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

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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Change in Iron with Ultraviolet Rays and Water

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Change in Iron with Ultraviolet Rays and Water
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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

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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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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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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.

PPS020-P14 Room:Convention Hall Time:May 25 10:30-13:00

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