COSMIC DUST ABSTRACTS

Challenges in Determining the Mass and Composition of Supernova Ejecta Dust

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Core collapse supernovae (CCSNe) are known to be important sources of interstellar dust. Determining the mass and composition of the dust remains an observational and theoretical challenge. Observationally, the presence of dust in supernovae (SNe) ejecta can be derived from changes in their atomic and ionic line profiles and intensities, and from the infrared (IR) emission from the newly-formed dust. Ascribing any observations to the formation of dust requires knowledge of alternative effects that can affect the line profiles and intensities, and alternate sources, such as IR echoes from pre-existing or shock-produced circumstellar dust, that can give rise to IR emission. Even after having established a SN dust origin for the IR emission, determining the dust mass and composition depends on the wavelength coverage of the observations, and detailed physical modeling of the dust heating sources. The challenges in determining the mass and composition of SN ejecta dust will be illustrated through the analysis of the IR emission from the extensively studied SN 1987A, the strongly interacting SN 2010jl, the remnant of Cas A, and the pulsar wind nebula (PWN) driven remnant G54.1+0.3.

Formation of SiC grains in the ejecta of core-collapse supernovae

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SiC grain is one of the most well-studied grain species among presolar grains discovered in primitive meteorites. According to their unusual isotopic signatures, a tiny fraction of SiC grains, called type X, are believed to be produced in the ejecta of core-collapse supernovae. However, there has been no theoretical study that predicted the formation of SiC grains in supernovae. This is mainly because, in the C-rich environment, C grains, whose condensation temperature is higher than that of SiC grains, first condense to consume up C atoms available for the formation of SiC grains (Nozawa et al. 2003).

In this study, we explore the formation of SiC grains in supernovae, considering the novel formation path via SiC molecules. In terms of grain formation, we consider, as growth processes of SiC grains (clusters), the attachment of SiC molecules onto SiC grains (accretion growth) and the coagulation through grain-grain collisions (coalescence growth). This is the first study that treats the formation of molecules, nucleation of stable clusters, accretion growth, and coalescence growth of grains in a consistent way.

We first show that a significant amount of SiC molecules can form in a C-rich environment. Then, we find that the formation of SiC grains is possible even after C grains form: by considering the formation path involving SiC molecules, SiC grains can condense without being affected by the formation of C grains. We emphasize that this study realized, for the first time, the formation of SiC grains in the supernova ejecta theoretically. However, the size of SiC grains calculated for the typical physical condition of supernovae is smaller than those measured for type X SiC grains ($<$ 0.1 micron). This implies that large SiC grains with 0.1-20 micron as observed would be formed in highly dense gas clumps in the ejecta.

Presolar Stardust in the Solar System

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Presolar grains of stardust are a trace component of primitive extraterrestrial materials, including chondrite meteorites and cometary interplanetary dust particles [e.g., 1,2]. They have isotopic compositions distinct from materials of solar system formation and pointing to an origin in the outflows and explosions of evolved stars. Therefore, they serve as bona fide examples of circumstellar, interstellar, and protoplanetary dust that can be studied in detail in the laboratory. They are typically sub-micrometer in size and a large number of phases have been identified, including a wide range of crystalline and amorphous silicates, SiC, partially graphitized carbon, oxides (e.g., Al_2O_3, $MgAl_2O_4$,TiO_2, FeO), and silicon nitride (Si_3N_4). Because their isotopic compositions reflect those of their parent stars, they provide a unique source of information on stellar evolution, nucleosynthesis, and galactic chemical evolution. Their elemental compositions and microstructures provide a wealth of information about dust formation processes in stars and the interstellar medium. Moreover, because different presolar phases react differently to parent body processes (e.g. asteroidal aqueous alteration and/or thermal metamorphism) their abundances in different extraterrestrial samples can provide information about such processes. This talk will review many examples of how presolar grains can be used as probes of a wide range of astrophysical and chemical processes, with emphasis on recent results enabled by technical breakthroughs in microanalytical research.

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Metal Pollution of Low-Mass Population III Stars through Collision of Interstellar Objects

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Direct observation of Population III stars (Pop. III stars) is important to understand the cosmic dawn era and Pop. III stars themselves. Pop. III stars can be explored in the Galaxy, since theoretical studies have predicted the formation of low-mass Pop. III stars that have their lifetimes of more than the Hubble time. We call such low-mass Pop. III stars "Pop. III survivors". In order to discover Pop. III survivors, we need to know their current metallicity. Pop. III survivors must be originally metal-free, and may be polluted, accreting interstellar medium (ISM). However, it have been shown that radiation pressure prevents the accretion of ISM dust [1], and that stellar wind prevents the accretion of ISM gas [2, 3]. The metallicity of Pop. III survivors polluted by ISM is estimated at [Fe/H] ~ -14 [2]. Pop. III survivors can be little polluted by ISM accretion.

We calculate accretion mass of interstellar objects (ISOs) like 'Oumuamua [4] onto Pop. III survivors, and estimate surface pollution of Pop. III survivors [5]. An ISO number density estimated from the discovery of 'Oumuamua is so high (~ 0.2 au^{-3}) that Pop. III survivors have chances at colliding with ISOs $\gtrsim 10^5$ times per 1 Gyr. In contrast, Pop. III survivors never collide with free floating planets and Pop. I/II stars in the Hubble time. 'Oumuamua itself would be sublimated if it approaches to Pop. III survivors, since it has small size, ~ 100 m. However, ISOs with size $\gtrsim 3$ km would reach the surfaces of Pop. III survivors. Supposing an ISO cumulative number density with size larger than D is $n \propto D^{-\alpha}$, Pop. III survivors can accrete ISO mass $\gtrsim 10^{-16} M_\odot$, or ISO iron mass $\gtrsim 10^{-17} M_\odot$, if $\alpha < 4$. This iron mass is larger than the accretion mass of ISM by several orders of magnitude. Taking into account material mixing in a convection zone of Pop. III survivors, we obtain their surface pollution is typically [Fe/H] $\lesssim -8$ in most cases, however the surface pollution of Pop. III survivors with $0.8 M_\odot$ can be [Fe/H] $\gtrsim -6$ because of the very shallow convective layer, if the ISO cumulative number density is shallow ($\alpha \sim 2.5$) up to $D \sim 10$ km. The dependence of the metal pollution is as follows. If $\alpha > 4$, Pop. III survivors have no chance at colliding with ISOs with $D \gtrsim 3$ km, and keep metal-free. If $3 < \alpha < 4$, Pop. III survivors would be most polluted by ISOs up to [Fe/H] ~ -7. If $\alpha < 3$ up to $D \sim 10$ km, Pop. III survivors could hide in metal-poor stars so far discovered. Although the metal pollution strongly depends on the power α, we first show the importance of ISOs for the metal pollution of Pop. III survivors.

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Properties of Dust and Galaxies in Dusty Era at z=1-2 explored by Multi-wavelengths Survey toward the North Ecliptic Pole

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To understand the physical process of evolution of galaxies over the cosmic time, it is essential to directly probe the "Dusty Era" at $1 < z < 3$. This era is hidden to optical tracers, and represents the bulk of the star formation and black hole accretion. Although near to far-infrared wavelengths are quite rich in various mineral, organic and ice features of cosmic dust, spectroscopic diagnostic study of such obscured galaxies has not yet been done so much by the space infrared telescopes ever launched due to their limited sensitivity, and therefore the dust properties in "Dusty Era" need to be studied by observations of broad-band spectral energy distributions. We have undertaken multi-wavelength deep surveys toward the North Ecliptic Pole (NEP) (0.5 deg^2, NEP-Deep, and 5.4 deg^2, NEP-Wide). The survey provides us with a few ten-thousands of 15 μm or 18 μm selected sample of galaxies, which is the largest sample ever made at this wavelengths. Here we introduce recent major results on the properties of dust and obscured galaxies out to z = 2 revealed by the NEP survey.

