High redshift starburst galaxies revealed by SPT, ALMA, and gravitational lensing

Joaquin D. Vieira[1]

[1]*California Institute of Technology, Pasadena, CA, USA*

The South Pole Telescope (SPT) has systematically identified a large number of high-redshift strongly gravitationally lensed starburst galaxies in a 2500 square degree cosmological survey of the millimeter (mm) sky. These sources are selected by their extreme mm flux, which is largely independent of redshift and lensing configuration. The flux magnification provided by the gravitational lensing enabled us to perform a spectroscopic redshift survey with the recently commissioned Atacama Large Millimeter Array (ALMA). We targeted 26 SPT sources and obtained redshifts via molecular carbon monoxide (CO) lines. We determine that roughly 40% of these sources lie at z>4, indicating the fraction of dusty starburst galaxies at high-redshift is far higher than previously thought. Two sources are at z=5.7, placing them among the highest redshift starbursts known, and demonstrating that large reservoirs of molecular gas and dust can be present in massive galaxies near the end of the epoch of cosmic reionization. These sources were additionally targeted with high resolution imaging with ALMA, unambiguously demonstrating them to be strongly gravitationally lensed by foreground structure. We are undertaking a comprehensive and systematic followup campaign to use these ``cosmic magnifying glasses'' to study the infrared background in unprecedented detail, inform the condition of the interstellar medium in starburst galaxies at high redshift, and place limits on dark matter substructure. I will discuss the scientific context and potential for these strongly lensed starburst galaxies, give an overview of our team's extensive followup efforts, and describe our latest science results.

Cosmic Dust in the Early Universe

Aigen Li

Department of Physics and Astronomy, University of Missouri, Columbia, MO 65211, USA

Dust is a ubiquitous feature of almost all high-redshifted objects. The unexplained dust spectral phenomena such as the 217.5 nm extinction bump, the diffuse interstellar bands, and the unidentified infrared emission features seen in the Galactic interstellar medium are also seen in the early universe, including high-redshifted damped Lyman alpha absorbers, gamma-ray burst host galaxies , and quasar intervening systems. I will review the observations and their constraints on the nature of the dust in the early universe and discuss whether the dust properties evolve with redshifts.

DUST EVOLUTION AND POPULATION III-II TRANSITION IN YOUNG GALAXIES

Daisuke Yamasawa[1,2], Asao Habe[2], Kazuyuki Omukai[1,3], Takashi Kozasa[2], Takaya Nozawa[4], Hiroyuki Hirashita[5]

[1]*Astronomical Institute, Tohoku University, Japan,* [2]*Hokkaido University, Japan,* [3]*Kyoto University, Japan,* [4]*Kavli Institute for the Physics and Mathematics of the Universe (WPI), Todai Institutes for Advanced Study, University of Tokyo, Japan,* [5]*Institute of Astronomy and Astrophysics, Academia Sinica, Taiwan*

Dust grains are essential for a transition from the massive, first stars (Population III stars, $\sim$ a few $\times 10\ M_{\odot}$) to the low-mass, normal stars (Population I/II, $\sim 0.1-1.0\ M_{\odot}$), since the dust grains cool the star-forming gas and cause the low-mass fragmentaion resulting in low-mass star formation. We couple the evolution of mass and size distribution of dust grains with an analytic model of galaxy formation and evolution and investigate the Population III - Population I/II transition. In our model, we construct merger trees to follow the hierarchical structure formation of dark matter halos and take into account the suppression of star formation by the Lyman-Werner background and the photoionization heating.

We find that the Population III stars can form in the massive galaxies with virial temperatures $T_{\rm vir} \geq 2.2 \times 10^4$ K even in the redshift $z \leq 6$ and these Population III galaxies consist of progenitors hosting only the Population III star formations. We conclude that since the Population III galaxies are not enriched by dust from asymptotic giant branch stars, the Population III-II transition due to dust cooling can be well described by the critical metallicity.

The Infrared Excess-UV spectral Slope Relation of Galaxies at $0 < z < 3$

Tsutomu T. TAKEUCHI[1], Atsuko T. KAWAKITA[1], Katarzyna MAŁEK[1], Tomoko L. SUZUKI[1], Akio K. INOUE[2], Véronique BUAT, Denis BURGARELLA[3], Stefan NOLL[4],

[1]Nagoya University, Japan, [2]Osaka Sangyo University, Japan, [3]LAM, OAMP, France, [4]Universität Innsbruck, Austria

In the studies of galaxy evolution, the genuine galaxy spectrum without attenuation is often needed, and the evolution of the attenuation curve is also fundamental for the investigation for the evolution of dust in galaxies.

In this study, we aim at exploring the attenuation curve in galaxies at redshifts of z ~ 1-3 by the new deep galaxy survey data from MUSYC and GOODS-Herschel projects. This time, we show one of the important aspects of dust attenuation, the infrared-excess-ultraviolet slope (IRX-β) relation as an early result. This relation plays a vital role in evaluating the dust attenuation of distant galaxies whose infrared (IR) emission is generally difficult to measure, since IR observation is not required to estimate the attenuation by this method. However, various studies showed that the IRX-β relation has a large variety depending on the properties of galaxies, e.g., ultraviolet (UV) selected or IR selected, star-forming or quiescent, etc. Especially, when we are interested in the evolution of galaxies, first we must clarify the evolution of the IRX-β relation.

We present the evolution of the global IRX-beta relation. We found that the relation has a very large scatter at all redshifts. We also found that the average relation show little evolution with redshifts. Then we show its dependence on various physical properties, like star formation rate, FUV and FIR luminosities, and stellar mass, etc., with the aid of spectral energy distribution (SED) fitting with a code CIGALE.

AKARI observations of interstellar dust grains in our Galaxy and nearby galaxies

Hidehiro Kaneda[1], Daisuke Ishihara[1], Toru Kondo[1], Mitsuyoshi Yamagishi[1], Akiko Yasuda[1], Yasuki Hattori[1], Shinki Oyabu[1], Rika Yamada[1], Takashi Onaka[2], Itsuki Sakon[2], and Toyoaki Suzuki[3]

[1]Nagoya University, Japan, [2]University of Tokyo, Japan, [3]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Japan

In star-forming regions, dust and polycyclic aromatic hydrocarbons (PAHs) absorb a significant fraction of stellar ultraviolet photons and re-radiate them in the infrared (IR). Hence the IR luminosities due to dust and PAH emission are both powerful tools to trace star-forming activities in galaxies. Beyond such star-formation tracers, however, spectral information on dust and PAH emission would have much deeper physical implications for understanding the properties of the ISM. With AKARI, the first Japanese infrared astronomical satellite launched in 2006, we have performed a systematic study of interstellar dust grains in various environments of galaxies including our Galaxy. Because of its unique capabilities, such as near- and far-IR spectroscopy combined with all-sky coverage in the mid- and far-IR, AKARI has provided new knowledge on the processing of dust, particularly carbonaceous grains including PAHs, in the interstellar space.

For example, we find that copious amounts of large grains and PAHs are flowing out of starburst galaxies by galactic superwinds, which are being shattered and destroyed in galactic haloes. With near-IR spectroscopy, we detect notably strong aliphatic emission relative to aromatic emission in the halo of M82, indicating structural changes of hydrocarbon grains. We also detect strong aliphatic emission from the inner bar of NGC 1097, which indicates that the gas and dust in the bar are in a turbulent motion, likely fueling the central AGN from the starburst ring. From early-type galaxies, we detect PAHs which show spectral features with unusual inter-band ratios and spatial distributions more centrally-concentrated than large grains, again demonstrating importance of material processing in the interstellar space.

AKARI is capable of far-IR spectral mapping with the imaging FTS. For some spectra obtained near the Galactic center, we find that there is a significant excess on top of the modified blackbody continuum around 110−130 μm. We find that a dust model including large graphite grains can at least reproduce the observed spectrum with the excess emission fairly well. The detection of the excess feature from this region might be related to the (past) activity of the Galactic center, because thermal annealing with very high temperatures is needed to graphitize carbonaceous grains. This result may also be related to the abundant PAHs at the centers of early-type galaxies, because many early-type galaxies are known to possess galactic nuclei with declining or ceased activity like our Galaxy.

In this talk, we review the results obtained from our AKARI observations on the processing of interstellar dust grains in various harsh environments of our Galaxy and nearby galaxies, together with our future prospect for this topic with SPICA, which is scheduled to be launched in the early 2020’s.

Infrared Observations of Methanol Ice in the Large Magellanic Cloud

Takashi Shimonishi[1], Emmanuel Dartois[2], Francois Boulanger[2], Takashi Onaka[3], Yuri Aikawa[1]

[1]*Kobe University, Japan,* [2] *Institut d'Astrophysique Spatiale, France,* [3]*The University of Tokyo, Japan*

Star-/planet-formation activities can occur in various kinds of galaxies, which differ in many ways such as size, shape, and environment. Thus it is important to understand how galactic characteristics affect the properties of materials around young stellar objects (YSOs). Observations of ices and dust around extragalactic YSOs are important to understand which environment parameters are relevant to chemistry of solids in circumstellar environment. Since circumstellar materials are closely related to the interstellar medium (ISM), it is highly probable that different galactic environments (e.g., metallicity , radiation field) could affect the properties of circumstellar materials around YSOs.

The Large Magellanic Cloud (LMC) is the nearest extragalaxy to the our Galaxy and known as a low-metallicity galaxy (one-third of solar neighborhood). We have been conducting an observational study of YSOs in the LMC to understand the effect of its unique galactic environment on the properties of ices and dust around YSOs.

In this presentation, we will report the results of ground-based infrared observations of methanol ice bands toward eight embedded YSOs in the LMC with VLT/ISAAC. Methanol is an important ice mantles component and a starting point for the formation of more complex carbonaceous molecules. As a result of the observations, we could set a strong upper limit on the methanol ice abundance toward LMC's YSOs for the first time. We will discuss the effect of galactic environment on the grain surface chemistry based on the above observational results and a numerical simulation model relevant to ice chemistry.

Evolution of the extinction curves in galaxies

R. S. Asano[1] , T. T. Takeuchi[1] , H. Hirashita[2] , and T. Nozawa[3]

[1] *Nagoya University*

[2] *Academia Sinica Institute for Astronomy and Astrophysics*

[3] *Kavli IPMU*

Dust grains absorb or scatter the stellar light (called extinction), in particular, shorter wavelength like ultraviolet and re-emit the thermal emission as far-infrared. Thus, the understanding of dust grains is necessary for getting the information of galaxies from observation accurately. Also, the effect of extinction depends strongly on the size distribution, amount, and species of grains. We construct an evolution model of the extinction curves based on the theoretical model for the evolution of grain size distribution we constructed before and investigate the evolution of the extinction curves in galaxies.

In the first stage of the galaxy evolution, supernovae mainly produce dust grains. Since these dust grains are relatively large, the extinction curves become flat. As the galaxy evolution proceeds, since the effect of shattering becomes large, the number of small grains (< 0.01 μ m) increases. Further, the small grains grow due to the metal accretion onto the grains. Consequently, the number of dust grains with the radius of ~ 0.01 μ m becomes large, the extinction curves become steep. And, we found that the bump of 2175Å becomes large at the same time.

After the coagulation becomes effective, the extinction curves become flatter and approaches the extinction curve of the Milky Way. However, compared with the extinction curve of the Milky Way, the predicted extinction at wavelength 0.1 μ m is larger.

There are three solutions of the problem as follows: (1) neglect the effect of the metal accretion, (2) neglect the shattering of silicate dust (3) introduction of larger contribution of coagulation. Among the three solutions, since the evolution of dust mass cannot be explained in the solutions of (1) and (2), (3) looks the most plausible solution, i.e., the effect of coagulation may be larger than we have considered that of coagulation.

Environment of different types of dusty galaxies

Agnieszka Pollo [1,2], Tsutomu T. Takeuchi[3], Katarzyna Małek[3], Aleksandra Solarz[3], Agata Pepiak[1] et al.

[1]Jagiellonian University, Poland, [2]National Centre for Nuclear Research, Poland [3]Nagoya University, Japan

It is already well established that environmental effects and intergalactic interactions can play an important role in starting star formation processes in galaxies, which is reflected in the properties of dust emission of these galaxies. We plan to show our results on studies of local environments of different types of dusty galaxies - including (Ultra) Luminous Infra-Red Galaxies (so-called ULIRGs) - found in the AKARI data, in particular in its two deep surveys: ADF-S and NEP. We plan to discuss how different environment may determine different properties of dust in these galaxies.

(Ultra)Luminous Infra-Red Galaxies in the AKARI deep fields

Katarzyna Małek

Department of Physics and Astrophysics, Nagoya University, Furo-cho, Chikusa-ku,
Nagoya, 464-8620, Japan

I would like to present the results of the analysis of *Ultra* Luminous Galaxies (*U*LIRGs) found in the AKARI Deep Field-South and AKARI North Ecliptic Pole Surveys. AKARI, as a far-infrared satellite, allows for detailed study of the dust properties of the extragalactic sources. Both ULIRGs and LIRGs are characterized by very high IR luminosity ($L_{TIR}>10^{11}$ Lsun, and $L_{TIR}>10_{12}$ Lsun for LIRGs and ULIRGs, respectively), related to the dust properties. Far-infrared data in connection with optical and UV measurements enable us to fit Spectral Energy Distribution (SED) models and investigate physical properties of *U*LIRGs and normal galaxies detected by AKARI. I will discuss the properties of a *U*LIRGs sample found in both AKARI fields, and average SEDs reflecting global properties of analyzed galaxies.

Searching for Debris Disks around Isolated Neutron Stars

Zhongxiang Wang[1]

[1]*Shanghai Astronomical Observatory, Chinese Academy of Sciences, China*

I will review the current status of searches for debris disks around isolated neutron stars. Such disks could have formed from supernova fallback and their existence have been proposed to explain a few observed properties of neutron stars. Mid-infrared counterparts to two magnetars, 4U 0142+61 and 1E 2259+586, have been detected, and the broad-band spectrum of the first source, which is relatively well determined, can be described by emission from an X-ray heated dust disk. Deep infrared searches, including Spitzer observations, for similar emission around a few neutron stars of different types have been conducted, while with no detections thus far. Using recently released WISE all-sky survey data, we are working on searches for mid-infrared counterparts to all known pulsars. The results will also be presented.

Mid-term change of dust formation activity of AGB stars

Takafumi Kamizuka[1], Takashi Miyata[1], Shigeyuki Sako[1], Kentaro Asano[1], Mizuho Uchiyama[1], Kazushi Okada[1], Tomohiko Nakamura[2]

[1]*Institute of Astronomy, the University of Tokyo, Japan,*
[2]*Department of Astronomy, the University of Tokyo, Japan*

Asymptotic Giant Branch (AGB) stars are one of the birth places of interstellar dust grains. The pulsation of AGB stars levitates stellar materials to the outer region. Dust grains will be formed from the levitated materials when they are sufficiently distant from the star. This cycle repeats on a timescale of a few years (~ pulsation timescale). Therefore, AGB stars can show a mid-infrared variability caused by the dust formation in a timescale relatively easy to observe, and they are useful to investigate real-time dust formation process.

However, such variability is often difficult to observe because of the contamination of the emission from the outer dust shell formed by a series of previous dust formation. To observe the sign of dust formation, the objects which recently activate dust formation and do not have a thick outer dust shell are suitable. Mid-term (100-yr scale) change of dust formation activity is suggested by some works (Mauron & Huggins 1999; Marengo et al. 2001), and it is possibly detected as a mid-infrared color change between IRAS and AKARI all-sky survey data, taken in a ~20 yr interval. In order to find such objects, we examined the IRAS and AKARI data and observed some objects to confirm their mid-infrared spectral change with our mid-infrared instrument MAX38 on miniTAO telescope in Chile.

