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

FUKAGAWA, Misato[1]*

[1]Osaka University

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

OKUZUMI, Satoshi[1*]

[1] Nagoya University

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

Japan Geoscience Union Meeting 2012
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PPS24-03 Room:106 Time:May 25 14:15-14:30

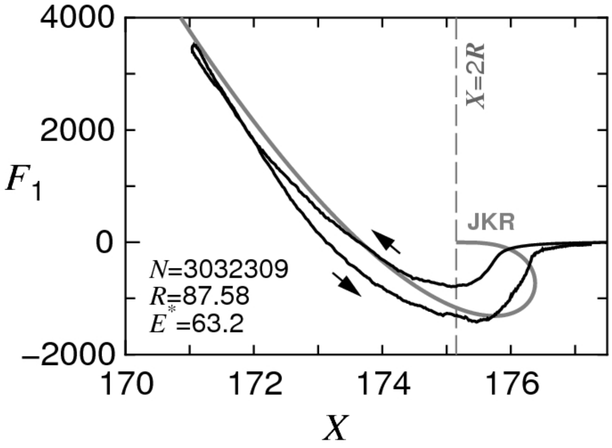
Molecular dymnamics simulation of sticking process of sub-micron particles

TANAKA, Hidekazu[1]*

[1]ILTS, Hokkaido University

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



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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?

HAMA, Tetsuya[1*], WATANABE, Naoki[1], KOUCHI, Akira[1]

[1]Institute of Low Temperature Science, Hokkaido University

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

MATSUNO, Junya[1*], TSUCHIYAMA, Akira[1], YAGISHITA Masahito[2], KOYAMA Seiji[2], WATANABE Takayuki[2]

[1]Graduate School of Science, Kyoto University, [2]Granduate School of Science and Engineering, Tokyo Institute of Technology Interdisciplinary

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

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

”Astromineralogy” as mineralogy: until now and from now

TSUCHIYAMA, Akira[1*]

[1]Graduate School of Science, Osaka University

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

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PPS24-P01 Room:Convention Hall Time:May 25 10:45-12:15

Nucleation process from vapor due to molecular dynamics simulations: effect of the sticking probability

TANAKA, Kyoko[1]*, KAWANO, Akio[2], TANAKA, Hidekazu[1]

[1]Institute of Low Temperature Science, Hokkaido University, [2]Institute For Research on Earth Evolution, Japan Agency for Marine-Earth Science and Technology

In the previous studies (Tanaka et al. 2005, 2011), we performed molecular dynamics (MD) simulations of nucleation from vapor of Lennard-Jones (L-J) type molecules and found that the semi-phenomenological (SP) model reproduces very well the nucleation rates obtained from the MD simulations. In this study, we performed MD simulations of nucleation from vapor for systems of 4000 water molecules to test nucleation theories. Simulations were done for wide ranges of the initial supersaturation ratio (S=4-400) and temperature (T =250-375 K). Through comparison with the nucleation rates and the cluster size distributions obtained from our MD simulations, we investigated the validity of the SP model. Our results show that the semi-phenomenological model reproduces well the size distributions of the clusters and the nucleation rates. Furthermore, the sticking probability of vapor molecules onto clusters was examined in MD simulations, by observing the growth rate of stable clusters larger than the critical size. In all runs in the present study, the values of the sticking probability are larger than 0.1. Our results show that the obtained sticking probability depends on the supersaturation ratio.

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K. K. Tanaka, H. Tanaka, T. Yamamoto, and K. Kawamura, J. Chem. Phys. 134, 204313, 2011

Keywords: nucleation process, water, condensation, MD simulation

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PPS24-P02 Room:Convention Hall Time:May 25 10:45-12:15

In-situ observation of nucleation process under microgravity by an aircraft

KIMURA, Yuki[1]*, TANAKA, Kyoko[2], MIURA, Hitoshi[1], TSUKAMOTO, Katsuo[1], Yuko Inatomi[3]

[1]Tohoku University, [2]Hokkaido University, [3]JAXA

To understand the formation process of cosmic dust particles with nm to sub-micrometer in size, dust analogues have been produced in the laboratory. The gas evaporation method has a similarity in the dust formation process in space, where dust forms by a condensation from gas phase via homogeneous nucleation in most case. Nucleation determines characters of dust, such as size, number and composition. However, nucleation process has been unknown not only in universe but also in the laboratory. Recently, we succeeded in directly observing the temperature and concentration during homogeneous nucleation in the vapor phase by interferometer under the gravity [1,2] To understand the homogeneous nucleation quantitatively, we applied nucleation theories to the experimental results and determined the following results: the surface free energy, the size of critical nuclei, determination of polymorph, fusion growth and sticking probability. In particular, surface free energy and sticking probability are most important parameters to know the characters of cosmic dust. Here, we will show the recent results in microgravity by using an aircraft. Microgravity experiment has an advantage to determine above mentioned values more certainly due to suppress the thermal convection, which generates inhomogeneous formation condition and secondary growth in the flow.

