COSMIC DUST ABSTRACTS

Circumplanetary Dust: Spokes in Saturn's B Ring

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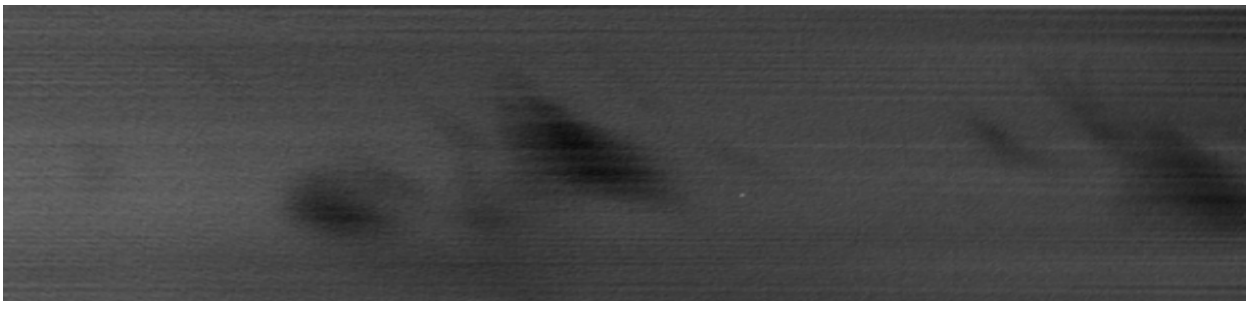
An enduring mystery that has eluded planetary scientists for almost forty years is the origin of the ghostly spokes that appear in Saturn's main rings. Spokes are dark and roughly radial features that are seen on the lit side of Saturn's rings, although they sometimes also appear as bright features on the dark side. This scattering behavior is indicative of dusty material and detailed analysis yields a typical particle size of slightly less than a micron. The radiation and electromagnetic perturbations that act on dust are small on these visible spokes particles, so they must follow nearly Keplerian orbits. Spokes are seen to begin as purely radial features which gradually become triangular in shape as particles at different distances from Saturn orbit at different angular rates. For the first few hours, however, one side of a triangular spoke typically remains vertical, indicating active generation of new dusty material along that edge.

For the past several years, we have progressed in developing a physical model involving a collisional cascade of dust particles to explain these observations. The process starts with an interplanetary impact into the ring that creates myriad dust grains of different sizes in a single localized spot. For simplicity, consider just two sizes: visible micron-sized spoke particles and invisible submicron sized dust. Tiny invisible submicron grains are strongly affected by Saturn's magnetic field which causes them to gyrate around field lines just as ions do. After these particles are ejected from a parent ring, they leave the ring plane, are accelerated to high relative speed by the magnetic field, and then return to a different radial location. When they strike ring particles at high speed, they create further submicron grains that can continue the process. In this way, an initially localized disturbance is propagated radially in the rings. With each submicron impact, some visible micron-sized material is also created to become visible as spokes. We identify the length of time that an edge is active with the time in which the collisional cascade is ongoing.

To test our Collisional Cascade model, we are currently analyzing 10,000 images of Saturn's rings taken by Cassini (see example below, unfolded into ring radius vs. longitude). We are developing a pipeline to identify and catalog spokes in each of the images with the goal of generating a large database that can be used to answer statistical questions. We will be able to look for changes in spoke behavior with spoke age, with the season on Saturn, and with longitude and radius in the ring. These investigations will provide important new constraints on spoke behavior and will put to the test our Collisional Cascade model as well as other models that hope to explain spokes. In this paper, we will give an update on the status of the project.



The 2014 and 2016 dust occultations observed by Cassini CDA

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Star occultations are a common tool in astronomy and photons are normally blocked by an object. Here, we do report about the occultation of nanodust particles in the Saturnian system observed by Cassini.

The Cosmic Dust Analyzer (CDA) onboard Cassini characterized successfully the dust environment at Saturn from 2004 to 2017. The instrument measured the primary charge, speed, mass and composition of individual submicron and micron sized dust grains. The detection threshold scaled with speed^3.5 such that the detection of fast nanograins (~100 km/s) was possible. Saturn's nanodust environment (streams) is studied since many years. However, a special geometric condition of Saturn, Cassini and Titan during the Titan flyby in 2014 (DOY 65) provided a special dust occultation opportunity. Titan and its atmosphere blocked the stream of fast nanoparticles such that CDA registered a clear drop in impact rate around Titan closest approach. An analysis of the data allows to constrain the source region of the nanograins, which is compatible with a source region in the ring plane at distances from Saturn between 4 and 8 Saturn radii. Backward and forward modelling was performed leading to dust grain sizes between 3 and 9 nm and speeds between 80 and 150 km/s. A second dust occultation by Titan was predicted in 2016 (DOY 223). Finally, the measured impact rates by CDA confirmed the occultation model.

Cometary Dust: a perspective from mid-infrared spectroscopy

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Comets are made of ice and dust and are the frozen relics of the early solar nebula. These materials in comets are clues to investigate the environment in the early solar nebula and the formation process of planetesimals and planets.

A silicate feature is often observed in comets as a 10-μm resonant feature. In many cases, the feature shows the existence of crystalline silicate together with amorphous silicate. Since the crystalline silicate grains are generally made in the high-temperature environment from the amorphous ones, it is believed that there should have been the radial transportation of the materials in the proto-solar disk. An abundance of the crystalline dust grains was therefore expected to be smaller as far from the Sun.

Complex organic materials in comets are also important as well as ices and minerals because they are essential pieces of the puzzle regarding the evolution of organics in the proto-solar disk and the origin of life on Earth. Various kinds of complex organic molecules have been observed in warm environments (> 100 K) outside the Solar System, such as hot molecular cores. If comets generally contain complex organics, it suggests the warm environment of the comet-forming region. The STARDUST sample return shows evidence for polycyclic aromatic hydrocarbons (PAHs) in the samples returned from Comet 81P/Wild. However, the detection of the PAH feature in comets is still under debate, although the possible detection of PAH feature in the mid-infrared spectra of comets 9P/Tempel 1 and C/1995 O1 (Hale-Bopp) is reported.

We have carried on infrared observations of comets to understand the formation mechanism of ice and dust incorporated into a cometary nucleus. Through our effort until now, it is revealed that the shape and strength of the 10-μm emission feature itself seem to be different from comets to comets, and there cannot be seen a major difference between Oort cloud comets and Jupiter-family comets. In this talk, I will focus on the results of mid-infrared spectroscopic observations and discuss the evolution of the cometary dust.

The Morphological, Elastic, and Electric Properties of Dust Aggregates in Comets: A Close Look at COSIMA/Rosetta's Data on Dust in Comet 67P/Churyumov-Gerasimenko

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The Cometary Secondary Ion Mass Analyzer (COSIMA) onboard ESA's Rosetta orbiter has revealed that dust particles in the coma of Comet 67P/Churyumov-Gerasimenko are aggregates of small grains. We study the morphological, elastic, and electric properties of dust aggregates in the coma of Comet 67P/Churyumov-Gerasimenko using optical microscopic images taken by the COSIMA instrument. Dust aggregates in COSIMA images are well represented as fractals in harmony with morphological data from MIDAS (Micro-Imaging Dust Analysis System) and GIADA (Grain Impact Analyzer and Dust Accumulator) onboard Rosetta. COSIMA's images, together with the data from the other Rosetta's instruments such as MIDAS and GIADA do not contradict the so-called rainout growth of 10 μm-sized particles in the solar nebula. The elastic and electric properties of dust aggregates measured by COSIMA suggest that the surface chemistry of cometary dust is well represented as carbonaceous matter rather than silicates or ices, consistent with the mass spectra, and that organic matter is to some extent carbonized by solar radiation, as inferred from optical and infrared observations of various comets. Electrostatic lofting of cometary dust by intense electric fields at the terminator of its parent comet is unlikely, unless the surface chemistry of the dust changes from a dielectric to a conductor. Our findings are not in conflict with our current understanding of comet formation and evolution, which begin with the accumulation of condensates in the solar nebula and follow with the formation of a dust mantle in the inner solar system.

Challenges for understanding dust in planetary systems

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It is ironic that the first planetary material imaged around another star consisted of micron-sized dust particles, but dust remains a critical pathway to understanding the formation and evolution of planetary systems thirty-five years after the debris disk of **β** Pictoris was first imaged in visible light. As astronomers are poised to routinely image planets around nearby stars in reflected light, several challenges remain in our fundamental understanding of dust that may help or hinder humanity's search for another Earth-like planet. I will review two particular challenges that span the full lifetime of planet-hosting stars: understanding the chemistry of planetary systems as revealed in scattered light and in the dust of dead planetary systems and predicting the typical brightness of dust in the terrestrial planet forming region. I will also discuss how future space-based observatories will solve some of these persistent mysteries—while raising new questions.

Mineralogy of interplanetary dust investigated from mid-infrared spectroscopic observations with AKARI

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Interplanetary dust (IPD) diffusely distributes in the interplanetary space in our solar system and is thought to be recently supplied from primordial planetesimals like asteroids or comets. The IPD's grain properties, such as mineral composition and crystal morphology, can give us the information on the environment in the proto-solar system. Those properties can be investigated in terms of silicate features around 10 μm seen in the zodiacal emission spectra, because its feature shape is determined by the absorption coefficients of the IPD grains included in the line of sight, which depend on their grain properties.

We analyzed mid-infrared slit-spectroscopic data of the zodiacal emission in 74 different sky directions obtained with the Infrared Camera on board the Japanese AKARI satellite. After we subtracted the contamination due to instrumental artifacts, we have successfully obtained high signal-to-noise spectra and have detected detailed shapes of excess emission features in the 9–12 μm range in all the sky directions (Takahashi et al. submitted).

From the comparison between the feature shapes averaged over all directions and the absorption coefficients of candidate materials, the typical properties of the IPD were identified. As candidate materials, we assumed 4 types of silicate: amorphous with olivine composition, amorphous with pyroxene composition, forsterite (Mg_2SiO_4, one of olivine crystals), and ortho-enstatite ($MgSiO_3$, one of pyroxene crystals). The IPD was found to typically include small silicate crystals that appear to be enstatite-rich. If we focus on a main peak seemed to originate from enstatite, the peak wavelength is shifted toward longer side compared with the model assuming the spherical enstatite grains. It may indicate that the enstatite grains in the IPD have crystal morphologies not spherical but elongated along certain crystal axes.

