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

PPS21-01 Room:201A Time:May 21 15:30-15:45

In-situ flash X-ray observation of impact crater formation in porous gypsum

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Introduction: In order to understand the impact histories related to the asteroid formation processes, it is very important to study the impact craters found on the surfaces of asteroids. So, we should study the crater formation mechanism and establish the formation theory of the impact crater based on the physical mechanism. From recent spacecraft explorations, many asteroids were found to have low density and be porous bodies [1]. Porosity has an important effect on the crater formation: the void spaces were crushed due to impact pressure and the large craters with a compaction layer below the surface were formed [2]. So, the crater formation mechanism on the porous materials is important to understand the impact history of asteroids. The target internal structure changing with time during the crater formation process has not been studied yet by laboratory experiments because it is difficult to observe the target interior by visible light. In some previous works, impact experiments were conducted by using the porous transparent silica aerojel to visualize the target interior [3]. In this study, we tried to visualize the interior of the target during the crater formation process by using a flash X-ray generator and studied the elementary processes of the crater formation, and observed the projectile penetration and the cavity expansion in the target.

Experimental method: We prepared the targets of porous gypsum having cylindrical shape with two different diameters of 34 and 64 mm. Impact experiments were conducted by a two-stage H_2-gas gun in ISAS/JAXA. The impact velocities were 1.9-2.4 km/s (low-velocity) and 5.4-6.1 km/s (high-velocity) by using three types of projectile, stainless spheres with diameters of 1.6 and 3.2 mm, and Al sphere with 3.2 mm. We set two flash X-ray generators to take two images at different times for one test. Multiple images were obtained from several tests at the same impact condition and the different trigger timing from 0 to 250 micron-s.

Results: From the analysis of X-ray images, we found that the crater shape of target depended on the impact velocity and the projectile type. In the case of low-velocity collisions, the stainless projectile penetrated through the target without deformation and the penetrated hole was formed while the Al projectile collided the target surface and the hemispherical cavity was formed. In the case of high-velocity collisions for stainless projectile, the projectile with a diameter of 3.2 mm deformed and the hemispherical cavity was formed in the target, accompanied with some narrow pits on the cavity front. When the projectile with 1.6 mm collided, the hemispherical crater was formed on the surface. We measured the penetration depth (d), cavity diameter on the target surface (D) and the maximum diameter in the target (D_{max}). In the case of penetration hole, the D was almost constant for projectile diameter while the d increased with time exponentially. In the cases of hemispherical cavity, all parameters increased with the time until 20 micron-s, however, the increases of d and D_{max} stopped at 20 micron-s. Beyond 60 micron-s, the behavior depended on the stainless projectile size. In the case of small projectile, the D became the maximum and the spalling occurred on the target surface. In the case of large projectile, the d increased due to the progress of some disrupted projectiles. Conclusively, all parameters increased because the target was disrupted and many fragments were ejected. We examined the drag coefficient (C_d) of projectile by using the deceleration model [3], and found that the C_d for penetration was about 0.9 while that for other cases was about 2-3. This high value might be caused by the deformation of projectiles [4].

Reference: [1] Veverka *et al.* (1999), Icarus 140, 3-16. [2] Housen and Holsapple (2003), Icarus 163, 102-119. [3] Niimi *et al.* (2011), Icarus 211,986-992. [4] Tamaki and Hinada (1966), Seisankenkyu 18, 219-221.

Keywords: impact crater, penetration, pit, drag coefficient, flash X-ray, H-gas gun

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The effects of multiple impacts on the impact strength of ice targets

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High velocity collisions among icy bodies played an important role in the formation and the evolution of icy planets, icy satellites and KBOs. Actual icy bodies could have experienced multiple-impacts events however most of studies were single-impact experiments rather than multiple ones. In the previous studies related to multiple impacts experiments (Gault et al., 1969; Housen, 2008), it has been reported that cracks induced by pre-impacts have reduced the impact strength of targets. Furthermore, in their experiments, they changed the number of impact times using the same target and the sum of each impact energy in the same set of the experiment was always constant for each target. And, they found that the relationship between the largest fragments and the cumulative energy densities was consistent with that of single-impact experiments. The cracks formed by each impact are not distributed homogeneously in the target. Thus, in the multiple-impacts experiments, it is necessary to quantify the crack density inside the target generated by the pre-impacts. Then, we conducted multiple-impacts experiments to reveal the quantitative relationship between the pre-crack distribution and the impact strength.

Impact experiments were conducted using gas gun installed in a cold room at the Institute of Low Temperature Science, Hokkaido University. An ice projectile was impacted at several times (1 to 4) on the same target, and each impact was conducted on the different surface. The temperature was -10 deg C in the cold room. The impact velocity was from 140 to 480km/s. The projectiles had a cylindrical shape and the mass was 1.6 g. The target was cube made of polycrystalline water ice, and the mass was from 240 to 1280 g. To quantify the crack density of the recovered targets we measured P and S wave velocities of the target when they were not disrupted catastrophically. Then, in the next impact experiment, we used it again.

We changed the energy density (Q) of the first shot of each target, and the second shot were done at the same Q. From this experiment, in the case of high Q at the first shot, m_L/M, which is the largest fragment mass normalized by the initial target mass (M), became smaller. Thus, we found that m_L/M of pre-impact targets was much smaller than m_L/M of the previous results derived from the single-impact of icy projectile on ice target (Arakawa et al., 2002). These results suggest that the pre-cracks reduce the target strength, and moreover this mean that the relationship between the pre-cracks and the target strength strongly depends on the impact record of the target. On the other hand, the size distribution of fine fragments whose m/M, the fragment mass normalized by M, were less than 10^{-4}, was constant regardless of the number of impacts. This suggests that there is a lower limit of the fragment size affected by the pre-crack.

Furthermore, the relationship between m_L/M and sigma Q (the sum of Q for all impacts) for the targets which experienced multiple-impacts was consistent with that for the intact ice targets. Figure 1 shows the relationship between m_L/M and sigma Q. The vertical axis means the m_L/M and the horizontal axis means sigma Q, and each mark is classified by the number of pre-impact times. In this figure, the value of m_L/M depends on sigma Q, and the pre-impact and the target mass have few effects on m_L/M. These data were fitted by a power law equation and we obtained the empirical formula described by m_L/M=7.8 times $10^5 Q^{-3.2}$.

