bump detected by JWST in JADES-GS-z6-0. This suggests that PAH molecules had already been pervasive in the Universe at an epoch when asymptotic giant branch stars had not yet evolved to make dust.

Exploring the Dusty Hearts of Active Galactic Nuclei: Constraints from Mid-Infrared and X-ray Simultaneous Torus Modeling

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Dust in the nuclear regions of active galactic nuclei (AGNs) is key to understanding their observational properties and the interplay between radiation and the interstellar medium in extreme environments. This study presents a multi-wavelength analysis of 24 nearby AGNs classified as Seyfert galaxies using simultaneous spectral fitting of Spitzer mid-infrared and NuSTAR X-ray data. By combining physically motivated torus models across both regimes, we constrain the geometry, spatial distribution, and physical properties of the obscuring dust and gas.

Our results indicate that the dust and gas associated with AGN are co-located within 10 parsecs of the central engine. We observe a strong correlation between AGN classification and accretion properties with dust parameters, such as covering factor and half-opening angle. Additionally, more luminous AGNs appear to host more extended dusty structures.

Our findings reinforce the connection between circumnuclear dust and gas properties and AGN activity. Expanding this approach to larger samples and incorporating upcoming data from facilities such as JWST and XRISM will be key to unveiling the full complexity of dust in galactic nuclei. Moreover, studying AGN dust in conjunction with gas across multiple wavelengths not only refines our models of obscuration but also addresses broader questions in galaxy evolution, feedback processes, and the lifecycle of cosmic dust in extreme environments.

Magnetically Aligned Dust as a Source of Chiral Symmetry Breaking via Spin-Polarized Electrons

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The homochirality of organic moleculessuch as amino acids and sugars is a defining biosignature of life on Earth, yet its origin remains a fundamental question in astrobiology. Spin-polarized electrons (SPEs) from the -decay of radioactive nuclei have been proposed as a possible mechanism for chiral symmetry breaking, though their role is still under debate. In this work, we propose a novel source of low-energy SPEs: magnetically aligned interstellar dust grains. These grains can emit spin-aligned electrons via the Barnett effect, triggered by interstellar UV radiation and cosmic rays (CRs). We focus on protostellar environments, where we demonstrate that icy grains can achieve magnetic alignment through a radiative torque mechanism enhanced by magnetic susceptibility. We then investigate how CRs produce thermal electrons via ionization of H_2 and CR-induced UV radiation, using an attenuated CR spectrum derived from a continuous slowing down model. These thermal electrons, initially unpolarized, become spin-polarized upon capture by aligned grains due to the Barnett effect, effectively converting them into secondary low-energy SPEs. We suggest that these SPEs, especially those emitted by superparamagnetic grains with substantial iron inclusions, can induce chiral asymmetry in prebiotic molecules formed within ice mantles, similar in effect to circularly polarized UV light. This mechanism offers a compelling pathway for the origin of molecular homochirality in the early stages of star and planet formation.

References:

Thiem Hoang 2025, ApJ, in press: arXiv:2410.02291

Thiem Hoang 2024 ApJ 976 26

Submillimeter excess emission from very small dust grains as a cause of Galactic dust spectral flattening

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Observations of the Galactic dust emission spectrum have revealed a flattening at far-infrared to millimeter (mm) wavelengths [1], deviating from what is expected from an ideal crystalline grain. Although several models have been proposed to explain this spectral flattening (e.g., emission from the very cold dust, magnetic nanoparticles, and amorphous dust), the underlying cause remains unresolved.

We propose that the sub-mm excess emission from very small dust grains (VSGs), predicted based on our new emission model [2], is responsible for the observed spectral flattening. In this emission model, we treat VSGs as mesoscopic systems — an intermediate scale between microscopic and macroscopic with unique physical properties. In such systems, the quantization of vibrational energy levels results in a minimum excitation energy equivalent to ~50 K, meaning that the thermal properties of VSGs can no longer be described by lattice vibrations below ~50 K. To address this, we applied a method of energy level statistics [3] to describe the low-temperature thermal properties of VSGs in terms of free electrons. This model enhances the emission from low-temperature carbonaceous VSGs, which possess free electrons, resulting in an excess emission in the sub-mm wavelengths.

To test our hypothesis, we derive dust size distributions that include both carbonaceous and silicate grains and are consistent with observed extinction and emission spectra by varying the carbonaceous dust constituents. Using these size distributions, we calculate the expected emission spectra under our new VSG model and compare them to observational data.

In this presentation, we will discuss whether the sub-mm excess emission predicted by the carbonaceous VSG model can account for the observed spectral flattening and evaluate how well it improves the fit compared to conventional models.

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Very Large Interstellar Grains as Evidenced by the X-ray Halo of Nova Cygni 1992

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The small-angle scattering of X-rays by interstellar dust produces a diffuse "halo" within approximately a 1° region around the X-ray point source. The total X-ray scattering cross-section is proportional to the fourth power of the dust grain size, while the X-ray differential scattering cross-section scales with the sixth power. As a result, X-ray halos serve as effective probes of large-sized dust grains. Using a dust model containing very large interstellar grains, we model the X-ray halo and compare it with observations of Nova Cygni 1992. We find that silicates are the primary contributors to X-ray halo formation. When the observation angle θ is less than 100″, differences among dust models become significant, but no data are available to validate them. For θ below 50″, the influence of large-sized dust grains becomes particularly prominent. Observational data at small angles are therefore essential to discriminate among the three dust models.

