Grain alignment in protoplanetary disks

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Recently, ALMA has so far been revealed polarimetric properties of protoplanetary disks in (sub-)millimeter wavelengths. However, the origin of polarized light in these wavelengths is still controversial. In order to understand how polarized light is produced in these wavelengths, we apply the theory of radiative torque (RAT) alignment for studying protoplanetary disks around a T-Tauri star and perform 3D radiative transfer calculations to provide the expected maps of polarized radiation to be compared with observations, such as with ALMA. We revisit the issue of grain alignment for large grains expected in the protoplanetary disks and find that mm-sized grains at midplane do not align with magnetic field as the Larmor precession timescale for such large grains becomes longer than the gaseous damping timescale. Hence, for these grains the RAT theory predicts that the alignment axis is determined by the grain precession with respect to the radiative flux. As a result, we expect that the polarization will be in the azimuthal direction for a face-on disk. It is also shown that if dust grains have superparamagnetic inclusions, magnetic field alignment is possible for (sub-)micron grains at the surface layer of disks, and this can be tested by mid-infrared polarimetric observations.

Keywords: Protoplanetary disks, polarimetric observations, grain alignment

3D radiation hydrodynamics simulations of gravito-turbulence in protoplanetary disks

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Angular momentum transport in protoplanetary disks controls their time evolution and thus strongly affects the planet formation process within them. In some cold and massive protoplanetary disks, angular momentum can be transported by shear stresses associated with the gravitational instability (GI). A natural consequence of the long-range nature of gravity is formation of spiral arms as a result of GI, which globally transport angular momentum. On the other hand, Gammie (2001) showed another nonlinear outcome of GI, called gravito-turbulence, in which angular momentum transport can be described locally as in the alpha disk model (Shakura & Sunyaev 1973). Following Gammie (2001), many authors have studied numerically various aspects of the gravito-turbulence, but, in most cases, a simple cooling function with a constant cooling time has been used as in Gammie (2001).

In this paper, we present 3D radiation hydrodynamics simulations in a local shearing box to explore the outcome of self-gravity in a protoplanetary disk with realistic thermodynamics. We found that gravito-turbulence is sustained for a finite range of the surface density, from 20 to 50 times the one in the minimum mass solar nebula at 50AU, when the grazing angle of the irradiation is 0.02. The flow is laminar below the range while fragmentation occurs above the range. In the range of gravito-turbulence, the Toomre parameter decreases monotonically from 1 to 0.7 as the surface density increases while an effective cooling time takes an almost constant value that depends on the radius. The turbulent motions are supersonic at all heights, which dissipates through both shock waves and compressional heating. The compressional motions, occurring near the midplane, create upward flows, which not only contribute to supporting the disk but also to transporting the dissipated energy to the disk surfaces. We also show that the simple cooling function with a constant cooling time does not approximate the realistic cooling.

Keywords: protoplanetary disk, gravitational instability, turbulence

Synthesis of cosmic dust analogue particles in the newly developed ITP (induction thermal plasma) system

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Cosmic dust formed by condensation from high temperature gas around young and evolved stars or in the primordial solar nebula [1,2]. Some of them could be building block of our solar system.
The ITP (Induction Thermal Plasma) system enables the formation of nanoparticles from supersaturated vapors by homogeneous nucleation and growth because it offers vaporization of refractory materials at thousands of degree Celsius and very rapid quenching rates [3]. It can also control the evaporation and condensation environments by adjusting the characteristic of the thermal plasma. Moreover, condensation experiments from gases with various chemical compositions can be relatively easily performed in the ITP system because almost any reagents can be introduced into the plasma. For example, GEMS-like materials were reproduced in the different ITP system in the previous study [2].
In order to examine the formation processes of various cosmic dust analogues, a new ITP system (JEOL TP-40020NPS, max. 6 kW) was set up in our laboratory. The objective of the research is examination of the performance of the newly developed ITP system on production of nano-sized condensates simulating cosmic dust formation in circumstellar environments. We have already performed preliminary examinations using starting materials of SiO_2 (quartz), MgO (periclase), and Si-Mg-Fe-Na-Al-Ca-Ni-O in our ITP system [4]. In this study, we performed condensation experiments in the system of MgO-SiO_2 and examined the performance of the ITP system by changing plasma conditions.
We used mixtures of periclase and quartz powders with 1:1 molar ratio as stating materials for all experiments. The various operating parameters were applied to improve the evaporation rate and condensation conditions, such as feeding rates of starting material, reactor pressures, the presence of an additional slit gas, and the injecting direction of plasma forming gas. Plasma input power was fixed at 6 kW. The produced powders were analyzed by XRD, FT-IR, SEM, and TEM. Nano-sized condensates of amorphous silicate, forsterite, and protoenstatite were observed in most of the experimental products. We found that (1) the feeding rate of the starting material and reactor pressure control the vapor density and residence time at the high temperature regions of the plasma flame, (2) the vapor condenses into particles more rapidly by injecting the slit gas into the plasma flame, and (3) the injecting direction of the plasma forming gas changes temperature distribution of the plasma flame, which most influences condensation conditions. The plasma forming gas flows into the plasma generating torch axially (tangential flow) or swirly (radial flow). The radial flow provides a longer and narrower plasma flame that improves the residence time of the starting material at the high temperature region than the tangential flow. The more uniform nanoparticles were produced in the radial flow condition.