Elastic wave velocities for the recovered targets were measured and they were found to decrease with the increase of the crack density, and this relationship was theoretically discussed by O'Connel and Budiansky (1974) and they showed the theoretical equation showing the relationship between the crack density and an elastic body. By using this equation in this study, we found that the crack density linearly increased with sigma Q regardless of the number of impacts

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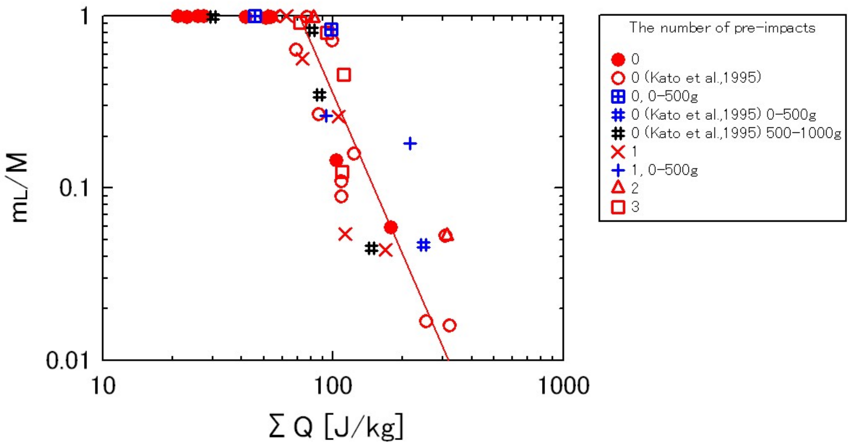

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PPS21-03 Room:201A Time:May 21 16:00-16:15

Experimental study on equal-sized collision of sintered porous ice spheres: Porosity dependence of collisional sticking

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The formation process of planetesimals in protoplanetary disk thought to be involved in collisional process of dust aggregates, but has not been fully understood yet. The relative collision velocity of dust aggregates in plotoplanetary reaches several 10s m/s. Recent numerical and experimental studies suggest that the collisional sticking growth of silicate dust aggregates in protoplanetary disk cease at centimeter size because of bouncing barrier [1]. Another numerical simulations about collision of highly porous dust aggregates indicate that icy dust aggregates could grew in size up to ~50 m/s [2], but for icy material it is necessary to consider sintering of ice particles [3]. In this study we performed the low-velocity collisions of isometric porous ice spheres with the porosity from 40% to 80% and examined the effect of sample porosity on the restitution coefficient and the deformed volume by impact.

All experiments were conducted in a large cold room at temperature of -10 ?C at Institute of Low Temperature Science, Hokkaido University. The samples were sintered porous ice spheres with a diameter of 30 mm and a porosity of 40% to 80% (mass of 7.52-2.54 g). The ice particles used to construct the samples had an average diameter of ~28 um and prepared by freezing small water droplets in liquid nitrogen. The ice particles were put into a spherical mold and compressed gradually. To distinguish the projectile from the target, the target was made up by colored ice particles prepared by adding red ink. By using two-stage release system, samples with same porosity were collided during free fall with relative velocity of 0.43-4.12 m/s at nearly head-on. The samples were landed on an airbag. The collisional behavior was recorded by two high-speed video cameras perpendicularly and the impact and rebound velocity (V_i, V_r) and the impact parameter were measured, then the restitution coefficient ($e=V_r/V_i$) was calculated. After the impact experiment, the mass and contact area during impact were measured.

All of the collisional outcomes were classified into bounce, no-bounce and sticking according to the recorded video images. The restitution coefficient of porous ice was found to be independent on the impact parameter and the impact velocity, but strongly dependent on the porosity (P) and become zero at 70% porosity. By comparing our data to result of polycrystalline ice [4], we obtained empirical equation as follows;

$$e=11.3(1-P)^{-0.9log(1-P)}.$$

The contact area during impact was found to increase with the increase of the impact velocity and the porosity. The relationship between the estimated deformation volume and the impact energy was fitted by power law equation and found that its slope is 0.81 to 1.31, indicating that they are almost proportional. If we assume that the impact kinetic energy was divided into the rebound kinetic energy and volume deformation, the dynamic compressive strength to achieve required deformation was found to be 2-4 times larger than the static compressive strength.

[1] Blum 2010, Res. Astron. Astrophys. 10 1199. [2] Wada et al. 2009, Apj 702 1490. [3] Sirono 1999, A&A 347 720. [4] Higa et al. 1996, Icarus 44 917.

Keywords: Ice, dustaggregate, impact, restitution coefficient, planetary formation

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PPS21-04 Room:201A Time:May 21 16:15-16:30

Experimental Studies on Impact Disruption of Rocky Rubble-Pile Bodies

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Rubble-pile bodies, which are constructed from the rocky fragments accumulated gravitationally, are common in the history of the solar system. It is important to evaluate the effect of the rubble-pile structure on the impact disruption in order to clarify the collision process of the solar system bodies. In particularly, the impact strength Q_{D*} is an important parameter for planetary collisional evolution. Then, we carried out high velocity impact experiments using several types of rubble-pile targets constructed from glass beads, and we examined the disruption condition of these rubble-pile targets. It is found that a lot of intact beads of rubble-pile targets were ejected very slowly and the enormous impact energy is necessary to shatter all of the beads constructing the rubble-pile targets. We defined the total mass of the small fragments M_{fsum} as a new parameter of impact disruption for rubble-pile targets, and calculated the crater volume for rubble-pile targets using this parameter, the crater volume is defined by the region where the beads are broken catastrophically. We compared them to that formed on for homogeneous basalt targets by using P_i-scaling and found that the crater on rubble-pile targets was larger than that on basalt targets. Furthermore, in order to understand the characteristics of the impact disruption for rubble-pile targets, we estimated the attenuation rate n of the shock pressure decay with the distance by assuming a billiard collision model and we obtained n=1.6~2.7 for the power law index of the propagation distance. From these results, we calculated the energy fraction f defined by the kinetic energy of the projectile transferred into the kinetic energy of the intact beads and we estimated the Q_{D*} of rubble-pile bodies from the re-accumulation condition of the dispersed intact constituents.

Keywords: Rubble-pile body, Impact disruption

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Measurement of 3D shape distribution of fragments ejected by impact experiments

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It has been accepted that impact phenomena play a major role throughout the history of the solar system, such as formation and evolution of asteroids and satellites. Regolith on asteroid's surface is also formed by impact of small celestial bodies and cosmic dust onto the surface. Regolith particles on the asteroid Itokawa, which were recovered by the Hayabusa spacecraft, have been examined. In the preliminary examination, surface structures and size and 3D shape distributions of Itokawa particles were elucidated using x-ray microtomography [1], and micro-surface structures of the particles were observed using high-resolution scanning microscopy [2]. Processes on the asteroid surface will be understood comprehensively together with space weathering [3] and implantation of solar wind noble gases [4].