We also found the variations in the feature shapes and the related grain properties among the different sky directions. The spectra at higher ecliptic latitude showed a stronger excess, which indicates the size distribution biased toward small grains in the lines of sight at high ecliptic latitudes. According to the dependence of detailed feature shapes on ecliptic latitudes, the IPD at higher ecliptic latitudes was found to have a lower olivine/(olivine+pyroxene) ratio for small amorphous grains. The variation of the mineral composition of the IPD in different sky directions may imply different properties of the IPD from different types of parent bodies, because the current spatial distribution of the IPD depends on the type of parent body.

New techniques for computer modeling of light scattering by the dust layers on cosmic bodies

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The talk will present two techniques that allow modeling characteristics of the scattered light on such cosmic bodies as Moon, Mercury, asteroids and atmosphereless planetary moons. One of them, called PWPP (Plane Wave Plane Parallel) technique, is a solution of the Maxwell equations for a randomly distributed particles in the 2D infinite layer of a given thickness. It was developed by Daniel Mackowski (see Mackowski, D. and Ramezanpour, B., 2018, JQSRT, 213, 95-106; and other recent papers of those authors) and tested by comparison with the radiative transfer and T-matrix results. The other one is a further development of the radiative transfer theory with application to densely packed media using static structure factor correction. Although this approach was developed some years ago (see Mishchenko, M., 1994, JQSRT, 52, 95-110), it has been recently updated by Gen Ito et al. (2018, JGR, 123, 1203-1220) to allow considering aggregates as the elements of the media. The talk will describe both approaches, their advantages and shortages, and show the results obtained with them for the spectra of icy satellites of Saturn acquired by the VIMS Cassini instrument and for the photometry of the nucleus of comet 67P/ Churyumov-Gerasimenko studied by the Rosetta OLSIRIS instrument. Fitting the observational data with the computations allowed estimations of the regolith particle size and composition as well as the porosity of the surface layer. This work has been supported by the NASA Solar System Workings grant.

Rotationally resolved infrared (3.0–4.0 μm) spectra of Jupiter Trojans

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Jupiter Trojans (hereafter JTs) are swarms of small bodies orbiting the Sun in the Lagrangian points of Jupiter, L_4 and L_5. Because of their orbital stability and proximity to Jupiter, a substantial amount of primitive materials (i.e., water ice and organics) has been presumed to exist either on the surfaces and/or the interiors, yet been detected directly.

Diagnostic absorption lines of such materials can be searched via reflectance spectroscopy. In the visible and near-infrared wavelengths (0.5–2.5 μm), weak overtones and combinations of the functional groups of H_2O/OH and hydrocarbons exist, but opaque elements (e.g., amorphous carbon, silicate) are too overwhelming to detect weaker absorption bands of interest. In longer infrared wavelength (particularly 3.0–4.0 μm), however, as the opaque matters become transparent and stronger fundamental bands of interest emerge, it is far more favorable to study compositions of two JTs, but severe telluric lines often degrade the quality of the spectra. Herein, we present the unpublished results of infrared spectroscopic observations of JTs using the 8 m Subaru telescope atop Mauna Kea, which cover one full rotational periods of each target with high signal-to-noise ratio for the first time. We will report the results of spectral properties (continuum slopes, possible absorption features) of JTs and any rotational variations of them. Based on the observational evidence, we will discuss the surface characteristics and their implications on the evolutionary history of the targets.

Characterizing Dusty Debris with the Gemini Planet Imager

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Some exoplanetary systems contain not only planets but also minor body belts, analogous to the asteroid and Kuiper belts in our Solar System. Planets in these systems gravitationally perturb minor bodies, placing them on crossing orbits where they collide, creating debris dust. Detailed studies of the scattered light from the debris dust can constrain the size and porosity of the grains and therefore the mechanisms by which the dust and parent bodies are processed. The Gemini Planet Imager (GPI) has provided high Signal-to-Noise Ratio (SNR) spectroscopic and polarimetric observations of predominantly bright, highly inclined debris disks. These observations enable detailed measurements of the total intensity and polarization fraction phase functions and the near-infrared reflected light spectrum. We present some recent results using GPI to constrain the properties of circumstellar dust in debris disks from the Gemini Large and Long Program "Characterizing Dusty Debris in Exoplanetary Systems".

The Effects of Neighbouring Planets on the Formation of Circumsolar Resonant Dust Rings in the Inner Solar System

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The presence of a circumsolar ring of dust near the orbit of Venus has first been indicated by photometry data of the Venus-orbit crossing Helios probe. Since then, imagery data from STEREO, as well as in situ dust measurements made by the IKAROS mission have further supported the existence of a circumsolar ring associated with Venus. It has been theorized that the ring is an analogue of the resonant ring of Earth, arising from dust particles being trapped in the planet's external mean-motion resonances (MMRs). Attempts to model this phenomenon as a result of trapping of migrating dust have so far been unable to produce a meaningful density enhancement due to an overall low trapping efficiency of Venus's external MMRs. Recently, Pokorny et al. (2019) have found that only dust stemming from a hypothetical population of Venus co-orbital asteroids can produce enough signal to adequately match the observations. This might indicate a fundamental difference between Earth's resonant ring – dust migrating from the asteroid belt being trapped in external MMRs – and Venus's resonant ring – dust being released directly into a co-orbital resonance. However, the underlying cause for the low trapping probability of Venus's external MMRs remains unclear.

In this work we present an approach to model resonant features associated with the inner planets and specifically look into the dependency of these dust structures on the multi-planet configuration. We conduct a series of simulations for dust of different particle sizes, migrating through the inner solar system. We confirm previous results suggesting that the observed dust enhancement at Venus orbit cannot be caused by trapping in external MMRs. Furthermore, we try to isolate the effects of neighbouring planets on the formation of resonant features by removing individual planets from the simulation. We find that the single most important reason for the absence of Venus's external MMR ring is the perturbing influence of Earth, destabilizing resonating particles or preventing entry into a resonance altogether. The closer distance to the Sun is of minor importance as under the absence of Earth, Venus is able to produce an external MMR ring comparable in strength to the nominal ring of Earth. In the same manner, Venus affects the internal MMRs of Earth, diminishing their displacing effect. On the other hand, we find that Mars is neither capable of trapping significant amounts of dust, nor does it affect the trapping efficiency of Earth due to its low mass. Likewise, Mercury is unable to produce a meaningful enhancement of migrating dust – with or without its neighbour Venus. Finally, we see a minor facilitating effect for specific resonances under the gravitational interaction of Earth and Venus.

Infrared light polarization as a tool to study circumstellar disks dust properties

E. Pantin; Li, D., Zhang, H., Telesco, C., Barnes, P.

Light polarization is a powerful tool to investigate the nature, the shape of dust grains and their interactions with local physical conditions such as the presence of a magnetic field in circumstellar disks.
Very recently, it has been possible, thanks to polarimeters on mid-infrared intruments mounted on large ground-based telescopes, to investigate both the B-field content and some dust properties in the AB Aur protoplanetary disk.

In this talk, I will discuss recent observational results obtained using polarimetric observations, also as their limits and potential degeneracies.

Probing dust aggregate structure in protoplanetary disks by millimeter-wave polarization

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Dust coagulation in protoplanetary disks is the first step of planetesimal formation. However, a pathway from dust aggregates to planetesimals remains unclear. Both laboratory and numerical studies have so far shown that the structure of a dust aggregate plays important roles in planetesimal formation. However, the aggregate structure has been poorly constrained by disk observations. Recently, ALMA opens a new window to observe (sub-)millimeter-wave polarization of disks, which is expected to provide additional constraints on dust aggregate properties. In this study, we perform 3D radiative transfer simulations in order to study how the structure of dust aggregates affect millimeter-wave polarization from disks. As a result, it is found that relatively compact particles are favorable to explain observed millimeter-wave scattering polarization of disks, whereas highly porous and fractal particles fail to explain the observations. Our results imply that the presence of some dust compaction process in disks. Furthermore, it is also shown that observed millimeter-wave scattering polarization is consistent with grain radii of a few hundreds of microns, which are an order of magnitude smaller than previously estimated values. We discuss a possibility that these relatively small grains are due to efficient fragmentation of CO_2-ice coated grains in disks.

A Micro-Wave analogy experiment to measure the scattering properties of dust aggregates: Experimental set-up and first results for protoplanetary disks

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Young Protoplanetary disks are central to the process of planetary formation. Observationally, planets around main sequence are ubiquitous and the case for planets detected during their formation, i.e, still within their parent disk, is growing. The formation of a planet requires the growth of solids (dust) by several orders of magnitudes, from (sub-)micron sizes to kilometer sizes ... and this is a major problem! because disks are short-lived, collisions are expected to shatter pebbles / boulders when they reach decimeter-meter sizes, particles are rapidly drifting inward because of gas drag, etc...

Instruments on large telescopes are providing novel insights on the structure and content of protoplanetary disks. Rings and gaps are found that may trace the presence of planets. Interestingly, the signature of dust scattering are now measured not only in the optical and NIR with better resolution than before, but also at mm wavelengths with ALMA, probing larger particles. Scattering phase functions, in intensity and linear polarisation, are slowly becoming available. The first results are pointing toward the presence of dust aggregates whose exact properties are not well known... just yet.

The scattering and polarisation properties of aggregates depend on several parameters. In this contribution we will present the first results of a Micro-Wave analogy experiment to measure the scattering properties of large aggregates.

Contrarily to most other experiments, our set-up allows to control the position, size, shape and refractive index of the aggregates with high accuracy. Aggregates are fabricated by 3D printing, with material carefully tailored to match the complex refractive index of astronomical dust.

The talk will be split in three parts: (1) We will present the experimental set-up, (2) the protocol to build the aggregate analogs, and (3) the results of first measurements to explore the effets of surface roughness on the shape of the scattering phase function.

