CPS 9th International School of Planetary Sciences

Across the Earth into Exoplanets

24 – 29 June, 2012

Seapal Suma, Hyogo, Japan

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Hosted by
Center for Planetary Science (CPS) under the MEXT Global COE Program: "Foundation of International Center for Planetary Science", a joint project between Kobe University and Hokkaido University.

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Sunday, 24 June, 2012

15:00 - 18:00	Registration
18:00 - 21:00	Opening Reception

Monday, 25 June, 2012

7:30 - 8:45	<Breakfast>
8:45 - 9:00	**Opening Keynote**: Yushitsugu Nakagawa (CPS, Japan)
9:00 - 10:15	**Lecture 1**:David J. Stevenson (California Institute of Technology, USA) *Theoretical overview of structure and dynamics of the Earth: its particularity and universality*
10:15 - 10:45	<Break>
10:45 - 12:00	**Lecture 1**: David J. Stevenson
12:30 - 13:30	<Lunch>
14:00 - 15:15	**Lecture 2**: Taku Tsuchiya (Ehime Univ., Japan) *High pressure physics of the Earth and beyond*
15:15 - 15:45	<Break>
15:45 - 17:00	**Lecture 2**: Taku Tsuchiya
18:00 - 19:00	<Dinner>
19:00 - 21:00	**Poster session 1 with short talks** (Poster presenter who allotted an odd number)

Tuesday, 26 June, 2012

7:30 - 9:00	<Breakfast>
9:00 - 10:15	**Lecture 3**: Shun-ichiro Karato (Yale Univ., USA) *Earth mantle dynamics from planetary perspective*
10:15 - 10:45	<Break>
10:45 - 12:00	**Lecture 3**: Shun-ichiro Karato
12:30 - 13:30	<Lunch>
14:00 - 15:15	**Lecture 4**: Philippe Lognonné (Institut de Physique du Globe de Paris, France) *Planetary seismology and geophysics*
15:15 - 15:45	<Break>
15:45 - 17:00	**Lecture 4**: Philippe Lognonné

18:00 - 19:00	<Dinner>
19:00 - 21:00	**Poster session 2 with short talks** (Poster presenter who allotted an even number)

Wednesday, 27 June, 2012

7:30 - 9:00	<Breakfast>
9:00 - 10:15	**Lecture 5**: Francis Nimmo (Univ. of Santa Cruz, USA) *Evolution of rocky and icy planets in the solar system*
10:15 - 10:45	<Break>
10:45 - 12:00	**Lecture 5**: Francis Nimmo
12:30 - 13:30	<Lunch>
13:30 - 18:00	<Excursion>

Thursday, 28 June, 2012

7:30 - 9:00	<Breakfast>
9:00 - 10:15	**Lecture 6**: Yasuhito Sekine (The Univ. of Tokyo, Japan) *Coupled evolution of the interior and surface environment of the Earth and planets*
10:15 - 10:45	<Break>
10:45 - 12:00	**Lecture 6**: Yasuhito Sekine
12:30 - 13:30	<Lunch>
14:00 - 15:15	**Lecture 7**: Diana Valencia (Massachusetts Institute of Technology, USA) *Earth-like exoplanets: predictions and observations*
15:15 - 15:45	<Break>
15:45 - 17:00	**Lecture 7**: Diana Valencia
18:00 - 21:00	<Banquet>

Friday, 29 June, 2012

7:30 - 9:00	<Breakfast>

End of the school

Poster Presentations

- All posters will be on display Sunday - Thursday)
- Core time and short talk of a poster who allotted

  an odd number is Monday 19:00 - 21:00
  an even number is Tuesday 19:00 - 21:00

P-01 Edward Gillen
Modelling protoplanetary disks in the process of planetary formation

P-02 Takayuki Tanigawa
Formation of Circumplanetary Disks

P-03 Isa Oliveira
Tracing the evolution of dust in protoplanetary disks - The first steps of planet formation

P-04 Himadri Das Sekhar
Development of a virtual scattering laboratory software package to study the optical properties of cosmic dust aggregates

P-05 Gregor Golabek
Towards combined modeling of planetary accretion and differentiation

P-06 Eucharia Okoro
Dependence of geomagnetic storm on interplanetary magnetic field across latitudes.

P-07 Andre Izidoro
Can a local depletion in protosolar nebula explain the low mass of Mars?

P-08 David Baratoux
The petrological expression of the thermal evolution of Mars

P-09 Yasuhiro Nishikawa
Designing a martian broadband seismometer system under surface wind environment.

P-10 Soile Kukkonen
Evolution of the fluvial systems in the eastern Hellas region, Mars: A case study of Dao Vallis.

