Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-01 Room:304 Time:May 20 09:00-09:15

Evolution of Venusian mantle with magmatism and compositional differentiation in a numerical modeling

Takatoshi Yanagisawa[1*], Masaki Ogawa[2]

[1]IFREE, JAMSTEC, [2]Graduate School of Arts & Sciences, Univ. Tokyo

The surface age of Venus is estimated to be 300-600 Myr on average, and is young in contrast to Mars, where magmatism has mostly subsided on the early stage of its history. Detailed surface observations suggest that magmatism is still ongoing on Venus, at least locally. On the other hand, Venus is a planet where the lithosphere is stagnant and plate tectonics does not operate, which is similar to Mars. When the lithosphere is stagnant, the solid-state mantle convection is unlikely to cool the mantle so efficiently as to extract all the heat internally generated by heat producing elements. In such a situation, it is crucial to take account of melting of mantle materials in the modeling of thermal history, as we suggested for the evolution of Martian mantle (Ogawa and Yanagiawa, 2011, 2012). Here, we apply our numerical model of mantle evolution with coupled magmatism for Venus to understand its thermal history, the history of magmatism, and structural evolution of the mantle. In the numerical experiments, we discuss how the crust enriched in heat producing elements develops, how the crust recycles back into the mantle, and how the mantle evolves to affect the history of magmatism and the lithosphere in accordance with the crustal evolution. We take account of the barrier effect of the phase transitions at the top of the lower mantle, and our model allows compositional differentiation of the mantle by magmatism. Based on the numerical results, we discuss the difference of evolution between Venus and Mars.

Keywords: Venus, evolution of mantle, magmatism, numerical simulation

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-02 Room:304 Time:May 20 09:15-09:30

Internal structure and thermal evolution of Mercury with highly reduced composition

Akifumi Nakayama[1*], Kiyoshi Kuramoto[2]

[1]Department of Earth Sciences, School of Science, Hokkaido University, [2]Department of Cosmosciences, Graduate School of Sciences, Hokkaido University

According to topography, surface composition and gravity data obtained by MESSENGER, a new internal structure model of Mercury have been proposed (Smith et al., 2012). The core radius and solid mantle density have been estimated on the basis of the moment of inertia are 2030 +/- 37 km and 3650 +/- 225 kg m^{-3}, respectively. To explain the high mantle density, the presence of FeS layer at the bottom of mantle is suggested. The observed surface composition (Nittler et al., 2011) is poor in FeO. This suggests Mercury formed from highly reduced precursors like enstatite (E) chondrite (Wasson, 1998). Because these results are very different from the previous model, it is necessary to reestimate the precursors and thermal evolution of Mercury.

E chondrite contains significant amount of S in metal components. If such a significant amount of light element is also contained in the Mercurian core, silicate mantle layer should be very thin in order to explain the higher average density of Mercury. In previous thermal evolution models assumed the relatively thick silicate mantle (e.g. Stevenson et al., 1983), the fluid core is not thermally convective today, because heat transport through the mantle sufficiently decreases. If this is the case, no FeS is solidified in the core. However if Mercury has a thin mantle, the heat transport efficiency through the mantle does not decrease so much and the core could be cooled to allow FeS solidification. In this study we calculate the thermal evolution of Mercury with supposing new internal structure and discuss thermal state of the core and thermal history of Mercury.

Assuming spherical symmetry, the heat balance calculation of silicate mantle and core performed in accordance with the mixing length theory (Abe, 1997) and box model (Stevenson et al., 1983), respectively. The silicate and metal components have chemical compositions similar to those of E chondrite, respectively. The thickness of silicate mantle and the core density are 170-340 km and 6000-6981 kg m^{-3}, respectively, which agree with the core radius and solid mantle density estimated by Smith et al. (2012). In this calculation we varied the mantle thickness while adjusted the concentration of sulfur in the core, so as to keep the mean density of Mercury. The viscosity of a silicate mantle assuming enstatite composition is about 1000 times that of the Earth's upper mantle, hence the heat transport efficiency by convection is weaker than previous models. We give the solidus temperature of enstatite for the initial temperature of mantle, and the adiabatic temperature distribution continuous with the temperature of the core-mantle boundary (CMB) for the initial temperature of the core. Initial temperature of the core is higher than the melting curve of Fe-S alloy, so the core is entirely molten.

In all the models of different mantle thickness, heat transport by convection is weakened rapidly and dominant heat transport mechanism is switched to thermal conduction during the first 1 billion year. Heat is still efficiently transported by thermal conduction, because the silicate mantle is thinner than previous models. When the silicate mantle is thinner than 270 km, the temperature of the CMB drops below the eutectic point of Fe-FeS binary within 4.5 billion years. This explains the formation of solid FeS layer. In addition, the heat flow across CMB after 4.5 billion years exceeds the value achieved by the thermal conduction in the core with adiabatic temperature profile. This suggests that it is possible to drive the liquid outer core dynamo by the thermal convection even today.

Keywords: Mercury, thermal evolution

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-03 Room:304 Time:May 20 09:30-09:45

Mantle convection in super-Earths with high compressibility, high Rayleigh number, and temperature-dependent viscosity

Takehiro Miyagoshi[1*], Chihiro Tachinami[2], Masanori Kameyama[3], Masaki Ogawa[4]

[1]IFREE/Jamstec, [2]Department of Earth and Planetary Sciences, Tokyo Institute of Technology, [3]Geodynamics Research Center, Ehime University, [4]Department of Earth Sciences and Astronomy, University of Tokyo

Understanding mantle convection in super-Earths is a key to clarifying their habitability, because mantle convection determines the surface environment and the magnetic field intensity through the influence on the activity of core convection. The large size of super-Earths implies that the depth of their mantle far exceeds the thermal scale height. In this paper, we present numerical simulation results of mantle convection in super-Earths with high compressibility, high Rayleigh number, strongly temperature-dependent viscosity and depth-dependent thermal expansivity.

Thermal convection of compressible infinite Prandtl number fluid is solved in a rectangular box under anelastic approximation by the ACuTEMAN (Kameyama et al. 2005). The model of the super-Earths, including depth-dependent thermal expansivity and density, is the same as Tachinami et al. (2013, submitted). The dissipation number is 5, which corresponds to terrestrial planets of ten times the Earth's mass. The Rayleigh number defined with the viscosity at the core-mantle boundary (CMB) Ra is from 6E6 to 1E10. A viscosity contrast r up to 1E7 arises between the CMB and the surface owing to the temperature-dependence of viscosity. The employed grid number is 1024 (horizontal) and 256 (vertical).

Numerical results show that the efficiency of heat transport by the mantle convection in super-Earths becomes smaller than that in the Earth owing to adiabatic compression effect. For example, at Ra=1E10 and r=1E3, the Nusselt number is only about twenty, less than the expected value when the effect of adiabatic compression is neglected. This low efficiency of heat transfer strongly affects the evolution of the super-Earths. The magnetic field of super-Earths, for example, is probably weak because the core is not cooled efficiently. The weak magnetic field can be fatal for the habitability of super-Earths. We also found that in some cases it takes time longer than the age of the Universe for the calculated mantle convection to go through with the initial transient stage. This suggests that the initial transition stage, not the statistically steady stage, is more relevant to most of the time in the evolutionary history of super-Earths. The temperature and flow field show that at high Ra and at strong temperature-dependent viscosity the stratosphere develops in the middle of the mantle. Hot plumes from the CMB does not ascend to the surface of the planet. Cold plumes that grow at the base of the lithoshere are weak or are totally inhibited by the strong effect of adiabatic compression. The thermal structure of the mantle in super-Earths is totally different from that of the Earth.

Keywords: mantle convection, super-Earths

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-04 Room:304 Time:May 20 09:45-10:00

Laboratory generation and observation of super-Earth's interior using high-power laser

Norimasa Ozaki[1*], Tomoaki Kimura[3], Takuo Okuchi[4], Martin French[5], Tomoyuki Kakeshita[1], Mika Kita[1], Kohei Miyanishi[1], Ronald Redmer[5], Takayoshi Sano[6], Tomokazu Sano[1], Katsuya Shimizu[7], Tomoyuki Terai[1], Ryosuke Kodama[1]

[1]Graduate School of Engineering, Osaka University, [2]Photon Pioneers Center, Osaka University, [3]Geodynamics Research Center, Ehime University, [4]Institute for Study of The Earth's Interior, Okayama University, [5]Institut fur Physik, Universitat Rostock, [6]Institute of Laser Engineering, Osaka University, [7]Center for Quantum Science and Technology under Extreme Conditions, Osaka University

We reports the first laboratory generation of super Earth planet interior states. We focused a high-power laser pulse onto a water target, thereby dynamically compressing the water to pressures to ˜100-200 GPa. Our pressure-volume-temperature equation-of-state data are in good agreement with water-world super Earth GJ1214b interior conditions predicted by first principle calculations. Simultaneous optical reflectivity measurements also show that the warm dense water behave as an electronically conducting fluid capable of generating a significant magnetic field. This high-power laser experiment is an important step toward understanding the interior structure of super Earths, which can provide a clue for understanding a scenario for formation of the expoplanetary systems.

Keywords: Super Earth, Water, High pressure, Phase transition, Power laser, Laser shock

PPS21-05 Room:304 Time:May 20 10:00-10:15

Anelastic convection model in rotating spherical shells for stars, gas and icy giant planets.

