Interstellar and Solar Nebula Materials in Cometary Dust

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Laboratory studies of cometary dust collected in the stratosphere and returned from comet 81P/Wild 2 by the Stardust spacecraft have revealed ancient interstellar grains and molecular cloud organic matter that record a range of astrophysical processes and the first steps of planetary formation. Presolar materials are rarer meteorites owing to high temperature processing in the solar nebula and hydrothermal alteration on their asteroidal parent bodies. The greater preservation of presolar materials in comets is attributed to their low accretion temperatures and limited planetary processing. Yet, comets also contain a large complement of high temperature materials from the inner Solar System. Owing to the limited and biased sampling of comets to date, the proportions of interstellar and Solar System materials within them remains highly uncertain.

Interstellar materials are identified by coordinated isotopic, mineralogical, and chemical measurements at the scale of individual grains [1]. Chondritic porous interplanetary dust particles (CP IDPs) that likely derive from comets are made up of 0.1 – 10 µm-sized silicates, Fe-Ni-sulfides, oxides, and other phases bound by organic material [2]. As much as 1% of the silicates are interstellar grains that have exotic isotopic compositions imparted by nucleosynthetic processes in their parent stars. Crystalline silicates in CP IDPs dominantly have normal isotopic compositions and probably formed in the Solar System. 81P samples include isotopically normal refractory minerals that resemble Ca-Al rich inclusions and chondrules common in meteorites [3]. The origins of sub-µm amorphous silicates in IDPs are not certain, but at least a few % of them are interstellar grains [4]. The remainder have isotopic compositions consistent with Solar System origins and elemental compositions that are inconsistent with interstellar grain properties, thus favoring formation in the solar nebula [4]. The organic component in comets and primitive meteorites has large enrichments in D/H and $^{15}N/^{14}N$ relative to terrestrial materials. These isotopic signatures are probably due to low temperature chemical processes in cold molecular clouds or the outermost reaches of the protoplanetary disk. The greatest isotopic anomalies are found in sub-µm organic nanoglobules that show chemical signatures of interstellar chemistry [5].

The observation that cometary dust is mostly composed of isotopically normal minerals within isotopically anomalous organic matter is difficult to reconcile with the formation models of each component. The mineral component likely formed in high temperature processes in the inner Solar System, while the organic fraction shows isotopic and chemical signatures of formation near 10 K. Studying more primitive remnants of the Solar System starting materials would help in resolving this paradox. Comets formed across a vast expanse of the outer disk under differing thermal and collisional regimes, and some are likely to be better preserved than others. Finding truly pristine aggregates of presolar materials may require return of a pristine sample of comet nucleus material.

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Size constraints on presolar silicate grains from atomic diffusion processes in thermally evolving planetesimals

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Presolar grains are tiny materials in meteorites and their isotopic compositions are different from those of materials in the Solar System. A typical size range of presolar silicate grains is from 0.1 to 1.0 μm and they might be originated from nearby stars (supernovae and/or asymptotic giant branch stars). Their abundance varies among meteorites: as the degree of thermal metamorphism of meteorites increases, their abundance decreases. This indicates that the presolar grain abundance could be related to thermal history of their host meteorites's parent bodies. If the atomic diffusion affected the isotopic composition of presolar grains while they were embedded in the parent bodies, the original information of their isotopes might be eliminated. Then, we cannot identify such grains as presolar grains anymore. We examine the diffusion process in thermally evolving planetesimals, parent bodies of meteorites, to reveal whether it can wash out the isotopic composition of presolar grains.

We compute the diffusion length of oxygen in presolar silicate grains using a diffusion coefficient of ^{18}O in olivine. We numerically calculate the thermal evolution of various planetesimals (size and formation time) and the diffusion length of ^{18}O in a consistent way, because the diffusion coefficient depends on temperature. The results shows that as temperature increases, the diffusion length increases. We also find that the maximum temperature of planetesimals governs the diffusion length of ^{18}O. Then, we compare the measured size of presolar silicate grains in meteorites and our numerical results. The size of presolar silicate grains in petrologic type 3 chondrites are above the calculated diffusion length, when the maximum temperature is $\sim$ 600 °C which is the estimated peak metamorphic temperature of type 3. This means that the isotopic composition of presolar grains as large as type 3 chondrites are not affected by the atomic diffusion. On the other hands, the grains less than 1.0 μm cannot keep their original isotopic compositions when the maximum temperature is higher than 750 °C, which roughly corresponds to the peak temperature of types 4-6. This could be the reason that we cannot find any presolar grains in types 4-6. Thus, the diffusion process can explain the abundances and size distribution of presolar silicate grains. We also discuss that this process could explain the abundance difference of presolar grains between interplanetary dust particles and chondrites. We propose that the diffusion process could be a key to organize the size distribution of presolar grains in some petrologic types of chondrites.

Investigation of silicate feature in zodiacal emission at various ecliptic latitudes with AKARI/IRC

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Interplanetary dust in our solar system originates from collisions of asteroids and/or sublimation of comets, and the spatial distribution depends on the type of origin [1][2]. Therefore, comparison of dust properties in different field is useful to investigate the evolutional history of the different types of planetesimals. In particular, if we know the thermal history of dust, we can specify the distance from the sun at which the dust had been incorporated into the original planetesimals, and the subsequent orbital history to the present distribution. This becomes a clue to understand the orbital history of the original planetesimals.

To trace the thermal history of dust, we focus on a silicate feature around 10 μm in zodiacal emission, which have been reported from mid-infrared space-based observations [3][4]. The shape of the feature depends on physical and chemical properties of the dust: grain size, olivine/pyroxene ratio, crystal/amorphous ratio, and Mg/Fe ratio and so on [5]. These properties reflect the physical and chemical environments that dust grains had experienced.

In this study, we use mid-infrared spectroscopic data of zodiacal emission at 74 different directions obtained with AKARI/IRC. We have carefully examined and subtracted artifacts including scattered light in the detector and ghost caused by the bright sources in the field of view, and successfully obtained the high S/N spectra in 5 - 12 μm with R $\sim$ 50. For each of these 74 spectra, we fit the continuum to diluted blackbody of a single temperature ($\tau B_\nu(T)$) and divided the observed spectra by the modeled continuum. As a result, we detected the silicate feature around 10 μm in all pointing data and recognized the variations in the shape and the strength of this feature among different ecliptic latitudes. We have also found that the dust temperature is higher at high ecliptic latitude than near ecliptic plane. We will present these results and talk about future works for more progressive discussion.

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Separation of the Near-Infrared Extragalactic Background Light and Scattered Sunlight by Interplanetary Dust

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Extragalactic background light (EBL) consists of the entire radiation from the reionization era to the present epoch. The EBL measurements are thus crucial in the study of star formation history of the universe and any unknown radiation process, such as particle decay of elementary particles. To derive the near-infrared EBL, foreground emissions including zodiacal light, integrated starlight, and diffuse Galactic light must be subtracted properly from the total sky brightness. Among these components, the zodiacal light, the scattered sunlight by interplanetary dust (IPD), is the dominant contributor to the sky brightness, indicating that the accuracy of the EBL intensity is sensitive to the evaluation of the IPD properties. Literatures have shown that the observed isotropic residual emission including the EBL are several times larger than the integrated light of galaxies[1,2,3] and it is difficult to attribute the entire intensity to other potential extragalactic sources, such as first stars[4] or intra halo light[5].

By compiling the previous results from optical to near-infrared, the spectrum of the residual emission is similar to that of the sunlight, indicating the presence of the scattered light component from an additional IPD[6]. Since such a component is expected to show nearly isotropic distribution around the sun, the residual emission exhibits the solar elongation dependence if it contains the scattered light component in the solar system. To confirm the presence of such dust, weekly-averaged all-sky maps obtained with Diffuse Infrared Background Experiment (DIRBE) on board *Cosmic Background Explorer* (*COBE*) are analyzed. The maps provide observed near-infrared sky brightness in various solar elongation angle, $64° - 124°$, which are suitable for the investigation of the angle dependence.

As a result of the analysis, the expected dependence on solar elongation angle is found in the residual emission at $1.25\,\mu$m, indicating that the residual emission consists of the additional IPD contribution. Compared with models of the isotropic IPD, it is possible that the most part of the residual emission are attributed to the IPD and the EBL intensity is closer to the integrated light of galaxies. This suggests that the extragalactic contribution other than normal galaxies is smaller than the previous prediction, though the origin of the EBL is still uncertain.

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The Dynamics of Dust in Planetary Rings

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Aspects of circumplanetary dust rings are reviewed, summarizing the state of observations and highlighting recent discoveries. The physical processes underlying the formation and evolution of dust grains are discussed and how the determine the shape and appearance of the circumplanetary dust configuration.

In-Situ Dust Analysis of Interplanetary and Interstellar Dust Particles on board the DESTINY+ mission to 3200 Phaethon

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About 40,000 metric tons per year of extraterrestrial materials enters the atmosphere and eventually reaches the ground. This extraterrestrial materials are derived either from cosmic dust background or from meteor showers. The former consists mostly of interplanetary dust and with minor interstellar dust. The latter are meteoroids generated from breakup of comets and asteroids. Parent bodies which are dynamically linked with major annual meteor showers have been identified. Meteoroid dusts are rare and important extraterrestrial matters of which origins are identified. Asteroid 3200 Phaethon is a parent body of the Geminids meteor shower, which is among the most active meteor showers. While most of the parent bodies of meteor showers are comets, cometary activity of Phaethon has only been reported near its perihelion at 0.14 AU. Phaethon is likely a comet to asteroid transitional body. Depletion of sodium, which is a moderately volatile element, and high dust density (about 2.9 g/cm3), relative to other meteor showers are reported from spectroscopic study of the Geminids meteoroid. Because of its small perihelion distance, dehydration of the surface material by solar heating is expected, but some primitive, hydrous material may still reside in its interior. Phaethon is an ideal body to understand the origin of meteoroid dusts and thermal evolution of primitive bodies in the near-Earth orbit. Also, Phaethon is the largest body among potentially hazardous asteroids (PHAs), of which cross the Earth`s orbit.