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Keywords: Cosmic dust, GEMS, Induction thermal plasma, Condensation experiment, Nanomaterial synthesis, Infrared spectrum

Condensation experiments in the Mg-Si-O system for understanding of circumstellar dust formation: dependence on the Mg/Si ratio.

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Silicates are major dust species around young and evolved stars, and in the interstellar medium. Experimental and theoretical studies on solid formation are crucial for understanding the origin of precursor materials of chondrites and dust formation around stars. Condensation experiments of silicates were performed in various systems, where most of the studies evaporated starting materials with compositions of $(Mg_x, Fe_{1-x})_2SiO_4$, SiO_2, and MgO [1-7]. Condensation from vapors with different Mg/Si ratio, however, has not been studied systematically. In this study, we performed condensation experiments of silicates from vapors with various Mg/Si ratios to examine the condensation sequence in different circumstellar environments.
Condensation experiments were carried out in a vacuum chamber. We produced Mg-Si-O gases by evaporation of (1) melts with Mg/Si~1 (Exp02 and 03) and (2) SiO_2 and MgO powders separately filled in Knudsen cells (Exp04-06) placed on the bottom of the crucible of 90 mm in depth. Here, the Mg/Si ratio was controlled by changing the size of the hole on the rids of the Knudsen cells to be 0.9, 1.6, and 20.0, respectively. The vapors condense onto Pt (Exp02-05) and Ir (Exp06) wires of 50-80 mm in length hung from the top of the crucible. The temperature gradient on the wire was measured by thermocouples before the experiments.
A mixture of SiO_2 and MgO powders were heated as a gas source at 1650 (Exp02) and 1580˚C (Exp03), which are higher than the melting temperature. We obtained condensates on the Pt-wires. In Exp02, forsterite was obtained at ~1570˚C and clino-enstatite at lower temperature regions. In Exp03, ortho- (or proto-) enstatite was observed at the highest temperature region (~1520˚C) and forsterite was not confirmed. Clino-enstatite covered the Pt-wire at lower temperatures than 1510˚C.
Quartz and periclase powders were put into Ir Knudsen cells separately and heated at 1580˚C (Exp03-06). No condensate was observed at >1360˚C. Forsterite covered the wires at <1350˚C and enstatite was not condensed at lower temperatures. No clear difference was observed between the three experiments with different Mg/Si ratio of 0.9-20.0.
Fractional evaporation may have occurred from Mg-Si-O melts, and the gas composition gradually enriched in Si compared to Mg during the experiments. We did not use Knudsen cells for the experiments Exp02 and 03. Therefore, the differences between the condensation experiments from gases evaporated from melts and powders may be the Mg/Si ratio and gas fluxes. As future works, we plan to perform experiments with much lower Mg/Si ratios and with higher gas fluxes (higher supersaturation ratios) to determine the condition to form clino- and proto-enstatite from gas phases.

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Keywords: condensation, experiments, silicate, circumstellar dust

Evolution of molecules in space: from interstellar clouds to proto-planetary nebula

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Our understanding of the origin and evolution of planetary systems has been mostly limited to the dynamics. The importance of chemistry has been emphasized, however, systematic studies about chemical evolution have not yet been performed. We have thus started research project on “Evolution of molecules in space” supported by Grant-in-Aid for Scientific Research on Innovative Areas from MEXT, Japan from 2013.
We focus our attention on the most abundant solid materials in space: ices and organic materials. How do these molecules evolve in space? We aim at answering this question by interdisciplinary approaches including laboratory and theoretical studies about surface processes, observation of young stellar objects, modeling of molecular cloud and protoplanetary-disk chemistry, and analyses of extraterrestrial materials.

