Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

PPS020-01 Room:103 Time:May 24 08:30-08:45

The Lifetime of Protoplanetary Disks in Low-metallicity Environments

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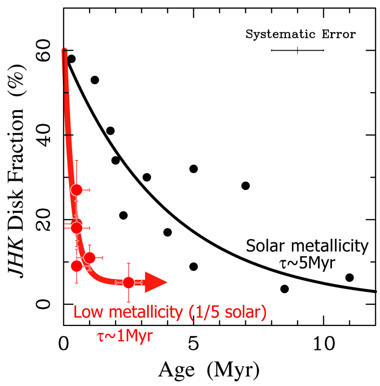
Although as many as over 500 exoplanets are now known, these planets are unexpectedly found to be diverse in terms of, e.g., mass, orbital period, and eccentricity. Perhaps the most telling discovery in exoplanet study is the "planet-metallicity correlation," the higher probability of a star hosting a giant planet with increasing metallicity, suggesting that metallicity could be the most crucial parameter for giant planet formation.

We studied near-infrared disk fractions of six young clusters in the low-metallicity environments (~1/10 solar metallicity) using deep JHK images with Subaru 8.2 m telescope. We found that disk fraction of the low-metallicity clusters declines rapidly in <1 Myr, which is much faster than the ~5-7 Myr observed for the solar-metallicity clusters (see Figure), suggesting that disk lifetime shortens with decreasing metallicity possibly with an ~10^Z dependence. Since the shorter disk lifetime reduces the time available for planet formation, this could be one of the major reasons for the strong planet-metallicity correlation. Although more quantitative observational and theoretical assessments are necessary, our results present the first direct observational evidence that can contribute to explaining the planet-metallicity correlation.



Keywords: protoplanetary disk, metallicity, disk dispersal, exoplanet

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Evolution of the size of dust grains by evaporation and condensation

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1.Background

The coagulations of dust grains of sub micron size which have silicate cores covered by ice mantle form the dust aggregates with high porosities in the outer protoplanetary disk in the initial phase of the planet formation. Whether dust grains grow up by coagulations in initial phase affects the planet formation materially.

On the other hand, the previous experiments indicate that the chondrules in meteorites were formed by temporal heating and cooling. If temporal heating events which increase the temperature to 10^3 K occurred in the disks, temporal heating events which increase the temperature to 10^2 K such that the ice evaporates often occurred. Thus, we consider that dust grains experience the evaporation and the condensation through the temporal heating events

We consider that H_2O gas molecules condense on the surface of dust grains through the decreasing temperature in the temporal heating event. In this process, the dust grains are covered by the ice in this process to grow up for the ice mantle thickening. Then the larger size of dust grains has the lower saturation pressure of water vapor than smaller by the effect of the surface tension for sub-micron size of dust grains. Thus, the larger dust grains become larger by condensation. This process changes the size distribution of dust grains. The size development of the dust grains affects collision velocity and static adhesion, and changes the mechanical property of the dust aggregates.

2.Purpose

We calculate the time development of the probability distribution function for the size of dust grains through the temporal heating event by the numerical simulation.

3.Results

We calculate at 3AU from the central star in typical disk. We set the initial time at the time of beginning the condensation and that initial distribution function for the size of dust grains is proportional to power low -3.5 of size (Mathis et al. 1977). We calculate in the range of cooling rates from 10^6 Kh^{-1} to 10^2 Kh^{-1}. The results indicate that the growth phase bisects and time evolution of size is stopped. In the stopped time, the size distribution of the dust grains becomes the bipolar distribution of many small dust grains of silicate and a few large dust grains covered by the ice.

We divide the growth phase between the first phase and the second phase. In the first phase, the larger dust grains become larger from the largest dust grains by the condensation for the decrease of saturation pressures of water vapor of dust grains by the temperature. On the other hand, the decrease of the pressure of surrounding water vapor by the condensation catches up with the decrease of the saturation pressures to decide the minimum size covered by the ice. Next phase is the second phase. In this phase, the transferring H_2O molecules among smaller dust grains and larger dust grains works because the decrease of the surrounding pressure is larger than the decrease of the saturation pressures of dust grains. The transferring effect evolves small dust grains covered by the ice into smaller dust grains. In the case, dust grains once developed become initial size by the evaporation. Finally, few surrounding H_2O gas molecules by the condensation and the lower temperature stop the size development. The distribution of dust grains becomes the bipolar distribution of a few larger dust grains and many smaller dust grains. We discuss possible effects of the bipolar distribution to the planet formation.

Keywords: dust grain, evaporation, condensation

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PPS020-03 Room:103 Time:May 24 09:00-09:15

Dust particle growth and fragmentation in the dust layer with a weak turbulence

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I studied dust sedimentation and formation of the midplane dust layer at the first stage of planet formation. I assume that the gas disk is initially in a state of laminar flow. When the dust settles at the midplane and the dust-to-gas ratio there exceeds a certain value, the dust layer becomes turbulent because of the velocity difference from the upper gas layer. The strength of the turbulence is estimated from the gravitational energy liberated as the dust particles accrete toward the star. For single-sized particles with the stopping time of 0.1 Kepler time, the turbulent strength is estimated such that the alpha parameter is of the order of 10^{-6}-10^{-5}. Under such a weak turbulence, sedimentation of the dust particles results in a strong concentration of the dust at the midplane. Consequently, in the dust layer, the gas drag effect weakens, and the radial drift velocity and mutual collision velocity of the dust particles become small. If the average dust-to-gas ratio of the whole disk is similar to the solar abundance value, the particle collision velocity does not become extremely small. For disks with the dust-to-gas ratio as large as several times the solar value, however, the maximum collision velocity cannot exceed 10 m/s. Thus, we expect that icy dust particles do not experience violent collisional destruction. I solved the coagulation equation of dust particles taking the fragmentation effect into account, and showed that icy dust particles can overcome the so-called "fragmentation barrier" if the initial dust-to-gas ratio is large enough.

Keywords: Protoplanetary disks, Dust, Planet formation

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Coagulation and radial drift of dust aggregates: the effect of porosity evolution

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Coagulation of dust grains is the first step towards planetesimal formation. A major obstacle is radial inward drift of macroscopic dust aggregates due to frictional coupling between gas and dust. Previous studies have predicted that the radial drift of meter-sized compact solid bodies is faster than their local collisional growth, suggesting a difficulty of direct collisional formation of planetesimals.

In this talk, we discuss how this picture can be altered by considering porosity evolution of dust aggregates. Recent laboratory and numerical experiments have revealed that dust grains evolve into highly porous aggregates as they experience low-energy collisions. The porosity evolution is important because porous aggregates have a large collisional cross section and hence a short growth timescale. We have for the first time simulated coagulation and radial drift of dust aggregates properly taking into account fractal evolution at low collisional velocities (Okuzumi et al. 2009) and collisional compression at higher velocities (Suyama et al. 2008). We find that macroscopic aggregates maintain a low internal density (typically ~10^{-4} g/cc) in spite of the occurrence of the compression and are thus resistive to the radial infall. We plan to report this result and discuss an expected planetesimal formation scenario.

Keywords: dust aggregate, planetesimal formation, porosity evolution, radial drift

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PPS020-05 Room:103 Time:May 24 09:30-09:45

The calculation of ionization degree in planetary gaseous disks: the effect of charged dust grains

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There are many studies on the ionization degree of the protoplanetary disks, but no one has calculated that of circumplanetary disks with dust grains yet. It is important to understand the structure and evolution of circumplanetary disks, since the mass accretion through the disk onto the central planet is important in the early formation phase of the disks, and in addition, they are the sites of satellite formation. Despite the low temperature, the circumplanetary disks are ionized weakly because of galactic cosmic rays and radionuclides. Resultant ionized particles make secondary ions and molecules, and they are captured by dust grains. Weak ionization of the disk has important consequence for their evolution since the coupling between magnetic field and gas produces turbulence driven by magnetorotational instability. Thus, it is important to investigate the ionization fractions of various particles in the circumplanetary disk.

Inclusion of the effect of dust grains is essential when we calculate the ionization fraction, because the capturing of charged particles by dust grains makes the ionization degree lower. In the circumplanetary disks, dynamical timescales are shorter than that of protoplanetary disks, and timescales of various reactions are even shorter than the dynamical timescale of disks, which suggests the importance of accurate time-dependent calculation of ionization degree in disks. However, it remains difficult to calculate highly time-dependent ionization degree numerically. Okuzumi (2009) has shown that the charge distribution of dust grains can be approximated by a normal distribution. That approximation decreases the number of equations, and makes us calculate the ionized degree more quickly.

In this presentation, I will describe the important ionization processes and our fast method for calculation of charge state distributions of various particles and dust grains.

Keywords: protoplanetary disk, circumplanetary disk, ionization degree, dust grain, magnetorotational instability, numerical simulation

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On the Interaction between a Protoplanetary Disk and a Planet in an Eccentric Orbit

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The number of planets discovered so far has exceeded 500, and approximately 200 of them have eccentricity more than 0.2. If such planets are born in a disk environment, it is important to study how they interact with the disk and how the orbital parameters of such eccentric planets evolve. In this talk, we present a new analytic approach to the disk-planet interaction that is especially useful for planets with eccentricity larger than the disk aspect ratio. In the study of disk-planet interaction conducted so far, the eccentricity of the planet is assumed to be small, and the planet orbit is decomposed into the power series of eccentricity. In this work, we make use of the dynamical friction formula to calculate the force exerted on the planet by the disk, and the force is averaged over the period of the planet. The advantage of this approach is that it is possible to apply this formulation to arbitrary large eccentricity. The resulting migration and eccentricity damping timescale agrees very well with the previous works when eccentricity is of the order of 0.2-0.5. If the planet eccentricity is close to the order of the unity, the orbital evolution timescale behaves very differently. Moreover, we have found that the timescale of the orbital evolution depends largely on the adopted disk model in the case of highly eccentric planets. We discuss the possible implication of our results to the theory of planet formation. We also present fitting formulae for the timescale of the eccentricity and semimajor axis evolution. These formulae can be especially useful in the study of population synthesis models.

Keywords: planet formation theory, disk-planet interaction, planetary migration

PPS020-07 Room:103 Time:May 24 10:00-10:15

High-resolution simulations of giant impacts of terrestrial planets using a tree-Godunov-SPH method on GPU

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Smoothed Particle Hydrodynamics (SPH) method is a useful numerical tool in studying a number of astronomical and planetary science problems.
A wide variety of astrophysical and planetary science problems are studied by SPH method.
The giant impact hypothesis, one of the possible scenario of the Moon formation, is one of such a problem.
In order to examine the giant impact scenario for the Moon formation, numerical simulations of collisions between planetary embryo have been done by SPH method.
However, the problem that the current SPH method does not have resolution enough fine for debris disk is pointed out.
In the SPH method, the resolution is determined by the number of SPH particles.
To obtain high resolution, we must construct fast calculation code.

In this study, a procedure for construction of new fast SPH code is described.
We implement the following three improvements to the code.
First, we implement so-called Tree method to SPH.
While the direct search of neighbors and calculations of self-gravity among N particles require ˜O(N^2) computations, the introduction of the tree method reduces the number of computations to ˜O(N log N).
Secondly, we implemented approximate Riemann solver to the SPH method, which is called the Godunov SPH.
The application of the Riemann solver enable us to simulate phenomena with strong shocks.
Furthermore, Godunov SPH method includes appropriate dissipation in solving shock flows.
The calculation time becomes 10 times faster than that of the standard SPH.
Finally, we write the SPH code to run the program on massively parallel Graphical Processing Units (GPU) supporting the NVIDIA CUDA architecture.
The calculation time of GPU is about O(10) times faster than that of CPU.

In order to check the accuracy and performance of this code, we perform two types of benchmark tests.
One is the model of the adiabatic collapse of an initially isothermal spherical gas cloud to check the performance of GPU.
We performe this test by two methods, tree Godunov SPH on GPU and tree standard SPH on CPU.
Another is the collision between planet-size objects to check the correct treatment of non-ideal EOS.
From these tests, we otain that our code is about 300 times faster than the prevailing SPH method.

By using this code, simulations with large number of particles, namely high resolution simulations, are feasible.

In future work, to obtain further improvement of the performance of GPU, we will implement memory rearrangement algorithm.
This allows us to obtain the most efficient memory bandwidth.

Keywords: giant impact, SPH, GPU

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Proto-atmosphere of a giant icy satellite accreted in a gas-starved circumplanetary disk

Hidetaka Okada[1*], Kiyoshi Kuramoto[1]

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The interiors of Ganymede, Callisto and Titan are differentiated, but the mechanism and timing of their differentiation remain an open question.

For this problem, there are two types of theories; one assumes the differentiation during satellite accretion and another assumes that after the satellite formation.

The major heat source during satellite accretion is the accretional energy by planetesimal collision. If ice compornent supplied from planetesimal evaporates by the accretional energy, it is possible that a proto-atmosphere form. In that case, the blanketing effect of proto-atmosphere raises the satellite surface temperature higher than that of the case without proto-atmosphere. If the blanketing effect is so strong as to melt ice component, the internal differentiation is possibly induced.