Youhei SASAKI[1*], Shin-ichi Takehiro[2], Kensuke Nakajima[3], Yoshi-Yuki Hayashi[4]

[1]Department of Mathematics, Kyoto University, [2]Research Institute for Mathematical Sciences, Kyoto University, [3]Deptartment of Earth Planetary Sciences, Kyushu University, [4]Center for Planetary Science/Department of Earth and Planetary Science, Kobe University

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 have been revealed and knowledge about this issue is increased under the assumption of Boussinesq approximation, which ignores compressibility of the fluid. However, compressible convection in rotating spherical shells has not yet understood 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, 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 so many discovered with recent sophisticated technologies of astronomical observations, compressibility could not be ignored for considering fluid motion in their interiors. Investigation into effects of compressibility on convection in rotating spherical shells is expected to contribute to the basic knowledge for considering fluid motions in the interiors of these many celestial bodies.

In the present study, we develop a numerical model of an anelastic fluid in rotating spherical shells in order to assess effects of compressibility on convective motions. The governing equations are anelastic equations with polytrope basic state. We already developed numerical model of Boussinesq convection in rotating spherical shells as a member of Hierarchical Spectral Models for Geophysical Fluid Dynamics "SPMODEL". On the development of the anelastic model, we extended our numerical model of Boussinesq convection in rotating spherical shells accomplished so far to the anelastic system.

In all calculations, the ratio of inner and outer radii, the Prandtl number, the Ekman number are fixed to 0.35, 1, 10^{-3}, respectively. The Rayleigh number is also fixed 1.2 times the critical Rayleigh number. The inverse density scale height, N, is varied from 10^{-5}, 1, 2, 3, and 5. For each combination of parameters, time integration is carried out until quasi-steady state is established. When the case of N is 10^{-5}, columnar convection along the rotation axis emerged near the inner boundary. This feature is similar the Boussinesq case. On the other hand, the location of convection column becomes close to the outer boundary, and the convective motion occurs are near the outer boundary as the value of N is increased.

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

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-06 Room:304 Time:May 20 10:15-10:30

Ancient Cratered Southern Highland Province, Mars:

James Dohm[1*], Shigenori Maruyama[1], Hideaki Miyamoto[2]

[1]Earth-Life Science Institute, Tokyo Institute of Technology, [2]The University Museum, The University of Tokyo

The geologic provinces of Mars, as identified through a synthesis of geologic, paleohydrologic, topographic, geophysical, spectral, and elemental information [1], are windows into its evolution, with the ancient southern highland province being a key to the extremely ancient geological and possible biological pasts. The ancient cratered southern highland province includes Noachian (>3.7Ga) geologic terrains that are marked by magnetic anomalies [1]. The terrains include: (1) Noachian mountain ranges, Thaumasia highlands and Coprates rise, both of which exhibit com-plex structures such as thrust and normal faults and rift systems, as well as cuestas and hogbacks along their margins, (2) basin and range topography, including salt-containing, structurally-controlled basins, as exemplified at Terra Sirenum, (3) faults that are tens to thousands of kilo-meters long, and (4) degraded promontories, many of which are interpreted as silica-rich volca-noes or in some cases, impact crater massifs.

These terrains can be aptly explained through dynamic endogenic activity, including some form of primitive plate tectonism and/or mobile crust, as well as planetary shrinkage due to cool-ing, rather than impact events. The ancient cratered southern highland province could comprise extremeley ancient (>3.9 Ga) geologic and habitable environmental information, including granite and primordial continental crustal materials. Such materials are considered to be critical to the emergence to life on Earth [2].

References
[1] Dohm, J.M. et al., (2013?in press), Mars evolution. Nova Science Publishers, Inc.
[2] Shigenori Maruyama, this conference.

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-07 Room:304 Time:May 20 11:00-11:15

Control mechanisms of the tropopause level and cloud top in Jovian atmosphere.

Yasuto TAKAHASHI[1*], George HASHIMOTO[2], Masanori Onishi[3], Kiyoshi Kuramoto[1]

[1]Hokkaido Univ, [2]Okayama Univ, [3]Kobe Univ

The primary definition of the tropopause of a planetary atmosphere may be the level which divides the convective region and upper stably stratified region. On the other hand, the tropopause is often defined as the level of first temperature minimum which occurs in the temporal-mean vertical temperature profile above the surface. This definition makes it easy to find the tropopause altitude, but it may be an approximation of the true boundary between the two regions, because the stably stratified region possibly includes a layer with negative vertical temperature gradient. This approximation could work for the Earth atmosphere because the change in lapse rate around the tropopause level is sharp and therefore the difference from the primary definition is minimal, but being not sure whether it is applicable for another planet or not.

Equilibrium cloud condensation models (ECCMs, e.g. Weidenschilling and Lewies 1973) and cloud convection models (e.g. Sugiyama et al. 2011) assume that the Jovian atmosphere is enough convective in the region below a level about 0.1 bar, where the temperature minimum exists in the representative temperature profile retrieved by observations. However, we need to revisit it more carefully as mentioned above. In a radiative-convective model of Jovian atmosphere (Appleby and Hogan, 1984), the temperature minimum occurs at a level around 0.1 bar, while the radiative-convective boundary may occur at a much deeper level around 0.5-0.75 bar. It means that the generation of NH3 cloud by convection, a widely accepted picture for the Jovian uppermost cloud formation, may be indeed marginally possible because little NH3 would condense at such deeper level.

In order to understand how the tropopause level is controlled in the Jovian atmosphere, we utilizes a new numerical model of radiative-convective equilibrium in H2-rich atmosphere taking into account the up-to-dated gas absorption models and knowledge on the atmospheric composition. Our model is a 1D radiative-convective equilibrium model for a plane parallel atmosphere. In this model, the temperature of lower boundary (taken 10 bar) is given constant in accordance with the Galileo probe data. We only solve the transfer of long wave radiation with wave number range from 0 to 10,000 cm-1. Here, we use HITRAN2008 database(Ruthman et al. 2009) for line absorption for condensable gas species, and Borysow (1989, 2002) for continuum absorption due to H2-H2 and H2-He collision. The temperature of each atmospheric layer is changed step by step according to the calculated amount of radiative heating or cooling until it converges into the steady state, or radiative-convective equilibrium state with applying convective adjustment for the unstable layer. Atmospheric compositions are given within the range consistent with the Galileo probe experiment.

From our preliminary results, it is confirmed that the tropopause by primary definition is formed around 0.5 bar level almost independent on the mixing ratio of condensable species. Note that the temperature tends monotonically decreases with altitude for most cases because the solar heating is neglected in these calculations. If the solar heating was included, the tropopause level would likely shift deeper. Our obtained temperature profiles are compared with the NH3 condensation curves, showing that little NH3 condensation occurs within the convective region when given nominal NH3 concentration or below. On the other hand, a NH3 condensable layer spans above the tropopause. This implies that the uppermost cloud layer of Jovian atmosphere would be mostly composed of stratospheric cloud and/or convective cloud associated with upwelling penetrating stratosphere. Because the uppermost cloud play an important role in determining the planetary albedo, model development for cloud formation in the stratosphere would be essential to understand the radiative energy budget in the Jovian atmosphere.

Keywords: Jupiter, Atmosphere, Cloud, Tropopause, Radiative transfer

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-08 Room:304 Time:May 20 11:15-11:30

Follow-up Observation of Jupiter's Atmosphere 19 Years after the SL9 Event

Takahiro IINO[1*], Tac Nakajima[1], Tomoo NAGAHAMA[1], Akira Mizuno[1]

[1]Solar-terrestrial Environment Laboratory, Nagoya University

Cometary Impact as the Supply Source of Volatile Gases on Planetary Atmosphere

In 1994, the impact of comet Shoemaker-Levy 9(hereafter SL9) had changed the Jupiter's atmospheric composition. The abundance of CO and HCN had increased vigorously to realize 10ˆ3 to 10ˆ4 times larger value than before the SL9 event. Besides, some S-bearing molecules were found and produced newly(Moreno et al. 2003)?. Similarly, on Neptune, it is expected that similar impact process has realized 50 ? 1000 times as large CO abundance as the other three gas giants(Lellouch et al. 2005)? (A. Marten et al. 2005)?. Studies on such huge disturbance induced by cometary impact is very important because such process can affect the atmospheric composition of gas giant largely. Revealing the chemical evolution of the solar system planet's atmosphere is main issues in planetary science. Detailed studies on the entire chemical processes from cometary impact to the end of reaction are needed.

Our observation in 2012

Studies on the SL9 event and its aftermath are very important especially because it is the only case where the cometary impact can be monitored in detail. Even now, little is known about how long the influence of the SL9 continues to affect on Jupiter's atmosphere. Constructing and examining the chemical evolution are the key for full understanding of cometary impact as part of atmospheric evolution processes.

We have focused on the sulfur chemistry because CS and S-bearing species were known to be produced after the SL9 event. Studies on the chemical evolution of S-bearing species suggest that CS is a daughter species of S2 and CS2, and had been continuously produced for a year after the SL9 event (Moses et al. 1995). This scenario is supported by stable abundance variations measured from 1995 to 1998 (Moreno et al. 2003). However, since no observation was reported since 2003, we have planned a new observation of impact remnant gases to obtain their abundance and derive their decay time in 2012. We observed CS(J=2-1), CO(J=1-0) and HCN(J=1-0) rotational lines in millimeter waveband using Nobeyama 45-m telescope of NAOJ. Our observation found that CS abundance has decreased significantly, placing its upper limit as one tenth of the abundance measured in 1995. The finding may allude to a hypothetical scenario that the CS destruction process has already begun and its destruction mechanism may be due to photochemical evolution.

CS Destruction Processes and Our New Observation Plans

It is suggested that only a few processes can remove CS permanently (Moses et al., 1996). Furthermore, photo-dissociation process is important as well because the lifetime of CS against photolysis is very short at 1AU (Canaves et al., 2001) and as to be taken into account. We have tested the recycling process of photolysis with simple one-box model. The modeled time variation of the CS abundance, assuming the lifetime of CS only, as against photolysis has shown clear discrepancy with the observed result. Thus, dissociated S atom is suggested to be recycled.

