Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

PPS24-01 Room:106 Time:May 25 13:45-14:00

Imaging observations to understand dust grains in young circumstellar disks

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Circumstellar disks around young stars are the likely sites of planet formation, thus observations of physical and chemical properties of disk material are essential to understand planet building processes. One of the recent highlights of observations for such disks is the discovery of transitional disks with clear spiral arms by high-angular-resolution and high-contrast imaging with Subaru. Those observations employ polarization differential imaging (PDI) method, combined with adaptive optics, where the scattered light from dust grains is detected while the un-polarized stellar component is subtracted out. The technique is very powerful to probe the inner part of the disk compared to classical methods, thus to reveal the signs of interaction between the disk and possible planets. For instance, observations with the state-of-the-art instruments have successfully detected disks typically beyond 30 AU from the central stars with the angular resolution of about 9 AU. In addition, the polarized light tells us about properties of scatteres in the disk since polarization depends such as on gain size, composition, shape, and porosity as well as the scattering angle. Given the current situation that PDI is becoming the major technique for disk imaging, it is useful to discuss how we can derive information on realistic dust grains from such data. In this talk, I will review the recent observational efforts especially in PDI and introduce the attempts to put constraints on grain properties in young circumstellar disks.

Keywords: astronomical observations, polarization, circumstellar disks, dust grains

PPS24-02 Room:106 Time:May 25 14:00-14:15

Collisional and orbital evolution of dust particles in protoplanetary disks

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Collisional growth of dust particles is the first step of the formation of solid bodies in protoplanetary disks. Dust growth is also a key to understand observational appearance of disks since the disk opacity depends on the dust size distribution. However, collisional evolution of protoplanetary dust is poorly understood because of the complexity of aggregate collision. In addition, it has been theoretically suggested that dust particles can experience significant radial migration, which further complicates the pathway of dust evolution in the disks.

In this talk, I will present a current theoretical picture of dust evolution in protoplanetary disks. Recent laboratory and numerical collision experiments have revealed how the outcome of aggregate collisions depends on the collision velocity and internal structure of the aggregates. At the same time, theoretical tools have been also established for treating the evolution of radial size distribution and aggregate porosity simultaneously. With the experimental and theoretical progress, we have performed the first global simulation of dust evolution including collisional porosity evolution. We find that, at distances of a few to 10 AU from the central star, dust particles grow into planetesimal-mass objects on a timescale of 10000 years without experiencing radial drift. Further out the disk, dust particles are found to undergo significant radial inward migration, leading to the pileup and mixing of dust materials in inner disk regions on a longer timescale.

Keywords: dust, collision, protoplanetary disks

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PPS24-03 Room:106 Time:May 25 14:15-14:30

Molecular dymnamics simulation of sticking process of sub-micron particles

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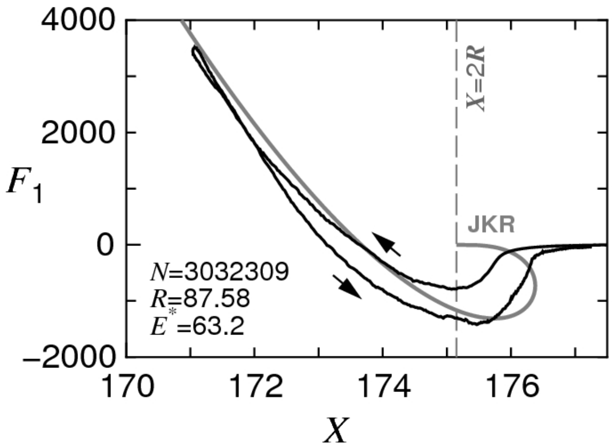
Dust collisional growth is the first step of the planet formation process, which is governed by adhesion forces frictions between sub-micron particles. Adhesion and inelastic interaction between nano- or submicron-sized solid particles are an important subject in many areas of technology and applied science as well as in astrophysics. However, detail of the particle interaction in such a size range has not been studied yet even for simple and homogeneous molecular systems. We examined interactions between small particles which consist of up to 100 millions of Lennard-Jones molecules, by performing molecular dynamics simulation. With molecular dynamics simulation, we can see clearly how the energy dissipation proceeds at collisions or rolling motions of particles. The figure shows the interaction force between two particles obtained from a MD simulation. This result almost agrees with JKR theory and also indicates that the interaction force has hysteresis, which causes energy dissipation. I will further report the detail of the molecular dynamics simulations of particle collisions, rolling, sliding, and twisting and show results on comparisons with the previous theoretical models of particle interaction.

Keywords: cosmic dust, grain aggregate, planet formation, planetesimal, tribology



PPS24-04 Room:106 Time:May 25 14:30-14:45

Does nuclear-spin temperature of water molecules in comet coma reflect the formation temperature of the cometary ice?