Pioneering studies about the proto-atmosphere of giant icy satellite during accretion are Lunine and Stevenson (1982) and Kuramoto and Matsui (1994). For environment of satellite accretion, the former assumed satellite formation in a thick circumplanetary disk, and the latter assumed that in vacuum. According to the most recent theory widely accepted, satellite may have accreted in a gas-starved circumplanetary disk (Canup and Ward, 2002, 2006). This model points out the internal differentiation of giant icy satellite does not take place during accretion because the accretion timescale is estimated to be longer than that in previous studies. However, this diagnostic is based on the model analysis of a steam proto-atmosphere assuming gas-free accretion and neglects the effect of surrounding disk gas. The properties of proto-atmosphere composed of mixed gas from the disk and ice evaporant may be significantly different from those of previous atmospheric models.

In this study, we have estimated the radiative-convective equilibrium structure of a proto-atmosphere connected with a thin gas disk hydrostatically, and calculated the satellite surface temperature as a function of satellite size and accretional energy flux. We then attempt to clarify the condition for internal differentiation of giant icy satellite accreted in a gas-starved circumplanetary disk.

As a preliminary calculation, radiative-convective equilibrium structures are solved for the present sized Ganymede embedded within the disk gas with temperature and pressure of 180 K and 12 Pa, respectively, given thermal energy fluxes at the satellites surface. When the thermal energy flux exceeds 300 W / m^2, the total optical depth for infrared radiation exceeds 1 mainly because of absorption by H_2O vapor in the proto-atmosphere. In this case, strong blanketing effect emerges and thereby the surface temperature becomes higher than the melting point of H_2O. Such value of thermal energy flux is equivalent to that of the accretional energy flux when Ganymede is accreted for time slightly shorter than 10^6 yr.

As the thermal energy flux is larger than about 600 W / m^2, the position of tropopause locates beyond the radius of the gravitational sphere of satellite. In this case, it is expected that proto-atmosphere enriched in H_2O vapor flows out into surrounding disk. The similar result is obtained by Kuramoto and Matsui (1994) for gas-free accretion model, however, this study confirms that atmospheric outflow is possible even when surrounding nebula gas exists.

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PPS020-09 Room:103 Time:May 24 10:45-11:00

An effect of adiabatic compressibility on mantle convection within super-Earths

Chihiro Tachinami[1*], Masaki Ogawa[2], Hiroki Senshu[3], Shigeru Ida[1]

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see Japanese version

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PPS020-10 Room:103 Time:May 24 11:00-11:15

Magma ocean cooling and hydrodynamic escape under steam atmosphere

Keiko Hamano[1*], Yutaka Abe[1], Hidenori Genda[1]

[1]The University of Tokyo

The current planet formation theory suggests that giant impacts would have marked the final stage of terrestrial planet formation. The large amount of energy released in the giant impact event would have melted a significant part of the terrestrial planet, forming a deep magma ocean. The magma ocean would begin to cool and solidify just after the impact and its cooling time affects the differentiation of the mantle and the timing of subsequent water ocean formation.

The magma ocean cooling rate especially in the early stage should have been controlled by the radiation from the top of the atmosphere into space. It is expected that the cooling rate of the magma ocean strongly depends on the amount of the potent greenhouse gases such as water vapor and carbon dioxide. On the other hand, the amount of the gases could be controlled through the exchange between the atmosphere and the magma ocean because of their high solubility in magma. Since the melt fraction in the magma ocean decreases with its cooling, more water and carbon dioxide would be degassed into the atmosphere, which in turn leads to reduce the cooling rate. This means that the evolution of the magma ocean should have been coupled with the atmospheric growth through the volatile exchange between both reservoirs.

Elkins-Tanton (2008) calculated the time scale of the magma ocean on Earth and Mars considering the water and carbon dioxide exchange. The results suggest that the magma ocean cooling time would be at most 5 Myr even in the case of the high-volatile contents. Although the atmospheric blanketing effect was considered in terms of the heat balance on the surface, the atmospheric structure was not calculated for the cooling rate of the magma ocean in her model. Moreover, the effect of condensation of water was not included. Since the water vapor is condensable, the atmosphere would start to be saturated from its top with the cooling. In general, the outgoing radiation decreases with the cooling of the planetary surface. In the optically thick and water-saturated atmosphere, however, the outgoing radiation has a lower limit. This is because the temperature structure at the optical depth of unity is independent on the surface temperature in such an atmosphere. It is expected that whether or not the solar insolation exceeds the radiation limit would make a significant difference in the thermal history of the magma ocean.

If the insolation exceeds the radiation limit, the outgoing radiation could balance with the insolation. In this case, the hot steam atmosphere may persist for a long time so that the significant amount of water could be lost by hydrodynamic escape of hydrogen. The solar UV radiation dissociates water vapor into hydrogen and oxygen atoms in the upper atmosphere. Some previous studies suggest that the strong EUV from the young Sun could drive hydrodynamic loss of hydrogen, while that oxygen could be left behind because of its heavier atomic weight. If the oxygen accumulates into the atmosphere, this would cause the slowdown in the hydrogen escape. During the magma ocean stage, however, such an accumulation would not happen because the oxygen left in the atmosphere behind would be absorbed to oxide the magma at the surface. This significant water loss also would affect the magma ocean cooling.

We developed a simple coupled atmosphere-magma-ocean model to calculate the magma ocean cooling time under steam atmosphere and the amount of water at the end of solidification, taking into account the water loss by hydrodynamic escape. We used a 1D radiative-convective equilibrium model of condensable gray gas atmosphere. The temperature structure was assumed to be adiabatic in the convective magma ocean. Hydrogen loss rate was given by the energy-limited escape rate. We will present the results of a parametric study on the cooling timescale and the amount of the steam atmosphere varying the orbit radius and the initial amount of water on the Earth-sized planet.

Keywords: Magma ocean, Hydrodynamic escape, Giant impact, Water, Radiation limit

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PPS020-11 Room:103 Time:May 24 11:15-11:30

The amounts of liquid water when the oceans occupy half of the planet, under the local precipitation

Miyuki Wakida[1*], Yutaka Abe[1], Hidenori Genda[1]

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It is more than 15 years since the first discovery of extrasolar planet, and more than 500 planets have been discovered. Most of the known exoplanets are gas giant planets like Jupiter. However, the discovery of terrestrial planets is just beginning through the improvements in observational instruments, which make us expect that some exoplanets may have life.

The presence of liquid water on the planetary surface is considered to be an important condition for habitable planets. But exoplanets with liquid water do not always have globally covered oceans like Earth. Some exoplanets may have a small amount of liquid water on their surface as the lakes, which may be also habitable.

Abe et al. (2005) considered a hypothetical planet not having topography and transportation of liquid water on its surface. Precipitation and evaporation are balanced in local on such planets. Abe et al. (2005) called them 'land planets'. Numerical experiments with 3 dimensional atmospheric general circulation model (GCM), assuming that the planet have a very little water (less than 1 meter on average), showed that liquid water localizes at high latitude and it is dry at low latitude of land planets. It is also found that the habitable zone of land planets is 3 times wider than that of planets with globally covered oceans like Earth (we call them 'aqua planets'). This is because the destabilizing effect of water on climate, (i.e., the runaway greenhouse effect and the ice albedo feedback), are both weaken on land planets.

The condition for being land planet is that the location where evaporation is higher than precipitation maintains wet owing to the transportation of liquid water on the surface. To extract a condition for distinction between land planets and aqua planets, systematic GCM experiments with various amounts of water under a lot of topographic maps are needed.

However, doing experiments with all parameters on GCM is very difficult, because the experiments using GCM take a lot of time. In this research, for preparing the experiments on GCM, we estimate the amounts of water for a distinction between land planets and aqua planets as follows. Abuku (2009) used percolation theory and showed mathematically that a condition for global covered oceans is equivalent to a condition that oceans occupy about a half of the planet, assuming that low potential area become ocean on a 2 dimensional random potential area. But on real planets, all low potential area does not always become ocean because precipitation localizes. Precipitation occurs at high latitude on land planets (Abe et al., 2005). So we made a lot of random topographic maps using planets' topographic data and poured water from north and south poles. We consider that the amounts of liquid water when oceans occupy a half of the planet is close to the amounts of liquid water for distinction between land planets and aqua planets. So we estimated the amounts of liquid water when oceans occupy a half of the planet, under various topographic maps.

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Effects of obliquity and carbon cycle on the multistable solutions of climate of water-rich extraterrestrial planets

Yoshiyasu Watanabe[1*], Eiichi Tajika[2], Shintaro Kadoya[1]

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Water-rich terrestrial planets like the Earth are expected to be found in the extrasolar planetary systems in the near future. To discuss habitability of such planets, we have to investigate characteristic features of climate system of the water-rich terrestrial planets.

One of the key factors which controls climate is "obliquity", that is, the inclination of planet's axis. The climate of the Earth is stable partly because the Earth's obliquity is stabilized by the existence of the Moon, although it is not the case, in general, for other planets. Considering a large influence of obliquity on the solar energy distribution on the planetary surface, obliquity variations could induce large climate change on the planets.

In this study, we investigate the climate of the water-rich terrestrial planets systematically under various obliquities and solar flux conditions, and with a negative feedback mechanism of carbonate-silicate geochemical cycle. We use a one-dimensional energy balance climate model (1D-EBM) with a simple model of carbonate-silicate geochemical cycle in order to understand characteristic behaviors of the climate system of water-rich terrestrial planets.The main results obtained in this study are as follows;

1. We classified the behaviors of the climate system without carbonate-silicate geochemical cycle (i.e. a constant pCO_2 condition) into the following 4 stable solutions: 1) ice-covered solution (snowball solution), 2) seasonal ice-cap solution, 3) permanent ice-cap solution, and 4) ice-free solution. Seasonal ice-cap solution exists at lower solar flux conditions compared with ice-free solution at low obliquity, shrinking with an increase in the obliquity and disappearing at 54 degrees. Permanent ice-cap solution also exists at lower solar flux compared with seasonal-ice-cap solution at the obliquity less than 28 degrees. Above the obliquity of 54, either ice-free solution or snowball solution can exist.

2. When carbonate-silicate geochemical cycle is taken into account, the range of solar flux condition for all the solutions expand at any obliquities, indicating that the carbon cycle make the condition for habitable climate broader range of semi-major axis inside the habitable zone.

3. In the planets with carbonate-silicate geochemical cycle, we found that pCO_2 does not depend strongly on obliquity, even if the climate mode is different. This is because, with an increase in obliquity, a decrease of weathering rate at low latitudes may tend to be compensated by an increase of weathering rate at high latitudes.

4. Large CO_2 degassing rate could maintain warm climate even if the solar flux is lower. At low obliquity (for example, 23.4 degrees), warm climate cannot be maintained by much lower CO_2 degassing rate (for example, 0.6 times the degassing rate of the Earth today). However, at high obliquity (for example, 90 degrees), warm climate can be maintained by lower CO_2 degassing rate (for example, at most 0.3 times the degassing rate of the Earth today), compared with at small obliquity condition.

Keywords: extraterrestrial planet, planetary climate, obliquity, carbonate-silicate geochemical cycle, degassing, EBM

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Effects of Orbital Eccentricity on Habitability of Earth-like Extra-solar Planets with Carbon Cycle

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In this study, we systematically investigate the climate of the planets with varying orbital eccentricity and semi-major axis, and with carbonate-silicate geochemical cycle. We adopt a one-dimensional energy balance climate model and weathering model by Walker et al. (1981). We try to find conditions for the Habitable zone (HZ) of eccentric planets, and clarify the factors to determine the Habitable zone of eccentric planets. The results shows that there are three possible climate phases, namely Ice-free, Ice-cap, and Snowball phase, and nine climate modes, namely Runaway Greenhouse (RG), Ice-Free (IF), Seasonally Ice-cap (SIC), Ice-cap (IC), Seasonally Snowball/Ice-free (IF), Seasonally Snowball (SSB), Snowball (SB), Cyclic Snowball (CSB), and CO 2 Condensation (CO2C) modes. The term 'phase' is defined here as a transient state of climate, and the term 'mode' as an annual or long-term state of climate. The HZ is consist of the regions where a planet has liquid water on its surface, i.e. IF, SIC, IC, SSI, and SSB mode. The inner boundary of IC mode and the lower boundary of SSB, which are both the limits of the HZ, are found to be determined by annual mean insolation and perihelion distance, respectively.

If the heat capacity was very large, surface temperature would be averaged over a long period. It means that the climate of the planet would be affected by the annual mean insolation. This is why the inner boundary of IC is determined by annual mean insolation because of large heat capacity of IC mode planets.

On the other hand, if the heat capacity was very small, the temperature would follow the variation of insolation instantly. It means that the variation of the distance between from the central star, i.e. the perihelion and aphelion distance, would determine the climate of the planet. This is why the lower boundary of SSB is determined by perihelion distance because of the small heat capacity of SSB mode planets.

It appears that carbonate-silicate geochemical cycle also affects on the width of the HZ due to negative feedback effect which stabilizes the climate. When carbon cycle is considered, the width of the HZ becomes broader than when it is not considered.

The eccentric planets with large semi-major axis are habitable even in the early stage of stellar evolution. On the other hand, planets with small semi-major axis withdraw from the HZ in earlier stage of stellar evolution.

We, therefore, conclude that planets with large semi-major axis and high eccentricity should to be in the HZ for a long time.