The targets were selected from the Mira- and Semi-Regular-type variable stars listed on General Catalog of Variable Stars (GCVS) with high-quality photometric data of IRAS and AKARI, and mid-infrared spectra of Low Resolution Spectrometer (LRS) on IRAS. In addition, the objects with feature-less LRS spectra (class1n objects) were chosen because they are easy to judge the emergence of dust emission from recently formed dust. Their mid-infrared color was examined with the IRAS and AKARI data. So far 10 objects with a large mid-infrared color change, which indicates possible emergence of dust emission, were selected and observed with N-band imaging mode of MAX38. As a result, three objects showed clear spectroscopic change from the LRS spectrum. Especially, T Col showed clear emergence of dust feature.

T Col is a Mira variable star in a distance of 0.66 kpc (Whitelock et al. 2008). Its LRS spectrum does not show any dust feature. On the other hand, a 10-micron feature was clearly detected by our observation. It can be reproduced with emission bands of hot silicate and alumina dust. Its strength is about 10 Jy at 10-micron. The total mass of the silicate dust responsible for the emission is estimated at 7×10^{-10} solar-mass based on the feature strength and the distance. This amount of dust can be formed in a few decades with a usual mass-loss rate of AGB star. Therefore, T Col may have activated its dust formation in the last few decades and can be an interesting monitoring target.

In the workshop, these results and additional observation programmed in June will be reported.

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FIR Observations of the Host Galaxy of GRB 110422A with *Herschel*

Maohai Huang[1], Bing Zhang[2], Jinsong Deng[1], Dong Xu[3], Yulei Qiu[1], Liping Xin[1]

[1]*NAOC, China,* [2]*University of Nevada Las Vegas, USA,* [3]*DCC/NBI, University of Copenhagen, Denmark*

The *Herschel* far infrared (FIR) space observatory was designed to study the cold universe by observing continuum emission from dust below $\sim 50K$ in the local universe, and from relatively warmer dust at higher redshift up to $z \sim 4$. Although the in-orbit operations of *Herschel* has ended, the exploitation of *Herschel*'s legacy data has but just started. I give a brief report of our observations of the Gamma-ray burst (GRB) 110422A at $z \sim 1.77$ with the PACS and SPIRE instruments on-board *Herschel*, a first time in the 60 μm - 600 μm FIR wavelength range. The host galaxy of the GRB is identified in *Herschel* images. Fitting the FIR SED we derive dust temperature, dust mass, and gain insight of other properties of the host galaxy.

Non-Steady State Formation of Dust Grains in the Ejecta of Type Ia Supernovae

Takaya Nozawa[1], Takashi Kozasa[2], Keiichi Maeda[1], and Ken'ichi Nomoto[1]

[1]Kavli IPMU, Japan, [2]Hokkaido University, Japan

Dust formation in supernovae is one of the most important issues for disclosing the inventory of interstellar dust in the early universe as well as in our Galaxy. Recent infrared to sub-millimeter observations have reported the presence of sub-solar mass of cool dust formed in the ejecta of SN 1987A, Cas A, and Crab, which are known as remnants of core-collapse supernovae. On the other hand, there has been no convincing evidence for dust formation in normal Type Ia supernovae that are likely to be thermonuclear explosions of white dwarfs. This indicates that the formation process of dust in the ejecta depends on the explosion mechanisms of supernovae.

Formation process of dust in the ejecta of supernovae has been studied mainly with the classical nucleation theory and its extension. In the nucleation theory, the condensation of dust is described by the formation of stable seed nuclei (critical clusters) and their growth, where the formation rate of critical clusters is derived by assuming the nucleation current to be in a steady state. However, it has been argued that the classical nucleation theory could not be applicable in the rarefied gas typical of dust-forming region of astrophysical interest, although the effect of a non-steady state on the formation process of dust has not been fully explored.

In this paper, we develop a method of calculations that manage dust formation processes without postulating a steady state, and compare the results of the calculations with those obtained with the steady state nucleation rate. We show that the steady state nucleation rate is a good approximation in the situation where the timescale of supersaturation is much longer than the timescale of gas collisions, and that this condition is met for the ejecta of core-collapse supernovae. We also illustrate that the average grain radii and condensation efficiency are uniquely determined by the ratio of the supersaturation timescale to the collision timescale of the gas at condensation.

Then, applying the non-steady dust formation formulae, we investigate the possibility of dust formation in the ejecta of Type Ia supernovae, for which the effect of a non-steady state is expected to be remarkable because of a much lower ejecta density than that in core-collapse supernovae. We show that the average radii of dust grains formed in Type Ia are significantly small but their mass is still a similar order to those in core-collapse supernovae. We discuss the inconsistency between the calculated and observed masses of newly formed grains in Type Ia, as well as the roles of Type Ia supernovae as sources of interstellar dust.

Interstellar dust Modelling from a New Vantage Point

Ant Jones

Institut d'Astrophysique Spatiale, CNRS and Université Paris Sud, Orsay F-91405, France

The evolution of amorphous hydrocarbon materials, a-C(:H), principally resulting from UV photon absorption-induced processing, are likely at the heart of the variations in the observed properties of dust in the interstellar medium. The key aspects of their evolution are the size-dependence of their properties and the compositional variations in a-C(:H), from aliphatic-rich a-C:H to aromatic-rich a-C. This will be presented within the context of the observed variations in interstellar dust extinction and emission. The optical properties of a wide range of a-C(:H) materials were recently derived (Jones, 2012, A&A, 540; A1, 540, A2 and 542, A98) and these, combined with that for an amorphous forsterite-type silicate with iron nano-particle inclusions, a-$\mathrm{Sil_{Fe}}$, are used to explore dust evolution in the interstellar medium.

A new dust model is presented (Jones *et al.* 2013, A&A, submitted), which consists of a power-law distribution of small a-C grains and log-normal distributions of large, a-SilFe and a-C(:H) grains. This dust model contains no 'interstellar' PAHs, astronomical silicate, graphite or any of the usual MRN-type power law dust size distributions. The model, which is firmly anchored by laboratory-data, is shown to quite naturally explain the variations in the IR-FUV extinction, the 217 nm UV bump, the IR absorption and emission bands and the IR-mm dust emission. The model is additionally able to explain efficient H_2 formation in photo-dominated regions (PDRs), even up to moderately high radiation field intensities where the dust is rather warm, $T_{\rm dust} > 25\,$K (Jones, Habart *et al.*, in preparation).

The major strengths of the new model are its inherent simplicity and built-in capacity to follow dust evolution in interstellar media. Further, it is shown that mantle accretion in the diffuse ISM and molecular clouds has many interesting consequences (Jones 2013, A&A, submitted) and that UV photo-processing in PDRs are likely the major drivers of dust evolution.

Are the carriers of the UIR bands aromatic or aliphatic? Gas phase infrared spectroscopy of polycyclic aromatic hydrocarbons (PAHs) and of their monomethyl derivatives

X.J. Yang[1,2], R. Glaser[2], Aigen Li[2], J.X. Zhong[1]

[1]*Xiangtan University, China* [2]*University of Missouri-Columbia, USA*

The unidentified infrared emission (UIE) features at 3.3, 6.2, 7.7, 8.6, and 11.3 μm are commonly attributed to polycyclic aromatic hydrocarbons (PAHs). Recently, however, Kwok & Zhang (Nature 2011, 479, 80) have ascribed these features to mixed aromatic–aliphatic organic nanoparticles (MAONs). Li and Draine (ApJL 2012, 760, L35) estimated the aliphatic fraction of the UIE carriers to be <15% based on the observed intensities of the 3.4 μm and 3.3 μm emission features by attributing them to aliphatic and aliphatic C–H stretching modes, respectively. This estimate assumed $A_{3.4}/A_{3.3} \approx 0.68$ based on a small set of aliphatic and aromatic compounds.

Here, we report the results of theoretical studies of the ratio $A_{3.4}/A_{3.3}$ to improve the estimate of the aliphatic fraction. We studied benzene, napththalene, anthracene, phenanthrene, pyrene, perylene, and coronene, and all isomers of their monomethyl derivatives with density functional theory (DFT) and second-order perturbation theory (MP2) and with various basis sets from 6-31G* to 6-311++G(3df,3dp). Direct comparisons are made to gas phase quantitative infrared spectra whenever possible. The theoretical level dependencies are discussed of the computed IR intensities, and especially of the ratio $A_{3.4}/A_{3.3}$, and methods for intensity scaling are described. The study suggests that the $A_{3.4}/A_{3.3}$ ratio is well over 1.5 and, hence, it is concluded that the UIE emitters are predominantly aromatic (>95%).

Silicate nanometric dust production and characterization and its use as interstellar grain analogs to simulate the formation of H_2

T. Sabri[2], L. Gavilan[1], J.L. Lemaire[1], C. Jäger[2], G. Vidali[3,1]

[1]*Observatoire de Paris/Université de Cergy-Pontoise, 5 mail Gay Lussac, 95000 Cergy-Pontoise, France*

[2]*Laboratory Astrophysics Group, Friedrich Schiller University, 07743 Jena, Germany*

[3]*Syracuse University, Syracuse, NY 13244-1130, USA*

Silicate grains as an important fraction of dust in the general diffuse interstellar medium (ISM) are of great interest to astrophysicists. Silicate surfaces allow the recombination of the most abundant molecule, H_2, which drives further chemical complexity. Their properties depend on their location and lifetime in the ISM, where they can be irradiated by energetic photons and ions.

Nanometre-sized silicate samples (forsterite and fayalite, Mg_2- or Fe_2- SiO4 end-members of the olivine family) are prepared (with both amorphous and micro-crystalline structure) in the laboratory via laser ablation.

These silicates are carefully characterized using high-resolution transmission electron microscopy (HRTEM), energy-dispersive X-ray spectroscopy (EDX), scanning electron microscopy (SEM) and atomic force microscopy (AFM), building a bridge to the morphology, structure, and chemical composition of dust, just condensed and subsequently processed [1].

They are then used as surface catalysts in molecular hydrogen formation experiments within the FORMOLISM setup. The aim is to explore the direct effect of these different dust species on H_2 formation and the ensuing formation energy partition. In addition to a summary of previous results [2-8], we will present (in a joint poster) preliminary results on H_2 formation on such silicates and the dependence on temperature, possible nuclear spin conversion effects, and rotationally "hot H_2".

Such a study provides a major link to astronomical observations as a tool for identification of cosmic dust properties.

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Condensation of Silicon Monoxide at Cryogenic Temperatures

Gaël Rouillé[1], Serge A. Krasnokutski[2], Karsten Potrick[1], Cornelia Jäger[1], Friedrich Huisken[1], and Thomas Henning[1]

[1]*Max Planck Institute for Astronomy, Germany,* [2]*Friedrich Schiller University, Jena, Germany*

We have recently started the experimental study of silicate condensation at very low temperature. This project is motivated by two facts. First, silicates are the main components of cosmic dust. Second, the estimated amount of silicate dust formed at high temperature in stellar environments, considering the lifetime of the grains, cannot account for the comparatively large quantity of silicate dust that is osberved in the interstellar medium (ISM). Thus the formation and growth of silicate grains must occur in the ISM, more specifically in dense clouds where temperatures in the range 10–50 K prevail.

As the first stage of our project, we have studied the condensation of SiO molecules, which we can reasonably expect to be among the main building blocks of interstellar silicates.

A first set of experiments has been carried out at 0.37 K in superfluid He droplets with a technique that makes use of mass spectrometry. After seeding the droplets with two to four SiO molecules, the formation of $(\mathrm{SiO})_x$ ($x = 2$–4) clusters has been observed despite the extremely low temperature. Hence it is concluded that there is no energy barrier that could prevent the condensation of SiO molecules at the temperatures found in the ISM.

In a second set of experiments, we have deposited SiO molecules in Ne matrices at 6 K, using UV absorption spectroscopy to monitor the process. After annealing of the matrices at 10–12 K and after their evaporation, we have found that white grains had been formed. Images obtained by transmission electron microscopy show that the grains are fluffy, amorphous, and $\sim$10 nm to $\sim$10 μm in size. Chemical analysis by energy-dispersive X-ray spectroscopy gives SiO as their formula. Thus SiO grains can be formed at low temperature and can survive to room temperature.

These experiments and their results will be presented in detail before introducing the latest progresses of this ongoing project.

Nucleation Experiments of Iron Dust under Microgravity

Yuki Kimura[1], Yuko Inatomi[2], Shinsuke Takeuchi[2], Katsuo Tsukamoto[1], and Kyoko K. Tanaka[3]

[1] Tohoku University, Japan, [2] Institute of Space and Astronautical Science, Japan, [3] Hokkaido University, Japan

Cosmic dust forms from a super cooled vapor in an ejecta gas from a dying star. The condensation sequence, number density and size of the cosmic dust can be expected using nucleation theories. Then, the undetermined physical parameters of materials with the same size range of cosmic dust (100 nm or less) have prevented explanation of formation process of cosmic dust based on nucleation theories. Recently, we constructed an experimental system using interferometry, which can be determined temperature and concentration simultaneously at nucleation site in vapor phase. Using the new system, we succeeded to determine surface free energy and sticking probability of nanoparticle from timescale for gas cooling, condensation temperature and resulting particle size based on nucleation theories **[**Kimura et al. *Crystal Growth & Design* **12** (2012) 3278**]**. To understand a formation process of cosmic iron dust more precisely, in addition to ground based experiment, we performed a microgravity experiment using a specially designed double wavelength Mach–Zehnder-type interferometers with an evaporation chamber and a camera recording system installed into the sounding rocket S-520-28.

The working chamber was a stainless-steel cylinder with an internal diameter of 6.5 cm and a length of 15 cm, containing three viewports for optical observation and temperature measurement of the evaporation source by pyrometer, two ports for thermocouple, which measure a temperature at the end of the evaporation source, and electrodes. The cylinder was evacuated through a valve by a combination of a turbo-molecular pump (50 L/s) and a scroll type dry vacuum pump. Because the refractive index of the argon buffer gas (>99.9999% purity) used in producing the iron nanoparticles is very low [$(n - 1)Ar = 5.266 \times 10^{-5} \pm 0.016 \times 10^{-5}$ at 632.8 nm and 293.15 K for 2.0 $\times 10^4$ Pa], the evaporation source was prepared certainly parallel to the evaporation source and as long as possible to increase the column density, which is advantageous for the detection of tiny changes in the refractive index. With this experimental setup, we could detect a difference in refractive index of less than 1×10^{-6}, which, for example, corresponds to the difference in temperature from 298 K to 301 K for Ar gas at 2×10^4 Pa.

The experiments were run sequentially and automatically started from 100 s after launch of the rocket. Iron vapor was evaporated by electrical heating of an evaporation source in an Ar gas atmosphere of 2.0×10^4 Pa or 4.0×10^4 Pa. Evaporated iron vapor was diffused, cooled and condensed in the gas atmosphere. The temperature and concentration at the nucleation site are determined from the changing of the refractive index, which is obtained from a movement of the fringes in the interferogram. Here, we will show the first results of the microgravity experiment and ground-based experiments for comparison.