Tensile Strength of Porous Dust Aggregates in Protoplanetary Disks

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Kilometer-sized planetesimals are thought to be building blocks of planets. However, the formation process of planetesimals from submicrometer-sized dust grains in protoplanetary disks has not yet been unraveled. In this process, it has been indicated that the porous structure of dust aggregates is a key factor and it can influence the material strength of planetesimals. Here, we focus on comets, which are the most primitive bodies in our solar system and are thought to be leftover planetesimals. Their properties have been investigated by both observation and exploration. Recently, *Rosetta* reached comet 67P/Churyumov–Gerasimenko and its tensile strength was estimated.

As a first step toward constraining the formation process of planetesimals, we conducted N-body simulations considering the interaction model of dust particles (Wada et al. 2007, ApJ, 661, 320) to derive the tensile strength of porous dust aggregates and compare it with that of the comet. In our simulations, we gradually moved periodic boundaries to pull a dust aggregate, which mimics the static stretching process of porous dust aggregates. During the stretching, we measured the tensile stress at each time step. As a result of these simulations, we found that the tensile stress has the maximum value, which we define as the tensile strength of the dust aggregate. We also found that the maximum tensile stress is realized when many connections of constituent particles start to break. Then, we conducted a series of these numerical simulations with changing the initial aggregate porosity. Finally, we succeeded in deriving the tensile strength from our simulations. In addition, it is found that the derived tensile strength is reproduced by using a semi-analytic model that the tensile strength is determined by connection-breaking between constituent particles. Our model is consistent with previous experimental and numerical studies of the tensile strength (Blum & Schräpler 2004, PhRvL, 93, 115503; Blum et al. 2006, ApJ, 652, 1768; Seizinger et al. 2013, A&A, 559, A19; Gundlach et al. 2018, MNRAS, 479, 1273). The derived tensile strength of porous dust aggregates is much larger than that of the comet when the constituent particle radius is the same as the interstellar dust radius, i.e., 0.1 μm. To achieve the tensile strength of the comet, the constituent particle radius is needed to be from several to ~ 100 μm or other mechanisms to make dust aggregates fragile are needed.

Collisional Growth From Dust to Planets in a Protoplanetary Disk

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Planets are considered to be formed in a protoplanetary disk composed of gases and solids. In the standard scenario, kilometer-sized or larger planetesimals are generated from dust grains and collisional coagulation of the planetesimals forms planetary embryos. Once planetary embryos are as large as 10 Earth masses, the embryos start rapid gas accretion, which results in gas giant planets (Mizuno 1980; Ikoma et al. 2000; Hori & Ikoma 2010).

Dust particles grow to meter-sized pebbles via collisions in a protoplanetary disk. Pebbles lose substantial angular momentum due to gas drag because of the sub-Keplerian rotational velocity of gas and spiral onto the central star. If pebbles are compact, then radial drift is too rapid to grow to planetesimals (Weidenschilling 1977). However, successive collisions of dust produce highly porous aggregates (Suyama et al. 2008, 2012). Icy porous aggregates that consist of a number of spherical submicron particles do not suffer from catastrophic disruption unless the impact velocities exceed 60–90 m/s (Wada et al. 2009, 2013). Okuzumi et al. (2012) investigated the collisional evolution of the mass and porosity of icy dust aggregates, whereby icy fluffy dust aggregates were determined to grow into planetesimals faster than they drift. The filling factor of the aggregates becomes as low as 10-5 when radial drift is most effective. Since the compaction of aggregates by ram pressure and self-gravity is effective with the growth of aggregates, the filling factor of kilometer-sized or larger planetesimals increases up to ~ 0.1 (Kataoka et al. 2013).

Because the mechanisms for planetesimal formation was unclear, planet formation was usually investigated from planetesimals. However, we can consider planet formation from dust grains because fluffy dust aggregates overcome the drift barrier. We investigate the collisional evolution of dust grains in protoplanetary disks. Planets are formed only via collisional growth in inner disks ($< 10\,\mathrm{AU}$) if turbulence is weak. However, growing dust aggregates drift inward without planet formation. Drifting dust from the outer disk contributes the growth of planets in the inner disk, if planets can grow as large as the Earth.

Reactive desorption of methanol from amorphous solid water at 10K

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Many kinds of gaseous molecules have been observed in molecular clouds. It implies the following two facts: first, the molecule synthesis occur in spite of very low temperature circumstances (~ 10K), second, the formation rate of gaseous molecule (ie. the rate of synthesis in the gas phase and desorption from the icy dust) is larger than the loss rate (ie the rate of destroy in gas phase and accretion on icy dust). Therefore, to understand the formation process of gaseous molecules observed contributes to evaluate the physical and chemical conditions in molecular clouds. From such background, methanol molecule have attracted astronomer's and astrochemist's interest in the formation process, because it has been abundantly observed in many molecular clouds and has been considered to be a precursor of complex organic molecules.

For the synthesis in the gas phase, most plausible and efficient reaction would be dissociative electron capture of $CH_3OH_2^+$ formed by ion-molecule reactions[1]. However, the formation rates by this process have been proven inefficient to explain the observed amount of methanol. On the other hand, successive CO hydrogenation on icy dust surface, $CO \rightarrow HCO \rightarrow H_2CO \rightarrow CH_3O \rightarrow CH_3OH$, was proposed theoretically and confirmed by experimentally as an efficient pathway[2]. That is, if methanol molecules desorb to some extent at the formation on the dust, it can be a dominant process in the supply of gaseous methanol.

The desorption processes triggered by energy inputs such as photodesorption and thermal desorption are inefficient in the molecular clouds, because of low UV fields and low temperatures. As the promising desorption process which will work effectively even in molecular clouds, reactive desorption has been proposed. Because this desorption process is triggered by the heat of reaction when the molecule is synthesized by chemical reactions, any additional energy input is not required. Although this desorption process may play an important role in supplying gaseous methanol, only small number of studies have been performed. In this presentation, we introduce the chemical desorption process of CH_3OH on ASW triggered by following reactions:

$$CH_3OH + H \rightarrow CH_2OH + H_2\uparrow$$
$$CH_2OH + H \rightarrow \mathbf{CH_3OH}\uparrow.$$

Our experimental results show that this process will strongly depend on the adsorption sites of CH_3OH on the surface. Additionally, we will introduce the geometric structure of ASW observed by an atomic force microscope, because the surface structure affects directly the characteristic of adsorption site.

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Dust particles interactions with interstellar molecules

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Interstellar clouds contain gas and dust. The latter may be composed of grains characterized by ndifferent sizes, shapes, chemical composition and crystalline structures as extinction law differes usually from object to object. Grains may also play an important role in producing some interstellar molecules. It seems interesting to relate different extinction curves to column density ratios of known, simple radicals, such as CH, CH^+ and CN. Such an analysis was performed for a pretty big sample of reddened OB stars observed through single interstellar clouds. High resolution spectra allow precise measurements of the interstellar spectra features. It is evident that differences in extinction curves lead to varying strength ratios of molecular features. The same concerns also diffuse interstellar bands – believed to be carried by more complex molecules.

Tori, disks, and winds: the infrared emission in active galactic nuclei

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Dust accretion from the host galaxies onto supermassive black holes has been a cornerstone of AGN unification as it provides the angle dependent obscuration required to explain the various AGN types by a pure viewing angle effect. This accretion process happens on small spatial scales – indeed, too small for single infrared telescope to resolve it. Thanks to advancements in infrared interferometry, the last decade saw the dusty environment around an ever-growing number of AGN becoming directly accessible. Those spatially resolved observation shook up the idea of a “passive” torus causing the obscuration and led to a more dynamic picture of inflowing and outflowing dusty gas with significant dust processing occurring in the vicinity of the AGN. In this talk, I will present recent results from high angular resolution observations. Specific emphasis will be put on new constraints of the spatial distribution of the dust around the AGN and the dust composition, with an inferred predominance of large graphite grains. I will also show new results on the PAH emission within 100 pc of AGN and their usefulness (or lack thereof) as starformation tracers on these scales.

An infrared spectroscopic study of silicate dust in heavily obscured AGNs with AKARI and Spitzer

Takuro Tsuchikawa[1], Hidehiro Kaneda[1], Shinki Oyabu[1], Takuma Kokusho[1], Kumiko Morihana[1], Hiroshi Kobayashi[1], Mitsuyoshi Yamagishi[2], and Yoshiki Toba[3, 4, 5]

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Heavily obscured active galactic nuclei (AGNs), which are surrounded by dusty AGN tori, showing almost no optical sign of AGN activities, have been found by many observational studies (e.g., [1], [2]). Many heavily obscured AGNs are known to show deep silicate absorption features (e.g., [3], [4]), which can be important spectral probes to study the AGN activity and potentially the evolutionary history of AGN tori. However detailed properties of the circumnuclear silicate dust, such as grain size, chemical composition and crystallinity, are still poorly understood. In this presentation, we show the recent result of our spectroscopic study of silicate dust in heavily obscured AGNs with AKARI and Spitzer [5].

LEDA 1712304, a nearby (z=0.0645) heavily obscured AGN, was serendipitously observed by AKARI/IRC slit-less spectroscopy. We detected a deep (τ_{sil}~2.3), broad absorption feature due to silicate grains at around 10 µm in the spectrum with a high signal-to-noise ratio. We find that the spectrum is reproduced well by a dust model consisting of a 0.1 µm-sized amorphous olivine ($Mg_{0.8}Fe_{1.2}SiO_4$) absorption feature and a hot (~500 K) dust blackbody continuum. In particular, the obscured silicate absorption feature calls for a significant porosity with 4% crystalline pyroxene. We also perform spectral energy distribution (SED) fitting to the flux densities in the UV to sub-millimeter range to investigate the global spectral properties. The resultant total IR luminosity and stellar mass are estimated to be $L_{IR}=(5\pm1)\times10^{10}\ L_{sun}$ and $M_{star}=(2.7\pm0.8)\times10^{9}\ M_{sun}$, respectively.