We are planning new observation to obtain CS abundance with more sensitive observation in sub-millimeter waveband. Next, survey observation of S-bearing species which are candidates of daughter species of CS. In this presentation, detail of our observation and a model of chemical processes will be presented.

Moreno, R, A. Marten, H.E Matthews, and Y Biraud. 2003. Planetary and Space Science, 51, 591?611
Lellouch, E, R Moreno, and G Paubert. 2005. A&A, 40, 37?40.
Marten, A, H E Matthews, T Owen, R Moreno, T Hidayat, and Y Biraud. 2005. 1097?1105.
Moses, J. I. 1996. The Collision of Comet Shoemaker-Levy 9 and Jupiter: IAU Colloquium 156, 243 ? 268
Moses, J. I, A, Allen. 1995. GRL, 22, 1597-1600
Canaves, M. V., A. A. de Almeida, D.C. Boice, G. C. Sanzovo. 2007. Adv. In Space Res. 39, 451-457

Keywords: Jupiter, comet, radio astronomy

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-09 Room:304 Time:May 20 11:30-11:45

Hugoniot curve for forsterite under extreme conditions: O2 supply into the surface environment on the early Earth

Kosuke Kurosawa[1*], Toshihiko Kadono[2], Yoichiro Hironaka[3], Keisuke Shigemori[3], Hideharu Kuwahara[4], Tatsuhiro Sakaiya[5], Takayoshi Sano[3], Sohsuke Ohno[6], Toshimori Sekine[7], Norimasa Ozaki[8], Ryosuke Kodama[8], Shogo Tachibana[9], Takafumi Matsui[6], Seiji Sugita[4]

[1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, [2]School of Medicine, University of Occupational and Environmental Health, [3]Institute of Laser Engineering, Osaka University, [4]Department of Complexity Science and Engineering, The University of Tokyo, [5]Department of Earth and Space Science, Osaka University, [6]Planetary Exploration Research Center, Chiba Institute of Technology, [7]Department of Earth and Planetary Systems Science, Hiroshima University, [8]Division of Electrical, Electronic and Information Engineering, Osaka University, [9]Earth and Planetary System Science Department of Natural History Sciences, Hokkaido University

Recent dynamical model for impact flux to the Earth-Moon system based upon the chemical analyses of lunar samples and crater chronology suggests that impactors during the late heavy bombardment period are highly dynamically excited and their impact velocities to the Earth reach ~30 km/s. The amount of silicate vapor and its chemical composition, which are important factors to investigate the geological consequence after such hypervelocity impacts, have not been understood. This is because reliable Hugoniot curve for silicate materials higher than 200 GPa is not established due to technical difficulities, resulting in large uncertainty in the thermodyanamic path of isentropic release from shocked state. Although there is an EOS model, M-ANEOS, for silicate materials which is widely used for hydrocode calculations [e.g., Canup, 2012, Cuk & Stewart, 2012], the entropy gain for silica predicted by M-ANEOS is considerably smaller than that investigated by experiments. In this study, We carried out laser shock experiments at GEKKO XII-HIPER facility of Institute of Laser Engineering of Osaka University to obtain the Hugoniot curve for actual silicate material, forsterite, up to 1200 GPa on an entropy-pressure (S-P) plane. Shock temperatures and pressures during the propagation of laser-induced shock waves were measured simultaneously. Shock-induced entropy gain can be calculated using the obtained peak shock temperatures and pressures and thermodynamic relations. We found that the entropy gain for forsterite is much larger than the M-ANEOS prediction as well as silica. The amount of forsterite vapor after isentropic release can be calculated using the lever rule when the shock-heated forsterite is under thermal equilibrium during expansion. The amount of forsterite vapor is ~2 times than the M-ANEOS prediction. The redox state in impact-induced vapor clouds strongly depends on the degree of vaporization of silicates because the molar fraction of oxygen in silicate materials is higher than 0.5. Then, we conducted thermochemical calculation along with the isoentrope at ~30 km/s to calculate the molecular composition of released gas into the atmosphere after a meteoritic impact with CI-like chemical composition. We found that a large amount of molecular oxygen, which is not considered to be existed on prebiotic Earth, is likely to be released into the atmosphere. Hypervelocity impacts during the late heavy bombardment period might supply a large amount of oxygen into the surface environment. Such impact-induced oxygen might play important roles in a chemical evolution phase on the early Earth because oxidation reaction by molecular oxygen produced a large amount of free energy.

Keywords: Meteoritic impacts, Forsterite, Late heavy bombardment, Laser shock compression, Hugoniot curve, Surface environment on the early Earth

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-10 Room:304 Time:May 20 11:45-12:00

Revised fragmentation model of planet-sized collisions

Tomoaki Fujita[1*], Hidenori Genda[1], Hiroshi Kobayashi[2], Hidekazu Tanaka[3], Yutaka Abe[1]

[1]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, [2]Department of Physics, Nagoya University, [3]Institute of Low Temperature Science, Hokkaido University

In the process of planet formation, collisions between planetesimals or a planetesimal and a protoplanet occur frequently and let them grow up. Recent studies (e.g., Kobayashi and Tanaka 2009) suggest that the upper limit on the mass of planets varies by the amount or size of fragments scattered by such collisions. Therefore, in order to develop the more accurate theory of planet formation, it is important to investigate how destructive each collision is under various conditions. The critical impact energy for catastrophic disruption $Q_{D}*$, where the largest remnant has half the target mass, has been well investigated under various conditions (e.g., Benz and Asphaug 1999), and only this value has been regarded as important for the planet formation to date. However, there are some doubtful points in the accuracy of this value because of the low-resolution simulations and unclearness of the analytical method. Moreover, according to Kobayashi and Tanaka 2009, the collisions with less than critical impact energy are also important for planet formation. Although they presumed that the total mass of fragments is linear with the impact energy, its dependence on impact energy has not been examined.

We systematically performed the hydrodynamic simulations of collisions with various impact energies in SPH method, and reexamined $Q_{D}*$ and investigated a relation between total mass of ejected material and impact energy. In our simulations, bodies with different size collide against 100km- and 10km-diameter bodies at different speed, and the amount of the total mass of ejected material can be calculated. In addition, we checked the dependence on the resolution and performed simulations in high enough resolution, and analyzed with the original analytical method, that can be recognized objectively.

We found that the $Q_{D}*$ value we derived is about one order of magnitude smaller than that of the previous work (Benz and Asphaug 1999). This means collisions between planetesimals or a planetesimal and a protoplanet are more destructive than before.

In the case of collisions with impact energy less than $Q_{D}*$, contrary to the expectation of Kobayashi and Tanaka 2009, the total mass of fragments is not linear with the impact energy due to the curvature of the target. On the other hand, in the case of collisions with very low impact energy, the effect of the curvature is so slight that the total mass of fragments is linear with the impact energy. Considering these two facts, the fragmentation model can be built on such a small scale.

Moreover, since we improved the existing SPH code, it became possible to evaluate the collisions where the not gravity but material strength is dominant; the size of target is less than 1km-diameter. Then, we are going to show this result.

Keywords: planet formation, fragmentation, planetesimals

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-11 Room:304 Time:May 20 12:00-12:15

Analysis of shocked quartz grains inside the Chicxulub crater and constraints on ejecta deposition processes.

Yu Chang[1*], Kazuhisa Goto[2], Yasuhito Sekine[3], Eiichi Tajika[3]

[1]Earth and Planetary Sci., Univ. of Tokyo, [2]Tohoku Univ. IRIDeS, [3]Complexity Sci. & Eng., Univ. of Tokyo

Impact cratering is a ubiquitous process which occurs on terrestrial planets and small bodies in the solar system. Geological and geochemical studies of impact craters on Earth provide essential and unique information, such as a three-dimensional structure and lithological characteristics of craters, for understanding impact cratering process. The Chicxulub crater, located in the Yucatan Peninsula in Mexico, is 180-200 km in diameter, which is one of the largest impact structures found on Earth. This impact event is considered to have caused a mass extinction at the Cretaceous-Paleogene (K-Pg) boundary at 66 Ma. Thus, knowledge on the cratering process associated with the Chicxulub impact event will be important both for understanding the cratering process of a large-scale impact and its environmental consequences. However, the detailed formation processes of the Chicxulub crater have been still unknown.

In this study, we analyzed both the size distribution of and planar deformation features (PDFs) on shocked quartz grains contained in the Yaxcopoil-1 (YAX-1) drilling core samples derived from the Chicxulub crater. PDFs are planar micro structures generated under high-pressure conditions (~10-35 GPa). The crystallographic orientation of PDFs is known to preserve information of shock pressure achieved by impacts. We found 525 shocked quartz grains from top to bottom of impactite sequences in the YAX-1 core. In the present study, 574 sets of PDFs were measured from fifteen vertical levels in the impactite sequences.

We found that shocked quartz grains in the impact melt layer (Unit 5) of the YAX-1 core were predominantly undergone high shock pressures (>25 GPa). Whereas, shocked quartz found in other impactite sequences (i.e., Units 6 and 4-1, in ascending stratigraphic order) are mixtures of quartz grains experienced various shock pressures. These results suggest that Unit 5 is likely to have been formed by an outward flow of impact melt-sheet from the transient crater cavity during the central uplift and collapse of the transient crater. In Unit 1, i.e., the uppermost impactite units, we found an opposite correlation between shocked quartz grains undergone high peak shock pressures (>25 GPa) and those undergone medium degree of shock pressures (12-25 GPa) associated with upward grain fining in the sequences. These results strongly support the idea that Unit 1 was repeated impact-induced tsunami deposits. Given both our results of impact melt-sheet origin of Unit 5 and the results of hydrodynamic simulation of the Chicxulub crater, Unit 6, underlying Unit 5, could be interpreted as ejecta curtain deposits. Our results of ejecta curtain deposits of Unit 6 provide the geological evidence that the position of YAX-1 core is located outside the transient crater cavity, which support the hydrodynamic simulations and seismic data of the Chicxulub crater.