In this study, we performed impact experiments of cratering and recovered impact fragments to compare the results with regolith particles on Itokawa. The experiments were made using a two-stage light gas gun at Kobe University with the impact velocity of 4 km/s. A projectile was a nylon projectile (2.2 mm in diameter and 2.5 mm in length), and two kinds of a target (10 x 10 x 3 cm), marble (compressive strength of 96.9 MPa) and limestone (compressive strength of 53.9 MPa) were used. If we consider regolith formation process, it is reasonable to expect that ejecta with high velocities was easily lost into space while those with low velocities remained on the asteroid's surface as regolith. Therefore, to compare experimental fragments with regolith particles, it is important to recover fragments by considering their ejection velocities. In previous experiments, however, impact fragments were usually collected without separating their velocities except for a few experiments [5,6]. In the present study, we have developed a collection method, where the target was surrounded by Styrofoam boards. In this method, high velocity ejecta were captured into a Styrofoam, while low velocity ejecta fell down on the bottom of a Styrofoam board.

Recovered impact fragments were analyzed by high-resolution x-ray micro- tomography at Osaka University. In previous studies, analysis of fragments has been made using caliper, micrometer, and/or microscope. Therefore, only a limited data have been obtained on the 3D shape distributions. In the present study, 3D shapes of individual fragments were obtained by the x-ray microtomography, and the 3D shape information was successfully obtained from best-fit ellipsoids and compared with Itokawa particle data, which were obtained by similar method.

From the 3D shape information, we calculated size and shape distributions of fragments with the different impact velocities into the two different targets. There is a tendency that high velocity fragments are more spherical than low velocity ones irrespective of the targets. Moreover, low velocity fragments have similar 3D shape distribution to Itokawa particles. This is consistent with the expectation that Itokawa particles should be low velocity fragments ejected by cratering.

[1] Tsuchiyama A. et al. (2011) *Science, 333*, 1125-1128. [2] Matsumoto T. et al., (2012) JGUM abstract, this volume. [3] Noguchi T. et al. (2011) *Science, 333*, 1121-1125. [4] Nagao K. et al. (2011) *Science, 333*, 1128-1131. [5] Asada, N. (1985) *J. Geophys. Res. 90*, 12445-12453. [6] Yamamoto S. and Nakamura A. M. (1997) *Advances Space Res., 20*, 1581-1584.

Keywords: Impact experiments, Cratering, Regolith, X-ray microtomography

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A study on identification of terrestrial impact craters using spectral data obtained by ASTER

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The 182 terrestrial impact craters have been identified so far [1]. This number is much lower than those on the other solid bodies in the Solar System such as Moon, Mars, or Venus. On the Earth, most of structures of impact craters have been eroded and tectonized. In addition, some of preserved impact structures may have been buried or obscured by sediments and vegetation. However, since there are few studies on the global survey of terrestrial impact craters using satellite remote sensing, it is still unclear whether or not more impact craters are preserved on the Earth. The recent survey by Google Earth images discovered a new impact crater in Egypt, which has been already identified as impact origin by the later geophysical analysis [2]. In addition, four new impact structures were confirmed as terrestrial impact craters last year [1], suggesting the existence of more unidentified impact craters on the Earth. Therefore, it is expected that more candidate structures of impact craters would be found by the global survey using satellite remote sensing data.

In this study, we discuss the feasibility to find candidates of impact craters using spectral data by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument, which is an imaging instrument with 14 bands, from the visible to the thermal infrared wavelengths, onboard NASA Terra satellite. We show that the discrete concentric patterns in the multispectral data obtained by ASTER can be identified for several terrestrial impact craters. We also analyze the ASTER data for volcanos or dome structures formed by intrusive rocks. Based on these results, we will discuss the feasibility of global survey to identify terrestrial impact craters by ASTER data.

[1] Earth Impact Database, 2012, http://www.passc.net/EarthImpactDatabase/ Accessed: 02/Feb./2012.
[2] Folco, et al., The Kamil Crater in Egypt. Science, 329, pp.804-804, 2010.

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PPS21-07 Room:201A Time:May 22 09:00-09:15

Habitable Zone and Water World Regime around Main-Sequence Stars

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Habitable zone (HZ) around main-sequence stars is defined as an orbital region in which H2O may exist as liquid water on the surface of terrestrial planets. The inner and outer limits of HZ should correspond to the condition of total evaporation and total freezing of water, respectively. It is, however, assumed implicitly that the atmosphere has enough greenhouse effects due to greenhouse gasses, such as CO2, CH4, and NH3, to maintain the climate warm enough for H2O to be liquid phase. In this respect, HZ is not a sufficient condition but just a necessary condition for H2O to be liquid water. That is to say, if there is not enough greenhouse effect, liquid water on the planet should freeze totally even when the planet is orbiting within HZ.

The condition for the planets to have liquid water on the surface is affected not only by semi-major axis (distance from the central star) but also by other factors such as orbital eccentricity, obliquity, degassing rate of CO2 via volcanism, carbonate-silicate geochemical cycle, land-sea distribution, water abundance, and so on. It is therefore suggested that the concept of HZ should be extended to include these factors.

We also propose a sufficient condition for H2O to be liquid water if the planet has abundant H2O on the surface. This is an abusolutely habitable zone, and we name it a "Water World Regime" (WWR). It is defined as an orbital condition which permits H2O as liquid phase unless there is no greenhouse gass other than water vapor in the atmosphere. If there is H2O on the planetary surface, it is in a liquid phase owing to the energy flux from the central star and greenhouse effect of water vapor without any other greenhouse gasses in the atmosphere. Ice giants and icy satellites around gas giants and/or ice giants, as well as terrestrial planets, are expected to have oceans if they are orbiting within the WWR.

Keywords: Extrasolar planetary system, habitable zone, habitable planet

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Debris Disk Ejected by Giant Impacts: Its Dynamical and Chemical Influences on the Terrestrial Planets

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During the last stage of terrestrial planet formation called the giant impact stage, Mars-sized protoplanets collide with each other. These collisions among protoplanets have a large influence on the various features such as the number of terrestrial planets formed, their mass, and spin state (Kokubo and Genda 2010). Giant impacts are highly energetic events and are responsible for the creation of large satellites, such as the Moon and planets with extremely large cores such as Mercury.

Genda et al. (2012) performed more than 1000 simulations of giant impacts to investigate the merging criteria for giant impacts. We made further analysis of the collision outcomes, and found that significant amount of colliding protoplanets is ejected during giant impacts. In the typical giant impact that occurs during the giant impact stage, several percents of protoplanets are ejected from protoplanets. We developed the hybrid code that includes both orbital evolution of protoplanets and impact process of protoplanets, and investigated the total amount of ejected material during the giant impact stage. We found that about 10% of the mass of the planetary system is ejected. We also found that such ejected materials contain metallic iron. In this study, we focus on the ejected materials by giant impacts, and investigate the dynamical and chemical influences of such ejected materials on the terrestrial planets.