In such low L_{IR} and M_{star} ranges, there are few AGNs which show that large τ_{sil}, and thus LEDA 1712304 is likely to be a rare galaxy from the aspect of having both deep absorption feature and low IR luminosity. We compare the silicate absorption feature of LEDA 1712304 with those of other AGNs observed by Spitzer/IRS (e.g., [6], [7]) which show deep (τ_{sil} >2) silicate absorption features. As a result, we find that the wing shapes of the silicate absorption profiles vary from galaxy to galaxy, although the overall shapes are notably similar despite the fact that their L_{IR} values (i.e., AGN activities) are much different by more than 2 orders of magnitude. The variations of the profiles can be explained by differences in the compositions of amorphous olivine and/or the crystallinity.

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Radiation-pressure-driven dust transport to galaxy halos at high redshift

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Dust is known to exist in a wide volume in the Universe, not only in the interstellar medium (ISM) but also in the circum-galactic and intergalactic medium (CGM and IGM) (e.g., Ménard et al. 2010, MNRAS, 405, 1025). Since dust in the CGM and IGM affects the opacity toward distant objects in the Universe (Aguirre 1999, ApJ, 512, L19), it is important to clarify the origin and evolution of dust in the entire cosmic volume. Dust in the CGM is also of fundamental importance in the total dust budget in galaxies and in the Universe, since Ménard et al. (2010) estimate that the dust mass in a galaxy halo is on average comparable to that in a galaxy disc. Moreover, as Inoue & Kamaya (2003, MNRAS, 341, L7) argued, dust could affect the thermal state of the IGM through photoelectric heating. However, the origin of dust in galaxy halos or in the CGM is still a mystery.

When did the CGM and IGM start to be enriched with dust? Recent sensitive observations by ALMA have found some dusty "normal" galaxies at $z > 7$ (e.g., Watson et al. 2015, Nature, 519, 327). These galaxies could be the first sources of the dust in the IGM and CGM. We investigate if the radiation pressure in high-redshift ($z \sim 10$) galaxies can efficiently transport dust to halos. To clarify the first dust enrichment of galaxy halos in the early Universe, we solve the motion of a dust grain considering radiation pressure, gas drag, and gravity in the vertical direction of the galactic disc. Radiation pressure is estimated in a consistent manner with the stellar spectra and dust extinction. As a consequence, we find that dust grains with radii $a \sim 0.1$ μm successfully escape from the galactic disc if the ongoing star formation episode converts more than 15 per cent of the baryon content into stars and lasts $\gtrsim 30$ Myr, while larger and smaller grains are trapped in the disc because of gravity and gas drag, respectively. We also show that grain charge significantly enhances gas drag at a few–10 scale heights of the galactic disc, where the grain velocities are suppressed to ~ 1 km s^{-1}. There is an optimum dust-to-gas ratio ($\sim 10^{-3}$) in the galactic disc and an optimum virial mass $\sim 10^{10}$–10^{11} M$_\odot$ for the transport of $a \sim 0.1$ μm grains to the halo. We conclude that early dust enrichment of galaxy halos at $z \gtrsim 10$ is important for the origin of dust in the CGM.

Finally, we discuss other mechanisms of injecting dust into the IGM and CGM based on our recent simulations (Hou et al. 2017, MNRAS, 469, 870; Aoyama et al. 2018, MNRAS, 478, 4905). Each model has each prediction on the typical grain size in the IGM, so that we compare our previous constraints on the grain radii in the CGM and IGM (Hirashita & Lin 2019, Planetary and Space Science, in press) with various theoretical predictions.

Dust production in galaxies at z > 6

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Dust production is a very important issue in galaxy evolution. Unfortunately, we are still unable to determine its formation mechanism. I will present the investigation of dust production in nine galaxies at the redshift $z > 6$, for which dust emission has been detected. In recent years, more accurate measurements were made using the most powerful instruments, eg ALMA, which contributed to better estimates of luminosities and sizes, and thus to determine the masses of gas, dust and stars in the studied galaxies. We conclude that asymptotic giant branch stars did not contribute to the dust formation significantly in these Early Universe galaxies, and that supernovae are unlikely to produce the bulk of the dust mass. This suggests that there must be some non-stellar mechanism, for example grain growth in the interstellar medium.

Far-infrared metal and Dust Emission in a Galaxy at Redshift ~ 8

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When, how, and what amount of dust was formed for the first time in the Universe is one of the fundamental questions in astrophysics. Actually, significant number of detections of dust from galaxies at very early cosmic ages have been reported, pushing the age of the first dust production even back to the Epoch of Reionization. We report the Atacama Large Millimeter/submillimeter Array (ALMA) detection of the [OIII] 88 μm line and rest-frame 90 μm dust continuum emission in a *Y*-dropout Lyman break galaxy (LBG), MACS0416_Y1 lying behind the Frontier Field cluster MACS J0416.1−2403. This [O III] detection confirms the LBG with a spectroscopic redshift of z = 8.3118 ± 0.0003, making this object one of the farthest galaxies ever identified spectroscopically. The observed 850 μm flux density of 137 ± 26 μJy corresponds to a de-lensed total infrared (IR) luminosity of $L_{\rm IR} = (1.7 \pm 0.3) \times 10^{11}\ L_\odot$ if assuming a dust temperature of $T_{\rm dust}$ = 50 K and an emissivity index of β = 1.5, yielding a large dust mass of $4 \times 10^6\ M_\odot$. The ultraviolet-to-far-IR spectral energy distribution modeling where the [O III] emissivity model is incorporated suggests the presence of a young ($\tau_{\rm age} \approx 4$ Myr), star-forming (SFR ≈ 60 $M_\odot\ {\rm yr}^{-1}$), moderately metal-polluted ($Z \approx 0.2\ Z_\odot$) stellar component with a mass of $M_{\rm star} = 3 \times 10^8\ M_\odot$. An analytic dust mass evolution model with a single episode of star formation does not reproduce the metallicity and dust mass in $\tau_{\rm age} \approx 4$ Myr, suggesting a pre-existing evolved stellar component with $M_{\rm star} \sim 3 \times 10^9\ M_\odot$ and $\tau_{\rm age} \sim 0.3$ Gyr as the origin of the dust mass. We discuss the relative importance of dust formation in the final stage of stars and the grain growth in the ISM for these galaxies.

Levitating dust clouds on orbital platforms: pathways to support the experimental calibration of interstellar dust models

J. Brisset[1], J. Blum[2], A. Vedernikov[3], R. Schräpler[2], I. Von Borstel[2], D. Balapanov[3], A. Coskun[2]

The study of dust particles in the universe is relevant to numerous fields of research and it is an exciting and challenging area of current astrophysics. Dust grains are omnipresent from the disks and halos of the most distant galaxies to the zodiacal cloud in the vicinity of Earth in our Solar System, and dust is involved in some of the most important processes in the universe, such as star and planet formation. In addition, dust clouds in the universe interfere with the way we see stellar objects, so that the understanding of how these dust grains behave, evolve, and in particular, interact with light is therefore essential to the advancement of our understanding of our universe.

In addition to their composition, the size and shape of interstellar medium (ISM) dust grains have a significant impact on absorption spectra collected from a variety of stellar objects. In particular, interstellar extinction presents a **flat feature in the mid-IR from 3 to 8 µm** that can be seen in the Spitzer Infrared Array Camera (IRAC). It has been speculated that the absence of common ISM spectral features from stellar objects in that wavelength range is due to **the agglomeration of the dust grains into larger clusters** (up to 10 µm). So far, only theoretical and numerical models are used to support this hypothesis. We are working on an experimental investigation on light absorption by clouds of 10 nm to µm-sized particles at wavelengths in the mid-IR in order to study (1) the effect of grain sizes and shapes on absorption lines, and (2) if grain size and/or shape is at the origin of the observed mid-IR flat extinction feature. The goal is a better understanding of spectra flattening by ISM dust and therefore for a better calibration of stellar and galactic observations.

The main challenge in the laboratory study of interstellar dust clouds is induced by the presence of gravity. While the levitation of clouds of particles can (and has) been achieved using transparent bounding media (liquids, gels, gas), ultrasounds, electromagnetic and mechanical effects, the results of such experiments are only conclusive when same-sized spherical particles are used. Indeed, gravity will sort any population of levitated grains by size and gas/liquid drag will orient irregular grains in preferred directions, so that realistic populations of irregular grains with a distribution of sizes cannot be studied. These limitations are significant, as it has been shown that the shape and size of dust grains in a cloud have an important effect on the way they interact with stellar light. For these reasons, microgravity experiments have been performed for several decades on-board platforms such as drop towers and parabolic flights. We will present an experimental setup currently developed for the study of protoplanetary dust on suborbital rockets that we plan to leverage for spectral absorption measurements in the mid-IR on orbital platforms. This hardware setup uses thermophoresis and allows for the observation of an undisturbed (no physical contact between grains and test cell walls) dust cloud for several minutes (no cloud shifting). It builds on past experiments and offers a flexible, long-term microgravity platform for the experimental study of homogeneous dust cloud absorption in the mid-IR.

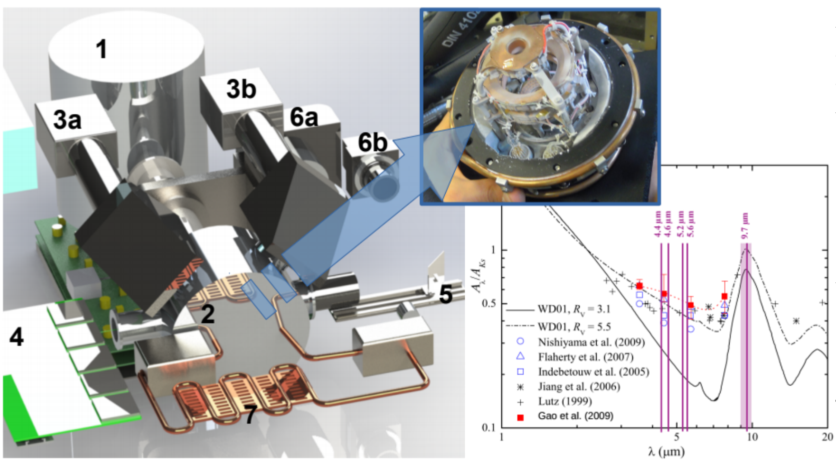

Figure 1: Payload concept for the study of mid-IR absorption by simulated ISM dust clouds. (left) Hardware design for suborbital flight. (1) Dust production chamber; (2) Cloud manipulation chamber; (3a,b) Cloud positioning cameras; (4) Laser light sources; (5) mirror; (6a,b) IR cameras; (7) Cooling loop for the Peltier elements. (top) Picture of the cloud manipulation Peltier rings. (right) Wavelengths of absorption measurements over the observed 3-8 µm flat feature and the 9.7 µm silicate absorption peak (Gao, et al. 2009).