The Japanese Space Exploration Agency (JAXA) recently down-selected a small-scale deep space mission launched by Epsilon rocket, DESTINY+ (Demonstration and Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby with reUSable probe). Its mission target is the active asteroid 3200 Phaethon, which a spectrally B-type, Apollo asteroid with an orbital period of 1.4 years. The launch is currently planned for 2022, and the DESTINY spacecraft with a daughter satellite, Procyon-mini will be orbiting the Sun between 0.8 and 1.2 AU, with a Phaethon flyby planned for 2025 (Sarli et al., 2016). Among the proposed payload is an in-situ dust analyzed, DESTINY+ Dust Analyzer (DDA), developed based on the Cosmic Dust Analyzer (CDA) onboard the Saturn orbiting Cassini spacecraft (Srama et al., 2004). The DDA is an impact ionization time-of-flight mass spectrometer, which is capable of analyzing sub-micron and micron sized dust grains with a mass resolution of $m/\Delta m=150$. In addition to surface imaging of Phaethon and its dust environment, its mission goals comprise the analysis of interplanetary and interstellar dust grains with DDA. Here, we present DESTINY+ mission objective, goals, and requirements with current design of DDA.

Scattered light observations of the dust in debris disks systems

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Debris disks consist of populations of planetesimals releasing through collisions smaller dust particles that are blown away on wider orbits or expelled by the radiation pressure of the star. Despite the large occurrence rate of debris disks (17% to 33%), their detection in scattered light is still scarce because they are faint extended structures, often hidden in the glare of their host star. Through a few well-focused examples of disks recently imaged with high-contrast instruments such as VLT/SPHERE, we will review the new insight on the dust properties brought by the measurements of their scattering phase function, reflectance, polarized light or surface brightness.

Machine-learn a dust spectrum: what kind of disk is this?

Grant Kennedy

University of Cambridge, UK

The era of big data has clearly arrived, yet our ability to sort through this data is still developing. Many instances arise where we wish to characterize large numbers of targets, yet want to ensure reliable enough results that rare objects can be identified. When the characterization involves fitting of models, one challenge is therefore ensuring that the appropriate model is used.

Most of my work is on circumstellar disks, and the standard way to characterize these systems in the first instance is by fitting stellar and dust models to photometry and spectra over a wide range of wavelengths. When dealing with systems on an individual basis, figuring out which type of model to fit is relatively easy because a trained eye can discern among different possibilities, and usually chose the most appropriate one. For large numbers of systems however, choosing the best model in an automated way can be challenging and time-consuming.

A possible way to aid this challenge is with some form of machine learning. The basic concept is that a set of "training" data with known properties are used to condition a model, which is then applied to real data with unknown properties. My overall aim with this work is to use machine learning to classify photometry and spectra of stars and disks. Initially the goal is to inform automated model fitting, for example to discern among protoplanetary and debris disks. Further work will be to identify specific spectral features, for example silicates, PAHs, Be-star emission lines, and perhaps contamination from extragalactic sources, primarily in Spitzer IRS spectra (of which there are over 20,000).

This work is in the early stages, so my hope is to present it at the Cosmic Dust meeting and get feedback and ideas from dust experts, and discuss if and how it should be developed to make it applicable to a wider audience.

Debris disks: What dust tells us about extrasolar comets and asteroids

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Debris disks are dusty belts of comets and asteroids found around a sizeable fraction of main-sequence stars of all spectral types and ages. Of course, the comets and asteroids in alien systems are not visible directly, yet debris disks are observed by the emission of dust that these small bodies release through mutual collisions and sublimation. Interpreting the dust emission with the assist of collisional and dynamical models, one can infer various properties of extrasolar comets populating Kuiper-belt analogs around other stars. I will discuss current constraints on the location, masses, sizes, dynamical excitation, and chemical composition of comets, and even on possible scenarios of their formation. Finally, I will review the status of searches for extrasolar asteroid belts in the inner regions of planetary systems.

Dust production in young debris disks: the case of HR 4796

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Debris disks are the footprint of star and planet formation processes. Pluto-sized planetesimals are continuously being ground down in a collisional cascade, thus continuously releasing small dust grains. Even though our understanding has greatly improved over the past decades, especially thanks to high angular resolution imaging, from an observational point of view we currently know very little about how the production rate and mechanism of these small dust grains.

We recently obtained deep, high angular resolution images of the young debris disk around HR 4796 at optical wavelengths (VLT/SPHERE, ZIMPOL instrument). We modeled the spatial distribution of the small dust grains that we detect. These dust grains are strongly affected by the radiation pressure from the star, but we can model the effect that radiation pressure has on the radial distribution of these dust grains. We can therefore indirectly infer the distribution of the underlying population of parent planetesimals. I will present in this talk the modeling approach and what we can learn when applying it to high-end observations with exquisite angular resolution.

Giant planets or exo-plutos?
Bayesian constraints from debris disk SEDs and numerical modeling.

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Debris disks are collisionally excited dust disks around 10 Myr or older stars, which have lost their original gas. Using photometry from more than 350 debris disk systems and imaging data, we find a simple description of a planetesimal disk population which is mostly consistent with the data. We show that this population of A, F and G star systems when evolved from a few million to 5-10 Gyrs using a numerical model of fragmenting and coagulating planetesimals (code from Kobayashi and Lohne 2014) to match our data, point to very narrow planetesimal disks. But our Bayesian technique also shows what fraction of disks are required to be wider. We discuss in this work, the main physical reasons for these findings and how the systems vary across spectral types. Finally, we address the question: what fraction of systems are likely to form giant planets, and what fraction are probably in steady state evolution and do not produce giants?

Enormous Accumulation of Hot Dust Grains in the Immediate Vicinity of Main-sequence Stars

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Near-infrared interferometric observations of main-sequence stars have revealed an enormous accumulation of hot dust particles in the vicinity of the stars, irrespective of their spectral types. The vast dust accumulation is, however, not expected, since the size of hot dust particles lies in the submicrometer range where stellar radiation pressure immediately sweeps away the particles from near-stellar environments, A-type stars in particular. One and only mechanism proposed for prolonging the residence time of hot grains in the near-stellar environments is trapping of charged nanoparticles by stellar magnetic fields. The model of magnetic grain trapping predicts that hot dust grains are present in the vicinity of main-sequence stars with high rotation velocities. On the contrary, we find no correlation between the detection of hot dust grains and the rotation velocities of central stars nor their magnetic field strengths. Our numerical evaluation of electric grain charging indicates that the surface potential of submicrometer-sized grains in the vicinity of main-sequence stars is typically 4–5 V, more than one order of magnitude smaller than the value assumed by the model of magnetic grain trapping. On the basis of our numerical simulation on sublimation of dust grains in the vicinity of a star, it turns out that their lives end due to sublimation in a timescale much shorter than the period of one revolution at the gyroradius. It is, therefore, infeasible to dynamically extend the dwell time of hot grains inside the sublimation zone by magnetic trapping and thus some other unrecognized mechanism must be at work. We will present consequences of a dynamical effect that counterbalances the Poynting-Robertson effect in the vicinity of stars and results in an enormous accumulation of hot dust particles at the outer edge of sublimation zone.

Gas in Debris Disks

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The circumstellar disks observed around several hundred main-sequence stars are mostly revealed by excess infrared emission around the stars, which are called debris disks. The evolution of protoplanetary disks, say growth or formation of planets, may form debris disks. Gas depletion of protoplanetary disks affects planet formation such as gas giant formation, planetary migration, and so on. CO gas is observed in some debris disks, but the population of hydrogen molecule, the major gas component in protoplanetary disks, is still unclear. Higuchi et al. (2017) first majored the amount of neutral carbon gas [C I] in the debris disks around 49 Ceti and beta Pic using ASTE. We calculate the ratio of [C I]/ [CO] as a function of the amount of H_2, using the Meudon PDR (Photon Dominated Region) code. High ratio of [C I]/[CO] indicates the depletion of H_2.

Ices in star-forming regions: the role of metallicity

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Understanding properties of interstellar medium in diverse metallicity environments are crucial to reveal the formation and evolution history of cosmic materials from the past metal-poor galaxies to the present metal-rich galaxies. In dense and cold molecular clouds where stars are formed, the formation of ices on dust surfaces plays a central role for physical and chemical evolution of interstellar medium. To elucidate a possible link between properties of dense molecular clouds and the cosmic time evolution, it is necessary to understand characteristics of ice chemistry as a function of galactic metallicity and related environmental factors. In this talk, I will review recent observational and theoretical studies of ices in various metallicity environments ranging from the Galactic center to nearby low-metallicity dwarf galaxies (the Large and Small Magellanic Clouds), and discuss the role of galactic metallicity on physical and chemical processing of ices in star-forming regions.

Modeling the first millimeter detection of the disk around a young, isolated, planetary-mass object.

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OTS44 is, up to date, one of only four free-floating planets known to have a disk. In Joergenst et al. (2013), we showed that it is the coolest and least massive known free-floating planet ($\sim$12 $M_{\rm Jup}$) with a substantial disk that is actively accreting. Recently, we have obtained Band 6 (233 GHz) ALMA continuum data of this very young disk-bearing object (Bayo et al. 2017). The data shows a clear unresolved detection of the source. We performed radiative transfer modeling of the full SED of the object and compared the parameters obtained to disk mass estimates via empirical correlations derived for young, higher-mass, central (substellar) objects. The range of values obtained are between 0.07 and 0.63 $M_\oplus$ (dust masses). We compare the properties of this unique disk with those recently reported around higher mass (brown dwarfs) young objects in order to infer constraints on its mechanism of formation. While extreme assumptions on dust temperature yield disk-mass values that could slightly diverge from the general trends found for more massive brown dwarfs, a range of sensible values provide disk-masses compatible with a unique scaling relation between $M_{\rm dust}$ and M_* through the substellar domain down to planetary masses. In addition, the constraints on the flaring index imposed by our modeling, suggests that, given the youth of the source, dust settling must have not proceeded too far yet (which explains the apparent contradiction with the results of Liu et al. 2015).

Probing the Grain Growth Signatures in Class 0 Young Stellar Objects

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When and how does the maximum dust grain size grow from micron-size to millimeter-size in protoplanetary disks? This is one of the crucial questions when addressing the formation of planetesimals and planetary systems in star-forming regions. Observationally, the maximum size of dust grains could be constrained by the dust opacity indices β.

We are motivated by the recent measurements of β around young stellar objects (YSOs), which suggest that efficient grain growth may have occurred earlier than the Class I stage. The present work makes use of abundant archival interferometric observations at submillimeter, millimeter, and centimeter wavelength bands to examine grain growth signatures in the dense inner regions (<1000 AU) of nine Class 0 YSOs. A systematic data analysis is performed to derive dust temperatures, optical depths, and dust opacity indices based on single-component modified black body fittings to the spectral energy distributions (SEDs). The fitted dust opacity indices (β) are in a wide range of 0.3 to 2.0 when single-component SED fitting is adopted. Five out of nine observed sources show β values close to or consistent with 1.7, the typical value of the interstellar dust. Remaining four sources show β lower than 1.7, which may be explained by the effect of dust grain growth. Alternatively, the very small observed values of β may be interpreted by the presence of deeply embedded hot inner disks, which only significantly contribute to the observed fluxes at long wavelength bands.