Ejected materials have a dynamical influence on the orbits of the terrestrial planets through the gravitational interaction and reaccretion. Especially, gravitational interaction between ejected materials and terrestrial planets decreases the eccentricity of the terrestrial planets down to the present level (~0.01). Using N-body simulation of such configuration, we confirmed that the eccentricity of the terrestrial planets decreases down to 0.01.

Ejected materials also have a chemical influence on the terrestrial planets. Especially, re-accretion of metallic iron would greatly increase the concentration of highly siderophile elements in the Earth's mantle, which would be source of supply of late veneer. Additionally, re-accretion of metallic iron changes redox state of the Earth's surface from oxidized state to reduced state. Reduced surface environment will be maintained for about 1 Gyr.

Keywords: giant impact, BARAMAKI, late veneer, redox state

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Newly proposed formation process of terrestrial ocean: Application to the early evolution of Earth and Venus

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Many possible sources of water on the Earth have been proposed so far (Matsui & Abe, 1986; Gomes et al., 2005; Ikoma & Genda, 2006). Recently, the snow line is considered to passes the heliocentric distance of 1 AU during the planet formation stage (Oka et al., 2011). How much amount of water accumulated into terrestrial planets should be a fundamental question. From the viewpoint of origin and evolution of life, it is also considered to be necessary to accumulate (or escape) of proper amount of water on the early Earth.

There is a paradox of redox state of early Earth. The chemical analysis based on the incorporation of cerium into zircon crystals showed that the mantle reached its present-day oxidation state (FMQ) about 4,350 Myr ago (Trail et al., 2011). On the other hand, the isotopic analysis of sulfur requires the Earth's atmosphere to be maintained reductive at least 2,500 Myr ago (Farquhar et al. 2000). For Venus, there is a problem about the escape of ocean. The hydrogen would escape from the Venus by hydrodynamic escape while the oxygen would be left behind even though thermal/non-thermal escape and oxidation of surface are considered. The oxygen inevitably concentrates in the Venusian atmosphere (Sasaki & Abe, 2008).

In this paper, we propose a new scenario for loss and re-formation of ocean based on Genda et al. (in prep.) as below: (1) Accretion of Fe into primitive ocean as late veneer makes the ocean lose and generates hydrogen atmosphere. (2) Hydrodynamic escape of the hydrogen atmosphere and re-formation of ocean by adding the volcanic gas into the atmosphere occur. (3) One ocean mass is generated taking about one billion years. (4) Coexistence of oxidative mantle and reductive atmosphere on early Earth is realized. (5) Two times ocean loss produces CO_2-dominated Venusian atmosphere.

Our new scenario present an exhaustive framework of early evolution of terrestrial planets especially for the formation of ocean on the Earth. The scenario would be able to applied to extrasolar terrestrial planets as well.

Keywords: formation of ocean, early evolution of planets, Earth, Venus, atmospheric escape, redox

PPS21-10 Room:201A Time:May 22 09:45-10:00

Structure of the proto-atmosphere on Titan accreted in a gas-starved circumplanetary disk

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Titan, the largest satellite in the Saturn system, is characterized not only by its size comparable to the rocky planets but also by its thick N2 rich atmosphere with the surface pressure as high as 1.5 bar. Recent Cassini gravity measurements imply that its interior is differentiated into a rock-rich core and ice-rich shell. It is therefore likely that Titan has been gone through melting of ice during its history. To understand the origin of atmosphere and the differentiation of interior, it is important to clarify the thermal evolution and possible atmosphere formation of Titan during accretion.

Supposing gas-free accretion, Kuramoto and Matsui (1994) estimated the thermal evolution of an accreting Titan considering the blanketing effect of a steam atmosphere formed by vaporization of icy component. According to their calculation, the surface temperature exceeds the melting point of H2O ice thereby Titan differentiates if the accretion time is within 10^5 yr. Simultaneously, the surface temperature rises above 500 K, which cause significant outflow of atmosphere from Titan's gravity field. However, according to more plausible scenario for the satellite formation, satellites are accreted in gas-starved circumplanetary disks (Canup and Ward, 2002, 2006). This theory implies that Titan captured H2 and He gas from the gas disk. This study, therefore, estimates the thermal structure of the proto-atmosphere which is in hydrostatic equilibrium with a gas-starved circumplanetary disk and discusses its possible roles in differentiation of Titan and origin of N2 rich atmosphere.

The proto-atmosphere is assumed to consist of mixture of disk gas component (H2, He) and volatilized gas component (H2O) with isothermal stratosphere and troposphere where temperature follows the moist-adiabatic lapse rate under hydrostatic equilibrium with the surrounding disk gas. Hydrostatic structures are solved by changing tropopause. By solving the radiation transfer equation regarding H2 and H2O as continuum absorptions, we calculated the outgoing thermal radiation from the top of atmosphere for each hydrostatic structure. The disk temperature and pressure at the orbit of Titan is estimated by a disk model (Canup and Ward, 2002)

For the atmosphere in hydrostatic equilibrium and continuously connected with the surrounding disk, there exists the upper limit of the surface temperature about 300 K. If the surface temperature is higher than upper limit, the assumption of hydrostatic equilibrium and continuousness breaks up and the outflow of proto-atmosphere is likely induced because the pressure at the Hill radius becomes higher than the disk pressure.

By comparing outgoing thermal radiation from the top of the atmosphere with the accretional energy flux, one can estimate that the surface temperature exceeds the melting point of H2O during accretion if the accretion time is shorter than 10^6 yr. Moreover, there exists the upper limit of thermal radiation for the hydrostatic atmospheres. This is about 400 W/m^2, which is equal to the accretional energy flux when the accretion time is 0.4 Myr. Since Titan likely accreted within 10^4 yr to 10^6 yr, the surface temperature may exceed the critical temperature due to the heating by the difference in accretional energy and thermal radiation during accretion. In this case, the outflow of proto-atmosphere is expected to occur.

When such outflow occurs, it is likely that H2, He, and rare gases insoluble to water escape preferentially. The building blocks of Titan likely contain NH3 as a icy component. Because NH3 is highly soluble into water, NH3 likely remains on the satellite surface even if outflow occurs. Chemical conversion of remaining NH3 to N2 may explain why the present atmosphere of Titan is N2 rich but Ar poor in spite of their similarities in chemical properties and cosmic abundance. Impact induced shock chemistry is a candidate mechanism to produce N2 from NH3 on the proto-Titan (McKay et al., 1988).