We are now investigating the evolution of molecules by following groups; (1) Experimental studies about surface reactions of atoms and molecules and photochemical reactions of solids at low temperatures to mimic phenomena occurring in molecular clouds (PI: A. Kouchi, Hokkaido Univ.), (2) Heating experiments of molecular-cloud organics and Fischer-Tropsh type surface reaction experiments to mimic phenomena occurring in proto-planetary nebulae (PI: H. Nagahara, Univ. of Tokyo), (3) Observation of young stellar objects by radio telescopes (ALMA, ASTE etc.) to understand the evolution and variety of organic molecules (PI: S. Yamamoto Univ. of Tokyo), (4) Modeling of surface processes and developing of chemical network model (PI: T. Fukazawa, Meiji Univ.), and (5) Analyses of chemical and isotopic composition of organic molecules in meteorites and cometary dust (PI: H. Yurimoto, Hokkaido Univ.). I will introduce some important achievements of respective groups.

Our project will contribute to not only the understanding of origin and evolution of molecules in space but also the analysis of returned samples by Hayabusa 2 and OSIRIS-REx. We have developed some new analytical setups: High-resolution imaging-type soft X-ray microscope/spectrometer, two-dimensional HPLC-MS for amino acids analysis, high-sensitive HPLC-MS for organic material analysis, etc.

Keywords: Evolution of molecules, Ices, Organic materials, Interstellar molecular clouds, Proto-planetary disk

Reproducing interstellar infrared spectrum by modeling a hydrocarbon pentagon-hexagon combined molecule

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Interstellar infrared spectrum coming from polycyclic hydrocarbon molecules shows a ubiquitous pattern in a wavelength of 3-15 micrometer (1). These years, thousand kind of molecules were test and discussed as a candidate. However, any convincing single molecule was not discovered by both experiment and calculation. Here, promising single molecule was studied by quantum-chemistry first principles calculation focusing on hydrocarbon pentagon-hexagon combined molecule parametarizing charge and spin state. Among many candidates, better one was dication (C23H12)+2 having two pentagons and five hexagons (2). Calculated main peaks were 3.2 , 6.4, 7.6, 7.8, 8.6, 11.2, 12.7 and 14.1 micrometer. Those show very good coincidence with astronomically observed values as 3.3, 6.2, 7.6, 7.8, 8.6, 11.2, 12.7, and 14.3 micrometer. Also, another small molecule (C12H8)3+ having one pentagon and two hexagons shows good coincidence at major wavelength of 3.2, 6.4, 7.5, 7.8, and 11.2 micrometer. This is the first case to give good coincidence by a single molecule. References: (1)Christiaan Boersma et al, Astrophysical Journal 690.1208(2009) (2)Norio Ota, arXiv:1402.0009(2014) (3)Norio Ota, arXiv:1510.07403(2015)

Keywords: interstellar dust, infrared spectrum, PAH

Detections of Long Carbon Chains CH_3CCCCH, C_6H, *linear*-C_6H_2 and C_7H in the Low-Mass Star Forming Region L1527

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A richness of long carbon chains in the warm carbon chain chemistry (WCCC) region has been searched in the 42-44 GHz region by using Green Bank 100 m telescope. Long carbon chains C_7H, C_6H, CH_3C_4H, and *linear*-C_6H_2 and cyclic species C_3H and C_3H_2O have been detected in the low-mass star forming region L1527, performing the WCCC. The detection of C_7H is for the first time in molecular clouds. While the abundance ratios of carbon chains in between L1527 and the starless dark cloud Taurus Molecular Cloud-1 Cyanopolyyne Peak (TMC-1 CP) have a trend of decrease by extension of carbon-chain length, column densities of CH_3C_4H and C_6H are on the trend. However, the column densities of *linear*-C_6H_2, and C_7H are as abundant as those of TMC-1 CP in spite of long carbon chain, i.e., they are not on the trend. The abundances of *linear*-C_6H_2 and C_7H show that L1527 is rich for long carbon chains as well as TMC-1 CP.

Keywords: carbon chain, radio, molecular cloud

Reaction efficiency between hydrogen and carbon monoxide on a catalytic substrate of iron, nickel or its alloy