Smoke particles of WO_3, SiO, Mn, Fe, Au or NaCl were produced in a specially designed smoke chamber setting with a Mach?Zehnder-type interferometer with two wavelengths lasers, which can obtain two unknown parameters simultaneously, i.e., concentration of evaporant and temperature.

When an evaporant is initiated in an inert gas, the evaporated vapor subsequently cools and condenses homogeneously in the gas atmosphere. Condensation temperature depends on surface energy and sticking probability. Both parameters can be determined from the condensation temperature and the size of produced particles, respectively.

In case of Mn and WO_3, condensation occurred at 660 and 600 K below the equilibrium temperatures, and the degree of supersaturation was as high as 10^5 and 10^9, respectively. The condensation temperature, number density, and size of particles for Mn experiment were consistent with the values calculated by the semi-phenomenological nucleation theory. On the other hand, however, the results have a gap with the values calculated by the nucleation theories in case of WO_3 and NaCl. One of the reasons may be due to secondary growth. Since there is strong thermal convection generated by the hot evaporation source in the chamber, condensed particles follow the convection and possibly grow in the way as gas cools. As the result, size and number density could be different from the theory. In the same reason, estimation of the sticking probability will be difficult. It has been expected that microgravity experiment gives us more certain results due to suppress the thermal convection.

Recently, we firstly performed the gas evaporation experiments in microgravity using the aircraft. Here, we will present the brief results and show the difference from gravity experiment. Since microgravity environment strongly suppresses the thermal convection, evaporated vapor diffused simply to the direction of centric distance and condensed at the wider area compared with gravity condition due to no convection. Then, it can be concluded that condensation in microgravity occurred farther from the evaporation source compared with gravity experiment. In case of microgravity experiment, since condensation and growth occur at the same place due to no convection, secondary growth is negligible and the results are able to compare with the nucleation theories. As the result, surface free energy and sticking parameter will be determined more certainly.

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[2] Y. Kimura, et al., J. Crystal Growth, 316 (2011) 196.

Keywords: Nucleation, dust, nanoparticle, in-situ observation

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Thermal instability of gas-dust fluid system

WATANABE, Keisuke[1*], NAKAMOTO, Taishi[1]

[1]Department of Earth & Planetary Sciences, Tokyo Institute of Technology

We carry out hydrodynamics linear stability analysis of 1-dimensional gas-dust fluid system. We focus on the thermal instability caused by the radiative cooling. If the cooling in a region takes place effectively, the gas temperature and the pressure decrease, and a flow converging to the region is driven. Then the dust particle number density in the region is enhanced by the gas drag force, and the cooling rate from the region can be raised as well because the cooling rate is proportional to the dust number density. This one-way process would lead to instability.

As an initial state, we assume that the system is static and the gas temperature is higher than the dust temperature. For retaining this state, we assume a hypothetical heat function for gas that is a function of the gas temperature and the gas density. As the cooling mechanism of the system, we suppose that the radiation from dust particle leaves the system without being absorbed again. Thermal energy is transferred between the gas and the dust particle by gas-dust collisions. At the same time the gas and the dust particles are dynamically coupled by drag force.

As a result of our linear analysis, we obtain a dispersion relation. We find that when a gas-temperature derivative and a gas-density derivative of the heat function satisfy certain criteria, an unstable mode emerges. When the instability takes place, the fluctuation of the dust particle number density grows.

Our result implies that if a realistic heat function meets the obtained criteria, a dust accumulation may occur in a protoplanetary disk. And this accumulation may lead to the planetesimal formation.

Keywords: hydrodynamics linear stability analysis, dust accumulation, chondrule formation, planetesimal formation

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PPS24-P04 Room:Convention Hall Time:May 25 10:45-12:15

Cr-54 anomalies and accretion ages of meteorite parent bodies

SUGIURA, naoji[1]*, FUJIYA Wataru[1]

[1]Department of Earth and Planetary Sci. University of Tokyo, Tokyo, Japan

A positive correlation between 54Cr excesses and accretion ages is observed among meteorites including iron meteorites, pallasites, mesosiderites, aubrites, HED meteorites, angrites, ureilites, acapulcoites and chondrites (including E, O, R, CK, CO, CV, CH-CB, CR, CM and CI) [1]. This suggests that 54Cr carriers were injected into the forming solar nebula. We could constrain the solar system evolution based on this observation. However, there are still many unsettled issues concerning the 54Cr anomalies, the accretion ages and the interpretation of the correlation. Here, we examine some of the most important issues.