Cosmic dust through X-ray eyes: a laboratory and space study

Julia C. Lee

[1]*Department of Astronomy and Harvard-Smithsonian Center for Astrophysics, 60 Garden Street MS-6, Cambridge MA 02138 USA*

Direct measurements of dust in astrophysical environments have traditionally relied on infrared and radio spectral studies of rotational and vibrational spectra. (Optical studies also provide much information, but based on depletion measurements, the dust detections are *in*-direct.) With its ability to penetrate through atoms, X-rays enable a powerful direct probe of both gas *and* ($\lesssim 10\mu$m) dust over orders of magnitude absorption and temperatures, to provide complementary knowledge to the wealth of existing information. I will discuss how the combination of experimental programs at synchrotron beam-lines and high spectral resolution X-ray studies of compact objects (e.g. black holes and neutron stars) can be used as a powerful new tool for revealing information about cosmic dust properties, including the element-specific gas-to-dust ratio in addition to its composition and structure. I will discuss how these studies together with physiochemical modeling can be used to track the environment in which the dust was formed, and our plans for a publicly available database of standards.

Sulfur in Dust

Ulysses J. Sofia[1] and Margaret While[1,2]

[1]*American University, USA,* [2]*Lovett School, USA*

Seven elements have the potential to be the dominant constituents of interstellar dust: C, N, O, Mg, Si, Fe and S. These are the non-noble gases with cosmic abundances greater than 10^{-5} that of hydrogen (the next most abundant element, Al, has less than 14% the abundance of S). Studies have, in fact, shown that C, O, Mg, Si and Fe are dominant elements in dust by number and by mass (Jenkins 2009). N is not a major constituent of dust, but this is explained by its inclusion in the highly stable gas form of N_2 (Gail & Sedlmayr 1986). Of the principal dust-composition candidates, only the role of sulfur remains enigmatic.

Interstellar grains, identified by their isotopic compositions, recovered from within interplanetary dust particles (IDPs) embedded in meteorites, show that S is often incorporated into interstellar silicates (Bradley 1994, Bradley & Ireland 1996, Bradley et al. 1999). In fact, these grains, GEMS (glass with embedded metals and sulfides), have sulfur-to-silicon ratios that are 60 - 80% of the solar value (Bradley 1994). Further support for the interstellar origin of GEMS comes from the identification of their infrared spectral characteristics that match what is seen in interstellar environments (Bradley et al. 1999). The combined evidence makes a strong case for GEMS, and therefore sulfur, being a major component of the interstellar grain population.

It is therefore surprising that the best measurements of interstellar abundances, those determined from high-resolution *HST* observations, suggest that sulfur is not depleted into interstellar grains (Spitzer & Fitzpatrick 1993, 1995; Sofia, Cardelli & Savage 1994; Fitzpatrick & Spitzer 1994; Savage & Sembach 1996; Howk et al. 1999; Welty et al. 1999). It is only very recently (Jenkins 2009; White & Sofia 2011) that there has been a suggestion, based on high-quality interstellar abundance measurements, that there may be large S depletions along some sight lines. Martin (1995) summarizes the importance of determining whether sulfur-bearing grains are in the interstellar medium: "Understanding GEMS would then hold promise of fresh insight into diverse problems concerning interstellar grains, such as their origin and processing in the interstellar medium, differential depletion of the elements, grain alignment, the effective dielectric function of dirty silicates, and the infrared spectra of amorphous silicates."

This uncertainty of sulfur's incorporation into dust does not only affect the study of sulfur. It is so well accepted that S is undepleted in the gas-phase ISM that authors are using sulfur as a proxy for H when they are deriving depletions for other elements. This is such a potential problem that Jenkins (2009) says about sulfur: "A study of the depletion behavior of sulfur is especially important, since many studies of gas in both our Galaxy and very distant systems have relied on this element as a standard for what should be virtually zero depletion. We need to re-examine whether or not this is true." Jenkins (2009) further suggests that "We could certainly benefit from some future, far more comprehensive survey of sulfur abundances."

We present our initial results for S depletions in the neutral ISM based on all of the available HST sight lines (40 total) with appropriate observations. Our results show that S is an important dust component. As such, it has implications for extinction models and for abundance studies (Galactic and extragalactic) that rely on S as a proxy for H when determining dust compositions.

X-ray absorption spectroscopy and scattering of interstellar dust

Randall K. Smith[1], Eli Dwek[2], and Lynne Valencic[2,3]

[1]*Smithsonian Astrophysical Observatory, USA,* [2]*NASA Goddard Space Flight Center, USA,* [3]*Johns Hopkins University, USA*

Interstellar (IS) dust grains are an integral part of IS evolution in galaxies, but to date our knowledge of their properties primarily derives from observations of the UV/optical extinction, infrared emission, and polarization from grains. We can also learn about grains by studying the X-ray halos seen around absorbed X-ray sources in combination with studies of the line of sight X-ray absorption by these grains. Small-angle X-ray scattering creates halos that arcminutes in scale via the coherent interactions of all of the electrons in the grains. As a result, X-ray halos are strongly affected by the size distribution of the grains, and to a lesser extent their position, composition (including porosity), and shape. I will describe how X-ray observations with Chandra and XMM-Newton have been used to survey Galactic X-ray halos and, with the gratings, to observe their composition directly in order to answer the many outstanding questions about IS dust grains, such as the total grain mass, density, and composition. Combining this X-ray halo data with the other UV, optical, and IR observations have allowed us to place tight constraints on all dust models. By analyzing data from many lines of sight, we have characterized both the mean X-ray halo and the variation. This will include sightlines through dense clouds where UV/optical extinction cannot be measured, and in-depth studies towards lightly absorbed sources where absorption lines can be used to characterize the sightline. With the upcoming launch of Astro-H, we expect an explosion in usable lines of sight for such work which should lead to a revolution in our understanding of IS dust grains.

The Mid-Infrared Extinction Law and its Variation in the Coalsack Nebula

Shu Wang[1,2], Jian Gao[1], B.W. Jiang[1], Aigen Li[2], Yang Chen[1]

[1]*Beijing Normal University, China,* [2]*University of Missouri-Columbia, USA*

In recent years the wavelength dependence of interstellar extinction from the ultraviolet (UV), optical, through the near- and mid-infrared (IR) has been studied extensively. Although it is well established that the UV/optical extinction law varies significantly among the different lines of sight, it is not clear how the IR extinction varies among various environments. A better understanding of the regional variation of the IR extinction law will allow a more accurate reddening correction of the photometric and spectroscopic measurements. This is also crucial for a complete description of the varying dust properties across the Milky Way.

To reveal whether and how the mid-IR extinction law relates to the interstellar environment, in this work we explore the possible variations of the mid-IR extinction within the Coalsack nebula, a nearby starless dark cloud. By using the color-excess method and taking red giants as tracers, we determine the interstellar extinction A_λ in the four *Spitzer*/IRAC bands in [3.6], [4.5], [5.8], [8.0] μm (relative to $A_{\rm K_S}$, the extinction in the *2MASS* $\rm K_S$ band) of the Coalsack nebula based on the data obtained from the *2MASS* and *Spitzer*/GLIMPSE surveys. We select five individual regions across the nebula that span a wide variety of physical conditions, ranging from diffuse, translucent to dense environments, as traced by the visual extinction, the *Spitzer*/MIPS 24 μm emission, and CO emission. We find that $A_\lambda/A_{\rm K_S}$, the mid-IR extinction relative to $A_{\rm K_S}$, decreases from diffuse to dense environments, which may be explained in terms of ineffective dust growth in dense regions. The mean extinction (relative to $A_{\rm K_S}$) is calculated for the four IRAC bands as well, which exhibits a flat mid-IR extinction law, consistent with previous determinations for other regions. The extinction in the IRAC 4.5 μm band is anomalously high, much higher than that of the other three IRAC bands. It cannot be explained in terms of the 4.27 μm absorption band of CO_2 ice and the 4.67 μm absorption band of CO ice. It may be caused by the 4.6 μm absorption feature of CO gas in the circumstellar envelopes of some red giants. The mid-IR extinction in the four IRAC bands have also been derived for four regions in the Coalsack Globule 2 which respectively exhibit strong ice absorption, moderate or weak ice absorption, and very weak or no ice absorption. The derived mid-IR extinction curves are all flat, with $A_\lambda/A_{\rm K_S}$ increasing with the decrease of the 3.1 μm H_2O ice absorption optical depth $\tau_{\rm ice}$.

Three players in the interstellar clouds: dust grains, known free radicals and diffuse band carriers

Jacek Krełowski

Centrum Astronomii Nicolaus Copernicus University
Toruń, Poland

Translucent interstellar clouds produce typically three kinds of absorptions: continuous extinction, identified bands of simple radicals (OH, OH^+, CH, CH^+, NH, CN, C_2 and C_3) and more than 400 unidentified diffuse interstellar bands. The latter are commonly believed to be carried by some complex molecular species but none of them was until now identified beyond a doubt.

Extinction is believed to be caused by interstellar dust particles of various sizes and shapes. The recent surveys of the extinction curves (extinction law) demonstrate a great variety of the observed curves which proves that grains are different if observed in different clouds. The applicability to a majority of object the average extinction curve follows the fact that a majority of distant OB stars is observed through several clouds and thus we observe usually an ill-defined average which does not differ substantially from one distant object to another.

The most popularly observed CH molecule does correlate with the colour excess (caused by grains) but it is a rather poor correlation. It is also interesting that CH and CH^+ may occupy completely different environments (of different radial velocities) and are thus likely being formed in different reactions, i.e. CH^+ is not a result of CH ionization. The abundance of CN molecule is completely uncorrelated with the colour excess. It is a very specific molecule: the strength ratios of the first observed CN band lines gave the first suggestion that the molecule is rotationally excited. Some 25 years later the source of excitation was indicated as cosmic background radiation.

It seems important that an exceptionally high abundance of CN is observed together with high far-UV extinction and very low intensity of diffuse interstellar bands. In fact interstellar molecules can be formed either in the gas phase or on grain surfaces. Small grains, responsible for the far-UV extinction, can efficietly catalyse molecule formation reaction – perhaps that of CN. However, the simple species, such as CN, can also be formed as a result of disruption of larger species, such as diffuse band carriers. It is difficult to guess which of these processes takes place in at least some of translucent interstellar clouds.

The shortest carbon chain molecules (centrosymmetric ones) are seemingly abundant in the same clouds in which CN is abundant. However, the observations of such species are scarce because their spectral bands contain many weak features and thus are not observed in many objects.

DIBs and UV Extinction Curve: The Missing Link

F.Y. Xiang[1,2], Aigen Li[1], & J.X. Zhong[1,2]

[1]*University of Missouri* [2]*Xiangtan University*

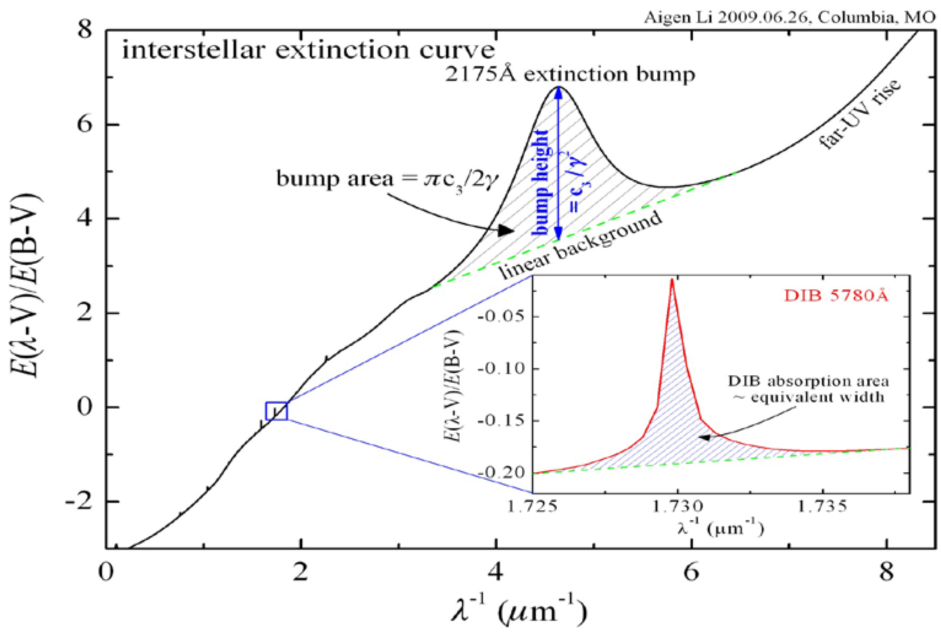
The diffuse interstellar bands (DIBs) are ubiquitous absorption spectral features arising from the interstellar medium (ISM). Since their first detection nine decades ago, over 600 DIBs have been observed in the visible and near-infrared wavelength range in both the Milky Way and external galaxies, both nearby and distant. However, the identity of the species responsible for these bands remains as one of the most enigmatic mysteries in astrophysics. An equally mysterious interstellar spectral signature is the 217.5 nm extinction bump, the strongest absorption feature observed in the ISM. Its carrier also remains unclear since its first detection nearly half a century ago.

We explore the possible relations between these two mysterious interstellar phenomena and try to place constraints on the properties of their enigmatic carriers. We also examine the relation between the far ultraviolet (far-UV) extinction and the DIBs: on one hand, they may be anti-correlated as the shielding of energetic photons by far-UV extinction would protect the DIB carriers from being photo-dissociated; on the other hand, they may be correlated *if* the DIB carriers result from the fragmentation of small grains responsible for the far-UV extinction. We also discuss the best way to characterize the far-UV extinction: the steepness of the far-UV extinction rise, the total amount of far-UV extinction, the far-UV color excess, or the total amount far-UV extinction integrated with inverse wavelength?

DIBs vs. 2175Å Extinction Bump and far-UV Extinction

Xiang, F.Y., Li, A., & Zhong, J.X. 2011, ApJ, 733, 91

Xiang, F.Y., Li, A., & Zhong, J.X. 2013, ApJ, To be submitted



Dust Growth in Star-Forming Regions and its Possible Impacts on Galaxy Evolution

Hiroyuki Hirashita[1], Kazuyuki Omukai[2], and Zhi-Yun Li[3]

[1]*ASIAA, Taiwan,* [2]*Tohoku University, Japan,* [3]*University of Virginia, USA*

Dust grains are considered to have large impacts on galaxy evolution. The effect important in the early evolutionary stage is dust cooling: With a sufficient amount of dust, dust cooling is able to induce fragmentation into subsolar mass cores. This means that dust cooling induce a transition from massive Pop III stars to low-mass Pop II stars [1, 2]. On the other hand, dust properties are also modified in the star-forming enviromentns through coagulation (grain–grain sticking). The modification of grain sizes may affect the efficiency of cooling.

We investigate if dust coagulation affects the thermal properties of star-forming clouds. We calculate coagulation in collapsing pre-stellar cores with different metallicities by considering the thermal motions of grains. We show that coagulation does occur even at low metallicity $\sim 10^{-6}$ $Z_\odot$. However, we also find (i) that the H_2 formation rate on dust grains is reduced only after the majority of H_2 is formed and (ii) that the dust opacity is modified only after the core becomes optically thick. Therefore, we conclude that the effects of dust coagulation can safely be neglected in discussing the temperature evolution of the pre-stellar cores for any metallicity as long as the grain motions are thermal [3].

Some observations in the Milky Way show "pre-growth" of dust grains in dense molecular cloud cores. Recent *Spitzer* observations have found the mid-infrared emission from deep inside a number of dense cores, the so-called "coreshine," which is thought to come from scattering by micron (μm)-sized grains [4, 5]. Based on numerical calculations of coagulation starting from the typical grain size distribution in the diffuse interstellar medium, we obtain a lower limit to the time t to form μm-sized grains: $t/t_{\rm ff} > 5.5(5/S)(n_{\rm H}/10^5\ {\rm cm}^{-3})^{-1/4}$ (where $t_{\rm ff}$ is the free-fall time at hydrogen number density $n_{\rm H}$ in the core, and S the enhancement factor to the grain-grain collision cross-section to account for grain fluffiness). At the typical core density $n_{\rm H} = 10^5\ {\rm cm}^{-3}$, it takes at least several free-fall times to form the μm-sized grains responsible for coreshine. The implication is that those dense cores observed in coreshine are relatively long-lived entities in molecular clouds, rather than dynamically transient objects that last for one free-fall time or less [6].