Keywords: habitability, orbital eccentricity, carbonate-silicate geochemical cycle, EBM

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Coupled macro-spin models for polarity reversals — earth, sun, and planets —

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We propose a coupled macro-spin model to describe magnetism and its polarity reversals of the earth, the sun and the planets in this talk. This model is based on the idea that the whole dynamo mechanism is described by global interactions of many small dynamo elements. This is the minimal model to elucidate the essence of the polarity reversal dynamics described by the complicated magneto-hydrodynamics equations.

This simple model naturally yields many of the observed features of geomagnetism: its time evolution, the power spectrum, the frequency distribution of stable polarity periods, etc. In case of the earth, the dynamo element, that a macro-spin describes, is considered to be the Tayler cell in the iron fluid core produced and supported by the Coriolis force.

Keywords: geomagnetism, dynamo, scaling, coupled-spin, solar magnetism

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PPS020-15 Room:103 Time:May 24 14:15-14:30

A satellite impact created Chicxulub crater

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[1]MAROSA

1. Introduction

It is a well known hypothesis that the Chicxulub crater was created by an asteroid impact and the impact caused the extinction of dinosaurs about 65 million years ago. However, this hypothesis has difficulty to explain the extinction of dinosaurs. The most persuasive hypothesis is 'the gravity increase hypothesis'. Although only a very large scale celestial impact can explain such a great increase of the earth's gravity, but the Chicxulub asteroid is too small to increase the earth's gravity enough. Therefore, we must assume much larger celestial body impact than the Chicxulub asteroid. In truth we can explain consistently the Chicxulub crater with such a huge scale celestial impact that is enough to increase vastly the earth's gravity.

2. Difficulty in the hypothesis of the Chicxulub asteroid impact

The huge impact which created the Chicxulub crater at Yucatan peninsula about 65 million years ago, caused a global scale serious climate change that brought dinosaurs their extinction. The Chicxulub asteroid is estimated to be about 10 kilometers in diameter. However, that hypothesis has serious difficulty to explain the extinction of dinosaurs, because remained reptiles had to evolved to be dinosaurs again unless another reason to prevent them from such evolution. The most persuasive hypothesis is the gravity increase hypothesis.

3. The gravity increase hypothesis

The gravity increase hypothesis says that a sudden and large scale increase of the earth's gravity caused the extinction of dinosaurs. This hypothesis is plausible because the main feature of dinosaurs is their large body. The largest dinosaur was more than about 10 meters tall. Now the largest animal on the ground except for snakes is a giraffe which is about 5 meters tall. The tallest dinosaur was at least twice taller than the tallest animal on the ground is today. A considerable increase of the earth's gravity prevented remained reptiles from their evolution to become as large size as dinosaurs again. Except for a tremendous scale celestial impact which caused such increase in mass of the earth, no reason can explain such a large scale increase in the earth's gravity. The Chicxulub asteroid is too small to explain such a great scale increase in the earth's mass. Therefore, we must assume much greater scale celestial impact. It is plausible to think that such a great scale celestial impact must be a planetary collision between two planets of the solar system.

4. Chicxulub crater and satellites of Mars

Mars has two satellites. Phobos is about 26.8 kilometers in diameter. Deimos is about 15 kilometers in diameter. The scale of martian moons are similar to the Chicxulub asteroid. Therefore, we can say that 'the Chicxulub asteroid' is a satellite of a terrestrial planet of the solar system, in its scale.

5. Conclusion

We are able to give a rational explanation to the Chicxulub crater as follows. The hitting celestial body had been a satellite of another planet. The planet also hit the old earth later and enlarged the new earth greatly. Therefore, we are able to think the Chicxulub crater to be one of proofs of the planetary collision between the old earth and the other planet of the solar system.

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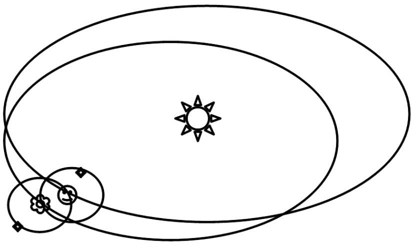

Keywords: extinction of dinosours, celestial impact, planet, satellite, gravity, Chicxulub crater

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Formation process of ejecta morphology around the crater formed on glass beads in laboratory

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The ejecta morphologies around impact craters represent highly diverse appearance on the surface of solid bodies in our Solar System. It is considered that the ejecta morphologies depend on the emplacement processes and/or the environments when its formed, such as the atmospheric pressure, the volatile content in the subsurface, etc. Clarifying the relationships between the ejecta morphologies and formation processes/environments could constrain the ancient surface environment and the evolution of the planets.

We investigated the ejecta patterns around the impact crater which formed on a glass beads layer in laboratory, and found that the patterns depend on impact velocity, atmospheric pressure, and initial state of packing of the target [Suzuki et al., 2010, JpGU]. Now, we focus on one of the ejecta patterns which has the petal-like or concentric ridges. This ejecta pattern is very similar to so-called "rampart" morphology observed around Martian impact craters.

This series of the experiments are performed by using the two-stage light gas gun placed in Kobe University. The projectile is an aluminum cylinder, having a diameter of 10 mm and a height of 10 mm. The target is a layer of glass beads (nearly uniform diameter) in a tub with 28 cm in diameter. The bulk density is 1.7 g/cm^3. The following three parameters are varied: 1) the diameter of the target glass beads (50, 100, 420 microns), 2) the ambient atmospheric pressure in the chamber (500 Pa - atmospheric pressure), 3) the impact velocity of the projectile (a few - 90 m/s).

In our experiments, the ridged patterns are observed with the condition of, 1) the diameter of the target glass beads is 50 and 100 microns, 2) the ambient pressure in the chamber is higher than 10^4 Pa, 3) the impact velocity is higher than 16 m/s. Eventually, we succeed to capture the formation of the ridges with high-speed video camera. The ridges are formed just outside of the base of the ejecta curtain. It is found that erodible surface around the crater is essential to produce the ridges.

Keywords: Impact Experiments, Cratering, Ejecta

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Trial to make ramparts: Granular flow model of fluidized ejecta on Mars

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Ejecta deposits of Martian craters show evidence for extensive surface flow not typically seen at other craters on the Moon and Mercury. The exact mechanism for why such surface flow occurs remains unclear, but it must be indicating some unique surface environmental condition. Typically fluidizing agents such as water or an atmosphere have been proposed to be responsible for the formation of these deposits.

Simple granular flows can explain a wide range of flow features at landslides including their long run-out distance and lineaments, without necessarily invoking any volatiles. They might also explain fluidized deposits, with their long run-out, circumferential lineaments, thin deposit layers, and ramparts, also without necessarily invoking any volatiles or an atmosphere. In order to investigate simple granular flow models for such ejecta deposition, we use the three dimensional distinct element method (DEM). This method calculates the motion of each individual ejecta grain, taking into account mechanical interactions between grains. Our initial study showed that the surface condition is important: smooth plains with a low coefficient of friction, or readily erodible plains can produce long run-out ejecta flow (Wada & Barnouin-Jha 2006, MAPS 41, 1551). Such smooth or readily erodible Martian surfaces could be the result of sedimentary processes associated with large amounts of water that existed on Mars.

While our initial model showed that ejecta surface flow was fairly easy to achieve, it possessed too many simplifications that did not permit the formation of ramparts at the distal end of the ejecta deposits. One of the obvious simplification was that all the grains in our model were true spheres without any rolling resistance. As a consequence, grains kept rolling on flat surfaces even if the surface had a finite friction. A necessary condition to make a rampart is that the distal ejecta must stop advancing. In the DEM, this implies giving the ejecta grains rolling resistance that reflects their natural angularity. This study, thus, investigates how giving ejecta grains rolling resistance in the DEM might generate ramparts, and impact the overall emplacement and flow of granular ejecta.

In our DEM model, the mechanical interaction forces and torques between spherical grains in contact (and the floor) are expressed by the Voigt-model, which consists of a spring and dash-pot pair, in both normal and tangential directions. The spring gives elastic forces based on the Hertzian elastic contact theory. The dash-pot expresses energy dissipation during contact to realize energy dissipation with a given coefficient of restitution. For the tangential direction, a friction slider is introduced to express Coulomb's friction law with a given coefficient of friction. In this study, we introduce a rolling resistance between grains (and also the floor), which models the difficulty of rolling due to the grain angularity, expressed by a critical rolling displacement.

As an initial condition of our DEM calculations, we consider a 5-degree wedge of an ejecta curtain composed of 2958 grains with a radius of 35 m, each traveling on ballistic paths prior to deposition. This initial condition was obtained by using the ejecta scaling relationship, assuming a transient crater with a radius of ~5 km.

By introducing rolling resistance in our granular flow model, we have succeeded in stopping ejecta motion effectively. However, we have not yet succeeded in making an obvious rampart. This may be due to other simplification of our model such as the small number of grains considered, and their fairly large size. Secondary cratering of the surface material and their subsequent flow might also play a role. Further studies will explore all these factors.

Keywords: rampart, crater, Mars, granular flow, simulation, DEM

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Global Survey of Impact Craters on the Earth by Satellite Hyperspectral Remote Sensing

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Although more than 140 terrestrial impact craters are currently known [1], it is not clear how frequently impacts occurred in ancient Earth history. This is mainly because most of the old impact craters on the Earth are too degraded (owing to weathering and/or tectonic modification) to be identified, although intensive global survey to find impact crater structures using satellite remote sensing has not been conducted.

In this study, we try to find the traces of old impact structures on the Earth based on the visible and near infrared spectra data obtained by satellite remote sensing. Recently, the global survey using hyperspectral data by Spectral Profiler (SP) onboard SELENE/Kaguya revealed the global distribution of olivine-rich exposures on the Moon [2]. Although this global survey did not use any terrain information for the lunar surface, the location map of the detected olivine-rich spectra shows concentric distribution pattern associated with large impact structures (impact basins) on the Moon. This finding suggests that we may also find the traces of ancient impacts for even degraded impact craters on the Earth, if we focus on the distribution pattern of specific spectral features in visible and near infrared wavelength. (Here the specific spectral features do not mean the shock indicators such as Coesite and Stishovite.) If so, we can reveal the global distribution of terrestrial impact craters by satellite hyperspectral remote sensing.

To this end, it is important to understand how the terrestrial impact craters are observed in the visible and infrared spectral data by satellite remote sensing. Therefore, we examined some terrestrial impact craters, which have been identified as impact origins, using the spectral data obtained by ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), which is an imaging instrument?with 14 bands, from the visible to the thermal infrared wavelengths, onboard NASA Terra satellite. Based on the results, we will discuss the feasibility of global survey of terrestrial impact craters by future satellite hyperspectral remote sensing.

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Experimental study on penetration and sticking of snow projectiles on sintered snowball

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[Introduction] Icy planetesimals could be formed by collisional growth of ice dust aggregates, thus they would have an initial porosity larger than 90% [e.g., 1,2]. Since icy planetesimals are supposed to be the size of ˜10km, so they would have small self-gravity to cause the difficulty for re-accumulation of the fragments ejected by collisional disruption among planetesimals. Highly porous bodies such as a planetesimal would dissipate impact energy through the compression of the pores and this process allows them to stick each other. When the two bodies collide each other in sufficient different size, they could stick easily as the smaller body could penetrate into the larger body [3]. Therefore, it is expected that the initial growth of icy planetesimals is expected to be driven by direct sticking among them. In this study, we examined the impact conditions for the collisional sticking and the impact disruption of porous icy bodies; the dependencies on the porosity and the mass ratio of the projectile to the target were studied.

[Method] All impact experiments were carried out in a cold room at the temperature of -15^{o}C in Institute of Low Temperature Science, Hokkaido University. Snow targets were made of ice particles with the average size of several 10s um, which were prepared by spraying tiny water droplets into liquid nitrogen reservoir. These ice particles were put into a spherical mold with a constant volume, and it was gently compressed with the maximum pressure of 1 MPa. After the compression, the target was removed from the mold and it was kept in a plastic bag in order to sinter them at - 15^{o}C. All the targets had diameters of 60 mm and a porosity of 40 to 70 % (mass of 62.4 - 31.1 g), and they were sintered from 1 hour to 1 month. The projectiles were cylindrical snow with the diameter of 10 mm and the porosity of 30 % (mass of 0.35 g) sintered in 1 day at -15^{o}C. We used three methods in order to accelerate a projectile; free fall (impact velocity of 2 - 3 m/s), spring gun (10 - 20 m/s) and He gas gun (30 - 200 m/s). The projectile was launched onto the center of the target (head on collision). The impact phenomenon was recorded by using a high-speed digital video camera with the recording rate from 1,000 - 5,000 flames per seconds and the shutter speed of 20 us. After the impact, the mass distribution of recovered fragments was measured and the velocity distribution of the fragments was also measured. Additionally, the crater profile of the target was measured by using a laser displacement when we observed the sticking.

[Result] We classified the collisional types into 5 types according to the largest fragment mass normalized by the original target mass (ml/Mt) and the antipodal fragment velocity (Va); they are rebound of the projectile (ml/Mt ˜ 1), sticking of projectile (ml/Mt $>$ 1), cratering (1 $<$ ml/Mt $<$ 0.5), catastrophic disruption (ml/Mt $<$ 0.5), catastrophic disruption with penetration of the projectile (ml/Mt $<$ 0.5 and Va $>>$ Vg). As a result, it was found that sticking of projectile occurs at the target porosity larger than 60% and at the sticking velocity from 40 to 90 m/s for the porosity of 60% and from 15 to 70 m/s for the porosity of 70%. The depth of a crater hole formed by sticking of projectile was measured to find that the penetration depth was nearly proportional to the impact velocity and that the depth formed on the target with the porosity of 70% was 5 times deeper than that of 60% target at the same velocity. The penetration depth derived at the impact condition of $Q*$ was 1/6 of the target length for 60% and 1/2 of the target length for 70%.

