COSMIC DUST ABSTRACTS

Probing the Interstellar Dust in Galaxies over >10 Gyr of Cosmic History

Varsha P. Kulkarni

Dust has a profound effect on the physics and chemistry of the interstellar gas in galaxies and on the appearance of galaxies. Understanding the cosmic evolution of dust with time is therefore crucial for understanding the evolution of galaxies. Despite the importance of interstellar dust, very little is known about its nature and composition in distant galaxies. We describe the results of our ongoing programs using observations of distant quasars to obtain better constraints on dust grains in foreground galaxies that happen to lie along the quasar sightlines. These observations consist of a combination of mid-infrared data obtained with the Spitzer Space Telescope and optical/UV data obtained with ground-based telescopes and/or the Hubble Space Telescope. The mid-IR data target the 10 and 18 μm silicate absorption feature, while the optical/UV data allow determinations of extinction curves, 2175 Å bumps, element depletions etc. Measurements of such properties in absorption-selected galaxies with redshifts ranging from z ~0 to z > 2 provide constraints on the evolution of interstellar dust over the past > 10 Gyr. The optical depth of the 10 μm silicate absorption feature (τ_{10}) in these galaxies correlates well with the amount of reddening along the sightline. But there are indications [e.g., based on the τ_{10} / E(B-V) ratio, possible grain crystallinity] that suggest that the dust in these distant galaxies may differ in structure and composition from the dust in the Milky Way and the Magellanic Clouds. We discuss the implications of these results for the evolution of galaxies and their star formation history.

This work is supported in part by NASA through grant NNX14AG74G and an award issued by Jet Propulsion Laboratory/California Institute of Technology, and by the US National Science Foundation grants AST-0908890 and AST-1108830 to the University of South Carolina.

Gamma-ray burst afterglows: Dust extinction properties from low to the high redshift Universe

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Long duration Gamma-ray bursts (GRBs) are powerful spectacles since the Big Bang. The long duration GRBs are associated with the death of massive stars, have simple intrinsic power-law spectrum, and their cosmological occurrence stretches out to the epoch of reionization, a time when the first galaxies and stars were forming. These advantages make GRBs potentially unique and effective probes to study dust extinction in the Universe over broad range of redshifts. The knowledge of the dust properties in GRB host galaxies is very useful to understand the interstellar medium of high redshift galaxies and the cosmic star-formation history. Using an X-ray and optical spectroscopic sample of GRB afterglows, we construct the spectral energy distributions to determine the dust extinction in the GRB local environment. It is found that usually the featureless Small Magellanic Cloud type extinction law could explain these data. However, the rare Milky Way type 2175Å extinction feature is also seen in five GRB cases, with a large diversity of extinction curve shapes. This suggests that GRBs occur in diverse environments from young, low-mass, blue galaxies to the evolved, massive, red galaxies. Moreover, presence of various extinction laws hints the nature of the dust (grain population, sizes and composition), varying from silicates to carbonaceous grains. The results indicate a decrease in dust content in star-forming environments at high redshifts.

A Statistical View of the Evolution of Grain Size Distribution and Extinction Curve in Galaxies

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The evolution of dust in galaxies is characterized by two aspects; dust abundance and grain size distribution, both of which are important in determining the radiative properties of galaxies through dust extinction and emission. Recently we have been developing a theoretical framework that treats these two aspects consistently. In this presentation, we introduce our model of dust enrichment in a galaxy with a simplified treatment of grain size distribution [1].

We include in the model dust supply from stellar ejecta, destruction in supernova shocks, dust growth by the accretion of gas-phase metals, grain growth by coagulation and grain disruption by shattering, and consider how these processes work on the small and large grains. In spite of its simplicity, the model correctly catches the same features of dust evolution as is shown by a full treatment of grain size distribution [2]: Dust enrichment starts with a supply of large grains from stars. At a metallicity level, referred to as the critical metallicity of accretion, the abundance of small grains formed by shattering becomes large enough to increase grain abundance rapidly by accretion. Associated with this epoch, the abundance ratio of small grains to large grains reaches a maximum. Afterwards, this ratio converges to the value determined by the balance between shattering and coagulation, and the dust-to-metal ratio is determined by the balance between accretion and shock destruction.

Using a Monte Carlo simulation, we demonstrate that the simplicity of our model has an advantage in predicting statistical properties of galaxies. We also present some applications for predicting observational dust properties such as extinction curves. In particular, our models are computationally light; thus, they are suitable for parameter survey studies, which are indeed useful in finding a dust evolution scenario that reproduces the variety of extinction curves observed in nearby galaxies [3].

References

[1] Hirashita, H. 2015, MNRAS, 447, 2937

[2] Asano, R., Takeuchi, T. T., Hirashita, H., & Nozawa, T. 2013, MNRAS, 432, 637

[3] Hou, K.-C., & Hirashita, H. 2015, in preparation

Dust-regulated galaxy formation and evolution

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I will discuss how interstellar dust influences galaxy formation and evolution processes based on the results of my new chemodynamical simulations with dust physics (Bekki, K., 2015, ApJ, 799, 166; Bekki, K., 2015, MNRAS, 449, 1625). The galaxy-scale simulations include, for the first time, various dust-related physical processes in interstellar medium (ISM), such as photoelectric heating, H2 formation on dust, and stellar radiation pressure on dust. A novel point of the simulations is that different dust species in a galaxy are represented by `live dust' particles (i.e., not test particles). Therefore, dust particles in a galaxy not only interact gravitationally with all four components of the galaxy (i.e., dark matter, stars, gas, and dust) but also are grown and destroyed through physical processes of ISM. The preliminary results are as follows. The evolution of dust distributions driven by radiation pressure of stars is very important for the evolution of star formation rates, chemical abundances, H2 fractions, and gas distributions in galaxies. The evolution of silicate and carbonaceous dust is quite different (e.g., in the evolution of their spatial distributions) in galaxies, if these dust grains are under strong radiation pressure of the stars. The radial distributions of dust can be significantly influenced both by galaxy-scale dynamics and by radiation pressure in disk galaxies. I will discuss several key implications of these results in the context of galaxy formation and evolution and the origin of pre-solar grains.

Presolar grains in meteorites

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Presolar grains are defined as grains formed in the stellar outflow or ejecta, and were preserved in meteorites. These dust grains retain memory of their birthplaces, exhibiting huge isotopic anomalies that cannot be explained by process occurring in the solar system. Mineral types of presolar grains include diamond (Lewis et al. 1987), SiC (Bernatowicz et al. 1987; Tang & Anders 1988), graphite (Amari et al. 1990), Si_3N_4 (Nittler et al. 1995), oxides (Huss et al. 1994; Hutcheon et al. 1994; Nittler et al. 1994), refractory carbides inside host grains (Bernatowicz et al. 1991; 1996; Croat et al. 2003), and silicates (Messenger et al. 2003; Mostefaoui & Hoppe 2004; Nagashima, Krot, & Yurimoto 2004; Nguyen & Zinner 2004). Their abundances range from a few ppb (Si_3N_4) to a few hundred ppm (diamond and silicates) (Huss & Lewis 1995; Floss & Stadermann 2012). Studies of these grains have yielded a wealth of information about nucleosynthesis in stars, mixing in stellar ejecta, and the Galactic chemical evolution (= temporal variation of isotopic and elemental abundances in the Galaxy).

In this talk, I will review what we have learned from presolar grains, and discuss biases in presolar grain populations in meteorites due to experimental methods of identification and isolation to help better understand differences and similarities of presolar grains and grains from other observations.

References

Amari, S., Anders, E., Virag, A., & Zinner, E. 1990, Nature, 345, 238

Bernatowicz, T., Fraundorf, G., Tang, M., Anders, E., Wopenka, B., Zinner, E., & Fraundorf, P. 1987, Nature, 330, 728

Bernatowicz, T. J., Amari, S., Zinner, E. K., & Lewis, R. S. 1991, Astrophys J, 373, L73

Bernatowicz, T. J., Cowsik, R., Gibbons, P. C., Lodders, K., Fegley, B., Jr., Amari, S., & Lewis, R. S. 1996, Astrophys J, 472, 760

Croat, T. K., Bernatowicz, T., Amari, S., Messenger, S., & Stadermann, F. J. 2003, Geochim Cosmochim Acta, 67, 4705

Floss, C., & Stadermann, F. 2012, Meteorit Planet Sci, 47, 992

Huss, G. R., Fahey, A. J., Gallino, R., & Wasserburg, G. J. 1994, Astrophys J, 430, L81

Huss, G. R., & Lewis, R. S. 1995, Geochim Cosmochim Acta, 59, 115

Hutcheon, I. D., Huss, G. R., Fahey, A. J., & Wasserburg, G. J. 1994, Astrophys J, 425, L97

Lewis, R. S., Tang, M., Wacker, J. F., Anders, E., & Steel, E. 1987, Nature, 326, 160

Messenger, S., Keller, L. P., Stadermann, F. J., Walker, R. M., & Zinner, E. 2003, Science, 300, 105

Mostefaoui, S., & Hoppe, P. 2004, Astrophys J, 613, L149

Nagashima, K., Krot, A. N., & Yurimoto, H. 2004, Nature, 428, 921

Nguyen, A. N., & Zinner, E. 2004, Science, 303, 1496

Nittler, L. R., Alexander, C. M. O'D., Gao, X., Walker, R. M., & Zinner, E. K. 1994, Nature, 370, 443

Nittler, L. R., et al. 1995, Astrophys J, 453, L25

Tang, M., & Anders, E. 1988, Geochim Cosmochim Acta, 52, 1235

Formation and properties of astrophysical carbonaceous dust. I: *ab-initio* calculations of the configuration and binding energies of small carbon clusters

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The binding energies of $n < 100$ carbon clusters are calculated using the *ab-initio* density functional theory code *Quantum Espresso*. Carbon cluster geometries are determined using several levels of classical techniques and further refined using density functional theory. The resulting energies are used to compute the work of cluster formation and the nucleation rate in a saturated, hydrogen-poor carbon gas. Compared to classical calculations that adopt the capillary approximation, we find that nucleation of carbon clusters is enhanced at low temperatures and depressed at high temperatures. This difference is ascribed to the different behavior of the critical cluster size. We find that the critical cluster size is at $n = 27$ or $n = 8$ for a broad range of temperatures and saturations, instead of being a smooth function of such parameters. The results of our calculations can be used to follow carbonaceous cluster/grain formation, stability, and growth in hydrogen poor environments, such as the inner layers of core-collapse supernova and supernova remnants.

On the Reddening Law Observed for Type Ia Supernovae

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The reddening of Type Ia supernovae (SNe Ia) by dust grains is one of the largest uncertainties that limit the current precision of the cosmological parameters. In particular, the total-to-selective extinction ratios, *Rv*, along the lines of sight to SNe Ia are known to be considerably low (*Rv*=1.0-2.0), compared to the average value (*Rv*=3.1) in the Milky Way. The origin of such an unusually low *Rv* is thus an important issue to be resolved for the applicability of SNe Ia as the cosmic standard candles, and also casts challenging problems in modelling the extinction properties by dust grains as well as the intrinsic emission spectrum of SNe Ia.