The possibility of "pre-growth" in dense clouds (at least in the solar metallicity environments) indicates that we should reconsider the initial condition for the grain size distribution in collapsing pre-stellar cores. Moreover, if such μm-sized grains are somehow dispersed into the diffuse interstellar medium, dust growth in dense molecular cores is an important source of big dust grains. We also discuss these points in the context of galaxy evolution.

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Near-Infrared Circular Polarimetry of NGC 6334-V: The Origin of Circular Polarization

Jungmi Kwon[1], Motohide Tamura[2], and SIRPOL team

[1]*Japan Society for the Promotion of Science, Japan,* [2]*University of Tokyo, Japan*

Linear polarization is easily produced and widely observed in star-forming regions being produced by scattering from dust (resulting in reflection nebulae) and dichroic extinction of starlight by aligned grains. On the other hand, circular polarization is much less observed in star-forming regions, even though circular polarization can provide evidence for changing grain/field alignment directions along the line-of-sight and hence the presence of twisting fields. There are only five star formation regions with near-infrared circular polarimetric studies published in refereed journals. In this presentation, we present deep and wide circular polarization images of the NGC 6334 massive star-formation complex observed in the near-infrared bands. The observations were conducted with the unique *JHKs*-band simultaneous Polarimeter (SIRPOL) on the 1.4m IRSF telescope placed in South Africa. Our results of circular polarimetry observations show high degrees of circular polarization, as much as 22% in the Ks band, in the infrared nebula associated with the outflow. The circular polarization has an asymmetric positive/negative pattern and is very extended (0.65 pc). Both the high circular polarization and its extended size are larger than those seen in the Orion circular polarization region. Three-dimensional Monte Carlo light-scattering models are used to show that the high circular polarization may be produced by scattering from the infrared nebula followed by dichroic extinction by an optically thick foreground cloud containing aligned dust grains. Our results show not only the magnetic field orientation of around young stellar objects, but also the structure of circumstellar matter such as outflow regions and their parent molecular cloud along the line of sight. We also report our results of the first systematic near infrared circular as well as linear imaging polarimetry of 9 star forming regions covering from high-mass to low-mass stars. We have found that (1) the circular polarization is ubiquitous in star forming regions, (2) their degrees are very high (>~20 %) in massive star forming regions, (3) their spatial extension is extensive (~0.1 pc) in massive star forming regions, (4) there is a clear trend between the circular polarization degrees and the stellar masses, (5) the dichroic polarization of scattered light is most likely the origin of large circular polarization, and (6) these may support the circular polarization in star forming regions as an origin of the biological homochirality on Earth, as proposed for the Orion nebular.

Mapping the magnetic field structure in the filamentary cloud IC5146 with optical dust polarization observations

Shih-Ping Lai[1] and Jia-Wei Wang[2]

[1]*National Tsing Hua University, Taiwan*

Recent Herschel and Spitzer survey discover numerous filamentary clouds in the star-forming regions. Stretching many parsecs in the sky, these filaments often encompass dense clumps that are fertile ground of massive stars or clusters. However, how filamentary clouds form is still on debate. The filamentary clouds may form from compression of large scale convergent flows (Mac Low & Klessen 2004), while other theoretical works suggest filamentary clouds may result from the gas collapsing along the field line of a strong magnetic field (Ostriker et al. 2001). To evaluate the relative importance of these two mechanisms on filament formation, we map the magnetic field structure of IC5146 though the optical polarization produced by the dust absorption of the background starlight. IC5146 is one of the first filamentary clouds observed by Herschel Gould Belt Survey, and the complex network of filaments discovered within the cloud favors the scenario that the filaments network are generated by large scale MHD turbulence and fragment into prestellar cores by gravitational instability (Arzoumanian et al. 2011). Our observations reveal that the large scale structure of magnetic field is well perpendicular to the main filament, but is likely parallel to the sub-filaments, extended out from the main filaments. In addition, our CO observations show that the material in the sub-filament is flowing into the main-filament along the magnetic field. Those results suggest that the sub-filaments may be gravitationally unbound clouds, thus can freely flow along the magnetic fields. On the other hand, the main-filament is possibility reach the gravitationally bound stage. Our results will be a good example to demonstrate how a magnetized filament evolves from gravitationally unbound to bound.

A Study on Paramagnetic Anisotropy of Amorphous Silicate Particle Orientated to Solve the Mechanism of Dust Alignment in the Dense Regions

C. UYEDA, M.YOKOI and K. HISAYOSHI

Institute of Earth and Space Science, Graduate School of Science, Osaka University

According to the observed results of infra-red emission, the majority of dust particles in the dense regions are composed of non-crystalline silicates along with various types of rock forming crystals. The cause of dust alignment is not clear as yet in the dense region, since the conventional Davis-Greenstein theory is not effective in a condition where dust and the gas are in a thermal equilibrium state. An model was proposed to solve the mechanism of alignment in this region, which was based on a simple balance between rotational Brownian energy $\frac{1}{2}k_BT$ and magnetic anisotropy energy $\frac{1}{2}m\Delta\chi B^2$; m and $\Delta\chi$ describes the mass and anisotropy of susceptibility per unit mass of dust particle, respectively [1]. Previously the above model was considered only for the crystalline dust particles, because amorphous material was generally considered to bear an isotropic magnetization. In the present study, anisotropy of paramagnetic susceptibility $\Delta\chi_{PARA}$ is detected on a sub-millimeter sized tektite (Moldavite, Czech Republic), which is a typical amorphous silicate produced in nature. The tektite samples were formed into rectangular plates (0.5 x2.0 x 2.0 mm); with the plate being parallel to the surface of the bulk tektite sample. An uni-axial anisotropy of $\Delta\chi_{PARA}$ = (7±3)x10^{-7}emu/g was obtained for the tektite plates; the surface plane of the bulk sample was identified as the easy plane. In order to examine the origin of the observed magnetic anisotropy, electron spin resonance (ESR) was carried out on the same tektite plate used in the $\Delta\chi$ measurement. A clear variation of g-value with respect to applied field direction was observed, which was consistent with the properties of $\Delta\chi_{PARA}$. It was confirmed that $\Delta\chi_{PARA}$ derive from the anisotropy of the molecular field of a Fe. ion. Based the obtained $\Delta\chi_{PARA}$ value, the practicability of the above-mentioned model is quantitatively examined for all the types of dusts identified in the dense region. The cause of $\Delta\chi_{PARA}$ observed for an amorphous material is not clear as yet. Due to the large temperature gradient along a normal vector of tektite during its cooling process, the principle axes of the molecular field of individual Fe ion may be preferentially aligned along the normal vector.

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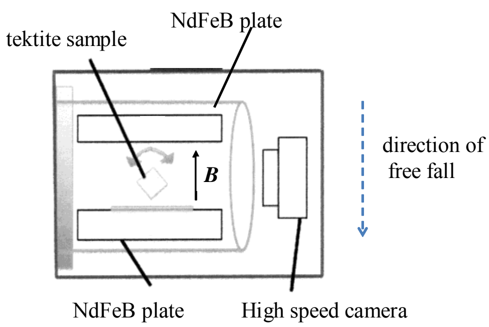

The $\Delta\chi_{PARA}$ value is obtained from a period of rotational-oscillation observed for a direction of magnetically stable axis with respect to field [2]; sample was released in an μg area produced by a short drop shaft.

Interpretation of XRD and IR features in amorphous $MgSiO_3$ before crystallization of enstatite with heat treatment.

Junya Matsuno[1], Akira Tsuchiyama[1], Chiyoe Koike[2], Hiroki Chihara[3], Shinji Kohara[4], Yoshinori Kitajima[5], Akira Yoshiasa[6], Yusuke Seto[7], Ryohei Takahashi[1], Yuta Imai[8], and Keisuke Murata[8]

[1]Dep. of Geology and Mineralogy, Kyoto Univ., [2]Ritsumeikan Univ., [3]Osaka Sangyo Univ., [4]Japan Synchrotron Radiation Research Institute, [5]Photon Factory, High Energy Accelerator Research Organization, [6]Dep't Earth Sci., Kumamoto Univ., [7]Dep. of Earth and Planetary Sci., Kobe Univ., [8]Dep. of Earth and Space Sci., Osaka univ.

Anhydrous silicate dust such as enstatite ($MgSiO_3$) or forsterite (Mg_2SiO_4) are observed around the circumstellar environment [1]. In contrast the interstellar dust is almost amorphous [2]. They were incorporated into the circumstellar disk of young stars, and crystalline silicates could form by heating. In order to understand the formation and evolution of the circumstellar dust, crystallization of amorphous silicates have been performed (e.g., [3-6]). Imai [3] carried out heating experiments of amorphous $MgSiO_3$ prepared by an induction thermal plasma (ITP) technique. Powder X-ray diffraction (XRD) and infrared (IR) absorption were used for identification of the phase and estimating the degree of crystallization. These results suggested structural changes in the amorphous silicates before the crystallization of enstatite. Thus, we measured high energy X-ray diffraction (HEXRD) data and X-ray absorption fine structure (XAFS) spectrum of the amorphous samples to investigate bond distance. Previous heating experiments of amorphous Mg-silicates synthesized by sol-gel method showed the similar features in their starting materials by XRD [4-6]. The sol-gel method is performed with water, suggesting the peak features may be related to the effect of water. We examined the effect of hydration to the XRD and IR features, by performing hydrothermal experiments too.

Total correlation functions obtained in the HEXRD show that Mg-O distance is slightly expanded and contracted before enstatite crystallization. The XRD pattern of the run product on the hydrothermal experiment at 150 ºC for 3 weeks with a water/rock ratio of 0.1 by weight is very similar to the result of the heating experiments using the starting material prepared by the ITP technique. These results suggest that the weak peaks correspond to hydrous phyllosilicates and should relate to the mixed-layer mineral of serpentine and stevensite [7], for example. In the ITP method, H_2O or OH molecules (or H and O separately) which were originated by decomposition of $Mg(OH)_2$ of the starting material, should be incorporated into the amorphous $MgSiO_3$ during the rapid condensation. In this case, a possible scenario is follows: (1) phyllosilicate minerals crystallized from the O and H bearing amorphous silicate, (2) they were dehydrated and became amorphous, and finally (3) anhydrous silicate (enstatite) crystallized.

The present results suggest that H_2O (or H and O) should be included in amorphous silicates condensed in circumstellar regions and hydrous silicates may form by mild heating, such as at ~1000 K for a few hours, although more kinetic experiments are needed.

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Dust growth and settling in protoplanetary disks and radiative transfer calculations

Koji Murakawa[1]

[1]*School of Physics and Astronomy, University of Leeds, United Kingdom*

Circumstellar disks play important roles on mass accretion toward the central star and planet formation in the subsequent evolutionary phases. At the first step of planet formation, dust particles with the interstellar population, ie. submicron sizes, grow to meter sizes by mutual collision in the gas disk. Meanwhile, the dust particles are condensed toward the disk midplane due to the vertical gravity and a dust dominant layer forms. Planetesimals may form in regions where are fragmented by gravitational instability and the density exceeds the Roche density.

In the past 40 years, this problem has been studied in both theory and observation. The dust and gas motions in protoplanetary disks have been solved by hydrodynamic treatments. Various important parameters such as the particle sizes, the thickness of the dust dominant layer, and their time scales are calculated. However, they depend on the strength of the turbulence in the disks. Although theoretical modeling with given parameters allow to predict the behaviour and properties of the disks precisely, observed data are necessary to determine these physical parameters. In observations, flux excesses or shallow spectral flux indices are obtained in (sub)millimetre wavelength ranges, and low optical depth or even gaps are detected in the inner part of the disks in high-resolution mid-infrared imaging. These results evidence the presence of pebble or boulder sized particles in the protoplanetary disks. On the other hand, little evidence for settling has been reported so far. To better understand the dust growth and settling theory, physical models that can be compared with the observations are necessary.

We have modeled stratified disks of low-mass young stars with and without a dust dominant layer in which the dust growth is also taken into account. For these models, the spectral energy distribution and images are produced by means of radiative transfer calculations. We also discuss the interpretation on the observed data from these model results.

Dust in Debris Disks: Imprints of Extrasolar Planetary Systems

Kate Y. L. Su[1]

[1]*Steward Observatory, University of Arizona, USA,*

Debris disks are tenuous dusty disks generated through collisions among the leftover planetesimals and evaporating comet-like bodies. They provide us with a long-lived record of planet formation in extrasolar planetary systems. The large surface area of debris makes these disks detectable through infrared thermal emission or optical scattered light, providing insights into the nature of unseen planetesimal populations. In my talk, I will review recent studies of debris disks focusing on the following topics: (1) signposts for multiple low-mass planets revealed from multi-wavelength debris disk structures and (2) systems that are the sites of recent large collisions or episodes of a high level of dynamical activity in the terrestrial planet building zone.

Debris Disk Formation induced by Planet Formation

Hiroshi Kobayashi[1]

[1]Department of Physics, Nagoya University, Nagoya, Aichi 464-8602, Japan

Debris disks are found around main sequence stars. The disks are faint and gas-poor. The disk dust has a short lifetime in the disks caused by radiation pressure, mutual collisions, and Poynting-Robertson drag, and hence the dust is supplied by collisional fragments of kilometer sized or larger planetesimals. However, the collisional destruction of the planetesimals requires dynamical excitation of the planetesimals. If the initial planetesimals are dynamically cold, the planetesimals start runaway growth, resulting in large protoplanets. The stirring of leftover planetesimals by the protoplanets induces debris disk formation. Recently, I improved the collisional fragmentation model consistently with previous the laboratory experiments and numerical simulations of collisions (Kobayashi and Tanaka 2010) and developed the planet formation simulations using the new collisional outcome model (Kobayashi et al. 2010, 2011,2012). Through the simulation, we try to give constrains on the spatial and size distribution of initial planetesimals, and their total mass in a disk from comparison of my model with observational data.

Cold, Warm and Hot Dust in Extrasolar Planetary Systems

Jean-Charles Augereau[1]

[1] *UJF-Grenoble 1 / CNRS-INSU, Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) UMR 5274, Grenoble, F-38041, France*

It has now been exactly 30 years that belts of rocks and dust around Main sequence stars have been discovered. These so-called debris disks are thought to represent the leftovers from planet formation. Like in the solar system, debris disks around other stars come in different flavors, from cold exo-Kuiper belts to warm and hot exo-asteroids and exozodiacal belts. The former are by far the most studied, thanks in particular to a fleet of space facilities like IRAS, ISO, HST, Spitzer and Herschel.

About one third of nearby stars are now known to host cold dusty debris disks, which are thought to derive from collisions in Kuiper Belt analogs at tens to hundreds of AU from their host stars. Spatially resolved cold debris disks usually show asymmetries and structures caused by detected or suspected planets. Much less was known until recently about the dust in the inner few AU of debris disks. This region is of particular interest because it encompasses the terrestrial planet formation region and the habitable zone. Detecting tenuous warm and hot debris disks requires an instrumentation with high angular resolution and high contrast capabilities, currently best provided by near- and mid-infrared interferometry.

In this talk, I will start by presenting recent Herschel observations of cold debris disks analogous to our Kuiper Belt. I will show that, when combined with spatially resolved images, it is possible to derive reasonable constraints on the dust properties despite the lack of spectroscopic signature. Then, I will focus on the inner regions of extrasolar planetary systems and will review the current understanding of warm and hot dust around Main Sequence stars, both recent observational progress and theoretical advances. Finally, I will highlight the new challenges raised by the study of exozodiacal dust.