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Keywords: impact experiment, icy planetesimal, porosity, sticking, penetration

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Effects of medium filling pores on impact disruption of rubble-pile bodies

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Introduction

Rubble-pile bodies could be constructed from collisional fragments and these fragments were re-accumulated by mutual gravitational force. It is expected that rubble pile bodies have large macro porosity with the size of the same order of the constituent fragments because the fragments were accumulated randomly. According to our previous impact experiments on rubble pile bodies, we found that these macro pores caused the attenuation of the impact pressure drastically and, therefore, the rubble-pile structure was quite efficient to prevent impact disruption of the constituent fragments. Furthermore, these macro pores might be filled with solid medium, such as regolith and dusts, actually. The medium filling the pores among the fragments would surely affect the impact disruption. Thus, we performed high-velocity impact experiments on rubble pile targets to investigate the effect of medium filling the pores on impact disruption.

Experimental methods

We used 1/4-inch Nylon spheres for the projectile and it was launched by a two-stage light gas gun. These projectiles were impacted on cylindrical targets at the velocity ranging from 2~7km/s. These targets are made of 7mm glass beads and the pore spaces were filled with gypsum or ice. Impact fragmentation was observed by a high-speed video camera with the framing rate of 10000~125000 frames $sec^{-1}$and the fragment velocities were analyzed for each shot. Additionally, we recovered these fragments after the shot and estimated the impact damage of the target

Experimental results and discussions

We proposed M_{fsum} as a new parameter to describe the impact damage of rubble-pile targets, quantitatively. M_{fsum} is defined to be the total mass of fragments whose mass is less than a half mass of the original bead. We compared the impact damage of the targets whose pore spaces filled with gypsum or ice with that of the target without medium. As a results, M_{fsum} obtained from the targets with medium was found to be about two times larger than that without medium. Antipodal velocity observed for the target with medium also was found to be two to four times higher than that of the target without medium Therefore, we expect that the impact disruption of rubble-pile targets could be enhanced by the medium filling the pore spaces among constituent fragments. Furthermore, the degree of disruption of rubble pile targets might be controlled by the physical properties of the medium.

Keywords: rubble-pile bodies, impact disruption, minor body, planetesimals, re-accumulation, attenuation of impact pressure

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Highvelocity impact flashes by porous impactors II

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Impacts at velocities of several km/s generate luminous flashes. The visible luminous efficiencies (or optical efficiencies) are defined as the ratio of the luminous energy in the visible wavelengths to the impact energy (kinetic energy of projectile). We obtained the visible luminous efficiencies in laboratory experiments in the two stage light gas gun facility in ISAS/JAXA. Spherical nylon projectiles of 7 mm in diameter were shot at tiny targets of about 1 mm in size. The tiny targets are made of solid nylon or porous nylon. The experiments are approximately equivalent to the impacts of these tiny impactors onto semi-infinite plane of nylon. Thus, we can compare the luminous efficiencies, between the impacts of solid and porous impactors, onto semi-infinite plane. The experimental results show that the efficiency for the porous impactors could be larger than that for the solid impactors.

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Keywords: high velocity impact, impact flash, Lunar impact flash

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Observation of Spallation Phenomena in Hypersonic Wind Tunnel Experiment Simulating Atmospheric Entry of Icy Object

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The hypersonic wind tunnel, which has been used for the research and development of high speed aircrafts and spacecrafts in the aerospace engineering, is also a useful tool to simulate the flowfield around an atmospheric entry object, such as a meteorite, and to observe the various phenomena induced by the flow (Suzuki, et al., JpGU Meeting 2010, PPS004-10, Imamura, et al., AIAA Paper 2010-4512). In this paper, we present the spallation phenomena observed in the wind tunnel experiment using an ice piece. The experiments have been conducted at the hypersonic and high-enthalpy wind tunnel (http://daedalus.k.u-tokyo.ac.jp/wt/wt_index.htm) in Graduate School of Frontier Sciences, the University of Tokyo. In this facility, the uniform flow at Mach number 7.0-7.1 is obtained in the region of about 120mm diameter around the tunnel axis for 60s at maximum. Assuming an icy object entering the atmosphere, we prepare the test piece of a 40mm-diameter sphere made from water ice around the 15mm-diameter spherical core made from acrylic resin or foam aluminum. The ice piece is set in the test section by the supporting rod via thermal insulator (bakelite rod) and is injected into the test section after the uniform flow has been established.

The attached figure shows the snapshots taken by the high-speed camera at about 25s from the injection into the flow. The frame rate is 200Hz and 400Hz for the upper and lower images, respectively. In both cases, the pressure and heating rate at the stagnation point on the surface are estimated as about 14kPa and 100kW/m^2, respectively. The maximum temperature of the flow is 800-920K. In the case of the lower picture, the test piece is made from black water dyed with Indian ink (5% wt.). In the stagnation region, the recession of the surface occurs by the melting and/or evaporation under the severe aerodynamic heating. The liquid water and vapor go downstream and are refrozen into ice due to the temperature decrease at the rapid expansion flow in the shoulder region. The pile of icy columns grows outward, forming a brim-like shape around the icy body. In the upper image, we successfully captured the spallation, in which very small icy pieces are ejected from tips of frost-like icy columns. The triangular symbols in the image indicate the beginning and end points of a streak of a spalled particle during the exposure time of the camera (5ms). In this case, the ejection velocity is estimated as in the order of 1-10m/s from the length of a streak. However, there are a variety of the streak shape and length. This means that the ejection speed and trajectory of the spalled particle are not uniform.

The high-speed video image shows that such spallation frequently occurs after the pile of the icy columns has been constructed. The mass loss due to the spallation is not negligible in comparison with that by the evaporation at the surface. At the tip of the icy column, the detailed shape looks similar to the frost. The size of the spalled particle is in the same order of the scale of the frost-like shape, which is much smaller than the size of the icy object. In the similar way, a large amount of small spalled particles are expected to be ejected into the wake flow of a meteorite.

The pile of icy columns in the shoulder region remains by the balance of the refreezing and spallation. After long exposure time, the breakup of a icy column occurs at some timing. The lower image shows the snapshot of the test piece just after the breakup, where the light scattering is observed due to a large amount of mist injected from cracks on the ice.

Such simulation experiments using a hypersonic wind tunnel are expected to provide useful information for understanding the phenomena of an atmospheric entry object such as meteorite.

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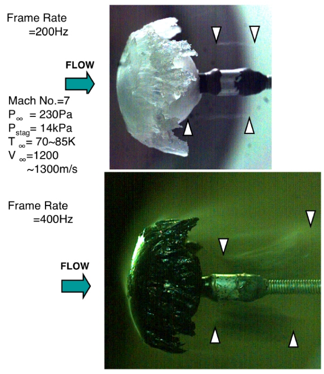

Keywords: atmospheric entry, ice, ablation, spallation, hypersonic flow, wind tunnel experiment

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Observations of Internal State in Oblique-Impact-Induced Vapor Clouds

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Organic supply processes on prebiotic Earth are thought to be contributed by chemical synthesis in the atmosphere, exogenic delivery via cometary/asteroidal impacts, and in situ production driven by impacts (Chyba and Sagan, 1992). Because organic synthesis process due to impacts occurs in limited periods of time and limited spatial extents, it would lead to a higher concentration of organics for a given total amount of organic supply and higher efficiency of sequent chemical reactions. Previous experiments show that most organics originally contained in meteorites are decomposed by intense shock heating at near-vertical impact angles (Mukhin et al., 1989). In the case of oblique impacts, it was suggested that the most organics also decomposed by intense aerodynamic heating during the downrange drifting (Sugita and Schultz, 2003a). Low-angle impact experiments using polycarbonate projectile within a nitrogen atmosphere, however, show that CN is formed efficiently from reduced carbon supplied from the projectiles and nitrogen in the atmosphere (Sugita and Schultz, 2009). However, there are neither time-series nor spatially-imaged detail observations of the interior thermochemical state of the vapor cloud. Therefore, the details of physical and chemical reaction within the vapor cloud, the distributions of compositional gas and fragment, and the region for chemical reaction with ambient atmosphere are still unknown. {cr/}

Thus, we performed the oblique impact experiments with a two-stage light gas gun at ISAS. Projectile, impact velocity, impact angle, and ambient pressure of nitrogen atmosphere are polycarbonate spheres (7 mm in diameter), 4.8-6.5 km/s, 30 degree from the horizontal, and 30 hPa, respectively. We observed the motion of self-luminous vapor clouds and gas/fragments distribution in the clouds using two high-speed cameras of framing rate at 2 us/frame with different band-pass filters. Transmission wavelength ranges of the band pass filters are 373 nm to 387 nm (CN), 400 nm to 410 nm (Blackbody) and 505 nm to 515 nm(C{sub}2{/sub}). A high-speed time-series spectrometer observed to measure time variation of spectrum and blackbody temperature of fragments in the vapor cloud.{cr/}

Thus, we revealed the spatial difference among distributions of projectile fragments and gas components. These three components are sequentially distributed; projectile fragment, C{sub}2{/sub} gas, and CN gas from the top to the back of the vapor cloud. The sequence suggests a scenario that the gas decomposed of projectile fragments within the top of the vapor cloud is flowed down with wake flow, and chemically changed to CN radical within the back of the vapor cloud. In addition, we measured the transitional velocity of the horizontally drifting vapor cloud which almost keeps its shape during its motion. First, instant acceleration of vapor cloud to 1.9 times the impact velocity is seen. Then it decelerates to the degree of impact velocity during almost 25 us due to air resistance. Additionally, we solved the equation of motion of the vapor cloud to analyze its motion. Because the measured vapor velocity is well explained when it was assumed constant mass and cross-section toward drifting direction, it was indicated that mass concentrated locally in the cloud.

Measured temperature is achieved to 5000 K at 10 us after impact when the vapor came into the field of view of the spectrometer, then it fell down to 2500 K at 45 us after the impact. Vaporization rate is estimated from the temperature and measured velocity based on heat balance on fragment surface. It is higher than Sugita and Schultz (2003b). The primary reason of such a difference is that they assume the downrange velocity of impact vapor clouds to be approximately the same as the horizontal component of the impact velocity, which is only about the half the actual value as revealed by the high-speed imaging observation in this study.

Keywords: impact, organic resynthesis, impact vapor cloud, aerodynamic heating

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Gas-phase chemical analysis in an open system using a 2-stage light gas gun: HCN production due to small-scale impacts

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Hydrogen cyanide (HCN) is one of the most important molecules in the origin of life. Amino acids and Nucleic acid basis can be produced from concentrated solution of HCN. We focus on HCN production by meteoritic impacts because the impact-induced HCN is concentrated into a narrow region and produced within a very short period of time.

The geologic record of the Moon investigated by the Apollo Project show that impact flux on the Earth at 3.8 ? 4.0 Gyr ago is ~103 times higher than that on the present Earth (late heavy bombardment period). In this period, the influx of both materials and energy into the Earth may have been the largest in its history. Such intense bombardment may have controlled the evolution of surface environments on the early Earth. Our goal is to investigate the production efficiency of HCN due to hypervelocity impacts and to understand the role of meteoritic impacts on the origin of life on the early Earth.

We are developing the experimental method to reproduce hypervelocity impacts in the early Earth atmosphere using a 2-stage light gas gun at JAXA. As a first step, we developed the experimental procedure of gas-phase chemical analysis in an open system. In previous studies with 2-stage light gas guns, chemical analyses were usually conducted in closed systems using containers to pretend the chemical contamination by gunpowder. In this case, thermodynamic path of shock-heated material, however, is different from natural impacts. To conduct chemical analysis in an open system, we set a large-volume chamber, an air-driven automatic gate valve, and an Al diaphragm to uprange of an experimental chamber to prevent intrusion of contaminant gas into the chamber. In this study, we used polycarbonate, polystyrene, and N2 gas as projectiles, targets, and atmospheres respectively. The total pressure in the chamber was fixed at 105 Pa. The impact velocity was fixed at 6.5 km/s. After the shoot, we measured the final gas phase products in the chamber using a detecting tube for HCN. We successfully detected HCN with molar concentration of ~50 ppm. We roughly estimated the conversion efficiency from vaporized carbon to gaseous HCN as ~0.1%.

For the future works, we are planning to a series of hypervelocity impact experiments using actual meteoritic materials and simulated early Earth atmospheres. The developed procedure can be widely used for impact-induced degassing phenomena.

Keywords: Hypervelocity impacts, Chemical gas-phase analysis in an open system, 2-stage light gas gun, Hydrogen cyanide, The origin of life, Impact degassing

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PPS020-25 Room:103 Time:May 24 17:00-17:15

Recovery experiment of high-power laser shock compressed olivine and Application to Planetary Science

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It is important to recover the shock-compressed samples for understanding the synthetic mechanism of high-pressure phase, shock metamorphism and shock-melt vein in meteorites. In the past, many impact experiments have conducted by using explosive or gas guns. In fact, although high-pressure phase in meteorites is recovered by the impact experiments (the impact velocity is 1.5km/s and the impact pressure is 26GPa) [1], the impact velocity in these methods is limited below 10km/s less than second escape velocity on the Earth. Recently, impact experiments at the velocity over 10km/s were conducted by using projectiles which were accelerated by high-power laser [2]. In previous experiments on the laser-shocked compression, the samples were recovered on the pressure below 100GPa (the olivine which is samples in this experiment is molten at the pressure of 150GPa).