P-11 **Sharad Tripathi**

Plasma and current experiment (PACE) for Mars exploration

P-12 **Shin-ichi Takehiro**

Effects of latitudinally heterogeneous buoyancy flux conditions at the inner boundary on MHD dynamos in a rotating spherical shell

P-13 **Teresa Wong**

Comparison of convection with Arrhenius viscosity and exponential viscosity: application to initiation of plate tectonics

P-14 **Miki Nakajima**

The initial state of the Moon forming disk and the mantle of the Earth

P-15 **Mizzon Hugau**

Implications of the lopsided growth for the viscosity of Earth's inner core

P-16 **Hao Cao**

Does Saturn have a solid core? Evidence from its intrinsic magnetic field

P-17 **Takashi Sasaki**

Outcomes and duration of tidal evolution in a star-planet-moon system

P-18 **Daigo Shoji**

Enceladus' tidal heating from ice rheology

P-19 **Peter Gao**

How does nonhydrostaticity affect the determination of icy satellites moment of inertia

P-20 **Jun Kimura**

Dehydration of primordial hydrous rock in Ganymede: formation of the conductive core and the grooved terrain

P-21 **Ryuichi Nomura**

Deep dense magma and radioactive elements into the metallic core

P-22 **Yuichiro Cho**

Young mare volcanism in the Orientale region contemporary with

~2Ga PKT volcanism peak period

P-24 **Minami Yasui**
In-situ observation of impact crater formation in porous gypsum using a flash X-ray

P-25 **Kang-Shian Pan**
The rotational period and the surface properties of Phaethon

P-26 **Youhei Sasaki**
Development of an anelastic convection model in rotating spherical shells for stars, gas and icy giant planets.

P-27 **Ryan Vilim**
The effect of lower mantle metallisation on the dynamo generated magnetic fields of super Earths

P-28 **Shintaro Azuma**
Rheological structure of earth and venus inferred from strength contrast between plagioclase and olivine

P-29 **Yuki Kudo**
Sound velocity of $CaSiO_3$ perovskite under ultrahigh-pressures

P-30 **Patru Fabien**
High contrast imaging techniques for exoplanets detection

P-32 **Ikechukwu Obi**
An effective temperature scale for a sample of M dwarfs

P-33 **Yasunori Hori**
On the accretion of atmospheres onto super-Earths

P-35 **Hanlie Xu**
The asymmetry relationship between the winter NAO and precipitation in southwest China

P-38 **Shun-ichi Kamata**
Viscoelastic deformation of major lunar impact basins: Implications for concentrations of heat-producing elements in the lunar crust

Lecture Abstracts

Earth in the Context of Exoplanets

David J .Stevenson, Caltech

There are three primary ingredients for planets: gas (meaning predominantly hydrogen), ice (dominated by water molecules) and rock. Here, “rock” includes iron, much of which is usually in a metallic phase. This talk will be primarily about bodies that are almost entirely “rock”, though it will prove necessary to say something about the role of the other very cosmically abundant materials.

There are perhaps five primary features of Earth: (1) A mantle and well-separated core. The presence of this primary layering is a consequence of immiscibility between core forming and mantle forming materials and would not happen otherwise, despite the much higher density of iron. (2) A heat engine that expresses itself through two dynamical features: mantle convection and generation of a magnetic field. In the case of Earth, mantle convection expresses itself through plate tectonics, but this is not mandatory and the precise requirements for plate tectonics are not well understood. The persistence of a core dynamo is also imperfectly understood and may depend on “details” (e.g., the nature of the light elements in the core). (3) A crust that arises from partial melting of the mantle. The most abundant crust (basalt) is recycled but some crust (primarily continental) accumulates at Earth’s surface. Water is probably important to this process. (4) A water ocean that profoundly affects the climate and landscape. Water participates in a cycle, affecting the mantle, subduction and volcanism. This water cycle is a central feature of Earth in multiple ways and is imperfectly understood. (5) An atmosphere whose properties depend on the overall chemistry of Earth, the provenance of materials delivered and interaction with the surface and interior. The atmosphere cannot be understood independently of the rest of the planet.

These five primary features form the basis for examining the properties of Earth and Earthlike planets. It is evident that in many cases we are unsure why Earth behaves as it does; this suggests caution when claiming to know what exoplanets might do. I will discuss each of these features in turn and assess the extent to which they are generic (common features of all “earthlike” planets) and the extent to which they are special (merely one of many possible outcomes for such a planet).

Key Words: Earth structure, exoplanets

High pressure physics of the Earth and beyond

Taku Tsuchiya (Geodynamics Research Center, Ehime University, Japan)

Ab initio calculation method based on the density functional theory is a very strong research technique originally developed in the solid state physics and now applied to problems in many fields including the Earth and planetary science, in particular in the high-pressure mineral physics. The method provides access to a wide variety of physical and chemical properties non-empirically not only at zero temperature and zero pressure but also at high temperature and high pressure. Presently, calculations are being extended from several fundamental properties such as electronic structure, crystal structure, equation of state, elasticity, thermodynamics, and phase transition, chemical reaction to further larger-scale more complex properties including multi-component properties, transport and mechanical properties.