Extinction Law of Nearby Molecular Clouds Based on the LAMOST, 2MASS, and Gaia Surveys

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[2]*National Astronomical Observatories, Chinese Academy of Sciences, China*

[3]*Center for Astrophysics, Guangzhou University, China*

The extinction law from ultraviolet (UV) to infrared (IR; 0.2–24 μm) is determined by relying on the blue-edge method and color-excess ratios for some nearby molecular clouds (Taurus, Orion, Perseus and California), from the low-mass star-forming region to the massive star-forming region. The observational data are collected from nine photometric surveys, along with stellar parameters from the Apache Point Observatory Galaxy Evolution Experiment and LAMOST spectroscopic surveys. Within the uncertainties, the optical ratio of selective to total extinction (R_{GBP}) does not vary substantially across the clouds, irrespective of the density, specifically R_{GBP}=2.302+-0.027, where $R_{GBP}= A_{GBP}/E(G_{BP}- G_{RP})$. The IR extinction law is consistent with Wang & Chen 2019. The extinction law in the UV band is compromised by the shallow depth with $A_V \leq 2$ mag and is hard to describe by one parameter R. In addition, the extinction in the WISE/W1 band is significantly larger than in the Spitzer/IRAC1 band in the dense regions, which is attributed to the ice water absorption.

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 analogues 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.

Diffuse Galactic Light in Deep Wide-field Imaging by the Dragonfly Telephoto Array

Qing Liu[1], Peter Martin[2], Roberto Abraham[3], Pieter van Dokkum[4], and William Bowman[4], and Steven Janssens[5]

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Interstellar dust grains in the Milky Way (MW) absorb and scatter the interstellar radiation field (ISRF), producing diffuse radiation referred to as the diffuse Galactic light (DGL), which is one of the major manifestations of the diffuse interstellar medium (ISM). The DGL is resolved into wispy, filamentary structures in dust emission at high Galactic latitudes by all-sky infrared mapping, which became known as 'Galactic cirrus'. Observations of Galactic cirrus can offer unique insights into the physical properties of dust grains (e.g., size distributions, compositions, albedos), scattering anisotropy, and the characteristics of the incident ISRF.

Observations of the optical DGL, however, have not yet been utilized extensively as a tool to study the diffuse ISM, because in the optically-thin regime the signal is very faint, typically only a few percent as bright as the night sky (>26 mag/arcsec^2 in g-band). This leads to the signal being susceptible to various systematics. Only recently have advancements in instrumental design and data reduction tailored for low surface brightness (LSB) science largely mitigated the challenges. These improvements have facilitated the imaging of the optical DGL, opening new opportunities to study the scattered light from MW dust.

In this presentation, I will talk about imaging of the optical cirrus obtained with the Dragonfly Telephoto Array, a telescope optimized for LSB science through its novel instrumental design and data reduction dedicated to control the systematics. By incorporating priors from Planck thermal dust models into sky modeling, we are able to preserve the radiometry of dust-scattered light. Applying these techniques to the ongoing DragonFly Ultra Wide Survey (DFUWS) will provide the community with an unprecedentedly wide ($\sim$10,000 deg^2) sky area of dust foreground map down to 28.5 mag/arcsec^2 in SDSS g-band. I will present early results based on Dragonfly observations using complementary statistical approaches – including intensity statistics and power spectrum analysis – and compare them with those derived from Herschel, WISE, and Planck data. Our findings offer promising avenues for linking the analysis of coherent structures traced by dust-scattered light to the underlying physical processes (e.g., the turbulence cascade) in the ISM. Finally, I will demonstrate why an unbiased characterization of the dust foreground from direct imaging is crucial for extragalactic LSB studies in the era of the forthcoming Vera C. Rubin Observatory.

The survey is expected to be completed this year and will be publicly available. While the survey primarily targets extragalactic science such as ultra-diffuse galaxies, we invite collaborations from the dust community to exploit the broad potential of this dataset across fields.

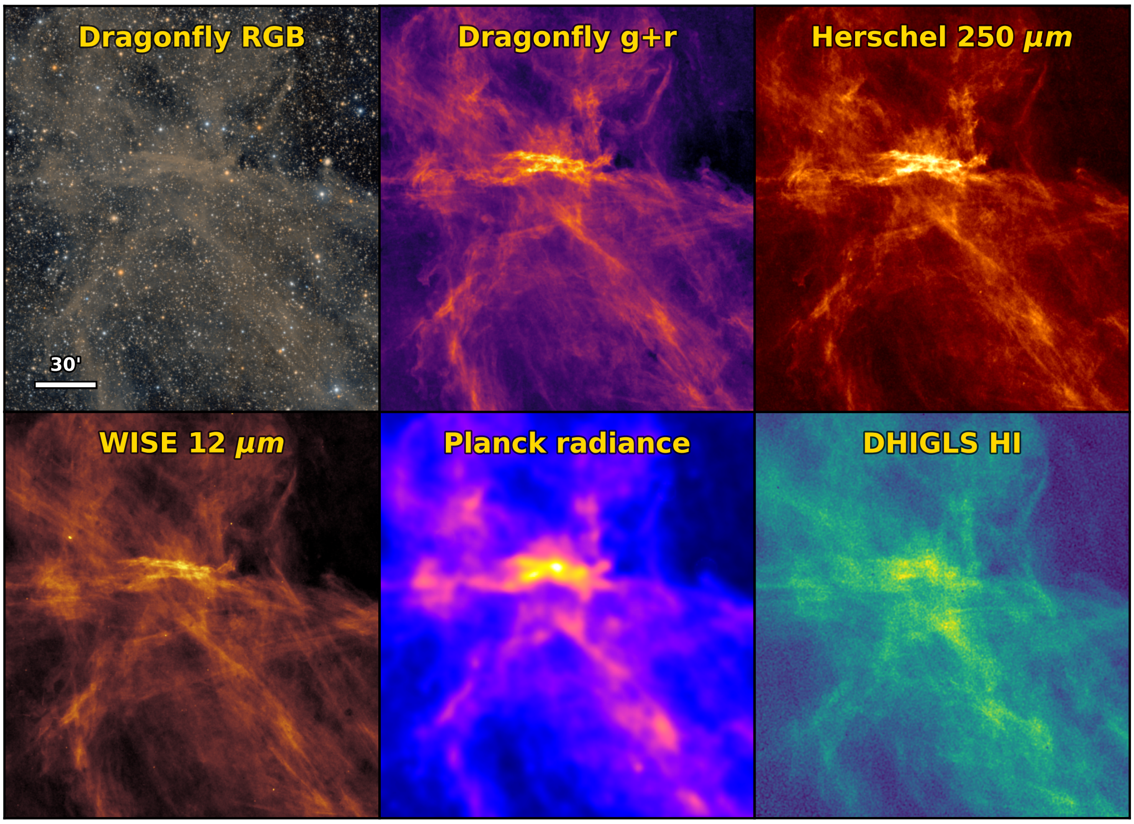

Figure 1: Example dataset of the DGL in different dust tracers. (Liu et al. to be submitted)