We developed the recovery technique of the laser-shocked materials at higher pressure (at 200-300GPa in this experiments) by high-power laser system and analyzed the pressure range of the production conditions from the structure of shock metamorphism. We used the single crystal olivine (from San Carlos, USA) which is a major mineral of meteorites and the mantle of the Earth. We used GXII/HIPER laser system at Institute of Laser Engineering, Osaka University [3]. The deformation, fracture and phase identification of the recovered olivine were observed comprehensively by optical microscopy, field emission-scanning electron microscopy, electron backscatter diffraction and micro-Raman spectroscopy.

We designed the new recovery cell. In this cell, Ti plate was put in front of olivine to prevent the sample from blowing off. We could recover 100wt% of the sample by using this cell. In the recovered sample, there are the region of some distinctive structures. We will report the detail of the recovery technique and the results of the observation of the recovered samples.

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Japan Geoscience Union Meeting 2011
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PPS020-26 Room:103 Time:May 24 17:15-17:30

Development of a laser ablation isochron K-Ar dating method for landing planetary missions

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Absolute age measurements of planetary surfaces are extremely important for understanding the evolution of planets. However, no chronological measurements of planetary materials with known geological contexts have been made except for the lunar samples. Although the absolute age estimates for Martian surfaces have been proposed on the basis of the lunar chronology and the orbital calculations of asteroids, there still remain uncertainties as large as 1 billion years. If the absolute ages of rock samples from a geologic unit, where crater number density is known, are determined down to around 10% accuracy, it will make a significant contribution to understandings of the evolution of Mars.

In this study, we developed a new in-situ dating method based on the Potassium-Argon (K-Ar) dating technique toward future landing planetary missions. We propose a simpler and more accurate in-situ K-Ar dating method than those employed in previous mission plans, using laser-induced breakdown spectroscopy (LIBS) and a quadrupole mass spectrometer (QMS). We conducted the following experiments to evaluate the feasibility of the K-Ar dating with the LIBS-QMS method.

In the first part of this study, we measured K abundance using LIBS. First, we irradiated laser pulses on 13 samples with 100 ppm to 5 wt% of K2O and observed the emission lines of K from these samples. We obtained two calibration curves from K emission lines at 766.49 nm and 769.89 nm. Our results show that K concentration can be quantified within the relative accuracy of 10% for 2000 ppm to 5 wt% range. The detection limit was 1000 ppm.

Second, the volumes of laser-ablated craters on rock samples are measured with a microscope. The observations indicate that the crater volumes of basaltic rocks are within the uncertainty of 11% except for some minerals such as olivine. When these results are combined, the absolute abundance of K inside a crater is estimated within the accuracy of 15%.

In the second part of this study, we built a new Ar experimental system optimized for K-Ar dating, based on experimental results from a previously established system. As a first step, we used the previously established gas analytical system to estimate the detection limits and the pulse numbers required to the K-Ar dating. We estimated 40Ar=10^-12 cc/pulse and 36Ar=10^-15 cc/pulse are released from desirable Martian rocks. The blank levels for the system were 5x10^-10 cc and 1x10^-10 cc at m/Z = 40 and 36, respectively, and the electric noise level was 1x10^-11 cc. These blank levels should be 10-100 times lower in order to detect Ar from the rocks within 1000 laser pulses.

A measurement of the blank using the new gas analysis system indicates that the detection limit of 40 and 36 and electrical noise of the detector are on the order of 10^-11 cc, less than 10^-11 cc and less than 10^-11 cc, respectively. This is an improvement by one order of magnitude compared with our former experimental system. These results indicate that a sufficient amount of 36Ar can be evaporated by 1000 laser pulses on the Martian rocks.

These experimental results using our breadboard model strongly suggests that an experimental system that can simultaneously measure K and Ar released from the same laser-vaporized mass of a sample can be built with currently commercially available parts. Thus, the new K-Ar measurement method proposed in this study using a pulse laser, a spectrometer and quadrupole mass spectrometer is a viable candidate for an on-board instrument for a future Mars landing mission.

Keywords: Chronology, LIBS, QMS, Planetary exploration

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PPS020-27 Room:103 Time:May 24 17:30-17:45

Remote sensing observations of Hayabusa2: Linking ground-based observations and the returned sample analysis

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Hayabusa-2 is the second Japanese sample return mission from a C-type asteroid 1999JU3. In this presentation, we introduce the specification and operation plan of the four nominal onboard remote-sensing instruments, i.e. Asteroid Multi-band Imaging CAmera (AMICA), LIDAR, Near-Infrared spectrometer (NIRS3) and Thermal InfraRed Imager (TIR). The in-situ observations will provide the gelogoic context of the returned sample. We expect to link the global structure of asteroid belt revealed by ground-based telescopic observations and detailed analysis of returned sample from a specific asteroid through remote-sensing by Hayabusa-2 spacecraft.

Keywords: remote sensing, asteroid, Hayabusa2, sample return, camera

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An attempt to estimate the stability of Jupiter's atmosphere based on the vertical structure of large-scale disturbances

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1. introduction

The vertical structure of Jupiter's atmosphere, namely the composition in far below the visible cloud, remains as an unresolved issue presently, because the only direct observation, which is done by the Galileo Probe in 1995, presumably did not succeeded in obtaining the global properties. Thermodynamics calculations (e.g., Weidenschilling and Lewis, 1973; Sugiyama et al. 2006) can estimate the atmospheric structure once a hypothetical composition in the deep levels is employed, but the results must be verified by observation.

Allison (1990) argued that the large-scale disturbances observed in the North Equatorial Belt may serve as a clue. Stratospheric temperature profiles obtained by the Voyager radio occultation suggest the existence of vertically propagating waves (Lindal et al. 1981). Assuming that the wave are equatorial Rossby waves, Allison(1990) compared the vertical wavelength of the observed waves and that of the vertical eigenmodes of a simplified atmosphere consisting of 4 layers, one of which is cloud layer, and estimated the thickness and stability of the cloud layer. In this study, we generalize the approach of Allison so that we can consider more complex atmospheric structure and try to estimate the deep atmospheric composition.

2. Method

We numerically solve the vertical structure equation as a forced problem and search the values of the equivalent depths at which the response in the stratosphere become resonantly large, and compare those values with the equivalent depth of the vertically propagating waves found by the radio occultation. We employ three types of the atmospheric structure, which are based on the Jupiter's atmospheric static stability profiles with solar, 5 times solar and 10 times solar abundance of condensible components obtained by Sugiyama et al.(2006). The forcing is a vertically localized layer of heating in the water cloud level.

3. Results

We found a set of discrete values of equivalent depths that are related to the resonant excitation with all of the three atmospheric profiles. The value of the equivalent depth of the first mode, which is the largest equivalent depth of resonance, is 0.4km, 1.9km, and 3.9km for solar, 5 times solar and 10 times solar abundance of condensible components, respectively. The waves found in Lindal et al (1981) has the equivalent depth of 2.2km (Allison,1990) and is explained best with 5 times solar abundance of condensible gasses.

Keywords: Jupiter's Atmosphere

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PPS020-29 Room:103 Time:May 24 18:00-18:15

Numerical experiments of synchronously rotating planets with increasing solar constant

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Many exoplanets orbit nearby central stars and are thought as synchronously rotating planets because of the strong tidal force of the star. In the vicinity of small and low luminous stars such as M dwarfs, there may exist synchronously rotating terrestrial planets with liquid water on their surface.

In order to investigate the climate of synchronously rotating planets, we have performed numerical experiments with various rotation rate and solar constant fixed at Earth's value. These experiments showed that, according to rotation rate, there existed several climate regimes: equilibrium states in which a direct circulation from day side to night side dominate, equilibrium states in which disturbances with precipitation and equatorial waves dominate, and so on.

However, for increased solar constant, the atmosphere cannot reach equilibrium states and the runaway greenhouse state appears. In these cases, liquid water cannot exist on the planetary surface. In this study, for the purpose of examining the dependence of threshold values of solar constant at which the runaway greenhouse occurs (hereafter, "runaway limit") on planetary rotation rate, we perform numerical experiments with varying the values of solar constant and planetary rotation rate.

The model utilized here is atmospheric general circulation model, dcpam5 (http://www.gfd-dennou.org/library/dcpam/index.htm.en). The atmosphere consists of the dry air (noncondensable component) and vapor (condensable component).

The radiative processes are quite crude. Shortwave radiation is not absorbed by the atmosphere, while longwave radiation is absorbed only by vapor. We assume no scattering by cloud. Moist convective adjustment (Manabe et al., 1965) is used to include effects of cumulus convection.

The surface is assumed to be covered with swamp (zero heat capacity wet surface) and surface albedo is zero. The values of radius and surface pressure are the same as those of the Earth.

We use two types of the insolation pattern. One is the synchronously rotating condition (SR) in which the subsolar point is fixed to a point on the equator. Another is the annual and diurnal mean insolation pattern of the Earth (nonSR). The values of rotation rate we examine are zero and same value of the Earth. In the experiment with these two rotation rates

and solar constant of Earth's values, we have obtained different equilibrium states. In this study, five values of solar constant are used:

from the Earth's value to increased values. All experiments consist of 18 cases (see table).

The resolution used in this study is 5.6 degrees longitude-latitude grid with 48 vertical layers. The model is integrated for 2000 Earth days from isothermal atmosphere at rest.

Results of experiments show that equilibrium state is not reached in all cases with solar constant of 1600 W/m2. In these cases, global mean outgoing longwave radiation flux decreases monotonically with time, while global mean surface temperature increases monotonically. It is considered that the runaway greenhouse state occurs in these cases.

The value of the runaway limit tends to increase with decreasing the rotation rate of the planet. On the other hand, for same values of rotation rate, the runaway limit in nonSR case is larger than that in SR case.

Run summaries in each insolation pattern('Pattern', 'SR' represents synchronously rotating condition, and 'nonSR' represents the Earth like condition), rotation rate(Ω, normalized by the Earth's value), solar constant(S, W/m2). Circles represent the atmosphere reaches equilibrium state, while crosses represent the atmosphere does not reach equilibrium state. blank is not calculated.

Pattern	SR		nonSR	
$S \setminus \Omega$	0	1	0	1
1600	×	×	×	×
1550	×	×	○	×
1500	○	×	○	○
1450	○	○		
1380	○	○	○	○

Keywords: synchronously rotating planet, general circulation model, exoplanet, runaway greenhouse state, solar constant

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SPICA Coronagraph Instrument (SCI) and study of exoplanets

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We present Space Infrared telescope for Cosmology and Astrophysics (SPICA),

SPICA Coronagraph Instrument (SCI), and observation of exoplanets with them. SPICA is an international mission led by JAXA with contribution of ESA and others. The launch of SPICA is planned in 2018. SPICA will have 3m class telescope and whole of it will be cooled to 6K to realize high sensitivity and special resolution. In various scientific objective of SPICA, one of the most important target of SPICA is detail observation of exoplanets. SCI is a specially designed instrument for the high contrast observation of exoplanets. SCI is expected to provide unique data for the study of exoplanets, not only detection but a catalogue of spectrum of Jovian exoplanets. Monitor observation of transiting planets, imaging and spectroscopy of sircumstelar discs are also important target of SCI. Observation of diversity of exoplanets with SPICA is complementally with detail study of the solar system planets.

Keywords: SPICA, coronagraph, SCI, exoplanet, infrared, transit

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PPS020-P01 Room:Convention Hall Time:May 25 10:30-13:00

Formation of Cosmic Spherules: Relationships among Shapes, Compositions, and Textures

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Cosmic spherules are extraterrestrial origin, spherical silicate grains; they are collected from polar ice, ocean floor sediments, and stratosphere. In this study, we focus on cosmic spherules that are once molten completely.

Compositions, sizes, and textures of cosmic spherules have been measured. And some works suggest that compositions and textures are related to each other. On the contrary, quantitative measurement on the shape of cosmic spherules and a relationship among shape, composition, and texture have not been done. Those should be investigated to reveal the nature of cosmic spherules and their formation process. In addition, the formation process of cosmic spherules may have an implication for the formation of chondrules. Thus, in this study, we attempt to reveal the relationships based on a new measurement of the shape, compositions, and textures, using a theoretical model.

We use samples collected from Antarctic ice. From ice in the blue ice field at the Cape Tottuki, 903 micrometeorites of sizes in a diameter range from 0.100 mm to 0.238 mm were identified based on the surface element abundance. The micrometeorites include fully, partially, and no melted particles. Among them, we only use the fully melted particles. The number of such cosmic spherules is 525.

In addition, we select cosmic spherules that have a smooth surface, because the smooth surface suggests that they are once molten completely. We analyze 50 cosmic spherules with smooth surface. After the measurement of the shape, each sample is polished to have a flat surface and analyzed for major element concentrations by an EPMA. In the analysis, we exclude samples which have cavities or unmelted parts in them. Then, the final number of samples becomes 27.

The shape of cosmic spherules are approximated by three-axial ellipsoids. After the measurement of shape, bulk composition of each cosmic spherule is analyzed by EPMA. Observing the polished section, we can see the texture of each sample.