A continuous filter coverage in the mid-infrared wavelength (7, 9, 11, 15, 18, and 24 μm) of AKARI is unique and vital to unveil the luminosity density evolution from both starbursts and dusty AGNs out to z = 2. For example, rest-frame 8 μm is covered by AKRI bands at 11, 15, 18 and 24 μm bands for galaxies at $0.15 < z < 0.49$, $0.75 < z < 1.34$, $1.34 < z < 1.7$ and $1.7 < z < 2.05$, respectively. Goto et al. (2015) estimated rest-frame 8 and 12 μm, and total infrared luminosity functions at $0.15 < z < 2$, which were found to be consistent with previous works, but with reduced uncertainties. In order to study the evolution of dust attenuation, Buat et al. (2015) built an 8 μm selected sample of galaxies (about 4000 sources) in the NEP-Deep field. The attenuation in our mid-IR selected sample is found ~2 mag higher than that found globally in the universe or in UV and Hα line selections in the same redshift range. This difference is well explained by an increase of dust attenuation with the stellar mass, in global agreement with other recent studies. We conclude that the galaxies selected in IR and dominating the star formation exhibit a higher attenuation than those measured on average in the universe because they are massive systems. Furthermore, Oi et al. (2017) selected 47 dust-obscured galaxies (DOGs; defined by $R - [24] \geq 7.5$ AB mag; Dey et al. 2008), most of which are either bump-DOGs or power-law DOGs, and found that the dust temperature of power-law DOGs are higher than that of bump-DOGs, probably due to the AGN activity.

Recently, we carried out deep imaging of the NEP-Wide field in 5 broad bands (g,r,i,z, and y) using Hyper Suprime-Camera (HSC) on Subaru telescope (Goto et al. 2017). Also the NEP is now selected as a JCMT/SCUBA-2 legacy survey field (PI: Hyung Mok Lee), and 850 μm deep survey is on-going. Finally, it is noteworthy that NEP is one of high visibility regions in the sky with future space observatories; JWST, e-ROSITA, Euclid, and SPICA. Namely SPICA, the unique next-generation infrared space telescope with unprecedented spectroscopic sensitivity, will unveil the composition and physical properties of cosmic dust in the "Dusty Era".

Dust masses of high-redshift galaxies from SED fitting and ALMA upper limits

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Dust production in the early Universe (at high z, where z is the redshift) is the starting point of dust evolution. The early dust enrichment is considered to be dominated by dust condensation in supernovae (SNe). The dust mass in high-z galaxies may reflect the efficiency of dust formation by SNe (or other sources). We aim at constraining the dust mass in high-z (here, high z means redshifts typically higher than 5) galaxies using the upper limits obtained by Atacama Large Millimetre/submillimetre Array (ALMA) in combination with the rest-frame UV–optical spectral energy distributions (SEDs). For SED fitting, because of degeneracy between dust extinction and stellar age, we focus on two extremes: continuous star formation (Model A) and instantaneous star formation (Model B). We apply these models to Himiko at $z = 6.6$ (as a representative UV-bright object) and a composite SED of Lyman break galaxies (LBGs). For Himiko, Model A requires a significant dust extinction, which leads to a dust temperature higher than ~ 70 K for consistency with the ALMA upper limit. This high dust temperature puts a strong upper limit on the total dust mass (2×10^6 $M_\odot$), and the dust mass produced per SN, m_d smaller than 0.1 $M_\odot$. Such a low m_d suggests significant loss of dust by reverse shock destruction in SNe or outflow from the galaxy, and implies that SNe are not the dominant source of dust at high z. Model B allows dust mass 2×10^7 $M_\odot$ and $m_\mathrm{d} \sim 0.3$ $M_\odot$. We could distinguish between Models A and B if we observe Himiko at wavelength shorter than 1.2 mm by ALMA. For the LBG sample, we obtain dust mass smaller than 2×10^6 $M_\odot$ for a typical LBG at $z > 5$, but this only puts an upper limit for m_d as ~ 2 $M_\odot$. This weaker constraint for the LBGs than for Himiko is due to a much smaller number of SNe expected from their much lower UV luminosity. This clarifies the importance of observing UV-bright objects (like Himiko) to constrain the dust production by SNe.

We extend our analysis to a few high-z LBGs in which dust emission has recently been detected by ALMA. We find that the dust temperatures are generally high ($\sim$ 40–50 K), confirming that the high dust temperature derived above for Himiko is a common property for high-z star-forming galaxies. We also discuss the similarity of the dust emission SED in those high-z LBGs to that in nearby low-metallicity star-forming dwarf galaxies.

Tracing cosmological evolution of PAH and dust in galaxies with unbiased large spectroscopic surveys by SPICA

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SPICA (SPace Infrared telescope for Cosmology and Astrophysics) is a future mid- and far-infrared (IR) astronomy mission after AKARI, Spitzer and Herschel, with a 2.5 m telescope actively cooled down to below 8 K (Roelfsema et al. 2018). Thanks to the cryogenically-cooled telescope as well as the advanced instrument technologies, SPICA provides unprecedented high sensitivity. In particular, SPICA is extremely sensitive to broad spectral features such as dust spectral bands from faint objects, which is essential to study the properties of dust in distant galaxies. SPICA is proposed as an international project between JAXA and ESA, and very recently SPICA has been selected as one of the 3 candidates for the ESA Cosmic Vision M-class 5th mission out of the 25 proposals. SPICA will launch in the late 2020's and operate for a goal lifetime of 5 years.

With SPICA, we plan to conduct unbiased large spectroscopic surveys of galaxies in the mid-IR range which contains many spectral features associated with dust grains such as polycyclic aromatic hydrocarbons (PAHs) and silicates. These features are usually very strong compared to gas lines, and thus valuable in studying the spectral properties of faint distant galaxies. The SPICA Mid-IR Instrument (SMI; Kaneda et al. 2016, Sakon et al, 2016) is one of the two focal-plane scientific instruments aboard SPICA, which is developed by a nation-wide university consortium in Japan. SMI would trace the evolution of the dust-obscured star-formation and AGN activity in galaxies since the re-ionization epoch using the PAH and silicate features, and at the same time reveal the cosmological evolution of PAH and dust through spectral variations in the peak positions and the profiles of the dust features. For example, with a 10 deg^2 blind survey for a given observation time of 600 hours, we estimate that the SMI survey would produce as many as $\sim 5 \times 10^4$ spectra of PAH galaxies at redshift $z > 1$ as well as $\sim 2 \times 10^4$ spectra of AGN at $z > 1$ (Kaneda et al. 2017).

In this presentation, we show the scientific capabilities of SPICA for studies of dust in galaxies, focusing on the scientific potential of the unbiased large spectroscopic surveys with SMI, together with the latest information on the SPICA project.

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A Brief Post-Cassini Review of the Ring-Atmosphere Interaction at Saturn

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The rings of Saturn had attracted the attention of astronomers since the time of Galileo. But the recognition of the complex nature and time-changing behavior of the ring system had to wait until the close flyby observations of the Voyager 1 and 2 spacecraft in November, 1980, and August, 1981, respectively. Not just the fine-scale structures of the ringlets were amazing to see; the sharp edges of the outer A-ring, both sides of the Cassini division and the inner B-ring were also found to be an integral part of the majestic architecture that is the Saturnian ring system. Another totally curious fact was about the finding that the planetary magnetic field of Saturn is perfectly dipole-like except for a small shift of the center of the magnetic moment. Very intriguing radial features of dust clouds appeared from time to time during the rapid crossings of the Voyager spacecraft. These observational recipes have fed into the imagination of a number of plasma physicists and atmospheric scientists leading to the picture of constant injection of charged nano-dust particles of icy composition into the Saturnian ionosphere. This theoretical model or rather a collection of such models of dusty plasma dynamics would predict the formation of the sharp B-C ring boundary and the depletion of the ionospheric electron density via the so-called “ring rain” effect.