Atmospheric and Dust Properties of Brown Dwarfs Based on JWST Observations

Shu Wang

National Astronomical Observatories, Chinese Academy of Sciences, China

Brown dwarfs are substellar objects with masses between the heaviest gas giant planets and the lightest stars, exhibiting complex and dynamic atmospheric processes. Investigating their atmospheric structure, chemical composition, and dust characteristics is essential for understanding the physics and chemistry of low-temperature atmospheres, as well as improving models of stellar evolution and planet formation.

With effective temperatures generally ranging from approximately 250 to 2500 K, brown dwarfs are cool enough to allow the formation of atmospheric dust clouds composed of high-temperature condensates such as metal oxides and silicates. Additionally, young brown dwarfs may retain circumstellar dust disks from their formation stages. However, due to their low temperatures and infrared-dominated radiation, systematic observations of brown dwarfs have historically been limited by instrumental capabilities, resulting in a relatively small number of confirmed objects and limited related studies.

The James Webb Space Telescope (JWST), with its exceptional infrared sensitivity, provides an unprecedented opportunity to investigate the atmospheric and dust properties of brown dwarfs in detail. Based on JWST/NIRSpec and MIRI observations, we analyzed the spectra of 20 extremely cold brown dwarfs, identifying prominent absorption features from H_2O, CH_4, and NH_3. In even colder objects, absorption lines of CO and CO_2 were also detected. Furthermore, we conducted a systematic search of over 40,000 JWST/NIRSpec PRISM-mode spectra, identifying 65 brown dwarf candidates with effective temperatures below 2000 K, including 13 newly discovered objects. Based on these brown dwarfs, we will further investigate their molecular compositions, dust characteristics, and circumstellar environments.

Probing the baryon cycle of primordial galaxies: Insights from ALPINE survey with HST, ALMA and JWST

Prasad Sawant[1]

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Observational facilities such as Atacama Large Millimeter/submillimeter Array (ALMA) and James Webb Space Telescope (JWST) have propelled astronomy into a new era. With an increasing influx of observations, we are encountering cosmic objects that challenge our theoretical frameworks. In particular, recent studies reporting unexpectedly large reservoirs of gas and dust in high-redshift galaxies challenge our current understanding of dust formation processes in the early Universe.

In this work, we employ chemical evolution models to investigate the build-up of gas and dust within star-forming galaxies at redshift of ~ 5, observed by the ALMA Large Program ALPINE. These galaxies, formed within the first billion years after the Big Bang, represent a critical epoch during which the Universe transitioned from primordial structure formation to the onset of the cosmic star formation peak. The ALPINE survey benefits from the panchromatic observations providing fundamental information about their gas/dust content, their morphological and kinematical properties and mechanisms influencing their baryonic cycle highlighted in the studies in recent years.

We model the evolution of gas and dust in these galaxies by incorporating various dust production pathways, including Type Ia and II supernovae, asymptotic giant branch (AGB) stars, and grain growth within the interstellar medium (ISM). Our models reproduce the observed gas and dust masses for the majority of the sample, highlighting the dominant role of Type II supernovae and ISM grain growth in dust production, removal of gas and dust via galactic outflows and moderate accretion of pristine gas. However, a subset of galaxies exhibit rapid dust enrichment on remarkably short timescales (~ 20 - 100 Myr), which cannot be fully accounted for using standard prescriptions. This fast dust production is partially explained by adopting a top-heavy initial mass function (IMF), thus favoring the formation of more massive stars and a more rapid dust production.

I will also discuss the role and synergies between ALMA and JWST in advancing our understanding of chemical enrichment in the early Universe. With new ALPINE observations from JWST, I will discuss their role in constraining the IMF and the nature of dust production in these primordial galaxies.

Exploring the dependence of PAH emission on metallicity and starlight spectrum in M101

Bo Yang and Aigen Li
University of Missouri Columbia, Missouri, USA

Polycyclic aromatic hydrocarbon (PAH) molecules are abundant and widespread throughout the Universe, as revealed by their distinctive set of emission bands at 3.3, 6.2, 7.7, 8.6, and 11.3 micron. The excitation of PAH emission depends on the spectrum or "hardness" and intensity of the illuminating starlight. Exposed to a harder radiation field, PAHs are transiently heated to higher temperatures and therefore emit more at 3.3, 6.2 and 7.7 micron than at 11.3 micron. On the other hand, "hard" photons could potentially also photo-dissociate PAH molecules. Observationally, it is also well recognized that PAH emission is also affected by metallicity: PAH emission is deficient or lacks in low-metallicity galaxies, although the exact reason is not clear. The giant, face-on spiral galaxy M101, also known as the Pinwheel galaxy, is ideal for exploring the dependence of PAH emission on metallicity and starlight "hardness" and intensity. At a distance of 6.7 Mpc, M101 has one of the largest metallicity gradients as well as starlight hardness and intensity gradients among SINGS member. Spatially-resolved PAH emission obtained by Spitzer/IRS revealed considerable variations M101 from the nucleus to outer regions. We have modeled the PAH excitation and emission in M101, revealing the dependence of PAH emission on metallicity, starlight "hardness" and intensity.