Many researchers have believed that the low *Rv* observed for SNe Ia is the consequence of the scattered light echo, i.e., multiple scattering of photons in the circumstellar dust shell with an optical depth of $\tau_V \sim 1$ in V band (Wang 2005, ApJ, 635, L33; Goobar 2008, ApJ, 686, L103). If there are such moderately optically thick dust shells around SNe Ia, we also expect the infrared (IR) light echo, i.e., thermal emission from circumstellar dust heated by the SN radiation. Johansson et al. (2013, MNRAS, 431, L43) observed three nearby SNe Ia about a few months post-explosion with *Herschel*, but only gave an insignificant upper limit of $M_{dust} \sim 0.01$ M_{sun} as the mass of circumstellar dust. This limit is well above $M_{dust}=10^{-4}$ Msun, with which circumstellar dust can cause an unusually low *Rv* through the multiple scattering (Amanullah & Goobar 2011, ApJ, 735, 20).

In this talk, we report the MIR photometric observations of SN 2014J about one year after the explosion with Subaru COMICS. SN 2014J is a normal Type Ia supernova discovered on 21 Jan in 2014, and the distance to the host galaxies (M82) is 3.5 Mpc, which is the nearest among SNe Ia reported in the last thirty years. This SN is highly reddened and indicates a low value of *Rv* =1.4 (Amanullah et al. 2014, 788, L21). Therefore, given its close proximity and high extinction, SN 2014J offers the best opportunity to date to search for the circumstellar dust.

From the results of this IR observation, we will show the distribution of the dust shell around SN 2014J or we will put much better constraints on the upper mass limit of circumstellar dust than that ($M_{dust} \sim 10^{-2}$ Msun) from the previous work with *Herschel*. We note that the non-detection of IR light-echo can allow us to conclude that a very low Rv seen in SNe Ia cannot be due to the multiple scattering by circumstellar dust, so it must be the interstellar dust origin. We also discuss the properties of interstellar dust to reproduce the reddening law as low as *Rv* =1.4.

Physical Dust Models for the Extinction toward Supernova 2014J

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Type Ia supernovae (SNe Ia) are powerful cosmological standardizable candles and the most precise distance indicators. However, the ultimate limiting factor in their use for precision cosmology rests on our ability to correct for the dust extinction toward them. SN 2014J in the starburst galaxy M82, the closest detected SN Ia in three decades, provides unparalleled opportunities to study the dust extinction toward this SN. In order to derive the extinction as a function of wavelength, we model the color excesses toward SN 2014J observationally derived over a wide wavelength range in terms of dust models consisting of a mixture of silicate and graphite.The resulting extinction laws steeply rise toward the far ultraviolet, even steeper than that of the Small Magellanic Cloud (SMC). We infer a visual extinction of $A_{\rm V} \approx 1.9$ mag, a reddening of $E(B-V) \approx 1.1$ mag, and a total-to-selective extinction ratio of $R_{\rm V} \approx 1.7$, consistent with that previously derived from photometric, spectroscopic and polarimetric observations. The size distributions of the dust in the interstellar medium toward SN 2014J are skewed toward substantially smaller grains than that of the Milky Way and the SMC.

The Interstellar Extinction Law in the Near- and Mid-Infrared Based on the APOGEE Spectroscopic Survey

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It is widely accepted that the interstellar extinction law in UV/optical differs apparently in the diffuse and dense environments and can be parameterized by the ratio R_V of the total extinction in the visual band A_V to the color excess $E(B-V)$. Meanwhile, the variation of the extinction law in the infrared has no such consensus. Whether or how the law changes with sightline or environment is controversial. An important reason for the discrepancy between studies is that previous studies are mostly based on stellar photometry, in which the uncertainty is induced when assuming a constant intrinsic color for the selected extinction-tracer sample stars and brings about the uncertainty of the results. With the availability of stellar parameters (mainly $T_{\rm eff}$, log g and Z) from the APOGEE spectroscopic survey, the stellar intrinsic colors can be calculated with significantly higher accuracy than from photometry only. Based on this spectroscopical database, the intrinsic colors of giant stars are derived by taking the blue envelop in the color index vs. $T_{\rm eff}$ diagram. Using the newly determined intrinsic colors, the near- and mid-infrared extinction law is revisited. The extinctions relative to the K_S band are derived in the 1-20μm range, covering the photometric bands involved in the 2MASS, WISE, Spitzer/IRAC and AKARI surveys. The near-infrared extinction law is found to be universal in a wide range of interstellar extinction with a stable $E(J-H)/E(J-K_S)$~0.64, corresponding to a power law index of 1.95. With the WISE and AKARI bands for the first time to be taken into account, the mid-infrared extinction law is more completely covered and still agrees with previous results, being much flatter than classical interstellar dust model derived from UV/optical extinction curve.

Measurement of binding of oxygen on dust grains (amorphous silicates and amorphous water ice): consequences for oxygen chemistry in the interstellar medium

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We performed experiments to quantify the ability of dust grain analogues to hold atomic oxygen[1]. We find that atomic oxygen is retained on an amorphous silicate surface with a much higher binding energy (1850K ± 90K) than previously estimated (800K). We then used such value in the simulation of the chemical evolution of an interstellar environment – a molecular cloud edge in star-forming regions in Orion exposed to FUV illumination, and found that OH and H_2O formation on grains is considerably enhanced while O formation is suppressed because of the higher O binding energy. These effects are especially important in dense gas exposed to high FUV fields because of the wider temperature range in which oxygen can reside. Because of the higher binding energy, photodesorption controls the gas phase chemistry. Consequences of this discovery for observations will be discussed.

This work is supported by the NSF Astronomy and Astrophysics Division (Grant No.1311958 to GV) and by NASA support for US research with the Herschel Space Observatory (RSA No. 1427170 to MJK).

[1] He et al. Astrophys.J., 801, 120 (2015)

Using Spinning Dust Emission To Constrain The Abundance Of Small Dust Grains In Dense Cores

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Within many molecular clouds in our Galaxy there are cold, dense cores in which stars form. These dense environments represent a crucial step in the life cycle of dust and provide a great location in which to study dust grain evolution. However, the size distribution of dust grains in these environments is still the subject of much debate. In this analysis we constrain the abundance of small dust grains in a sample of dense cores using cm observations of spinning dust emission. If small dust grains are present in these cores, then even though stellar photons cannot penetrate deep enough to excite them to emit at mid-IR wavelengths, the small dust grains will be spun-up by collisions and emit spinning dust radiation. Therefore spinning dust emission can be used as a direct probe of the small dust grains in these cores. With this in mind, we present the first attempt to observe spinning dust emission in molecular cores and use it to constrain the abundance of the small dust grains, and hence help to determine the evolution of dust within these dense environments.

Dust evolution in protoplanetary disks

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The first steps of planet formation are believed to be the growth of initially small, micrometric dust grains and their decoupling from the gas phase via vertical settling and radial migration. With the advent of ALMA and extreme adaptive optics system, such as MagAO, SPHERE or GPI, it is now possible to probe the dust in disks at resolutions of about 0.05 arsec from the optical to the millimeter regimes. Recent observations have revealed a incredible diversity of structures in the dust phase of disks, with gradients of dust properties, gaps, spirals, dust traps, ...

In this talk, I will present a few of these recent results and illustrate how these observations can be coupled to detail models in order to put quantitative constraints on the evolution of dust grains and on the mechanisms of planet formation.

Ejecta mass produced at collisions of monomers against large dust aggregates

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Collisional growth of dust aggregates is one of the essential processes to form planetesimals. High-velocity collisions produce a large number of small aggregates as ejecta fragments. Since ejecta would play an important role in dust growth and the total ejecta mass is a key to determine the mass loss rate through collisional cascades, we need a model of ejecta mass at high-velocity collisions of dust aggregates [1]. In our previous study, we numerically investigated collisions between aggregates with high mass ratio, i.e., collisions of small aggregates (impactor) against large aggregates (target) [2]. As a result, we found a useful and important scaling relation that the ejecta mass produced at collisions of high mass ratios is proportional to not the kinetic energy but the momentum of impactors. This is interpreted as that the impact energy is sufficiently dissipated within aggregates and the ejecta fragments are driven by the momentum of impactors. There remains, however, a question about the application limit of this scaling relation: What is the effective range of mass ratio for the scaling? To investigate this, we test collisions of monomers against large aggregates as an extreme case of the mass ratio using our numerical code. On the contrary to the previous results, we obtained preliminary results showing that the ejecta mass is proportional to the kinetic energy of monomer impactors. This relation would indicate that the kinetic energy of monomers is directly transferred to the ejecta fragments without significant dissipation. This result is inconsistent with other laboratory experiments [3] and numerical simulations [4]. We discuss the reason of the discrepancy and the application limit of the scaling relation giving ejecta mass at dust aggregate collisions.

[1] Kobayashi, H., & Tanaka, H. 2010, Icarus, 206, 735.
[2] Wada, K., Tanaka, H., Okuzumi, S., Kobayashi, H., Suyama, T., Kimura, H., & Yamamoto, T., 2013, A&A, 559, A62.
[3] Schräpler, R., & Blum, J., 2011, ApJ, 734, 108.
[4] Seizinger, A., Krijt, S., & Kley, W., 2013, A&A, 560, A45.

How to put Heated Grains into Frozen Comets

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Comets are rich in water ice and must have formed in the outer parts of the solar system. Yet samples from Comet Wild 2 contain abundant refractory grains including CAIs (Brownlee et al. 2006). CAIs are thought to have formed during a brief period in the hot inner region of the solar nebula. We suggest that CAIs can be transported within the disk by hydrodynamic processes. We model the solar nebular as a marginally gravitationally unstable disk such as is thought to occur during the FU-Orionis stage of a young star. We follow trajectories of small (0.1 - 10 cm) melilite grains through the disk as they interact with the spiral arms formed in the disk (Boss 2008, Haghighipour and Boss 2003).

Such grains can traverse large regions of the disk and visit regions that are at radial distances of 1 to 10 AU. During these journeys the grains experience temperatures that vary from 60 K to more than 1500 K (Boss et al. 2012). This leads to an interaction with the surrounding gas that includes vaporization of the melilite grain, recondensation of the evaporated material, and condensation of water vapor as well. Typical trajectories will be shown and the resulting grain structure discussed. Some additional results for larger particles, up to 10 m will be presented and the implications for the composition of small bodies will be discussed.

References

Boss, A.P., 2008. Mixing in the solar nebula: implications for isotopic heterogeneity and large-scale transport of refractory grains. Earth Planet. Sci. Lett. 268, 102-109.

Boss, A.P., Alexander, C.M.O., and Podolak, M., 2012. Cosmochemical consequences of particle trajectories during FU Orionis outbursts by the early Sun. Earth Planet. Sci. Lett. 345, 18-26.

Brownlee, D. E. et al.,2006. Comet 81P/Wild 2 under a microscope. Science 314, 1711-1716.

Haghighipour, N., Boss, A. P., 2003. On pressure gradients and rapid migration of solids in a nonuniform Solar Nebula. Astrophys. J. 583, 996-1003.

Dust and Gas in Protoplanetary Disks

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The internal physical and chemical structure of protoplanetary disks is fundamentally important to understand how planets form. To infer this structure from observations, new 'holistic' disk models have been developed which include detailed 2D dust and PAH radiative transfer, thermo-chemical gas and ice modeling, and 3D diagnostic radiative transfer to consistently predict all kinds of line and continuum observations from optical to centimeter wavelengths.