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Reaction of hydrogen and carbon monoxide on a catalytic substrate to form methane and water has widely been used to synthesize fuel and called the Fischer-Tropsch reaction (FT reaction). Typical conditions of the FT reaction for manufacturing application is a total gas pressure of 10^5-10^6 Pa with a ratio of H_2 / CO = 2 at 500-650 K together with a catalysis of Fe, Co or Ru[1]. Then, water-gas shift reaction has been occurred as a side reaction; carbon dioxide and hydrogen molecules form from carbon monoxide and water. The efficiencies of both reactions depend on the substrate, temperature, pressure and other conditions. Cobalt has most been used as a catalysis because of the lower activity of the side reaction [2,3]. Although the FT reaction has been used for long years, the atomic/molecular scale mechanisms that govern the FT reaction are still disputable [4]. Therefore, it is not obvious that the results of the reaction experiments are able to extrapolate to the actual solar nebula environment. Here we demonstrate the reaction rates in the solar nebula conditions (below 500 K and under 10^2 Pa) on the surface of cosmic dust particles, such as iron, iron-nickel alloys and nickel.
We developed an experimental system to test the catalytic chemical reactions in the temperature and pressure ranges of 50-800 K and 10^{-3}-10^3 Pa, respectively, using a metallic plate as a catalytic substrate. Our experimental system has a temperature-controlled substrate, a Fourier transform infrared spectrometer (FT-IR), and two quadrupole mass spectrometers (Q-MSs). FT-IR is able to measure the vibration modes of adsorbed and produced molecules on the substrate. Currently, several IR features has been detected at the temperature below 150 K. To identify the mass signal of produced methane and water in the Q-MSs spectra, deuterium was used instead of hydrogen. The intensity of the signal of masses 20 and 44 decreases as temperature decrease from 800 K. The mass 20 corresponding to D_2O and CD_4, which are first products in the Fischer-Tropsch type reaction, was detected. Simultaneously, mass 44 corresponding to CO_2 was also detected. In our presentation, the substrate dependence of the reaction efficiency will be presented.

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Acknowledgment: This work was supported by a grant-in-aid for Scientific Research on Innovative Areas "Evolution of molecules in space from interstellar clouds to proto-planetary nebulae" supported by the Ministry of Education, Culture, Sports, Science and Technology, Japan (25108003).

Keywords: Fischer-Tropsch reaction, Surface reaction, Solar nebula

New formation mechanisms of meteoritic amino acids based on the discovery of hydroxy amino acids identified in the Murchison meteorite

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ntroduction: Carbonaceous chondrites contain a diverse suite of extraterrestrial amino acids, which have various structures such as α, β, γ or δ amino-group [1], while terrestrial life use only α-amino acids. The distribution of meteoritic amino acids had been influenced by aqueous alteration on the meteorite parent body (e.g. α-aminoisobutyric acid versus β-alanine [2], and L-enantiomeric excess of isovaline [3]). However, a comprehensive formation mechanism, which could explain the diversity of meteoritic amino acids, remains unclear. In our previous study, nine new hydroxy amino acids and one β-aminodicarboxylic acid were identified in the extract of the Murchison for the first time (Koga and Naraoka, under revision). In this study, the simulation experiments of amino acid synthesis were performed under plausible conditions of the meteorite parent body in order to pursue their formation mechanisms.

Materials and Methods: The aqueous solutions containing ammonia/formaldehyde/acetaldehyde and/or glycolaldehyde (100/10/1/1 by mol) with NH_3/H_2O (1/100 by mol) were heated at 60 °C for 6 days in a N_2-purged glass ampoule with or without olivine or quartz powder with the water/mineral ratio of 1/9 (by weight). The reaction mixtures were extracted with hot water at 100 °C for 20 h. The supernatants were divided into three fractions: one hydrolyzed with 6M HCl for analysis of amino acid distribution, and two non-hydrolyzed for investigation of their precursors. The hydrolyzed and one non-hydrolyzed fractions were analyzed by GC/MS with a Chirasil-L-Val capillary column. The other non-hydrolyzed fraction was analyzed by GC/MS with a DB-5 capillary column.

Results and Discussion: The simulation experiments gave totally 20 amino acids including the nine new amino acids identified in the Murchison extract by our previous study (Koga and Naraoka, under revision). Glycine was the most abundant (approximately 0.1 % relative to the total initial carbon concentration of aldehydes), which is the similar occurrence as observed by the previous study. The amount and variety of amino acids increased in the presence of olivine compared to those in the absence of olivine and the presence of quartz. When glycolaldehyde was used in addition to formaldehyde, acetaldehyde and ammonia, the yield of hydroxy amino acids increased 1.4 times, but β-aminodicarboxylic acid decreased by one-fifth relative to the experiment in the absence of glycolaldehyde. These results indicate that formose reaction with ammonia in the presence of mineral is an important formation pathway to produce meteoritic amino acids during aqueous alteration on the meteorite parent body. In addition, the identification of a hydroxy amino acid precursor (3-Hydroxy-2-pyrrolidinone) is suggestive of a possible formation pathway using the formose reaction products with ammonia.