The Offset Dust Ring of HR 4796A

Zahed Wahhaj[1], Michael C. Liu[2], Eric L. Nielsen[2], Beth A. Biller[3], Tom L. Hayward[4] and the Gemini NICI Planet-Finding Campaign Team.

[1]*European Southern Observatory, Chile,* [2]*University of Hawaii, USA,* [3]*MPIA, Germany,* [4]*Gemini South Observatory, Chile* [4]

We present images of the dust ring around the 10 Myr old star, HR 4796A, in the J, H, K_S and narrow-band methane filters, obtained using the Near Infrared Coronagraphic Imager on the 8-m Gemini South Telescope. These unsaturated images, for the first time, clearly show the position of HR 4796A relative to its circumstellar ring (radius $1''$). We used a Bayesian approach with Markov Chain Monte Carlo simulations to constrain the offset vector between the two. The resulting probability distribution from this analysis, demonstrates with $>15\sigma$ confidence that the ring center is offset from the star along of PA of 206.7 ± 2 degrees. This agrees with PA of the South-West extension of the disk, which is 206.47 ± 0.04 degrees. Thus the brighter side (North-West) is closer to the star. This finding supports the previous theory of "peri-center glow". It is difficult to explain the offset without the hypothesis of an orbiting planet. We also find that the reflectivity of the dust, which extends from 45 AU to 120 AU, is uniform across the JHK_S-bands.

What’s new about single-scattering from dust particles?

Robert Botet[1]

[1]*LPS, CNRS 8502 – Université Paris-Sud, Orsay 91405 France*

Single-scattering theory is nowadays underrated due to the profusion of efficient multiple-scattering numerical codes. However, we should not forget that the single-scattering theory has many unique features, such as deep analytical results and immediate physical interpretations. In this presentation, the problem of electromagnetic-wave single-scattering patterns from dust particles made of aggregated small grains will be reassessed in the context of the modern light-scattering framework.

Actually, single-scattering theory is of prime importance for particles of vanishing optical cross sections, such as loose aggregates of very small grains or particles illuminated with very small wavelength photons. The latter case deals with *any* dust particle in X-ray beam, thus synchrotron facilities are commonly used on Earth to characterize aerosol dust particles or colloidal aggregates through scattered intensity measured at various phase angles. Natural cosmic X-ray sources exist too, but phase angles cannot be varied. Instead, one can use a remarkable characteristic of the single-scattering theory: the normalized scattered intensity, I, at the wavelength λ and phase angle α, depends on the ratio: $\lambda/\sin(\pi-\alpha)/2$. Then, the data needed for getting the two-points mass correlation function can be obtained either through: “phase-angle variation at a given wavelength” (convenient for experiments) or through: “wavelength variation at a given phase angle” (convenient for observations). Moreover, this theory predicts simple behaviors such as: $I(\lambda) \propto \lambda^{D_f}$ for scattering from particles of fractal dimension D_f at any given phase angle. This robust formula results from scan of the particle morphology by probes (photons) of “extension” λ. Therefore, fractal structure of particles in a dust cloud can, in principle, be deduced from the X-ray background originated from the cloud. These results hold as well for particles “loose enough”, such as grain-aggregates of fractal dimension $D_f < 2$, or for grains with refractive index $n \approx 1$. Moreover, other essential characteristics - such as the particle size distribution - are obtained through mathematical manipulation of the single-scattering data.

All these results push to the idea that, to conclude about the morphology of dust particles, we should first search for physical conditions of observation where the single-scattering theory be usable. Along this line, we will present known cases where the single-scattering theory does apply, as well as some yet unexplored cases.

Beyond this approach, we will discuss deviations from the single-scattering results when this theory is no more expected to hold true. In particular, we will see how robust is the λ^{D_f} -law, when second-scattering, …, multiple scattering, is taken into account. Actually, the old single-scattering theory appears to be a pretty good approximation in the cases far from resonance, though under limited conditions. At last, well, in the case where multiple-scattering codes must really be used, we have to leave behind us the clear analytical formulas. It is more precise, but is it better than a robust approximation?

Light Scattering from Agglomerated Debris Particles: Comparison with Feldspar Data

Gorden Videen,[1] Evgenij Zubko,[2,3] Karri Muinonen,[2,4] Olga Muñoz,[5] Timo Nousiainen,[6] Yuriy Shkuratov,[3] and Wenbo Sun,[7]

[1]*Space Science Institute, 4750 Walnut Street, Suite 205, Boulder, CO 80301, USA*
[2]*Department of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland*
[3]*Astronomical Institute, Kharkov National University, 35 Sumskaya St., Kharkov, 61022, Ukraine*
[4]*Finnish Geodetic Institute, P.O. Box 15, FI-02431 Masala, Finland*
[5]*Instituto de Astrofísica de Andalucía, CSIC, Granada, Spain*
[6]*Department of Physics, P.O. Box 48, FI-00014 University of Helsinki, Finland*
[7]*Science Systems and Applications, Inc., Hampton, VA 23666, USA*

Using the discrete dipole approximation (DDA), we model light scattering by a sample of feldspar particles and compare the results against laboratory measured light-scattering properties at two visible wavelengths. The shape of feldspar particles is approximated with the so-called agglomerated debris particles [see, e.g., Zubko et al., 2009, J. Quant. Spectr. Rad. Trans. 110, 1741–1749]. These model particles have irregularly shaped, agglomerate morphology with material packing density being 0.236. We consider a large number of sample particles (500+) that makes our computational results statistically reliable. The refractive index is assumed to be m = 1.5 + 0i and nearly coincides with what was measured in experimental feldspar samples. The light-scattering response is computed over a wide range of particle sizes spanning the range from 0.14 to 4.5 micron. We compare the non-zero light-scattering Mueller-matrix elements of agglomerated debris particles with those of well-characterized experimentally measured feldspar samples at blue (0.442 microns) and red (0.633 microns) wavelengths [Volten et al., 2001, JGR 106, 17375–17401]. It is important to stress that we also account for the polydispersity of feldspar particles, adapting the size distribution measured by Volten et al. The only completely free parameter in our comparisons is the small-size cut-off of the sample, which was not known. The significance is that both the light scattering and the measured properties of model and real particles agree very well at both blue and red wavelengths simultaneously. While some tweaking of the particle parameters could achieve some improvement, the fits are remarkably good. We suggest that the reason for the good fits is not that the agglomerated debris particles exactly represent those of the sample particles, but rather that both sets of particles belong to a class of highly irregular particles, whose high degree of irregularity dominates the resulting scattering behavior, suppressing the effect of any characteristic morphological features. The ability to replicate the light-scattering Mueller matrix elements at two wavelengths using particles having the same physical properties as those of the experimental sample is the primary advantage of using the agglomerated debris particles over more regularly shaped particles.

Modeling photo-polarimetric response in Comet C/1975 V1 (West)

Evgenij Zubko[1,2], Karri Muinonen[1,3], and Gorden Videen[4]

[1]University of Helsinki, Finland, [2]Institute of Astronomy, Kharkov National University, Ukraine, [3]Finnish Geodetic Institute, Finland, [4]Space Science Institute, USA

The photo-polarimetric properties of Comet C/1975 V1 (West) were measured over a wide range of phase angles α. The phase function in the visible was observed at α = 30 – 146° in [1]; whereas, the degree of linear polarization was investigated with a narrow-band green filter (λ = 0.53 μm) at α = 14 – 98° [2]. We model these measurements using the discrete-dipole approximation (DDA) [e.g., 3] and the so-called *agglomerated debris particles* (e.g., [4]). We take into account the size polydispersity of the agglomerated debris particles, mimicking what was measured *in situ* for comets [5]; namely, it is assumed that the model particles obey a power-law size distribution r^{-a} with the index a = 1.5 – 2.

We have investigated a wide range of refractive indices m and found that a homogeneous ensemble of the *agglomerated debris particles* with a single value of m cannot reproduce the polarimetric response in Comet C/1975 V1 (West). However, a two-component mixture of weakly and highly absorbing agglomerated debris particles can satisfactorily reproduce the observations. Fig. 1 shows results of our modeling (dashed and solid lines) versus measurements (dots). The dashed line presents results for a mixture of particles having 26% (by volume) of $m = 1.5 + 0i$ and 74% of $m = 2.43 + 0.59i$. The solid line corresponds to a mixture of 24% of $m = 1.6 + 0.0005i$ and 76% of $m = 2.43 + 0.59i$. The refractive indices Re(m) = 1.5 – 1.6 and Im(m) ≈ 0 are representative of Mg-rich silicates; whereas, the case $m = 2.43 + 0.59i$ corresponds to amorphous carbon. Both materials are abundant species in comets. Furthermore, the ratio of weakly and highly absorbing particles being about 1:3 is consistent with *in situ* findings in Comet 1P/Halley [6].

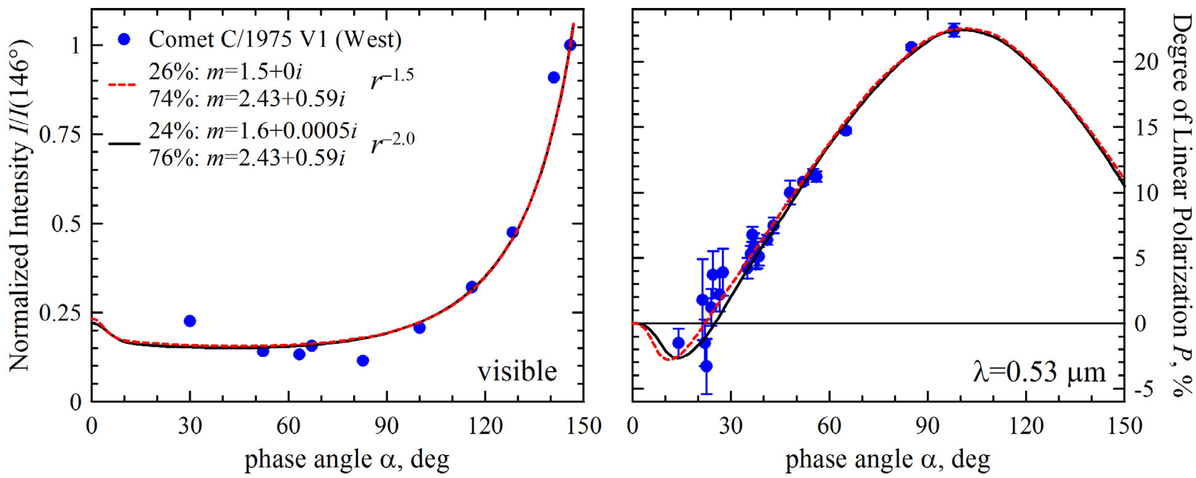

Fig. 1: Modeling (lines) vs. photometric (left) and polarimetric observations (right) of Comet West

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How to measure interstellar dust in the Solar System

Ralf Srama[1,2,3], Veerle Sterken[1,2], Georg Moragas-Klostermeyer[1,2], Harald Krüger[4], Peter Strub[1,4], Rachel Soja[1], Nicolas Altobelli[5], Katherina Fiege[6], Frank Postberg[1,6], Jon K. Hillier[6], Eberhard Grün[2]

[1]University Stuttgart, Germany, [2]Max Planck Institute Nuclear Physics, Heidelberg, Germany, [3]Baylor University, Waco, USA, [4]Max Planck Institute Solar System Research, Katlenburg-Lindau, Germany, [5]ESA, Madrid, ESP, [6]University Heidelberg, Germany

The in-situ measurement of interstellar dust in the Solar System by Ulysses in 1993 was largely unexpected. Since then, further datasets have demonstrated clear evidence for interstellar material at various distances from the Sun. Today, interstellar grains have been identified between 0.6 AU and 9.5 AU by in-situ dust measurements. How successful were the interstellar dust campaigns of Stardust?

Here, we present an overview of current in-situ measurements and provide recommendations for future missions. Which time frames and mission trajectories are optimal for the measurement of interstellar dust populations? What are the instrument requirements with regard to the sensitive area and mass resolution? What are the advantages and limitations of sample return missions? Can we combine the measurement of interstellar dust with interplanetary dust measurements? What are the pointing, power and data rate requirements? Which magnetospheric parameters can be measured in conjunction with interstellar dust campaigns? The answer to these questions are relevant for the design of future missions that aim to investigate the seeds of our Solar System. As a detailed example, we describe the capabilities of Cassini dust instrument suite and the procedures to perform interstellar dust measurements.

Technical aspects are often underestimated when planning a scientific mission. The data required to fulfill the scientific goals of the mission can only be achieved if the mission design, spacecraft operations and instrument operations, project management, the spacecraft bus and the instrument capabilities are designed to optimise the success of the scientific tasks. Thus, the early planning of a pointing profile and limited spacecraft bus constraints (forbidden FOVs) is essential for a successful mission. New technologies allow for a low instrument mass and power while simultaneously increasing the scientific performance.

This paper describes the instrument methods required for a successful measurement in terms of operations and software design. If the mission trajectory is adjusted to the interstellar dust flow, an in-depth mapping of our cosmic dust environment is possible. Cassini represents only a first step that has sucessfully demonstrated the power of Dust Astronomy: we now have to prepare for the future with advanced instrument and mission concepts.

Diversity among the Polarization Opposition Effects for High-Albedo Atmosphereless Solar System Bodies

Nikolai Kiselev[1], Vera Rosenbush[1], Sergii Zaitsev[1], Feodor Velichko[2], Sergej Kolesnikov[3], and Dmitrij Shakhovskoy[4]

[1]MAO, Ukraine, [2]Institute of Astronomy of Kharkiv National University, Ukraine, [3]Observatory of Odessa National University, Ukraine, [4]CrAO, Ukraine

The negative polarization (meaning that the electric field vector component parallel to the scattering plane dominates the perpendicular component) has been observed near opposition for objects of quite varying nature, such as Mars, Mercury, planetary satellites and rings, asteroids, cometary and interplanetary dust as well as meteorites and laboratory samples. The angular dependence of negative polarization depends strongly on albedo of bodies. It can exhibit a wide, almost parabolically shaped negative polarization branch (NPB) with a minimum near 5°−12° (e.g., for regolith of moderate- and low-albedo asteroids, cometary, interplanetary and perhaps circumstellar dust) while some high-albedo bodies display an asymmetric NPB with a sharp minimum centered at about 0.5°-2° (e.g. Jupiter's satellite Europa) – called the polarization opposition effect (POE). What are the differences in the negative polarization branch and the polarization opposition effect for different high-albedo bodies? To answer this question the additional observations near opposition are required.

We present the results new near-oppositions polarimetric observations of high-albedo E-type asteroids 44 Nysa (the geometric albedo is p_V=0.55) and 64 Angelina (p_V=0.48), the Galilean satellites of Jupiter Io (p_V=0.62), Europa (p_V=0.68), Ganymede (p_V=0.44), the Saturn's high-albedo satellite Enceladus (p_V=1.04) and Rhea (p_V=0.70) as well as bright trailing hemisphere of Iapetus (p_V=0.6) obtained in 2010-2013. The measurements of linear polarization for satellites and asteroids were carried out at the 2.6-m telescope of the Crimean Astrophysical Observatory in the R and RW filter (550–750 nm) and with the photoelectric polarimeter at the 0.7-m telescope of the Chuguyev Observation Station (Institute of Astronomy of Kharkiv National University) and at the 1-m RC telescope of the Crimean Astrophysical Observatory (Simeiz) in the V and R filters.

We will discuss the results of observations as well as why different objects with high albedo show differences in the shape and parameters of the POE ranging from a sharply asymmetric NPB (e.g. Enceladus, Rhea and Iapetus) to a secondary minimum of negative polarization distinctly separated from the main NPB minimum (e.g. asteroids 64 Angelina and 44 Nysa).