Measured compositions and textures show that barred olivine and cryptocrystalline particles have lower SiO2 and olivine-like compositions, while glassy particles have higher SiO2 content and pyroxene-like compositions. Compositions and textures are tightly correlated.

A motion of dust particles entering the Earth atmosphere from the space is modeled. The equation of motion takes into account the frictional gas drag and the gas density distribution in the atmosphere. To evaluate the deformation, the ram pressure is calculated. The degree of deformation is evaluated using a theoretical model.

The melting temperature of the dust particle is given by the composition of the particle. The compositional change of the dust particle due to the evaporation is also taken into consideration.

Numerical results of our theoretical model show that the final composition would depend on the entry parameters such as the entry angle, velocity, the size, and the initial composition. Since Fe is likely to evaporate, as the evaporation proceeds, the composition becomes Fe-poor. A comparison of the measured composition with the numerical results suggests that observed cosmic spherules have not experienced a heavy evaporation. Initial composition of cosmic spherules seems to determine the final composition and structure.

Measured shapes of cosmic spherules show that shapes of most of samples are consistent with our model. However, some samples have smaller deformation than the theoretical model. This suggests that those samples re-solidified under the ram pressure that is lower than our model estimates. This may happen if the grain does not re-solidify even under the melting temperature and experiences the super cooling. We have also realized that less deformed spherical cosmic spherules have glassy textures and pyroxene rich compositions. This seems consistent with our theory: the ram pressure drives the deformation.

Keywords: cosmic spherule, shape, composition, texture, formation

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PPS020-P02 Room:Convention Hall Time:May 25 10:30-13:00

Change in Iron with Ultraviolet Rays and Water

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Change in Iron with Ultraviolet Rays and Water
Nobuo komori
Minamirokugo junior high school

I have been examining the influence that ultraviolet rays and water exert on the rock etc. in junior high school science club since 2002. This time, it aimed to irradiate ultraviolet rays to the iron plate soaked in the

distilled water and to examine the change. I think that it is necessary to examine changing pure iron first of all to know how iron in the rock and mineral changes with ultraviolet rays and water.

In this research, The iron plate is put in the test tube filled with distilled water. And ultraviolet rays c is irradiated to the test tube. The peak of ultraviolet rays c is 254 nm. The iron plate is a size of 0.3mm thick 3cm length 1cm wide and the iron purity is 99% or more.

It experimented when ultraviolet rays c was not irradiated as a control experiment on the same condition. Ultraviolet rays c was irradiated for five months. The mean illuminance of ultraviolet rays c is 20w/m2.

As a result of this experiment, a lot of reddish brown powders are generated in the test tube that irradiate ultraviolet rays. From the result of the x-ray diffraction analysis the powder is goethite and magnetite. In the test tube that did not irradiate ultraviolet rays puce powders are generated. From the result of the x-ray diffraction analysis the powder is goethite only.

Moreover, it has been understood that in case of irradiation of ultraviolet rays, the amount of iron oxide is much larger than that of no irradiation of ultraviolet rays.

It is presumed that water existed in the past in Mars surface.

I think that there is a possibility that the magnetite is generated by ultraviolet rays and water on Mars surface.

Keywords: Ultraviolet C, water, Iron oxide, Goethite, Magnetite, Mars

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Non-contact Measurements for Thermal Inertia of Granular Materials

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Thermal inertia is defined as a combination of thermal conductivity, density, and heat capacity. It represents the ability of the subsurface to conduct and store heat energy away from the surface during the day and to return that heat energy to the surface through the night [Mellon et al., 2000]. Thermal inertia is an important parameter which controls surface temperature of planetary surface.

It is important to measure the thermail inertia of granular materials because planetary soils are composed of small grains. Many existing researchs focus only on thermal conductivity of granular materials, and use "line-heat method" which affects the pacikng state of granular materials to measure the thermal conductivity.

We applied a non-contact measuremet for thermal inertia [Buettner, 1951] to the layers of granular materials. The mothod is a simple way to measure thermal inertia and don't disturb the packing state of granular materials.

We measured the thermal inertia of artificial granular materials (e.g. almina ball) and natural soil samples (e.g. small grains of pyroclastic fall deposit) and compared our results with the results of previous studies [e.g. Presley and Christensen, 1997; Iwasaki, 2009 (Master Thesis, The Univ. of Tokyo)].

Keywords: thermal inertia, granular material, planetary surface

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Considering heat transfer mechanism in powders by thermal conductivity measurements of different constituent particles

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Surface of atmosphere-free planets, asteroids, and satellites is covered with the fine regolith, whose thermal conductivity is extremely low compared with that of rocks. The thermal conductivity of the regolith layer is a fundamental physical quantity for estimation of crustal heat flow. Therefore, in order to understand thermal state and thermal evolution of the bodies, it is necessary to determine the thermal conductivity of the surface. However, although the thermal conductivity of powder media is considered to depend on many parameters, such as particle size and its distribution, porosity, applied stress, temperature, particle shape, constituent of particles, and optical property of the particle surface, these dependencies have not been clarified. We aimed at understanding the heat transfer mechanism in the low thermal conductive materials under vacuum conditions by means of the measurements of the thermal conductivity of powder media with well-controlled parameters. In this instance, we report the experimental result obtained by changing the two parameters; constituent of the particles and optical property of the particle surface.

Five samples were used for thermal conductivity measurements; solid glass beads, hollow glass beads, titanium powder, carbon coated glass beads, and oxidized titanium coated glass beads. The particle size of these samples is from 100 to 500 micrometers approximately. The ambient temperature was about 20 degC. The thermal conductivities ware measured at the depth of 1 cm for all samples. The thermal conductivity measurement was conducted by the line heat source method, in which a constant heat is supplied to a line heater in the sample and the thermal conductivity is estimated from the temperature increase rate of the heater line. Nichrome wire was used for the line heater, but because of the electric conductive property of titanium powder and carbon coated glass beads, a nichrome wire coated with electrical insulator was made for measuring the thermal conductivity of these two samples. The temperature increased by less than 5 degC during the measurement time of 1000 seconds. The effect of this temperature increase on the thermal conductivity is negligibly small. In this abstract, the experimental results for the solid glass beads and hollow glass beads are described as an example. The particle size, bulk density, and bulk porosity of these samples are shown in above table.

First, thermal conductivities were measured at atmospheric pressure. As the results, while the thermal conductivity was 0.211 W/mK for the solid glass beads, it was 0.048 W/mK for the hollow glass beads. That is, the hollow glass beads have lower thermal conductivity than the solid glass beads with the air remaining. On the other hand, under vacuum conditions ($<$ 0.01 Pa) at which the heat transfer by the gas is negligible, both solid and hollow glass beads had the thermal conductivity of 0.0022 W/mK. This result possibly indicates that the heat transfer under vacuum condition are almost contributed to the radiative heat transfer, and independent of the particle constituent and contact network between the particles. In addition, the oxidized titanium coated glass beads with the particle size of almost the same had the thermal conductivity of 0.0037 W/mK. The thermal conductivity difference between the oxidized titanium coated glass beads and the solid glass beads may caused by the difference of the radiative heat transfer due to the variations of optical properties of the particle surfaces.

	particle diameter (μm)	bulk density (kg/m^3)	bulk porosity
solid glass beads	90-106	1540	0.39
hollow glass beads	90-115	40	0.98

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The effect of target rheology on impact cratering.: case for a wet sand

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We report the results of experiments of impact cratering using wet sand target in order to understand the effect of target rheology. Many craters exist on the surface of planets and satellites, which were formed from meteorite impacts. Various forms of craters are found, such as a bowl-shaped simple crater and a crater with a small central peak. On mars, rampart craters, which are accompanied by distinctive fluidized ejecta, are found. Pit craters are also found on mars and on icy satellites. One cause for the variety of crater morphology is the difference of the surface rheology. There have been experiments using dry granular materials with variable grain size, in order to address the effect of rheology (e.g., Walsh et al, 2003). However experiments using wet granular materials have been limited (e.g., Gault & Greeley, 1978).

Our experiments were performed by releasing a steel ball from a holder so that it fell vertically into a cylindrical container (diameter:180mm, hight:90mm) filled with beach sand (grain size 0.2mm). We use a high-speed camera to record the crater formation process and laser displacement meter to measure crater profiles, from which we obtain the crater diameter and depth. For dry sand target (packing fraction phi=51.3 plus minus 0.1%), we conducted experiments using ball diameters in the range of 10mm-22.2mm and release heights of h=200-1100mm. For wet sand target (packing fraction phi=50 plus minus 2%), we fix ball size (22.2mm) and the release height (h=1100mm) and vary the water saturation(S) from 0 to 80%. We also measure the yield stress of the wet sand using rotating viscometer sheared at 10 rpm.

In dry sand target, we observed a simple crater and a crater with a central peak. Central peak crater formed under a large impact energy. In wet sand target, crater shape changed with S as follows: cone-shaped crater (S=0-3%), cylindrical crater with an outer ring (S=4.1-5.5%), cylindrical crater (S=5.8-72.5%), bowl-shaped crater whose shape is more rounded than the cone-shaped crater (S=74.1-77.4%). Cone-shaped crater formed central peak crater and its diameter decreased as S increased. With stiffening of the wet sand, the crater slope became resistant to collapse and became rougher. For a ringed cylindrical crater, the ring appears when the cylindrical crater begins to form. This phenomenon seems to be related to the increase of the yield stress of the wet sand, which limits the radial extent in which the crater is being excavated. As S increases further, ejecta volume decreases and the ring disappears. For cylindrical craters with small S, the surface is raised after the impact, whereas when S is greater than 62.5 %, the surface becomes depressed after the impact. For a bowl-shaped crater, the excavation occurs and ejecta reappears. The crater diameter changes with S as follows: first it decreases with S, then it becomes constant from S=6-10% to 60-70, after which it increases again. The change of diameter is anticorrelated with the change of the yield stress (sigma y) as a function of S. Stress arising from the inertia of the impacting ball can be estimated from sigma I ~ $(mv^2/R)/pi*R^2$ to be about $1.8*10^5$ [Pa] (m : ball bass, v : terminal velocity, R : ball diameter). The ratio of inertial stress to yield stress (sigma y / sigma I) becomes ~10^{-2} for dry sand, and ~10^{-1} for wet sand. Our experiments suggest that the morphological transiton occurs at around sigma y / sigma I ~10^{-1}.

Keywords: impact cratering, wet sand, rheology, experiment

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Expansion velocity of the impact vapor cloud

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The vapor cloud is generated by hypervelocity impact of the planetesimals and the protoplanets in space. This is called a impact vapor cloud. As for this, the shape of the cloud is different depending on the impact velocity and impacting material, etc. It is said that Expansion velocity of impact vapor cloud is proportional to the sound velocity (which is defined from the pressure and the density of the nylon prejectile after passing of the

shock wave) regardless of the impact velocity and angle and the target material. The early experiment concerning expansion velocity has only been carried out with the exact materials. But, the planet that impact in space is a porous quality.

So, we carry out an equivalent experiment with the experiment that uses the porous quality materials for the projectile. The impact vapor cloud generated in that case is taken pictures with the high-speed camera, and analyzed in the present study. We consider the relation between the void ratio and the expansion velocity by using these results.

As the result, the expansion velocity is about twice that of the sound velocity, and is consistent with theoretical considerations.

Because the influence by the void ratio is included in the elicitation process of the sound velocity, it is necessary to take the void ratio into consideration in the relation between the expansion velocity and sound velocity.

Keywords: Highvelocity impact, Impact flash, Vapor cloud, Lunar impact flash

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Blackbody radiation in impact flash

Yuta Takahashi[1*], Ryosuke Ebina[1], Masahisa Yanagisawa[1], Sunao Hasegawa[2]

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The highvelocity impact like the impact of the meteoroid to the surface of the moon gives the flash.There are the one that originates momentarily of the collision and the one from the generated impact vapor cloud in the flash.If the flash of the vapor cloud is a blackbody radiation, the temperature of the vapor cloud can be presumed from the spectrum.The truth has not been understood yet though the flash of the vapor cloud might be assumed to be a blackbody radiation.In the present study, photometry is done by the highvelocity impact experiment in some wavelength bands, and it is examined whether the flash of the impact vapor cloud is a blackbody radiation.

Keywords: Highvelocity impact, Impact flash, Vapor cloud, Blackbody radiation, Lunar impact flash

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Impact Cratering Experiments on Basalt Targets

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Impact cratering experiments on basalt targets were performed. Aluminum and steel spheres were impacted to basalt targets with velocities from 3100 to 5300 m/sec. Diameter of formed craters were 30 to 100 mm. Details of results and implications to the scaling law will be presented in the session.

Keywords: Impact Phenomena, Scaling Law

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PPS020-P09 Room:Convention Hall Time:May 25 10:30-13:00

Measurements of impact strength of simulated regolith materials

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Asteroid and lunar surfaces are covered with regolith, which was impact fragments accumulated on their surfaces. The regolith layer consists of fragments with a wide range of size distribution from sub-microns to meters. They are compacted by stress or pressure induced by impact and self-gravity, then they would have mechanical strength according to the degree of compaction. The strengthen layer could be excavated and fragmented, and they are mixed with surface non-cohesive fine fragments, so that the solid rock fragments were consolidated by the fine fragments among them to form monomict or polymict breccias. A part of ancient regolith layer of extra-terrestrial planets is now obtained to be lunar rock and meteorite such as achondrites, e.g. HED. In order to study the origin of these breccias on the planetary surfaces, we should consider the impact strength of regolith layer, which would have a wide variety of strength depending on the internal structure and composition. In this study, we assume that the regolith might be composed of solid rock fragments consolidated by fine fragments with relatively weak strength, so the effect of this structure on the impact strength was investigated hereafter.