The dust size and opacity parameters applied in the models are found to have a decisive influence on most predicted observations, not only on the continuum observations (as expected), but also on the resulting gas temperatures, chemical composition, and line observations. More evolved dust properties (larger grains) and stronger dust settling are generally found to amplify gas emission lines at optical to far-IR wavelengths, because the heating UV radiation can penetrate deeper into the disk gas in these cases. This could possibly imply that the observation of gas emission lines can help to determine dust properties in protoplanetary disks. We are proposing new dust opacities for protoplanetary disk models, which account for the properties of evolved dust, aiming at setting new disk modeling standards.

[(1)]: European FP7 project about the *Analysis and Modelling of Multi-wavelength Observational Data from Protoplanetary Discs*, see `http://www.diana-project.com`.

Dust formation and the emergence of ionised clouds in atmospheres of planetary objects

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Brown dwarfs and extrasolar atmospheres are forming clouds that can be very different from clouds on solar system planets. Such clouds resample what is commonly know as 'comsic dust' in form of mineral particles of varying sizes. Recent observational effords point to the need of a fundamental modelling bejond the widly used S=1-ansatz in modelling ultra-cool atmospheres and their spectral energy distribution. We have therefore developed a cloud formation model that treats
– seed formation (nucleation) via the formation of larger and larger clusters,
– growth/evaporation through gas-solid surface reactions
– element conservation
– gravitational settling,
which allows for a detailed modelling of material composition, cloud particles sizes, number of dust particles and the feedback on the local gas chemistry. While cluster data for nucleation modelling (seed formation) can be obtained via computational chemistry methodes, material data required to model the surface growth, like reaction efficiencies for individual surface reactions, are sparcely available. The impact of data uncertainties on cloud properties like grains size and number will be demonstrated. Recent developments in charge and discharge processes in ultra-cool atmosphere that might influence the cloud particle population, their chemistry as well as the gas-phase chemistry will be discussed.

Debris disks:
Seeing dust, thinking of asteroids, comets, and planets

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Dust is seen to orbit many main-sequence stars, and in many cases is thought to originate from ongoing collisions with a mass reservoir of larger objects. Thus, these populations of circumstellar dust are generically known as “debris disks”. The large bodies that supply the dust can be the leftovers of planet formation (asteroids and comets) or planetary embryos that are still growing and will reach planet status in the future. As shown by the cometary contribution to our Zodiacal cloud, the bodies that supply the dust may not originate where the dust is observed. Because relatively small masses of dust can be detected by scattered light and thermal emission, debris disks provide a unique window into the formation and evolution of planetary systems.

The dust has been detected at all possible locations around other stars, in some cases residing at a few stellar radii and in others extending to thousands of astronomical units. Generally, the closer any detected dust is to the star, the more poorly it is understood. The cool belts seen beyond tens o AU are thought to be analogues of our Edgeworth-Kuiper belt, but the warm “exo-Zodi” may be Asteroid belt analogues, the aftermath of planetary-scale collisions, or extreme versions of our own Zodiacal cloud supplied by comets scattered in from elsewhere. The “hot dust” phenomenon seen towards 30% of nearby stars is currently being treated as a debris disk problem, but could in fact be more relevant to stellar astrophysics.

I will discuss the debris disks in general, and talk about their strengths and weaknesses as a probe of the properties of extra-Solar planetary systems. I will focus on the current challenges, and areas where a better of understanding of the dust is needed for progress.

Dust and Polycyclic Aromatic Hydrocarbon in the Debris Disk of HD 34700

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The debris disk around the Vega-type star HD 34700 is detected in dust thermal emission from the near infrared (IR) to millimeter (mm) and submm wavelength range. Also detected is a distinct set of emission features at 3.3, 6.2, 7.7, 8.6, 11.3 and 12.7 μm which are commonly attributed to polycyclic aromatic hydrocarbon (PAH) molecules. We model the observed dust IR spectral energy distribution (SED) and PAH emission features of the HD 34700 disk in terms of porous dust and astronomical-PAHs. Porous dust together with a mixture of neutral and ionized PAHs closely explains the dust IR SED and PAH emission features observed in the HD34700 disk. Due to the stellar radiation pressure and Poynting-Robertson drag together with the photodissociation of PAHs, substantial removal of dust and PAHs has occurred in the disk, and continuous replenishment of these materials is required to maintain their current abundances. This implies that these materials are likely not primitive but secondary products probably due to mutual collisions among planetesimals, asteroids, and comets.

Exploring the Structure of Magnetic Fields of Young Circumstellar Disks & their Environments using CanariCam at the 10.4-m GTC

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CanariCam is the mid-IR multi-mode facility camera that has been obtaining exciting science at the 10.4-m Gran Telescopio Canarias (GTC) on La Palma, Spain, since early 2012. CanariCam can carry out imaging and spectroscopy, but CanariCam's truly unique science mode is polarimetry, often working near the GTC's diffraction limit of 0.3 arcsec. Polarimetry in the mid-IR wavelength region offers some very special advantages, particularly with a telescope as large as the GTC. I will review the technique, and then show highlights from the initial phases of our program using both imaging polarimetry and spectropolarimetry. These early results indicate that CanariCam is a potentially powerful tool for determining the magnetic field morphology and dust properties in young disks circumstellar disks as well as more complicated regions associated with star formation. The GTC is a partnership of Spain, Mexico, and the University of Florida.

Improving Signal to Noise in the Direct Imaging of Debris Disks with MLOCI

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We present a new algorithm designed to improve the signal to noise ratio (SNR) of point and extended source detections around bright stars in direct imaging data. One of our innovations is that we insert simulated point sources into the science images, which we then try to recover with maximum SNR. This improves the recovery SNR of real point sources elsewhere in the field. The algorithm, based on the Locally Optimized Combination of Images (LOCI) method, is called Matched LOCI or MLOCI. Earlier we showed with Gemini Planet Imager (GPI) data on HD 135344 B and Near- Infrared Coronagraphic Imager (NICI) data on several stars that the new algorithm can improve the SNR of point source detections by 30-400% over past methods (Wahhaj et al. 2015). Here, we discuss the MLOCI reduction of the NICI data for the HD 32297 debris disk. The debris disk is recovered with improved signal to noise by a factor of 3, and detected as close to the star as $0.3''$ (33 AU). We discuss new features found in the disk and their physical implications.

Dust Impact Monitor (SESAME-DIM) Measurements at Comet 67P/Churyumov-Gerasimenko

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The Rosetta lander Philae successfully landed on the nucleus of comet 67P/Churyumov-Gerasimenko on 12 November 2014. Philae carries the Dust Impact Monitor (DIM) on board, which is part of the Surface Electric Sounding and Acoustic Monitoring Experiment (SESAME). DIM employs piezoelectric PZT sensors to detect impacts by sub-millimeter and millimeter-sized ice and dust particles that are emitted from the nucleus and transported into the cometary coma. The sensor measures dynamical data like flux and the directionality of the impacting particles. Mass and speed of the grains can be constrained for pre-defined density and elastic grain properties.

DIM was operated during three mission phases of Philae at the comet: (1) Before Philae's separation from Rosetta at distances of about 9.6 km, 11.8 km, and 25.3 km from the nucleus barycenter. In this mission phase particles released from the nucleus on radial trajectories remained undetectable because of significant obscuration by the structures of Rosetta, and no dust particles were indeed detected. (2) During Philae's descent to its nominal landing site Agilkia, DIM detected one approximately millimeter-sized particle at a distance of 4.97 km from the nucleus' barycenter, corresponding to an altitude of 2.4 km from the surface. This is the closest ever dust detection at a cometary nucleus by a dedicated in-situ dust detector. Laboratory calibration experiments showed that the material properties of the detected particle are compatible with a porous grain having a bulk density of approximately $250\,\mathrm{kg\,m^{-3}}$. Particles leaving the comet on radial trajectories were detectable with only a very small sensitive area of the DIM sensor while backfalling particles or particles in orbit about the nucleus had a more favorable detection geometry. (3) At Philae's final landing site, Abydos, DIM detected no dust impact which may be due to low cometary activity in the vicinity of Philae, or due to shading by obstacles close to Philae, or both.

Impactor fragmentation and capture laboratory experiments

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Direct collisions of solid bodies may result in sticking, rebound, erosion, and even shattering of the bodies. The smaller body (i.e., the impactor) may stick to the larger body (the target), rebound from the body, erode the surface (i.e., produce a crater) producing dust, penetrate beneath the surface, or be comminuted upon impact. The pieces generated by comminution of an impactor would be scattered over the surface of the larger body and mixed with the original materials. The Dawn mission detected dark material on the surface of asteroid 4 Vesta. This dark material was interpreted as fragments of carbonaceous chondrite impactors. In comparison, howardite–eucrite–diogenite (HED) meteorites, for which Vesta is potentially the parent body, contain carbonaceous chondrite clasts. Collectively, this evidence suggests that fragments from carbonaceous chondrite impactors were mixed with material from Vesta, consolidated, ejected from the surface of Vesta, and delivered to the Earth as meteorites. The mixing of solid materials of different origins depends on the efficiencies of fragmentation, penetration, and ejection of impactor materials. Although cratering and fragmentation of the larger body (the target) has been studied in a wide parameter space in laboratory experiments and numerical simulations, few studies have examined the fate of the smaller body (the impactor) due to the small size of the impactors and difficulty accelerating brittle projectiles in laboratory experiments.

We performed laboratory impact experiments using various impactors, including rocks, metals, and porous sintered materials, to examine the degree of fragmentation, penetration, and consolidation of impactors. The size of the impactors ranged from 1 to 3 mm in diameter, and the impact velocity from a few to several km/s. The impactor was accelerated using a two-stage light-gas gun at the Institute of Space and Astronautical Science (ISAS), JAXA, Japan.. The targets were simulated porous parent bodies consisting of silica sand, gypsum, or sintered hollow glass beads. We collected the impactor fragments in the targets, weighed the mass of the fragments, and observed the cut surface of the impactors.

The experiments showed that the impactors fragmented when the initial pressure roughly equaled the dynamic tensile strength of the impactor. The degree of impactor fragmentation increased with the initial pressure. However, when impactors struck fine sand at high velocity, consolidation of the impactor fragments themselves and of the fragments with sand particles occurred. This consolidation may have resulted from the temperature increase as well as from compression. Impactors with large initial porosity were compacted, and a larger fraction survived and could penetrate deeper into the target. Therefore, impactor survivability, as represented by the apparent largest fragment mass fraction, in high-velocity impact is greater than would be expected from the extrapolation of the results of previous lower-velocity experiments.

Rosetta COSIMA - Cometary Dust Analysis next to Comet 67P/Churyumov-Gerasimenko

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In-situ cometary dust observations are obtained by COSIMA (COmetary Secondary Ion Mass Analyser) which is one of the scientific instruments onboard the ESA mission Rosetta that presently orbits the nucleus of Jupiter-family comet 67P/Churyumov-Gerasimenko. COSIMA is collecting cometary dust particles in the inner coma on special metal target plates. These particles are subsequently imaged and identified with an optical microscope and their composition is analyzed with a secondary ion mass spectrometer. COSIMA has collected more than 12.000 cometary particles in the inner coma, at various distances from 10 to hundreds of kilometers off the cometary nucleus. The obtained mass spectra contain ions of complex mixtures of mineral compounds and organic molecules as well as molecular fragments representing the elements and molecules on the surface of these particles and the targets. We will discuss the observations of the inner coma dust particles as observed for the collected, imaged and analyzed cometary particles.