The Widespread Presence of Nanometer-size Dust Grains in the Interstellar Medium of Galaxies

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Interstellar dust spans a wide range in size distribution, ranging from ultrasmall grains of a few Ångströms to micronmeter-size grains. While the presence of nanometer-size dust grains in the Galactic interstellar medium was speculated six decades ago and was previously suggested based on early infrared observations, systematic and direct analysis of their properties over a wide range of environments has been lacking. Here we report the detection of nanometer-size dust grains that appear to be universally present in a wide variety of astronomical environments, from Galactic high-latitude clouds to nearby star-forming galaxies and galaxies with low levels of nuclear activity. The prevalence of such a grain population is revealed conclusively as prominent mid-infrared continuum emission at $\lambda \sim 10\,\mu m$ seen in the *Spitzer*/IRS data, characterized by temperatures of ~ 300–$400\,\mathrm{K}$ that are significantly higher than the equilibrium temperatures of common, submicron-size grains in typical galactic environments. We propose that the optimal carriers of this pervasive, featureless hot dust component are very small carbonaceous (e.g., graphite) grains of nanometer size that are transiently heated by single-photon absorption. This grain population accounts for $\sim$1.4% of the total infrared emission at $\sim$5–3000 μm and $\sim$0.4% of the total interstellar dust mass.

Rotational Disruption as a New Mechanism of Dust Destruction and Implications

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We will first introduce a new mechanism of dust destruction based on centrifugal stress within extremely fast rotating grains spun-up by radiative torques, which is termed RAdiative Torque Disruption (RATD) mechanism. We will show that the RATD mechanism can successfully explain several puzzles in dust astrophysics, including (i) the NIR-MIR emission excess from young massive star clusters, (ii) the anomalous dust extinction and polarization towards SNe Ia, (iii) and Small Magellanic Cloud-like extinction curves with a steep far-UV rise in starburst and high redshift galaxies. We will then discuss the implication of RATD to probe internal structure of dust grains with observations which is currently a mystery of dust astrophysics. Finally, we discuss the effect of RATD for desorption of icy grain mantles and complex organic molecules (COMs) around young stellar objects. We will show that by disrupting the ice mantle on the grain surface into fragments, COMs can desorb from ice mantles at much lower temperatures than the classical sublimation from the original grain, which can explain observations of COMs in cold regions.

Ensemble study on the efficient radiative alignment fraction of interstellar grains

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The radiative torque (RAT) mechanism is, based on a number of earlier studies, the most promising way of explaining observed polarization arising from aligned grains. The efficiency of grain alignment by an anisotropic radiation flow for an extensive ensemble of grain shapes, grain sizes (a), and wavelength (λ), can be described by a single parameter, $q^{\max}$ which depends on the aforementioned quantities. In certain situations, where the dynamical timescales so allow, dust polarization by grain alignment can be summarized using a single derived parameter, the fraction $f_{\mathrm{high}J}$ of the grain population for which a particularly stable dynamical state exists.

In this presentation, we explore the behavior of $f_{\mathrm{high}J}$ for different grain ensembles with different distributions of $q^{\max}$, when the relative importance of magnetic relaxation and drag effects is varied. We find that the studied grain ensembles exhibit values of $f_{\mathrm{high}J}$ dependent on both the relative orientation of the scattering plane and external magnetic field and the distribution of $q^{\max}$. These results have important implications on the expected dust polarization in different astrophysical conditions and e.g. pave way for better observational constraints of interstellar dust properties.

Rapid Luminosity Decline and Subsequent Reformation of the Innermost Dust Distribution in the Changing-look AGN Mrk 590

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We examined long-term optical/near-infrared (NIR) flux variability of a "changing-look" active galactic nucleus (AGN) Mrk 590 between 1998 and 2007. Multi-band multi-epoch optical/NIR photometry data from the SDSS Stripe 82 database and the Multicolor Active Galactic Nuclei Monitoring (MAGNUM) project reveal that Mrk 590 experienced a sudden luminosity decrease during the period from 2000 to 2001. Detection of dust reverberation lag signals between V- and K-band light curves obtained by the MAGNUM project during the faint state in 2003 − 2007 suggests that the dust torus innermost radius $R_{\rm dust}$ of Mrk 590 had become very small [$R_{\rm dust} \simeq 32$ light-days (lt-days)] by the year 2004 according to the aforementioned significant decrease in AGN luminosity. The $R_{\rm dust}$ in the faint state is comparable to the Hβ broad line region (BLR) radius of $R_{{\rm H}\beta,{\rm BLR}} \simeq 26$ lt-days measured by previous reverberation mapping observations during the bright state of Mrk 590 in 1990 − 1996. These observations indicate that the innermost radius of the dust torus in Mrk 590 decreased rapidly after the AGN ultraviolet-optical luminosity drop, and that the replenishment time scale of the innermost dust distribution is less than 4 years, which is much shorter than the free fall time scale of BLR gas or dust clouds. We suggest that rapid replenishment of the innermost dust distribution can be accomplished either by (1) new dust formation in radiatively-cooled BLR gas clouds or (2) new dust formation in the disk atmosphere and subsequent vertical wind from the dusty disk launched by radiation pressure.

Amazing Grains - The nature of interstellar dust as revealed by light scattering

Cesare Cecchi Pestellini, INAF – Osservatario Astronomico di Palermo

Dust grains are formed in several types of near-stellar environment. However, once they enter the interstellar medium these grains will be modified in size, shape and even composition by a variety of physical processes. These modifying processes may continue to act throughout the lifetime of a grain. Thus, we should consider the possibility that grains evolve in the interstellar medium.

In the diffuse medium, some materials will be affected by starlight or by cosmic rays, and some may be modified by chemical reactions with gas phase species. All grains will be eroded and possibly reduced to atoms or small molecular fragments in the intermittent passage of interstellar shock waves, with some materials (such as silicates) being more resistant to this kind of erosion than others (such as hydrocarbon polymers). The response of dust to local conditions may be reflected in the variations in interstellar extinction curves along different lines of sight in the Milky Way, and in other galaxies.

Starting from the mathematical techniques that enable the optical properties of spherical grains and clusters of spheres to be computed, I'll present a dust model specifically constructed on the assumption that dust grains evolve in space, and discuss it in the context of current approaches to modelling the properties of interstellar dust. The model is inherently time-dependent with its properties modified by the interaction with the environments in which grains are embedded. Timescales are set by the deposition time of carbon in a hydrogen-rich gas (mainly aliphatic), and the time for its conversion to aromatic carbon by the local ultraviolet radiation field. Another timescale is associated with the occasional swift ablation of the carbon layers and their recycling in the gas-phase when a shock, or other impulsive phenomena occur.

Finally, I'll consider possible limitations, and suggest revisions that may be required to take account of these concerns.

Dust studies in the era of precision Galactic astronomy

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With large scale surveys such as Gaia and LAMOST, we are entering an era of precision Galactic astronomy, whereas basic astrometric, photometric, and spectroscopic stellar parameters are measured to extreme high precision. Using the "star pair" technique, we have measured multi-band reddening values of about 5 million stars at a 1 per cent accuracy, providing a great opportunity to trace the distributions and properties of dust in the Galaxy. In this contribution, we will focus on three topics: 1) the 3D large scale distribution of dust in the Galaxy, i.e., the first discovery of (thin and thick) dust disks and dusty halo in the Galaxy and discussions of their properties and origins; 2) possible detection of dust reddening effects caused by zodiacol dust within the solar system; 3) the needs and challenges of high precision dereddening of Galactic and extra-galactic targets.

The Circumstellar Dust Shell Around the Likely Progenitor Star of SN 2017eaw

Ruining Zhao[1,2,3], Jian Gao[3], Biwei Jiang[3] and Jifeng Liu[1]

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Stars of initial masses $8 - 17M_\odot$ are likely to evolve through red supergiant (RSG) stage and burst into core-collapse supernovae shortly after. This process may be a significant contribution to cosmic dust, and also have critical influence on the possible circumstellar material around the progenitor of supernova. A RSG found in archived data is identified to be the progenitor star of the Type II-P supernova (SN II-P) 2017eaw in NGC 6946. In this work, we model the circumstellar dust shell around the progenitor star by fitting the photometric observations carried out by Hubble Space Telescope (HST) and Spitzer Space Telescope (Spitzer) at $\sim$ 200 d before the explosion. By assuming a central star of $\sim$ 3300 K obscured by a circumstellar dust shell, the dereddened spectral energy distribution (SED) of the RSG is reproduced with a radiation transfer equilibrium process. Synthesized spectra calculated from MARCS code are utilized as intrinsic stellar SEDs. Dust grains are assumed to be a power law ($dn/da \propto a^{-\alpha}$) distributed in size and a modified power law [$dn/dr \propto (1 - r_{\rm in}/r)^\beta (r_{\rm in}/r)^\gamma$] distributed in density along the shell radius. As to the dust components, we consider both astronomical silicate and amorphous carbon. The best fitting suggests that the dust shell had an inner edge of $\sim$ 18 AU and extended beyond 5000 AU with distribution indices $\alpha \sim 4.6, \beta \sim 5$ and $\gamma \sim 3$. The derived optical depth is around 1.8 which is consistent with other previous results.