Impact experiments were conducted by using a two-stage light gas gun set in ISAS, and a nylon spherical projectile with the size of 200 mg was launched at from 2 to 6 km/s on a simulated regolith sample. The sample was prepared by using pebbles with the saize of 5 to 10 mm and gypsum: they are mixed each other with the mass ratio of gypsum to pebbles about 1/6. The sample had a cylindrical shape with the diameter and he height of 15cm and the mass of about 2.8kg. Most of the disrupted samples were recovered to measure the mass of the largest fragments and their size distributions depending on the energy density.

Impact strength of this regolith sample was determined from the relationship between the largest fragment mass and the energy density in this study. The impact strength is obtained to be 300 J/kg and this strength is rather smaller than that of basalt, 1000 J/kg, and gypsum, 2500 J/kg. The typical disruption mode of core type disruption in the high velocity impact higher than 1 km/s was never observed in this sample. The sample was disrupted and simply removed from the impact surface without any special failure events like spallation and radial split. The removed depth was observed to increase with the impact velocity monotonically. The weak impact strength of the regolith sample could be strongly related to the failure mechanism of this sample: the failure could be dominated by peeling pebbles from gypsum matrix. This strength required for peeling off pebbles from gypsum might be rather smaller than that of pebble and gypsum themselves.

Keywords: regolith, impact strength, compaction, crater, breccia, lunar meteorite

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Flow law of ice-rock mixtures: Effects of particle size and shape

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Introduction:

In order to study the flow process of ice sheets on the Earth and Mars and the thermal evolution and the tectonics of icy satellites, it is crucial to understand the rheological properties of ice-rock mixtures constituting them. Particularly, the flow law, which shows the relationship between the stress and strain rate as a power law, is one of the most important physical property to apply the experimental results in the laboratory to a large-scale phenomena such as a flow of ice sheet on Mars. The authors examined the flow law of ice-rock mixtures and the dependencies of rock content, porosity, and temperature in detail and proposed a new flow law including these parameters. On the other hand, we should examine more physical parameters such as rock particle size to apply the results to the ice sheets and the icy satellites. In this study, we examined the flow law of ice-rock mixtures depending on the size and the shape of solid particles systematically.

Experimental methods:

We prepared the samples mixing ice grains having the diameter less than 710 micron with two kinds of solid particles, silica beads with a spherical shape and serpentine powder with a polygonal shape. The diameters of silica beads used were 1 mm and 1 micron, and that of serpentine powder was about 100 micron. We made the samples by two methods. One is a pressure-sintering sample (p.s.s.) that the mixtures of ice grains and solid particles were compressed at a pressure of about 50 MPa, and the another is a frozen sample (f.s.) that the mixtures of ice grains and rock particles, and the water at 0 ^{o}C were mixed in a mold. The mass fraction of solid particles was changed from 0 to 80 wt.%. The temperature was -10 ^{o}C. We made uniaxial compression tests under the constant strain rate at ILTS, Hokkaido Univ. The strain rate was from about 10^{-3} to 10^{-6} s^{-1}.

Results:

The strength of both the p.s.s. and the f.s. including 1 mm beads was almost similar to that of pure ice at the beads content lower than 50 wt.%, while it decreased as the beads content increased at the content higher than 50 wt.%. This result for 1 mm beads sample is noted to be quite different from the result for the f.s. including 1 micron beads: the strength for f.s. of 1 micron beads increased with the increase of the content. This could be caused by the difference of the internal structure: in the case of 1 mm beads sample, the ice grain size is almost the same as the bead size, and the beads distribute evenly in the sample. It is supposed that the stress concentration occurs around the beads in the ice grains, so the local deformation rate of the ice increases there. At the beads content lower than 50 wt.%, the distance among beads was enough long, so that the local high deformation rate around the beads does not affect the bulk deformation rate of the sample. At the content higher than 50 wt.%, the distance among beads was enough short, so that the local high deformation rate of ice grains caused by the stress concentration around the beads affected the bulk deformation of the sample. This mechanism causes the difference of the strength depending on the content. On the other hand, the strength of serpentine sample was almost same as that of 1 micron beads sample at the same content. That is, the effect of shape on the flow law was negligible small. Finally, the power law index n of flow law increased with the increase of solid particle content for all samples. This might be caused by the generation of micro-crack.

Keywords: ice-rock mixture, ice sheets on Mars, icy satellites, rheology, rock particle size, rock particle shape

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Evolution from aqua planet to land planet by water loss ; the inner edge of habitable zone

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Liquid water on the planetary surface is thought to be important for the origin and evolution of life. Habitable zone (HZ) has been defined as the region from the central star where liquid water is stable in the planetary surface. Kasting et al.(1993) have estimated the width of HZ around various types of the main sequence stars for the Earth-like planets (called 'aqua planet') which possess the ocean with the present Earth's ocean mass. The inner edge of HZ is determined by water escape and the outer edge of HZ is determined by CO2 condensation. In the results, they estimated HZ ; 90% - 110% of the present solar radiation at 1 AU. Both of the inner edge and outer edge of HZ are controlled by the strong positive feedback mechanism of H2O. On the other hand, Abe et al. [2011,prep] have considered a hypothetical planet with very small amount of water (called 'land planet'). On a land planet, water circulation is limited in atmospheric circulation, and the distribution of ground water is completely determined by the local balance between precipitation and evaporation. Using GCM (general circulation model) they have calculated the inner and outer edges for a land planet. HZ for a land planet is located between 77% and 170% of the present solar radiation at 1AU. HZ on a land planet is about three times wider than that on an aqua planet. Therefore, the amount of water on the planetary surface is important for the width of HZ. Here, we focus on long term processes of water escape and calculate the evolution of water content on the planet. If the water is efficiently lost during stellar age (~10Gy), there is a possibility that an aqua planet changes to a land planet which means that the HZ becomes wider. In this case, the aqua planet inside or outside of HZ would become habitable planets as a land planet.On a hypothetical planet with various initial water contents and distances from central star, we calculate the evolution of water content on the planet and discuss planetary states by considering the hydrodynamic escape of water and star evolutions. In our results, in case of solar type stellar and a planet that initially possesses about 0.1ocean masses, planets change from the mode of aqua planet to the mode of land planet at about 0.7 AU. The planets are classified into "Water planets" (liquid water on the surface), "Steam planets" (runaway greenhouse state) and "Dry planets" (no liquid water on the surface). For the change from an aqua planet to land planet, the following two timescales are essential. One is timescale of loss of ocean by escape. Another is timescale of evolution of central star. When the timescale of loss of water is shorter than the timescale of the evolution of central star, the aqua planets become the land planets. On the other hand, when the latter is shorter than the former, the aqua planets become runaway greenhouse state (Steam planets or Dry planets). It's not always true that extrasolar terrestrial planets have the same amount of the present Earth's ocean mass. The exoplanets that has been discovered so far orbit various types of stars. Generally, the evolution of stars that are lighter than the sun is slow and the evolution of stellar that are heavier than the sun is fast. During the evolution of planets that orbit stars that are lighter than the sun, they could easily change from an aqua planet to a land planet because such planets experience the efficient hydrodynamic escape caused by the slow stellar evolution. On the other hand, the planet that orbits a star that is heavier than the sun becomes the runaway greenhouse state easily. In this presentation, we discuss the evolution of planetary states and the inner edge of the HZ by parameterizing stellar types, the distance form central star, planetary size and initial amounts of water on the planets.

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PPS020-P12 Room:Convention Hall Time:May 25 10:30-13:00

A suggestion for complete evaporation limit on land planet using 1-dimensional energy-balance model

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Presence of liquid water on the planetary surface is thought to be essential for the origin and evolution of life. Using a simple one-dimensional radiative-convective equilibrium model, Nakajima et al. (1992) have calculated the atmospheric structures, and obtained the relationship between the surface temperature and the outgoing infrared radiation. They have shown that there is an upper limit of the outgoing infrared radiation (called 'radiation limits') if there is liquid water on the surface. From their results with 0.3 of albedo, the radiation limits on an Earth-like planet which has a globally covered ocean (called 'aqua planet') corresponds to be 122% of the incident solar flux that the present Earth receives. On the other hand, Abe et al. (2011 submitted) have investigated the climate on planets which have little water on their surface (called 'land planets'). The notable features of land planets are the local balance between precipitation and evaporation. They, using GCM (global circulation model), have shown that liquid water is localized on the high latitudes, while the low latitudes are dried up. As a result, the value for incoming radiation by which the liquid water on the planet is completely evaporated ('complete evaporation limit') corresponds to 170% of the incident solar flux the Erath receives, which is substantially larger than that on an aqua planet. The key for a land planet to have a large value for the complete evaporation limit seems to be localization of liquid water on the surface. The GCM used by them, however, includes the climate to be controlled only by transportation of water vapor. In other words, it does not include the transportation of water on the surface of the planet. We investigate how much influence water transport on the surface may have upon the climate of the planet which possesses little water. We expand the atmospheric model used by Nakajima et al. so that we can consider limited water content. We investigate the relationship among the surface temperature, the water content and the outgoing infrared flux. Then, in order to take water transport into account, we expanded the meridionally 1-dimensional EBM (energy-balance model) used by North (1975) by giving efficiency of water transport as a parameter and adding a term for latent heat.

It is revealed that when water on the surface is transported very efficiently (in our model, one tenth as efficient as the water vapor transport in the atmosphere), liquid water can exist from the high latitudes to the low on the planet. The complete evaporation limit corresponds to 122% of the incident solar flux the Earth receives, which is the same value for that on an aqua planet, despite the planet possesses little water. On the other hand, when liquid water on the surface is not transported so easily (one five hundredth the efficiency of the water vapor transport), liquid water on the surface is localized on the high latitudes. In our model, the complete evaporation limit of the planet corresponds to 130% of the incident solar flux the Earth receives, which exceeds the radiation limits of the aqua planet. If a planet possesses little water, water transportation on the surface is thought to be quite different from that on an aqua planet. Given that a land planet possesses very little water, the liquid water on the surface should be absorbed into the soil. Consequently, it would act like groundwater. The efficiency of water flow through a medium that consists of sand or mud can be estimated by applying Darcy's law. In fact, we can see that the water flow through fine sand is roughly 10^{-10} times as smaller as the transportation of water vapor in our model. In such cases, the liquid water cannot exist on the low latitudes because the mechanism that transports water from the high latitudes to the low does not work. Thus, the climate of such planets would act like a land planet.

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Upper limit of carbon monosulfide in Neptune's atmosphere

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The observed mixing ratio of carbon monoxide (CO) in Neptune's atmosphere was around 1 ppm. This abundant mixing ratio suggests that external sources like comets or asteroids may affect the CO abundance in Neptune's atmosphere. In the case of Jovian atmosphere, after collisions of comet Shoemaker-Levy 9, carbon monosulfide (CS) and other minor components have been produced into its atmosphere. We observed the rotational line of CS (J=7-6, 342.88 GHz) toward Neptune's atmosphere using the ASTE (Atacama Submillimeter-millimeter Telescope Experiment) radio telescope of the NAOJ and derived the upper limit. In this poster, details of our observation and result will be presented.

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From Hadley Circulation to Superrotation: effects of equator-off heating on the transition of atmospheric circulation

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The oblique angle of planetary rotation axis is thought as one of the most important parameters for the atmospheric circulation. We study the effects of equator-off heating on the transition from Earth-like Hadley cell to Venus-like superrotation. The effect of equator-off heating drives the seasonal variation of the atmospheric circulation.

We use a simple model; axisymmetric primitive equations on the spherical coordinates with the Boussinesq and Newtonian cooling approximation. The thermal Rossby number(RT), the horizontal Ekman number(EH), and the latitude at which radiative equilibrium potential temperature is maximum(f0), are treated as parameters. We construct the numerical calculation model and integrate until the steady-state is established, however for some sets of the parameters the steady-state is not established because of symmetric instabilities. A measure of a rigid rotation, Rg, and a measure of the intensity of superrotation, S, are introduced as Yamamoto et al. (2009). Also we attempt to describe the effects by analytic calculations.

We find that when f0 increases, Rg decreases, and larger EH is needed to transit from Hadley cell to a rigid rotation, because the zonal winds inside and outside the Hadley cells lose the component of a rigid rotation and gain the component of a non-rigid rotation. We make the expression of the divisional latitude between the summer and winter cells as a function of S, RT and f0 for large EH. S decreases with increasing f0 for large EH . In the case of two cells for large EH , the main upward transport of the angular momentum through vertical wind at the divisional latitude between the summer and winter cells is effective and the total transport of the angular momentum through vertical wind is upward because of the difference between the distribution of upward flow and that of downward flow.