Keywords: impact cratering, Chicxulub crater, shocked quartz, Planar deformation features (PDFs)

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-12 Room:304 Time:May 20 12:15-12:30

Impact crater formation on the snow-ice layered structure

Masahiko Arakawa[1*], Mika Saita[1], Minami Yasui[2]

[1]Graduate School of Science, Kobe Univeristy, [2]Organization of Advanced Science and Technology, Kobe University

Impact craters are found on every solid bodies in the solar system, and they are formed by high speed impacts of small bodies. The study on the crater scaling law has been conducted to estimate the formation condition of these craters, so the cratering experiments have been made for the various materials to refine the scaling law. The icy bodies which exist usually in the outer solar system have a wide variety of the size and the density, and the icy bodies with the middle and the large sizes could be covered with the snow regolith on the icy crust. In this two layer structure, the crater size and the formation condition of the crater on the icy crust could be affected by the regolith layer. However, there are no cratering experiments on two layer structure made of snow and ice although most of the experiments were made for the homogeneous rock and ice or the basalt block covered with rocky regolith. In this study, we tried to clarify the effect of the snow regolith layer on the crater formed on the ice layer. Moreover, the particle velocity of snow layer should be determined to estimate the crater size formed on the ice block. Then, the snow plate simulating the regolith layer was used to measure the particle velocity and it was used to refine the scaling law applicable to the layered structure on the icy bodies.

Impact experiments were made by using a vertical gas gun set in a cold room at -10 degree. The cylindrical projectile was launched at 300 and 450m/s and made of ice and polycarbonate. The mass of ice and polycarbonate is 1.60g and 1.68g, respectively. The ice target was a rectangular ice block with the mass of 8kg. The ice block was covered with a snow layer which was made of ice particles with the size less than 710 microns and the snow thickness was from 5 to 30mm. After the impact, the crater formed on the ice block was measured to describe the diameter, the volume and the depth. In the case of the measurements of particle velocity for snow plates, the snow plate thickness was changed from 10 to 40mm and they were impacted by an ice and a polycarbonate projectile. A high speed digital video camera was used to record the ejection of the snow particles with the frame rate of 2x10ˆ4 to 5x10ˆ3.

We found that the antipodal velocity of the snow plate decreased with the increase of the plate thickness at the constant impact velocity. Moreover, the decay rate of the particle velocity for ice projectile was found to be larger than that for polycarbonate projectile. The ice projectile was completely disrupted at the moment of impact but the polycarbonate projectile was observed to be intact through the snow plate, so that it was recovered without disruption. The relationship between the antipodal velocity of v_e and the plate thickness (t) was obtained to be v_e=a t/d^{-b}, where d is the thickness of the projectile 10mm.

In the case of the cratering experiments, we compared the crater size formed on the ice block for ice projectile with that for polycarbonate projectile and noticed that the crater formed by ice projectile was always smaller than that formed by the polycarbonate projectile at the constant impact velocity. The crater size decreases with the increase of the thickness of the snow plate for each projectile and each relationship was empirically determined. This relationship was theoretically related to the particle velocity of snow plate at the boundary between snow plate and ice block. This theory was proposed in Dohi et al. (2012), in which the crater scaling law was extended to the two layer target. We applied their modified scaling parameter Pi$*$ to our results and obtained the following relationship between the crater volume and the Pi$_{*Y}$, Pi$_v$=2.05x10^{-9}Pi$_{Y}*^{-2.6}$.

Dohi, K., Arakawa, M., Okamoto, C., Hasegawa, S. and Yasui, M. (2012) The effect of a thin weak layer covering a basalt block on the impact cratering process, Icarus, 218, 751-759.

Keywords: regolith, icy bodies, crater, layered structure, scaling law, shock wave

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-13 Room:304 Time:May 20 14:15-14:30

PERC CubeSat project: Meteor-observing satellite S-CUBE (S3)

Ryo Ishimaru[1*], SAKAMOTO, Yuji[2], KOBAYASHI, Masanori[1], NAMIKI, Noriyuki[1], SENSHU, Hiroki[1], WADA, Koji[1], OHNO, Sohsuke[1], ISHIBASHI, Ko[1], YAMADA, Manabu[1], ARAI, Tomoko[1], MATSUI, Takafumi[1], HOSOKAWA, Shigeru[1], TANABE, Yuta[2], YAGISAWA, Hitoshi[2], ABE, Shinsuke[3], KUROSAWA, Kosuke[4], NAKASUKA, Shinichi[5], YOSHIDA, Kazuya[2], AKIYAMA, Hiroaki[6], SATO, Mitsuteru[7], TAKAHASHI, Yukihiro[7]

[1]Planetary Exploration Research Center, Chiba Institute of Technology, [2]Tohoku University, [3]Institute of Astronomy, National Central University, [4]JAXA, [5]The University of Tokyo, [6]Wakayama University, [7]Hokkaido University

Introduction: A CubeSat is a type of miniaturized satellite for space research. The standard 10∗10∗10 cm cubic satellite is often called a 1U CubeSat meaning one unit, and has a mass of 1 kilogram. CubeSat has been a familiar tool for engineers to test new technologies in space and often used for Earth remote-sensing, too. On the other hand, use of CubeSat for astronomical and planetary sciences has been rare because of severe constraints on payload. We propose in this work to use a CubeSat for the first time in planetary sciences, specifically to observe meteors entering into Earth's atmosphere. A development of a science-oriented CubeSat brings about many difficulties, but our challenge can possibly open a new field of observational research in astronomy and planetary sciences. An advantage to use a CubeSat in comparison with previous missions led by national space agency is that a CubeSat project can be carried out within a limit of cost, technology, and organization available in academy. This allows a development of a satellite in a few years.

Our new project is called "Shooting star Sensing Satellite (S3: S-CUBE) Project." The S-CUBE Project was a project started by a partnership between Planetary Exploration Research Center of Chiba Institute of Technology (PERC/Chitech) and Tohoku University to develop a 3U CubeSat (30∗10∗10 cm; 4 kg) based on the design of RAIKO that was developed and launched by Tohoku University in October, 2012. The S-CUBE is equipped with optical sensors, such as a camera and photomultipliers, to observe luminous emission of meteors from a low-Earth orbit. The launch date is planned in the 2014. For command uplink and data downlink, an UHF antenna and an S-band antenna at Chitech are used.

Scientific Objectives: Meteors are luminous phenomena induced by hypervelocity entry of meteoroids into the Earth's atmosphere. Because most meteoroids are thought to be originated from comets and asteroids, the meteor give us valuable opportunities of an indirect exploration of the primordial objects in the solar system.

Although meteors have been observed mainly from the ground so far, the ground-based observations have weak points: narrow observational range and weather dependent. In contrast to the ground-based observations, a space-based observation by an earth-orbiting satellite enables a continuous global observation of meteors. Further, a space-based observation can detect ultraviolet emission from meteors because it is not hindered by ozone layer.

The S-CUBE is designed to be equipped with one camera and 2 (or possibly 4) photo multiplier. The camera points nadir direction to take images of meteors during flight over the night side of the Earth. We can estimate the meteoroid size from brightness of meteors. The photo-multipliers are attached with UV band-pass filters so as to extract UV light of meteors from lights from the Earth. Detection of UV light of meteors is used as a trigger of the camera. It is also suggested that UV light of meteors includes emissions of some light elements, such as sulfur, which have not been observed by previous ground-based observations.

Keywords: Meteor, CubeSat, Optical observation, UV observation

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-14 Room:304 Time:May 20 14:30-14:45

3D FDTD simulation of Rosetta/CONSERT radar tomography observation

Takao Kobayashi[1*]

[1]Korea Institute of Geoscience and Mineral Resources

Rosetta is a comet exploration project of ESA which aims to approach Comet 67P/Churyumov-Gerasimenko in 2014. It carries various onboard missions, one of which is a radar tomography mission called Comet Nucleus Sounding Experiment by Radiowave Transmission (CONSERT). CONSERT consists of two radar systems on the Rosetta platform and on the Philae lander, and is to perform bi-static radar sounding observations by using CONSERT transmits radar pulses of which the center frequency is 90 MHz.

We built a 3D simulation code based on Finite Difference Time Domain (FD-TD) algorithm. It simulates CONSERT observation in which the Philae lander transmits radar pulses and the Rosetta platform received them. The Philae radar transmitter is approximated by a point current source whose pulse shape is a differentiated Gaussian. Received echo at the Rosetta platform was approximated by the electric field at the receiving point, which was calculated by based on Near-to-Far-Field conversion algorithm. The comet nucleus model is represented by spatial distribution of dielectric constant in the simulation space.

The simulation results are utilized in developing the tomography imaging algorithm.

Keywords: Rosetta, CONSERT, radar, tomography, FDTD, simulation

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-15 Room:304 Time:May 20 14:45-15:00

Investigation for the precise measurement method of lunar and planetary heat flow and development of heat flow probe

Yamato Horikawa[1*], Satoshi Tanaka[2], Naoya Sakatani[3], Jun Takita[1], Kazunori Ogawa[2]

[1]The University of Tokyo, [2]Japan Aerospace Exploration Agency, [3]The Graduate University for Advanced Studies

The precise measurement of lunar and planetary heat flow is an essential method for constraining their internal temperature distribution, thermal history, and material composition. Besides the Earth, the in-situ measurements were only conducted in the Apollo 15 and 17 missions on the Moon. About 20 years later from the Apollo missions, a high speed penetration probe (so-called penetrator), developed at Institute of Space and Astronautical Science in Japan, has an advantage that the heat flow measurements can be conducted at many sites at once mission. However, because the heat flow measurement devices on board a penetration probe including the probe of Apollo mission and penetrator are exposed on the regolith, they are easily influenced on the thermal distribution of the regolith varying from the heat conduction of the penetration probe. Therefore the heat flow measurement devices have the uncertainty for determining the planetary intrinsic heat flow value.