The radio occultation measurements of the Cassini spacecraft provided very valuable information on the Saturnian ionospheric profile. It is interesting to note that, while the “ring rain” effect as a consequence of gravito-electrodynamical instability would predict electron depletion at mid-latitude region with magnetic connection to the C-ring, the electron depletion detected by the radio science experiment showed up repeatedly at the equatorial and low-latitude region. The Grand Finale of the Cassini mission in 2017 with 22 fly-throughs of the no-man’s land between the inner edge of the D ring and Saturn’s upper atmosphere with closest approach at 2000 km above the 1-bar pressure level, until its final plunge on September 14, 2017, was therefore the climax of our long quest of the origin and dynamical evolution of the rings of which the dusty plasma effect could play a fundamental role. As of May, 2018, many of the very interesting, new results are still being reviewed and compared. We hope to be able to give a preliminary view of the once-upon-a-lifetime Cassini findings in contrast to the post-Voyager ideas as an invitation to new ideas from the young generation of the post-Cassini era.

Scattered light of cometary dust: A window to look at the evolutionary product of comets

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Comets are the most pristine reservoir of the materials left over from the formation epoch of the solar system. When they are heated and expel such ancient materials in their orbital motions around the Sun, however, a dust mantle could be developed over the surface as a result of sublimation-driven cometary activity, disguising natal information encoded in each comet as similar properties of the evolved dust particles.

Cometary dust in the coma and on the nuclei scatter sunlight mainly at visible and near-infrared (NIR) wavelengths. In general, linear polarization (P) of cometary dust particles can be exploited to constrain physical properties, such as their size and porosity (see, e.g., Kiselev et al. 2015). Most comets show a quite homogeneous distribution of P with regard to the phase angle (an angle of the Sun-Comet-Observer), suggesting their similar dust properties. Herein, we report the results of two interesting comets, comet 2P/Encke and 252P/LINEAR observed all at high phase angle (>70 deg). Both comets show significantly different polarimetric behaviors from that of a majority of comets. We observed comet 2P/Encke in its 2017 apparition via spectropolarimetry at optical wavelengths (0.5–1.0 μm). For comet 252P/LINEAR, we observed it via NIR imaging polarimetry (simultaneously in JHK_S filters), covering its perihelion passage in 2016. Based on the observational evidence, we will discuss their abnormal P behaviors in terms of the aging of the surface dust structure.

Composition of Cometary Dust Particles Families of Comet 67P/ Churyumov-Gerasimenko

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COSIMA, the COmetary Secondary Ion Mass Analyzer, is one of the three in-situ dust instruments onboard the Rosetta spacecraft, the ESA mission to comet 67P/Churyumov-Gerasimenko. From August 2014 to September 2016, Rosetta has been escorting the comet nucleus on its journey inwards and outwards the inner solar system. The instrument COSIMA collected cometary dust particles on metal targets in the inner coma, from 10 to hundreds of kilometers off the cometary nucleus. The targets are imaged and identified with an optical microscope and a selection of the collected particles are analyzed by secondary ion mass spectrometry (SIMS). Thousands of dust particles have been collected and the sizes of the identified particles and particle agglomerates range from 10 um up to sub-millimeter sizes. The mass spectra contain either positive or negative ions revealing both, mineral and organic, components. We will discuss the cometary dust particle composition and heterogeneity.

Physical properties of cometary dust particles collected in situ by Rosetta/COSIMA

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More than 35,000 cometary dust particles were collected at low velocity on metallic targets in the inner coma of the comet 67P/Chuyumov-Gerasimenko by the COSIMA (Cometary Secondary Ion Mass Analyzer [1]) instrument on-board the Rosetta spacecraft. All the particles have been imaged with a resolution of 14 um x 14 um with the internal camera of the instrument, the COSISCOPE [2].

Even at the low velocities of impact, most of the particles were fragmented on the collection targets, revealing their fragile nature [3]. We will show how the impact patterns can be used, by comparison with numerical models, simulations [4] and laboratory experiments [5], to retrieve the physical properties of the particles such as their tensile strength but also their original porosity and internal structure. A second information on the internal structure of the dust particles can be obtained by the way the light is scattered by these particles. The optical properties of the particles were analyzed [6] and we could show that scattering of light occurs inside the particles and not only at their surface for a large number of aggregates, which can be interpreted in terms of porosity.

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The Isotopic Composition of Cometary Dust Measured With COSIMA On Board Rosetta

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The isotopic composition of a substance can provide important information about the substance's history, since isotopic fractionation is sensitive to many conditions such as chemistry, temperature, and radiation. The isotopic ratios of elements have been measured in many extraterrestrial materials, such as chondritic meteorites, interplanetary dust particles, and comets. The great majority of such cometary measurements have been in the gas phase, with relatively few measurements in the dust. Here we present measurements of isotopic composition for several elements measured in cometary dust using the COSIMA instrument.

COSIMA was a Time of Flight – Secondary Ion Mass Spectrometry (ToF-SIMS) instrument aboard the Rosetta orbiter that spent approximately 2 years within tens to hundreds of kilometers of the nucleus of comet 67P/Churyumov-Gerasimenko. COSIMA collected 35000 dust particles and fragments from 67P. Practical considerations restricted the number of particles upon which ToF-SIMS analysis was performed to a few hundred, and a subset of these particles will be discussed here. Comparison to measurements of the isotopic composition of other extraterrestrial matter will be made and the implications for the history of comets will be considered.

Property of Interplanetary dust in our solar system investigated from infrared spectroscopic observations

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Planets and their materials like dust have been thought to stay on the same orbit during the planets' formation. Recently, however, it was found that dust in protoplanetary disks were well mixed along the heliocentric direction. Once dust get close to the central star, they are heated, crystallized and evaporated. When they turn back to outwards, they will re-condense with a different cooling rate depending on the mixing speed and their properties will diverge. Since different mixing speeds result in capturing dust to planetesimals on different orbits, comets and asteroids, which are the survived planetesimals on outer and inner orbit respectively, can be composed by the dust of different properties. In the current solar system, comets and asteroids release interplanetary dust into the different distribution of ecliptic latitudes. Therefore, we aim to compare the properties of interplanetary dust among various ecliptic latitudes.

For this purpose, we focused on the spectral feature seen in the thermal emission of interplanetary dust, because the shape depends on the dust properties; Mg/Fe, olivine/pyroxene and crystal/amorphous ratio. 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~50. After grouping their spectra depends on the ecliptic latitude and averaging in same ecliptic latitude bin, we fit the continuum to a diluted blackbody of a single temperature ($\tau B\nu(T)$) and divided the averaged spectra by the modeled continuum.

As a result, we detected the spectral feature around 10 μm in all ecliptic latitudes and recognized the variations in the shape and the strength of this feature among different ecliptic latitudes. We compared their shapes to absorption coefficient spectrum of some types of minerals derived from laboratory measurements and estimated the mineral composition of interplanetary dust. As the conclusion, we found that interplanetary dust has lower olivine/pyroxene ratio at higher ecliptic latitudes. We will present these results and talk about future works for more progressive discussion.

Scattering properties of the dust in distant comet C/2014 A4 (SONEAR).

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Cometary dust preserves the materials left from the early stages of the solar system formation. In the comets that reach close distances to the Sun, the dust does not represent the pristine materials due to sublimation of its volatiles and other changes caused by the solar radiation. However, there are some comets whose orbits keep them far away from the Sun. Some of them exhibit considerable activity at heliocentric distances much larger than 4 au and, thus, allow us to study the dust not notably modified by solar radiation. Since 2011, we are conducting a comprehensive program of polarimetric, photometric, and spectral investigations of active distant comets with the 6-m telescope BTA (SAO RAS) with multi-mode focal reducer SCORPIO-2 (Afanasiev & Moiseev, 2011, Baltic Astron., 20, 363).