In this lecture, I will first describe an overview of the high-pressure solid-state physics, including fundaments of the electronic structure theory and *ab initio* theoretical mineral physics: the band theory combined with the density functional theory which allow us to compute electronic property and static lattice energy of materials, how to deal with the thermal effects (computation of dynamical and thermodynamic property), further extensions from harmonic to higher-order theory, from bulk to polycrystalline property, and from equilibrium to transport property, etc.

Then, I will show some recent progresses on the study of the Earth and planetary materials with major topics on the high-pressure post-perovskite transition and spin crossover transition of dominant silicates and oxides, further challenges to phase relations under extreme multi-megabar planetary pressure condition including post-pyrite transitions of SiO_2 with its melting relation and successive transitions in H_2O ice, pressure-induced metallization in some oxides, high-pressure transport property including thermal and electrical conductivities of silicates and iron, and also dissolution reactions between liquids and solids. After estimating some key parameters for planetary dynamics such as temperature structure, Rayleigh number, etc. based on the obtained information, new views on the Earth and planetary interiors will be discussed.

Karato Shun-ichiro

Mantle convection, tidal dissipation and water in terrestrial planets

Mantle convection and tidal dissipation are two important processes in terrestrial planet that control their evolution. In both of them rheological properties of planets play an important role. Among the various factors, water (hydrogen), pressure and temperature (and time-scale) have important influence on the rheological properties. The rheological properties of materials composing the mantle of terrestrial planets (i.e., minerals) can change by many orders of magnitude by the change of these parameters. Consequently, (1) understanding of dependence of rheological properties on these factors, and (2) inferring the distribution of water content, pressure and temperature in planetary interiors are critical to the understanding of dynamics and evolution of terrestrial planets. The first is a materials science issue, and the second is a planetary physics issue. Among other factors, the water content in a terrestrial planet is important in relation to the "habitability" issue and I will provide discussions on water distribution using Earth and the Moon (and Mars) as an example. A particularly interesting case is water in the Moon. I will provide evidence for a substantial amount of water in the deep mantle of the Moon based on "geo"physical observations, and discuss a plausible model to explain the relatively large water content of the Moon in the context of the giant impact model of the Moon formation.

The plan of my lectures is as follows:

Part I: Introduction
- Mantle convection and plate tectonics
- Tidal dissipation: orbital and thermal evolution

Part II: Some mineral physics bases Solubility of water (hydrogen) in liquids and solids
- Three states of matter: Importance of pressure on the condensation sequence
- Sensitivity of physical properties on water content
  - Seismological properties
  - Electrical conductivity
  - Rheological properties
- ABC of rheological properties of planetary materials:
  - seismic Q, tidal Q, long-term deformation

Influence of pressure on rheological properties
- Theoretical models
- Experimental studies

Part III: Some planetary science applications
- Plate tectonics on terrestrial planets
- Tidal dissipation, tidal heating and orbital evolution
- Water in terrestrial planets
  - Water distribution in Earth
  - Water in the Moon
  - Giant impact and water in the Moon

Planetary seismology

Philippe Lognonné, Institut de Physique du Globe de Paris- Sorbonne Paris Cité, Université Paris Diderot, (lognonne@ipgp.,fr, 4 Avenue de Neptune, 94100 Saint Maur des Fossés, France)

The first attempts in planetary seismology started 50 years ago, with the launches of the Ranger-3-4-5 US missions to the Moon, which all failed… Success was reached however 40 years with the Apollo missions, which deployed a network of 4 passive seismometers on the Moon, at landing sites 12, 14, 15 and 16. A seismometer was also deployed on Apollo 11 and a gravimeter on Apollo 17. More than 12500 events were cataloged during the operation and although this network stopped its operation in 1977, the analysis of the data is still ongoing, and has led to the determination of many features of the lunar interior, as well properties of the seismic sources.

The first part of the lecture summarizes the state of the art of the lunar interior determination achieved with the Apollo data, as well as the major differences of lunar seismology as compared to Earth seismology, especially in terms of seismic wave propagation and seismicity. We will present the major results achieved in term of lunar structure determination, including the recent discovery of seismic core phases. Special focus will be given to the crustal structure, both in term of thickness and lateral variation, and to the core structure in term of radius, core state, temperature and composition. We also discuss the existence of possible discontinuities in the mantle, proposed by some early seismic models but challenged by others, and interpreted as the possible limit of an early magma ocean. A critical analysis will however be also provided, addressing the limitations of these models, their complementarities with those generated by other source of geophysical data (e.g. gravimetry, electromagnetic sounding, geodesy) as well as the typical uncertainties remaining on the lunar structure.