In this study, we investigate the thin heat flow probes which can be extended from surface of the penetration probe to a point indicating more intrinsic heat flow value of the planet (requirement of accuracy: better than 10%). On this presentation, we report the result of comparison investigation with the accuracy of heat flow from the measurement principle of thermal conductivity and thermal gradient and the numerical simulation based on the model of penetrator, and the accuracy of heat flow measured by the developed heat flow probe.

From the measurement principle and the numerical simulation, in case of the heat flow probe which has several sensor points, the two of their sensor points are tip of the probe which is the most accurate position of thermal gradient, and center of the probe which is the most accurate position of thermal conductivity. The accuracy of heat flow at these points is found to be 2.4% on the lunar regolith, and 1.9% on the martin regolith. In addition, we constrained the variety, length, and diameter of the probe material as considering the accuracy of heat flow and the strength of heat flow probe extending to regolith.

From restriction of development of heat flow probe, we made the heat flow probe of multiple sensor point, and conducted the experiment of heat flow measurement of glass beads at atmosphere pressure and vacuum. As a result, at atmosphere pressure, when the sensor point is from center to 3cm from center of the probe, we can accomplish the requirement accuracy of thermal conductivity (about 5%). When the sensor point is center of the probe, the best accuracy of thermal conductivity was determined to about 1.8%. On the other hand, at vacuum, comparing with the thermal conductivity by the heat flow probe and by line heat source method, the relative error of about 35-84% occurred when the sensor point is from 1cm to 3cm from center of the probe. Therefore the accuracy of thermal conductivity from the experiment of the heat flow probe was found not to be consisted with that from the measurement principle of thermal conductivity at vacuum.

To distinguish whether these error were caused by the glass beads or the heat flow probe, we measured rise profile in temperature of air which is more uniform distribution of thermal conductivity than that of grass beads. In the result, we found that the error at 1,2cm from center of the probe was caused by the probe, and the error at 3cm from center of the probe was caused by the glass beads. As future work, this error cause is required to discuss quantitatively to determine the measurement accuracy of heat flow probe at vacuum.

Keywords: heat flow, moon, planet, regolith

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-16 Room:304 Time:May 20 15:00-15:15

Effect of compressional stress on thermal conductivity of powdered materials under vacuum

Naoya Sakatani[1*], Kazunori Ogawa[1], Yu-ichi Iijima[1], Shoko Tsuda[1], Rie Honda[2], Satoshi Tanaka[1]

[1]Institute of Space and Astronautical Science, [2]Kochi University

Lunar and asteroid surface is covered with powdered materials and planetesimals in the early solar system are considered to have consisted of powdered materials. Thermal conductivity of powdered materials is one of the essential parameters in order to examine thermal state or thermal evolution of these bodies. Especially under vacuum conditions, the thermal conductivity of powdered materials is known to be extremely low (order of 0.001 W/mK). Therefore, existence of such powders significantly affects the above problems. For example, to measure crustal heat flow on the moon, it is necessary to insert a heat flow probe. However, compaction of the regolith due to the inserting can change the thermal conductivity of the regolith from original one, which enlarges the error of the estimated heat flow (Grot et al., 2010). It is important to expect the degree of the compaction and correct the thermal conductivity values. In addition, Ogawa (2013) calculated thermal evolution of planetesimals composed of powdered materials. She showed that planetesimals as small as 10 km possibly experience melting or differentiation.

However, it is difficult to estimate the thermal conductivity value of the powder materials, because under vacuum it depends on various parameters such as particle size, density, and compressional stress. We have investigated the parameter dependence of the thermal conductivity of powder samples. In this presentation, we report the effect of compressional stress. It is one of the essential parameters in order to correct the heat flow values and to estimate the difference of the conductivity by planetesimals size (gravity) and the variation in the direction of the depth.

For the measurements of the stress dependence, we designed and fabricated a new experimental apparatus. The stress range we require is up to relatively low stress about a few tens kPa. To achieve this, we adopted a technique, in which six weights with known mass superimpose the powder sample by turns for controlling the compressional stress. Each weight suspended with strings at interval of 2 cm and they were moved up and down by an ultrasonic motor. Total mass of the weights was 7.5 kg, which corresponds to the maximum stress of about 18 kPa. Under such system, there was a sample container having two stress transducers with relatively low capacitance and a thermal conductivity measurement system by the line-heat source method. The sample was spherical glass beads of 0.1 mm diameter. Above apparatus was evacuated in the vacuum chamber and the thermal conductivity was measured without and with the weights.

As a result, the thermal conductivity was ranged from 0.003 to 0.008 W/mK and definitive trend that the conductivity increases with the compressional stress. This trend is considered to be due to increasing thermal conductance through elastically deformed and enlarged contact area between the particles.

The effective thermal conductivity under vacuum condition is defined as a sum of contributions of thermal conduction through the solid particles (so-called solid conductivity) and thermal radiation between particle surfaces (radiative conductivity). Because the observed trend is due to the variation of the solid conductivity, we subtracted the radiative conductivity for the same sample, which was determined by another experiment (Sakatani et al., 2013), from the measured conductivity and deduced the solid conductivity as a function of the stress. By fitting of these data by an appropriate function, we found that the solid conductivity depends on the stress with an exponent of 0.32 to 0.40. This value is compared with Hertzian theory that states the contact radius between spherical particles is proportional to the confined pressure with 1/3 exponent. This consistency strongly supports that the observed stress dependence is caused by the elastic deformation of the particles and that the solid conductivity is proportional to the contact radius.

Keywords: thermal conductivity, powdered materials, compressional stress, vacuum

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-17 Room:304 Time:May 20 15:15-15:30

Formation and thermal evolution of Ceres infered from hydrothermal experiments and mineralogical analyses

Megumi MORI[1*], Yasuhito Sekine[2], KUWATANI, Tatsu[2], SHIBUYA, Takazo[3], SIZUKI, Katsuhiko[4], MASAKI, Yuka[4]

[1]Dept. Earth & Planet. Sci., Univ. Tokyo, [2]Dept. Complexity Sci. & Engr., Univ. Tokyo, [3]Precambrian Ecosys. Lab., JAMSTEC, [4]IFREE, JAMSTEC

The dwarf planet Ceres is the largest body in the asteroid belt and is frequently referred as one of the few protoplanets remaining in the inner solar system. Ceres' low density and spherical shape indicate that its interior is highly likely differentiated into a rocky core and water-rich ice mantle. Theoretical models of thermal evolution suggest that Ceres possibly underwent significant melting to explain the interior structure. These results further suggest that primitive minerals, such as olivine, would have been hydrothermally altered inside Ceres. The compositions of such secondary minerals may vary according to not only temperature but also the composition of aqueous solution, such as CO_2 abundances. Accordingly, the mineral assemblages on Ceres' surface would provide clues for understanding the timing of formation and chemical compositions of planetesimals that formed Ceres. Recent observations of Ceres suggested the possible presence of brucite, magnesium carbonates, Fe-rich serpentine, and magnetite on the surface. However, it remains unclear the temperature conditions and aqueous compositions that can account for the formation of these minerals.

In this study, we conduct hydrothermal experiments simulating chemical reactions that would have occurred in the interior of Ceres. In particular, we aim at investigating the effects of temperature and the amount of initial CO_2 on mineralogical and chemical compositions of secondary minerals formed from olivine. The experiments were conducted at temperatures of 200, 300, and 400^oC and a pressure of 400 bar. We used powdered San Carlos olivine (Mg/(Mg/Fe)=0.9) as starting materials. Aqueous solution of 0.02% or 0.6% of $NaHCO_3$ (as a source of CO_2) and 1% of NH_3 was also used in the experiments. After the experiments, we collected rock residues and analyzed their mineralogical and chemical compositions using a XRD and SEM-EPMA, respectively.

Our experimental results suggest that temperature dependency of oxidation of Fe(II) to magnetite strongly affects the mineralogical and chemical compositions of secondary minerals. Magnetite formation proceeds efficiently at 300^oC, which diminishes partitioning of Fe(II) into secondary minerals resulting in low Fe/Mg ratios in serpentine. At 200^oC, serpentines with relatively high Fe/Mg ratios and a very small number of magnetite were found in rock residues. These results suggest that oxidation of Fe does not proceed efficiently at 200^oC, leading to partitioning of Fe(II) into secondary minerals during serpentinization. Brucite was found in rock residues formed only at 300^oC. There are few brucite in rock residues formed at 200^oC. Because olivine is thermodynamically stable, any alteration minerals were not formed at 400^oC.

Initial amount of CO_2 also affects the compositions of secondary minerals via carbonate formation. Brucite tends to be abundant under a low CO_2 condition in rock residues, whereas few brucite are formed under a high CO_2 condition. Serpentines with relatively high Fe/Mg ratios were produced under a high CO_2 condition. These results suggest that efficient carbonate formation under a high CO_2 condition prevents from formation of brucite and results in formation of serpentines with relatively high Fe/Mg ratios.

In our experiments, we cannot find a single condition, under which the secondary mineral assemblages found on Ceres' surface are reproduced. Especially, we found that brucite tends to be formed more efficiently under lower CO_2 conditions. In contrast, formation of Fe-rich serpentine prefers lower temperature (~200^oC) and higher CO_2 conditions. These results suggest that Ceres' surface would be compositionally heterogeneous owing to geological activities, such as impact cratering. Our experimental results suggest that formation of brucite requires moderate temperatures, such as 300^oC. To achieve such temperatures, Ceres is required to have been formed at ~200-300 My after the formation of CAIs.