The effect of gravity acceleration and internal friction angle of regolith on impact crater size on asteroid surface

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Because gravitational acceleration at an asteroid surface is very small, it is not known which scaling should determine the size of an impact crater, gravitational scaling or strength scaling. In order to estimate the evolutional processes of asteroid surfaces, it is important to understand the gravity dependence of crater diameter. However, not many impact cratering experiments under low gravity conditions have been conducted. A few hypervelocity impact experiments were conducted under increased gravities (Schmidt and Housen, 1987) and under low gravities (Gault and Wedekind, 1977; Takagi et al., 2007). These studies show different gravity dependences and further study is required to understand why the results look inconsistent.

We developed a drop mechanism which can simulate gravities smaller than 1 G: a target container was suspended by springs of constant force. We conducted experiments under a gravity range of 0.25-1 G. We used silica sand of average diameter 140 μm and glass beads of average diameter 500 μm as the target material. Stainless steel sphere of 8 mm diameter was dropped and impacted onto the target. The impact velocity was between 1 and 4 ms^{-1}. As a result, the crater diameter formed under the gravity range between 0.25-1 G was proportional to -0.188 ± 0.008 power of the gravity acceleration for the silica sand and -0.183 ± 0.007 for the glass beads. These values are roughly in agreement with previous studies at hypervelocity (Schmidt and Housen, 1987; Gault and Wedekind, 1977).

Internal friction angle of granular material is important factor for crater size. A crater formed on particles which have large internal friction angle is typically smaller than the one formed on particles which have small internal friction angle. The internal friction angle is related to particle shape, for example, spherical particles have smaller internal friction angle than irregular shaped particles. It is shown that the internal friction angle under ultra-high vacuum was larger than the one under 1 atm (Perko et al., 2001). Because ambient pressure at the surface of an asteroid is very low, it is important to examine a relationship between the internal friction angle and the crater size.

We conducted low velocity impact experiments onto granular materials with different internal friction angle and obtained a relationship between internal friction angle and crater size. We applied this relationship to an environment of asteroid surface by considering the relationship between internal friction angle and ambient pressure and will present the results.

Dust in comet 67P/Churyumov-Gerasimenko

Marco Fulle - INAF Trieste

Single particle detections by the in-situ dust sensor GIADA and optical sensors WAC and NAC of OSIRIS cameras on board Rosetta Mission, are here considered to extract the loss rate, size and velocity distributions of dust ejected by Jupiter Family comet 67P/Churyumov--Gerasimenko from 3.5 AU to 2 AU before perihelion. GIADA data allow us to constrain the dust bulk density values, ranging from that of very fluffy particles, of equivalent density below 1 kg m^{-3} (consistent with pristine interstellar dust), to typical silicate values of 3 10^3 kg m^{-3} (consistent with dust processed in the early phases of Solar System formation). The good agreement between the size distributions obtained from 67P ground-based observations before 2010, from the Rosetta orbiter at distances of about 100 km from the nucleus, and of the individual stones of size larger than some mm observed on the nucleus surface by the ROLIS camera during the lander descent, imply that sublimation and fragmentation processes have so far negligible observable effects on 67P dust.

Synchrotron IR Microscopy of Manually Arranged Aggregate Particles

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Cosmic dust grains are in most cases not well segregated mutually in nature but rather are formed in the state of aggregates, which strongly influences the optical properties. The aggregation effects such as degree of porousness, size and shape of aggregates on infrared (IR) band profiles are not well understood in detail because the aggregate structures are not sufficiently well defined. The overall morphological effect (considering size, shape, and agglomeration state all together) on IR spectra has been verified by aerosol spectroscopy. However, the particles, which were produced by an aerosol generator, were hardly separated from each other. Thus it was virtually impossible to quantify the relative importance of each morphological effect.

In order to understand the influence of particle aggregation on the diagnostic phonon bands of solid particles, we carried out IR microscopy of well-defined aggregates which were systematically manufactured on a highly transparent substrate (Si) in mid-IR region by means of a scanning electron microscope (SEM) coupled to a focused ion beam (FIB) at Max Planck Institute for the Science of Light (Germany). The positioning of particles was achieved by a nanomanipulator, which was controlled under the SEM, enabled the defined motion of a probe by the extension or contraction of piezo crystals under electrical voltage. Six complex aggregate structures (a single particle, linear 2, 3, 4 particles, a triangle shape with 3 particles, a diamond shape with 4 particles) were all composed of 1μm-sized amorphous SiO_2 monosphere particles. A clear transition of the Si-O stretching vibration band at 10 μm (absorption intensity, band broadening, peak shift), which depends on the numbers of particles as well as the structure of them, is anticipated to observe via the mid-IR extinction measurements. The IR extinction measurements have been performed at SOLEIL synchrotron facility in Paris, France, since IR light from the synchrotron can be focused to sample spots close to the diffraction limit which allows achieving high spatial resolution and is possible to improve signal-to-noise ratio. In addition, a polarizer was employed for the extinction measurements so as to investigate the polarization effects caused by the particle orientation except for the single particle.

Extinction spectra obtained by various patterns of particle arrangements can directly compare not only with observed spectra, but also serve as a benchmark for corroborating the precision of the light absorption/scattering theoretical calculations such as Mie theory, discrete dipole approximation (DDA), and finite-difference time-domain (FDTD) method.

We report herein the first detailed experimental results obtained by synchrotron IR microscopy of systematically arranged 1μm-sized SiO_2 monosphere particles considering the polarization effects caused by the particle orientation. Furthermore, the experimentally measured extinction spectra were compared with theoretical calculations.

Cometary dust at the nanometre scale - latest results from the MIDAS experiment on Rosetta

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The spatial and size distribution of dust emitted from cometary nuclei can be estimated remotely, but only in a limited size range and far from the nucleus. Several nuclei have been visited by spacecraft carrying remote and in-situ detectors, but the details of the dust release, acceleration and fragmentation process remained elusive.

Rosetta carries a payload suite adapted to the unique nature of the mission - a comet rendezvous mission to intercept the nucleus before the onset of activity and through its perihelion passage. Amongst this payload is MIDAS, an atomic force microscope designed to collect and image the smallest dust emitted from the comet with nanometre resolution.

MIDAS has been operating since arrival at the comet in August 2014, alternating between exposing targets to the local dust environment, and searching for and imaging particles with the AFM. The number of particles collected in the first few months of operating was smaller than expected. This is believed to be partly due to the intrinsic dust distribution, and partly due to dust and spacecraft charging. Those particles that have been found can be classified as either micro-sized compact dust, or larger aggregate grains with a size of tens of microns.

The results of the MIDAS dust observations to date will be summarised as well as their implications for cometary and Solar System science.

Dynamics of polydisperse charged dust particles

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Compaction of a system of hard small particles is a problem common to a number of applications in physics. According to the domain in science, the context is called : "granular matter" (e.g. sand dune formation), "colloidal particles" (such as ceramic processing), or "regolith" (as for the dynamics of the dust on the surface of the moon or asteroids). Statistical Physics is the general theoretical background, and this makes the theory of such systems always intricate. Consequently, a number of approximations are often used to make the theoretical approach simpler, such as : the particles are all the same, the particles are spherical in shape, etc. Even within these approximations, description of the various behaviors of a system made of many small hard particles under mechanical stress is noticeably incomplete, whatever the physical context. Recently, it appeared unavoidable to revisit the usual approximation considering that all the particles of a given system are of same size. Reasons to do that were either the observation that particles are naturally polydisperse – with polydispersity depending on the formation process –, or the hope that particle polydispersity could induce new effects.

In this presentation, we will review the state-of-the-art results about intriguing behaviors of a system of polydisperse hard charged spheres in a stress field, with focus on the micrometer and sub-micrometer size particles. A central question is about the overall homogeneity of the system : when does the external field induce size segregation in the system? Subsequent questions are many, for example: self-organization and mechanical properties of charged dust sediment, profile of the size-distribution of charged dust particle levitating over a surface due to photoelectric effect, etc.

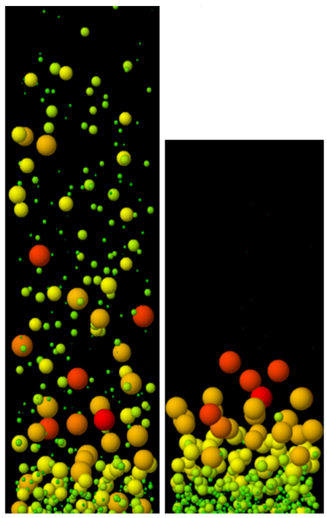

Figure 1: Example of Molecular Dynamics simulation of 3D system of charged spheres with log-normal radius-distribution in a vertical pressure field. Colors are the particle sizes (red = big, green = small). The right-hand figure is the final state (sediment), in which the big particles 'float' over the small ones.

With this in mind, the problem of charged particles in a uniform gravitational field is of particular importance. It was recently shown that in this case, big particles tend to 'float' at the surface of the system. The mechanism is that the particles most repulsive (the biggest ones) tend to form a loose crystal, and the gravitational field pushes the small particles (weakly charged, then less sensitive to the electric repulsions) inside the voids below the big particles. Then, schematically, the big particles levitate on the electric field made of a background of weakly repulsive particles. This behavior has consequences in various domains : in the ceramic processing, it forbids the capability to form compact Apollonian arrangement ; in the context of lunar regolith, it makes light scattering a particular haze-like signature, since the layer of 'big' dust particles (*i.e.* around 1μm diameter) are much interacting with the electromagnetic field.

Zodiacal dust bands observed in far-infrared with AKARI

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The zodiacal emission is the thermal emission from the interplanetary dust and the dominant diffuse radiation in the mid- to far-infrared wavelength region. Although the zodiacal dust cloud has a relatively smooth distribution, from the results of the Infrared Astronomical Satellite (IRAS) observations, it was found that there are many small-scale structures in the zodiacal emission distribution, such as dust band pairs at the ecliptic latitudes of $\pm 1.4^\circ$ and $\pm 10^\circ$. It is suggested that recent disruption events among multikilometer bodies in the main asteroid belt within the last several million years are major supply sources of the dust particles in the dust bands, and they produce a edge-brightened toroidal distributions of dust. In the previous studies, the structure of the dust band is mainly discussed with the IRAS and DIRBE data at 25 μm, because the band structure, in particular the $\pm 10^\circ$ dust band, is faint in the far-infrared wavelength region. The Japanese infrared satellite AKARI conducted a far-infrared all-sky survey, which covered 97% of the whole sky in four photometric bands with band central wavelengths of 65, 90, 140, and 160 μm. AKARI clearly detects the zodiacal dust bands structure at 65 and 90 μm bands. The AKARI observational data during more than one year has advantages over the 10-month IRAS and COBE/DIRBE data in studying the structure of the zodiacal dust bands. We will show the dust bands structure observed in far-infrared with AKARI and discuss the origin and the physical properties of the zodiacal dust.

Modeling of the Zodiacal Emission for the AKARI Mid-Infrared All-Sky Diffuse Maps

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We are creating all-sky diffuse maps from the AKARI 9 and 18 μm mid-infrared (IR) survey data. The AKARI 9 μm map is crucial to investigate the all-sky distribution of polycyclic aromatic hydrocarbons, while the 18 μm map is useful to trace hot dust grains. At the same time, the AKARI mid-IR all-sky maps are useful data for the study of the interplanetary dust (IPD) in our Solar System because the zodiacal emission from the IPD grains is the dominant foreground emission in those wavelengths.