We present continuum polarization measurements for unique distant comet C/2014 A4 (SONEAR) with perihelion distance more than 4 au. The comet showed significant activity at large heliocentric distances. Since no emission lines could be detected with our spectroscopic observations, all this activity can be attributed to the dust Polarization map of this comet, obtained at phase angle 3.8 deg., shows spatial variations of polarization over the coma from about –2% near the nucleus to –8% at the heliocentric distance r=4.2 au (the polarization images of the comet were taken in the g-sdss (λ4650/650 Å) and r-sdss (λ6200/600 Å) filters). Thus, the negative polarization is significantly greater than the typical polarization (~ -1%) observed at the same phase angles for the dust in the comets close to the Sun. Possible explanation of the unusual polarimetric properties of the dust in this comet is provided. It is based on the computer modeling of the dust as a polydisperse ensemble of rough multishaped spheroids, which change their size and composition with the distance from the nucleus.

High Performance Computing of Light Scattering by Aggregate Dust Particles of Organic-rich Submicron Grains with Improvements to the MSTM Code

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Primitive dust particles in planetary systems and the interstellar medium are expected to contain organic matter as a major constituent, which might contribute to the origin of life in habitable planets. Collisional growth of primitive dust particles in molecular clouds and protoplanetary disks inevitably form fluffy aggregate particles of organic-rich submicrometer-sized grains. Organic matter plays a crucial role not only in sticking of the particles, owing to its highly cohesive nature, but also in light-scattering properties of the particles, owing to its highly absorbing nature. Astronomical data on dusty environments are often ascribed to electromagnetic waves that are scattered, absorbed, or emitted by fluffy aggregate particles of organic-rich submicrometer-sized grains. One the one hand, considerable knowledge of light scattering by fluffy aggregate particles of submicron constituent grains (monomers) is a requisite for the correct interpretation of astronomical data. On the other hand, our knowledge of light scattering by fluffy aggregate particles in the visible wavelength range is limited to a small number of monomers, due to the difficulty of numerically evaluating light-scattering properties of aggregate particles if their sizes are much larger than the wavelength and their monomers are absorptive.

The MSTM (Multi Sphere T-Matrix) Fortran 90 code developed by Daniel Mackowski (Auburn University, USA) is a powerful tool for computing light-scattering properties of aggregate particles. We have improved the publicly available MSTM code (version 3) to reduce computational resources such as CPU time and RAM size by rewriting its source programs with cache-efficient and memory-efficient optimized source programs. Since the computational speed is more than twofold and the memory requirement is reduced in our MSTM code at present, light-scattering properties of large aggregate particles are computed with the MSTM code on a multi-core personal computer as well as a supercomputer. We will present how light-scattering properties of aggregate particles consisting of organic-rich submirometer-sized monomers evolve with particle growth (i.e., the number of monomers). Our results will give new insights into interpretations of astronomical data on the angular profiles of intensity and polarization for dust particles in optically thin environments such as comets, debris disks, and the diffuse interstellar medium.

Exploring Grain and Gas Properties in Debris Disks with Millimeter Interferometry

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At least 20% of nearby main sequence stars are surrounded by disks of dusty material resulting from the collisional erosion or evaporation of planetesimals, large bodies leftover from the process of planet formation. The small dust grains produced through these collisions can be observed via scattered light at visible to near-infrared wavelengths or thermal emission at mid-infrared to millimeter wavelengths. Since the dust-producing planetesimals are expected to persist in stable regions like belts and resonances, the locations, morphologies, and physical properties of dust in these 'debris disks' provide probes of planet formation and subsequent dynamical evolution. Thus, observations of these systems can simultaneously reveal the locations of planet formation and the compositions of the resulting planets. Observations at millimeter wavelengths are especially critical to our understanding of debris disks, since the large grains that dominate emission at these long wavelengths do not travel far from their origin and therefore reliably trace the underlying planetesimal distribution.

In this talk, I will present ongoing investigations into the grain and gas properties of nearby debris disk systems. We can constrain the grain size distribution by measuring the spectral dependence of the flux density at long wavelengths, providing the first observational test of collision models of debris disks. In addition, there is now a growing sample of debris disks with atomic and molecular gas detections. Resolved ALMA observations of molecular gas lines allow us to explore the kinematics of this gaseous material, and test theories of its origin and evolution. Together, measurements of both dust and gas properties can reveal the composition and distribution of planetesimals in these systems, and probe the environments where young planets are formed and acquire their final compositions.

Grain alignment with fast, numerically exact methods in 3D radiative transfer

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We have developed a 3D radiative transfer code, which will calculate the full Stokes vector of the scattered light, not just the intensity. In addition, we will be able to have grains aligned in the magnetic field, using fast and numerically exact methods of solving the alignment of non-spherical grains. This allow the calculation of their effect on the arising polarization of the scattered light.

Polarized scattered light has been observed in cometary comae [1] and in circumstellar disks [2]. Polarized scattered light carries information about the grains from which the light scattered. However, modelling polarized scattered light is a complicated problem. So far, most scattering codes consider either optically thin cases, where radiative transfer is not necessary, or only do one-dimensional (1D) radiative transfer. Three-dimensional (3D) radiative transfer is mainly focused on unpolarized radiation, which is easier to calculate.

Interstellar dust grains are aligned with magnetic fields. However, in many scattering codes, the grains are assumed to be randomly aligned, allowing for a simplification of the problem. In this work, we utilize a new 3D Monte Carlo radiative transfer code which incorporates the full Stokes vector for both the incoming radiation and the radiation scattered by aligned dust grains.

The dust model can include different populations of dust, differing in composition, size distribution, shapes, and orientation. Based on the dust populations and the fraction of alignment, we calculate the average scattering matrix as well as the extinction matrix in each computational cell. Due to the limits of memory, this calculation is done on the fly, based on pre-calculated critical aligned size, scattering and extinction matrices per dust population.

In recent works [3,4], we have presented a full solution to the scattering problem of non-spherical grains and the corresponding dynamical problem in a numerically exact manner. The solution provides a means of studying how cosmic dust grains spin under radiative torques. In this work, we apply the previously developed scattering dynamics framework to obtain the pre-calculation scattering and extinction matrices of gradually aligning dust populations.

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Characterizing dust in debris disks:
Recent advances and unsolved issues

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Debris disks are tenuous gas-poor, dusty disks that are often found around Main Sequence stars. In our Solar System, the zodiacal light is empirical evidence that even stars several Gyr old can possess such dusty disks. The dust grains these disks contain are the result of the continuous collisional grinding of planetesimals (asteroids and comets) that are the leftover byproducts of the planet formation process. Furthermore, the dynamics of the dust grains can be significantly influenced by gravitational interactions with planetary-mass objects. Studying the properties and spatial distribution of dust in debris disks therefore provide key insight on the structure of mature planetary systems. A number of observational approaches are available to study these disks, in particular by spatially and/or spectrally characterizing the thermal emission from the dust, or by imaging scattered starlight off the dust grains. All of these provide independent and complementary insights on the properties of the dust grains hosted in the system.

Here I will review the fundamental methodologies employed in this context and describe how a series of instrumental developments over the past two decades has led to major improvements in our understanding of debris disks. I will focus on what we have learned about dust properties, specifically the composition, size distribution and structure of dust grains, highlighting both key discoveries and currently unexplained features. Whenever possible, I will also discuss direct comparisons to the dust populations found in our Solar System and in protoplanetary disks.

Modeling the ringworld of GG Tau A with the RT code POLARIS

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With its high complexity, the ringworld around GG Tau A is a great example to study the formation and evolution of protoplanetary disks around binary (or tertiary) systems. In this study, we investigate the physical characteristics of the circumbinary and circumstellar disks around the stellar components of GG Tau A.

To achieve our aims, we perform radiative transfer (RT) simulations with the code POLARIS (Reissl et al. 2016; Brauer et al. 2017) to obtain emission maps at multiple wavelengths. These simulations consider the complex density structure of the circumbinary and circumstellar disks as well as the direct and scattered emission of the multiple stellar components. By comparing the simulated emission maps with observations that are performed at various wavelengths, we derive constraints on various parameters and characteristics of our model such as the density distribution, inclination, and dust grain properties.