How does the JWST impact on our understanding of interstellar dust grains?

Takashi Onaka
University of Tokyo

JWST observations provide an unprecedented quality of infrared data for the study of interstellar physics and chemistry as well as interstellar dust grains. This talk focuses on the JWST observations of the Orion Bar region, an Early Release Science (ERS) program, PDR4sAll, Radiative Feedback from Massive Stars (Berné et al. 2022; Habart et al. 2024; Peeters et al. 2024). The observations have been successfully performed to obtain near- to mid-infrared spectra across the ionized to molecular regions of the Orion Bar, a prototypical photo-dissociation region, with NIRSpec and MIRI/MRS integral field units (IFUs). They provide significant data for Aromatic Infrared Bands (AIBs) and their carriers (Chown et al. 2024; Elyajouri et al. 2024; Pasquini et al. 2024; Goicoechea et al. 2025; Khan et al. 2025). This talk gives an overview of the observations of PDRs4All and discusses several results relating to interstellar dust grains. A study of excess emission in the near-infrared continuum based on the spectroscopic observations of the Orion Bar is also presented.

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The Lack of Spectral Diversity of the Aromatic Infrared Bands: Implications for the PAH Hypothesis

Alan T. Tokunaga[1], Lawrence S. Bernstein[2], Takashi Onaka[3]

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The emission profiles from the main Aromatic Infrared Bands (AIBs) at 3.3, 6.2, 7.7, 8.6, 11.3, and 12.7 μm show a notable lack of spectral diversity. These strong emission bands are assumed to arise from polycyclic aromatic hydrocarbons (PAHs). Both *JWST* and *ISO SWS* spectra show only small variations in the red wing of the 3.3 μm AIB and the blue wing of the 11.2 μm AIB, regardless of excitation conditions or whether the AIB carrier was recently produced in a planetary nebula or was highly processed in the diffuse interstellar medium. Examples are shown in Fig. 1 and 2. This suggests that there is a uniform set of PAHs and a uniform excitation temperature of the PAHs in all sources, and we critically examine the consequences of this for the PAH Hypothesis.

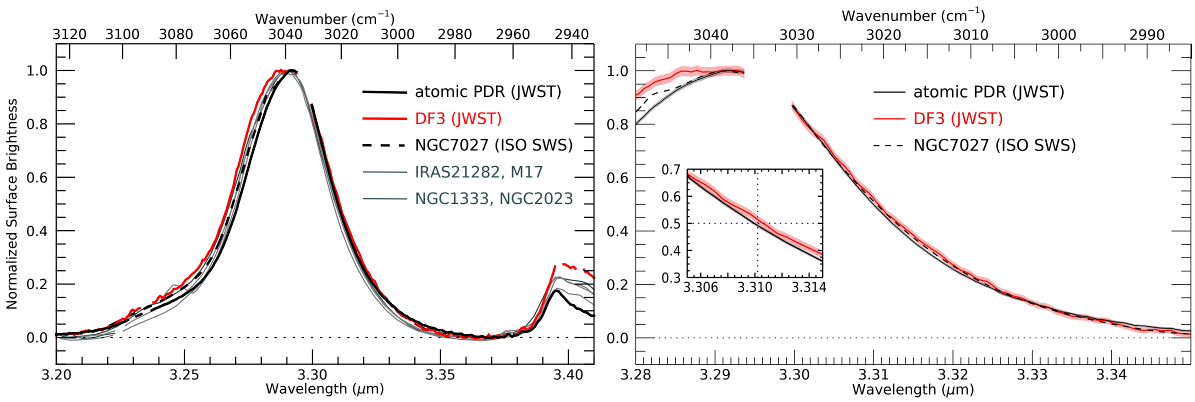

Figure 1: (left) Comparison of the 3.3 μm AIB *JWST* Orion Bar spectrum of the atomic PDR and DF3 regions to the *ISO SWS* spectra of NGC 7027, IRAS 21282+5050, M17, NCG 1333, and NGC 2023. The continuum, plateau, and emission lines have been removed. (right) Expanded view of the red wing of the 3.3 μm AIB.

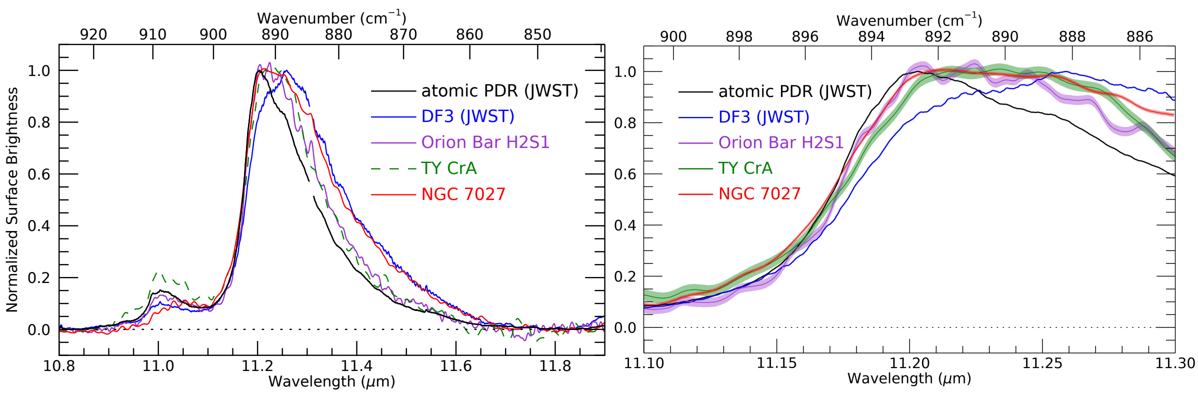

Figure 2: (left) Comparison of the 11.2 μm AIB *JWST* Orion Bar spectrum of the atomic PDR and DF3 regions to the *ISO SWS* spectra of the Orion Bar H2S1, TY CrA, and NGC 7027. The continuum, plateau, and emission lines have been removed. (right) Expanded view of the blue wing of the 11.2 μm AIB. The DF3 spectrum has an 11.25 μm component that affects the blue wing when normalized as shown in this plot.