Keywords: hydrothermal reactions, Ceres, early solar system, mineralogical analysis

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-18 Room:304 Time:May 20 15:30-15:45

Experimental study of ice lens formation and application for planetary surface environment

Tomotaka Saruya[1*], REMPEL, Alan W.[2], Kei Kurita[1]

[1]Earthquake Research Institute, University of Tokyo, [2]University of Oregon

Ice lenses are formed by the migration and freezing of water in partially frozen state during soil freezing. Nucleation and growth of ice lenses cause the upwards displacement of ground surface and formation of periglacial landforms. Beyond the terrestrial environment, similar processes are believed to occur in planetary environment. For example, periglacial landforms or high-purity ice are observed at the Phoenix landing site on Mars. Formation of ice lenses is complicated phenomena including heat and mass transport. Several theoretical models address its physical processes in terrestrial environment, however, many questions still remain for the formation of ice lenses. Especially, experimental constraints are not enough. We performed systematic cooling experiment using granular materials to observe the behavior of ice lenses. Our experimental results demonstrate the relationships between the behavior of ice lenses and particle size, temperature conditions and force balance. We also compared our experimental results to numerical model of ice lens formation that focuses on the force balance of thermomolecular force and hydrodynamic force. As a results of comparison, qualitative consistency is obtained, however, important quantitative differences existed. We developed initial numerical model using kinetic effect around particle surface and obtained good agreement.

Application experiments that simulate planetary surface environments are also performed (e.g., low pressure environment, carbonated water etc.) and we observed different behaviors as compared with basic experiments.

In this presentation, we report the comparison between the experimental results and theoretical model and application experiment under simulated planetary environment.

Keywords: ice lens

PPS21-19 Room:304 Time:May 20 16:15-16:30

Large scale transportation of materials and hcemical evolution in protoplanetary disc

Hiroko Nagahara[1]*

[1]Hiroko Nagahara

Introduction: Large scale material transport in protoplanetary disks has been proved by finding of the high temperature components in comet Wild 2, and it has been supported by physical consideration (e.g., Ciesla, 2009). Meteorites show a wide range of variation of oxygen isotopic compositions, which have been thought to be inherited from the precursor molecular cloud. However, recent high precision by ion microprobes has revealed that the variations are a mixture of isotopic mixing and mass-dependent isotopoic fractionation [e.g., Tenner et al., 2012].

Model: In order to understand material transport and oxygen isotopic characteristics recorded in meteorites in a protoplanetary disk, we have developed a model that describes mixing of two components, one transporting outward from the inner edge and one transporting inward by accretion of a protoplanetary disk with different oxygen isotopic compositions. We assume that the proto-sun had 16O-rich composition as suggested by the solar wind component captured by the Genesis mission, which is represented by refracotry inclusions and forsterite grains in primitive chondrites. The planetary composition is represented by the Earth with slight deviation as Mars and asteroids. The materials from outer region were assumed to have oxygen isotopically heavy composition, which we tentatively assume to be that observed in tmagnetite in a unique carbonaceous chondrite.

The model investigates isotopic trajectory of solid materials condensed at high temperature region with proto-Sun composition, which changed the composition by isotopic exchange in gas with heavy oxygen isotope composition. The solid materials cools exponentially with time. The system has the composition of the solar abundance elemental rations except for H2O as a source of heavy oxygen isotope in gas; isotopic exchange is temperature dependent; material transport flux is a steady state. The model contains two free parameters; one is cooling rate and the other is isotopic mixing rate.

Results and Discussions: The solids become isotopically heavier with time due to isotopic exchange, and the time of the increase is shorter and the final composition becomes heavier when the mixing rate is large. The time of the increase of the heavy isotope becomes later and the final composition becomes isotopically lighter with decreasing mixing rate. Considering that the planetary composition of oxygen isotopes is delta18O=zero by definition, the most plausible mixing rate is obtained. We have confirmed that the mixing lines on the three oxy-gen isotopic plot are straight for both solids and gas, which means that the solid changed its composition from -50 to 0 permil and that the gas from +200 to 0 permil.

A plausible range of the mixing rate was obtained for a range of cooling rates. The mixing ratio of solids with light oxygen and gas with heavy oxygen and cooling rate are linearly related in logarithmic plots. In other words, more abundant low temperature component with heavy oxygen is required if the solid materials cool rapidly. The model results are converted to the real scale for forsterite grains condensing in light oxygen gas, which moves outward, cools, and exchanges oxygen isotopes with ambient gas with heavy composition. Cooling rate of the model corresponds to advection or diffusion rate at the midplane and the mixing rate corresponds to the ratio of inward flux of isotopically heavy water ice to outward flux of high temperature condensates with light oxygen isotopes. Larger values of cooling rate and mixing rate may be realized at the early stage of disk evolution.

In summary, planetary oxygen isotopes were achieved through the evolution of the disk due to larger inward and outward transportation of materials and ice at the early stage and smaller transportation at the later stage.

Keywords: protoplanetary disc, solid materials, transportation, oxygen isotope

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-20 Room:304 Time:May 20 16:30-16:45

Disk lifetime of protoplanetary disks surrounding intermediate-mass stars in the inner Galaxy

Chikako Yasui[1*], Naoto Kobayashi[1], Masao Saito[2], Alan T. Tokunaga[3]

[1]University of Tokyo, [2]National Observatory of Japan, [3]University of Hawaii

Disk lifetime is one of the most important parameters which can control planet formation. The disk lifetime has been estimated by various studies to be ˜5–10Myr. However, this value is applicable only to studies for the solar metallicity. For a thorough understanding of planet formation, the disk lifetime should be determined in other (metallicity) environments. This may impose a strong constraint on the disk evolution mechanisms and the planet formation processes.

We previously derived disk fraction in the outer Galaxy (˜15 kpc from the center of the Galaxy), which is known to be the low-metallicity environments (˜1/10 solar metallicity), and found that disk lifetime is much shorter (˜1Myr) than that of the solar metallicity. For the next step, we derived the disk fraction of intermediate-mass stars in the inner Galaxy (˜4kpc from the center of the Galaxy), which is a high-metallicity environment (˜3x solar metallitity), and found a relatively high disk fraction for a cluster with the age of ˜20Myr. This cluster is older than the disk lifetime in solar metallicity clusters, and this suggests that the disk lifetime is much longer in higher metallicity environments. In this talk, I am going to discuss metallicity dependence of disk lifetime in a wide metallicity range from 0.1 to 3 times solar metallicity

Keywords: protoplanetary disk, metallicity, planet formation

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-21 Room:304 Time:May 20 16:45-17:00

Concentration of dust aggregates at the snow line

Sin-iti Sirono[1*]

[1]Nagoya University

Planetesimal formation process is still an important, unresolved problem in planetary formation. There are two major problem in the planetesimal formation. One is the large impact velocity induced by radial drift of dust aggregate. This might lead to fragmentation of aggregates. The other is decrease of solid mass due to the radial drift. Here I propose a new scenario of planetesimal formation, focusing the sublimation of H2O ice from infalling dust aggregates.

The temperature of a dust aggregate increases as it infalls. The temperature increase causes the sublimation of H2O ice from an icy dust aggregate. The sublimation of the H2O ice produces a bump of gas pressure distribution. Around the bump, the pressure gradient changes its sign, and the infalling of a dust aggregate stops. Then the number density of the aggregates increases, and relative impact velocity between aggregates decreases. I show that planetesimals are formed quite quickly due to the concentration of the dust aggregates.

Keywords: grain aggregate, planetesimal, sublimation

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-22 Room:304 Time:May 20 17:00-17:15

Three dimensional shapes and internal structure of chondrules from Allende CV3 chondrite

Ayaka Tsuda[1], Keisuke Nishida[1*], Eiichi Takahashi[1], Taishi Nakamoto[1], Tetsuya Yokoyama[1], Osamu Sasaki[2], Kanou Harumasa[2], Yasuhiro YANAGIDA[3], Satoshi Okumura[3], Michihiko Nakamura[3]

[1]Earth and Planetary Sciences, Graduate School of Science and Technology, Tokyo Institute of Technolo, [2]The Touhoku University Museum, [3]Department of Earth Science, Graduate School of S

Origin of chondrules in meteorite is still controversial issue. Miura and Nakamoto have developed a shock-wave heating model for chondrule formation in a series of papers (Miura et al., 2002, 2005, 2008). According to the model, systematic relation would be expected between 3D shapes and internal structure of chondrules. Using X-ray CT at SPring-8 synchrotron, Tsuchiyama et al. (2003) measured 3D shapes and internal structure of 47 chondrules separated from Allende CV3 meteorite. They found that 4 out of 20 chondrules show prolate-shape (like a rugby-ball) and others show near spherical shapes. The prolate-shape could be explained by high-rotation during the shock wave heating episode, while the shock wave heating model predicts oblate-shape (like a pancake) chondrules without rotation. However, oblate-shaped chondrules were not observed in Tsuchiyama et al's study, most probably due to small number of samples analyzed.

In order to clarify 3D shapes and internal structure of chondrules, we have separated 180 chondrule grains from the Allende meteorite by a freeze-thaw method and hand picking. The internal structure of chondrules was investigated using the X-ray CT apparatus (Scan Xmate-D180RSS270) recently installed at the Museum of Natural History, Tohoku University. The 3D shape of chondrules was examined by an optical device newly developed (Nishida et al. JPGU 2013).