Our current analysis found no firm evidence of grain growth in these YSOs. A comparison with the previous observations of Class II sources implies that grain growth would start to significantly reduce the values of β no earlier than the late-Class 0 stage but before the Class II stage of YSOs.

The effect of radiation pressure on dust size distribution inside HII regions

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Abstract & Conclusions: Inside HII regions, past observations indicate that radiation pressure may affect distribution of dust size (Paladini et al. 2012). We therefore investigate the impact of radiation pressure on spatial dust distribution inside HII regions using one-dimensional radiation hydrodynamic simulations. In order to investigate the distribution of dust grains, we introduce two additional fluid components describing large and small dust grains. In a cloud of mass $10^5\ M_\odot$ and radius 17 pc, we find that radiation pressure accelerate large (0.1 μm) dust grains more efficiently than small (0.01 μm) grains, the large to small grain mass ratio becomes smaller by an order of magnitude relative to the initial one. Resulting dust size distributions depend on the luminosity of the radiation source. The large and small grain segregation becomes weaker when we assume stronger radiation source, since dust grain charges become larger under stronger radiation and hence coulomb drag force becomes stronger.

Methods: In our simulations, we place a radiation source at the centre of a spherically symmetric gas distribution. We solve the radiation transfer equation to include following processes: chemical reactions, heating-cooling processes of gas, and radiation pressure. The species we include in our simulations are H, He, electrons, and graphite (0.1, 0.01 μm). In order to determine the relative velocity between dust and gas, we include collisional drag force and coulomb drag force.

Results: We present densities, large-dust-to-gas mass ratio, small-dust-to-gas mass ratios, large-dust-to-small-dust mass ratios, and the dust charge as functions of radius in Fig 1. Note that the radiation source becomes stronger from Cloud 1 to Cloud 3. We find that radiation pressure preferentially removes large dust grains from HII regions in almost all simulations.

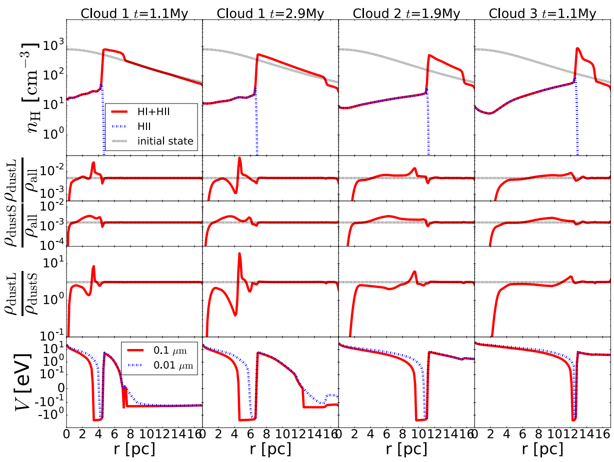

Figure 1: Density (top), large-dust-to-gas-mass ratio (second from the top), small-dust-to-gas-mass ratio (middle), large-dust-to-small-dust-mass ratio (second from the top),and dust charge (bottom) profiles. From left to right, we show the results for Clouds 1 at $t = 1.3$ Myr, Cloud 1 at $t = 2.9$ Myr, Cloud 2 at $t = 2.2$ Myr, and Cloud 3 at $t = 1.3$ Myr. The black dotted lines show the initial profiles. The red solid lines represent the results of simulations. The blue dashed lines at the top panels show the ionized hydrogen density profiles. In the bottom panels, the red solid lines and blue dashed lines show the charge of the large dust and the small dust respectively.

Dust Reddening, Diffuse UV maps and Modelling Dust Scattered Radiation in the Taurus

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We have studied the dust reddening E(B-V) in the Taurus region with three all sky dust reddening maps, the *Schlegel et al. 1998*, the recent *PLANCK* and the latest 3D *Green et al. 2015.* We have observed that the *PLANCK* dust map has the advantage of matching with Arce & Goodman (1999) results in Taurus region while the most widely used *Schlegel et al. 1998* dust map is not a good choice to explre dust distribution in the region. We find that the *Green et al. 2015* overestimate the reddening than the *PLANCK* but we believe that it is an indication of clumpiness in the region which is very important while modelling the dust scattered radiation.

We have studied the diffuse ultraviolet background in the region with the latest diffuse GALEX observations. We have used the diffuse GALEX data by Murthy 2016 for the present work. Since most part of the diffuse Ultraviolet background is contributed by dust scattered radiation, we modelled dust scattering in the region with a Monte Carlo multiple scattering model. We have modelled the Milky-Way Galaxy as a 500x500x500 grid with a bin size size of 2pc. We further assumed the number density of Hydrogen nuclei at the galactic plane $n_H = 1$ cm^{-3} which falls exponentially with galactic latitude with a scale-height of 125 pc, independent of galactic longitude. We have modified the dust distribution in the vicinity of the Taurus with the *Green et al. 2015* dust reddening values. We have run a series of Monte Carlo code for different combinations of albedo (a) and phasefactor (g) to constrain these optical parameters of dust grains in the region.

We find that most part of the dust scattered radiation originates from the foreground (below 140 pc) and very little radiation originates from, within and behind the TMC assuming the cloud's heliocentric distance and thickness 140 pc and 20 pc respectively from the literature surveys. We have tabulated flux contribution from each bright stars towards the region. We have used the diffuse flux as a function of galactic longitude as a metric of goodness of fit of the model and find that the phase factor (g) is independent of the level of scattered radiation and the best fit albedo (a) is around 0.3.

Recent advances in the study of dust in Protoplanetary Disks

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Small solid particles, usually referred to as dust by astronomers, are a key ingredient of circumstellar disks surrounding young stars. They play an important role in the physics and chemistry of disks and the formation of planets in general. In the core accretion model of planet formation, the growth of dust grains from the micron size range to much larger sizes is the first step in planet formation. The recent commisionning of very potent instrument operating at optical and near-infrared wavelengths (e.g., VLT / SPHERE, GEMINI / GPI, SUBARU / ScexAO) and radio wavelengths (ALMA, JVLA) are currently transforming our view of protoplanetary disks. Images with unprecedented sensitivity and angular resolution are revealing fine structures (i.e., rings, gap, warps, shadows), some of which still challenge our detailed understanding.

The wavelength coverage, the availability of linear polarisation measurements, spectroscopy now available from these instruments all contribute to also provide a wealth of new information regsrding the properties of dust located in disks. In this contribution I will review some of the most striking observational results obtained recently. I will discuss their implications for the dust properties in protoplanetary disks. Finally, I will place these results in the context of planet formation and protoplanetary disk evolution.

Radiative transfer modeling of fluffy dust disk

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Planetesimals are formed from dust grains in protoplanetary disks; however, the theory of planetesimal formation involves many problems. Recent theoretical studies suggested that the fluffy dust aggregates can form planetesimals via coagulation, but their presence has not yet been confirmed by observation. We study how the presence of fluffy dust aggregate affects on the appearance of protoplanetary disks in near-infrared wavelength using 3D radiative transfer calculations.

We develop light scattering model of fluffy dust aggregates based on the Rayleigh–Gans–Debye (RGD) theory whose validity is tested using a rigorous method, T-Matrix-Method (Tazaki et al. 2016). We implement our light scattering model into the radiative transfer code, RADMC-3D (Dullemond et al. 2012). First, we show that when the effective medium theory, or a commonly used method, is applied to calculate light scattering of fluffy dust aggregates, the scattered light luminosity of protoplanetary disks becomes an order of magnitude fainter than that obtained by the RGD-theory. Secondly, we perform radiative transfer modeling of the GG Tau circumbinary ring. As a result, we find that fluffy dust aggregate can reproduce observed disk luminosity, brightness asymmetry and high degree of polarization for the GG Tau ring simultaneously, while compact dust grains model fails.

Dust from Supernovae and Evolved Stars

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Until the advent in the late 1990's of sensitive submillimetre detector arrays such as SCUBA, it was generally believed that the main sources of the interstellar dust found in galaxies were the dusty outflows from evolved stars such as AGB stars and M supergiants, although a dust contribution from supernovae had been suggested on theoretical grounds. However, the subsequent detection at submillimetre wavelengths of very large dust masses in some high redshift galaxies that were emitting less than a billion years after the Big Bang led to a more serious consideration of core-collapse supernovae (CCSNe) from massive stars as major dust contributors. But it was not until the 2009-2013 *Herschel* mission that direct observational evidence was obtained for the presence of large masses of newly formed dust (>0.2 Msun) in several young CCSN remnants.

I will review current methods for estimating dust masses and dust injection rates into the ISM from both evolved stars and supernovae, as well as current estimates for the lifetimes in the ISM of dust particles from these sources.

The dust mass in Cassiopeia A from a spatially resolved Herschel analysis

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The large reservoirs of dust observed in some high redshift galaxies have been hypothesised to originate from dust produced by supernovae from massive stars. Theoretical models predict that core-collapse supernovae (CCSN) can be efficient dust producers (0.1-1 $M_\odot$) potentially responsible for most of the dust production in the early Universe. Observational evidence for this dust production efficiency is however currently limited to only a few CCSN remnants (e.g., SN 1987A, Crab Nebula) that confirm this scenario.

We revisit the dust mass produced in Cassiopeia A (Cas A), a ∼330-year old O-rich Galactic supernova remnant (SNR) embedded in a dense interstellar foreground and background. We present the first spatially resolved analysis of Cas A based on Spitzer and Herschel infrared and submillimetre data at a common resolution of ∼0.6 arcmin for this 5 arcmin diameter remnant following a careful removal of contaminating line emission and synchrotron radiation. We fit the dust continuum from 17 to 500 micron with a four-component interstellar medium (ISM) and supernova (SN) dust model. We run different sets of SED models with varying dust composition ($MgSiO_3$, $Mg_{2.4}SiO_{4.4}$, $Mg_{0.7}SiO_{2.7}$, Al_2O_3, $CaAl_{12}O_{19}$, various types of amorphous carbon) for the warm and cold SN dust components.