Construction of a new galaxy spectral energy distribution model consistent with the evolution of dust

Kazuki Y. Nishida[1], Tsutomu T. Takeuchi[1], Takuma Nagata[1], Ryosuke S. Asano[1], Akio K. Inoue[2]

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The spectral energy distribution (SED) of galaxies is affected by the evolution of dust in the galaxy ISM. For example, dust grains scatter and absorb ultraviolet (UV) photons emitted from stars and re-emit the energy at infrared (IR) wavelengths. Also hydrogen molecules, which have an important roll in the star formation, are formed on the dust grain surface. The galaxy SED model should, then, treat the evolution of dust size/mass distribution. However, previous SED models have only used empirical properties for dust and have not considered the evolution of dust. In this work, we construct a new galaxy SED model based on our dust evolution model (Asano et al., 2013a, b, 2014) consistent with chemical evolution. To reduce the computational cost, we adopted the mega-grain approximation and one-dimensional galaxy approximation (Inoue 2005). With these approximations, we can solve the radiative transfer easily and provide SEDs and attenuation curves of galaxies. This SED model can used to fit a galaxy at any evolutionary phase.

A New Dust Evolution Model in Galaxies with Gas Infall

Sayaka K. Nagasaki[1], Tsutomu T. Takeuchi[1], Ryosuke S. Asano[1]

[1]*Nagoya University, Japan*

Dust is a tiny solid particle that influences the physical properties of galaxies, depending on the size distribution or quantity of dust. Thus, proper understanding of dust evolution is fundamentally important to understand the formation and evolution of galaxies.

Dust is provided by AGB stars and supernovae. After that It grows in the ISM. On the other hand, dust also experience the destruction by supernova shock. Furthermore Dust change the size distribution because of the shuttering and coagulation.Asano et al. (2013a, b, 2014) proposed a comprehensive theoretical model (hereafter Asano model) which consistently solves the chemical evolution of dust in galaxies, based on the assumption of the closed box model. Recently, galaxies with a large amount of dust have been discovered at very high redshifts. To explain the dust amount in these galaxies, it is necessary to supply a huge amount of dust at a very early stage in galaxy evolution where only a moderate stellar mass has accumulated. According to the Asano model, dust accretion in the dense interstellar matter is found to be crucial. However there remains some problems that have not been sufficiently explained yet.

In this study, we developed a new version of the Asano model, implementing the inflow of gas from intergalactic space. Nowadays the inflow is regarded as one of the basic processes in galaxy evolution. We found that even if the gas is significantly consumed to form stars, dust can grow in the interstellar matter infalling from outside of a galaxy. This can supply sufficient amount of dust at a young galaxy age when the stellar mass is quite small.

Mineralogy of Interstellar Dust with High Resolution X-ray Spectroscopy

Lía Corrales[1],

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When light from a bright X-ray source travels through interstellar dust, a unique spectroscopic absorption fingerprint becomes visible with high resolution X-ray spectroscopy. This X-ray absorption fine structure (XAFS) arises from the quantum interference of an excited electron probability wave as it scatters from the crystalline lattice in a solid material. XAFS features can be used to study dust crystallinity and atomic spacing, elemental composition, grain size, and orientation. Measuring XAFS from absorption and scattering by dust is frontier science that can answer key science questions about the composition and evolution of dust in the diffuse interstellar medium. I will discuss the state of current observations, where absolute elemental abundances, gas phase absorption, and the effect of X-ray binaries on their environment are key questions for interpreting low-resolution XAFS. I will then describe observations to be expected from next-generation X-ray telescopes, *Athena* and JAXA-led mission XRISM, which will provide crucial insights for the composition of interstellar dust by measuring high resolution spectra from dust scattering halos.

Evolution of Crystalline Phases and Diffusion of Elements in Ion Beam Irradiation Synthesized Cosmic Dust Analogues

Joshua M. Young, Satyabrata Singh, Daniel C. Jones, Bibhudutta Rout

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Laboratory astrophysics has become increasingly important to explore the evolution of cosmic dusts. Generation of experimental data for both diffusion of elements and crystalline phase modification due to conditions in the stellar winds of AGB stars is crucial to develop models for the growth of crystalline grains in amorphous silicate cosmic dust.

A new synthesis process is presented for experimentally simulating modifications in cosmic dust grains utilizing multiple ion beam irradiation techniques. Olivine type cosmic silicate dust analogues were prepared via implantation of 20-80 keV Fe^-, Mg^-, and O^- ions into silicon and quartz wafers. The olivine type analogues, $Mg_{2x}Fe_{2(1-x)}SiO_4$ (x: mixing ratio), had an average mixing ratio of 0.5, 0.7, and 0.9. The analogues were subsequently irradiated with energetic He^+ ions (~600 keV) to induce growth centers and improvement of the crystalline phase. Prior to the ion implantation and irradiation, Monte-Carlo based ion-solid interaction codes were used to model the dynamic redistribution of the target layers. The samples were then thermally annealed in laboratory conditions appropriate for the system of interest, M-class stellar winds, at temperatures ranging from 850-1100 K.

The elemental depth profiles and diffusion are measured utilizing Rutherford Backscattering Spectrometry (RBS) and X-ray Photoelectron Spectroscopy (XPS) in the samples before and after thermal annealing. X-ray diffraction (XRD) technique was employed for identification of various phases in crystalline minerals in post irradiated and annealed analogues. Theoretical solid state diffusion rates were calculated and compared to the experimentally observed rates. In this presentation the modification of crystalline phase as a function of ion beam stopping force, and thermally induced elemental diffusion will be reported in the formed silicate dust analogues.

Graphene-Molecule Compared with Fullerene-C60 in Carbon-rich Planetary Nebula by Quantum-Chemical Analysis

Norio Ota

University of Tsukuba, Graduate school of pure and applied sciences

It had been understood that astronomically observed infrared spectrum (IR) of carbon-rich planetary nebula comes from fullerene-C60. Whereas, it is well known by on-earth experiments that graphene-molecule is a source material for synthesizing fullerene. It will be simply supposed that graphene-molecule may float in astronomical space. In order to check such assumption, this study compared graphene-molecule with fullerene by the quantum-chemical calculation. Calculated IR's were also compared with observed one of carbon rich planetary nebula Tc 1 and Lin 49. Model graphene molecules are (C23), (C22), and (C21) having few carbon pentagons as shown in Fig.1. Calculated result was amazing that graphene-molecule could reproduce many observed bands as shown in Fig.2, where coincided bands are marked by green dot lines. On the other hand in case of fullerene-C60, calculation could reproduce only major bands, but was too poor to reproduce many detailed bands. We can predict that graphene-molecule may be major carbon material rather than fullerene. We should confirm it by on-earth study using actual graphene-molecules.

Fig.1
Model molecules

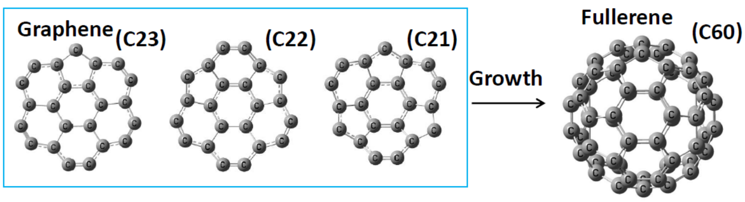
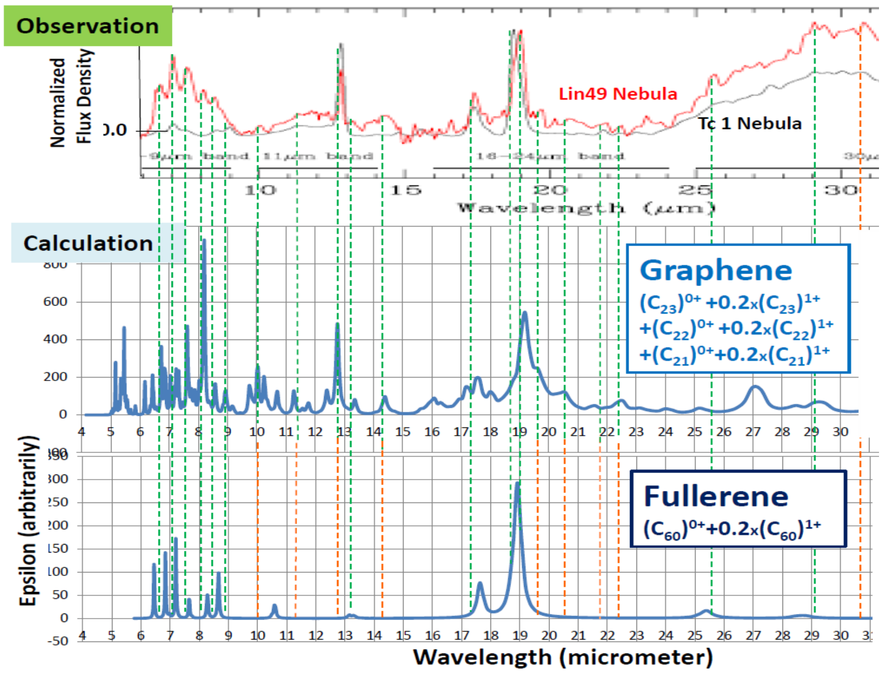


Fig.2,
Observed infrared spectrum identified by calculated bands of graphene and fullerene



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Graphene and Carbon Nanotubes in the Interstellar Medium

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Carbon is exclusively formed in the hot interiors of stars through the fusion reactions of three alpha particles (i.e., helium nuclei) and expelled into the interstellar medium (ISM) through stellar outflows and/or supernova explosions in the late stages of stellar evolution. As the fourth most abundant element in the universe and due to its unique property to form three different types of chemical bonds through sp^1, sp^2, and sp^3 hybridizations, carbon can be stabilized in various multi-atomic structures with different molecular configurations (i.e., allotropes), including amorphous carbon, graphite, diamond, polycyclic aromatic hydrocarbon (PAH), fullerenes, graphene, and carbon nanotubes (CNTs).

In this presentation I will focus on graphene and CNTs. I will present (1) our DFT calculations of the electronic and vibrational transitions of graphene and CNTs as a function of carbon atoms (N_C), (2) the infrared (IR) emission spectra of graphene and CNTs which are stochastically excited by single photons in the ISM, and (3) the possible contribution of graphene and CNTs to the UV interstellar extinction. The model-calculated UV extinction and IR emission spectra of graphene and CNTs will then be compared with the astronomical observations, allowing us to constrain the abundances of these nano species in the ISM. The possible connection of graphene and CNTs with the mysterious diffuse interstellar bands (DIBs) will also be examined.