Japanese-German Cooperation in Space Science

Carsten Henselowsky[1]

[1]*German Aerospace Center – German Space Agency, Germany*

Japan and Germany have been working together in the aerospace sector for more than forty years. Today, the Joint Space Declaration, signed between the Federal Ministry of Economic Affairs and Energy of Germany and the Cabinet Office of Japan in 2020, forms the political framework for cooperation between the two nations in the space sector.
At Space Agency level, the Strategic Partnership is reinforced by an Inter Agency Agreement signed in 2022 between Japanese Space Agency JAXA and German Aerospace Center DLR. The regular exchange on the topics of Earth Observation, Space Science & Exploration, Human Spaceflight & Space Research, Space Sustainability is part of the DLR-JAXA Strategy Dialogue.

In the field of space science, the cooperation's on Hayabusa 2, GALA/JUICE, BepiColombo, as well as on future missions MMX and DESTINY+ are prominent examples of the successful collaboration between Japan and Germany.

Dust Detection Reimagined: New Insights from the DESTINY+ DDA

The 15th Meeting on Cosmic Dust at Osaka Sangyo University, Osaka, Japan on Tuesday, September 16, 2025 - Saturday, August 20, 2025

Denis Acker[1], Jonas Simolka[1], Heiko Strack[1], Janwei Li[1], Florian Rieth[1], Ralf Srama[1]

[1] *Institute of Space Systems (IRS), University of Stuttgart, Germany*

The DESTINY+ Dust Analyzer (DDA) serves as the primary scientific instrument on the DESTINY+ mission, focusing on in situ analysis of cosmic dust. It examines interplanetary and interstellar dust within 1 AU of the Sun and explores the dust environment surrounding asteroid (3200) Phaethon. By integrating a trajectory sensor with a time-of-flight mass spectrometer, the DDA captures data on the size, velocity, charge, and composition of individual dust grains. Its two-axis pointing system enhances sky coverage, establishing the DDA as a crucial tool for advancing our understanding of cosmic dust streams and composition throughout the DESTINY+ trajectory.

The recent completion of the DDA flight hardware, combined with its extensive dust accelerator test campaign, has significantly enhanced our understanding of DDA's detection and diagnostic capabilities. These initiatives validated the instrument's performance across various particle sizes and speeds, confirming its ability to detect and analyse individual particles down to submicron dimensions. The test campaign demonstrated precise trajectory reconstruction and reliable mass spectral identification, even for complex and diverse dust samples. Additionally, impact simulations performed at realistic interplanetary and near-Phaethon velocities confirmed that DDA's high resolution enables it to identify spectral signatures of elements, including sodium. These signatures are crucial for comprehending the contentious activity mechanisms of Phaethon, which may include thermal fracturing, surface dehydration, or thermal breakdown of rock-forming minerals- processes recognised to emit volatiles such as sodium on other inner solar system bodies.

This talk summarises the recent test results, highlights performance improvements achieved through the calibration of PFM software and provides a scientific perspective on how these advancements enhance DDA's capability to detect dust during the Phaethon flyby (approximately 500 km altitude) and throughout the cruise phase compared to previous instruments.

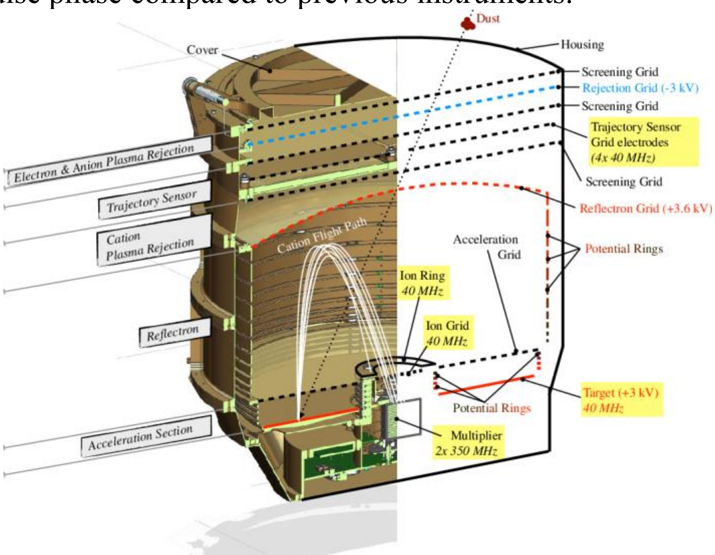

Figure 1: Schematics of the DDA sensor head. Dust enters from the top. Structures drawn in black are electrically grounded. Blue represents negative bias voltages, whereas red represents positive bias voltages. The labels with a green background indicate the locations of measurements. The number of measurement channels and digitisation frequency are given. On the left side of the figure, the flight path of the cations is illustrated.