The dust and gas interplay in star and planet forming regions

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Stars and planetary systems in our Galaxy form within dense ($n(H_2) \sim 10^5$ cm^{-3}) and cold ($T \sim 10$ K) fragments of interstellar molecular clouds, called pre-stellar cores. Important processes take place at this early stage thanks to the interplay of dust grains and the gas, such as isotope fractionation, production of complex organic molecules and formation of thick icy mantles onto dust grains, where water and organics are stored. These processes affect later phases of star and planet formation, which can now be traced with powerful interferometers such as ALMA and NOEMA. I shall review the chemical and physical structure of pre-stellar and protostellar cores, as well as theoretical work on prototostellar disk formation and early evolution. Links to protoplanetary disks and our Solar System will be made.

Importance of interstellar dust for the formation of complex molecules in hot cores

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Gas phase model can normally explain observed abundances of the smaller and many other large radicals but they are unable to explain observed abundances of most of the stable and complex, partially organic species in space. It is now well established that dust particles play an essential role towards the chemical enrichment of the ISM. They act as a reservoir and catalytic sites for the formation of complex interstellar species. In order to justify the observed abundances in the hot core region (for Galactic molecular cloud as well as for the Large Magellanic Cloud), two-phase model was emplyed. In the first phase, the cloud remains either in isothermal phase or in collapsing phase. Gas density and temperature can vary in the collapsing phase and dust temperature is calculated by using the empirical relation proposed by Hocuk et al. (2017). In order to make a distinction between the Galactic molecular cloud and Large Magellanic cloud, metallicity effect is included in the relation. The first phase continues for $10^5 - 10^6$ years which is then followed by a subsequent warm-up phase where the temperature can gradually increase up to 200 K in $10^4 - 10^5$ years. In this meeting, I will present my modeling results for the Galactic molecular cloud and Large Magellanic Cloud.

Organic molecules at 0.2 solar metallicity

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Properties of complex organic molecules in metal-poor environments will be crucial information for understanding organic chemistry in high-redshift galaxies where the metallicity was significantly lower than the present solar neighborhood. The Small Magellanic Cloud (SMC) is a nearby star-forming dwarf galaxy, whose metallicity is lower than typical Galactic values by a factor of ~5. Here we present observational and theoretical studies on the formation of complex organic molecules in the metal-poor environment of the SMC.

First, we report the results of sub-parsec scale submillimeter observations towards a high-mass young stellar object in the SMC with the Atacama Large Millimeter/submillimeter Array (Shimonishi et al. 2018, submitted). As a result of observations, we for the first time detected a complex organic molecule, methanol (CH_3OH), in the SMC. Besides CH_3OH lines, we also detect the dust continuum as well as emission lines of CS, $C^{33}S$, H_2CS, SO, SO_2, $H^{13}CO^+$, $H^{13}CN$, SiO, and tentatively HDS from the observed region. The target infrared point source is spatially resolved into two dense molecular cloud cores; one is associated with an embedded high-mass young stellar object, another is not associated with an infrared source but shows rich molecular lines including those from CH_3OH. The first detection of CH_3OH in the SMC has a strong impact on our understanding of the formation of complex organic molecules in metal-poor environments. The gas temperature is estimated to be ~10 K based on the rotation analysis of CH_3OH lines, suggesting that non-thermal desorption would contribute to the production of gas-phase CH_3OH in this source. The fractional abundance of CH_3OH gas in the observed dense core is estimated to be (0.5-2) x 10^{-8}, which is comparable with those of similar Galactic cold sources despite a factor of five lower metallicity in the SMC. This would indicate an enhanced production or an inhibited destruction of gas-phase CH_3OH in the present SMC source as compared to Galactic counterparts.

Next, we report the results of numerical simulation on gas-ice chemistry dedicated to the galactic environment of the SMC. Using the physical conditions constrained by the ALMA observations, the abundances of the detected molecular species are well reproduced by the astrochemical simulation. However, to achieve this, we need to assume (i) a higher elemental abundance of sulfur compared to the standard sulfur-depleted abundance model of the SMC, (ii) reactive desorption of grain surface species with a probability of ~1%, and (iii) a sufficiently low dust temperature (<15 K). The requirement (i) implies that gas-phase elemental sulfur is less depleted into dust in the metal-poor environment of the SMC compared to Galactic dark clouds. The requirement (ii) indicates that, by taking into account reactive desorption, observed and model-predicted molecular abundances show good agreement without incorporating energetic desorption processes such as shock sputtering. The requirement (iii) indicates that a cold and well-shielded region is necessary for the production of the observed amount of CH_3OH gas in the SMC, and such a source is actually found by our observations in the metal-poor environment.

Although it is still unclear if the observed source represents common characteristics of cold and dense molecular clouds in the SMC, this work provides observational evidence that an organic molecule like CH_3OH, which are largely formed on grain surfaces, can be produced even in a significantly lower metallicity environment compared to the solar neighborhood.

Surface reactions on interstellar grain analogues: From carbon grains to carbon-bearing ice species

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The formation of large Complex Organic Molecules (COM) and exobiologically-relevant species on the surface of dust interstellar grains and their processing during desorption represent an important step toward the understanding of the origin of life on earth. In order to gain more insight onto these physical and chemical processes, we have investigated surface reactions on carbon grains and on interstellar ice analogues. Such a study would help to justify the abundances of species already detected through astronomical observations or to guide the future exploratory observations. Interstellar grain analogues are prepared under ultra high vacuum of 1 x 10^{-10} mbar and at very low temperatures (3-20 K), conditions reproducing the extreme environments of the interstellar clouds. In the context of this conference, I will focus on the interstellar grain analogues irradiated by UV photons or high energy particles combined to the H-addition reactions, the most predominant reaction in the interstellar medium. This experimental study which combine energetic and non-energetic processing will bring more insight onto the route of COM formation and answer the question why different aldehydes like methanal, ethanal, propynal, propenal and propanal are present in dense molecular clouds while the only alcohol detected in those cold regions is methanol.

Adsorption Energies of Atoms and Molecules on Amorphous Ice Surface: A Systematic Estimation Based on Quantum Chemistry Calculation

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Chemical evolution from atoms to interstellar molecules is a key to explore the origin of molecules. However, collision of two or more atoms in the vacuum is elastic because an excess energy from formation of a molecule is not dissipated to the vacuum. Therefore, chemical reactions on the inter-stellar dust play a key role to form various molecules in the interstellar medium. The first step of such chemical reactions is adsorption of atoms onto the dust surface. In dense molecular clouds, the interstellar dust is generally covered by amorphous ice which mainly consists of water molecules. Thus, the adsorption onto amorphous ice surface at the low-temperature is of considerable importance to explore the chemical evolution in this stage.

In this work, we proposed a new computational model to systematically estimate adsorption energies of atoms and molecules onto the low-temperature amorphos ice surface based on quantum chemistry calculations, as following: (1) Clasical MD annealing from 300K to 10K to sample small amorphous water clusters (including 20 water molecules), (2) add an atom randomly surrounding the water cluester and optimized geometry based on quantum chemistry calculation (density functional theory with ω-B97XD functional), (3) search the maximum adsorption energy for each water cluster, and (4) average the maximum adsorption energies over the cluster samples.

Taking the maximum adsorption energy incorporates local geometry relaxation during long time-scale fructuation, and averaging over them averages stable adsorption site in the amorphous water ice surface.

Table. Calculated adsorption energies

	$C(^3P)$	$N(^4S)$	$O(^3P)$
$E_{\mathrm{ads.}}$	14,100	400	1440
Std. Error	420	30	160
Exptl.	N/A	720	1410

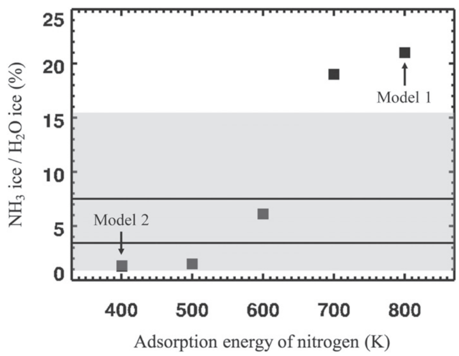

Figure. NH_3 abundance estimated by using various adsorption energies of N.