Experimental Study on Compaction Property of Constituent Material of Primitive Body

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The compaction property of the constituent material of the primitive body affects the porosity structure of the body because which determines the results of compaction due to self-gravity and impact pressure. The internal structure of the body is an important property that reflects their evolutional history and affects their physical and thermal evolution. It is difficult to observe the internal structure directly, however, internal porosity structure due to self-gravity, which is the most porous structure of the body, can be estimated when the compaction property of the constituent material is given.

The constituent material of the primitive meteorite parent body is a mixture of the matrix, which consists of dust particles, and other relatively coarse particles such as chondrule. The compaction property of the mixture depends on the volume fraction of each component and their particle size; they vary depending on the chondrite class *(Weisberg et al., 2006)*.

We investigated the relationship between the compaction property of the dust layer and the characteristics of constituent particles from laboratory experimental results of dust samples (*Omura and Nakamura, 2018*). Next, we investigated the effect of particle size of dust and the mixing ratio of components on compaction properties of meteorite analogs. Finally, we calculated the porosity structure of primitive meteorite parent body due to self-gravity using experimental results.

We made samples with dust or mixtures of dust and solid beads. We used various particles with the diameter of the order of 10^0-10^1 micrometers as dust. In cases of mixture samples, we only used two kinds of dust with a median particle diameter of 1.5 μm and 4.8 μm. We also used 4.8 μm particles containing 0.4 wt% of organic particles as dust. The diameter of the beads was 1 mm. These particle sizes are similar to that of the matrix and chondrule of Allende *(Toriumi, 1989; Forman et al., 2016; Weisberg et al., 2006)*. We modified the volume fraction of dust from about 0.2 to 1. We sieved or poured the sample into a cylindrical container and compacted the sample using a piston fixed to a compressive testing machine installed in Kobe University. The loading rate was set at 10 μm/s. The applied uniaxial pressure was up to ~5×10^6 Pa.

We approximated the obtained compaction curves with a modified polytropic relationship, $P=K'f^{(n+1/n)}$, where P is the applied pressure, K' is a constant, f is the filling factor and n is the polytropic index. In cases of dust only layer, values of K' and n were mainly determined by the median particle diameter of dust irrespective to their composition and particle shape. In a case of dust layer consists of lumps, the size of lumps rather than individual particles might determine the compaction property of the layer (*Omura and Nakamura, 2018*). In cases of the mixture of the dust and beads, their compaction behavior was dominated by dust in cases of the volume fraction of dust larger than ~0.5. Organic particles did not affect compaction behavior.

The approximated compaction curves were applied to the Lane-Emden equation to estimate the porosity structures of primitive meteorite parent bodies due to self-gravity. We compared them with the bulk porosity of asteroids. It was suggested that the volume fraction of the matrix is higher than ~0.4 to achieve the porosity of C type asteroids and typical matrix size of C type asteroids is smaller than 4.8 μm.

In-situ measurement of the circumsolar dust ring around Earth's orbit by IKAROS-ALADDIN

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Circumsolar dust rings (CDR) have been discovered around several planets, i.e. Mercury, Venus, and Earth, in our Solar System by optical observations of space telescopes orbiting around Earth. To reveal the ring's fine structure including blobs and gaps formed by the mean motion resonances (MMRs) with the planet, in-situ measurement of dust number density by using deep-space probe is a powerful and complementary approach. We use the measurement data obtained by the ALADDIN in-situ dust impact detector onboard the JAXA's solar power sail, IKAROS, launched in 2010 to find the CDR structure around Earth's orbit especially the blob region behind the planet where IKAROS passed through. As a result, it is possibly found that the spatial number density of dust particles around the blob region is significantly higher than the gap region in the vicinity of the planet. Constraining the formation mechanism of CDR in the Solar System will be expected to contribute the comprehensive understanding about the dust distribution even in the exo-solar systems.

German Space Science Programme and International Collaborations as Destiny+ Dust Analyzer

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As part of the German Aerospace Center, the German Space Agency acts as implementation organization of the German Space Programme. One pillar of the German Space Programme is the space science. Therefore enabling national and international collaborations of scientific experiments and projects designed to perform research in space is one of the main activity of the Space Science department at DLR Space Agency. The field of research covers objects within our solar system as well as far distant galaxies and the universe as a whole.

DLR Space Science divides thematically into three main topics:

Astronomy and Astrophysics

Scientists use telescopes and highly sensitive detectors to understand the origin, the evolution, and the macrostructure of the universe and its constituents from the earliest beginnings to present. Measurements of cosmic rays yield information about high-energy acceleration processes. At present, scientists are particularly interested in the relevance of black holes, in the investigation of dark matter and dark energy, and in the search for extrasolar planets.

Sun and Planetary System

Studying the sun with high spatial resolution allows researchers to understand fundamental physical processes. Their observations help us to understand the processes in the interior of the sun and in the space between the planets that is filled by the plasma and the magnetic field of the solar wind.

Investigation of planetary bodies, moons, comets and other primordial bodies as asteroids in the Solar System aiming, while delivering images and data to understand the origin, development, and structure of these bodies and to understand the origin and formation of life on Earth.

Fundamental Physics

Space offers conditions that are unattainable in laboratories on Earth, such as weightlessness and absence of vibrations. In metrology, quantum optics, and atomic physics, these conditions permit measurements at considerably higher precision, opening a door to answers fundamental questions in quantum theory and the general theory of relativity (gravitational theory) as well as to the potential unification of both theories.

Most projects are implemented either under the framework of missions by ESA, for which German scientists provide individual instruments or instrument sub-systems or within direct international cooperation as it is for the provision of the Destiny+ Dust Analyzer for the JAXA Destiny+ mission. Funding of individual projects then involves either placing contracts with the industry or providing grants to science institutes.

Ion-driven instabilities of surface dust ion-acoustic waves in a dusty space plasma layer

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The growth rates of the dust ion-acoustic (DIA) surface wave in the dusty plasma layer containing ion streaming passing through the stationary electrons and dusty grains at the speed of wave phase velocity are derived and numerically analyzed. We have found that the growth rates for the resonant symmetric and antisymmetric waves are similar to the case of semi-bounded plasma when we have a thick-layer. However, in the case of symmetric wave, the growth rate towards to the bulk wave as the layer thickness reduces. In the case of the antisymmetric wave, the growth rate increases fast as the layer thickness decreases. The growth rates of surface waves in a plasma layer are compared with those of semi-bounded and bulk waves.

Delivery of ammonia ice to Ceres by pebble accretion

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Ceres is the largest asteroid in the solar system, comprising almost one-third of the total mass of the asteroid belt. The spectrometer onboard the Dawn spacecraft revealed the presence of ammoniated phyllosilicates across the surface of Ceres (De Sanctis et al. 2015), suggesting that Ceres contained ammonia when it differentiated. However, ammonia alone is unstable on the surface of present-day Ceres, where the maximum temperature ($\approx$ 240 K) is well above the sublimation temperature of ammonia ice. This could imply that Ceres was born in the cold outer part of the solar nebula and subsequently migrated to the current orbit. Another possibility is that Ceres formed in situ but the solar nebula was cold enough to preserve ammonia ice even at the current orbit of Ceres.

In this study, we examine the latter scenario by quantifying how much ammonia ice could have been delivered to Ceres in the solar nebula. We use a standard viscous accretion disk model to infer how the temperature of the solar nebula decreased with time. We also simulate the coagulation, radial inward drift, and sublimation of ammonia-bearing icy particles in the background gas disk to compute the radial mass flux of the particles at 3 au as a function of time. The mass flux is then converted into the accretion rate of ammonia-bearing ice by Ceres and smaller asteroids using the state-of-the-art analytic formula for pebble accretion (Visser & Ormel 2016).

We find that the thickness of the ammonia-bearing ice layer forming on Ceres depends significantly on the initial mass $M_{\rm disk}$ and dimensionless viscosity parameter α of the solar nebula. A layer thick enough to globally cover the surface of Ceres forms when $M_{\rm disk} < 10^{-2} M_\odot$ and $\alpha > 10^{-3}$. Our results thus provide unique constraints on the fundamental parameters of the protoplanetary disk that formed the solar system. We also find that the layer thickness is highly sensitive to the initial asteroid mass, possibly explaining why ammoniated phyllosilicates are observed in the largest asteroid Ceres.

Mosses as biomonitors of airborne dusts and their potential application for monitoring cosmic dusts

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The use of mosses represents a cost-effective and eco-friendly approach to evaluate qualitatively and quantitatively the atmospheric particles, as alternative or complementary method to the conventional monitoring systems. Mosses are in fact well-known plants able to absorb and entrap airborne particles of different nature (Di Palma et al., 2017). The usefulness of mosses as biomonitors of airborne dusts is given by a huge literature produced in the last decades and some EU funded Projects such as the UNECE ICP Vegetation Programme Biomonitoring Network (Harmens et al., 2015) based on the collection of native species, and the EUFP7 project "MOSSclone" (Capozzi et al., 2016; Di Palma et al., 2016) aimed at developing a standardized protocol for the moss bag technique consisting in the exposure of mosses inside nylon bags in sites chosen for monitoring surveys (Ares et al., 2012).
It is well-known that some particular atmospheric particles defined as cosmic dusts can be considered as "historical archives" of the universe, as they can provide information on the origin and evolution of the universe and its components. However, the study of extra-terrestrial dusts can represent a hard challenge, particularly for those consisting of nanosized particles. Moreover, the cosmic dusts in their original form (i.e. before modification by the contact with our atmosphere) have very low concentrations in the environment, as they mostly resemble the dusts commonly found in the air, especially in terms of chemical composition and physical properties.
Recently, the occurrence of extra-terrestrial materials was investigated in mosses and lichens collected in remote areas of Antarctica (Mróz et al., 2018), thus opening new frontiers on the use of mosses as biomonitors and on the monitoring of cosmic dusts.
At the present, our research activities are aimed to the monitoring of airborne dusts in the environment by using mosses and on the characterization of the particles entrapped by the biomonitors, with a particular attention to those containing ^{137}Cs. Among the techniques we employ, the Electron Probe Micro Analyzer (EPMA) is the most useful to characterize the airborne particles entrapped by the biomonitors in terms of number, shape, size and chemical composition, and therefore it might be applicable in the perspective of investigations on cosmic dust biomonitoring.