Opposition Effect Produced by Icy Particles: Spectral Manifestation

Ludmilla Kolokolova[1], Karly Pitman[2], Anne Verbiscer[3]

[1]University of Maryland, USA, [2]Planetary Science Institute, USA, [3]University of Virginia, USA

When light experiences multiple scattering in a medium containing closely spaced dust particles, the rays, which travel along the same path but in opposite directions, interfere constructively, producing the coherent backscattering effect (CBE). Photometric (opposition spike) and polarimetric (narrow negative polarization feature) manifestations of CBE have been repeatedly observed for many Solar System objects including Saturn's ring, the icy satellites of the outer planets, bright asteroids, and Kuiper Belt Objects (KBOs).

We discuss a new effect: spectral manifestation of CBE. According to the physics of coherent backscattering, the decrease in reflectance as solar phase angles increase depends strongly on the absorption of the material, resulting in photometric phase curves of different steepness within and outside of the absorption bands. Thus, different depths of the absorption bands occur for different solar phase angles. Neglecting this effect in the analysis of spacecraft and ground-based spectral data may lead to erroneous conclusions about compositional and size differences of dust studied at different solar phase angles.

We study Cassini VIMS (Visual and Infrared Mapping Spectrometer) spectra of Saturn's mid-size icy satellites in order to identify and characterize the solar phase angle variations of the spectra, including changes in the depth and shape of the water ice absorption bands as well as the general slope of the spectra. We also analyze the results of ground-based observations of icy satellites of Saturn and Uranus. We compare the observational results with theoretical modeling that we perform using the MSTM (Multi Sphere T-matrix) code by D. Mackowski (http://www.eng.auburn.edu/users/dmckwski/scatcodes/). Such modeling allows us not only to separate phase angle effects from particle and composition effects but also to study properties of the regolith particles, specifically their size and packing.

This work is supported by NASA's Outer Planets Research program (NNX12AM76G; PI Pitman) and NASA's Advanced Supercomputing Division. Calibrated Cassini VIMS data cubes appear courtesy of B. J. Buratti and the Cassini VIMS team.

Recovery of Chondritic Micrometeorites in Snow Cover of Central East Antarctica (Vostok station): Preliminary Results

Sergey Bulat[1], Elena Bulat[1, 2] Jean Robert Petit[3], Lev Gindilis[4] and Vladimir Tselmovich[5]

[1] FSBI "Petersburg Nuclear Physics Institute", NRC Kurchatov Institute, Leningrad region, Gatchina, Russia, [2] Paleontological Institute, RAS, Moscow, Russia, [3] Laboratoire de Glaciologie et Geophysique de l'Environnement, CNRS/UJF Saint-Martin-d'Heres, France, [4] Sternberg Astronomical Institute Moscow University, Moscow, Russia, [5] Geophysical Observatory «Borok», Schmidt Institute of Physics of the Earth, RAS, Borok, Yaroslavl region, Russia

During the 2010/2011 season nearby the Vostok station the 56th Russian Antarctic Expedition has collected surface snow in a big amount from a 3 m deep pit using 15 220 L vol. containers (about 70 kg snow each). Snow melting and processing by ultra-centrifugation was performed in a clean (class 10000 and 100) laboratory. Total dust concentrations were not exceeded 37.4 mkg per liter with particle dispersal mode around 2.5 mkm. To analyze the elemental composition of fine dust particles aimed to reveal Antarctic micrometeorites (AMM) two electron microscopy devices equipped with different micro-beams were implemented. As a preliminary result, 3 particles (of 107 analyzed) featured by Mg content clearly dominated over Al along with Si and Fe as major elements (a feature of carbonaceous chondrites) were observed. By this the Vostok AMM CS11 collection was established. The occurrence of given particles was averaged 2.8% - the factual value obtained for the first time for chondritic type AMM at Vostok, East Antarctica which should be considered as the lowest estimate for all other families of AMM. Given the reference profile of total dust content in East Antarctic snow during Holocene (18 mkg/kg [1]) the MM deposition in Antarctica was quantified for the first time – 14 tons per day for carbonaceous chondrites for the Vostok AMM CS11 collection and up to 245 tons per day for all MM types for the Concordia AMM DC02 collection.

The results obtained allowed to prove that snow cover (ice sheet in total) of Central East Antarctica is the best spot (most clean of other natural locations and always below 0^{o}C) for collecting native MM deposited on the Earth during the last million years and could be useful in deciphering the origin and evolution of solid matter in our Solar System and its effects on Earth-bound biogeochemical and geophysical processes including the life origin. The farther analyses of the Vostok AMMs are in a progress.

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Electrostatic Lofting of Dust Aggregates Near the Terminator of Airless Bodies and its Implication in the Formation of Circumstellar Dust Rings

Hiroshi Kimura[1], Hiroki Senshu[2], and Koji Wada[2]

[1]*Kobe University, Japan,* [2]*Chitec/PERC, Japan*

Our current knowledge of launching dust grains from the surfaces of airless bodies appears to contradict in-situ observations of dust grains that are lofted off the surface of the Moon. We tackle the issue of high grain stickiness where cohesive forces estimated for compact spherical grains restrict the detachment of the grains from the surfaces of airless bodies. We show that electrostatic forces on irregular grains with rough surfaces, in particular, aggregates of the grains could overcome their cohesive forces, provide that their surfaces are hydroxylated. Our results suggest that levitation of lunar agglutinates takes place near the terminator of the Moon but that solar radiation pressure and organic refractory mantle prevent levitation of dust grains above the surfaces of asteroid 25143 Itokawa and short-period comets, respectively. The application of our results to extrasolar systems reveals a novel mechanism of forming tenuous dust rings in the vicinity of bright main-sequence stars by electrostatic lofting and subsequent radiative blown-out of dust grains from sub-km sized airless bodies.

Title: The dust content of galaxy clusters

Authors: Carlos M. Gutierrez & Martin Lopez-Corredoira
Instituto de Astrofisica de Canarias, SPAIN

Little is known so far from the observational point of view, about the presence of dust in galaxy clusters. Previous attempts to detect such dust in the intracluster media had been conducted directly by the detection of its infrared emission, or indirectly by estimating the attenuation of the light of objects situated in the background of clusters. We have developed a new technique to detect and measure the main properties of dust in clusters and applied it to the most complete sample of galaxy clusters obtained from SDSS. Our method is largely free of systematics, and represents an improvement on the estimation of dust content of at least an order of magnitude with respect to previous searches. This has allowed for the first time an unambiguous detection of dust in clusters of galaxies. In this contribution, we present the method and discuss the inferred properties of such dust, and in particular the spatial distribution through the cluster. We estimate which fraction of the dust is associated to individual galaxies and to the intracluster media respectively, and analyze the implications of our findings on models of formation and evolution of clusters.

ALL-SKY DUST MODELING USING PLANCK AND IRAS OBSERVATIONS

G. Aniano Porcile[1], M.-A. Miville-Deschenes[1], F. Boulanger[1], B. T. Draine[2]

[1]*CNRS - Institut d'Astrophysique Spatiale, Universit Paris-XI, Orsay, France*

[2]*Princeton University Observatory, Peyton Hall, Princeton, NJ 08544-1001, USA*

We have computed all-sky, high-resolution, model of the far infrared (IR) emission of the interstellar dust as measured by PLANCK and IRAS. We employ the Draine & Li (2007) [DL07] dust model to characterize: (1) dust visual extinction A_V, (2) dust mass surface density, (3) the starlight intensity heating the dust, (4) total infrared (IR) luminosity emitted by the dust, and (5) IR luminosity originating in regions with high starlight intensity. The present work extends to the full Milky Way dust modeling done on nearby galaxies with Herschel and Spitzer data.

The DL07 model reproduces the observed Spectral Energy Distribution (SED) in the 60-850μm range satisfactorily in most of the sky, with small deviations in the galactic disk near the galactic center. However, the DL07 optical reddening estimates over-predict independent estimates from stellar and QSO measurements by factors of 3 and 2 respectively. The dependences of the deviations of the DL07 estimates are analyzed and parametrized. We propose an empirical "renormalization" of the DL07 model that matches the observed optical extinction per unit of IR emission. The H gas column density inferred from the DL07 dust mass density also over-predict current ground-based observations by factors 1.3 to 3.0, and the renormalization procedure brings both estimates into agreement. This renormalization establishes the constrains for the next generation of dust models, which will have to include dust-evolution across the interstellar medium. I will present our work and discuss the implications for dust modeling.

Laboratory analogy of crystalline Fe_2SiO_4,(FexFe1-x)$_2SiO_4$ and SiC grain formation

Chihiro Kaito, Saito Yoshio, Chiyoe Koike

Department of Physics, Fuel Cell Center, Ritsumeikan University
Kusatsu, Shiga 525-8577, Japan

A new evaporation method by the use of carbon holy film have been used on the formation of crystalline Fayalite (Fe_2SiO_4), Olivine(Mg_xFe_{1-x})2SiO_4 and SiC grains by the evaporation in inert gas of He or Ar. Solid crystalline grains less than 50 nm have been produced from gas phase. As reported in previous paper(T, Sato et al, Planetary and Space Science 54 (2006)612-616), Fe crystalline particle covered with SiO layer produced and Fe_2SiO_4 particle was produced by heating at 800^{o}C. In the present paper, direct evaporation of mixture gas of (Fe, SiO), (Fe, Mg, SiO) and (Si, C) can be formed the crystalline particles from gas phase.

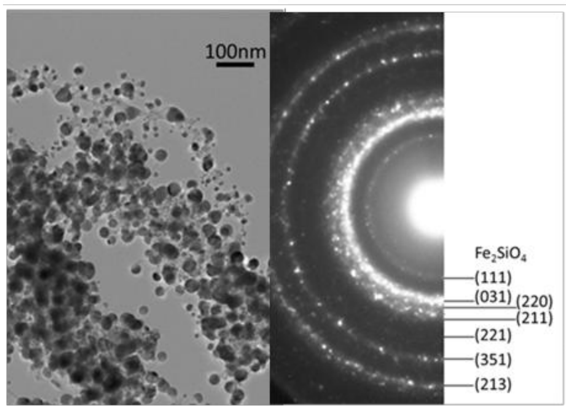


Fig1.Fe_2SiO_4

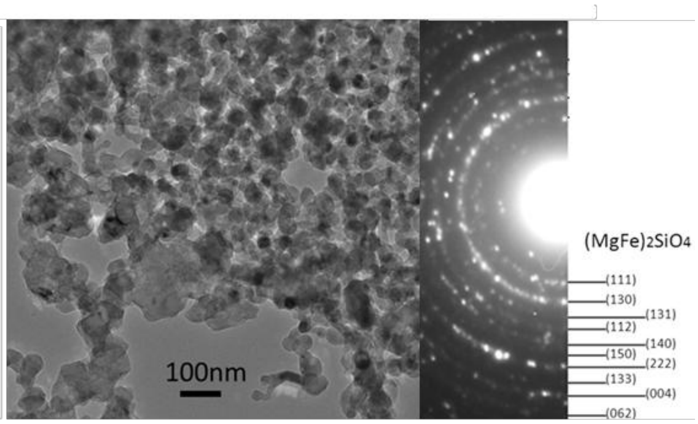


Fig2.(Mg,Fe)2SiO4

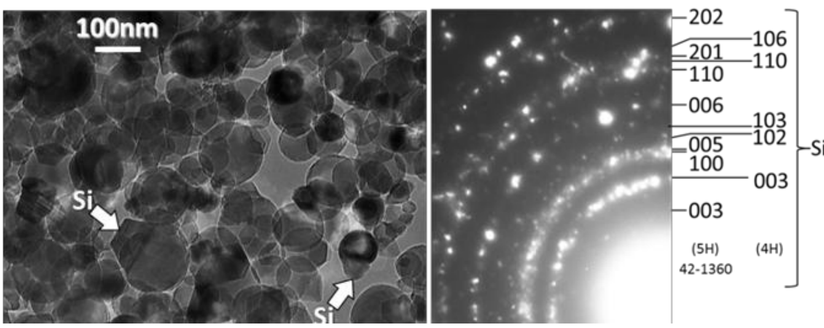


Fig3.SiC

The infrared spectra of iron oxides particles

Chiyoe Koike and Chihiro Kaito

Ritsumeikan University

The mysterious 21 μm emission feature seen in C-rich proto-planetary nebulae remains unidentified since its discovery in 1989 (Kwok, Volk and Hrivnak, 1989), and the candidate carriers have long been the subject of discussion.

Over a dozen of materials are suggested as the carrier candidates such as TiC nanoclusters (Von Helden et al. 2000), magnetite (Fe_3O_4) and maghematite (γ-Fe_2O_3) (Cox 1990), FeO (Posch et al. 2004) etc. Among many carrier candidates, FeO nano particles closely matche the observed 21 μm emission features and seems to be a viable candidate (Zhang et al. 2009).

As for FeO (wustite), the optical constants were derived with the reflectances of synthesized FeO bulk (Begemann et al. 1995, Henning and Mutschke 1997). But, fine particles of FeO were not synthesized by gas evaporation method in laboratory until now. We tried to synthesize fine particles of FeO and iron oxide particles in laboratory controlling O_2 gas pressure. These fine particles were analyzed with TEM and were measured with infrared spectra.

In order to compare to infrared spectra of the synthesized iron particles, we measured the infrared spectra of iron oxides particles of standard samples such as magnetite, hematite, wustite, and maghemite. We discuss about 21 μm feature compared with the results of synthesized iron oxide particles.

On FeO as a Carrier of the Mysterious "21μm" Emission Feature Seen in Protoplanetary Nebulae

J.M. Liu[1], B.W. Jiang[1,2] & Aigen Li[2]
[1] *Beijing Normal University* [2] *University of Missouri*

The mysterious "21 μm" emission feature seen in fewer than two dozens carbon-rich protoplanetary nebulae remains unidentified since its discovery in 1989 (Kwok et al. 1989, ApJ, 345, L51). Peaking at 20.1 μm, this feature is rather broad (with a FWHM of about 2.2-2.3 μm) and accounts for up to 8% of the total infrared power of protoplanetary nebulae. In recent years nano-sized iron monoxide (FeO) dust has been proposed as a promising candidate material for this mysterious feature (Posch et al. 2004, ApJ, 616, 1167; Zhang et al. MNRAS, 396, 1247). We test the FeO hypothesis by modeling the stochastic heating of nano FeO grains by single stellar photons and calculate their infrared emission spectra in protoplanetary nebula environments. The spectral match between model predictions and astronomical observations, and the Fe and O abundances as well as the condensing dust species in carbon-rich environments are also discussed.

The Mysterious "30μm" Emission Feature of Evolved Stars: MgS or Graphite?

Ke Zhang[1], Biwei Jiang[2,3] & Aigen Li[3]
[1]Caltech, [2]Beiing Normal University, [3]University of Missouri

A large number of carbon-rich evolved objects (asymptotic giant branch stars, protoplanetary nebulae, and planetary nebulae) in both the Milky Way galaxy and the Magellanic Clouds exhibit an enigmatic broad emission feature at ~30 μm. This feature, extending from ~24 to ~45 μm, is very strong and accounts for up to ~30% of the total infrared luminosity of the object. In literature it is tentatively attributed to magnesium sulfide (MgS) dust. Using the prototypical protoplanetary nebula around HD 56126 for illustrative purpose, however, in this work we show that in order for MgS to be responsible for the 30 μm feature, one would require an amount of MgS mass substantially exceeding what would be available in this source. We therefore argue that MgS is unlikely the carrier of the 30 μm feature seen in this source and in other sources as well. We further argue that graphite may be a promising candidate, as the free electrons in graphite seem to produce a strong resonance band at 30 micrometer.