The second part of the lecture will be devoted to our present knowledge on seismic sources in planetary seismology, which, for might be either related to quakes, impacts and, for planets with atmosphere, e.g. Mars and Venus and possibly Jupiter, continuous excitation from atmospheric turbulences. After a rapid comparative presentation of the expected quake rates on the terrestrial planets, a special focus will be given to the two later types of sources. Concerning impacts, we will focus on two extreme cases: The Shoemaker Levy-9 impact on Jupiter and the impacts detected by the Apollo seismic network. In both case, we will present the main physical properties of the seismic sources (and associated shock wave) associated to an impact on solid surfaces or in atmosphere including magnitude and duration. For the Moon, we will use the calibrated seismic signals generated by artificial impacts (e.g. LEM or SIVB), which craters have been furthermore be characterized by the recent NASA LRO mission. Such calibration enables to estimate the flux of impactors on the Moon as well as the expected continuous micro-seismic noise generated by the continuous impacts on our satellite. The methodology for the extrapolation of these results in the prediction of the rate of seismically detectable impacts on Mars, Venus and asteroids will be finally given. Atmospheric source will, on the other hand, be presented mainly by using the case of Jupiter and Mars, with, in the later case, an estimation of the micro-seismic noise associated to the atmospheric interaction.

The last part of the lecture will be a description of future missions or projects aiming to deploy seismometers or to perform remote sensing seismology, with a special attention on the instrumental constraints. We conclude by presenting the potential challenges, science objectives and discoveries of this future step in the seismic exploration of our solar system.

Evolution of rocky and icy planets in the solar system

Francis Nimmo (University of California Santa Cruz)

Rocky and icy exoplanets are as yet poorly characterized. Nonetheless analogies with bodies in our own solar system may prove helpful in interpreting forthcoming data. In this talk, I will focus on three processes: accretion; heat transfer; and tides.

Accretion is important for four reasons. Via the release of gravitational energy, it exerts a strong control on the initial temperature and volatile inventory of the body. Because accretion is not 100% efficient, it can cause variations in the body's bulk composition; the anomalous compositions of Mercury and the Moon are probably the result of accretionary processes. Accretion can control the body's initial spin and orbital states (Uranus is a possible example). And finally, smaller impacts post-dating the main accretionary and nebular blowoff epoch can have additional effects on bulk composition and (especially) atmospheric evolution.

There are four main sources of energy available to heat exoplanets. For close-in "roasters", stellar luminosity may be dominant, yielding an equilibrium surface temperature in some cases above the silicate solidus. Close-in planets may also experience tidal heating, at a rate dependent on their internal structure (Io is a good example). Finally, radionuclides, both short- and long-lived, and gravitational energy during accretion and differentiation, will always play a role irrespective of semi-major axis.

In the first few Myrs, the dominant heat sources are accretion and (if present) short-lived nuclides. The heating rates generally result in prodigious melting and the formation of magma oceans. The lifetime of such oceans depends on whether and when they develop a flotation crust and/or thick atmosphere. Advection of heat by melting is a very efficient cooling mechanism; as long as melts are less dense than their solid surroundings, planets will cool relatively rapidly (tens of Myr) to a temperature profile approximating the solidus.

Over 100 Myr timescales, sub-solidus convection likely transfers most heat, and is roughly balanced by long-term radiogenic heat production. The details depend on whether plate tectonics operates or not, which appears to be sensitive to factors such as water content (consider Earth vs. Venus) and is hard to predict on purely theoretical grounds. The efficiency of melting and convection can be judged by measuring what fraction of the ^{40}Ar produced has been outgassed. Whether or not a planetary body develops a dynamo is usually thought to depend on how rapidly heat is extracted out of the core into the overlying mantle.

In many ways, the best analogues to close-in synchronous exoplanets are the satellites of our solar system. For instance, satellite formation and migration in the presence of a gaseous disk is probably similar to exoplanet formation, and results in similar mass ratios. However, the distribution of angular momentum is quite different between exoplanet and satellite systems.

In solar system satellites, tides can play a major role in both thermal evolution and orbit/spin state. For bodies in resonance, thermal evolution need not be monotonic (Enceladus is a possible example) and eccentricities will be time-dependent. In some cases, the orbital characteristics of a resonance may be used to directly ascertain interior characteristics of a planet/satellite such as its Love number. If a tidally-locked body occupies a Cassini state, information about its interior mass distribution may be derived by measuring its obliquity, and obliquity tides may result in heating and inclination damping.

Coupled evolution of the interior and surface environment of the Earth and planets

Yasuhito Sekine, The University of Tokyo

Earth is an aqua planet that holds liquid water on the surface and can support life. For centuries, people have been wondering whether there are any other aqua planets in space. Until now, spacecraft explorations have revealed that there is no aqua planet in our solar system today, other than Earth. In our galaxy, however, billions aqua planets are predicted to orbit in the habitable zone around stars. In fact, the challenge for finding aqua planets has started using space telescopes.