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The nuclear-spin temperature (T_{spin}) is derived from the ortho-to-para ratio (OPR) of molecules such as H_2 or H_2O, which contains two protons with spin of 1/2; thus, its total spin state can be either 0 (singlet, para) or 1 (triplet, ortho). In the case of H_2O, the OPR is equal to 3 in statistical equilibrium, which is achieved at temperatures above ~50 K.

T_{spin} of interstellar H_2O molecules has been observed, because they are suggested to be indicators of these molecules' physical and chemical histories. In cometary coma, T_{spin} of H_2O has been derived to be typically ~30 K. Recently, it was found that there has been a wide range of the observed values of T_{spin} of H_2O from 13.5 K to ~50 K in interstellar space.

Since nuclear-spin conversion is unlikely to occur for isolated molecules in the gas phase. These values have been implicated as the temperature of cold grains at molecular condensation or formation in a molecular cloud, or in the solar nebula, for example. However, the real meaning of the observed T_{spin} remains a topic of continuing debate. For a proper interpretation of T_{spin} of molecules observed in interstellar space or cometary coma, the correlation between T_{spin} and temperatures of ice at condensation, formation, and desorption needs to be investigated. Even T_{spin} of thermally desorbed H_2O from water ice condensed or formed at low temperature is yet to be experimentally measured.

The present study measured the T_{spin} of H_2O thermally desorbed from pure amorphous solid water (ASW) deposited at 8 K by employing a combination of temperature programmed desorption and resonance-enhanced multiphoton ionization (REMPI) methods. We also produced ASW at 8 K by photolysis of a CH_4/O_2 mixture (photoproduced ASW) for the idea that T_{spin} of H_2O molecules formed at a low temperature relates to the formation environment.

As a result, thermally desorbed H_2O molecules at 150 K from all ice samples prepared at 8 K showed T_{spin} almost at the statistical high-temperature limit (>~30 K). T_{spin} of desorbed H_2O from vapor-deposited pure ASW is almost at the statistical high-temperature limit (>~30 K), while its value was almost the same after leaving it for 9 days at 8 K. These results suggest that the T_{spin} of gaseous H_2O molecules thermally desorbed from ice does not necessarily reflect the surface temperature at which H_2O molecules condensed or formed. We discuss the possibility of nuclear-spin conversion of H_2O in water ice.

Keywords: comet, nuclear-spin temperature, ortho-to-para ratio, interstellar molecules, laboratory experiment

PPS24-05 Room:106 Time:May 25 14:45-15:00

A synthesis experiment of GEMS analogue grains produced by thermal plasma

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Anhydrous IDPs (interplanetary dust particles), which is considered to have cometary origin, have a large amount of amorphous matter called GEMS (glass with embedded metal and sulfides). This is typically a few 100 nm in diameter and consists of SiO_2-rich silicate glass including small (typically 10-50 nm) and rounded grains of Fe, Ni metals and sulfides. There are two formation models proposed for GEMS: (1) condensate of Si-rich gas [1], and (2) amorphization of crystalline silicate dust [2]. It is important to reproduce GEMS analogue matter in a laboratory to understand conditions for GEMS formation process. Especially, we focused on whether or not amorphous silicate spheres that contain nano-grains of metal can be formed by condensation from a Si-rich gas in this study.

The Si-rich gas was obtained by using an induction thermal plasma (ITP) (TP12010, JEOL). The ITP can provide ultra-high temperature (~10,000 K) to evaporate a starting material immediately, and then, the gas is quenched rapidly with the cooling time scale of 10^4-10^5 K/sec to form nanoparticles, which are usually in an amorphous state. Powders of MgO, metallic Fe and SiO_2 were mixed together with the GEMS mean composition [1] (Mg/Si = 0.65, Fe/Si = 0.56) for preparing the starting material, which was an analogue to Si-rich gas in the early solar system. Mg, Si, Fe and O were taken into consideration as major elements in solid materials in the solar system for simplicity. It was proposed that GEMS was condensate as amorphous silicate including metals, and then, the metals near the surface of GEMS were sulfurized [1]. Moreover the experimental difficulty, we carried out this study with S-free system. The ITP experiments were produced under an Ar-He atmosphere at atmospheric pressure.

Run product attached on the chamber walls of the furnace was collected. Iron and amorphous silicate are identified by powder X-ray diffraction (XRD) pattern. No crystalline silicates, such as forsterite, pyroxene and silica mineral, are detected. Thus, amorphous silicate was formed directly from high-temperature gas by very rapid condensation. Micrographs by transmission electron microscope (TEM) show that the run product is composed of numerous spherical grains (typically ~50 nm in diameter) and each grain has an iron core (~20 nm in diameter) embedded in an amorphous silicate.