26Al Heterogeneity: Homogeneous distribution of 26Al is assumed for calculating accretion ages of chondrites parent bodies. It is also assumed for estimating accretion ages of differentiated meteorite parent bodies. But, at present heterogeneous distribution of 26Al [2] cannot be ruled out. Comparison of precisely determined Al-Mg ages and other ages is needed to solve this problem.

Exceptions: The NWA011 grouplet (basaltic achondrites) and Tafassasset (primitive achondrite) do not fit the correlation. They both have high 54Cr excesses [3,4] similar to that of CR chondrites and yet apparently formed early when there was enough 26Al. A possible explanation may be that early-formed planetesimals in the terrestrial-planet formation region were gravitationally scattered into the far end of the asteroidal belt, capturing CR-like materials. This is an ad hoc explanation but is shown to be possible by numerical simulations [5].

CAIs: CAIs have 54Cr, 50Ti and 48Ca isotope anomalies which are larger than those found in bulk meteorites. 54Cr and 50Ti anomalies in CAIs and bulk meteorites appear to be well correlated with each other [6] but 48Ca anomalies are not so well correlated with them [7]. Since CAIs formed early, they do not fit the trend formed by various meteorites on the 54Cr vs. accretion age diagram. If we consider that the isotope anomalies of neutron-rich isotopes in CAIs and bulk meteorites originated from a similar source, then, a kind of chemical fractionation that enriched carriers of the neutron-rich isotopes must have operated during CAI formation. Otherwise, the anomalies in CAIs may have originated from a totally different source.

Other issues such as the way to estimate accretion ages of differentiated meteorite parent bodies will also be discussed at the meeting.

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Keywords: 54Cr, accretion age, meteorite parent bodies

PPS24-P05 Room:Convention Hall Time:May 25 10:45-12:15

Condensation and gas-solid experiments of minerals in protoplanetary disk conditions

TACHIBANA, Shogo[1]*, TAKIGAWA, Aki[1], NAGAHARA, Hiroko[1], OZAWA, Kazuhito[1]

[1]Dept. Earth Planet. Sci., Univ. Tokyo

Condensation from vapor and gas-solid reaction may have been responsible for dust formation in the high-temperature region or during high-temperature events in the early solar system. Physical properties of condensed materials, such as size of individual components and textual relationship in a mineral assemblage, are important because they may change the efficiency of physical separation of dust and the interaction between dust and a radiation field, i.e., the thermal condition of the dust-forming environment. These properties are determined by reaction processes, but equilibrium calculations cannot deal with processes of reactions. It is thus crucial to understand condensation and gas-solid reaction processes of minerals and their kinetic aspects to understand the evolution of solar system materials. There have been many experimental studies on evaporation of major minerals in chondrites such as forsterite, enstatite, metallic iron, and troilite, while it has not been easy to carry out condensation and gas-solid experiments under low-pressure conditions for quantitative discussion on kinetic processes due to experimental difficulties. However, recent progresses of experimental studies have made it possible to determine the growth kinetics of minerals in chondrites. Here we report our recent condensation and gas-solid reaction experiments and the growth kinetics of minerals from vapor obtained in the experiments.

Keywords: dust, condensation, kinetics, protoplanetary disk

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Chemical evolution of the atmosphere of Netune and Jupiter induced by the cometary impact

IINO, Takahiro[1*], MIZUNO, Akira[1], NAGAHAMA, Tomoo[1], MAEZAWA, Hiroyuki[1], MORIBE, Nayuta[1], KUWAHARA, Toshihisa[1]

[1]STEL, Nagoya University

Gases produced after the collision of comet or asteroid in the atmosphere of giant planets, such as carbon monoxide, hydrogen cyanide, and sulfur compounds have key information to reveal the distribution and composition of minor bodies which exists in the outer solar system and the atmospheric evolution of gas giants. From the observational result, a collision of comet Shoemaker-Levy/9 on Jupiter in 1994 had produced large amount of short-lifetime volatile gases. Similar supplying process is predicted to be existed in the atmosphere of Neptune from the observational results that CO, which is not considered as a main reservoir of carbon, exists with high mixing ratio. In this presentation, I am presenting our observational results toward Neptune using ASTE telescope of NAOJ to constrain such supplying system and a new implication that the short-time variation of collision-induced gases in Jupiter using 45-m telescope.

Keywords: Radio astronomy, Jupiter, Neptune, Comet, Collision, Atmospheric evolution