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Numerical modeling of hydrodynamic escape from early Earth atmosphere

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The anoxic early Earth's atmosphere is considered to change its composition from some reduced one to oxidative one associated with hydrogen escape to space. Its changing rate is a clue for discussing whether the early Earth's surface environment is better suited for synthesizing organic compounds or not and for understanding climate changes on early Earth. In previous studies, escape of hydrogen was believed to occur rapidly by hydrodynamic escape driven by strong EUV radiation from the young Sun. Recently, Tian et al. (2005, hereafter T05) investigated numerically the hydrodynamic escape of hydrogen from the atmosphere of early Earth and indicated that the escape rate was lower than previously thought and thereby reduced surface environment might be maintained for long periods. However, the calculation of T05 has a critical problem that the conservation of mass is not satisfied.

In this study, we first performed recalculations of T05 and tested the accuracy of calculation for hydrodynamic escape with the Lax-Friedrichs scheme which they adopted. As a result, we found that their calculation does not satisfy the mass conservation owing to the strong numerical diffusion and the calculated escape rate increases with decreasing contribution of numerical diffusion by changing the configration of numerical grids. We therefore conclude that T05 underestimates the hydrodynamic escape rate.

We then constructed a new numerical model of the one-dimensional time-dependent nonviscous hydrodynamic equations for a single constituent atmosphere in spherical geometry with CIP & CIP-CSL2 method and performed the calculation with same parameter as T05. As a result, our new model predicts hydrodynamic escape rates are 5-10 times larger than those of T05 when the number density at the bottom is larger than n_0 = 5x10^{18} m^{-3} and the solar EUV flux is larger than 2.5 times than that of today. However, decreasing the energy deposition rate to atmosphere, the hydrodynamic escape rates of this study becomes smaller than those of T05. This is because the energy loss by heat conduction from upper boundary, which is taken to be zero in T05, becomes significant under such conditions.

Using our new results, we may estimate the hydrogen mixing ratio of about 7% for the anoxic atmosphere in the late Archean by balancing the geologically estimated volcanic hydrogen outgassing rate with hydrodynamic escape rate under the solar EUV 2.5 times that of today. In addition, the hydrogen mixing ratio had been rising through Archaean because of the decrease in solar EUV flux. The increase in hydrogen mixing ratio might result in CO_2-poor atmosphere, which would destabilize climate system. This result might be consistent with the occurrence of snowball earth event at 2.2 Gyr ago.

Keywords: Hydrodynamic escape

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

PPS21-12 Room:201A Time:May 22 10:45-11:00

Two evolutionary paths of early terrestrial planets with steam atmospheres

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Recent studies with N-body simulations suggest that Earth-sized planets would experience giant impacts among planetary-sized bodies during formation, implying that the planets would form in a globally molten state. Orbital crossing during the giant impact stage would cause significant radial mixing of material throughout the terrestrial planet formation region. It means that even the planets located close to their host star would still have a chance to acquire some water during formation.

Our goal is to clarify controlling processes of thermal history and water budget of terrestrial planets after the last giant impact until the magma ocean solidifies. Since water vapor is a potent greenhouse gas, the amount of steam atmosphere would strongly affect the thermal history of the planets. On the other hand, high solubility of water into silicate melts suggests that the amount of steam atmosphere would be controlled by water exchange between the atmosphere and the magma ocean. Elkins-Tanton (2008) calculated atmospheric growth and solidification time of the magma ocean, considering such a water exchange. In her model, the effect of condensation of water is neglected on outgoing planetary radiation. Also, it is assumed that the total amount of water of the planets is constant during solidification.

As reported by Nakajima et al. (1992), however, water-saturated atmospheres have radiation limits. The values of the radiation limits are common to the planets with the same mass, while the planet closer to the host star receives the larger incident stellar flux. Therefore, the existence of the radiation limits could make a fundamental difference in the cooling rates of the planets located at different orbital distance from their star. The recent studies with N-body simulations also suggests that planet formation lasts about 10-100 Myr. Strong EUV radiation from a young host stars could drive intense hydrodynamic escape of atomic hydrogen, which would also affect the amount of steam atmosphere and therefore the cooling rate of the planets.

We developed a steam-atmosphere and magma-ocean coupled model, in which a radiative-convective equilibrium model of grey atmosphere was incorporated in order to consider the effect of condensation of water vapor on planetary radiation. Water loss caused by the hydrodynamic escape was also taken into account. Using this model, we investigated solidification time and water budget of Earth-like terrestrial planets orbiting around a Sun-like star with respect to planetary orbital radius and initial water inventory.

Our results suggest that there would be two types of evolutionary paths of terrestrial planets, depending on orbital radius. The condition that separates the two distinctive evolutionary paths is whether the net incident stellar flux that the planet receives exceeds the value of the radiation limit from steam atmosphere or not. In this presentation, we will show the controlling mechanisms and also its implications to exoplanet observations and the early evolution of Earth and Venus.

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

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

PPS21-13 Room:201A Time:May 22 11:00-11:15

Estimation of Cooling Rate for H2-He Atmosphere with Radiative Convective Equilibrium Model

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In planetary atmosphere, it is generally thought that vertical convection is one of the major power sources of any atmospheric circulations. Intensity of these convections is dependent on atmospheric cooling rate, and atmospheric thermal structure is maintained by the equilibrium of this cooling and heating by convection carrying energy from lower hot atmosphere. This mechanism can be also occurred in the case of Gas Giant Planets, such as Jupiter, which have a thick atmosphere mainly consisted of hydrogen molecules.

In our study, we computed the radiative features and tried to reveal how they are determined, with calculation of energy transportation by radiation and convection in H_2-He atmosphere. We assumed plane parallel atmosphere, and calculated radiative transfer with formulations based on Appleby and Hogan (1984) in range 0.002-2 bar supposing the present Jovian atmosphere. The atmosphere consists of H_2 and He, and we took into account the collision induced absorptions of these molecules (Borysow 1988, 2002) as opacity sources. We calculated radiative trasfer for each 10 cm^{-1} bin over range 10-990 cm^{-1}. The solar radiation is neglected. At lower boundary, temperature was fixed and the flux from lower atmosphere was given by diffusion approximation. After the calculation of radiative transfer, we determined if the convective instability occurs at each layer, and gave dry adiabatic temperature profile for the entire unstable layers. We repeated these sequences until the time variation of thermal structure becomes small enough. Then, we got the energy equilibrium thermal structure.

In our results, the calculated vertical profile of cooling rate is almost consistent with the previous study by Sromovsky et al. (1998) base on the data of Galileo probe. The profile has a peak at 0.7 bar. At this level, optical depth for all wavenumber becomes nearly 1, so emission can effectively go through outward to space. This is the reason why such a profile is maintained. The peak value of cooling rate is 0.016 K/day, and which is much smaller than the typical value of the Earth's tropopause. This is due to the much lower temprature of the Jovian atmosphere. We also found that cooling rate approaches zero toward lower boundary. This might mean that the lower boundary of troposphere exists around 2 bar.