Are All Active Galactic Nuclei Born Equal? The Silicate Dust Mineralogy Perspective

Aigen Li & Melanie Köhler (*University of Missouri*)

Dust is the cornerstone of the unification theory of AGNs. This theory proposes that all AGNs are essentially the same object or "born equal" but viewed from different lines of sight and suffered different amount of dust obscuration. It is this crucial role played by dust in the unified model of AGNs that makes understanding dust properties very important in understanding AGNs. Little is known about the dust in the circumnuclear torus of AGNs. There is evidence suggesting that the size and composition of the dust in AGNs may differ substantially from that of the Galactic interstellar dust, as reflected by the flat/"gray" or steep, SMC-like extinction, and the anomalous silicate emission or absorption features observed respectively in type 1 and type 2 AGNs. The silicate feature profiles of AGNs are rather diverse in peak wavelengths, widths, strengths, and band ratios of the 18 μm O--Si--O feature to the 9.7 μm Si--O feature, suggesting that the AGN silicate grains were probably not "born equal". We report our recent studies on dust in AGNs, with special attention paid to the silicate mineralogy. We place constraints on the silicate composition and size by modeling the Spitzer IRS spectra of AGNs of various types, using a simple plane-parallel slab radiative transfer method. We examine whether (and how) the silicate composition and size properties vary with the properties of an AGN (e.g. type, luminosity).

Modeling the Infrared Emission of C_{60}

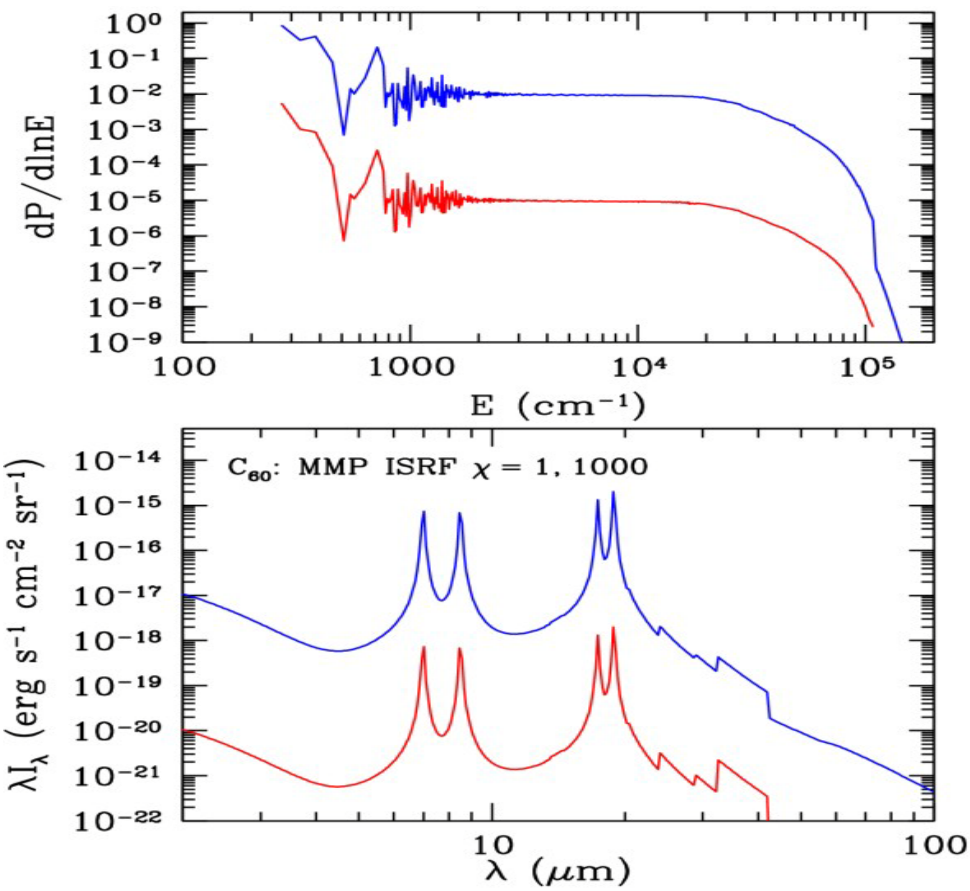
Aigen Li[1], B.W. Jiang[2] & J.X.Zhong[3]

[1]*University of Missouri* [2]*Beijing Normal University* [3]*Xiangtan University*

Neutral C_{60} has recently been detected in reflection nebulae, protoplanetary nebulae, planetary nebulae, Herbig Ae/Be stars, and young stellar objects through their characteristic infrared emission bands. We model the vibrational excitation of C_{60} and calculate the infrared emission spectra of C_{60} in a wide variety of regions (e.g. reflection nebulae excited by stars of a range of effective temperatures, (proto) planetary nebulae, and dust disks around Herbig Ae/Be stars). The strength of each band (per C atom) and the relative band strength are tabulated for these regions. By comparing with observed C_{60} spectrum, this table allowsone to derive the abundance of C_{60}, and the physical conditions (i.e. the starlight intensities).

Single-photon heating and IR emission spectrum of C_{60} illuminated by the general interstellar radiation field.

(Li, A., Jiang, B.W., & Zhong, J.X. 2013, ApJ, to be submitted)



The Dust Content of ELAIS-N1 Galaxies

Shalima Puthiyaveettil[1], Jayant Murthy[2], Ranjeev Misra[1], Amit Pathak[3], Rupjyoti Gogoi[3], Ranjan Gupta[1] and D. B. Vaidya[4]

[1]*IUCAA, Pune, India,* [2]*Indian Institute of Astrophysics, Bangalore, India,*[3]*Tezpur University, Tezpur, India,* [4]*Gujarat College, Ahmedabad, India*

Most of the mid-infrared (MIR) emission (3-40μm) from star-forming galaxies is due to thermal emission from dust grains heated by stellar radiation. The dust emission consists of two different components, i.e., broad emission features at 3.3, 6.2, 7.7, 8.6 and 11.3μm from molecules of sizes in the 6-20 Å range (Leiger and Puget 1984; Allamandola, Tielens & Barker 1985) and continuum emission from very small dust grains (15-40 Å, sometimes referred to as VSGs) (Sellgren 1984). The molecules as well as the VSGs are most likely to be made up of polycyclic aromatic hydrocarbons or PAHs which are known to have vibrational transitions at these wavelengths. They are excited by single photon heating and their MIR intensities are therefore independent of the radiation field density (Draine 2003). Their emission is correlated with cold dust emission at 160μm (Bendo et al. 2008), making them good tracers of the neutral ISM in galaxies (Peeters, Spoon & Tielens 2004). Laboratory studies have shown that neutral PAHs are excited mainly by UV photons (see Sellgren (2001) and references therein) and there have been several observations of these emission features in regions of intense UV radiation.

However, the detection of these emission features in regions with little UV radiation as well as in some early-type galaxies showed that they could also be excited by evolved stellar populations (for a recent review see Calzetti (2011)). The 8μm emission from PAHs is found to be strong outside HII regions where the smaller PAHs can survive and where they are irradiated by the general interstellar radiation field (ISRF) (Gordon et al. 2008; Helou et al. 2004). Since the PAH emission lines are associated with the diffuse ISM (Boulanger & Perault 1988) they are not good tracers of the current star formation rate of galaxies (Calzetti 2011).

On the other hand, the continuum emission from VSGs can only be excited by highly luminous UV emitting stars and is found to be associated with the centres of HII regions. Large ionized PAHs are the most likely carriers in this case as they are more stable than neutral ones in regions of high radiation fields. This is because larger PAHs are easily ionized making them better survivors in harsh environments, such as found near O-type stars. Zhu et al. (2008) have found a tight correlation between the 24μm (continuum emission from VSGs) and 70μm luminosities both of which are associated with hot dust. The 24μm continuum emission is one of the best indicators of the current star formation rate in the galaxy, since it is associated with hot massive stars.

These results suggest that the line and continuum emission are associated with different types of dust grains in different environments. Therefore using a combination of the MIR emission from VSGs and PAH molecules together with the UV emission from stars, we may expect to classify galaxies based on their stellar and dust content. In this work we have classified galaxies based on their UV and MIR emission in a region where there are observations in both the UV (from GALEX) and IR (from Spitzer) – the ELAIS-N1 field of the Spitzer Wide-area InfraRed Extragalactic Survey (SWIRE, Lonsdale et al. (2003)). We find that the PAH molecules are the main absorbers of UV radiation in galaxies where the strength of the radiation field is low while the absorption is split equally between PAHs and small grains in galaxies where the radiation field is high.

Silicate dust surface effects on H_2 formation: rotational temperature and nuclear spin conversion

L. Gavilan[1], J.L. Lemaire[1], G. Vidali[3,1], T. Sabri[2], C. Jäger[2]

[1]*Observatoire de Paris/Université de Cergy-Pontoise, 5 mail Gay Lussac, 95000 Cergy-Pontoise, France*

[2]*Laboratory Astrophysics Group, Friedrich Schiller University, 07743 Jena, Germany*

[3]*Syracuse University, Syracuse, NY 13244-1130, USA*

We have studied how silicate dust influences the formation of molecular hydrogen and how newly formed molecules are thereby affected by dust. In a joint collaboration, silicate analogs have been produced via laser ablation [1]. These dust grains are then processed to simulate inter- and circumstellar media conditions, providing extremes in: structure (fully crystalline or amorphous grains), and stoichiometry (the forsterite and fayalite end-members of the olivine family) [3-8].

These dust samples are then inserted in FORMOLISM, an ultra-high vacuum setup where they are cryogenically cooled (down to 5 K). Atomic beams are directed at the dust surfaces and the formation of new molecules is studied via REMPI(2+1) spectroscopy. With this technique, we explored the vibrational levels v”= 0 and 4 of the ground electronic state of H_2. These results are compared to those from the first silicate sample used in this setup, prepared by thermal deposition [2].

Surprisingly, the rotational structure of H_2 molecules following scattering on amorphous and crystalline grains is different. These results complement surface science studies usually performed on single crystal surfaces, and hint at the major role of surface structure. In addition, first-of-its-kind experiments have been performed to address the conversion of the nuclear spin of hydrogen on dust. These experiments had only been previously performed on icy surfaces. We deposited hydrogen molecules on both the Mg and Fe- rich dust surfaces and detected nuclear spin conversion in the presence of metallic oxides.

Because gas phase collisions are inefficient to form molecules in space, dust surfaces increase the atomic interaction timescale. We demonstrate that their structure and chemical composition affect the molecules that form on them and interact on their surface. We conclude that the analytic characterization of dust analogs is vital for our further understanding of the internal structure of molecules in space.

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An Investigation of the Mid-Infrared Extinction in the Galactic Plane Using AKARI data

Mengyao Xue[1], Jian Gao[1], B. W. Jiang[1]

[1]*Beijing Normal University, China*

The electromagnetic radiation from stars is dimmed and reddened by the absorption and scattering of interstellar dust which is known as the interstellar extinction. Measuring the variation of the interstellar extinction with wavelength, known as the interstellar extinction law, is crucial for properly restoring the color indices and the spectral energy distributions of celestial objects. It is also an important method to investigate the nature of the interstellar dust. Based on the data from the AKARI and Spitzer/GLIMPSE surveys, the mid-infrared extinction towards different sightlines in the Galactic Plane (GP) are derived, with RGB stars chosen as the extinction tracers. Using the color-excess method, the interstellar extinction at 9μm is derived for five different directions in the GP: $-10° < l < 10°$, $11° < l < 30°$, $31° < l < 65°$, $-30° < l < -11°$, and $-65° < l < -30°$. The average extinction at 18μm for all the GLIMPSE fields is also derived. The mean values of $A_{[9]}/A_{Ks}$ and $A_{[18]}/A_{Ks}$ are 0.466±0.165 and 0.350±0.125, respectively.

Dust in Molecular Clouds and the 3D Model of Interstellar Medium

Jiali Zhu and Maohai Hunag

National Astronomical Observatories, Chinese Academy of Sciences 20A Datun Road, Chaoyang District, Beijing, China

We use the Hi-GAL (the Herschel infrared Galactic Plane Survey) data to derive the 2D temperature map of the $l = 30°$ field by fitting spectral energy distribution (SED) of dust far infrared continuum. This temperature map indicates the dust absorption of FUV photons. Based on the temperature map, the distribution of molecular clouds derived from GRS data, and the properties of H II regions in the $l = 30°$ field, we construct the 3D model of ISM to calculate the absorption of dust grains associated with molecular clouds. The absorption calculated by 3D model is then projected to the Galactic Plane to derive a 2D simulated absorption map. The 2D absorbtion map varies with the 3D distribution of ISM density. We compare the simulated map with the one derived by SED fitting, to find a best-fit 3D distribution of ISM density. In the fitting process, Monte Carol method is applied. We find that the dust associated with molecular clouds can provied about 60% absorption in the $l = 30°$ field, indicating that 40% dust grains are not in molecular clouds.

Spiral Arms and Gaps in Protoplanetary and Protostellar Disks

James N. Imamura[1], Adrian E. Fraser[1], Erik Keever[1], and Rebecka Tumblin[1]

[1]*Institute of Theoretical Science, University of Oregon, Eugene, OR 97403, U.S.*

We modeled disk systems with properties typical of protostellar and protoplanetary disks to study the formation of spiral arms and gap structures in disks. We considered processes driven by gravitational instabilities (GIs) and embedded planetary cores. In particular, we modeled the development of spiral arms induced by nonaxisymmetric disk instabilities and Type I planetary core migration. Both processes are capable of producing low-m tightly wound spiral modes. Here, m is the azimuthal mode numbers for nonaxisymmetric modes with aziumthal dependence $\propto e^{im\phi}$. Tightly wound low-m modes may appear to show multiple dips. Further, for adiabatic disks with nearly constant specific angular momentum velocity distributions, the Toomre Q-parameter $Q > 10$ everywhere in the disks. The observational properties of the disks are determined from solution of the radiative transfer equation for the reflection of the stellar emission off the dust particles in the disk and through emission from dust particles in the disks, dust particles heated by hydrodynamic processes in the disk and by energy deposition in the disk by radiation from the central protostar using Monte Carlo techniques. The disk dust distribution is inferred from the mass distribution and velocity field of the gas in the disk.

High-resolution observations of protostellar and protoplanetary disks have recently revealed structure in the form of spiral arms and gaps in circumstellar disks. For example, observations of the Herbig-Haro object AB Aur have revealed two elliptical rings with major axes ~ 92 A.U.and 210 A.U., separated by an elliptical gap with major axis 170 A.U. (Fukugawa *et al.* 2004, Hashimoto *et al.* 2011). The ring/gap structure is seen in optically thick IR emission (Fukugawa *et al.* 2004) and optically thin sub-millimeter emission (Henning *et al.* 1998) suggesting that the features extend to the midplane of the disk and are more than corrugations in the surface density. Polarimetric high-resolution images obtained by the *Subaru* telescope have also revealed the presence of several dips in the intensity of the rings interpreted as spiral structures (Hashimoto *et al.* 2011). Hashimoto et al. noted that the appearance of the multi-armed spiral structure was consistent with expectations of GI. However, it was argued that GIs were not likely to be the explanation for the structure because of the large Q parameter estimated for the disk, $Q \sim 10$ (Pietu, Guilloteau, & Dutrey 2005) and other explanations such as gaps cleared by massive planetary cores (*e.g.*, Papaloizou & Terquem 2006) and spiral patterns excited by low-mass planetary cores (*e.g.*, Tanaka, Takeuchi, & Ward 2002) were proposed. We compare our numerical results with AB Aur and other protoplanetary systems to assess the viability of GIs as an explanation for the structure observed in protoplanetary and protostellar dust and gas/dust disks.