The IPD model constructed by Kelsall et al. (1998) (the Kelsall model) has been widely used as a standard model. This model is based on the COBE/DIRBE data. However, there still remains the residual zodiacal component whose level is $\sim$1 MJy sr^{-1} around the ecliptic plane in the mid-IR maps after removal of the zodiacal emission by the Kelsall model. We therefore try constructing the new IPD model by changing the method of determining the model parameters based on the Kelsall model, and by using the AKARI data which have higher spatial resolution than the DIRBE data and are better brightness-calibrated than the IRAS data. As a result, our new model better reproduces the zodiacal emission in the AKARI mid-IR all-sky maps than the Kelsall model. Through the analysis, we obtain new information about the zodiacal emission. We discuss the structure and physical properties of the IPD grains based on our new results.

Using wavelength dependence of the opposition effect to characterize regolith dust particles

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In this presentation I consider two opportunities to characterize regolith dust particles using the opposition effect: (1) through the wavelength variations in the steepness and width of the photometric opposition surge and (2) through the variations in absorption bands at small phase angles. The first effect is discussed using Rosetta OSIRIS data for asteroids Steins and Lutetia acquired in several filters. The second effect is studied using Cassini VIMS data for Saturnian satellites. I show that the behavior of asteroid Steins' opposition surge is consistent with coherent backscattering effect whereas asteroid Lutetia shows the photometric behavior that cannot be described either by coherent backscattering or by shadow hiding. The difference in the regolith particles of these two asteroids is considered and models of dust particles for both cases are suggested. The second effect is illustrated by the VIMS spectra of Dione and Rhea. It is shown that the depth of the absorption bands in their spectra varies with phase angle, and these variations can be explained by influence of the coherent backscattering effect. Modeling of this effect for the 2-micron ice band allows estimating the size of particles and porosity of the regolith.

Laboratory Analyses of Seven Particles of likely Interstellar Origin Returned by the Stardust Spacecraft

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Stardust was the first spacecraft ever to bring back to Earth extraterrestrial materials from beyond the Moon. Stardust was two missions in one spacecraft. It returned the first samples from a known primitive solar system body, the Jupiter-family comet Wild 2. Stardust also carried a separate collector consisting of aerogel and aluminum foil that was exposed the interstellar dust stream for 200 days before the encounter with the comet.

The Stardust Interstellar Preliminary Examination (ISPE) was the sixth official NASA Preliminary Examination — the first being the PE of the Apollo lunar samples. The goal of the ISPE was to characterize the materials collected by the Stardust Interstellar collector at a level of detail sufficient to enable the scientific community to productively request samples. Among the questions to be answered were these: *What is the size of the collection, and what is the distribution of particle sizes? What fraction of the materials are consistent with an interstellar origin? What fraction are crystalline? Are there organics?* and others. We formed a consortium of scientists to address these questions, using a variety on laboratory instruments, including six infrared and x-ray microprobes at four different synchrotrons. We also developed new techniques for extracting particles from the aerogel capture media, and for identifying impacts in the aerogel and the aluminum foils. We used an unusual and very successful approach for the identification of the impacts in the aerogel collectors: we developed a web-based virtual microscope that enabled >30,000 amateur dust-hunters to search for impacts in images collected by an automated microscope. We conducted a campaign of laboratory hypervelocity capture experiments at the Heidelberg Dust Accelerator to support our interpretation of the track morphology, and also did numerical modelling of interstellar dust propagation through the heliosphere to support interpretation of observations of the trajectories of the tracks. I report on the analyses of seven particles that have a likely interstellar origin, and discuss their implications for our understanding of the the properties of interstellar dust. I also discuss plans for future analyses of these candidates as well as others yet to be identified in the Stardust Interstellar Dust Collector. I will also discuss the implications of these results on the design of future interstellar dust sample return missions.

Missing organic materials from interstellar dust inside the Solar System

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We tackle the conundrums of organic materials missing from interstellar dust when measured inside the Solar System, while undoubtedly existing in the Local Interstellar Cloud (LIC), which surrounds the Solar System. We solve the mysteries by demonstrating that organic compounds sublimate almost instantaneously by exothermic reactions, when solar insolation triggers recombination of free radicals or rearrangement of carbon bonds in the compounds. It turns out that the triggering temperature lies in the range of 20–50 K, by considering that sublimation of organic materials takes place beyond the so-called filtration region of interstellar neutral atoms. We find that in-situ measurements of LIC dust in the Solar System result in an overestimate for the gas-to-dust mass ratio of the LIC, unless sublimation of organic materials is taken into account. We also find that previous measurements of interstellar pickup ions have determined the total elemental abundances of gas and organic materials, instead of interstellar gas alone. We conclude that one must await a future exploration mission to the inner edge of the Oort cloud for a thorough understanding of organic substances in the LIC.

Porous interstellar dust in the solar system?

Veerle Sterken[1], Peter Strub[2], Harald Krüger[2], Rudolf von Steiger[1], Priscilla Frisch[3], Georg Moragas-Klostermeyer[4]

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Interstellar dust from the local interstellar cloud passes through the solar system from an apparent direction of 259° ecliptic longitude and 8° ecliptic latitude due to its relative velocity of 26 km/s between the cloud and the solar system. Although the composition and size distribution of interstellar dust grains are roughly known from astronomical observations many questions remain open, such as the relation between size distribution of in-situ measurements from Ulysses and the astronomical models, the shift in dust flow direction in 2005 as reported by Krüger et al. (2007), and the composition and morphology of the grains.

In this work we present the advancements made in understanding the local interstellar dust surrounding the Sun from comparing Ulysses ISD data with simulations for the whole observation period between 1992 and 2008. We find two different bulk populations before ca. 2002 and after 2002, where the bigger grains (the population described by Landgraf et al. (2000)) dominate the ISD flow before 2002, while a population of grains with higher charge-to-mass ratio dominate after 2002. We show (quantitatively) how the Heliosphere boundary regions play a crucial role in the filtering of these populations, and find from the data and the simulations indications that these grains may be porous. We conclude the talk with an overview of the experiments currently conducted in the lab with porous ISD analogues.

Very Large Interstellar Grains as Evidenced by the Mid-Infrared Extinction

Shu Wang[1,2], Aigen Li[2], and Biwei Jiang[1]

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Interstellar grains span a wide range of sizes from a few angstroms to a few micrometers. The ultraviolet (UV) and optical extinction constrains the dust in the size range of a couple hundredth micrometers to several submicrometers. The near and mid infrared (IR) emission including the IRAS and COBE/DIRBE broadband photometry and the PAH emission spectroscopy constrains the nanometer-sized grains and angstrom-sized very large molecules. However, the quantity and size distribution of micrometer-sized grains remain unknown as they are gray in the UV/optical extinction and they are too cold and emit too little in the IR to be detected by IRAS or Spitzer. In this talk, we employ the ~3-8 micrometer mid-IR extinction which is flat in both diffuse and dense regions to constrain the quantity, size, and composition of the micrometer-sized grain component. We find that, together with nano- and submicron-sized silicate and graphite (as well as PAHs), micrometer-sized graphite grains with C/H ~ 137 ppm and a mean size of ~1.2 micrometer closely reproduce the observed interstellar extinction from the far-UV to the mid-IR as well as the near-IR to millimeter thermal emission obtained by COBE/DIRBE, COBE/FIRAS, and Planck. The micrometer-sized graphite component accounts for ~14.6% of the total dust mass and ~2.5% of the total IR emission.

Modeling the Dust in our Galaxy based on GALEX Observations

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Murthy (2014) has published maps of the diffuse UV radiation over the entire sky in which both the general Galactic radiation, distinguished by a cosecant law dropoff from the Galactic Plane, and small scale features associated with individual stars is seen. This radiation has canonically been assumed to be due to stellar photons from early-type (O and B) stars scattered by interstellar dust. There are very few O and B stars in the sky and catalog integrations have proved to be successful in predicting the interstellar radiation field. The dust has been more problematic as its exact location with respect to the stars can make a big difference in the level of scattered light.

I will discuss my Monte Carlo model for diffuse scattering in the Galaxy and how well it fits the data. There have been several suggestions recently that scattering from interstellar dust cannot fit the entire observed background and I will examine this hypothesis also.

The 8th Meeting on Cosmic Dust at CIT (Toyko Skytree Town Campus), Tokyo , Japan on Monday, August 17, 2015 - Friday, August 21, 2015

Diffuse Interstellar Bands and Carbon-hydrogen Interstellar Dusts

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In this talk, the Diffuse Interstellar Bands (DIBs) have been reviewed in a spectroscopic view considering their carriers might originate from carbon-hydrogen interstellar dust chemistry. The long carbon-chains and carbon-hydrogen species have been proposed as possible carriers of DIBs based on the observed spectral data measured in the gas-phase in the Lab during last 20 years. These long carbon chains and carbon-hydrogen species have been synthesized in the similar chemical conditions with interstellar environment that is dominated by plasma-dust chemistry in gas-phase or on the surface of the dust grains at very low temperature and less-collisions. The some details and discussions will be presented in meeting.

Co-condensation of Atomic and Molecular Precursors of Silicate and Carbon Grains at Cryogenic Temperatures

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

The existence of cosmic dust gives rise to questions regarding its formation, its evolution, and its destruction. During this life cycle, each stage sees complex chemical and physical mechanisms at work. We recently started to study the formation and growth of cosmic dust grains under conditions relevant to the interstellar medium, i.e., at cryogenic temperatures. In the case of silicate grains, we found that cryogenically-cooled atomic and molecular precursors could react to form a solid condensate consisting of aggregated nanometer-sized particles. As the process did not require external energy, this result implies that the condensation of silicates can proceed by means of barrierless chemical reactions. Similar experiments with carbonaceous precursors led to the formation of amorphous carbon condensates. Thus silicate grains as well as carbon grains can grow in the interstellar medium and, as a consequence, one would expect the growth of mixed grains as carbon precursors are present in all interstellar regions. Observations, however, suggest that cosmic dust grains are either siliceous or carbonaceous, not both. Our current laboratory work aims at shedding light on the separation of siliceous and carbonaceous cosmic dust. The latest results of our experiments on the formation of cosmic dust grains at cryogenic temperatures will be presented and discussed.

Variations of the Dust Properties in the Magellanic Clouds, Using *Herschel* and *Spitzer* Observations

Frédéric Galliano[1]

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The properties of interstellar dust (chemical composition, size distribution, etc.) depend on the local environmental conditions, and on the elemental enrichment history of the galaxy. However, the individual processes controlling this evolution (dust production by stars, dust growth in the ISM, dust destruction by shocks, etc.) are not known accurately enough to unambiguously model the evolution of galaxies. One of the ways to refine our knowledge of these evolutionary processes consists in studying the variations of local observed dust properties, measured via their spectral energy distribution (SED), as a function of the local physical conditions (gas density, temperature, metallicity, etc.). These trends between dust properties and physical conditions are valuable constraints on the nature and efficiency of the grain evolutionary processes.

The Large and Small Magellanic Clouds (LMC & SMC) are particularly relevant environments to address these questions, as their metallicity is sub-solar (1/2 and 1/6 solar for the LMC and SMC respectively), and they exhibit large gradients of physical conditions, from massive star formation to quiescent regions. Their proximity (50–60 kpc), allows us to resolve the ISM on parsec scale, in the far-infrared.