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Keywords: Carbonaceous chondrite, Amino acid, Formose reaction, Aqueous alteration, Meteorite parent body

Estimation of surface composition of asteroids in combination with Bus-DeMeo taxonomy and other physical observations

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The classification of asteroid's surface was done using the wavelength of visible light (eg, Tholen 1984, PhD thesis, Univ. Arizona; Bus & Binzel 2002, Icarus 158, 146), but due to the development of infrared observation technology in recent years, a method which extended to near infrared in addition to visible light has been proposed (DeMeo et al. 2009, Icarus 202, 160). By expanding the range of adaptation up to near infrared, in particular, those that were feature-less with visible light became clearly classifiable. Physical observations of asteroids are carried out also other than visible/near infrared spectroscopic observation. By adding the Bus-DeMeo classification method and other physical observation result information, it is thought that physical information of the asteroid surface layer can be extracted. It is the purpose of this research to derive new constraints on the composition of asteroids in the asteroid zone by combination of information.

Keywords: asteroid, meteorite

H^+ irradiation experiments to pyroxene and olivine for simulating space weathering by solar wind.

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The space weathering observed on the surface of asteroids is caused by micrometeorite bombardment, solar wind irradiation, and cosmic ray irradiation [1-3]. From the analysis of the regolith particles that Hayabusa spacecraft recovered from an S-type asteroid, 25143 Itokawa, the evidences of the space weathering on Itokawa, such as vesicle structures (blisters) and amorphous layers (space-weathered rims), have been confirmed [4-6]. It has been proposed that the blisters and space-weathered rims might have been formed mainly through solar wind irradiation rather than by micrometeorite bombardment [4].
Solar wind consists of 1 keV H^+ ions (95.41 %) and 4 keV He^+ ions (4.57 %) [7]. Irradiation experiments of 1 keV H^+ ions and 4keV He^+ ions to minerals consisting of the Itokawa regolith are important in order to evaluate the influence of solar-wind irradiation on formation of the blisters and space-weathered rims on the Itokawa regolith. Many irradiation experiments of 4 keV He^+ ions have been already performed, but the irradiation experiment of 1 keV H^+ ions has been hardly carried out [e.g., 8].
In this study, we examined the performance of the ion-irradiation equipment under development in ISAS/JAXA and then performed the irradiation experiments of 1 keV H^+ to orthoenstatite and olivine with different compositions, which are the major minerals consistent of ordinary chondrites.
We measured the shape and size of the ion beam by moving the one-dimensional multipoint Faraday cup. The half maximum full-width of the ion was 1.2-2.7 mm and the current density was 0.52-1.22 $\mu m/cm^2$. We verified the stability of the ion beam at least for ten hours. The confirmed performance of the ion irradiation system enables the 1 keV H^+ irradiation with a dose of at least 10^{17} ions/cm^2.
As targets of irradiation experiments, we prepared rectangular samples of orthoenstatite (En_{99}, Tanzania), forsterite (Fo_{100}, synthetsis), and olivine (Fo_{92}, San Carlos). The sample size is 3 mm x 5 mm x 0.5 mm. We mechanically polished the samples (until 0.25 μm roughness) and performed the chemical polishing with colloidal silica to remove the damage layer of the surface. Finally, the surfaces of samples were cleaned by the ultrasonic cleaning. The irradiated samples were observed with an FE-SEM (JEOL JSM 7001F). FIB-lift-out sections were prepared with FE-FIB (FEI Helios NanoLab 3G CX) and observed with FE-TEM (JEOL JEM 2100F).
On the surface of the irradiated enstatite (10^{17} ions/cm^2), an amorphous layer (26 nm) was observed. The thickness of the amorphous layer is consistent with the width of the damage layer promoted by 1keV H^+ irradiation calculated with the SRIM [9]. However, amorphous layer was also observed in the unirradiated area, which indicates that the damage due to the mechanical polishing in the sample preparation had not been removed by the chemical polishing. The blisters of 30 nm in diameter and 3×10^{10} cm^{-2} in density, and the sharper boundary of amorphous layer were observed only in the irradiated area. Compared with the Itokawa particles [4-6], the irradiated enstatite sample and Itokawa particles show similar size, density, and formation depth of the blisters, although the thickness of the amorphous layer of the irradiated enstatite (26 nm) is less than Itokawa enstatite particles (40-50 nm). The thicker amorphous layers on the Itokawa particles are due to deeper implantation depth of 4 keV He^+ than 1 keV H^+ [4,9]. These results suggest that the blisters on the surface of Itokawa particles were mainly formed by 1 keV H^+ ion

irradiation, but the thickness of the amorphous layer was due to 4 keV He^+ irradiation.

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Keywords: space weathering, solar wind