If aqua planets are discovered, people would then wonder the next questions. Is there life there? If so, what types of life? What are the signs of life there? Answering this question requires research at the interactions of life sciences, chemistry, physics, and earth sciences. Here, I will discuss how the atmosphere, oceans, and life have evolved and interacted over Earth's history, especially focused on the first and largest rise in atmospheric oxygen in 2.5–2.2 billion years ago.

Recent geochemical studies suggested that before the rise in oxygen, Earth's atmosphere had been composed mainly of nitrogen, carbon dioxide, and methane. In such a relatively reducing atmosphere, photochemical reactions of methane would have generated organic aerosols, as occurred in the atmosphere of Titan, Saturn's largest moon. The organic aerosols could have affected the atmospheric structure and surface temperature. Here I will discuss the climatic stability of an Earth-like planet with a methane-rich atmosphere and some possible reasons why Earth's reducing atmosphere had suddenly oxidized around 2.5 billion years ago.

It has been suggested the rise in oxygen would have occurred in the climatic recovery immediately after a global-scale glaciation (called "Snowball Earth event"). These studies suggest that a drastic climate change have promoted the atmospheric evolution, which in turn has strongly affected the evolution of life. In this talk, I also will discuss the mechanism how the climate change has promoted transition of atmospheric composition based on geochemical records. Knowledge on interactions between life and the Earth system would help us to consider alternative bio- and geochemistries that might occur on aqua planets beyond the solar system.

Super-Earths: Composition and Interior Dynamics

Diana Valencia
Earth, Atmospheres and Planetary Sciences Department
Massachusetts Institute of Technology

The increasing interest in low-mass planets spurs, at least in part, from the expectation that some of them may be similar to Earth and perhaps habitable. Before we can solve the question of habitability there are several previous steps needed to characterizing these planets. The first one is to determine their composition from the limited data that is currently available for exoplanets: masses and radii. In contrast to the giant planets that are mostly made of hydrogen and helium, low-mass planets are expected to be more complex in their constituents: rocks, metals, water/ices, some H/He. Thus, the problem is inherently degenerate in nature. I will present the current data, the basics behind an internal structure model that is needed to infer composition and our current understanding of the low-mass transiting exoplanets with measured masses.

While the data is restricted for exoplanets, and especially so for super-Earths, as they are challenging to detect, the good news is that they are numerous. Several surveys have shown that the occurrence of super-Earths is larger than massive exoplanets. And while uniquely constraining the composition of these planets is not possible, we can set lower and upper limits to their bulk chemical composition. The composition of a planet reflects the initial chemical inventory of the solar nebula from which they form plus any subsequent formation process (such as giant collisions and atmospheric evaporation). I will discuss possible connections we can draw from the detected super-Earths, and prospects for the future.

In addition, planets develop habitable conditions, thus understanding their thermal evolution is important. So far, there has been a debate about whether or not plate tectonics is a viable mode in which massive rocky planets can transport heat out. I will present the basic ideas behind mantle convection, the different approaches by the different models, and discuss their results. Also, I will discuss the connection between habitability and mode of tectonism.

Poster Abstracts

Modelling protoplanetary disks in the process of planetary formation

E. Gillen[1]*, S. Aigrain[1], A. McQuillan[1] & T. Harries[2]

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Recent simultaneous photometric and spectroscopic observations taken over multiple wavebands provide a unique data set with which to study protoplanetary disks in the process of planetary formation. Simultaneous observations of the young open cluster, NGC 2264, were conducted throughout December 2011 with the CoRoT, Chandra and Spitzer satellites, as well as ground based observatories. This has given us a wealth of data on young stellar systems in the process of planetary formation. The cluster is thought to be ~3Myr, which is believed to be the median lifetime of protoplanetary disks, i.e. the age at which disks are dispersed leaving gas giants and rocky planetesimals behind.

A particularly interesting system in NGC 2264 consists of a very close separation, low-mass eclipsing binary, whose light is occulted by circumstellar material. We believe the occultations are due to a warped disk and/or clumpy inner-disk material. An initial focus of my PhD is to model this disk using the photometric and spectroscopic data from all observed wavebands. I will simulate the disk with a static 3-dimensional radiative-transfer model, TORUS (e.g. Acreman et al. 2010), which solves for many disk properties including radiative and hydrostatic equilibrium, dust sublimation and disk chemistry. As the system is intrinsically variable, a dynamic element needs to be incorporated into the analysis and modelling. To interpret our light curves, I intend to employ a damped random walk technique (e.g. MacLeod et al. 2010), which is currently used to model quasar variability. In addition, to fully interpret our data, I would like to use dynamical models of the system in conjunction with TORUS to account for the variability and solve for the disk properties.