We find a concentration of cold dust in the unshocked ejecta of Cas A and derive a mass of 0.3-0.5 Msun of silicate grains freshly produced in the SNR. Silicates are thought to dominate the dust composition in this O-rich remnant, with a possible contribution from carbon grains. For a mixture of 50% of silicate-type grains and 50% of carbonaceous grains, we derive a total SN dust mass between 0.4 M_{sun} and 0.6 M_{sun}. We can exclude $Mg_{0.7}SiO_{2.7}$, $CaAl_{12}O_{19}$ and Al_2O_3 as dominant dust species based on the elemental yields predicted for a core-collapse supernova with a 30 $M_\odot$ progenitor and the amounts required to match the observed SED. These dust masses estimates are higher than from most previous studies of Cas A and support the scenario of supernova dominated dust production at high redshifts. Our resolved analysis shows that the cold SN dust component is mainly distributed interior to the reverse shock of Cas A, suggesting that part of the newly formed dust has already been destroyed by the reverse shock. We furthermore derive an interstellar extinction map which towards Cas A gives average values of A_V = 6-8 mag, up to a maximum of A_V = 15 mag.

Silicate Crystallinity and Mass Loss Rate of Oxygen-Rich Evolved Stars

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For decades ever since the early detection in the 1990s of the emission spectral features of crystalline silicates in oxygen-rich evolved stars, there is a long-standing debate on whether the crystallinity of the silicate dust correlates with the stellar mass loss rate. To investigate the relation between silicate crystallinity and mass loss rate of evolved stars, we carry out a detailed analysis of 28 nearby oxygen-rich stars. We derive the mass loss rates of these sources by modeling their spectral energy distributions from the optical to the far infrared. The silicate crystallinity is expressed by the flux ratios of the emission features of crystalline silicates to that of amorphous silicates, which has the advantage over generally used mass ratio by avoiding the uncertain dust temperature. The result shows no apparent correlation of silicate crystallinity and mass loss rate. In addition, a search for SiO maser emission is performed to the stars with spectral features of crystalline silicate. The SiO maser power is found to correlate with the dust mass while not correlated with silicate crystallinity. This fact indirectly supports that silicate mass loss rate is not correlated with mass loss rate.

Dust Model for the Extinction Curves of Type Ia Supernovae

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Abstract: Correcting the extinction of type Ia supernovae accurately is a prerequisite for accurate determination of cosmological parameters, which demands further research on the properties of dust in host galaxies of type Ia supernovae. Due to the different properties of dust in the Milky Way and host galaxies, fitting extinction curves of type Ia supernovae based on dust models of host galaxies becomes a new method to explore properties of dust in host galaxies. SN2012cu is a type Ia supernova in NGC4772, which is known to be an Active Galaxy, and its extinction curves indicate a visual extinction of $A_V \approx 2.8$ mag, a reddening of $E(B-V) \approx 0.9$ mag, and a total-to-selection extinction radio of $R_V \approx 3.1$, which is about the value of the Milky Way and much larger than other high reddening type Ia supernovae. However, the dust size distribution of its host galaxy shows that dust of large size has a greater proportion compared with the Milky Way.

Probing dust along Supernovae Ia sight lines using linear spectropolarimetry

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Understanding the effect of dust extinction on Supernovae Ia (SNe Ia) is essential for accurate measurement of cosmological parameters and the expansion history of the Universe. Different studies of the host galaxies dust extinction from SNe Ia yielded diverse values of the absorption to reddening ratio, R_V, ranging from R_V=1 to R_V=3.5 (see e.g. Cikota et al. 2016). Furthermore, studies of dust along the lines of sight of SNe Ia might lead to conclusions on the progenitor system, because the single degenerate (SD) and double degenerate (DD) models imply different circumstellar environments.

The wavelength of the peak of continuum polarization, λ_{max}, depends on the dust grain size distribution. For an enhanced abundance of small dust grains, λ_{max} moves to shorter wavelengths, and for an enhanced abundance of large dust grains to longer wavelengths (Serkowski et al. 1975). Thus, linear spectropolarimetry is an independent way to probe dust properties.

SNe Ia with low total-to-selective extinction ratio values, R_V, also show peculiar continuum polarization wavelength dependencies, raising towards blue, with polarization peaks at short wavelengths ($\lambda_{max} \lesssim 0.4\mu m$, Patat et al. 2015), while for comparison, normal sight lines in the Milky Way have polarization peaks at $\lambda_{max} \sim 0.55\mu m$.

It is not well understood why SNe Ia sight lines display such different polarization profiles compared to what we observe in the Milky Way. Possible explanations are that the composition of interstellar dust in SNe Ia host galaxies is different from the dust in our Galaxy, or that there is circumstellar dust with an enhanced abundance of small grains, which was ejected from the progenitor system before the explosion, causing such peculiar polarization profiles.

We will discuss the peculiar polarization profiles of SNe Ia sight lines, compare them to sight lines in the Milky Way, and argue possible implications on the progenitor system.

Probing supernovae from graphite grains from Murchison

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Presolar grains are stardust that formed in stellar outflow or stellar ejecta, and were contained in meteorites. The study of presolar grains in the laboratory has yielded a wealth of information about nucleosynthesis in stars, mixing in stellar ejecta and the Galactic chemical evolution. Presolar graphite grains contain an exotic ^{22}Ne-rich component called Ne-E(L). Bulk (= aggregates of grains) noble gas analysis showed that Ne-E(L) mostly consists of ^{22}Ne from ^{22}Na ($T_{1/2}$ = 2.6 a) with a small amount of ^{22}Ne from asymptotic giant branch stars.

Many low-density graphite grains show isotopic signatures of supernova origin, including Si isotopic anomalies (mostly ^{28}Si excesses, but, in a few cases, ^{29,30}Si excesses), the initial presence of ^{44}Ti, and high ^{26}Al/^{27}Al ratios (up to 0.15). A few grains contain ^{22}Ne from ^{22}Na. The abundance signatures in these grains are a crucial diagnostic for theoretical supernova models to probe stellar physics and nuclear physics uncertainties affecting the simulations. For instance, the production of the radioactive isotope ^{22}Na may be an important benchmark for stellar models In a 15M_{sun} model (s15a28c) by Rauscher et al. (2002), ^{22}Na is produced in the O/Ne zone, and the maximum mass fraction in the model is 2.2×10^{-6}. Recently, Pignatari et al. (2015) proposed supernova models including the effect of high shock velocities, and the H injection in the He/C zone. In these models explosive H- and He- burning produces large abundances of ^{22}Na. The largest production obtained is in model 25T-H, with a mass fraction of $\sim 5 \times 10^{-2}$ in the so-called O/nova zone, which is adjacent to the C-rich He/C zone. We will discuss supernova signatures of low-density graphite grains and supernova models with special emphasis on the origin of ^{22}Na.

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University College London

When does dust form in supernova remnants?

The discovery of 0.4-0.7$M_\odot$ of dust in the remnant of SN1987A 23 years after its explosion (Matsuura et al. 2011) demonstrated that supernovae can be efficient dust factories, but raised many questions. Among them, when did this dust form? Was it there at early times but previously undiagnosed by techniques for estimating dust masses, or did it form at later times? In Wesson et al. (2015) we created radiative transfer models to investigate this question, fitting the optical-far IR SED of SN1987A to calculate the dust mass at epochs from 600-9000 days after the explosion. We found that the rate of dust formation could be represented by a sigmoid curve with peak dust formation occurring many years after the explosion.

The far infrared observations necessary to constrain the emission from cold dust are lacking in most supernovae. An alternative method of estimating the dust mass exploits the blue-shifting of emission lines in the presence of dust to diagnose the dust mass. We have obtained optical-near IR spectra of supernova remnants of ages from 5-50 years with X-SHOOTER at the VLT. Broad emission lines are detected in a number of remnants, and we have used the radiative transfer code DAMOCLES (Bevan and Barlow, 2016) to calculate dust masses, to investigate the general pattern of dust formation with remnant age.

Dust masses in the ejecta of core-collapse supernovae from modelling their red-blue optical line profile asymmetries

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The source of the very large masses of dust observed in some very early Universe galaxies at redshifts z > 6 has been much debated. Core-collapse supernovae (CCSNe) have been predicted to be efficient producers of dust but the majority have only had small masses of warm dust ($< 10^{-3}$ $M_\odot$) detected in their ejecta during their early phases (t < 3 years), based on fits to their near-IR and mid-IR SEDs. However, observations in the far-IR by Herschel and ALMA of a few CCSNe have yielded far higher cold dust masses (0.1 – 1.0 $M_\odot$), which, if representative of the wider CCSN population, could potentially account for the dust masses seen in the early Universe. Unfortunately, there are now few instruments capable of detecting CCSN dust emission at far–IR and sub–mm wavelengths, so other techniques must be exploited.

The late-time optical and near-IR line profiles of many core-collapse supernovae exhibit a red-blue asymmetry caused by red-shifted emission from the receding parts of the ejecta, which must traverse the dusty interior of the ejecta, experiencing greater extinction than the blue-shifted emission. We present Monte Carlo line transfer models of asymmetric optical line profiles in the late-time spectra of SN 1993J, SN 1987A, SN 1980K and Cas A using the new code DAMOCLES (Bevan & Barlow 2016). We derive dust mass estimates at late times of 0.08 – 0.18 $M_\odot$ for SN 1993J, 0.12 – 0.3 $M_\odot$ for SN 1980K and ∼1.1 $M_\odot$ for Cas A. We also present a series of models of the [OI] and Hα line profiles for SN 1987A over a range of epochs. The derived dust masses as a function of epoch are consistent with continuous dust formation during the first few decades of ejecta evolution and final dust mass estimates of 0.4 – 0.7 $M_\odot$. We conclude that dust masses > 0.1 $M_\odot$ have formed in the ejecta of these objects supporting the case that CCSNe are the dominant sources of dust in the early Universe.

Theoretical Anharmonic Spectra of hot PAHs: the AnharmoniCaOS code

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Polycyclic Aromatic Hydrocarbons (PAHs) lock up between 10 and 20% of C in the interstellar medium (ISM), dominate the extinction curve in the UV via strong electronic transitions, convert most of the absorbed energy to vibrational excitation in the ground electronic state and then re-emit it via a cascade of vibrational transitions [1,2]. Most of these IR photons are emitted in hot bands, shifted around the fundamental 1-0 transitions due to anharmonicity. The resulting bands are thus broadened and shifted, and produced by an unknown mixture of species in several ionisation states, making their interpretation complex. Most astronomical PAH models are based on calculations under the so-called double harmonic approximation, with empirical scaling factors to account for anharmonic band shifts, and band widths assumed ad-hoc to match those observed in astronomical sources. The only models that attempt to deal with anharmonicity either restrict to transitions at 0K or neglect the effect of resonances to simplify the calculations at high temperatures [3].