The adsorption energies of C, N, and O atoms were estimated to be 14,100 K, 400 K, and 1440 K, respectively (see Table). Those of N and O are well consistent with the laboratory experiments by Minissale.[1] Interestingly, the adsorption energy of C atom was estimated to be considerably large, clearly indicating that the adsorption of C atom is clarified by chemisorption. On the other hand, the calculated adsorption energy of N atom was slightly lower than the experimental value. As a result, diffusion process is enhanced even at the low-temperature amorphous ice surface, and therefore, chemical abundance of N_2 increases while that of NH_3 decreases (see Model 2 in the Figure). Consequently, our newly proposed scheme to estimate the adsorption energy will give a new insights into the chemical evolution at the low-temperature interstellar space.[2]

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Near-Infrared Imaging Polarimetry as a Probe of Magnetic Field

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and
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Magnetic field plays an important role in many astrophysical processes. Yet it is seledomly considered in the theoretical works that deal with the evolution of celestial objects. One of the main reasons is that the magnetic field is very difficult to detect and measure. Here we give a brief introduction to the widely-used approach to study the interstellar magnetic fields – by means of near-infrared polarimetric imaging observations of background stars. We will talk about the mechanism of the polarization of star light, the observation techniques, and discuss the advantages and disadvantages of this method. In the epilogue we will give a number of examples on the study of the magnetic fields in the interstellar nebulae.

The inner dust shell of Betelgeuse detected by polarimetric aperture masking interferometry

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The origin of the dust-laden winds from evolved stars remains mired in controversy. Characterizing the formation loci and the dust distribution within the first stellar radius or so above the surface is crucial to understand the physics underlying the mass loss phenomenon. After introducing the topic, I will present how we can use interferometric polarimetry to derive the fundamental parameters governing the dust structure at the wind base of evolved stars.

Particularly, I will report on near-infrared aperture masking observations of Betelgeuse in polarimetric mode obtained with the NACO/SAMPol instrument.

We detected a dust halo located at only 0.5 $R_\star$ above the photosphere (meaning a dust halo inner radius of 1.5 $R_\star$) despite the high temperatures at this proximity to the stellar surface. Fitting to the data under the assumption of Mie scattering, we estimate the grain size and density for various dust species. Although the data constrains the shell and size of its constituent grains, alone it cannot disentangle the composition of dust. However such a study can be attempted using comparison of the dust shell models with SPHERE/ZIMPOL measurements. Extrapolating to the visible wavelengths using radiative transfer simulations, we confront our model with SPHERE/ZIMPOL data finding that models based on dust mixtures dominated by forsterite and/or enstatite are most favored.

The presence of such a close dusty atmosphere yields profound implications for dust formation mechanisms around red supergiants. It is possible that the new dusty structure reported here could form the base of a scattering-driven wind following the theoretical predictions reported in Höfner (2008). This scenario would be particularly attractive since the observed grain size range also corresponds to what is observed in the interstellar medium.

A Unified Model of the Emission, Extinction, and Polarization of Interstellar Dust

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We present a new model of interstellar dust composed of silicates, graphitic carbonaceous grains, and polycyclic aromatic hydrocarbons that reproduces the wavelength dependence of dust extinction (total and polarized) and emission (total and polarized) in the diffuse interstellar medium from UV to microwave wavelengths. In this talk, I will focus on 1) the development of a new model of spinning dust emission based on ultrasmall silicates, including its polarization properties and 2) the extension of the silicate+graphite+PAH model to polarization through use of spheroidal grains and guided by observations of polarized dust emission by the *Planck* satellite.

Size Distribution of Interstellar Dust Constrained by Near-infrared Diffuse Galactic Light Observed with MIRIS

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Diffuse Galactic light (DGL) is dust-scattered light of interstellar radiation field. Therefore, the DGL observation provides some properties of interstellar dust, such as size distribution and albedo of grains. We observed three diffuse clouds in high Galactic latitude at 1.1 and 1.6 μm with Multi-purpose Infra-Red Imaging System (MIRIS)[1], a wide-field camera instrument onboard the Korean satellite STSAT-3. After data reduction, the DGL brightness is measured by correlating the near-infrared (IR) images with a far-IR 100 μm map of interstellar dust thermal emission. The result is consistent with previous studies[2] and shows the most accurate DGL measurement achieved to date thanks to the wide-field observation of MIRIS. We also find a linear correlation between optical and near-IR DGL in the MBM32 field, using the data obtained in the ground-based observation[3]. The excess is found in the optical wavelengths, suggesting the presence of the extended red emission reported in several earlier studies. To constrain the size distribution of interstellar dust, we adopt recent dust models with or without μm-sized very large grains and predict the DGL spectra, taking into account reddening effect of interstellar radiation field. The population of very large grains is suggested by the flat extinction curve observed in the mid-IR[4]. The result shows that observed color of the near-IR DGL is closer to the model spectra without very large grains[5]. This may imply that dust growth in the observed MBM32 field is not active owing to its low density of interstellar medium. This is also consistent with some theoretical studies of dust growth in interstellar medium.

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Understanding the diffuse radiation field at the Galactic Poles.

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We have used GALEX observations of the north and south Galactic poles to study the diffuse ultraviolet background at locations where the Galactic light is expected to be at a minimum. We find offsets of 230–290 photon units in the far-UV (1531 Å) and 480–580 photon units in the near-UV (2361 Å). Of this, approximately 120 photon units can be ascribed to dust-scattered light and another 110 photon units (190 in the near-UV) to extragalactic radiation. The remaining radiation is, as yet, unidentified and amounts to 120–180 photon units in the far-UV and 300–400 photon units in the near-UV. We find that molecular hydrogen fluorescence contributes to the far-UV when the 100 μm surface brightness is greater than 1.08 MJy sr^{-1}.

I will discuss these observations and further observations of a high latitude cirrus cloud. I will describe our dust scattering model and the modifications we are making to understand the diffuse radiation. Historically, this has been one of the most useful methods of understanding interstellar dust and I will show that developing models to understand the diffuse emission in the UV and in the IR are important and feasible.

Site construction and observational researches at Ali observatory

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The Ali Observatory, located in the most west part of Tibetan plateau, has been newly established at an altitude above 5000 m, following a long term site survey over China. The original intention of selecting Ali site is just for detailed site characterization and small telescopes, but many projects tend to be especially optimistic about unique site qualities and constantly encourage to construct telescope facilities. The Ali site has been evaluated by East Asia Core Observatory Association(EACOA) and proposed to be a candidate site for East Asia Observatory(EAO). The site has also been reviewed as a candidate site for the Northern Cherenkov Telescope Array(CTA), for the Thirty Meter Telescope(TMT), and recently for the Chinese Large Optical and infrared Telescope(LOT). This talk will summarize the site characteristics and show site development of Ali observatory.

Apart from facilities of infrastructure and for site testing, a particular facility has been set up for experiments toward quantum teleportion from ground to satellite. There are also collaborations with Las Cumbres Observatory to set up an Ali knot of LCOGT, including two 1 meter telescopes with imaging and spectroscopy instruments, and with Hiroshima University to set up a 50cm telescope (HinOTORI) for follow-up observations of gravitational wave optical counterpart. There are ongoing constructions on the summit for facility toward the primordial gravitational wave detection and for survey projects with telescope arrays by Nanjing University and Yunnan University. The talk will also briefly introduce observational researches of the collaborative projects and propose a plan toward observations to interstellar dust.