Keywords: gas giant planet, atmosphere, cooling rate, radiation, convection

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PPS21-14 Room:201A Time:May 22 11:15-11:30

Vertical wavenumber spectra of gravity waves in the Venus atmosphere

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Vertical wavenumber spectra of Venus gravity waves were obtained for the altitude range 65-80 km from temperature profiles acquired by the Venus Express radio occultation experiments and classified in terms of four latitude regions; equatorial region (0-20 degree), middle latitude region (20-50 degree), high latitude region (50-80 degree), polar region (80-90 degree). As a result, the spectra, which cover vertical wavelengths from 1.5 to 15 km, generally show a decline of the spectral density with wavenumber similarly to those obtained in the terrestrial stratosphere and mesosphere. Moreover we compared observed spectrum with the theoretical spectrum of the saturated gravity waves described as Tsuda et al. (1991) and Tsuda and Hocke (2002). In equatorial region, spectral density is lower than those in the other latitude regions by up to one order of magnitude and does not reach the saturation value. This implies that gravity waves are not saturated in the equatorial region. In middle latitude region, logarithmic slope of the spectrum is nearly -4, although its density is near the saturation value. In high latitude and polar region, spectral density is almost consistent with theoretical saturation spectrum, which suggests that gravity wave saturation occurs also in these regions in the Venus atmosphere.

Moreover we calculated the intensity scintillation spectra near the altitude of 70 km from the time development data of the received intensity and classified in terms of four latitude regions as described above. As a result, spectral densities in the high latitude and polar region are 3-4 times as large as in the equatorial and middle latitude regions and Kolmogorov inertial subrange could be seen. This implies that turbulent diffusion associated with the gravity wave breaking occurs in these regions.

Keywords: Venus atmosphere, Gravity wave, Vertical wavenumber

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

PPS21-15 Room:201A Time:May 22 11:30-11:45

Current status of Subaru Strategic Exploration of Exoplanets and Disks (SEEDS)

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From the space- and ground-based survey for exoplanets, the number of planets are going to exceed 3,000, including candidates. These discover lead us to variety of planets which called hot-Jupiter, hot-Neptune and super-Earth. However our understanding of planetary systems and their formation is far from complete. A census of companions to stars over a wide range of ages will provide important clues to the formation and evolution of stars, brown dwarfs, and plants.

SEEDS is the first Subaru Strategic Observations to conduct the high contrast camera HiCIAO with 188 elements Adaptive Optics (AO188) imaging survey searching for giant planets as well as protoplanetary/debris disks at a few to a few tens of AU regions around ~500 nearby solar-type or more massive young stars. The ages of our exoplanet target stars span ~1-10 Myr for YSOs in nearest star forming regions, through ~100-500 Myr old stars in nearby open clusters, to ~1 Gyr old nearby stars. The protoplanetary disk targets are the YSOs in nearby star forming regions, while the debris disk candidates include both well known and newly discovered ones from Spitzer/AKARI satellites.

As demonstrated with one of recent successes of direct imaging of proto-planetary disks, we revealed the geometry of the disk of young (~10Myr) YSO, AB Aur. The disk structure shows the rich features and most inner part of the disk. Another recent success is the imaging for HR 4796 A their debris ring. The ring features imply existence of unknown inner planets. Previous observations shows simple disks but HiCIAO+AO188 revealed their complex disk structures which imply inner unknown planets. These results lead us to be connecting the planet formation research field and proto-planetary research field, which fields went on apart previously.

SEEDS project observations are from September 2009 to 5 years. The interesting results are increasing, in the first half our project time. In this talk, I would like to present about the middle status report not only disks but also direct detection of planet mass objects.

Keywords: Exoplanet, Proto-planetary disk, Near infrared, Direct imaging

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PPS21-16 Room:201A Time:May 22 13:45-14:00

Surface Density Distributions of Protoplanetary Disks with Dead Zones of Magneto-Hydrodynamic Turbulence

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We study evolution of the surface density distributions of protoplanetary disks taking into account the effect of turbulent viscosity via magneto-rotational instability. The inner part of a protoplanetary disk is inactive to MHD turbulence because of its low ionization degree. In such a region, called as a dead zone, gas accretion due to turbulent viscosity is suppressed, and consequently the gas from the outer part accumulates, making the surface density of the inner part higher than that of the outer part. At the outer boundary of the dead zone, which locates from a few AU to several tens AU, the surface density of the disk is expected to have a jump. Such surface density structures are expected to be detected by future dust continuum observations of ALMA.

The radial extent of the dead zone is determined by the ion-electron recombination on the dust surfaces, and depends of the total surface area of the dust particles. As the dust particles grow, the dead zone shrinks radially. There is an accretion flow at the surface of the dead zone, and its accretion rate depends on the strength of the vertical magnetic fields. The jump in the surface density depends on the vertical magnetic fields. Because the vertical magnetic fields advect or diffuse with the gas, both the gas density profile and the vertical magnetic fields should be determined self-consistently.

In this study, as a first step, we consider the case where the plasma beta is constant with radius. The ionization degree of the gas is calculated for various values of the dust particle size and the gas accretion rate, and then the extent of the dead zone and the surface density structure of the disk are determined. The ionization degree and accretion rate are calculated using the approximated formulae of Okuzumi (2009, ApJ, 698, 1122) and Okuzumi & Hirose (2011, ApJ, 742, 65), respectively. For the accretion rate of 10^(-8) M_sun / yr, the dust size of 1 micron, and the vertical magnetic fields of 0.1 mG, the surface density jumps 3 times at 20AU, and for stronger magnetic fields, the jump becomes weaker. For larger dust particles, the dead zone shrinks. We also discuss the effect of advection and diffusion of the vertical magnetic fields on the surface density structure of the disks.