We developed a tool to model full anharmonic PAH spectra and tested it on a medium-small PAH, namely pyrene, $C_{16}H_{10}$, fully accounting for both mechanical and electric anharmonicity. We sampled transitions from states vibrationally excited up to 12000 cm^{-1} and obtained temperature-dependent spectra via a Laplace transform. As the temperature increases from 0K to ~600K we observe fundamental bands broaden and additional bands appear all over the spectrum. We report on the evolution of some of the most important bands with increasing temperature, comparing theoretical predictions with previously obtained experimental spectra [4]. We analyse the performance, computational cost, and caveats of our tool, in view of its systematic application.

Acknowledgments: We acknowledge support from the CALMIP supercomputing facility and from the European Research Council (project ERC-2013-SyG NANOCOSMOS).

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Interstellar PAHs with five membered rings: TDDFT study

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The intriguing problem of the carriers of interstellar Diffuse Interstellar Bands (DIBs) remains unsolved despite of years of observational, theoretical and experimental effort [1]. Observational evidence has been found in support of molecular carriers [2] leading to experimental and theoretical investigations on polycyclic aromatic hydrocarbons (PAHs), carbon chains, fullerenes and other molecules. Intensive experimental and theoretical studies have shown that PAH molecules in various forms are the carriers of the unidentified infrared (UIR) bands. The stability of these molecules helps them to survive UV-rich interstellar conditions. The detection of ionized fullerene in the ISM [3] strongly supports the PAH proposal. Astronomers speculate that about 10% - 15% of the interstellar carbon budget is within PAHs.

We report the first *Time Dependent Density Functional Theory* (TDDFT) calculations on PAHs with five-membered rings. These PAHs are important as they are probably directly or indirectly related to the formation / dissociation of Fullerenes (C_{60}). The PAH molecules selected for investigation include Acenaphthylene ($C_{12}H_8$), Fluorene ($C_{13}H_9$), Fluoranthene ($C_{16}H_{10}$), Corannulene ($C_{20}H_{10}$) and Buckminsterfullerene (C_{60}). We report the TDDFT oscillator strengths for ionized as well as protonated versions of these PAHs. The results presented here assist in further narrowing down the carriers of DIBs. These results also act as pointers for laboratory studies.

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Interstellar Polarization and Grain Alignment

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Interstellar polarization is well-known to arise from the alignment of aspherical grains with the magnetic field. This fundamental effect has opened a new window into studying magnetic fields and its effect on star formation, leading to a golden age of interstellar polarimetry with many big instruments (e.g., with SOFIA, SMA, Planck, ALMA). In particular, polarized thermal emission from aligned grains is a critical challenge for the detection of CMB B-mode signal. To achieve a realistic understanding of the role of magnetic fields in star formation process and precise measurement of B-mode signal, a quantitative theory of grain alignment is required. In this talk, I will review the successful development of such a quantitative grain alignment theory and observational tests. I will first review our quantitative theory of radiative torque (RAT) alignment based on radiative torques arising from the interaction of anisotropic radiation fields with irregular grains. I will discuss RAT alignment for both ordinary paramagnetic grains and grains with iron inclusions. Second, I will present our ab-initio modeling of dust polarization by radiatively aligned grains for a variety of environments and compare modeling results with observations. Finally, I will present our latest work on mechanical torque alignment, outline environment conditions where MAT alignment may be important, and suggest observational tests.

The Variations of the Near and Mid-Infrared Interstellar Extinction Laws

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It has been well known that the extinction law changes with interstellar environments in the ultraviolet and visible, which can be characterized by the total-to-selective extinction ratio parameter R_V. However, whether and how the extinction law varies in the near (NIR) and mid-infrared (MIR) is still controversial. Recently, based on the stellar parameters derived from the *SDSS-III*/Apache Point Observatory Galaxy Evolution Experiment (*APOGEE*) spectroscopic survey, we (Xue, Jiang, & Gao, et al., ApJs, 224:23, 2016) selected a large samples of G-type and K-type giants as the tracers of the Galactic MIR extinction. We calculated the intrinsic stellar color excesses from the stellar effective temperatures and used them to determine the average NIR and MIR extinction of the entire sky of the Milky Way surveyed by *APOGEE*. In this work, using the same method, we recalculate the intrinsic colors of these *APOGEE* G-type and K-type giants by considering different [Fe/H]. Then, the extinction laws in the NIR and MIR are determined for a number of different sightlines surveyed by *APOGEE*. Our results show that the NIR extinction law varies a little with Galactic longitude and latitude, also the extinction depth *E*(J-K) , though it is generally considered as universal. In the *WISE*/3.4, 4.6, and 12 μm bands, and the *Spitzer*/IRAC/[3.6], [4.5], [5.8], and [8.0] μm bands, small variations of the MIR extinction laws are also found with the Galactic longitude and latitude.

Formation of Silicates at Cryogenic Temperatures in the Presence of Carbon Molecules and Others

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The re-formation of dust grains in the interstellar medium (ISM) is expected to contribute to the existence of the observed populations. Interstellar grains are otherwise subjected to various destruction mechanisms altogether faster than their condensation in stellar outflows and subsequent injection into the ISM. The re-formation is thought to proceed through the accretion of atoms and/or molecules found in the interstellar gas phase, and chemical reactions that incorporate the accreted species into the grain.

As accretion is favored by higher gas-phase densities and lower temperatures, its efficiency increases from the cold regions of the diffuse ISM, where temperatures of ≈100 K prevail, to the heart of dense molecular clouds, where the temperature approaches 10 K. Taking into account the fact that interstellar dust comprises essentially carbonaceous grains and silicate particles, two issues arise in the re-formation scheme. First, one must explain how such specific materials are re-formed while the interstellar gas phase contains many different species. Second, one must determine what chemical reactions make the re-formation possible at temperatures as low as 10 K.

We have already reported experiments on the growth of silicates through the accretion of atoms and molecules cooled to cryogenic temperatures as they were initially isolated in Ne ice. These atoms and molecules, precursors of silicate matter, were silicon oxides and relevant metal atoms. The experiments have shown the formation of amorphous silicate matter at temperatures as low as 13 K during the annealing and evaporation of the doped Ne matrices (Rouillé et al. 2013, Krasnokutski et al. 2014, Rouillé et al. 2014).

In new experiments, Ne matrices were doped with the silicate precursors, to which carbon atoms and molecules (C_n, $n = 1$–10) were added. The matrices contained also significant amounts of H_2O, CO, CO_2, and C_3O molecules. We have observed that amorphous silicate matter is formed during the annealing and evaporation of the Ne ice despite the presence of the carbon molecules, the H_2O molecules, and the other species. The experiments will be presented and their relevance to the re-formation of silicate grains in the ISM will be discussed.

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On the aliphatic versus aromatic content of the carriers of the ‘unidentified’ infrared emission features

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Although it is generally accepted that the unidentified infrared emission (UIE) features at 3.3, 6.2, 7.7, 8.6, and 11.3 micron are characteristic of the stretching and bending vibrations of aromatic hydrocarbon materials, the exact nature of their carriers remains unknown: whether they are free-flying, predominantly aromatic gas-phase molecules, or amorphous solids with a mixed aromatic/ aliphatic composition are being debated. Recently, the 3.3 and 3.4 micron features which are commonly respectively attributed to aromatic and aliphatic C—H stretches have been used to place an upper limit of ~2% on the aliphatic fraction of the UIE carriers (i.e., the number of C atoms in aliphatic chains to that in aromatic rings). Here we further explore the aliphatic versus aromatic content of the UIE carriers by examining the ratio of the observed intensity of the 6.2 micron aromatic C—C feature ($I_{6.2}$) to that of the 6.85 micron aliphatic C—H deformation feature ($I_{6.85}$). To derive the intrinsic oscillator strengths of the 6.2 micron stretch ($A_{6.2}$) and the 6.85 micron deformation ($A_{6.85}$), we employ density functional theory to compute the vibrational spectra of seven methylated polycyclic aromatic hydrocarbon molecules and their cations. By comparing $I_{6.85}/I_{6.2}$ with $A_{6.85}/A_{6.2}$, we derive the fraction of C atoms in aliphatic form to be at most ~000%, confirming the earlier finding that the UIE emitters are predominantly aromatic. We have also computed the intrinsic strength of the 7.25 micron feature ($A_{7.25}$), another aliphatic C—H deformation band. With $A_{6.85}$ appreciably exceeding $A_{7.25}$, this explains why the 6.85 micron feature is more frequently detected than the 7.25 micron feature.

Magnetic Field structures in the central parsec of the Galaxy

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Imaging polarimetry of the central parsec of the galaxy at 12 microns obtained with Canaricam at the Grand Telescopio Canarias is used to investigate the magnetic field structure at subarcsecond resolution. The data confirm earlier results, which indicate that the field lies predominantly in the direction of the flow, but in addition reveals new structures and further complexity. It appears that the field is compressed by the outflows from massive stars and that coherent structures link several of these regions, suggesting that the shape of the field is directly affected by the stellar winds.

Dust in galactic nuclei

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The central regions of galaxies are complex and harsh environments, where obscuration by dust often makes it difficult to gain a clear picture of the different components, structures and processes in the nuclear regions. In turn, the dust particles themselves are affected through irradiation and shocks, and we may expect the properties of dust near active galactic nuclei to be modified , for example by selective destruction of small grains or by annealing. The weak silicate emission features in many active galactic nuclei may provide evidence for destruction or depletion of the smallest dust grains while modifications to PAH emission spectra may also suggest a larger mean grain size in these regions. I will present high spatial resolution results obtained with large ground-based telescopes that indicate that much of the dust towards heavily obscured nuclei is in the galaxy ISM and has similar properties to that in the Milky Way and investigate the properties of dust in the central regions of galaxies.

Molecular absorption line systems with 2175Å bumps

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The 2175Å bump is seen almost everywhere we look within our Milky Way, but when looking to high-redshift galaxies, this spectral feature is rarely identified. Therefore, in order to study the bump and how it correlates with various parameters, we have performed a targeted search for high-redshift absorption systems exhibiting this characteristic feature towards quasars.
For such quasar absorbers it is possible to partly recover the extinction curve from the absorbing gas, and thereby one can correlate the extinction features with detailed abundances from the absorption lines seen in the spectrum of the background quasar. We have used this technique to study a specific absorption system in great detail, where we have absorption lines from molecular and neutral gas which can constrain the extinction curve independently from the reddening of the observed spectrum. Using this technique we can start to probe the relations between the 2175Å bump strength and the grain size and composition in high-redshift environments.