Investigating scattering by the impact induced ejecta curtain using the grid of its radiative transfer models

Keerthana U[1], P Shalima[1], Koji Wada[2], Johannes Markkanen[3], Hiroshi Kimura[2], Yasumasa Kanada[2] and Takafumi Matsui[2]

[1] *Manipal Centre for Natural Sciences, Manipal Academy of Higher Education, Karnataka, Manipal, 576 104, India,* [2] *Planetary Exploration Research Center, Chiba Institute of Technology, Tsudanuma 2-17-1, Narashino, Chiba –275-0016, Japan,* [3] *Institute of Geophysics and Extraterrestrial Physics, TU Braunschweig, Mendelssohnstrasse 3, Braunschweig, 38106, Germany*

One of the ways to understand the formation and evolution of dust grains in the solar system is through the study of impacts. Impact cratering of celestial bodies produces ejecta curtains that include the underground material excavated from crater cavities and form inverted conical so called ejecta cone. Therefore, studies of ejecta curtains help us in understanding the size distribution of subsurface grains and the surface evolution. As the in-situ measurements of ejecta curtains from planetary bodies are unavailable in most of the cases, we could use the already available observations, such as the images taken at the Hayabusa2's impact experiment, together with Monte-Carlo radiative transfer models to constrain the size and composition of less-processed grains in the underneath regolith layers of planetary bodies. Here we analyze how the predicted scattered intensities of the ejecta curtain are sensitive to different compositions, sizes and phase function of grains composing the ejecta curtain. In our model, the density of the ejecta curtain is assumed to decrease from the base to the upward direction of an ejecta cone. Further the phase function is compared with the often used Henyey-Greenstein(HG) phase function. We find that the composition and sizes of the grains play a significant role in studying the scattering by ejecta curtain formed. This study will enable us to gain useful insights into the evolution of planetary bodies.

Highly porous sintered materials as possible analogs for primordial boulders on the asteroid Ryugu

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Planetesimals formed through the accumulation of dust particles. Both experimental and numerical studies have investigated their bulk porosity, or bulk density (Omura and Nakamura, 2021; Tatsuuma et al., 2024). These studies suggest that the bulk porosities of planetesimals can exceed 70%, depending on their sizes and other parameters. Thermal observations by the spacecraft Hayabusa2 revealed the presence of anomalously low-thermal-inertia boulders on the asteroid (162173) Ryugu (Sakatani et al., 2021). The porosities of the boulders were estimated to be 70–90%. As boulders are considered fragments of their parent bodies (planetesimals), highly porous boulders may represent the most primordial rocks from these bodies and retain information on the accumulation of dust particles and the evolution of planetesimals. Thus, we produced highly porous samples with porosities of 77–82%, consisting of glass particles, and examined how closely they resemble the most primordial boulders. The samples prepared in this study were consolidated through sintering, a process that forms solid bonds between particles. Their porosities are about 15% higher than those in our previous study.

We sintered spherical and polydisperse glass particles in an oven under atmospheric conditions. The median diameter of the glass particles was 5 μm. We measured the tensile strength using the Brazilian test (e.g., Meisner et al., 2012) and the longitudinal wave velocity using the ultrasonic pulse transmission method (e.g., Shimaki and Arakawa, 2021). In addition, we examined the cross-section of a sample using field emission-scanning electron microscopy (FE-SEM).

From the FE-SEM images, we found that the sample contains pores that can be classified into two types based on their sizes. The lagger pores are several hundred micrometers in size, while the smaller ones are several tens of micrometers. The tensile strength of our samples is 28–160 kPa, which corresponds to approximately 10 to 100 times higher than that of dust aggregates (77% porosity) consisting of 1.5 μm silica particles (Blum et al., 2006). The longitudinal wave velocities of our samples are 800–1000 m/s.

Based on Hertzian heat conduction theory (Grott et al., 2019), the tensile strength of the boulders reported by Sakatani et al. (2021) is inferred to be 19–64 kPa, which is comparable to that of our samples. Therefore, the sintered samples produced in this study can be utilized as analogs for the most primordial boulders in future studies (e.g., collisional disruption experiments). However, the relationship between structural characteristics, such as inter-particle bonding and pore size distribution, and mechanical strength remains unclear, and further investigation is required.

Impact of dust evolution on B-field diffusion in molecular cloud

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Dust grains in molecular clouds affect the gas ionization degree and the coupling between gas and magnetic fields by adsorbing ions and electrons in the gas phase. The degree of the coupling (so-called ambipolar diffusion) can be measured by the drift velocity $v_{\rm drift}$ between ions that perceive electromagnetic forces and neutral gas particles that do not.

Recently, Pineda et al. (2021) obtained the important results that the drift velocity between ions and neutrals is $\sim$ 100 ms^{-1} in a filamentary molecular cloud by the NH_3 and N_2H^+ line observations. This data provides important information to pin down the strength of the magnetic field, the ionization degree of the gas, and the dust size distribution (i.e., possible dust size evolution) in the molecular cloud.

In this study, we investigated whether the dust size distribution should vary in molecular clouds from the MRN size distribution in order to explain the observed drift velocity. To this end, we combined a dust size evolution code that takes into account accretion and coagulation with an ionization chemistry calculation code that determine the strength of ambipolar diffusion from the dust size distribution. Then, we calculated the expected drift velocity and compared it with the observed value.

We found that the presence of micron-size dust grain is essential for the drift velocity values to be consistent with observations at the cloud core scale. However, the dust growth to micron-size within the core requires 3-10 free fall time. The cloud core is unlikely to be maintained for such a long time because the core undergoes spherical gravitational collapse within 1-2 free-fall time.

On the other hand, we found that the dust can grow to 1 μm in size during the formation of cores from filamentary molecular clouds. This is because filament fragmentation requires a relatively long timescale (1–3 $t_{\rm ff}$) and filaments can exhibit trans/super-sonic turbulence which accelerates the dust coagulation.

These results suggest a scenario that the dust grains grow somewhere in the evolution from molecular clouds to cores, thereby enabling ion-neutral drift within the cores. In the presentation, we will also discuss the consistency between our results and estimated values for cosmic ray intensity and magnetic field strength.

Simulating dust monomer collisions: temperature dependence

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Dust aggregates grow by collisional sticking, which is the first process of planet formation. In the dust collisions, there are some problems interrupting dust growth. One of the problems is the fragmentation of dust aggregates. When the dust aggregates collide with high impact velocities, they are broken and become fragments. To discuss this problem, we should understand the critical collision velocity of fragmentation, and many numerical simulations of dust aggregate collisions (e.g., Wada et al. 2007, 2008, 2009, 2013; Suyama et al. 2008, 2012).