DFT study of Interstellar PAH molecules with aliphatic side groups

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Polycyclic Aromatic Hydrocarbon (PAH) molecules have emerged as a potential constituent of the Interstellar Medium (ISM) that emit strong features at 3.3, 6.2, 7.7, 8.6, 11.2 and 12.7 μm with weaker and blended features distributed in the 3-20 μm region. These features are proposed to arise from the vibrational relaxation of PAH molecules on absorption of background UV photons. These IR features also known as Aromatic Infrared Bands (AIBs) have been observed towards almost all types of astronomical objects; say HII regions, photodissociation regions, reflection nebulae, planetary nebulae, young star forming regions, external galaxies, etc. Astrophysical PAHs are proposed to exist in various forms, viz, ionized, both substituted and unsubstituted. Some interstellar PAHs are also identified to carry an aliphatic component that gives rise to 3.4 μm feature near the aromatic 3.3 μm feature. The 3.3 and 3.4 μm features are characteristics of stretching of an aromatic and aliphatic C-H bond in a PAH molecule. Despite the extensive research and wide acknowledgement of PAH molecules as carriers for AIBs, the identification of exact form of carriers still faces major challenges. In this work, we consider PAH molecules with aliphatic side groups to see any spectral similarities with the observed UIR features. This work reports a Density Functional Theory calculation of PAHs with -H, $-CH_3$, $-CH_2$-CH_3, $-CH=CH_2$ to determine the expected region of emission features and to find an aliphatic/aromatic ratio from moderate to large PAHs. We also include a deuterium (D) component in the aliphatic side group to see any possible consequences. We present a detailed analysis of the IR spectra of these molecules and discuss the possible astrophysical implications.

The formation of astrophysical Mg-rich silicate dust

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I will present results for ground-state candidate energies of Mg-rich olivine (MRO) clusters and use the binding energies of these clusters, and determine their nucleation rates in stellar outflows, with particular interest in the environments of core-collapse supernovae (CCSNe). Low-lying structures of clusters $(Mg_2SiO_4)_n$ $2 \leq n \leq 13$ are determined from a modified minima hopping algorithm using an empirical silicate potential in the Buckingham form. These configurations are further refined and optimized using the density functional theory code Quantum Espresso. Utilizing atomistic nucleation theory, we determine the critical size and nucleation rates of these clusters. We find that configurations and binding energies in this regime are very dissimilar from those of the bulk lattice. Clusters grow with SiO_4-MgO layering and exhibit only global, rather than local, symmetries. When compared to classical nucleation theory we find suppressed nucleation rates at most temperatures and pressures, with enhanced nucleation rates at very large pressures. This implies a slower progression of silicate dust formation in stellar environments than previously assumed.

The Extinction Law of M31

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Dust extinction is crucial to recover the intrinsic energy distributions of celestial objects and infer the characteristics of the interstellar dust.

The Andromeda galaxy (M31), at a distance of $\sim$ 780 kpc, is the galaxy of which individual stars can be resolved. The extinction law of M31 can be determined in terms of "pair method". Bianchi et al. (1996) found the UV extinction law in M31 shows a MW-type extinction curve but with weaker 2175 Å feature than that in the MW. The extinction curves in the central region of M31 derived by Dong et al. (2014) have the values of $R_{\rm V}$ around 2.4, and are steeper than the average Galactic one. Clayton et al. (2015) constructed extinction curves for four reddened sightlines in M31, which show similarity to those seen in the MW and the Large Magellanic Cloud (LMC). The extinction law of M31 is still unclear, so that the extinction curves towards more different sightlines in M31 are needed.

In this work, we select the bright O-type and B-type giant stars in M31 as extinction tracers from the Local Group Galaxy Survey (LGGS, Massery et al. 2016). By combining the spectroscopic data obtained by the Hubble Space Telescope (HST) and the Large Sky Area Multi-Object Fiber Spectroscopy Telescope (LAMOST) with the photometric data availabled online, we try to derive the extinction law of M31 from UV to near-IR bands for more sightlines.

Similar to the method used by Clayton et al. (2015), we use the Tlusty stellar atmosphere model to obtain the intrinsic surface fluxes for our extinction tracers. However, instead of adopting the FM (Fitzpatrick & Massa, 1990) parameterized extinction curves used by Clayton et al. (2015), we use the theoretical extinction curves derived from the silicate-graphite dust model with a MRN (Mathis, Rumpl & Nordsieck, 1977) dust size distribution.

Photopolarimetric properties of irregular dust particles modeled using *Sh*-matrix method

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The majority of cosmic dust particles and planetary aerosols have complex shape and structure. Rigorous modeling of light scattering by such particles, usually done using Discrete Dipole Approximation (DDA, see Draine and Flatau, OSA, 11, 1994), requires significant computer resources. An approach we present, *Sh*-matrix method technique (e.g., Petrov et al., JQSRT, 112, 2012), allows modeling quite complex particles using rather limited computer time and memory. The method is based on the T-matrix technique (e.g., Mishchenko et al., JQSRT, 55, 1996) and was developed after it had been found that the shape-dependent factors could be separated from the size- and refractive-index-dependent factors and presented as a shape matrix, or *Sh*-matrix. Size and refractive index dependences are incorporated through analytical operations on the *Sh*-matrix to produce the elements of *T*-matrix. *Sh*-matrix method keeps all advantages of the T-matrix method, including analytical averaging over particle orientation. Moreover, the surface integrals describing the *Sh*-matrix elements themselves can be solvable analytically for particles of any shape. This makes *Sh*-matrix approach an effective technique to simulate light scattering by particles of complex shape and surface structure. In this paper, we model irregular particles, presenting them as an ensemble of Gaussian random particles. The shape of these particles is described by a log-normal distribution of their radius length and direction (Muinonen, EMP, 72, 1996). Changing one of the parameters of this distribution, the correlation angle, we can model a variety of particles from spheres (correlation angle = 90 deg.) to irregular particles of random complex shapes, corresponding to small correlation angles. We survey the angular and spectral dependencies of intensity and polarization resulted from light scattering by such particles, studying how they depend on the particle shape, size, and composition. We apply the results of our modeling to interpretation of photopolarimetric observations of comets.

Properties of Near Earth Asteroids S-, C-, E, and B-types based on polarimetry: from (1685) Toro to (3200) Phaethon

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The polarimetric study of the Near-Earth Asteroids (NEAs) allows us to cover the large range of phase angles, including the value and position of polarization maximum, and thereby supplement the inaccessible angles for the Main Belt asteroids. This gives the possibility to determine the geometric albedo of asteroids using the P_{max}–albedo relation, to compare the properties of surfaces of asteroids of different origin and with varying degrees of regolith maturity, and to investigate the similarities or differences between the mechanisms of scattering of light by dust particles of the cometary atmospheres and surfaces of asteroids. In addition, many NEAs are potentially hazardous objects.

Despite the long history of polarimetric studies, only several NEAs were explored at large phase angles and the most complete phase dependences of polarization were determined, including polarization maximum. They are: middle-albedo asteroids S-type (1685) Toro, (4179) Toutatis, and (23187) 2000 PN_9; high-albedo E-type asteroid 1998 WT 24 (33342); and intermediate-albedo B-type asteroid (3200) Phaethon. For two low-albedo asteroids (2100) Ra-Shalom and (152679) 1998 KU_2, the phase-angle dependence of polarization were obtained only up to 59.7° and 81°, respectively.

A special attention will be paid to the results of unique photometric and polarimetric multispectral observations of enigmatic asteroid (3200) Phaethon performed at the 6-m telescope of the Special Astrophysical Observatory of the RAS and the BVRI aperture polarimetry at the 2.6-m and 1.25-m telescopes of the Crimean Astrophysical Observatory during November–December 2017 within the range of phase angles of 19.2–134.9°. We found that the polarization maximum of Phaethon is $P_{\mathrm{max}}\approx48\%$ at the phase angle of about 110° in the V-band. To date, Phaethon shows the highest maximum degree of polarization that was determined among the earlier observed bodies in the Solar System. Note that Phaethon is the target of upcoming space mission the JAXA Destiny$^+$.

We analyze the similarities and differences in the parameters of phase-angle dependences of polarization between different taxonomical classes of asteroids as well as between asteroids and comets in the sense of the current theories of light scattering. In particular, to better understand the possible causes of unique polarization and color properties of asteroid Phaethon, we used the modified *T*-matrix method, called *Sh*-matrix method, for simulation of the scattering properties of particles of arbitrary shape. We will discuss the results obtained.