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Measurements of the density of dust clusters forming in a granular stream using flash X-ray

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For highly sticky icy dust, planetesimals could form by sticking during collision [1]; however, for silicate dust which has much lower stickiness than icy dust, bouncing was observed during collision and limits growth to millimeter-to-centimeter size in the laboratory [e.g., 2]. Nevertheless, numerical simulations have shown that bouncing never occurs in the situation of a protoplanetary disc and that bouncing can occur only if the coordination number of the dust aggregate is greater than 6 [3].

It has been shown that clusters form in a free-falling stream of particles of hundreds micron in diameter under atmospheric pressure and reduced pressure due to inter-particle force, i.e., stickiness of particles [4, 5, 6]. Such clusters may be useful to understand the collisional process of dust aggregates in proto-planetary discs. However, the bulk density and the coordination number of these clusters were experimentally unknown. In order to obtain an estimation of the average coordination number based on the averaged density of the clusters, we conducted flash X-ray imaging of the clusters.

The measurements were conducted by streaming spherical 45 or 53-μm glass beads, irregularly shaped 45-μm glass powder, or 70-μm quartz sand from a funnel within a vacuum chamber installed at ISAS/JAXA and imaging by flash X-ray at five heights under reduced pressure (0.1 atm). When we obtain the X-ray adsorption amount of a cluster or a stream and the length of absorption path, we can estimate the average filling factor.

As a result of the estimates of the average filling factor of the clusters, we found that the clusters consisting of spherical 45 or 53-μm glass beads had a filling factor of roughly 0.3–0.4 and that the clusters consisting of irregularly shaped 45-μm glass powder or 70-μm quartz sand had a filling factor of roughly 0.15–0.3. Next, we considered the average coordination number of the clusters based on the estimates of the average filling factor. Using the relationship between the average coordination number and the filling factor of the dust aggregates in numerical studies of collisional growth of dust aggregates [3], the average coordination number of the clusters consisting of spherical glass beads whose filling factor was 0.3–0.4 could be roughly 3–6. Similarly, we derived an average coordination number of 2–5 for the irregularly shaped particles with a filling factor of 0.15–0.3. These coordination number values of 2–6 are not greater than the coordination number at which numerical studies found bouncing therefore, when such clusters forming in a granular stream collide, they may grow by collision without bouncing.

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Dust evolution in the protoplanetary disk around TW Hya

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Understanding how dust grows in protoplanetary disks is crucial for understanding how planet formation begins. Theoretically, how far dust growth can proceed is highly uncertain because the stickiness of dust aggregates is largely unconstrained. Previous models assumed that water ice is sticky and facilitates dust growth in the outer part of protoplanetary disks. However, it is now under debate whether water ice grains are really sticky at low temperatures (Gundlach et al. 2018; Musiolik & Wurm 2019). It is also possible that some nonsticky materials like CO_2 ice cover the grains and prevent their collisional growth (Musiolik et al. 2016). Elucidating whether dust grains in the outer regions of disks are sticky or not is particularly important for understanding how icy planets and small solid bodies like comets form.

In this study, we derive constraints on the stickiness of icy aggregates from observations of the protoplanetary disk around TW Hya. TW Hya is a relatively old T Tauri star surrounded by a massive protoplanetary disk. Recently, high-resolution observations with the Atacama Large Millimeter/submillimeter Array (ALMA) revealed that the dusty disk has circular gaps at 25 au and 41 au (Andrews et al. 2016; Tsukagoshi et al. 2016). Based on the scenario that the gaps are created by two sub-Neptune-sized planets, we simulate how dust aggregates grow and radially drift in the gapped disk assuming that the aggregates fragment upon collisions at velocities above a given threshold. We find that the fragmentation threshold of as low as 0.5 m s^{-1} gives the best match to the ALMA observations. Higher fragmentation thresholds lead to significant dust accumulation at the outer edges of the planetary gaps and to dust depletion interior to the 25 au gap, both inconsistent with the observational appearance of the TW Hya disk. The derived fragmentation threshold is considerably lower than previously anticipated for aggregates made of 0.1 μm-sized water ice grains ($\approx$ 80 m s^{-1}; Wada et al., 2013). Possible explanations for this include (1) water ice grains are indeed not as sticky as previously thought, (2) the icy grains are larger than 10 μm, and (3) the grains are covered by nonsticky CO_2 ice.

Gas-to-dust ratio influenced by massive star formation

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How massive star formation influences the gas-to-dust ratio is still a mystery. As we know, during the process of its formation, a massive young stellar object gives out energetic feed-backs to and changes the physical conditions such as temperature and pressure and even chemical abundance of its surrounding. This will certainly change fraction of dust in the molecular cloud. We address this question by investigating the column density of the dust and molecular cloud in the massive star-forming region M17. The dust is traced by the near infrared extinction while the gas is traced by CO line emission. The spatial resolution has been set to 1 arcmin. We found that in some particular area near massive YSOs, the gas-to-dust ratio has been changed significantly. Our preliminary result suggests that the region deserves further study with higher resolution and more sensitive facilities.

Synthesizing of amorphous silicate with mechanochemical method

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Amorphous silicate is a major component of cosmic dust. In astronomy, substances that absorb at around 10 and 20 μm are called astronomical silicates, which are considered as representatives of amorphous silicates in space. But all their physical structure and spectroscopic characteristics have not been studied. In particular, after the ISO era, the research theme of laboratory spectroscopy shifted to crystalline silicate. Then it can be said that research on amorphous has become somewhat inadequate.

There are several ways to make amorphous material in the laboratory. The most representative method is to heat the material into a melt and then quench it. However, there are difficulties in the need of an experimental furnace capable of producing high temperatures of 1600-1800 °C. And producing of a sufficiently rapid cooling rate in the laboratory is also very difficult. A sol-gel method, which applies a liquid reaction, is also often used. This is a method of producing an amorphous materials by hydrolysis and polymerization reaction at a relatively low temperature using an agent called TEOS(Tetraethyl Orthosilicate) containing tetrahedron of SiO_4 and an alkoxide containing metal cations. Industrially, it is a mature method and is widely used as a method for producing functional glass materials. Furthermore, there is also a method of creating defects in the crystal structure by colliding relatively heavy particle beams with the crystal. In any case, there are not many ways to easily produce amorphous material. As far as we know, the absorption spectra of amorphous silicates prepared by various methods so far are certainly close to the astronomical silicates, but there is no positive report that they completely coincide.

In this study, we attempted to synthesize amorphous materials using a "Mechanochemical method" that promotes material formation by mechanically impacting and using the kinetic energy generated thereby as the energy of chemical reactions. A planetary ball mill was used to react of SiO_2 and MgO or $Mg(OH)_2$. It seems to have succeeded in synthesizing an amorphous material. The generated amorphous material is examined by XRD and IR spectroscopies, and the features of each spectrum are reported.

Astrochemical bistability

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We have made a detailed investigation of astrochemical bistability in dense molecular clouds. By studying the bifurcation behavior as the control parameters in the models are varied, we have determined the underlying chemical processes that lead to bistable solutions in astrochemical networks.

Keywords: Astrochemistry - ISM:abundances - molecules

Variations in the dust destruction efficiency and dust sticking coefficient

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Dust destruction efficiency (f_{des}) and dust sticking coefficient (C_s) are essential parameters that control dust evolution. They are commonly fixed to specific values in the literature although they vary according to the dust properties. Here we use chemodynamical simulations with a new treatment for dust destruction and growth timescales to investigate the influence of variations in f_{des} and C_s on dust temporal evolution and spatial correlations with the cold gas. We find that there is a specific range of f_{des} and C_s in which dust evolution on average ($D/G \propto Z^n$) is consistent with the average driven from galaxy samples. This range is between 0.01 and 0.02 for f_{des} in a single cloud near an SN, and between 0.5 and 1 for C_s. We also find that f_{des} and C_s values influence the abundance of the different ISM components as well as the dust abundance. Accordingly, simulations that produce more dust (low f_{des} and/or high C_s) result in a steeper correlation between dust surface density and H_2 surface density, and between D/G ratio and Z. In these simulations, the correlation between dust surface density and total gas surface density is shallower. We compare predictions of several simulations (with different star formation recipes, gas fractions, metallicities, and metallicity gradients) to the spatially resolved M101 galaxy and conclude that metallicity and dust–to–gas ratio are the primary drivers of the dust and gas spatial variations.

Investigation of Interstellar Polycyclic Aromatic Hydrocarbon molecules as carriers for mid-infrared emission bands: combined approach

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Interstellar Polycyclic Aromatic Hydrocarbon (PAH) molecules exist in diverse forms depending on the local physical environment of the Interstellar Medium (ISM). Formation of ionized PAHs (anions and cations) is favorable in the extreme condition of the ISM. Besides its pure form, PAHs are likely to exist in substituted forms, for example, PAHs with functional groups, dehydrogenated PAHs, protonated and deuteronated PAHs, etc (Buragohain et al., 2015, 2016). These PAHs may convert into alternate forms as a result of ongoing chemical processes in the ISM. Fullerene (C_{60}^{+}) has recently been detected as a crucial component of the ISM (Campbell et al., 2015; Ehrenfreund and Foing, 2015). Dehydrogenated PAHs might be an intermediary between PAHs and Fullerenes (Berné and Tielens, 2012).

The spectral evidence of PAH molecules and its variants in the ISM is observed via the mid-infrared bands, particularly at 3.3, 6.2, 7.7, 8.6, 11.2 and 12.7 μm (Tielens, 2008). These bands, also known as 'Aromatic Infrared Bands (AIBs)' are widely present in the ISM and arise from the vibrational relaxation of PAH molecules on absorption of background UV photons. However, the exact form of PAH molecules that are responsible for the AIBs is still ambiguous. Here, we discuss the possible form of interstellar PAH molecules as carriers for AIBs. Density Functional Theory (DFT) calculation on several classes of PAHs is employed to study its spectral characteristics in infrared. We compare our results with *SUBARU* observations in quest of any correlation that establishes its presence in the ISM.

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