In this talk, I will first review several recent studies of the Magellanic clouds, with *Herschel*, *Planck* and *Spitzer*. I will then present the results of an ongoing project aimed at modelling in details the near-IR-to-submm emission of a sample of star forming regions. This modelling is done using a new hierarchical Bayesian SED model, efficient at removing the numerous biases inherent to this type of model. I will discuss our results concerning: *(i)* the constraints on the general grain emissivity; *(ii)* the variation of the aromtic features throughout different environments; *(iii)* the ambiguity between accretion of material in dense regions and the massive presence of CO-free molecular gas (the so-called "*dark gas*").

Infrared spectroscopy in the C--H stretching region towards embedded high-mass young stellar objects in the Large Magellanic Cloud

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

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Since cosmic metallicity is believed to be increasing in time with the evolution of our universe, interstellar chemistry in low metallicity environments is crucial to understand chemical processes in the past universe. The Large Magellanic Cloud (LMC) is an excellent target to study such low metallicity interstellar chemistry thanks to its metal-poor environment and proximity.

Here we report the results of infrared spectroscopic observations of embedded high-mass young stellar objects (YSOs) in the LMC with the Very Large Telescope. We obtained medium resolution spectra in the 3--4 micron range for eleven LMC YSOs and detected absorption bands due to solid H_2O and CH_3OH as well as the 3.47 micron absorption band. The properties of these bands are investigated based on comparisons with Galactic embedded sources. We found that the 3.53 micron CH_3OH ice absorption band for the LMC high-mass YSOs is absent or very weak compared to that seen toward Galactic counterparts. We estimate the column densities and abundance of the CH_3OH ice using the obtained spectra, which suggests that solid CH_3OH is less abundant in the LMC than in our Galaxy. We propose that grain surface reactions at relatively high dust temperature (warm ice chemistry) are responsible for the observed characteristics of ice chemical compositions in the LMC; i.e., the low abundance of solid CH_3OH presented in this work as well as the high abundance of solid CO_2 reported in previous observations. The 3.47 micron absorption band, which is generally seen in embedded sources, is detected toward six out of eleven LMC YSOs. In contrast to the CH_3OH ice band, strength ratios of the 3.47 micron band and water ice band are found to be similar between LMC and Galactic samples. Although the carrier of the 3.47 micron band is still under debate, our result suggests that the low metallicity and different interstellar environment of the LMC have little effect on the formation of the band carrier.

In this presentation, we are going to discuss the characteristics of the C--H stretching region spectrum in low metallicity environments based on these observational results.

Interstellar ices as revealed by AKARI near-infrared spectroscopy

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The near-infrared (NIR) spectral region (2–5μm) contains a number of ice features, such as H_2O ice at 3.05μm, CO_2 ice at 4.27 μm, and CO ice at 4.67 μm, and XCN ice at around 4.62μm. The Infrared Camera (IRC) onboard AKARI has a NIR spectroscopic capability with high sensitivity for extended sources that allows us to study these major ice components in various diffuse Galactic objects for the first time (Onaka et al. 2007; 2010). In particular, H_2O and CO_2 ice absorption features have been detected towards a number of HII region-PDR complexes in observations with the IRC during the warm phase (Mori et al. 2014). The IRC spectra show a weak correlation between the column densities of CO_2 and H_2O ices. The ratio of the CO_2 to H_2O ice column densities is in a range 0.1–0.2, which is in agreement with previous observations towards massive young stars (Pontoppidan et al. 2008). The correlation supports the concurrent formation of both ice species on the grain surface (Oba et al. 2010). Both ice species also show a weak trend with Av with a threshold for the presence at Av~5, which is also in agreement with previous results towards the Taurus cloud (Whittet et al. 2001, 2007). These results suggest the presence of common physical conditions for the ice formation in general interstellar clouds. In this presentation, we will show the results of recent analysis of AKARI IRC NIR spectroscopy of ice species.

Mori, T. I., et al. 2014, ApJ, 784, 53
Oba, Y., et al. 2010, ApJ, 712, L174
Onaka, T., et al. 2007, PASJ, 59, S401
Onaka, T., et al. 2010, Proc. SPIE, 7731, 77310M
Pontoppidan, K. M., et al. 2008, ApJ, 678, 1005
Whittet, D. C. B., et al. 2001, ApJ, 547, 872
Whittet, D. C. B., et al. 2007, ApJ, 655, 332

Properties of dust and PAHs in early-type galaxies

Takuma Kokusho[1], Hidehiro Kaneda[1], Toru Kondo[1], Shinki Oyabu[1], Mitsuyoshi Yamagishi[1], and Katsuhiro Murata[1]

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Early-type galaxies (ETGs) are known to possess much smaller amounts of dust and polycyclic aromatic hydrocarbons (PAHs) than late-type galaxies, because the interstellar environments in ETGs are hostile against survival of dust (i.e., X-ray plasma) while low-mass old stars cannot efficiently supply dust into the interstellar space. Yet recent mid- and far-infrared (IR) observations, including Spitzer, AKARI, and Herschel, have shown that some ETGs contain a considerable amount of dust and PAHs, while their supply channels are not fully understood.

With the AKARI mid- and far-IR all-sky surveys, we performed a systematic study of dust and PAHs in ETGs in order to reveal their origins. From AKARI, 2MASS, and WISE data, we derived near- to far-IR spectral energy distributions for each sample ETG and fitted them by a model to estimate their dust mass, dust temperature, and PAH luminosity. We also obtained near-IR spectra for some of our ETG sample with AKARI, which show SiO/CO absorption features likely related to the photospheric component of low-mass O-rich stars. Based on the above results, we discuss the properties and possible origins of dust and PAHs in ETGs.

Silicate Dust in Active Galactic Nuclei

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An anisotropic dust torus is invoked by the unification theory of active galactic nuclei (AGNs) to account for the observational dichotomy, i.e., all AGNs are proposed to be the same kind of object or "*born equal*" but viewed from different lines of sight. 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 curves. Besides, the anomalous silicate emission or absorption features observed respectively in type 1 and type 2 AGNs suggests that the AGN silicate grains were probably not "born equal". To address and to clarify the observed silicate diversity among AGN dichotomy, we model the silicate emission or absorption of a large and well defined AGN sample, considering various dust compositions and grain sizes. By modeling the *Spitzer*/ IRS spectra of 147 AGNs of various types using the plane-parallel slab radiative transfer method of Laor & Draine (1993), we obtain constraints on the AGN silicate composition and size. We find that the Draine & Lee (1984) silicate can well explain the silicate emission in 110 AGNs while the rest requires amorphous olivine and pyroxene. Moreover, it appears that larger dust grains are preferred in quasars, specifically, in 129 AGNs the mid-infrared emission can be reproduced with silicate dust of radii $\sim 1.5\,\mu$m. The temperature of the ~ 5–$8\,\mu$m continuum emitter (which is essentially carbon dust) of AGNs is ~ 600–$1300\,$K, much higher than that of typical starburst which is ~ 30-$40\,$K. The correlations between the dust temperature, size and the AGN luminosity, types, black hole mass are also investigated.

INTERGALACTIC EXTINCTION

BRADLEY MILLS, AIGEN LI, AND LACEY DANIELS

University of Missouri

The apparent systematic dimming of high-redshift Type Ia supernovae has been interpreted as evidence of acceleration in the cosmological expansion of the universe. An alternative hypothesis to this interpretation is the gray extinction of intergalactic dust. Based on the intergalactic abundances of the dust-forming elements (C/H, O/H, Si/H, Mg/H and Fe/H), assuming these heavy elements all condensed to make dust of various composition and sizes, we place upper limits on the intergalactic extinction with various dust species and mixtures taken into account. We then examine the dimming of distant cosmological sources by intergalactic dust and aim at addressing such a question: to what extent the intergalactic obscuration affects the accelerating universe hypothesis?

Estimating the properties of gas and dust in clusters of galaxies

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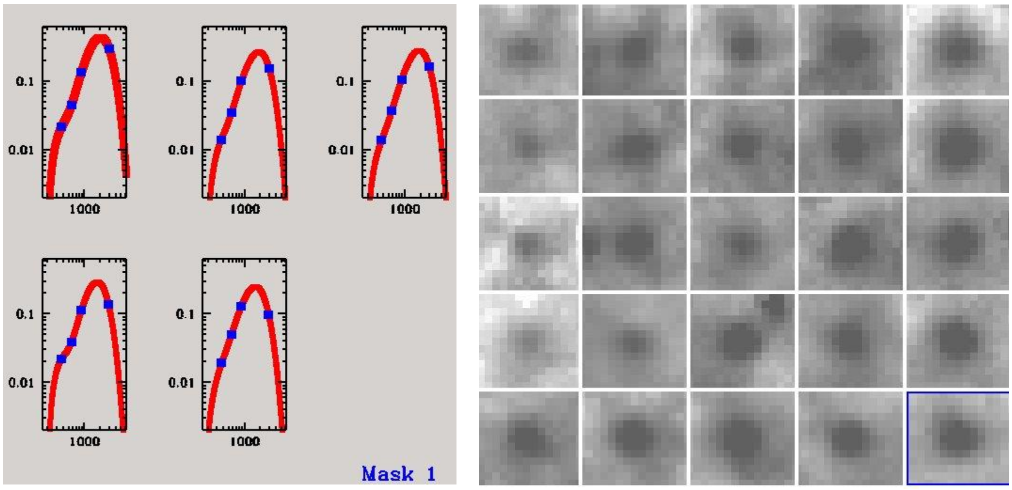
Instituto de Astrofísica de Canarias, Tenerife, SPAIN

Using IRAS and Planck LFI/HFI data we have determined the properties of dust and gas in a sample of ~100,000 clusters of galaxies detected in SDSS. The signal of such clusters is clearly detected in all Planck maps from 70 to 857 GHz. The signal detected corresponds to a temperature ~25 K, and is compatible with expectations accounting for the contribution of dust in cluster member galaxies. The dust in the intracluster media is not detected, but the analyses as a whole show that the amount of this component is very small. We study the relation between mass of dust and richness, and study the evolution with redshift. We find a clear increase in luminosity with redshift that agrees with the trend expected from current models.



Left: Blue dots are the mean flux obtained for five of the bins shown on the figure of the left. The red line are the best fit obtained parametrizing the Sunyaev-Zeldovich effect, and using for the dust a function $\sim\nu^{\alpha} B_{\nu}(T)$.
Right: Planck HFI maps (20'x20') at 857 GHz obtained by stacking and averaging the signal on each cluster. Each bin contains the signal of ~2000 clusters and corresponds to a given range in mass (increasing from left to right) and redshift (increasing from top to bottom).

The interplay between chemistry and nucleation in the formation of carbonaceous dust grains

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The formation of the seeds of cosmic dust is a key astrophysical process, since it is at the basis of the formation of any solid structure in the Universe. Contrary to the nucleation of most phase transition on Earth, astrophysical nucleation takes place ideally, in the absence of condensation nuclei. This makes nucleation a process that starts as a chemical reaction and gradually transitions to a physical process. We present the combined results of a new approach to nucleation and growth of pure carbon clusters in stellar explosions. Our approach includes *ab-initio* calculations of the structure of carbon clusters and molds the kinetic nucleation approach to a chemical network to follow the growth of dust grains even in the presence of weathering agents.