The impact of dust on the leakage of ionizing photons from galaxies

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If star-forming galaxies are to explain the reionization of the Universe at redshift z > 6, hydrogen-ionizing (Lyman continuum, LyC) radiation must be able to escape from these galaxies and into the intergalactic medium. Several detections of LyC leakage from galaxies have already been made both in the local Universe and at redshifts up to z ≈ 3—4, but the increasingly neutral intergalactic medium prevents direct observations of the LyC from galaxies at redshifts higher than this (Inoue et al. 2014, MNRAS 442, 1805). Indirect methods are therefore required to push LyC leakage studies into the actual reionization epoch. In a sequence of papers, we have developed methods of this type to constrain the LyC escape fraction from individual galaxies at z > 6 using emission-line diagnostics (e.g. Zackrisson et al. 2013, ApJ, 836, 79; Inoue et al. 2016, Science, 352, 1559; Jensen et al. 2016, ApJ, 827, 5; Zackrisson et al. 2017, ApJ, 837, 78). One potential problem with this approach is that the fraction of ionizing photons that are directly absorbed by dust within galaxies remains poorly constrained. Here, we combine far-UV, optical and far-IR data to make a first attempt to quantify this LyC extinction effect for a number of galaxies which exhibit LyC leakage in the local Universe, and discuss how such measurements can potentially be pushed to higher redshifts in the future.

Cosmological simulation with dust evolution

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Dust enrichment is one of the most important aspects in galaxy evolution. The evolution of dust is tightly coupled with the nonlinear evolution of the interstellar medium (ISM) , mainly driven by star formation and stellar feedback, which lead to the chemical enrichment in a galaxy. Numerical hydrodynamical simulation provides a powerful approach to studies of such nonlinear processes.

In this work, we perform a cosmological simulation using smoothed particle hydrodynamics (SPH) simulation in which dust evolution is implemented. We consider dust production in stellar ejecta, destruction in supernova shocks, dust growth by accretion and coagulation, and dust disruption by shattering and thermal sputtering for the processes driving the dust evolution. We also treat the evolution of grain sizes distribution by representing the entire grain radius range by small and large grains (divided at $\sim$0.03 μm).

We show that our cosmological simulation allows us to analyze the dust abundance and dust properties, such as dust-to-gas mass ratio ($\mathcal{D}$), dust-to-stellar mass ratio (M_d/M_*) and small-to-large grain abundance ratio ($\mathcal{D}_\mathrm{s}/\mathcal{D}_\mathrm{l}$), in galaxies statistically. Besides, we also examine the redshift evolution of dust content in galaxies. In particular, we show how the relation between dust abundance and galaxy properties evolves as a function of redshift (z).

The relation between dust-to-gas ratio and metallicity ($\mathcal{D}$–Z relation) at $z = 0$, predicted in our simulation is consistent with observations of the nearby galaxies. We also reproduced the nonlinearity of the $\mathcal{D}$–Z relation. The most important process for this nonlinearity is dust growth by accretion, which imprints a characteristic metallicity above which the increase of $\mathcal{D}$ as a function of Z becomes steeper. At $z > 0.5$, because the time-scale of chemical enrichment is shorter, the turning point in the $\mathcal{D}$–Z relation shifts to higher metallicities. Since the metallicity has a tight correlation with the stellar mass (M_*), $\mathcal{D}$ also correlates with the stellar mass, and the above nonlinear turning point shifts to higher stellar mass with increasing redshift. The dust-to-stellar mass ratio M_d/M_* has a peaks around $M_* \sim 3 \times 10^{10}\ M_\odot$ and decreases toward both high and low mass ends. At the low mass end, M_d/M_* increases significantly from high to low redshift. This is interpreted as down-sizing of dusty objects. $\mathcal{D}$ and M_d/M_* have correlation with the specific star formation rate (sSFR) which has a dependence on stellar mass and metallicity. In the local universe, $\mathcal{D}$ decreases with increasing sSFR, however, at high redshift, high-$\mathcal{D}$ galaxies have intermediate sSFR with low-$\mathcal{D}$ galaxies having a wide scatter in sSFR. For the grain size, results show that galaxy with higher Z (or M_*) has higher $\mathcal{D}_\mathrm{s}/\mathcal{D}_\mathrm{l}$, and that $\mathcal{D}_\mathrm{s}/\mathcal{D}_\mathrm{l}$ increases continuously from high to low z as small grains are produced by interstellar processing. We also discuss dust enrichment in the intergalactic medium (IGM) driven by feedback processes. In the IGM, $\mathcal{D}$ remains as low as $< 10^{-3.5}$, and $\mathcal{D}_\mathrm{s}/\mathcal{D}_\mathrm{l}$ is also low. The dominance of large grains indicates that most of the IGM dust was ejected from galaxies before being processed in the ISM.

Our predictions on the dust content in high-redshift galaxies can be tested by ALMA and future observations.

Importance of Dust Evolution to the H_2 and CO Abundances in Galaxies

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We present our recent efforts of clarifying the important role of dust in H_2 and CO formation in galaxies. Since stars form in molecular clouds, tracing molecular gas in galaxies is important in revealing how galaxies convert gas to stars. Molecular gas is usually observed by CO emission. The CO-to-H_2 conversion factor ($X_{\rm CO}$) is known to correlate with the metallicity (Z) (e.g., Bolatto et al. 2013). The *dust abundance*, which is related to the metallicity, is responsible for this correlation through dust shielding of dissociating photons and H_2 formation on dust surfaces. Thus, we investigate how the relation between dust-to-gas ratio and metallicity ($\mathcal{D}$–Z relation) affects the H_2 and CO abundances (and $X_{\rm CO}$) of a 'molecular' cloud (Hirashita & Harada 2017). For the $\mathcal{D}$–Z relation, we adopt a dust evolution model developed in our previous work (Hirashita 2015), which treats the evolution of not only dust abundance but also grain sizes in a galaxy. Shielding of dissociating photons and H_2 formation on dust are solved consistently with the dust abundance and grain sizes. As a consequence, our models predict consistent metallicity dependence of $X_{\rm CO}$ with observational data of nearby galaxies. Among various processes driving dust evolution, dust growth by the accretion of gas-phase metals has the largest impact on the $X_{\rm CO}$–Z relation. We also find that dust condensation in stellar ejecta has a dramatic impact on the H_2 abundance at low metallicities ($\lesssim 0.1\ Z_\odot$), relevant for damped Lyman α systems and nearby dwarf galaxies, and that the grain size dependence of H_2 formation rate is also important at low metallicities.

We further implement the above framework into hydrodynamical simulation of a galaxy (Chen, Hirashita, et al. 2017), thereby clarifying how the star formation law (relation between the surface densities of molecular gas mass and star formation rate) changes as a function of galaxy age and metallicity. The simulation treats the dust evolution consistently with the physical properties of the ISM, and the formation of H_2 and CO are treated by post-processing. Because of inefficient molecule formation at low metallicity ($\lesssim 0.4\ Z_\odot$), the star formation law is not established at young ages, especially if the molecular gas is traced by CO. We also find that the grain size distribution is important for the CO abundance; thus, if we trace the star formation law by CO, dust evolution should be carefully discussed. In summary, the results of the simulation indicate that the establishment of a star formation law is strongly regulated by dust evolution.

Faint young asteroidal dust bands observed with AKARI

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The zodiacal emission is the thermal emission from the interplanetary dust and the dominant diffuse radiation in the mid- to far-infrared (IR) wavelength region. It was found that there are many small-scale structures in the zodiacal emission distribution, including dust band pairs at the ecliptic latitudes of $\pm 1.4°$, $\pm 2.1°$, and $\pm 10°$, apart from a smooth background distribution. These three major dust-band pairs are well studied and are now considered to be associated with the Beagle, Karin, and Veritas asteroid families, respectively. It is thought that disruption events in the main asteroid belt, which would have occurred within the last 10 Myrs, are major supply sources of dust particles.

In addition to these three bands, several additional faint dust bands are suggested from the IRAS observations. Among them, there are dust bands which do not extend over all ecliptic longitudes. It is suggested that they are young and still in the process of forming. These young and partial dust bands are expected to preserve the original size distribution of the dust population ejected into the cloud by an asteroid disruption. However, the existence of partial dust bands are not well confirmed with the image quality of the IRAS map.

We investigate the geometry of the small-scale dust-band structures in the far-IR all-sky maps observed with the Japanese infrared satellite AKARI. AKARI clearly detects the zodiacal dust-band structure at 65 and 90 μm bands. In the AKARI far-IR map, we confirmed many partial dust bands and identified the dust bands at ecliptic latitudes of 6°, 8°, 13°, and 17°, corresponding to the IRAS faint bands (suggested in Sykes 1988, ApJ, 334, L55). We extract faint dust-band structures in the AKARI maps, in addition to the prominent three bands, by using image-enhancing techniques and discuss the formation process and dust properties of partial young dust bands based on the AKARI observations.

Experimental study on the effects of the interparticle force on the compaction of regolith layer due to vibration

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Many, if not most, surface of asteroids are covered with regolith, which is unconsolidated debris. Observations have shown that the regolith has a filling factor of ~0.4-0.6 *(e.g. Busch et al., 2007; Ostro et al., 2004)* and that this value is different for each asteroid. The filling factor of the regolith affects the results of impacts and the thermal evolution of asteroids. It can be changed by the thermal environment, impacts and the impact-induced vibration. Asteroids experience a lot of impacts during their lifetime, and impact-induced vibration may change the filling factor of the regolith after asteroid formation. The compaction behavior of granular material due to vibration is characterized by the dimensionless parameter Γ *(e.g. Phillipe and Bideau, 2002)*, which is the maximum vibrational acceleration normalized by the gravitational acceleration. The vibrational acceleration required to attain a certain Γ is very small on asteroids because of their extremely low gravity, and small impacts are thought to be sufficient to change the filling factor of the regolith. However, the Γ dependence of vibrational phenomena is obtained by experiments conducted under Earth gravity using relatively coarse (~mm) particles. The interparticle force acting on the particles is negligible compared to the gravitational force under this condition. However, under the low gravity of an asteroid, the effect of gravitational force acting on regolith particle is very small and the effect of the interparticle force becomes significant.

In this study, we investigated the effects of interparticle force on the compaction of regoliths under microgravity. We used particles smaller than 100 μm as a sample powder to mimic the regolith layer under microgravity because their particle mass is very small and the interparticle force is effective. The sample powder was sieved into the sample die and tapped by the free fall of the sample die. The vibrational acceleration applied to the sample was controlled by the falling height of the die and recorded by an accelerometer that was attached to the die. The maximum accelerations of the pulsed waves were 270 and 680 m/s^2 (Γ=28 and 69, respectively). Samples were tapped 10, 30, 50, 100, 500 and 1000 times and the filling factor of the sample before and after tapping was calculated based on the volume and mass of the samples.