One of the main goals of this project is to be able to extend our results for this system in order to make meaningful statements about systems undergoing planetary formation in general.

Two features of this work are worth highlighting:

- The simultaneous observations over multiple wavebands, spanning much of the electromagnetic spectrum, give us a unique dataset with which to work.
- This system is an eclipsing binary, which means that we can constrain model independent system parameters to accuracies that are unattainable for single star systems, presenting ideal circumstances to study the circumstellar material.

This combination amounts to an unprecedented data set, capable of making a vital contribution to the currently poorly understood process of planetary formation. As Earth-like planets form their atmospheres due to outgassing from their interiors, the atmospheric structure and composition of rocky planets are a direct result of both the original conditions of formation and subsequent evolutionary processes. An understanding of the Earth's history will inform my analysis of disk evolution and potential planet formation; conversely, improved models of these processes will provide constraints for evolutionary simulations of the solar system and observed exoplanetary systems. Interdisciplinary collaboration will be crucial for tackling these challenges, providing essential stimulus to innovative thinking. This school will offer ideal opportunities to benefit from discussion and assist in further advances.

References

Acreman, D M., Harries, T J. & Rundle, D A. (2010) Modeling circumstellar disks with three-dimensional radiation hydrodynamics. MNRAS 403:1143

MacLeod et al. (2010) Modelling the Time Variability of SDSS Stripe 82 Quasars as a Damped Random Walk. ApJ 721:1014

Formation of Circumplanetary Disks

Takayuki Tanigawa[1*], Masahiro N. Machida[2], Keiji Ohtsuki[3]

[1]CPS / ILTS, Hokkaido University, [2]Faculty of Sciences, Kyushu University, [3]Faculty of Sciences, Kobe University / CPS

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

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

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

Keywords: Satellite formation, giant planets, hydrodynamics

Tracing the Evolution of Dust in Protoplanetary Disks
The First Steps of Planet Formation

Isa Oliveira (UT Austin)

The origin of the Solar System and other planetary systems is in the process of being unveiled due to crescent number of observations of protoplanetary disks (the birthplace of planets), as well as extra-solar planets. While protoplanetary disks are a natural consequence of the formation of stars, the formation of planets within disks is not. How planets form in protoplanetary disks, and which mechanisms play a role in the process are not yet clear. What is clear is that planet formation is a rather common output of the evolution of protoplanetary disks, evidenced by the hundreds of planets already discovered.

The last decade has seen an incredible advance in the field of protoplanetary disks and planet formation, aided by new instruments such as the *Spitzer Space Telescope*. Observations have shown disks initially to be good mixtures of dust and gas, flared and extending several hundreds of astronomical units in radius. During its evolution, several physical and chemical processes take place within disks, modifying the dust into possibly complex planetary systems such as our own. Direct observations of protoplanetary disks spanning a wide range in wavelengths (and therefore probing different processes and regions in the disk) and evolutionary stages can shed a light on the progression of planet formation.

I will present the results from my PhD thesis, which focused on unbiased surveys of low-mass young stars and their dusty disks in nearby star-forming regions using optical/infrared telescopes to probe the evolution of dust in protoplanetary disks. It addresses the full star-disk system: the stellar characteristics and their effect on disk evolution, as well as the changes taking place in the dust itself by making use of statistically relevant samples. Spitzer IRS mid-infrared (5-35 μm) spectra of a complete sample of YSOs selected on the basis of their infrared colors in the young Serpens Molecular Cloud are presented. The presence, strength, and shape of different spectral features are used to infer dust properties and mineralogy for these systems, such as composition, crystallinity and grain size distribution. Additionally, the mid-infrared slope is used as a proxy for the geometry of the protoplanetary disks. The results for the disks in Serpens are compared to those in other star-forming regions with a range in median ages and environments in order to trace the evolution of dust on a bigger scale. These results inform us on the timescales and mechanisms to form giant planets and are ultimately put in context with the characteristics of our own Solar System and the new exo-planetary systems being discovered around other stars.

Development of a Virtual Scattering Laboratory Software Package to Study the Optical Properties of Cosmic Dust Aggregates

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Abstract

The following paper reports the development of a *virtual scattering laboratory software package* to study *the optical properties of cosmic dust aggregates*. This package consists of a Graphical User Interface (GUI) in the front hand and a database of related data's on the back hand. Both the interactive GUI and database package directly enables an astronomer to model by self-monitoring respective input parameter (viz. wavelength, complex refractive index, grain size parameter, etc.) to study the related optical properties (viz. Extinction, polarization, etc.), of cosmic dust (interstellar dust, interplanetary dust, circumplanetary dust, intergalactic dust) instantly, i.e. with zero computational time, which directly increases the efficiency of the user. The database of different optical properties of the cosmic dust aggregates is generated in a very wide range using many leading mathematical models available (Superposition T-Matrix code, Discrete Dipole Approximation code) with high computational accuracy. This package also has an option where users can compile and run the scattering code directly for aggregates in GUI environment.