Dust aggregates are composed of submicron-sized particles, which are called monomers. Numerical simulations have treated dust aggregates as powders and calculated the motion of monomers. Their motions are followed by the contact interactions between monomers using the JKR model, which is one of the elastic contact theories. However, the JKR model doesn't include molecular effects, which lead to viscosity (Krijt et al. 2013; Tanaka et al. 2012). Therefore, the monomer interaction should be investigated including molecular physics.

In this work, we use Molecular Dynamics (MD) simulation to analyze molecular motions and perform the simulations of monomers' head-on collision. We analyze the inter-monomer forces and the coefficient of restitution e and investigate the dependence on temperature.

First, we analyze the inter-monomer forces based on the monomers' motion. We find that there is hysteresis between the loading and unloading phases, which indicates energy dissipation. The force obtained in the MD simulations is smaller than that of the JKR model at the unloading phase although it agrees with that of the JKR model at the loading phase. This behavior is the same for different temperatures. However, the degree of hysteria increases with increasing temperatures. This result suggests that high temperatures result in a large energy dissipation in the collisions. Second, we calculate the coefficient of restitution (COR), which is the ratio of relative velocity between before and after the collisions. For different temperatures, the COR has a peak over the impact velocity. For small impact velocity, monomers are easily sticking due to the surface energy. On the other hand, monomers are deformed, and monomers' kinetic energy dissipates into the thermal and potential energy due to the molecular movements at high impact velocity. Then, the COR has a peak. The COR also decreases with increasing temperature. This agrees with the temperature dependence of forces because small COR indicates strong energy dissipation.

Our results are expected to the scenario of dust growth because the protoplanetary disks have the temperature distribution. We show that that high temperatures result in large energy dissipation in collisions, which suggests that the dust grows more rapidly in the inner region than the outer region. We also expect that the critical fragmentation velocity is large for inner disks. This temperature dependence will affect the theoretical study of dust growth.

Mechanical properties of dust layer influenced by hierarchical grain structure: Results from laboratory experiments

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The particle structure of dust layers in planetesimals significantly influences their physical properties, which play a crucial role in their evolution. Observations suggest that planetesimals are formed by self-gravitational instability in protoplanetary disks. In this case, planetesimals should have a hierarchical structure, i.e., an ensemble of agglomerates (pebbles) of individual grains. Initially, this hierarchical aggregate behaves as an assembly of pebbles. However, after considerable compaction due to mechanisms such as self-gravity, the aggregate should behave as a homogeneous assembly of grains, because the pebbles undergo deformation, fracturing, and merging. In this study, we focus on this transition process and investigate the compaction behavior and structural changes of pebble layers. In this presentation, we compare the results of compaction experiments on pebble and homogeneous particle layers to discuss the influence of pebble properties on compaction behavior. We also present observations of internal structural changes during compaction.

We used glass beads with a diameter of 4.2 μm (Potters-Ballotini, EMB-10) as the sample powder. There are two types of samples: a grain sample, in which the sample powder was sieved into a cylinder, and a pebble sample, which has a hierarchical particle structure consisting of agglomerates (pebbles) of the sample powder. The pebbles are naturally formed agglomerates (dry pebbles) that developed during storage in the laboratory, or agglomerates formed by adding water to the powder (wet pebbles). We sieved these agglomerates and used agglomerates with a diameter of 1–2 mm in the experiments. The strength of the pebbles varies depending on the formation process. Therefore, we measured the crushing strength of the pebbles for each sample. Compaction experiments were conducted using a universal testing machine (Shimadzu, AG-X). The samples were compacted until the pressure reached 6×10^6 Pa. For some samples, we adjusted the maximum pressure in the range of 1×10^4 to 6×10^6 Pa. The internal structure of these samples was observed using a CT scanner (NAOMi-CT 3D-M) after the experiments.

The pebble and grain samples showed similar compaction curves as compaction progressed significantly. However, at earlier stages of compaction, a higher pressure was required to achieve the same packing fraction in the pebble samples than in the grain samples. The required pressure increased as the strength of the pebbles increased. Moreover, during the early stages of compaction, the compaction curves normalized by pebble strength collapsed into a single line for samples composed of the same type of pebbles (wet or dry). This suggests that, in this stage, compaction proceeds through the fragmentation of pebbles. CT scan observations also confirmed that, as compaction progressed, the outlines of the pebbles inside the samples became unclear and eventually disappeared. These results confirmed that the deformation of the particle layer leads to the fragmentation and fusion of the pebbles, and eventually, the presence of pebbles in the initial structure no longer affects the compaction behavior of the particle layer.

Experimental Study on the Tensile Strength of Two-Component Dust Beds

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Knowledge of the tensile strength of dust aggregates or regolith piles is significant for understanding the early stages of planet formation in the solar system and the stability of planetary bodies that may be disrupted by collisions with other bodies or by their spin motion. Experimental studies on tensile strength have been conducted using samples composed of various single-component materials, but few have focused on mixtures.