As presented in Fig. 1, the 3D shapes of chondrules show wide distribution consisting of true spheres, prolate-spheres and oblate-spheres. Note that 25 chondrules with nearly spherical shapes were not examined for X-ray CT to save time. About 60% of the measured chondrule grains were omitted in Fig. 1 because of imperfect shapes due to destruction or presence of matrix. Chondrules with porphyritic texture distribute in all shape categories. Chondrules with granular texture (lower melting degree than porphyritic) also show nearly homogeneous distribution. Chondrules with barred olivine texture (quenched from super-heated melt) show a distribution between true sphere and oblate-shape. Implication of the 3D shapes and internal texture of chondrules will be discussed from the shock-wave heating model.

Keywords: Allende, Chondrule, X-ray CT, Three-dimensional shape, Shock-wave heating model

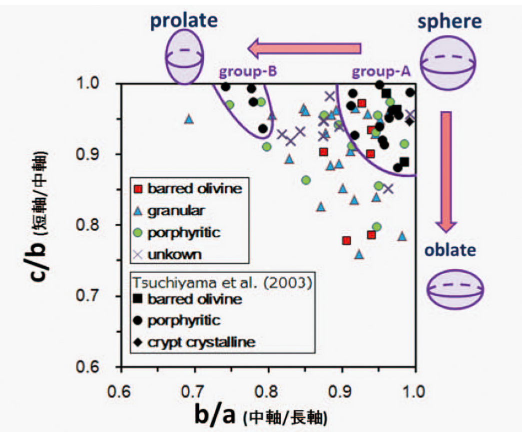

Fig.1 3D shape and internal texture of chondrules in Allende CV3 chondrite

PPS21-23 Room:304 Time:May 20 17:15-17:30

Planetary Migration in Dust-Rich Disks

Kou Yamada[1*], Satoshi Inaba[2]

[1]Graduate School of Political Science, Waseda University, [2]School of International Liberal Studies, Waseda University

There are still serious problems in the theory of planet formation. One of the problems is how to keep protoplanets with Earth-masses in a disk for a sufficiently long time until the disk gas is dispersed. A protoplanet growing in a disk interacts with a gas disk gravitationally and, as a result, changes the radial distance from the central star. This process is called the type I migration of a protoplanet. A variety of structures of extrasolar planetary systems might be a natural outcome resulted from the type I migration. The corotation torque and the Lindblad torque act on a protoplanet, leading to the type I migration of the protoplanet. The migration velocity of the protoplanet is determined by the sum of the torques. Recently, Yamada & Inaba (2012) showed that the magnitude of the torques depends on a thermal structure of a disk. The positive corotation torque acting on a protoplanet in a disk inside of the ice line becomes large enough to cancel the negative Lindblad torque. Protoplanets might accumulate at the location of the ice line of a disk with small viscosity.

Once dust particles grow, they move in a disk interacting with gas. Particles lose angular momentum and migrate inward toward the inner region of a disk. The particle density in the inner region of a disk is increased with time. Birnstiel et al. (2012) studied the evolution of the particle surface density considering the growth and fragmentation of particles and the radial motion of the particles as well. They showed the greatly increased particle-to-gas ratio in an inner region of a disk with small viscosity in 1Myr. We study the effect of particles on the type I migration of a protoplanet. We compare the torques acting on a protoplanet by disks with and without dust particles. Parameters in this model are particle radius (0.1mm to 1cm) and particle-to-gas mass ratio (0.01 to 0.1). We find that the magnitude of the positive corotation torque acting on a protoplanet is dependent on the particle size and increases with an increase in the particle-to-gas mass ratio. A protoplanet may be prone to migrate outward in dust-rich disks.

Keywords: type I migration, density wave, dust, planetary system, corotation torque, gravitational interaction

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-24 Room:304 Time:May 21 09:00-09:15

Detection of magnetic anisotropy of a single grain crystal orientated to investigate the origin of dust alignment.

Chiaki Uyeda[1]*

[1]Graduate School of Science, Osaka University

Distribution of magnetic fields in inter- and circum-stellar regions is commonly estimated from the observation of visible and infrared polarization, which is caused by the magnetic alignment of the dust particles. The origin of alignment in the diffuse interstellar region is explained by a paramagnetic relaxation model assumed for the grains. However in the high-density regions, efficiency of the above mechanism is still unclear since the dust is in thermal equilibrium with the gas molecules. An alternative possibility was proposed on the mechanism, which was based on the balance between the rotational Brownian energy and the magnetic anisotropy energy induced in the dust. Here the magnetic anisotropy are caused by paramagnetic anisotropy and/or by diamagnetic anisotropy.

A new principle to detect magnetic anisotropy of a small crystal is experimentally examined by measuring the anisotropy of paramagnetic apatite crystals having sub-millimeter sizes. The new method is based on a rotational oscillation of magnetically stable axis with respect to field direction. Here the crystal is released in a diffused area using a short microgravity condition. The method is hence free of mass measurement; anisotropy can be measured for a limitlessly small crystal grain, in condition that the oscillation is observable. In a conventional method to detect anisotropy, existence of a sample holder and difficulty of mass measurement had prevented the detection of small samples. A chamber-type drop shaft was newly developed to observe the field-induced oscillation; duration of microgravity was below 0.6s. Volume of drop box was as small as 100 cmˆ3, weight was below 1kg. The compact size of apparatus was realized by introducing a small NdFeB magnetic circuit with dimensions of 2.5 cm x 2.0 cm x 0.6 cm (B<0.6T).

Rotational oscillation was observed for 4 apatite crystals with different sizes, and the anisotropy value was determined in terms of a formula established for the period of harmonic oscillation. The obtained values of anisotropy both agreed fairly well with the published values. It was confirmed from the experiment that the position of the sample stage, located at the center of N and S pole, was effective to spontaneously release the sample by an attractive field gradient force. In previous micro-g experiments, release of sample was often prevented by a Coulomb attractive force between sample and holder deriving from the electric charges. The above-mentioned field-gradient force is effective to reduce the interference of the attractive force.

The mass independent property of the above oscillation was examined in wide range of sample size; namely between 1.0 and 0.1mm in diameter. The present technique of observing anisotropy of a sub-millimeter-sized crystal is a step toward realizing anisotropy measurements of micron-sized grains. Precise anisotropy values of single micron-sized grains can be used to examine the validity of a dust alignment model based on magnetic anisotropy energy induced in the dust particles.

[1] C.Uyeda et al: Jpn. Phys. Soc. Jpn. 79, 064709 (2010).

Keywords: magnetic alignment, rotational oscillation, dust alignment, apatite, diamagnetic anisotropy, micro-gravity

PPS21-25 Room:304 Time:May 21 09:15-09:30

Orbital evolution of eccentric, gas-accreting protoplanets

Akihiro Kikuchi[1*], Arika Higuchi[1], Shigeru Ida[1]

[1]Department of Earth and Planetary Science, Graduate School of Science and Technology, Tokyo Institut

Distant giant exoplanets with nearly circular orbits have recently been detected by direct imaging observations. The formation of these planets is not accounted for by the standard scenario of planet formation. According to this scenario, a protoplanet is first formed by the accretion of planetesimals. Once its mass exceeds a critical mass, runaway accretion of gas starts and it becomes a giant planet. However, at large distances from the central star, the long timescale for the accretion of planetesimals prevents any protoplanet from reaching this stage before the gas in the disk has disappeared. Another scenario has thus been proposed by Nagasawa (2008): it involves a formation of a giant planet close to the star followed by scattering by another giant planet. The planet that has been scattered outward can thus reach large distances, but not on a circular orbit.

We propose a new scenario for the formation of distant and circular giant planets: We first assume that while still in the gas disk phase, a protoplanet is scattered outward by an inner giant planet. We then show that the orbit of the protoplanet can become circular because of a damping of the eccentricity due to its accretion of gas. Since the sum of orbital and collisional energy is conserved, the semimajor axis must decrease while the planet accretes mass.

We provide an analytical solution to the orbital evolution assuming that the gas accretion rate remains constant along the planet's orbit, but can evolve slowly as a function of the planetary mass. We average the energy and angular momentum provided to the planet by gas accretion over each orbit to obtain differential equations for the orbital elements. The time-evolution of the semimajor axis and eccentricity are obtained by integrating of these equations.

We find that even highly eccentric protoplanets (e=0.99) can evolve into nearly circular orbits by gas accretion. When evolving from a protoplanetary mass of 10 Earth masses to a mass of Jupiter, we find that the final eccentricity is always less than 0.05. The inward migration of the protoplanet directly depends on the eccentricity, and it limited to a semi-major axis of about half its initial value. This scenario therefore can explain the orbits and masses of the giant exoplanets discovered by imaging techniques.

Finally, we examine the orbital evolution of a giant planet in a truncated gas disk. We derive a relation between the disk radius and the final semimajor axis of the giant planet. We will discuss the relation in detail and apply it to various disk model.

Keywords: exoplanet, distant jupiters in circular orbits, planetary formation, gas accretion, orbital evolution

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-26 Room:304 Time:May 21 09:30-09:45

Gap formation by a planet in a protoplanetary disk considering the change of disk rotation law

Kazuhiro Kanagawa[1*], Hidekazu Tanaka[2], Takayuki Muto[3], Takayuki Tanigawa[2], Taku Takeuchi[4]

[1]Department of cosmosciences, Gradient School of science, Hokkaido University, [2]Institute of Low Temperature Science, Hokkaido University, [3]Division of Liberal Arts, Kogakuin University, [4]Department of Earth and Planetary Sciences, Tokyo Institute of Technology

In a protoplanetary disk, earth-sized or larger planets interact gravitationally with the disk and, by this interaction, they can reduce the disk surface density around their orbit. This makes gaps in the gaseous disk. For larger planets, their gaps terminate the disk gas flow across orbits of the planets, which is thought to explain the formation of the transition disks with the inner hole. Many transition disks with inner holes or gap structures have been observed.
In the near future, more detail structures of transition disks will be revealed by the direct imaging by the Atacama Large Millimeter/submillimeter Array (ALMA).