Keywords: Atmospheric Circulation, exoplanets

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Gas velocity field around a vortex and the evolution of dust surface density distribution in a vortex

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Planetesimal formation in a vortex is one of the scenarios of planetesimal formation. We investigated the dust accumulation rate in a vortex by solving the equations of dust motion around a vortex semi-analytically. As the result, we obtained that dust surface density distribution in a vortex is independent of not only dust size but also the parameters of a vortex flow and increases in reverse proportion to the square of the length of the minor-axis of concentric ellipses. The parameters of vortex flow are the aspect ratio of vortex ellipse and angular velocity of vortex flow. By the result, mm-sized or bigger dust surface density in a vortex could increase to about 20 times in a vortex. And then, it is suggested that planetesimal formation by the self-gravitational instability would occur.

In this presentation, we evaluate how general is our above result by comparing our local analytical result with our global numerical simulation result. This numerical simulation based on Inaba & Barge 2006* is using two-phase fluid of gas and dust and is simulating vortices formation and dust accumulation in the vortices. Our comparison targets are gas flow field around a vortex and the evolution of dust surface density distribution.

About gas flow field around a vortex, we adopt the analytical flow also used in Johansen et al. 2004** for inside a vortex and modeled analytically by adding the stream functions of a vortex and a back ground Keplerian shear for outside a vortex. For inside a vortex flow, we checked that analytical flow corresponds with numerical flow. For outside a vortex, we also compare our analytical model with numerical result and discuss the difference.

About the evolution of dust surface density distribution, dust is accumulated in a vortex faster in analytical result than numerical result if numerical situation is closed to analytical situation by ignoring the back-reaction of dust motion to the gas flow and using the fixed gas friction coefficient and ignoring the back-ground gas pressure gradient. We discuss about the reason of this difference. We also compare the results in the situation that not ignoring the back-reaction or/and using the not fixed gas friction coefficient or/and not ignoring the back-ground gas pressure gradient. We also evaluate those effects to dust accumulation quantitatively.

*Inaba, S. & Barge, P. 2006, ApJ 649, 415
** Johansen, A. et al. 2004, A&A, 417, 361

Keywords: planetesimal formation, vortex, analytical solution, numerical simulation

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Planetary Embryo Growth with Atmosphere and Collisional Fragmentation

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In final stage of planet formation, planetary embryos grow through collisions with planetesimals. The gravitational scattering by the large embryo induces destructive collisions between planetesimals. Fragments produced by such collisions are ground down by successive collisions until the collisional velocities of very small bodies are

sufficiently dumped by gas drag. They are consequently removed by the gas drag. As a result, the surface density of bodies around planetary embryos decreases. Since embryos grow through collisions with such bodies, their growth halts by collisional fragmentation. The final planetary mass, which is determined by the equilibrium between the growth of the embryos and the depletion of planetesimals by collisional fragmentation, is smaller than the critical core mass for gas giant formation through core accretion. However, since planetary atmosphere enhance their collisional cross section with small bodies, planetary embryo can exceed the critical core mass from large initial planetesimals in massive protoplanetary disks.

Keywords: Planetary formation, collisional fragmentation, planetary atmosphere

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Temporary capture of planetesimals by a planet

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When planetesimals encounter with a planet, the typical duration of close encounter during which they pass within or near the planet's Hill sphere is smaller than or comparable to the planet's orbital period. However, in some cases, planetesimals are captured by the planet's gravity and orbit about the planet for an extended period of time, before they escape from the vicinity of the planet. This phenomenon is called temporary capture. Temporary capture may play an important role in the origin and dynamical evolution of various kinds of small bodies in the Solar System, such as short-period comets and irregular satellites. Recently, temporary capture of planetesimals by a planet from heliocentric orbits has been investigated in detail using three-body orbital integration (Iwasaki & Ohtsuki 2007). In the case of planetesimals initially on circular orbits, the rate of temporary capture was evaluated, and it was found that it increases with increasing semi-major axis of the planet, because the size of the planet's Hill sphere relative to its physical size increases with increasing distance from the sun. The rate of temporary capture in the case of low random velocity was also examined and shown to increase with increasing orbital eccentricity. However, cases of large orbital eccentricities were not examined in detail. Moreover, the above calculations assumed that planetesimals and a planet were initially in the same orbital plane, and effects of orbital inclination were not studied. In the present work, we examine temporary capture of planetesimals initially on eccentric and inclined orbits about the Sun.

We examine temporary capture using three-body orbital integration (i.e. the Sun, a planet, a planetesimal). We integrate Hill's equation for planetesimals with various initial orbital elements, using the eighth-order Runge-Kutta integrator. The initial azimuthal distance between planetesimals and the planet was taken to be large enough to neglect their mutual gravity. Planetesimals are uniformly distributed radially, and in the case of initially eccentric or inclined heliocentric orbits, their initial horizontal and vertical phase angles are also uniformly distributed. Orbital integration is terminated when the distance between the planetesimal and the planet becomes large enough again, or a collision between them is detected.

We found that the rate of temporary capture increases with increasing eccentricity, in agreement with the previous calculation with a limited range of parameters. In the case of low initial random velocity, temporary capture in the retrograde direction is common, and prograde capture is very rare. On the other hand, both prograde and retrograde captures become possible for large initial eccentricities. Also, shapes of the orbits during temporary capture are different between cases of prograde and retrograde orbits about the planet.

Keywords: planets, satellites

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Viscosity in planetary rings including spinning, self-gravitating particles

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Saturn's rings are composed of many icy particles, and angular momentum is transported due to collision and gravitational interaction between these particles. Viscosity in the rings arising from such interactions between particles governs the rate of dynamical evolution and structure formation in the rings. Local N-body simulations including collision and mutual gravitational forces between particles showed that, in optically thick rings, wake structures are formed due to their self-gravity. Assuming that the rings consist of smooth spherical particles, numerical results show that the viscosity is significantly enhanced due to the effect of self-gravity in dense rings with gravitational wake structures. Viscosity in planetary rings consisting of spinning, non-self-gravitating particles has been estimated, but effects of particles' surface friction and spins on the viscosity in self-gravitating rings was not studied.

In the present study, we examine the viscosity in planetary rings, by local N-body simulations taking effects of particle spins into account, in addition to collision and gravitational interaction between particles. Assuming that a local region in a ring is in a quasi-steady state, the viscosity in such a region can be estimated via the balance between energy loss due to inelastic collisions and the viscous gain due to the shear motion, even in the case of self-gravitating rings. When a collision between particles is detected in our simulation, we calculate the change of velocity due to collision using given restitution coefficients in the normal and tangential directions. In the case with surface friction, we also calculate the change of particles' spin rates. We investigate the dependence of the viscosity on various parameters such as optical depth, distance from Saturn, and normal and tangential restitution coefficients. We also calculate the viscosity with the velocity-dependent restitution coefficient based on laboratory impact experiments. In the case of rings with low optical depth, viscosity can also be evaluated using three-body orbital integration. We also compare our results obtained from N-body simulation with those obtained using three-body calculation.

First, we calculate viscosities in the case without surface friction. In the case of low optical depth, the viscosity was found to increase in proportion to the optical depth, and excellent agreement with the results based on three-body calculation was confirmed. However, in dense rings where gravitational wakes are formed, the results of N-body simulation deviate from the three-body results and the viscosity is significantly enhanced, in agreement with the previous results for rings with self-gravitating, smooth particles. Next, we examine the effect of surface friction and spins of particles. In the case of rings with low optical depth, we found that the viscosity becomes slightly smaller when surface friction is included, because the random motion of particles become suppressed due to the additional energy dissipation arising from the surface friction. On the other hand, in the case of optically thick rings in which wake structures are strongly formed, we found that the dependence of the viscosity on the tangential restitution coefficient is negligible. This is because, in dense rings, the enhancement of the viscosity due to rings' self-gravity is much more significant than the effect of particles' surface friction.

Keywords: planetary rings, viscosity, self-gravity, particles' spin, Local N-body simulation

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Radiative effect on the type I migration

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Gravitational interactions between a low-mass planet and a gas disk are one of the most important physical processes in planetary formation. A planet excites density waves in a disk, of which the tidal torque acts on a planet and leads to the migration of the planet. This is known as the type I migration of a planet. A planet migrates toward a central star on a shorter timescale than a lifetime of a disk. Previous studies adopted a disk with the constant temperature distribution and did not take into account the energy transfer in a disk. However, it was shown that density waves can be altered by a thermal structure of a disk. A planet might move away from a central star (i.e., outward migration) if the entropy gradient of a disk is negative.

Yamada and Inaba (2010, MNRAS) studied the type I migration of planets in disks, considering a cooling effect of gas due to radiation. They found that the total torque exerted on a planet by an adiabatic disk decreases with an increase in the power law index of the entropy distribution. The torque changes the sign from positive (outward migration) to negative (inward migration) at a= - 0.4, where a is the power law index of the entropy distribution. They also found that the total torque decreases with an increase in opacity of a disk if a cooling effect is taken into account. The type I migration is influenced by opacity of a disk. Yamada and Inaba used a constant opacity in a disk even though it is expected to change in a disk because it depends on the temperature.

We study the type I migration of a planet in disks with various opacities. We find that the total torque acting on a planet by a disk strongly depends on opacity of the disk. We adopt a more realistically opacity model and find that the sign of the total torque could change in a zone of a disk. Planets formed in other regions of a disk migrate toward the zone. Accumulation of planets in the zone might accelerate further growth of planets.

Keywords: migration, gravitational interaction, accretion disk, type I migration, density wave, radiation

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A Systematic Study of the Mass-Density Relation for hot-Neptune

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Recent progresses in transit photometry have enabled us to find short-period low-mass exoplanets with mass of several to several ten Earth-masses. If combined with radial-velocity measurements, both planetary mass and radius, namely planetary mean density, are determined. With the measured value of mean density, we can infer the composition and interior structure of a transiting planet, which give insights into the origin and evolution of the planet. Of about 100 exoplanets with measured masses and radii, while most of them are hot-Jupiters that are composed predominantly of hydrogen like Jupiter and Saturn, several planets are known to be water-rich like Uranus and Neptune. In this study we have simulated the interior structure and thermal evolution of planets composed of H2O, taking mass loss driven by intense stellar X-ray and UV irradiation into account. Then we have derived mass?density relationships for hot-Neptunes. Our prediction will be useful to be compared with future observations, which will improve our understanding of the origin and evolution of water-rich planets.

Keywords: extrasolar planets, planetary evolution, ice giant planets, water

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Effects of MHD-turbulence-generated electric fields on ionization states in protoplanetary disks

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Magnetorotational instability (MRI; Balbus & Hawley 1991) is one of the most important mechanisms for angular momentum transport in protoplanetary disks.

This instability requires a sufficiently high ionization degree, but it is uncertain whether such an ionization degree is maintained in all parts of the disks. In particular, small dust grains can significantly lower the ionization degree and make a large disk region MRI-inactive (Sano et al. 2000).

All previous studies on disk ionization have implicitly assumed that the electric field generated in MRI-driven turbulence is so weak that electric acceleration (heating) of ionized particles is negligible. However, a simple estimate based on numerical simulations imply that this effect is not necessarily negligible (Inutsuka & Sano 2005).

In this study, we have reanalyzed the ionization state of protoplanetary disks taking into account electric heating of ionized particles as well as their adsorption onto dust grains. The results are summarized as follows:

(1) If the electric field E exceeds a critical value E_{crit}, electric heating becomes effective for electrons, leading to the conductivity decreasing with increasing E. This effect could lower the saturation level of MRI turbulence when the initial vertical magnetic field is weak.

(2) If E is so strong that the mean electron energy exceeds 1 eV, runaway ionization occurs through collisions between high-energy electrons and neutral gas particles. This leads to jump of the conductivity by more than eight orders of magnitude. When the initial vertical magnetic field is strong, this effect allows MRI-driven turbulence to be self-sustained.

Keywords: protoplanetary disk, ionization state, dust grains, MHD turbulence, electric heating

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Origin of irregular satellites: the effect of Saturn on the temporary capture of asteroids by Jupiter

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We have investigated the possible origin of the irregular satellites in the asteroid belt. The irregular satellites might not be formed by accretion in a circumplanetary disk, as were the regular satellites. The inclination distribution and large semimajor axes of the irregular satellites tell us that they must have formed elsewhere and later been captured into their current orbits around their host planets. The original places where irregular satellites were formed have not been clarified so far. However, their low albedo (around 0.05) derived from the observations may indicate that they are physically similar to asteroids rather than Kuiper belt objects. Our study has been started on this observational indication.

The process of temporary capture of particles by a giant planet has been investigated by many authors. However, the effect of another planet on the capture process has not been clarified. How effective/ineffective is Saturn in the capture of asteroids by Jupiter? To answer the questions we calculate the orbit of mass-less particles initially distributed around the asteroid belt (2-5AU) under the perturbations by Jupiter and Saturn. Jupiter and Saturn have their current masses and in circular orbits with their current semimajor axes. These two planets have no gravitational interaction between them (so-called restricted circular 4-body problem). During the calculation, we count the number of encounters of the particles within the Hill radii of Jupiter and Saturn as the irregular satellite candidates (hereafter J-, S-candidates).

We find that (1) asteroids can be transported near both Jupiter and Saturn, (2) the number of J-candidates is about three times larger than that of S-candidates, and (3) the existence of Saturn is ineffective in the capture by Jupiter and changes the favored conditions for capture.

On our poster paper, we will show the detailed results and analytical expression of them, and discuss the consistency of the produced candidates by our calculations and the observational results referring to the scenario of the long-term dynamical evolution of the captured objects around planets proposed by several authors so far.

Keywords: irregular satellites, quasi-satellites, asteroids