In this study, tensile strength measurements using the Brazilian disk test were performed on mixtures of silica and graphite. Spherical silica particles with a volume-based median diameter of 1.2 μm and irregular graphite particles with a median diameter of 4.4 μm were used. Mixtures with silica weight fractions ranging between 0% and 100% were poured into a cylindrical container with a diameter of 1 cm and compressed at about 1.6 MPa using a pressing machine, resulting in volume filling factors between 0.37 and 0.60. The tensile strength σ at a volume filling factor Φ was normalized to Φ=0.5 using the empirical equation (Afrassiabian et al., 2016; Rumpf, 1970). The normalized tensile strength values ranged from approximately 3 kPa (100% silica) to 110 kPa (100% graphite), decreasing with increasing silica content, but not linearly. Assuming surface energies of 25 mJ/m^2 for silica (Kendall et al., 1987) and 96 mJ/m^2 for graphite (Fowkes, 1971), and applying Rumpf's equation for spherical particles, the estimated tensile strength for both materials would be about 15 kPa, which is 5 and 0.14 times greater than the measured results for silica and graphite, respectively. Possible causes of this discrepancy include particle shape, surface conditions (such as adsorbed water and surface roughness), and particle size distribution. The tensile strength was expressed as an exponential function of the silica content. In contrast, when the results of experiments using mixtures of two components among ice, silica, and fly ash (Haack et al., 2020) were normalized by the filling factor, they could not be represented by a single exponential function and showed different trends depending on the material combinations.

The Multi-wavelength Extinction Law and its Variation in the Coalsack Molecular Cloud Based on the Gaia, APASS, SMSS, 2MASS, GLIMPSE, and WISE Surveys

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Accurate interpretation of observations relies on the interstellar dust extinction law, which also serves as a powerful diagnostic for probing dust properties.
In this study, we investigate the multi-wavelength extinction law of the quiescent, starless molecular cloud Coalsack and explore its potential variation across different interstellar environments: the surrounding region, the nearby high Galactic latitude region, the inner dense region, and the inner diffuse region.
Using a sample of 368,524 dwarf stars selected from Gaia DR3 as tracers, we establish the effective temperature Teff-intrinsic color relations to derive the intrinsic color indices and optical-mid-infrared (MIR) color excess (CE) for 20 bands.
Linear fits to the CE–CE diagrams provide color excess ratios (CERs), which are subsequently converted into relative extinction.
The resulting extinction curves for different environments exhibit steep slopes in the near-infrared (NIR) and flat profiles in the MIR. In the optical-NIR range, the Coalsack extinction law is consistent with R_V = 3.1, while in the MIR it follows R_V = 5.5 similar to the results of active star-forming clouds. At an angular resolution of 1.3', our extinction map reveals fine cloud structures. No correlation is found between R_V and E(B-V) for E(B-V) > 0.3 mag, implying a uniform optical extinction law in the Coalsack cloud. The derived average R_V value is 3.24 ± 0.32.

Impacts of Diffuse Interstellar Dust on Precision Distance Measurements and Cosmological Inference

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Interstellar extinction caused by diffuse interstellar dust has a significant impact on photometry-based distance measurements and structural studies. In this report, we discuss the effects of diffuse dust extinction on studies of the Milky Way structure, the Galactic center distance, and the Hubble constant. To avoid systematic biases, investigations of extinction laws and dust properties must be conducted in regions of significant extinction. In high-extinction regions, the derived extinction laws typically follow the standard $R_V = 3.1$ curve. In the optical bands, degeneracies in extinction coefficients can lead to distance errors of up to 10%. In the infrared, extinction coefficient degeneracy must also be considered. These factors are essential in accurately modeling the structure of the Milky Way. In Hubble constant measurements, the mean extinction in Type Ia supernova host galaxies is approximately $A_V = 0.5$ mag. Although extinction corrections contribute minimally to the final H_0 value, the selection effects introduced by extinction can still lead to systematic biases of up to 5%. Future studies of dust properties in high-extinction regions using JWST will improve the accuracy of distance measurements.

Optical properties of elongated conducting grains

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Extremely elongated, conducting dust particles (also known as metallic ‘needles’ or ‘whiskers’) are seen in carbonaceous chondrites and in samples brought back from the Itokawa asteroid. Their formation in protostellar nebulae and subsequent injection into the interstellar medium have been demonstrated, both experimentally and theoretically. Metallic needles have been suggested to explain a wide variety of astrophysical phenomena, ranging from the mid-infrared interstellar extinction at ~ 3–8μm to the thermalization of starlight to generate the cosmic microwave background. To validate (or invalidate) these suggestions, an accurate knowledge of the optics (e.g. the amplitude and the wavelength dependence of the absorption cross sections) of metallic needles is crucial. Here we calculate the absorption cross sections of iron needles of various aspect ratios over a wide wavelength range, by exploiting the discrete dipole approximation, the most powerful technique for rigorously calculating the optics of irregular or nonspherical grains. Our calculations support the earlier findings that the antenna theory and the Rayleigh approximation, which are often taken to approximate the optical properties of metallic needles, are indeed inapplicable.

Toward Structural Constraints on Interstellar Amorphous Dust Based on Dielectric Properties

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Observations support that most of the large dust grains in interstellar space are composed of amorphous material. Interstellar dust emission models based on the two-level systems (TLS) model [1, 2] and its extended model, the soft potential (SP) model [3, 4], which are physically motivated by explaining the low-temperature thermal properties of amorphous materials, are considered promising for reproducing the characteristics of observations in the infrared to microwave wavelength ranges [5, 6, 7, 8, 9]. However, the specific structure and composition of amorphous dust that satisfy the dielectric properties expected from these models are unclear yet.

In this study, we aim to estimate the dielectric constant of interstellar amorphous dust using molecular dynamics simulations and impose constraints on the dust structure based on observationally constrained dielectric properties. We adopt a double-well potential for intermolecular interactions, which is assumed in the TLS and SP models. In simplified atomic systems, we then analyse the relationship between dust structure and macroscopic dielectric response. This study focuses on methodological aspects and qualitatively demonstrates the relationship between dielectric constant and structure through calculations in a system with significantly fewer atoms than large dust grains. In this presentation, we are going to introduce the characteristics of amorphous structures obtained in a double-well potential system and the trends in dielectric constants derived from them. By comparing these calculations with constraints on dielectric constants obtained from observations, we are going to discuss the limitations imposed on the microscopic structure of interstellar amorphous dust.

This study is expected to provide theoretical clues for elucidating the properties of amorphous interstellar dust.

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