Keywords: planet formation, protoplanetary disks, magnetohydrodynamic turbulence

PPS21-17 Room:201A Time:May 22 14:00-14:15

The Lifetime of Protoplanetary Disks Surrounding Intermediate-mass Stars

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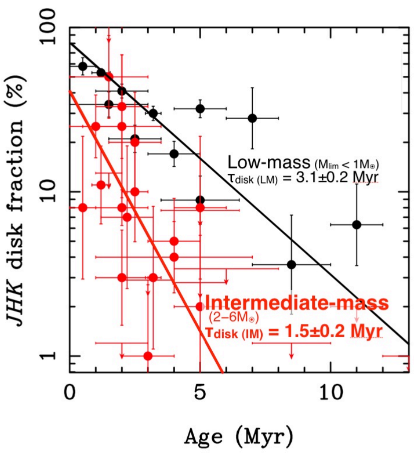
To quantitatively and comprehensively study the lifetime of protoplanetary disks surrounding intermediate-mass stars (~2-6 solar mass), we derived their disk fraction (IMDF) only using near-infrared JHK photometric data with a robust method with which the IMDF can be derived with high accuracy. We applied this method to all well-known nearby (heliocentric distance of $<\tilde{}$ 3kpc) and young (<~5Myr) clusters. The derived JHK IMDFs appear to approximately follow an exponential decay with the cluster age. From the best fit of the decay curve, the characteristic decay timescale for intermediate-mass stars is found to be 1.5 plus or minus 0.2Myr with an initial IMDF of 42 plus or minus 11 %. The estimated decay timescale is about half of that for low-mass stars (about 3Myr), showing the decay timescale is proportional to $M_{*}^{-0.5\ plus\ or\ minus\ 0.2}$, where M_{*} is stellar mass. This is consistent with previous works that qualitatively suggest this dependence. As for the disk lifetime, which is defined as the timescale of disk fraction to bottom out, we found that the outer MIR-disk traced by *Spitzer* 8um excess have about 4Myr longer lifetime than K-disk, which is the innermost dust disk traced by K-band excess emission. Because such time-lag is not seen for low-mass stars, this long "transient phase" may be a special characteristics for intermediate-mass stars, such as higher planet formation rate for higher mass stars, and faster inner disk dispersal compared to low-mass stars.

Keywords: protoplanetary disk, disk evolution, intermediate-mass stars, exoplanet



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

PPS21-18 Room:201A Time:May 22 14:15-14:30

Rapid formation of Saturn after Jupiter completion

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Although planets can rapidly migrate through the interaction with massive gas, Jupiter stays at the current location probably without significant migration. Jupiter is thus expected to have finished its formation during the depletion of gas nebula. Therefore, the following formation of Saturn should have occurred in a short timescale, about several million years. Since the core of Saturn is estimated to be about 10 Earth masses, it would be formed via core accretion. Although planetesimal accretion produces a core, a massive core induces the fragmentation of planetesimals, resulting fragments are then removed by their radial drift due to gas drag, and eventually the growth of the core stalls because of the reduction of surrounding bodies. After the completion of Jupiter formation, Jupiter formed a gap in the solar nebula. Since the drift velocities of fragments are lower around pressure maximum produced just beyond the gap in the nebula, the core of Saturn grows rapidly through the accretion of such fragments. At first, we investigate the case of no radial drift around the pressure maximum. In the minimum-mass solar nebula (MMSN), kilometer sized planetesimals can produce a core exceeding 10 Earth masses in several million years. Larger planetesimals need larger amount of solid, 3 times MMSN for 10 km and 10 times MMSN for 100 km. However, fragments drift due to their eccentric and inclined orbits even in the pressure maximum region. Fragments can halt inside the pressure maximum and may contribute the growth of the core. If we assume that such fragments cannot accrete onto the core, the depletion of fragments then stalls core growth. In MMSN, a core resulting from kilometer-sized planetesimals grows rapidly but the core reach only 2 Earth masses due to the depletion of fragments. Despite severe setup, a core can exceed 10 Earth masses within about one million years from kilometer-sized planetesimals in a disk with solid surface density larger than 4 times MMSN. Since the core can reach the critical core mass even in the severe case, Saturn would have formed in such a disk via core accretion.

Keywords: Planetary formation, Collisional fragmentation, Saturn

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PPS21-19 Room:201A Time:May 22 14:30-14:45

Gas Accretion Flow onto Circumplanetary Disks from Protoplanetary Disks: Effect of Gap

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Satellite systems around gas giant planets are thought to be formed in circum-planetary disks, which are believed to exist at the gas capturing growing phase of giant planets. However, the structure of the circum-planetary disks are poorly known and thus current formation theories of satellite systems are forced to be constructed under not-well-established disk structures, which could impact the results.

In this study, we performed a series of hydrodynamic simulations of gas accretion flow onto circum-planetary disks from proto-planetary disks in order to analyze the structure of circum-planetary disks. In order to obtain fine structure of the gas flow around the planet, we employ nested grie method, which enable us to calculate high-resolution structure with high efficiency. In our previous studies, we do not consider the effect of gap, which would be created by the gravity of giant planets. But, this time, we consider the effect of gap to see if the accretion flow structure changes.

We found that, when there is a gap with symmetry about planetary orbit, the power-law distribution function of gas accretion flux onto the disk, which we obtained in the previous work, does not change almost at all. However, when the gap has some asymmetry, the distribution function of the accretion flow becomes more center-consentrated. This result under the more realistic setting would be important for the formation and evolution of the circumplanetary disks, which produce satellite systems.

Keywords: Satellite formation, giant planets, hydrodynamics

Japan Geoscience Union Meeting 2012
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PPS21-20 Room:201A Time:May 22 15:30-15:45

Development of an anelastic convection model in rotating spherical shells for stars, gas and icy giant planets.

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The problem of convection in rotating spherical shells has been studied vigorously as a fundamental model of global convection presumably emerging in celestial bodies, such as stars, gas and icy giant planets, and terrestrial planetary interiors. Recently, according to development of numerical computational abilities, fundamental aspects and characteristics of convection has been revealed and knowledge about this issue is increased under the assumption of Boussinesq approximation, which ignores compressibility of the fluid. However, characteristics of compressible convection in rotating spherical shells has not been understood yet compared with Boussinesq convection, although some studies performed so far use the anelastic approximation in order to deal with compressibility. Compressibility is an important element for discussing deep convection of stars and gas and icy planets, since thickness of their convection layers is several times larger than the scale height. Not only for these celestial bodies but also for extra-solar gas giant planets, which have been discovered with recent sophisticated technologies of astronomical observation, compressibility cannot be ignored for considering fluid motion in their interiors. Investigation of effects of compressibility on convection in rotating spherical shells would contribute to the basic knowledge of fluid motions in the interiors of these many celestial bodies.

Based on the consideration described above, we are now developing a numerical model of an anelastic fluid in rotating spherical shells in order to assess effects of compressibility on convective motions. On the development of the model, we extended our numerical model of Boussinesq convection in rotating spherical shells developed so far to the anelastic system. We described mass flux with poloidal and toroidal potentials instead of velocity field in the case of Boussinesq fluid. This procedure enables us to extend our Boussinesq model constructed so far to the anelastic case in a natural way.

In the presentation, results of some numerical experiments using our newly developed model will be shown, and future plan is also discussed.

Keywords: Convection in rotating spherical shells, Compressible convection, Anelastic equations

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PPS21-21 Room:201A Time:May 22 15:45-16:00

Revisited to the impact erosion of early Earth atmosphere during the heavy bombardment period

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Impact-induced expanding vapor clouds resulting from hypervelocity impacts accelerate the srrounding planetary atmosphere. If the velocity of an accelerated atmosphere exceeds the escape velocity of the planet, the atmosphere is lost from the planet. This process is called impact erosion, which has been widely studied since 1980s. Especially, the early dense atmosphere of Mars (˜10ˆ5 Pa) was lost due to impact erosion during the heavy bombardment period [Melosh & Vickery, 1989].