However, the formation of gaps and inner hole by planets is still theoretically uncertain process, and there is no quantitative model to explain the relation between the planet mass and the shape and depth of gaps. The goal of our study is the construction of a formation model for the inner hole and gap around a planet, by using one-dimensional viscous accretion disk model with the disk-planet interaction. In previous studies on the gap formation, the change in the disk rotation law due to the gaseous pressure gradient has been neglected. However, owing to a steep surface density gradient in the gap, the deviation from the Keplerian rotation law can be remarkably large. Moreover, the surface density profile in the gap is strongly influenced by the deviation of the disk rotation law.

In this study, we examine the surface density profile of the gap in a self-consistent way, by taking into account the deviation of the disk rotation law due to the steep surface density gradient. Our results are as follows;
(1). The change of rotation law promotes the viscous angular momentum transfer in the gap, and, as a result, the gap becomes shallower than the evaluation by previous studies. This effect is stronger for a deeper gap, and the depth of the gap is significantly reduced.
(2). Owing to the significant change of rotation law for a deep gap, the Rayleigh criterion that is stable condition for the rotation disk can be broken. In this case, the structure would be shift to the marginally stable state for the Rayleigh criterion (Tanigawa & Ikoma 2007). Solving the gap structure including the breaking the Rayleigh criterion, we find that the viscous angular momentum transfer is promoted by the breaking of the Rayleigh criterion, and then, the depth of the gap is further reduced.

In addition to above results, I want to talk about the comparison between the result of numerical fluid simulation and the results of our model.

Keywords: protoplanetary disk, disk-planet interaction, disk evolution, gap formation

PPS21-27 Room:304 Time:May 21 09:45-10:00

Numerical simulations and analytical evaluations of type I migration in disks heated by the stellar irradiation

Naohiko Maeshima[1*], Sei-ichiro WATANABE[1]

[1]Division of Earth and Planetary Sciences, Graduate School of Science, Nagoya University

Planets are formed in protoplanetary disks and migrate radially by gravitational interaction with the disk gas. The type I migration was problematic because planets rapidly fall into the central stars in the isothermal disks. However, recent studies revealed that in the adiabatic disks planets can migrate outward in the region where the entropy gradient is negative (Paardekooper & Mellema 2006; Baruteau & Masset 2008; Paardekooper & Papaloizou 2008). There is a study calculating type I migration in the non-isothermal disks (Lyra et al. 2010), but they does not considered the stellar irradiation as the mechanism of the disk heating.

We studied the type I migration in the non-isothermal accretion disks heated by the central star using numerical calculation. As mechanisms of the disk heating, we considered both the viscous heating and the stellar irradiation. We find that 'equilibrium radii', where the torque exerting on a planet becomes zero, moves inward in the disk with the timescale of disk evolution, and planets move with the equilibrium radii until gas densities decrease so low that the planets stop migration. One of the equilibrium radii exists on the region where main heating mechanism changes from viscous heating to stellar irradiation and that the terminal position of a comoving planet with mass of 10 M_E is about 1AU. The terminal position is less sensitive to parameters such as turbulent viscosity, mass flux of photoevaporation, and mass of the central star. On the other hand, the planets migrating from the relatively inner disk arrive at the vicinity of the central star (disk inner edge). If core instabilities occur on the planets, hot jupiters are formed. We also obtain analytical expression of equilibrium radii and terminal positions of migrating planets, which coincides well with the results of our numerical simulations.

We compare our results with the distribution of the semimajor axes of observed exoplanets. Especially many giant planets ($>100M_E$) have been observed in the regions inside 0.1AU and outside 1AU, and the number ratio of planets is about 3:5. A relatively small number of exoplanets are observed between the two regions. Such a bimodal distribution of semimajor axes of exoplanets can be explained by the results of our simulation. We will discuss the ratio of the number of planets in the two regions quantitatively.

References

Baruteau, C., & Masset, F. 2008, ApJ, 672, 1054.
Lyra, W., Paardekooper, S.-J., & Mac Low, M.-M. 2010, ApJ, 715, L68.
Paardekooper, S.-J., & Mellema, G. 2006, A&A, 459, L17.
Paardekooper, S.-J., & Papaloizou, J. C. B. 2008, A&A, 485, 877.

Keywords: type I migration, protoplanetary disk, exoplanet

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-28 Room:304 Time:May 21 10:00-10:15

Effects of Evaporation of Hot-Jupiters on Exoplanets Population

Hiroyuki Kurokawa[1*], Taishi Nakamoto[1]

[1]Tokyo Institute of Technology

As the number of observed exoplanets increases, statistical discussions have been possible. It has been pointed out that there are correlations between semi-major axes (or orbital periods) of planets and planetary masses, surface gravities, or densities (Mazeh et al., 2005; Southworth et al., 2007; Jackson et al., 2012). One possible mechanism to account for the correlations is XUV-driven atmospheric escape due to the heating of upper atmosphere by stellar XUV (e. g., Lammer et al., 2003; Jackson et al.,2012).

Previous works which test the hypothesis neglected thermal cooling and evolutions of planetary radii or densities due to mass-loss. Also, the energy-limited escape was simply assumed. However, the changes of planetary radii and densities can result in a runaway mass-loss (Braffe et al., 2004). The Roche-lobe overflow might contributes to mass-loss in such a runaway regime. In addition, under an intense XUV environment which is possible in earlier stages of a host star, the thermal escape is in the recombination-limited regime (Murray-Clay et al., 2009; Owen and Jackson et al., 2012), not in the energy-limited regime as assumed in previous works on mass-loss evolutions. In this study, we develop a model to calculate the thermal evolution and the mass-loss evolution simultaneously taking the Roche-lobe overflow and the recombination-limited escape into account.

As a result, we show that a total evaporation of an envelope occurs for planets orbiting close to the host star (˜0.015 AU for a Jupiter-mass planet) and the evaporation is in the recombination-limited regime, not in the energy-limited regime. The mass-loss results in an expanding of the planetary radius and it is followed by the runaway mass-loss. The mass-loss evolution finally causes the Roche-lobe overflow. Because it strongly depends on the initial mass of the planet whether the planet experiences the runaway mass-loss or not, we can define a critical mass for a planet to lose whole envelope as a function of the semi-major axis. We show a comparison of the semi-major axis - critical mass relation obtained by our calculation and the observed population of exoplanets. Our results for Hot-Jupiters which have a small core of ˜10 Earth mass are consistent with the observation.

Keywords: exoplanet, atmospheric escape, gas planet, Hot-Jupiter, stellar XUV

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-29 Room:304 Time:May 21 10:15-10:30

Theoretical threshold mass and radius for close-in low-mass water-rich super-Earths: Implications for the main compositi

Kenji Kurosaki[1*], Masahiro Ikoma[2], Yasunori Hori[3]

[1]Tokyo Institute of Technology, [2]Tokyo University, [3]National Astronomical Observatory of Japan

Recent progress in observational technique has enabled us to find many exoplanets that have as small as several to several ten Earth masses and/or Earth radii (hereafter super-Earths). We can obtain the planetary mean densities from measured planetary masses and radii and thereby infer planetary compositions. It has been revealed that low-mass planets with short orbital periods (close-in planets) are diverse in composition. Despite of closeness, there are a significant number of close-in planets that have the potential to be mainly composed of water components (e.g., GJ1214b). Planetary composition is important to understand the planet's evolution and origin. I investigate mass-radius relationships for water-rich close-in planets, including the effects of thermal evolution and mass loss. Since close-in planets are strongly irradiated, they are rather hot and also experience mass loss. Nevertheless, impacts of those effects on the mass-radius relationships for water-rich planets have not been investigated previously. Through the investigation, I intend to derive threshold values for planetary mass and radius and constrain observations that can possess water components. I have calculated the interior structure and evolution of close-in water-rich planets, including the XUV-driven energy-limited hydrodynamic escape. I assume that the planet, orbiting a solar-type star, has three-layer structure: a water-vapor atmosphere, a water mantle and a rocky core from top to bottom. I have realized that the mass loss due to the intense stellar-XUV irradiation has a significant impact on evolution of close-in planets. In particular, water envelopes of the planets with mass of less than a few Earth masses, depending on distance from their host stars, are completely stripped off. I have derived a threshold value of the planet's initial mass below which the planet loses its water mantle completely. This threshold has been obtained as a function of the semi-major axis and other input parameters. The theoretical model of the structure and evolution of close-in water-rich planets in this dissertation predicts the domains in mass-period and radius-period distributions where naked rocky planets or water-rich planets are likely to be detected. This provides an essential piece of information for understanding the origin of close-in low-mass planets.

Keywords: Super-Earth, Mass loss, Interior structure

PPS21-30 Room:304 Time:May 21 10:30-10:45

Formation and stability of habitable moons around extrasolar giant planets

Takao Sato[1*], Takanori Sasaki[1]

[1]Department of Earth and Planetary Science, Graduate School of Science and Technology, Tokyo Institut

Since the discovery of planets in other systems, the question of whether these extrasolar planets are habitable has become relevant and addressable. However, it has been observationally difficult to catch an Earth-sized planet in the habitable zone. On the other hand, RV observations have shown large amount of giant planets exist in the habitable zone. In this paper, we focus on the exomoons around these extrasolar gas giants.

Williams et al. (1997) estimated the lower limit of satellite's mass to be habitable as 0.1-0.2 Earth masses. We examine the formation and orbital stability of satellites that has these masses around gas giants in the habitable zone. We showed the satellites tend to be rocky ones because of the high temperature profile of circum-planetary disks for massive gas giants. We also showed the orbits of these satellites are stable against type II migration of central planets and long-term tidal effect from the planets. Therefore, extrasolar giant planets in the habitable zone have a high probability of bringing "habitable moon" with.

Keywords: habitable moon, exoplanet, exomoon, satellite formation, orbital stability