Within this framework, nucleation of carbonaceous grains is delayed and proceeds more smoothly than in classical calculations, possibly providing a better fit to observations. We will finally discuss the possibility and challenges of extending this methodology to multi-species nucleation, such as the seeding and growth of silicate grains.

Optical properties of fractal dust aggregates

Ryo Tazaki[1,2], Satoshi Okuzumi[2], Akimasa Kataoka[2], Hidekazu Tanaka[3] and Hideko Nomura[2]

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Recent theoretical studies suggested the presence of highly porous dust aggregates in protoplanetary disks. Since optical properties of the aggregates is not completely understood, it is important to investigate how the fractal dust aggregates absorbs and scatters the lights. We calculated optical properties of fractal dust aggregates by using the rigorous method, T-Matrix Method, and compared the results with that obtained by using Rayleigh-Gans-Debye (RGD) theory and Effective medium theory (EMT). The dust model we used in the calculation is the Ballistic-Cluster-Cluster-Aggregates so that the fractal dimension of the aggregates is $D_f \sim 2$.

Firstly, we show that the angle dependent properties such as phase function and polarization obtained by using T-Matrix method can be well reproduced by using the RGD-theory. Since the aggregates has fractal dimension $D_f \sim 2$, the effect of multiple scattering can be neglected and it certainly satisfies the assumption of the RGD-Theory. We also show that the EMT fails to reproduce the phase function by an order of magnitude even if the wavelength is longer than the monomer radius, or $\lambda > 2\pi r_m$ where r_m is a radius of monomer. The phase function calculated by the EMT deviates from rigorous results when $\lambda < 2\pi r_g$ where r_g is a radius of gyration which gives a typical scale of the aggregates. Since the EMT assumes the sphere with the radius of gyration and the effective refractive index, the phase function is characterized by so-called Porod's law so that it's angular dependence is completely different from that of fractal aggregates. Secondly, we show that the angle integrated properties such as absorption and scattering cross-section can be well reproduced by both the RGD-Theory and the EMT when the wavelength is longer than the monomer radius. However, the EMT results deviates from rigorous results where the monomer's optical properties deviates from Rayleigh limit, such that $\lambda < 2\pi r_m$. However, the RGD-theory gives relatively good agreement with the rigorous results compared to the EMT at such wavelength domain. As a results, we conclude that the RGD-theory is a powerful method for calculating the fractal aggregates with $D_f \sim 2$ and it is quite easy to use than cost numerical methods.

Mid-IR Polarization of Protoplanetary Disks

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Polarization is an important observational technique for studying the orientation of magnetic fields and the properties of dust in protoplanetary disks.

In the mid-IR, polarization can result from dichroic absorption, emission and/or scattering. Regarding the dichroic absorption and emission, polarization arises from the differential cross sections of non-spherical dust grains, with directions parallel and perpendicular to the grain's symmetry axis. We adopt the package DDSCAT (Draine & Flatau 2013), to calculate these cross sections for astronomical silicates (Draine & Lee 1984) and ice-coated silicate grains for a range of axial ratios. We find that the polarizing capability of dust grains strongly depends on dust composition and geometry. Different dust compositions have different polarization profiles and larger oblateness leads to an increased degree of polarization. Our predicted mid-IR polarization can be as high as ~ 10%, while at sub-mm, it is ~ 1%, which is comparable to observed values. Assuming a hydrostatic disk model and the partly dust alignment (reduction factor R=0.6) in the magnetic field, with the temperature distribution calculated from the Monte Carlo radiative transfer code RADMC (Dullemond et al. 2010), we present the polarization distributions expected for various magnetic field morphologies (e.g., classical hour-glass, toroidal and poloidal). Scattering, previously regarded as negligible in the mid-IR, is taken into consideration in our modeling. Although we only consider scattering from spherical dust grains, dust polarizes light by scattering very efficiently and therefore scattering should no longer be ignored in the mid-IR. Our results suggest that dust size distribution and the scale height of the disk are significant parameters accounting for the fractional polarization from scattering.

As an illustration, we compare our modeling with mid-IR polarimetric images of AB Aur from *Canaricam* GTC at 10.3 μm. AB Aur is a well-studied Herbig Ae star surrounded by a disk inclined at ~20 deg from face-on. Our observations show a centrosymmetric pattern (i.e., the signature of polarization from scattering, appearing at the distance ~ 1 arcsec from the central star) superimposed on a uniform pattern (from emission, dominating at the inner disk). We show how our model can reproduce this observation and how polarization can constrain the dust properties, e.g., size. This research was supported in part by NSF grants AST-0903672 and AST-0908624 to CMT.

Planet Formation and Debris Disks

Hiroshi Kobayashi[1], Daisuke Ishihara[1]

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The circumstellar disks observed around several hundred main sequence stars are mainly gas poor, faint disks, which are called debris disks. They are mostly revealed by excess infrared emission around the stars. In a planetesimal disc, collisional coagulation of kilometer or larger planetesimals produces a small number of large bodies, oligarchies. Leftover planetesimals are strongly stirred by oligarchies, resulting in the violent collisions between planetesimals. The collisional fragmentation of planetesimals may form a debris disk. We aim to determine the properties of the underlying planetesimals in debris disks by numerically modelling the coagulation and fragmentation of planetesimal populations. We find that a radially narrow planetesimal disc is most likely to result in a debris disk that can explain the trend of observed infrared excesses of debris disks around G-type stars, for which planet formation occurs only before 100 million years. Planetesimal disks with underlying planetesimals of radii 100 km at   30 AU most readily explain the Spitzer Space Telescope 24 and 70 micron fluxes from debris disks around G-type stars. We expand this analisys for the AKARI debris disk samples.

Coloring Debris Disks

Aigen Li

University of Missouri, USA

The scattered-light colors of debris disks derived from multi-wavelength observations of scattered light in the optical and near-infrared provide one avenue for determining the dust composition of debris disks. So far, to the best of our knowledge, the scattered-light colors are known for eight spatially-resolved debris disks. Four of them scatter red, two scatter blue and two scatter neutral or gray. We consider porous dust consisting of amorphous silicates of different iron contents, amorphous carbon of different DC conductivities, and tholin made from different initial mixing materials. These dust materials are expected to scatter starlight differently. We model simultaneously the scattered-light colors and the dust infrared emission spectral energy distributions of three debris disks: AU Mic, HD 32297, HD 92945.

Seasonal Variations of the Zodiacal Light toward the Ecliptic Poles at the Infrared Wavelengths

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The zodiacal light (ZL), combination of the sunlight scattered by and the infrared light emitted by the interplanetary dust (IPD) particles, changes with time due to the asymmetric distribution of the particles with respect to the Earth's orbit. Especially, the variations of the ZL brightnesses toward the ecliptic poles are useful to probe the properties of the global distribution of the IPD because we can evade the effect of the small scale structures, such as the asteroidal dust bands. The ecliptic poles are frequently visited by the infrared (IR) space telescopes owing to their sun-synchronous orbits or for specific purposes. We collect and analyze the observations toward the ecliptic poles by COBE/DIRBE, AKARI, and MIRIS, covering the wavelengths from about 1 to 25 μm. The observations are not well described by a simple smooth cloud model and imply warping of the cloud's symmetry plane at least outside 1 AU from the Sun.

Aliphatics and aromatics in solar system bodies

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Aliphatic and aromatic hydrocarbon materials are seen in many solar system bodies, including asteroids, comets, satellites, meteorites, and interplanetary dust particles. They reveal their presence through the 3.3 micrometer aromatic C-H stretch spectral feature and the 3.4 micrometer aliphatic C-H stretch feature. We explore the nature of these materials with special attention paid to their chemical structures (e.g., the aliphatic fraction or the ratio of aliphatic C atoms to aromatic C atoms). We also examine the link of the aliphatic / aromatic materials seen in the solar system to that of the interstellar medium and carbon stars at their late stages of evolution.

The influence of high energy photoelectrons on the structure of photoelectric sheath and dynamics of dust grains

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

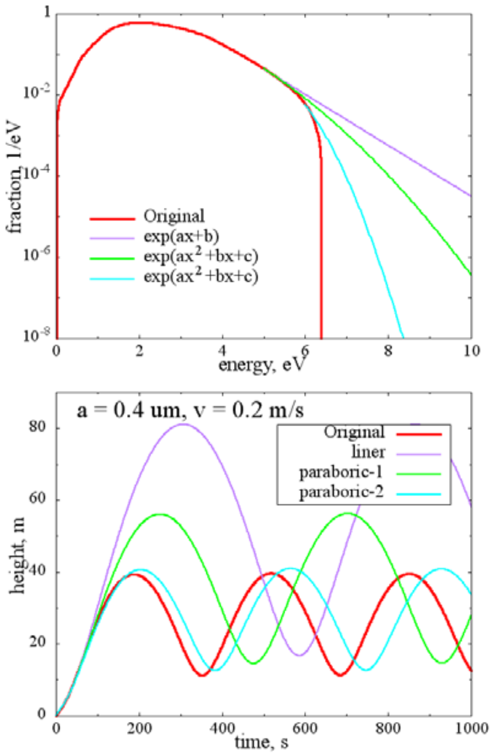
[1]*PERC/ ChiTech, Japan,* and [2]*Kobe University, Japan*

When an air-less body is irradiated from solar UV, photoelectrons are emitted from the surface making a photoelectric sheath above the surface of the body. If a dust grain is lofted from the surface, its charge will be changed not only by photoelectron emission but also impingement of sheath electrons and solar wind electrons. Thus the dynamics of a dust grain in the photoelectric sheath is affected by the structure of photoelectric sheath and is not straightforward.

We have shown that the previous studies used an energy distribution function of photoelectrons obtained from laboratory experiments inadequately [1]. Although the energy distribution function was experimentally measured for integrated value only in the emission angle from the normal to the surface to about π/4 [2], some of previous studies used the energy distribution function as a vertical component and others assumed Maxwellian distribution function for photoelectric energy using the mean energy obtained by the experimental study. Thus we developed a new analytical method to calculate an angle-resolved velocity distribution function of photoelectrons from the experimentally obtained data and studied the difference in the dynamic motion of a dust grain in the photoelectric sheath depending on the adopted energy distribution function of photoelectrons [1].

In the last meeting, however, we omit the high energy (> 6eV) component of photoelectrons because the fraction of high energy component is too low to be evaluated from the original figure. But, it is clear that irradiation of high-energy photons to lunar surface fines emit photoelectrons beyond 6 eV from the lunar surface. Indeed, the Apollo 14 charged-particle lunar environment experiment (CPLEE) on the moon revealed the presence of high-energy photoelectrons between 40 and 200 eV emitted from the lunar surface [3].

Because the extent of an electric sheath depends on high energy component of photoelectrons, a proper consideration of high energy component can be crucial to a correct understanding of the structure of photoelectric sheath and the dynamics of dust grains within the sheath. Therefore, we study the influence of high energy component of photoelectrons on the structure of photoelectric sheath and the dynamics of dust grains within the sheath by extrapolating the energy distribution function of photoelectrons in some manners.



Figures: Examples of extrapolated energy distribution function of photoelectrons (top) and the resunting dynamics of a dust grain launched with 0.2m/s from the surface of Eros (bottom).