Towards combined modeling of planetary accretion and differentiation

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Results of current 1D models on planetesimal accretion yield an onion-like thermal structure with very high internal temperatures due to powerful short-lived radiogenic heating in the planetesimals. These lead to extensive silicate melting in the parent bodies. Yet, magma ocean and impact processes are not considered in these models and core formation is, if taken into account, assumed to be instantaneous with no feedback on the mantle evolution.

It was pointed out that impacts can not only deposit heat deep into the target body, which is later buried by ejecta of further impacts [1], but also that impacts expose in the crater region originally deep-seated layers, thus cooling the interior [2]. This combination of impact effects becomes even more important when we consider that planetesimals of all masses contribute to planetary accretion. This leads occasionally to collisions between bodies with large ratios between impactor and target mass.

Thus, all these processes can be expected to have a profound effect on the thermal evolution during the epoch of planetary accretion and may have implications for the onset of mantle convection and cannot be described properly in 1D geometry.

Here we present a new methodology, which can be used to simulate the internal evolution of a planetary body during accretion and differentiation: Using the N-body code PKDGRAV[3] we simulate the accretion of planetary embryos from an initial annulus of several thousand planetesimals. The growth history of the largest resulting planetary embryo is used as an input for the thermomechanical 2D code I2ELVIS [4]. The thermomechanical model takes recent parametrizations of impact processes like impact heating and crater excavation [5] into account. The model also includes both long- and short-lived radiogenic isotopes and a more realistic treatment of largely molten silicates [6].

Results show that late-formed planetesimals do not experience silicate melting and avoid thermal alteration, whereas in early-formed bodies accretion and iron core growth occur almost simultaneously and magma oceans develop in the interior of these bodies. These tend to form first close to the core-mantle boundary and migrate upwards with growing internal pressure.

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Dependence of geomagnetic storm on interplanetary magnetic field –Bz across latitudes.

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Abstract

A comprehensive study of geomagnetic storm variations and its dependence on interplanetary magnetic field-Bz (IMF-Bz) at dip, low and mid latitudes has been extensively carried out. Data set of H geomagnetic component for the years under study was employed for only quiet conditions. The observed Sq field variation was attributed to the seasonal variation of ionospheric electron content (IEC). It was observed that the geomagnetic storms (GMSs) with H-component amplitude (ΔH) values larger than 45nT occurred more in the nighttime than the daytime. While values of GMSs with values between 80 and 150nT at the low latitudes were still larger during nighttime than daytime side, except for those near the equator latitude. This trend of amplitude variation was found to be associated with position of IMF-Bz. GMSs amplitudes were larger in nighttime, when IMF-Bz turned northward and larger still when it turned southward. We therefore inferred that GMS variation is dependent on IMF-Bz.

Key words: Interplanetary magnetic field, geomagnetic storm, latitudes, amplitude, H-component.

Can a local depletion in protosolar nebula explain the low mass of Mars?

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One major problem in the simulations of the formation of terrestrial planet in our solar system is the formation of Mars. In general, models of the collision and growth of planetary embryos have been successful to produce terrestrial-class planets with sizes in the range of Venus and Earth. However, these models fail to produce a Mars analog. The body that is usually produced around the current Mars' semi-major axis through most simulations is in general too massive when compared to the mass of Mars. Only when unlike in our solar system, Jupiter and Saturn are initially considered in eccentric orbits, Mars-like objects are produced. The recently proposed Grand-Tack model tries to overcome this difficulty by allowing Jupiter and Saturn to migrated inward-then-outward. However, that scenario may not entirely agree with the models of the formation and migration of giant planets. In this paper, we present a new scenario, suggesting that a local depletion in the density of the protosolar nebula in the region of Mars can result in a non-uniform formation of embryos which will ultimately result in the formation of Mars-sized objects. We have carried out extensive numerical simulations of the formation of terrestrial planets in such a disk for different disk's surface density profile and local density depletion, and for different orbital configurations of giant planets and their radial migrations. Results of our simulations indicate that it is possible to form Mars-sized bodies along with Earth-like planets with substantial amount of water depending on the characteristics of our disk of embryos and planetesimals. We present the results of our study and discuss their implications for the formation of terrestrial planets and water delivery in our solar system.