Outward Motion of Porous Aggregates in Protoplanetary Disks by Stellar Radiation Pressure

Ryo Tazaki[1], Hideko Nomura[1]

[1]*Kyoto University, Japan*

The Stardust mission and spectroscopic observations suggested the existence of crystalline silicates in comets(e.g., Brownlee et al. 2006). Although the comets were formed in the outer part of the protosolar nebula, these silicate grains are thought to be processed or crystallized in the inner hot region. This suggests that in the early phase of protoplanetary disks, there was a global motion that connects the inner and outer regions of disks.

We study the dust motion in a protoplanetary disk taking into account the stellar radiation pressure. Although the radiation pressure is effective only at the high latitude of the disk, the small dust grain can be stirred up to such latitude due to the turbulent mixing. We estimate the lower limit of the ratio of stellar gravity to radiation pressure, β, for porous aggregates and obtain the condition under which the aggregates in the inner disk can be carried to the comet formation region. Our calculation shows that the condition requires at least $\beta \sim 0.03$ for the aggregates with 1 micron size. Next, we investigate the optical properties of the porous aggregates and calculate β for a given incident radiation, using two different methods, the Maxwell-Garnett Mie theory and T-matrix method. Using the results, we discuss whether such outward motion is possible in the early solar system.

VLT/NACO Polarimetric Differential Imaging of HD169142

Mahesh Mohan[1], Tim Gledhill[1], Hector Canovas[2], Francois Menard[3], Antonio Hales[4], Matthias R. Schreiber[2] Andres Jordan[5], Simon Casassus[6]

[1]*Science and Technology Research Institute, University of Hertfordshire, College Lane, Hateld AL10 9AB, UK,* [2]*Departamento de Fsica y Astronoma, Universidad Valparaiso, Avenida Gran Bretana 1111, Valparaiso, Chile,* [3]*UMI-FCA, CNRS / INSU France (UMI 3386) and Departamento de Astronoma, Universidad de Chile, Santiago, Chile,* [4]*Joint ALMA Observatory, Alonso de Cordova 3107, Vitacura 763-0355, Santiago - Chile,* [5]*Departamento de Astronoma y Astrofsica, Pontificia Universidad Catolica de Chile, Santiago, Chile,* [6]*Departamento de Astronoma, Universidad de Chile, Casilla 36-D, Santiago, Chile,*

We present H band high contrast imaging data on the circumstellar disc of the Herbig Ae/Be star HD169142. The images were obtained through the polarimetric differential imaging technique with the adaptive optics system NACO. Previous polarimetric imaging of HD169142 have focused on the inner region of the circumstellar disc, while our observations use longer exposure times, allowing us to examine the edges of the disc. Current analysis shows distinct signs of polarization due to circumstellar material. The brightness profile is also being examined to locate any asymmetries in the disc.

Cooling Rate of Chondrule Estimated from Compositionally Zoned Olivine

Hitoshi Miura[1] and Tetsuo Yamamoto[2]

[1]*Nagoya City University, Japan*, [2]*Kobe University, Japan*

Chondrules are millimeter-sized and spherical-shaped crystalline grains consisting mainly of silicate material. Since chondrules occupy about 80 vol.% of chondritic meteorites in abundant cases, they must have rich information on the early history of our solar system. They are considered to have formed from molten droplets about 4.6 billion years ago in the solar nebula; it is believed that they melted and cooled again to get solidified in a short period of time. During the cooling process, some crystalline phases such as olivine and pyroxene grew from the bulk chondrule melt to form phenocrysts, and the residual melt solidified to form mesostasis. The cooling rate affects the size, morphology, and compositional zoning of phenocrysts, so many authors have investigated conditions for chondrule formation by crystallization experiments. However, the crystallization process has not been understood clearly because of a lack of theoretical considerations.

Compositional zoning in chondrule phenocrysts reflects the crystallization process from a molten chondrule melt droplet. We modeled the growth of phenocrysts from a silicate melt and proposed a new fractional crystallization model that provides a relation between the zoning profile and cooling rate. In our model, we took elemental partitioning at growing solid-liquid interface and time-dependent solute diffusion in liquid into consideration. We considered olivine as a model material because its thermodynamical properties are described by an ideal solution. In addition, we assumed equilibrium at the interface, namely, the concentrations at the interface are equal to equilibrium ones at a given temperature. We carried out numerical simulations of the fractional crystallization in one-dimensional system. The numerical simulations revealed that under a constant cooling rate the growth velocity of solid increases exponentially with time, and a linear zoning profile forms in the solid as a result. We obtained an analytic formulae of the zoning profile, which reproduces the numerical results for wide ranges of crystallization conditions. This analytic formulae would be a useful tool to estimate the cooling rate from compositional zoning. We applied the analytic formulae to the linear zoning profile in overgrown olivine phenocrysts and estimated the cooling rate to be $\sim 10^3$ K s^{-1}, which is orders of magnitude faster than that estimated previously from furnace-based experiments. Such high rate is consistent with the chondrule having cooled by radiation into ambient cool space.

Dust in the Deep Impact Ejecta Cloud during the First Seconds

Lev Nagdimunov[1], Ludmilla Kolokolova[1], Michael Wolff[2], Michael A'Hearn[1]

[1]*University of Maryland, USA,* [2]*Space Science Institute, USA*

In July 2005, Deep Impact space mission reached comet 9P/Tempel 1 and the spacecraft released an impactor that collided with the comet nucleus. The collision produced a large ejecta cloud with material excavated from the comet nucleus. The surprisingly thick cloud completely obscured the impact crater and cast a shadow on the surface of the comet nucleus. Analysis of the images taken by the Deep Impact Medium Resolution Instrument (MRI) showed that the shadow had a complex structure, thus revealing variations in optical thickness within the cloud. Over a few seconds of image data, the brightness distribution within the shadow changed with time, reflecting density and/or compositional variations of the dust in the ejecta cloud.

We model the scattering of sun light by the ejecta cloud to reproduce the shadow structure and its change with time. The modeling is based on the 3D radiative transfer code HYPERION[1]. Following [2], the ejecta cloud is presented as an oblique, hollow cone. The cone is populated with dust particles whose properties, primarily line-of-sight column and single scattering albedo, we adjust to get the best fit to the characteristics of the shadow. The variations in the properties of the dust that we study most likely reflect variations of the structure and composition of the nucleus of Comet Tempel 1, thus providing us an insight into the comet interior.

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Scaling and Structure of The Convective Velocity in A Vertically Vibrated Granular Bed

Tomoya Yamada and Hiroaki Katurgi

Department of Earth and Environmental Sciences, Nagoya University, Japan.

Miyamoto et al. reported that migrations and sorting on surface of the asteroid Itokawa could result from gravel fluidization induced by vibration caused by an impact [1]. It has not been considered that such phenomena occur under microgravity. In order to understand the mechanism of such phenomena, fundamental physics of vibrated granular matter must be revealed. When granular materials such as regolith are shaken, we can see various phenomena, e.g. convection, segregation, pattern formation, and so on. In this study, we study the granular convection by the experiment. Although many literatures have reported on both experimental and numerical studies of granular convection [2-5], most of them have used spherical grains as constituents. In general, geophysically relevant sand grains are not spherical. Thus, we use rough shaped sand as well as spherical glass beads, to examine the influence of grains shape to the granular convection. In the experiment, we investigate the global structure of granular convection and measure the convective velocity, and estimate the relation between the convective velocity and gravity with dimensional analysis.

The experimental setup consists of a cylinder made by plexiglass of 75 mm inner diameter and 150 mm height, which is mounted on an electromechanical vibration exciter (EMIC 513-B/A). The vibrator frequency f is varied from 10 to 300 Hz and the dimensionless vibrational acceleration is varied from 2 to 6. The grains used are glass beads (0.8 mm in diameter) and JIS (Japan Industry Standard) standard sand (from 0.71 mm and 1.4 mm in diameter). The height of granular layer is fixed to 50 mm. We use a high-speed camera (Photoron SA-5) with a macro lens to record the motion of grains at 1000 fps. PIV (Particle imaging velocimetry) method is used to compute the convective velocities on the side wall of the container.

We find that the global structure of convection shows a transition from single cycle roll to doughnut like roll as f increases. In the former, grains rise up on the one side wall and fall down on the other side wall. In the latter, grains rise up at the center of container and fall down on all over the wall. We also find that the convective velocity field of sand grain seems to have spatial and temporal inhomogeneities.

By the systematic dimension analysis, we find that the maximum convective velocity can be scaled by the characteristic velocities of gravity and vibration. The obtained scaling implies that the convective velocity decrease as the gravitational acceleration is reduced.

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Dust, chemical evolution and origins of life on Earth

Michael B. Simakov

Group of Exobiology, Institute of Cytology RAS, Tikhoretsky Av., 4, St.Petersburg, 194064, Russia

Since cosmic dust is the most primitive matter of the Solar System it could played a major role in bringing organic matter to the early Earth, enabling the prebiotic synthesis of the biochemical compounds. The dust particles are composed of a heterogeneous mixture of amorphous and crystalline silicates, organic material, and other minor constituents.

All young solar system objects are subjected to energetic processing by photons and ions. As a result, the chemical and physical properties of the materials composing these objects will change over time significantly. Energetic processing of organic compounds into more complex species can be driven by significantly enhanced UV field in star-forming regions, high energy particle bombardment and UV-radiation from the T-Tauri phase in stellar birth, and UV-radiation of different wavelengths, protons of Solar wind and flares at early stage of evolution and at present days. The «simulated space ice conditions» experiments have shown the synthesis of simple biochemical compounds in the form of amino acid's precursors (Bernstein et al., 2002; Munoz Caro et al., 2002) and pyrimidine bases (uracil, cyrosine and thymine) of the nucleic acids (Kobayashi et al., 2004). Our investigation dealt with further reaction of nucleic acid components to nucleotides – main components of RNA and DNA, and single amino acids to oligopeptides.

We have shown experimentally that the solid mixtures of amino acids produce more complex compounds when they are exposed to open space energy sources. Both irradiation and photolysis may destroy molecules as well as allow the synthesis of new and more complex ones. The chemical reaction of solid-state amino acids induced by different energy sources has been of increasing interest in several fields such as chemical evolution, polymerization of simple molecules, origin of homochirality in biomolecules and so on.

We investigated two types of reactions: (1) abiogenic synthesis of nucleotides from mixtures of nucleoside + inorganic phosphate; (2) abiogenic synthesis of dipeptides from mixtures of simple amino acids. As a result of VUV irradiation of the mixture of nucleoside and inorganic phosphate the natural monophosphates of corresponding nucleosides were found. The films containing a mixture of amino acids yielded various oligopeptides with summary yields of ~2.5% and ~2% after they were exposed to protons and VUV-radiation, respectively. Polymerization is an essential step in prebiological evolution and we have shown that this process probably could take place even at early stage of the Solar system formation, before planet accretion, on surface of cosmic dust.

In space flight experiment onboard of «BION-11» satellite the solid films from mixtures of different nucleosides and inorganic phosphate were exposed to space conditions. The abiogenic synthesis of the full set of the natural nucleotides is observed. In the last space experiments we also studied the in influence of mineral substrates on the reaction of oligomerization of amino acids in open space/ Simple oligopeptides can be formed on solid material not only by VUV-light but also by proton radiation, heat, and gamma-radiation. Thus, it can be assumed that the chemical evolution would have taken place during the early stage of the Solar system on the surface of dust particles.

Dust Impact Monitor DIM onboard Rosetta/Philae: Comparison of experimental results and the theory behind the instrument

Harald Krüger[1], Walter Arnold[2,3], Hans-Herbert Fischer[4], Alberto Flandes[5], Attila Hirn[6], Alexander Loose[1], Klaus Seidensticker[7], Matthias Sperl[8]

(1) MPI für Sonnensystemforschung, Katlenburg-Lindau, Germany; (2) Department of Materials, Saarland University, Saarbrücken, Germany; (3) 1. Phys. Institut, University of Göttingen, Germany; (4) DLR, Space Operations, MUSC, Köln, Germany; (5) Ciencias Espaciales, Instituto de Geofísica, UNAM, México; (6) MTA Centre for Energy Research, Budapest, Hungary; (7) DLR, Institute for Planetary Research, Berlin, Germany; (8) DLR, Institut für Materialphysik im Weltraum, Köln, Germany

1. Abstract

The Rosetta lander spacecraft Philae will land on the nucleus surface of comet 67P/Churyumov-Gerasimenko in November 2014. Philae is equipped with the Dust Impact Monitor (DIM). DIM is part of the SESAME instrument package onboard Philae [Seidensticker et al., 2007] and employs piezoelectric PZT sensors to detect dust particle impacts. The sensors are mounted on the outer side of a cube, facing in orthogonal directions, this way allowing for the detection of grains approaching normal to the nucleus surface and from two horizontal directions. DIM's total sensitive area is approximately $70\,\mathrm{cm}^2$. It will measure impacts of sub-millimeter and millimeter sized ice and dust particles that are emitted from the nucleus and transported into the cometary coma by the escaping gas flow. A grain-size dependent fraction of the emitted grains is expected to fall back to the nucleus surface due to gravity. DIM will be able to detect both these components, the backfalling particles as well as the grains hitting the detector on direct trajectories from the surface. With DIM we will be able to measure fluxes, impact directions as well as the speed and size of the impacting cometary particles.

We studied the performance of DIM based on impact experiments and compare the measurements with the sensor's expected theoretical behaviour as derived from Hertz' theory of elastic impact. We simulated impacts onto the DIM sensor with spherical particles of different materials (steel, glass, ruby, polyethylene), particle radii between 0.2 and 0.5 mm and impact speeds up to $2\,\mathrm{m\,s^{-1}}$ [Flandes et al., 2013]. Cometary grains on ballistic trajectories will have impact speeds below the escape speed from the nucleus surface (approximately $1.5\,\mathrm{m\,s^{-1}}$), thus the impact speeds achievable by our experiments cover the range expected at the comet. Our results show that the signal strength and the contact times measured with the DIM PZT sensors can be well approximated by Hertz' contact mechanics.

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Temperature Profiles and Turbulent States of Circumplanetary Disks

Yuri I. Fujii[1], Sanemichi Z. Takahashi[1], Satoshi Okuzumi[2], and Shu-ichiro Inutsuka[1]
[1]Nagoya University [2]Tokyo Institute of Technology

Circumplanetary disks, which form around gaseous planets, are thought to be the formation sites of satellites. In order to make realistic models of satellite formation, we need to know the temperature profiles and mass accretion rates of circumplanetary disks. These properties strongly depend on not only turbulence but also the disk opacities that are mainly due to dust grains.

In our previous work, we focused on magnetic turbulence driven by the magnetorotational instability (MRI). For a disk to sustain the MRI, gas must be sufficiently ionized. However, we found that non-thermal ionization –due to cosmic rays, X-rays from the host star, and the decay of radionuclides– is insufficient to drive MRI turbulence. If there is no effective gas accretion mechanism other than the MRI, a circumplanetary disk becomes very massive and gravitationally unstable due to gas infall from the surrounding protoplanetary disk. Once gravitational instability occurs, a disk becomes turbulent. If gravitational turbulence is dissipated as heat in situ, viscous heating may cause thermal ionization and thereby the MRI. The disk temperature profile strongly depends on opacity, and if there are sufficient dust grains the temperature will readily increase such that the disk can sustain the MRI. If MRI turbulence is too strong however, the disk becomes thin and opacity will decrease. In this presentation, we will discuss the conditions for a circumplanetary disk to sustain MRI turbulence.