Yamamoto & Hasegawa (1977) theoretically formulated homogeneous nucleation and growth of dust grains from a gas, proposed a non-dimensional parameter for the condensation and calculated the value for some astronomical environments such as presolar nebula at 0.1 AU (~$3x10^9$) or around AGB stars (0.9-90) [3]. This value in the present experiments was estimated to be ~$4x10^3$. This was not the same as but not extremely different from those in the astronomical events.

The textures of the run product are similar to that of GEMS, although, GEMS is composed of multiple metal grains. It means that sintering a number of amorphous silicate spheres including a metal grain can form the GEMS-like texture. Solar system origin of GEMS is proposed based on that GEMS has rare oxygen isotopic anomalies [1]. However, if GEMS was a mixture of primary grains of a few tens nm in size, exchanging of oxygen atoms between the primary grains and surrounding gas, which contained large amounts of H_2O and CO molecules, might occur even at low temperatures, and the oxygen isotopic anomalies disappeared in most GEMS. Therefore, the rare oxygen isotopic anomalies of GEMS might not be evidence of the solar system origin. Primary grains of GEMS might originally form around evolved stars by condensation, were transferred to interstellar region, incorporated into the primordial solar nebula, suffered by oxygen isotope exchange with surrounding gas, and accumulated into GEMS. Finally some iron grains near the GEMS surfaces were sulfurized.

[1] Keller & Messenger, 2011 [2] Bradley & Dai, 2004 [3] Yamamoto & Hasegawa, 1977

Keywords: GEMS, condensation experiment

PPS24-06 Room:106 Time:May 25 15:00-15:15

”Astromineralogy” as mineralogy: until now and from now

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Small solid-state grains called ”dust”, which are ubiquitously present in a variety of astronomical environments, control thermal balance in astronomical processes by absorbing the radiation of high-energy and radiating in the infrared region. They are also raw materials that form solids in the solar system. Since recent development of infrared astronomical observation reveled presence of minerals as dust, which has been once considered to be amorphous state, a field between astronomy and mineralogy called ”astromineralogy” has been developed [1]. In circumstellar regions of evolved and young stars, ˜15% of crystalline silicates (mainly Mg-rich olivine and pyroxene) has been observed as well as amorphous silicate as sub-micron dust. In interstellar regions, in contrast, any crystalline silicates have not been observed [2]. It is accepted that crystalline dust becomes amorphous by cosmic ray irradiation. If such interstellar dust is incorporated in a molecular cloud, ice condensed onto the amorphous silicate dust, and organic materials form from the ice. This composite dust called Greenburg particles [3] are considered as a solid raw material in the solar system. In a high-temperature region of a protoplanetary disk, crystallization of amorphous silicate and evaporation and recondensation should occur.

Astromineralogy has been developed mainly as a branch of astronomy. From the standpoint of material science, formation and evolution of dust has been discussed by considering infrared spectrum features, which are controlled by intrinsic properties (crystal structure, chemical composition and temperature) and extrinsic properties (particle size, morphology, anisotropy, lattice defects and aggregate form) of minerals (e.g., [4]). Based on the intrinsic properties, minerals in circumstellar regions have been identified and their chemical compositions have been estimated by comparing observed infrared spectrum. Researches based on extrinsic properties are now developing, and it is important in the future to promote mineralogical researches in addition to observation and theoretical researches.

Important issues for future studies are follows. (i) Origin of crystalline circumstellar dust: crystallization of amorphous silicate [5,6] or direct condensation from high-temperature gas [7]? Is there any possibility of impact fragments of larger crystals [8]? (ii) Behaviors of Fe and S. (iii) Relation with extra solar materials (presolar grains) [7] and the candidates (GEMS) [9]. (iv) Farther understanding physics of infrared absorption spectrum of minerals.

Finally, a following working hypothesis for a series of processes of dust formation and evolution is proposed here based on previous studies. (1) Mass loss from an evolved star. (2) Condensation of refractory minerals, such as corundum [7], followed by condensation of spherical particles of amorphous silicate [5] with an metallic iron nano-particle inside [9]. (3) Partially crystallization of the amorphous silicate [6]. (4) Transportation to interstellar region and amorphization [2]. (5) Incorporation into a molecular cloud, condensation of ice and formation of organic materials [3]. (6) Incorporation into a protoplanetary disc and sintering of spherical amorphous silicate particles (GEMS formation) [9]. (7) Crystallization in a high-temperature region near the central star. (8) Evaporation and recondensation of silicates in a higher-temperature region and recycling of the high-temperature materials.

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Keywords: circumstellar dust, interstellar dust, amorphous silicate, crystalline silicates, infrared spectrum, condensation