In this study, we focused on the impact erosion of early Earth atmosphere during heavy bombardment. Melosh & Vickery (1989) roughly estimated the required impact velocity for the massive blow off of the atmosphere above the tangent plane on the Earth as ˜25 km/s. In contrast, the median of impact velocity of asteroids onto the Earth is considered as 13-15 km/s [Chyba, 1991]. Thus, the impact erosion of Earth atmosphere has not been studied well. However, they employed the minimum value of the internal energy of the expanding vapor cloud for a conservative estimate because energy partitioning during hypervelocity impacts at higher than the escape velocity of the Earth was highly uncertain. Now, the Hugoniot curve up to ˜1TPa are available obtained using high power lasers. The equation for the internal energy of an expanding vapor cloud is modified using the pressure-entropy Hugoniot curve from the conservative estimate and is incorporated into the sector blow-off model, which is a semi-analytical model for impact erosion due to expanding vapor clouds [Vickery & Melosh, 1990]. We found that the threshold impact velocity for the initiation of atmospheric blow-off estimated by our equation is˜13 km/s, which is ˜3 km/s smaller than that estimated by the conservative estimate of the internal energy. The significance of the impact erosion of the early Earth atmosphere may be drastically changed from the current understanding because the median of impact velocity between the Earth and asteroids is located between the threshold velocities between both estimates.

In presentation, we are planning to present the systematic results on the change in the total atmospheric pressure as functions of impact velocity, initial atmospheric pressure, the total mass of impactor, the size distribution of impactor and to discuss the atmospheric evolution of the Earth during the heavy bombardment period.

Keywords: Impact-induced vapor clouds, Early Earth atmosphere, Impact erosion, Heavy bombardment period, Solar nebula, Noble gases

PPS21-22 Room:201A Time:May 22 16:00-16:15

Differentiation of silicates from H2O ice in an icy body induced by ripening

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Planetary differentiation is the process of the separation of the constituents of a planetary object as a consequence of their physical and chemical behavior. Distinct layers are develops in the object, and the denser materials sink to the center while the lighter materials rise to the surface.

One of the probable scenarios of differentiation between silicate-ice in an icy object is the settling of a silicate particle in water after melting of the object. In order for settling to proceed or occur, the size of a particle should be sufficiently large such that the settling velocity of the particle must exceed the background flow velocity induced by thermal convection. The sizes of the particles change because of dissolution and precipitation. This process is called ripening. In this study, I derive the critical particle sizes required for settling and the timescales for growth of the particles to these sizes through ripening. It is observed that settling is possible if the silicate particles coagulate with each other to form a network in water. If the particles do not coagulate, the probability of the occurrence of settling is low because the time duration required for the particle growth to the critical size is large. The coagulation of silicate particles strongly depends on the pH of water.

Keywords: Icy body, Differentiation, Ripening, Composition

PPS21-23 Room:201A Time:May 22 16:15-16:30

Hypersonic wind tunnel experiments on chemical reaction around an icy object with ablation using electric discharge

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When an extraterrestrial object enters the planetary atmosphere, a strong shock wave is formed in front of the object, and various gaseous materials including prebiotic ones are produced in the high temperature shock layer flow by the chemical reactions of the atmospheric gas and the ablation gas injected at the surface. Such products are distributed into the atmosphere through the wake flow behind the entry object. We conducted the numerical analyses of the Navier-Stokes equations for the chemically reacting hypersonic flow around an icy object with the ablation injection of H2O in the N2-CO2 atmosphere (Suzuki, AIAA Paper 2011-3756, 2011). The nonequilibrium chemistry of the 28 species (N2, O2, N, O, NO, NO+, e-, N+, O+, N2+, O2+, C, C2, C3, CO2, CO, CN, CO+, C+, H, H2, HCN, HCO, C2H2, C2H, CH, H2O, OH) is considered as well as the thermal nonequilibrium described by the two-temperature (translational and vibrational) model. The computational results show that HCN is produced near the surface in the stagnation region by the chemical reaction of H2, which comes from the decomposition of the ablation gas, and CN, which is produced behind the shock wave in front of the object. HCN is transported into the atmosphere via rapid expansion flow at the shoulder and the wake flow in almost frozen state. In the case of an icy sphere of 0.2 m radius with the uniform ablation rate 0.05 kg/(s m2) over the windward surface at the flight velocity, altitude and atmospheric composition 8 km/s, 60 km (equivalent to the present earth) and CO2:N2=0.93:0.07, respectively, the mass flux of HCN exhausted into the wake flow is in the order of 0.01% relative to the total mass loss rate of H2O.

The hypersonic wind tunnel facility, which is used in the aerospace engineering for research and development of a re-entry vehicle for the space transportation, is also a powerful tool to simulate the high-speed flow around an extraterrestrial entry object and the various phenomena caused by the ablation (Suzuki, et al., JpGU Meeting 2010, PPS004-10, 2011, PPS020-22, Imamura et al., AIAA Paper 2010-4512). Due to the operation limit of the facility, however, it is impossible to make the flow temperature high enough to excite the chemical reactions. Then the thermal energy was added to the flow by the electric discharge at the electrodes put on the surface of the test piece (Watanabe and Suzuki, AIAA Paper 2011-3736). The experiments were conducted at the hypersonic and high-enthalpy wind tunnel of the graduate school of frontier sciences, the University of Tokyo (http://daedalus.k.u-tokyo.ac.jp/wt/wt_index.htm). The figure shows a picture taken at a trial experiment using a flat plate model. In addition to the electrodes, a cavity having ice inside was installed on the plate. The ablation occurred at the surface of the cavity in the hypersonic flow. The image was taken through the narrow band pass filter at 380-384nm, where the emission of CN is observed. The stagnation temperature and the pressure on the surface are about 600K and 300Pa, respectively. The quasi-steady electric discharge was kept for about 1 sec at 5V and 6A. At the center of the discharge region, the vibrational temperature is estimated as about 6000K by the spectroscopy and the fitting technique for N2(1+) band. The high luminous region indicates the presence of CN, which is produced from N in the air and C in the ablation gas of the Bakelite, from which the plate is made.

As seen in the above, the hypersonic wind tunnel experiment using the electric discharge seems promising for simulating the chemical reactions around the atmospheric entry object with ablation.

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Keywords: atmospheric entry, hypersonic flow, wind tunnel, ablation, ice, chemical reaction

PPS21-23 Room:201A Time:May 22 16:15-16:30