We used spherical glass beads with a diameter of 50 μm as one of the sample powders. For this sample, the interparticle force acting on the particles was ~10^3 times larger than the gravitational force under Earth gravity. This is similar in strength to a 5 mm particle under the gravitational acceleration of 10^{-3} m/s^2. The filling factor of the sample before tapping was ~0.57 and it increased with the number of taps. The filling factor reached steady state after a certain number of tapping. In the case of Γ=69, the filling factor reached a steady state of ~0.63 after ~500 times tapping. We compared these filling factors and their evolutionary timescale with the results of a previous study that used millimeter sized particles. In the previous study, this steady state filling factor was obtained at a Γ smaller than ~1.3, and this timescale was obtained in the case of $1.8 \lesssim \Gamma \lesssim 2.3$ *(Phillipe and Bideau, 2003)*. This suggests that under a microgravity environment, where the interparticle force is effective, it is not suitable to use the same value of Γ obtained under Earth gravity to estimate the evolution of the filling factor on asteroids, and the interparticle force should be considered as a parameter.

A radiative transfer model of an impact-induced ejecta curtain consisting of dust aggregates

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Impact cratering of celestial bodies produces ejecta curtains that excavate the underground material present in them. Therefore, studies of ejecta curtains help us in understanding the physical and chemical properties of the interior of the bodies. However, remote-sensing observations of such an ejecta curtain is limited to the Moon. In-situ measurements together with Monte-Carlo radiative transfer models of ejecta curtains from an asteroid will enable us to constrain the size and composition of less-processed materials in the underneath regolith layers of the asteroid. Here we have analyzed the dependence of the predicted ejecta curtain scattered intensities on its dust density distribution and phase function. In our model, the density of the ejecta curtain is assumed to increase from the vertex to the base of an ejecta cone and the regolith particles are aggregates of small grains by analogy with lunar agglutinates and dust in debris disks. Apart from that, the orientation of the ejecta curtain is also varied with respect to the direction of stellar photon flux. We show how the intensity depends on the phase function of the grains, by comparison with the Henyey-Greenstein phase function. This study will enable us to gain useful insights into the morphology of the component dust grains.

The study of hexagonal Fe_2Si

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The tetragonal Fe_2Si in the Pm3-m symmetry group with CsCl structure was found at 1974. Then it was predicted that the compound could be existed on the lunar surface because it has to be formed under space weathering condition. e.g. within airless space or under meteorite impacts. Thereafter, it was indeed found inside a lunar meteorite of a highland-regolith breccia named as Dhofar 280. This kind of tetragonal Fe2Si is called hapkeite.

On the basis of first principle calculations, we showed that a hexagonal structure of Fe_2Si is a ferromagnetic crystal. The result of the phonon spectra indicated that it is a stable structure. Such material exhibits a spin-polarized and half-metal-like band structure. From the calculations of generalized gradient approximation, metallic and semiconducting behaviors, we observed with a direct and nearly 0 eV band gap in various spin channels. The densities of states in the vicinity of the Fermi level were mainly contributed by the *d*-electrons of Fe. We have also calculated the reflection spectrum of Fe_2Si, which had a minima at 275nm and 3300nm with reflectance of 0.27 and 0.49, respectively. The distinct reflection spectra provided a reference for the search of the compound in the future. Such results may provide a reference for the search of hexagonal Fe_2Si in experiments. It is possible that the hexagonal Fe_2Si will symbiont with other Fe-Si compounds under space weathering or meteorite impacts. Whether the hexagonal Fe_2Si exists in the lunar soil, regolith, dust or coexists with other Fe-Si compounds is worthy further study. In addition, we have established a laboratory called "Laboratory of Astrophysics and Astrochemistry" recently. The development of our laboratory follows 3 main directions: 1. To prepare for sample researches of meteorites and Chang'e 5 samples, as which will be the first sample return mission of Chinas; 2. Research on Lunar dust, Martian dust, and solar system evolution; 3 Experiments and simulations of asteroid spectrum. There are some basic equipment in our laboratory: Scanning electron microscope (SEM) with energy dispersive X-ray spectrometry (EDS), Atomic force microscope (AFM), X-Ray diffractometer (XRD), Particle size analyzer, Network analyzer (electrical), UV/Vis NIR Spectrometer and the Dust floating simulation system (which is designed by us). We are looking forward to establish any kind of collaboration with different research groups.

Hydrodynamic simulations of dust destruction in supernova remnants

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Dust plays a significant role in the composition and evolution of the universe and has long since believed to be mainly formed in the atmosphere of asymptotic giant branch (AGB) stars. However, recent observations of high redshift galaxies (z>6) have revealed dust masses of the order of 10^8 M_{sun} (Bertoldi et al. 2003). As such systems are far too young for dust enrichment by AGB stars, alternative dust factories need to be considered. One such possible dust factory that could explain the presence of large amounts of dust in the early universe is the core collapse supernova (CCSN), which is estimated to produce up to 0.7 M_{sun} of dust (Matsuura et al. 2011). How much of the so produced dust survives has been the subject of many studies, such as Jones (2004) and Nozawa et al. (2007), who found a grain lifetime of 400 to 600 million years for silicate and carbon grains and a complete destruction of grains with a radius below 10^{-4} μm for all grain species respectively.

In this study, we aim to investigate through (magneto)hydrodynamic simulations how much of the dust produced during a CCSN explosion can survive the reverse shocks in the supernova remnant (SNR). To determine whether CCSNe could be the dominate producers of dust in the early universe, we will consider a selection of grain species, grain size distributions, cooling functions and the effect of magnetic fields to estimate the lifetime of dust grains in such a volatile environment.

Our simulations are performed using the magnetohydrodynamic codes PLUTO (Mignone et al. 2012) and FRAGO3D (Benítez-Llambay & Masset 2016). We insert a cloud of gas populated with tracer particles into an ambient medium representing the SNR and analyze their evolution as shocks impact the gas cloud. Grain distributions are then assigned to each tracer particle retrospectively and sputtering effects as well as grain-grain collisions are considered during post processing.

We present our preliminary results for purely hydrodynamic simulations in 1D and 2D, including initial comparisons of the FARGO3D and PLUTO codes and comparisons to a similar study conducted by Silvia et al. (2010) for a selection of gas cloud density distributions and shock velocities.

Magnetic anisotropy observed in bulk & rod-shape amorphous silica and its implication to the origin of dust alignment

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Anisotropy of paramagnetic susceptibility $\Delta\chi$ (per unit mass) was detected in the surface area (0 mm< depth < 0.5 mm) of an synthesized amorphous silica; the material was synthesized by cooling a silica melt (maximum temperature < 1260 K) at a cooling rate of ～7 K/s. The anisotropy is considered to derive from the small amount of ferrous ion (0.06 wt %) included in the starting material. The produced silica serves as a reference sample to investigate the possibility of dust alignment in various galactic regions anisotropy based on magnetic anisotropy energy. Up to now, the possibility of magnetic alignment based on anisotropy energy is not considered on a amorphous silica in the researches of magnetism because they are believed to be magnetically isotropic.

A setup developed to observe the field-induced rotational-oscillation of a bulk sample in a short μg condition to observe the magnetic separation [2] was reformed in the present study. The sample chip separated from the surface of the bulk silica sample was set on a holder and installed in a transparent glass tube that was attached between the N and S pole of a compact NdFeB circuit. The magnetic line of force at sample position was normal to the tube. The above setup was installed in a wooden box (30 x 40 x 40 cm). This box was attached to an electromagnet of a short drop shaft that had a length of 1.5m [2], and the free fall of the box started by cutting off the power supply of the electromagnet. The sample piece was successively released from stage to the μg space by an attractive field-gradient force produced by a field gradient between the N and S pole [3]. In a μg experiment, it was generally difficult to release a small sample a diffuse area because of various attractive forces. The observed period of oscillation followed the formula of harmonic oscillation, and magnetic anisotropy was obtained without the necessity of measuring the mass of sample [3].

The $\Delta\chi$ value observed at the silica surface, was $1.1\text{x}10^{-7}$ emu/g, although below a depth of ~1mm, $\Delta\chi$ was diminished to $3.9 \text{ x } 10^{-8}$ emu/g. This variation of $\Delta\chi$ between surface and interior was comparable to those previously observed at the surface of two tektites, namely Moldavite [3] .

The cause of the the enormously enhanced anisotropy that appeared at the silica surface is an open question. In order to solve this problem, a structural anisotropy at atomic scale should be experimentally identified. We therefore performed Electron Spin Resonance (ESR) in the above sample plates, and angular dependence with uni-axial symmetry was obtained with its principle axis nearly normal to the silica surface. The result strongly indicates that structural anisotropy at atomic scale can be produced by rapid cooling. The comparison between the $\Delta\chi$ data and the ESR spectrum, as performed in the present report, will provide useful information to study the origin of the anisotropy that appeared at the silica surface. Further information will be obtained by changing the experimental conditions in synthesizing the samples, for example, concentration of paramagnetic ion, maximum temperature of silica melt as well as its cooling rate. The anisotropy is now measured in synthetic fiber samples (diameter ~ 50 microns) produced from the above silica melt, which will serve as a direct reference of the rod-shaped dust particles that is commonly assumed in the interstellar regions.

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Diamonds in Space

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Cosmic nanodiamonds were first detected in primitive carbonaceous meteorites and identified as presolar in origin based on their isotopic anomalies (Lewis et al. 1987), although their presence in the ISM was proposed almost two decades earlier by Saslaw & Gaustad (1969) to explain the interstellar UV extinction curve. Five years later, Allamandola et al. (1992) attributed the 3.47 μm absorption band seen toward a large number of protostars to the tertiary C-H stretching mode in diamond-like carbonaceous materials (this absorption feature has also been detected in the Large Magellanic Cloud; see Shimonish et al. 2016). Jones & d'Hendecourt (2000) further suggested that surface-reconstructed (to sp^2-bonded carbon) nanodiamonds could be responsible for the "unidentified infrared (UIR)" emission features, the 2175 Å extinction hump, and a part of the far-UV extinction at $\lambda^{-1} \gtrsim 7\ \mu m^{-1}$. Circumstellar nanodiamonds were identified in the dust disks or envelopes surrounding two Herbig Ae/Be stars HD97048 and Elias 1 and one post-AGB star HR 4049, based on the 3.43 μm and 3.53 μm C-H stretching emission features expected for surface-hydrogenated nanodiamonds (Guillois et al. 1999; van Kerckhoven, Tielens, & Waelkens 2002).