Characterizing dust in dust-poor comet 2P/Encke and dust-rich comet 67P/Churyumov-Gerasimenko from observations and modeling

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Previously, from photometric and polarimetric observations of *dust-rich* comet 67P/Churyumov–Gerasimenko at the 6-m telescope of the SAO RAS in 2015–2016, we revealed that the dust color in the near-nucleus area was red, 0.84 ± 0.05^m, and then gradually became bluer, reaching ~0.4^m at distance ~40000 km. At the same time, the polarization initially sharply decreased within the first 5000 km from ~8% to ~2% and then gradually increased reaching ~7% at 36000 km. Thus, there is the "turning point", where the polarization trend changes from decrease to increase, which may be a diagnosis of dust properties.

New results on the spatial variations of polarization and color of dust in *dust-poor* comet 2P/Encke were obtained at the same 6-m telescope in January 2017. As in the case of comet 67P/C-G, we found that the near-nucleus area is redder and more polarized than the adjacent coma. The dust color BC(λ4429/36 Å)–RC(λ6835/83 Å) gradually changed from 1.0^m in the innermost coma to about 0.3^m in the outer coma. At the same time, the corrected for gas contamination radial profiles of polarization in the r-sdss filter showed that the polarization in the near-nucleus area was almost 12%, sharply dropped to 6% at the distance 2000 km, and then gradually increased with projected distance from the nucleus, reaching 12% at 12000 km, i.e. we again observe the similar "turning point" and trend of polarization.

The radial variations of polarization and color suggest a change in the particle properties with distance from the nucleus, most likely fragmentation and/or sublimation of the dust particles, and, hence, in the mean scattering properties on a time-of-flight timescale. For computer modeling of scattering particles, the *Sh*-matrix method was used. We considered cometary dust as random Gaussian particles distributed over the cometary coma with power law X^{-n}, where the n depends on projected distance from the nucleus. In the case of comet Encke, we considered of cometary dust as a mixture of particles of three types: silicates, organic matter, and water ice. Our simulation allowed us to determine the microphysical parameters of these model particles which demonstrated a good agreement with observational data. Contrary, in the case of comet 67P/C-G, cometary dust was presented by particles of single type which decayed with distance from the nucleus. Calculations showed that physical decay of particles can also explain the spatial variations of polarization and color of dust in the comet. In order to understand how different physical properties of the dust particles affect the behavior of color and polarization, further numerical simulations of light scattering by cometary dust particles are required.

Estimating the formation region of the cometary nuclei based on the infrared observations of cometary dust

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Comets are made of ice and dust and are the frozen relics of the early solar nebula. Determination of the properties of cometary dust provides us insight into both the early solar nebula environment and the formation process of planetesimals and planets. Dust grains of crystalline silicate, which is rarely presented in an interstellar space, were found in cometary nuclei as the spectral features in the 10-μm wavelength region. It is thought that these crystalline silicates had formed by annealing of amorphous grains and/or condensation from gas phase near the Sun in the inner solar nebula, and incorporated into a cometary nucleus in the cold outer region by the radial transportation in the solar nebula. An abundance of the crystalline dust grains was therefore expected to be smaller as far from the Sun. We carry on infrared observations of comets to understand the formation mechanism of minerals incorporated into a cometary nucleus based on its mineral abundance. To derive the mineral abundance of comets, we applied a thermal emission model for cometary dust grains to mid-infrared spectra of comets taken with the COMICS mounted on the Subaru Telescope. Based on our toy model, we discuss the possibility that the minerals of comets formed under non-equilibrium condensation in the early solar nebula, and compare this result with theoretical experimental predictions for the vaporization and condensation of silicate grains in the solar nebula.

Measurement of Infrared Extragalactic Background Light Considering Interplanetary Dust Particles from Oort-cloud Comets

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Extragalactic background light (EBL) comprises the entire radiation from the reionization era to the present epoch and serves as a fundamental quantity to study the galaxy formation and exotic unknown objects. In the infrared (IR) wavelengths, it is reported that the residual emission derived by subtracting the foreground emissions, such as zodiacal light (ZL) and diffuse Galactic light from the total sky brightness exceeds the integrated galaxy light and the origin of the excess light is unclear[1]. It is possible that ZL brightness is underestimated in the removal analysis because the conventional ZL model[2] does not include isotropic component of interplanetary dust particles (IDP). The isotropic IDP can be supplied by Oort-cloud comets and is also suggested by some dynamical simulation of IDP evolution[3]. Assuming a simple isotropic dust cloud, we predict that the brightness of scattered light and thermal emission from it increases toward the regions of low solar elongation angle (ϵ). To study properties of the isotropic IDP, we analyze the weekly-averaged maps obtained with Diffuse Infrared Background Experiment (DIRBE) on board *Cosmic Background Explorer* (*COBE*), which covers $64° < \epsilon < 124°$ and near to mid IR wavelengths[4]. The result shows that the expected ϵ-dependence appears both in near and mid-IR wavelengths. In the mid-IR, we also find that the residual intensity increases toward the high-ϵ regions.

Density distribution of IDP as a function of heliocentric distance is thought to depend on their size in a recent model[5]. In the model, density of μm-sized grains simply decreases toward outer solar system, while that of several tens of μm-sized grains tends to increase toward outer solar system in the heliocentric distance of less than $\sim 70\,$AU. On the baisis of the density distribution, we calculate the intensity of scattered light and thermal emission, assuming the IDP compositions of astronomical silicate or carbonaceous grains. In the near-IR, the model calculation can be fitted to the observed ϵ-dependence. In the mid-IR, however, the model intensity is higher than that obtained in the mid-IR and cannot reproduce the feature observed in the high-ϵ regions. This might suggest that the mid-IR absorption efficiency of the grains is smaller than the assumed grain compositions and that the density of Oort-cloud comets increases toward the outer solar system more steeply than that of the recent model.

[1]Sano et al. 2015, ApJ, 811, 77
[2]Kelsall et al. 1998, ApJ, 508, 44
[3]Nesvorný et al. 2010, ApJ, 713, 816
[4]Hauser et al. 1998, ApJ, 508, 25
[5]Poppe et al. 2016, Icarus, 264, 369

Propagation of symmetric and anti-symmetric surface waves in a self-gravitating magnetized dusty space plasma layer

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The dispersion properties of surface dust ion-acoustic waves in a self-gravitating magnetized dusty space plasma layer with the (r, q) distribution is investigated. The result shows that the wave frequency of the symmetric mode in the plasma layer decreases with an increase of the wave number. It is also shown that the wave frequency of the symmetric mode decreases with an increase of the spectral index r. However, the wave frequency of the anti-symmetric mode increases with an increase of the wave number. It is also found that the anti-symmetric mode wave frequency increases with an increase of the spectral index r. In addition, it is found that the influence of the self-gravitation on the symmetric mode wave frequency decreases with increasing scaled Jeans frequency. Moreover, it is found that the wave frequency of the symmetric mode increases with an increase of the dust charge, however, the anti-symmetric mode shows the opposite behavior.

Effect of dust structure on scattered light images of protoplanetary disks

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We study how dust structure affects observational appearance of protoplanetary disks from infrared to millimeter wavelengths. First of all, we show that, at near-infrared wavelength, a disk with porous dust aggregates can show gray or slightly blue scattered light color in both total intensity and polarized intensity at near infrared wavelengths. In addition, by using the modified mean field theory (Tazaki & Tanaka 2018), we find that the effective albedo of large dust aggregates with fractal dimension of 2 show gray for less absorbing composition or slightly blue for absorbing composition, even if the radius is increased up to millimeter size. On the other hand, large dust aggregates with fractal dimension of 3 show reddish color in the effective albedo. Our results indicate that the presence of fluffy dust aggregates is not likely to be a primary solution to the color and brightness problem of scattered light images.

Next, we also study the importance of dust structure on (sub-)millimeter wave polarization due to scattering. We find that millimeter-wave polarization due to scattering is more likely to be detected when dust aggregates have compact structure rather than fluffy structure. Hence, a detection of millimeter-wave polarization due to scattering might require a mechanism for producing less porous particles at the disk regions where the polarization is detected.