References: [1] Senshu et al. (2015) *PSS*, in press. [2] Feuerbacher et al. (1972) *GCA* 3, 2655. [3] Reasoner and Burke (1972) *JGR* 78, 5844.

Comparison of the Diffuse Mid-IR and FUV emission in the Large Magellanic Cloud

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Dust scattering is the main source of diffuse emission in the FUV. For several locations in the LMC, *UIT* and *FUSE* satellites observed diffuse radiation with intensities ranging from 1000 - 3×10^5 photon units and diffuse fraction between 5% - 20% at 1100 Å. Here, we compare this FUV diffuse emission with the Mid-IR diffuse emission observed by the Spitzer satellite for the same locations. The relative intensities in the different Mid-IR bands for each of the locations will enable us to determine the type of dust contributing to the diffuse emission as well as to derive a more accurate 3D distribution of stars and dust in the region, which in turn can be used to model the observed scattering in the FUV.

On Graphene in Space

Xiuhui Chen[1], Jianxin Zhong[1], & Aigen Li[2]

1. Xiangtan University, 2. University of Missouri

ABSTRACT

The 217.5nm interstellar extinction bump, the most prominent spectroscopic absorption feature in the interstellar extinction curve, remains unidentified since its first detection in 1965 (Stecher 1965, ApJ, 142, 1681). It was originally attributed to graphite (Stecher & Donn, ApJ, 1965, 142, 1683). But graphite fails to simultaneously account for both the stability of the central wavelength of the bump and the variation of the bump width. More recently, polycyclic aromatic hydrocarbon (PAH) molecules have been suggested as a candidate (Joblin et al. 1992, ApJ, 393, L89; Li & Draine 2001, ApJ, 554, 778; Steglich et al. 2011, ApJ, 712, L16). Although PAHs do have a strong absorption band around 200nm due to the pi-pi* electronic transition, individual PAHs also show other sharp absorption features which are not observed in the interstellar medium (ISM).

Recently, the detection of C_{24} (a planar graphene) was reported in planetary nebulae (García-Hernández et al. 2011, ApJ, 737, L30). This discovery inspires us to explore whether and how much graphene would exist in the ISM and how it reveals its presence through its ultraviolet (UV) extinction and infrared (IR) emission. We examine graphene as a potential candidate for the mysterious 217.5nm extinction bump. Graphene could arise from PAHs through a complete loss of their H atoms (Berné & Tielens, 2012, PNAS, 109, 401) or from graphite through fragmentation (grain-grain shattering). Both quantum-chemical computations and laboratory experiments have shown that the pi-pi* electronic transitions cause a strong absorption band near 217.5nm (Trevisanutto et al. 2010, Phys. Rev. B, 81, 121405; Nelson, et al. 2010, Appl. Phys. Lett., 97, 253110). We calculate the UV absorption of graphene and place an upper limit of ~7 ppm of C/H on the interstellar graphene abundance. We also model the vibrational excitation of graphene in the ISM. Graphene is stochastically heated by single photons and undergoes temperature fluctuation in the ISM. We calculate its IR emission spectra following its vibrational excitation and radiative relaxation. We also derive the abundance of graphene in the ISM by comparing the model emission spectra with that observed in the ISM.

The Interstellar Medium viewed by the AKARI Far-Infrared All-Sky Survey

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We present a far-infrared all-sky atlas made from a sensitive all-sky survey using the Japanese AKARI satellite. The survey covers > 99% of the sky in four photometric bands centred at 65 μm, 90 μm, 140 μm, and 160 μm with spatial resolutions ranging from 1 to 1.5 arcmin. Having four to five times better spatial resolution as well as data at longer wavelengths comparing to IRAS, the data provide crucial information for the investigation and characterisation of the properties of dusty material in the Interstellar Medium (ISM). The comprehensive wavelength coverage from 50 μm to 180 μm provides SED information at the peak of the dust continuum emission, enabling us to make a precise evaluation of its temperature, which leads to a detailed investigation of the total amount of dust particles, and their irradiation environment. The large-scale distribution of dust in interstellar clouds, their temperatures and column densities, can be investigated in great detail from the largest spatial scales of entire giant molecular clouds down to those as small as individual molecular cloud cores. In addition to the point source distribution, the large-scale distribution of ISM cirrus emission, and its filamentary structure, are well traced. We have made the first public release of the full-sky data to provide a legacy data set for use by the astronomical community. The AKARI FIR images are a new powerful resource from which to investigate the detailed nature of ISM from the smallest scales that trace individual star forming cores, to the complex structures revealed that span the full sky.

The survey of near-infrared diffuse interstellar bands

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Diffuse interstellar bands (DIBs) are ubiquitous absorption lines in the spectra of reddened stars, which originate from foreground interstellar clouds. Although the carriers of any DIBs have not been successfully identified yet, they are considered to arise from the gas-phase large-sized molecules, such as polycyclic aromatic hydrocarbons (PAHs) and fullerenes, which would be deeply related to the formation and evolution of dust grains. Recent extensive observational studies have discovered no less than about 600 DIBs from the near-UV to the near-infrared (NIR) wavelength range. In particular, the NIR wavelength range is very useful in exploring DIBs toward the stars with heavy interstellar extinction because of its higher transmittance in interstellar clouds compared to the optical wavelength range. Using the DIBs in the NIR wavelength range, it become possible to investigate the behavior of the DIB carrier molecules in various environments, which will contribute to the identification of the DIB carriers. Also, the DIBs in the NIR wavelength range are expected to be the electronic transitions of ionized PAHs and fullerenes. However, there was no systematic study of NIR DIBs despite their potential importance probably because the NIR high-resolution spectroscopy have some difficulties compared to the optical, such as the lower performance of the spectrographs and many strong telluric absorption lines.

We are conducting the first comprehensive survey of NIR DIBs with the newly developed NIR high-resolution ($R = 28,300$) spectrograph WINERED, which offers a high sensitivity in the wavelength coverage of 0.91-1.36 micron. Using the WINERED spectrograph attached to the Araki 1.3m telescope in Japan, we plan to obtain the high-quality spectra of about one hundred reddened early-type stars to investigate the properties of NIR DIBs in various environments, such as diffuse interstellar clouds, dark clouds and star-forming regions. In our first results of the survey (Hamano et al., 2015, ApJ, 800, 137), we successfully identified 15 new NIR DIBs in 0.91-1.36 micron, where only five fairly strong DIBs had been identified previously. In addition, their properties, such as the correlation of their equivalent widths (EWs) with the reddening of the stars and the intrinsic molecular profiles, were investigated with an unprecedented accuracy. We found that all of the NIR DIBs are moderately correlated with the reddening of the stars, but their correlation coefficients seem to be systematically lower than those of some representative optical DIBs, suggesting that the EWs of the NIR DIBs are affected by other physical parameters of intervening gas clouds, such as UV field, than the column density. In this conference, we will present the some results and future prospects of the NIR DIB survey.

Analysis of Edge Structures of Polycyclic Aromatic Hydrocarbons using Infrared Emission Bands

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The emission observed from interstellar polycyclic aromatic hydrocarbons (PAHs) is shown to exhibit significant variation along different sightlines, apparently dependent on a number of factors including type of astronomical source under observation and degree of irradiation affecting the emitting material. Of interest are the bands corresponding to carbon-hydrogen vibrations, as these define the edge structures in aromatic molecules, and variations within them can give information on molecular morphology and degree of hydrogenation present. This can also give information on aliphatic material, which may be indicative of dust grain formation and growth processes occurring. This study examines archived spectroscopic data from AKARI and ISO in the 3μm, 11μm, and (where available) 5μm regions to investigate edge structure variation in PAHs. Results are discussed in terms of molecular processing and growth of carbonaceous dust grains.

The Carriers of the Unidentified Infrared Emission Features: Clues from Polycyclic Aromatic Hydrocarbons with Aliphatic Sidegroups

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The unidentified infrared emission (UIE) features at 3.3, 6.2, 7.7, 8.6, 11.3 and 12.7 μm are ubiquitously seen in a wide variety of astrophysical regions in the Milky Way and nearby galaxies as well as distant galaxies at redshifts $z \geq 4$. The UIE features are characteristic of the stretching and bending vibrations of aromatic hydrocarbon materials. The 3.3 μm feature which results from the C--H stretching vibration in aromatic species is often accompanied by a weaker feature at 3.4 μm. The 3.4 μm feature is often thought to result from the C--H stretch of aliphatic groups attached to the aromatic systems. The ratio of the observed intensity of the 3.3 μm aromatic C--H feature ($I_{3.3}$) to that of the 3.4 μm aliphatic C--H feature ($I_{3.4}$) allows one to estimate the aliphatic fraction (e.g., $N_{C,aliph}/N_{C,arom}$, the number of C atoms in aliphatic units to that in aromatic rings) of the carriers of the UIE features, provided that the intrinsic oscillator strengths (per chemical bond) of the 3.3 μm aromatic C--H stretch ($A_{3.3}$) and the 3.4μm aliphatic C--H stretch ($A_{3.4}$) are known.

In this work we employ density functional theory and second-order perturbation theory to compute the infrared vibrational spectra of seven polycyclic aromatic hydrocarbon (PAH) molecules with various aliphatic substituents (e.g., methyl-, dimethyl-, ethyl-, propyl-, butyl-PAHs, and PAHs with unsaturated alkyl chains). The mean band strengths of the aromatic ($A_{3.3}$) and aliphatic ($A_{3.4}$) C--H stretches are derived and then employed to estimate the aliphatic fraction of the carriers of the UIE features by comparing the ratio of the intrinsic band strength of the two stretches ($A_{3.4}/A_{3.3}$) with the ratio of the observed intensities ($I_{3.4}/I_{3.3}$).

We conclude that the UIE emitters are predominantly aromatic, as revealed by the observationally-derived ratio $I_{3.4}/I_{3.3} \approx 0.12$ and the computationally-derived ratio $A_{3.4}/A_{3.3} \approx 1.76$ which suggest an upper limit of $N_{C,aliph}/N_{C,arom} \approx 0.02$ for the aliphatic fraction of the UIE carriers.

Mid-Infrared vibrational study of substituted PAHs : implications to Aromatic Infrared Bands

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Polycyclic Aromatic Hydrocarbon (PAH) molecules have been long proposed to be a major source of the mid-infrared bands observed in the interstellar medium (ISM). Vibrational relaxation of PAHs on absorption of a UV photon produces distinct features at 3.3, 6.2, 7.7, 8.6, 11.2 and 12.7 μm popularly known as 'Aromatic Infrared Bands' (AIBs). Apart from these, several other weak features are distributed in an emission plateau of $3 - 20$ μm. Despite the fact that PAHs are ubiquitous in the ISM, the exact form of PAHs responsible for producing these features are not yet known. Several substituted PAHs have been studied both experimentally and theoretically to correlate with interstellar AIBs. Owing to the presence of deuterium in the ISM, deuterium containing PAHs are highly preferred among the substituted PAHs.

Density Functional Theory (DFT) calculation has been carried out on a variety of PAHs with a deuterium to study the infrared properties of these molecules. These include deuterated PAHs (PADs and D_n−PAHs), cationic PADs, deuteronated PAHs ($DPAH^+$s) and deuterated-deuteronated PAHs ($DPAD^+$s). A comparison has been made to see the size effect of PAHs and impact of deuteration. We present a D/H ratio calculated from our theoretical study to compare with the observationally proposed D/H ratio.