Presolar meteoritic nanodiamonds were found to have a log-normal size distribution with a median radius ~ 1.3 nm (Lewis, Anders, & Draine 1989) and an abundance as much as ~ 0.1% of the total mass in some primitive meteorites, more abundant than any other presolar grains by over two orders of magnitude. In the ISM, as much as 10% of the interstellar carbon (~36 ppm) could be in the form of nanodiamonds without violating the constraints placed by the interstellar extinction curve (Lewis et al. 1989). However, a much more stringent upper limit of ~ 0.1 ppm was derived by Tielens et al. (2000) based on nondetection of the characteristic 3.43 μm and 3.53 μm C-H stretching emission features in the ISM. Of course, interstellar nanodiamonds could be more abundant if the bulk of them are not hydrogenated.

In this meeting we will report our results on an extensive study of the absorption, scattering, luminescence, and infrared emission properties of nanodiamonds in the ISM

Commentary on Three-dimensional Dust Monte-Carlo Radiative Transfer Models

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Cosmic dust plays an important role in producing and processing of the interstellar radiation. Dust grains absorb starlight, converting into infrared thermal radiation. This radiative transfer process is very complicated. To study properties of the stellar and interstellar medium by using multi-band observation data, numerical models need to be constructed to simulate the complicated radiative transfer process. Comparing the simulation results with the observation data, we can invert the input parameters of the numerical models, so as to recover the astrophysical and chemical properties associated with the input parameters.

The three-dimensional (3D) distribution of dust requires the use of 3D radiative transfer models, to simulate radiative transfer more realistically. Monte-Carlo method is applicable to any 3D dust density distribution. Instead of solving radiative transfer equations directly, it uses probability distribution functions for random sampling. Monte-Carlo method propagates a large number of photons in a 3D grid to obtain the statistical results.

For simulating different physical environments, we introduce six 3D dust Monte-Carlo radiative transfer models, which are HO-CHUNK, Hyperion, 3D Mocassin, SKIRT, STOKES and RADMC-3D. These codes are open source codes developed based on the Monte-Carlo method. HO-CHUNK, 3D Mocassin, SKIRT and STOKES are used to simulate the protostar, photo-ionization environment, disk galaxies and active galactic nucleus respectively. Hyperion and RADMC-3D are general-purpose codes that can be used to simulate any 3D geometry. All of them calculate the dust local thermal equilibrium (LTE) emission, while HO-CHUNK and SKIRT can simultaneously calculate the non-LTE emission from very small grains and polycyclic aromatic hydrocarbon. All of the codes calculate the scattering of dust grains except HO-CHUNK. To improve the computing performance, all of them have been parallelized except STOKES.

Basic input parameters of all the codes are: 3D distribution of the dust, physical and chemical properties of the dust, 3D distribution of the radiation sources, physical and chemical properties of the sources, and parameters control the simulation process and outputs. General simulation performance of these codes have been summarized into a table, to help researchers finding appropriate code which is more suitable for their research objectives.

Temperature Dependent Laboratory Measurements of the Far-Infrared to the Millimeter Opacity of Carbonaceous Dust-Analogues

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We are measuring and analysing the FIR- and THz- Spectra of pyrolised micro-crystalline cellulose as an analogue of carbonaceous interstellar dust. We are using cellulose-powder with crystal sizes of 50 µm and 20 µm and are heating it up to 1000°C. First results of the mass normalised extinction are presented and compared to Jäger et al. (1998). The temperature dependent measurements took place in a dry environment at room temperature (RT) down to the environmental temperature of $T_{\mathrm{env}} = 10\,\mathrm{K}$.

Our aim is to assess carbonaceous dust analogues in terms of structure, nature and morphology. For theoretical and observational investigation we are going to determine the optical constants. Furthermore, we are going to calculate the emission cross section of particles with different geometry to compare them with the measured results.

Study of the Physical Properties of Interstellar Dust with the Frequency Dependence of the Degree of Polarization in Millimeter Wave Bands

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Detection of B-mode polarization signals imprinted in the cosmic microwave background (CMB) originated from primordial gravitational waves is the smoking gun signature of the inflation theory. A lot of efforts have been carried out to detect the signal. Since the wanted signals are buried under the Galactic dust emission, the success is controlled by how accurately one can separate the dust emission and the CMB. Further, high precision millimeter and sub-millimeter waves wide field polarization maps obtained by up coming CMB polarization experiments provide unique opportunity to study the physical properties of the interstellar dust. Therefore, it is important to clarify how the spectral properties of intensity and polarization emission from the interstellar dust are linked to the physical properties of the interstellar dust. In this study, we focus on how the frequency dependence of the degree of polarization depends on the physical properties of the dust and what we can study on them by using the available data.

We showed the degree of polarization of ellipsoid dust depends only on the real part of the complex permittivity in the millimeter wave range. On the other hand, the emissivity depends on both real and imaginary part. Therefore, these results indicate that observing the frequency dependence of the degree of polarization and intensity provides that of complex permittivity. For the various physical properties of amorphous dusts, the frequency dependence of absorption efficiencies and the degree of polarization in the millimeter waveband are demonstrated. Observational constraints on the frequency dependence of the degree of the polarization in millimeter wavebands by fitting the available data are going to be reported. Based on these results, physical properties of the interstellar dusts are going to be discussed.

DETERMINING THE SYSTEMATIC ERRORS IN FITS OF DUST THERMAL EMISSION: THE ROLE OF LABORATORY DATA IN UPCOMING MODELS

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Interstellar dust plays an important role the study of interstellar medium, especially since the development of far-infrared and submillimeter instruments in the last decades (e.g. IRAS, Herschel, *Planck*, ALMA) has allowed wide surveys of dust thermal emission. Using a dust emission model these observations can be converted to maps of quantities such as the dust column density and temperature, or to constrain dust masses in molecular clouds and galaxies.

Dust emission is commonly modeled as a blackbody with temperature T multiplied by an opacity κ that varies with wavelength as a power law: $\kappa \propto \lambda^{-\beta}$, usually with $\beta \sim 2$. However, we are learning from both astronomical observations and laboratory tests on dust analogues that T–β models are too simplistic. Two facts in particular emerge:

1) For most candidate dust materials the opacity $\kappa(\lambda)$ does not follow a power law: its slope decreases beyond a certain wavelength (typically around 400–700 μm);
2) The optical properties of materials often depend on temperature as well; for instance opacity often increases with T.

Our group is working on optical data on several candidate dust materials, collected by multiple laboratories, to parametrize the materials' opacities as functions of λ and T. This parametrization will be the first step in building a more physically realistic and flexible dust model. By fitting observations of molecular clouds and nearby galaxies, and by constructing synthetic observations to fit with conventional methods, the new model will allow to find potential systematics in T–β fit results. The model could also be applied to galaxies at high redshift, where recent dust mass estimates are posing a challenge to dust formation models, and understanding systematics on such measurements is essential.

Cosmic star formation history revealed by AKARI and Hyper Suprime Cam

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At z< 1, 90% of star formation is obscured by dust. To fully understand the cosmic star formation history, it is critical to investigate infrared emission. AKARI performed deep mid-infrared observation with its continuous 9-band filters in the NEP field (5.4 deg^2), using ∼10% of the entire pointed observations available throughout satellite ' s lifetime. AKARI ' s mid-IR data are truly unique in that Spitzer and WISE have filter gaps in mid-IR. No other telescope can provide continuous 9-band photometry in mid-IR wavelength (2-24 μ m) in foreseeable future.

However previously, we only had shallow optical imaging (with CFHT, r ∼25.9ABmag) in a small area of 1.0 deg^2. As a result, there remained 11,000 AKARI ' s infrared sources undetected in optical. Redshift and IR luminosity of these sources are unknown. They may carry a significant amount of cosmic star-formation rate density (CSFRD). For example, if they all lie at $1< z <2$, the CSFRD will be twice as high at the epoch.

With the advent of Hyper Suprime Cam, we were able to obtain deep enough optical images of the entire AKARI NEP field in 5 broad bands (g ∼27.5mag). These provided photometric redshift, and thereby IR luminosity for the previously undetected 11,000 faint AKARI IR sources. Combined with AKARI ' s unique mid-IR AGN/SF diagnosis, and accurate mid-IR luminosity measurement, we performed a complete census of dust-obscured cosmic star-formation/AGN accretion history in the entire AKARI NEP field.

Evolution of dust extinction curves in galaxy simulation

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Dust plays an essential role in galaxy evolution through dust extinction, emission, and dust surface chemical reactions. In order to understand the dust enrichment in galaxies, we developed a dust evolution model and implemented it in our code, `GADGET3-Osaka`, and calculated the evolution of dust in each SPH particle. In this code, non-equilibrium cooling is treated with the Grackle chemistry package including molecular hydrogen cooling. For the grain size distribution, we treat small and large grains separately. The following processes are included for dust evolution: dust production, destruction and feedback of type Ia and II supernovae and AGB stars, dust growth in molecular clouds, and grain disruption by shattering in the diffuse interstellar medium.

In this presentation, we consider the dust whose species are separated into carbonaceous dust and astronomical silicate in an isolated galaxy whose mass is almost same as the Milky Way. We investigated the dependence of extinction curves on the position, gas density, and metallicity in the galaxy. The 2175 Å bump and far-ultraviolet (FUV) rise become significant after dust growth by accretion. At $t \gtrsim 3$ Gyr, extinction curves show a very strong 2175Å bump and steep FUV rise because shattering works efficiently in the outer disc and low density regions. We included the necessary dust processes in the model so successfully that the extinction curves at $t \gtrsim 3$ Gyr are consistent with the Milky Way extinction curve. In addition, we found that the outer disc component caused by stellar feedback has an extinction curves with a weaker 2175 Å bump and after FUV slope. On the other hand, our simulation results tend to underproduce the FUV rise in the Small Magellanic Cloud extinction curve due to the strong contribution of carbonaceous dust.

On the Optical-to-Silicate Extinction Ratio as a Probe of the Dust Size in Active Galactic Nuclei

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Dust plays a central role in the unification theory of active galactic nuclei (AGNs). Whether the dust that forms the torus around an AGN is tenth micron-sized like interstellar grains or much larger has a profound impact on correcting for the obscuration of the dust torus to recover the intrinsic spectrum and luminosity of the AGN. Here we show that the ratio of the optical extinction in the visual band (A_V) to the optical depth of the 9.7μm silicate absorption feature ($A_V/\Delta\tau_{sil}$) could potentially be an effective probe of the dust size. The anomalously lower ratio of $A_V/\Delta\tau_{sil} \sim 5.5$ of AGNs compared to that of the Galactic diffuse interstellar medium of $A_V/\Delta\tau_{sil} \sim 18$ (Roche & Aitken 1984) reveals that the dust in AGN torus is substantially larger than the interstellar grains of the Milky Way and of the Small Magellanic Cloud, and therefore, one expects a flat extinction curve for AGNs.