The petrological expression of the thermal evolution of Mars

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Reconstruction of the geological history of Mars has been the focus of considerable attention, with important discoveries being made concerning variations in surface conditions. On the other hand, despite a significant increase in the amount of data related to the morphology, mineralogy and chemistry of the Martian surface, there was no clear global picture of how magmatism has evolved over time and how these changes relate to the thermal evolution of the planet. With this in mind we have used Silica, Iron, and Thorium global maps from the data Gamma Ray Spectrometer (GRS) onboard the Mars Odyssey spacecraft, focusing on 12 major volcanic provinces of variable age. This analysis reveals trends in chemical composition which are consistent with varying degrees of melting of the Martian mantle. In detail, there is evidence for thickening of the lithosphere (17–25 km/Gy) associated with a decrease of mantle potential temperature over time (30–40 K/Gy) [1]. This thermal scenario for the mantle of Mars may be now used to predict the composition of primary melts as a function of time. Then, the characteristics of mineralogical assemblages after crystallization of these primary melts may be calculated and directly compared to the variable proportions and compositions of pyroxene, olivine and plagioclase in igneous rocks as revealed by spectroscopic observations. In particular, a trend in the composition of pyroxene was revealed by OMEGA (Mars Express) and CRISM (Mars Reconnaissance Orbiter) data. This trend is characterized by a decrease of the ratio between low-calcium-pyroxene and rich-calcium pyroxene end-members at the Noachian/Hesperian boundary (3.7 Gy ago). Our thermodynamic calculations indicate that this change results from a higher degree of partial melting in the Noachian associated with a hotter mantle and/or a higher geothermal gradient. The thermal scenario inferred from GRS data [1] may be thus extended back to early Mars. This study of the igneous mineralogy and alterations phases of rocks and soils formed during this period of time is a major objective of the Mars Science Laboratory mission launched in November 2011. We thus hope to provide useful constrains (such as a range of possible geothermal gradients) to discuss the surface and sub-surface conditions at the landing site (Gale crater).

Taken together, these petrologic analyses are consistent with simple models of mantle convection and with the reconstruction of the thermal evolution of the mantle from paleo-heat flows inferred from the evolving elastic thickness of the lithosphere. They also argue for the existence of a period of active volcanism in the Noachian, which had participated to a large extent to the construction of the crust after the crystallization of a magma ocean. This scenario provides also non-geochronological arguments to the debate surrounding the age of a group of martian meteorite, and supports an old age for the basaltic shergottites.

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Designing a martian broadband seismometer system under surface wind environment.

Yasuhiro Nishikawa

The surface of Mars has been extensively investigated and huge amount of data have been acquired such as high resolution images. On the other hand interior of the Mars has been only weakly constrained by the mean density, the moment of inertia and gravity data. A major purpose of seismic observation on the planet is to detect the distribution of seismic velocities. Using the seismic velocity data, we provide the primary evidence for the process of differentiation whereby material within planets became composition- ally segregated during their evolution. But the current available Mars interior models based on indirect and insufficient data, since we have no seismic information about Mars. Melos project is Japan Mars exploration project. It is now under consideration. It will launch about 2020s. This project includes seismic observation plan. The plan is to install broadband and high sensitivity seismometer.

The purposes of this presentation are to reveal relationship of frequencies of the Mars planetary free oscillation to it's core states, by considering several set of 1 dimension models of elastic velocity and density. In addition to the calculation, we designed a martian seismometer wind shelter with a small torque (a large torque makes large noisy data) by using wind tunnel tests and computation fluid dynamics simulations.

EVOLUTION OF THE FLUVIAL SYSTEMS IN THE EASTERN HELLAS REGION, MARS: A CASE STUDY OF DAO VALLIS.

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Abstract

Dao Vallis is one of Martian large canyons on the eastern Hellas rim region. The canyon cuts the surrounding Late Noachian–Early Amazonian age sedimentary, volcanic and mixed materials mostly postdating their emplacement. Dao begins as a full size structure in a broad, flat-floored and closed depression and follows the regional slope toward Hellas. The general morphology and volume of the head depression ($11.4x10^3$ km^2) suggest that the canyon formed due to a release of a large mass of water. The current surface of the canyon floor has been modified by later processes.

In this study, we map and date the Dao Vallis in detail. Our aim is to identify how the units relate to each other and the canyon formation. The work is part of an ongoing project looking into the eastern Hellas fluvial systems, where the goal is to form a detailed picture of the drainage system evolution and to relate them to changes in the Martian climate.

Mapping is done at ConTeXt camera (CTX) 6 m/pixel resolution, available throughout the entire length of Dao. Unit relations and details are determined using 0.25 m/pixel High Resolution Imaging Science Experiment (HiRISE) images. Topography is obtained from Mars Orbiter Laser Altimeter (MOLA) tracks and gridded data, and High Resolution Stereo Camera (HRSC) level 4 DTMs.

Model ages are calculated from crater size-frequency distribution (SFD) plots from CTX and HiRISE datasets. The concept of the age determinations is to measure the number of craters accumulated on a given surface unit, i.e. the crater size-frequency distribution, and fit a known crater production function to it. When the crater frequencies for certain crater sizes are compared with a chronology function, it is possible to obtain an absolute age of the studied surface.

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PLASMA AND CURRENT EXPERIMENT (PACE) FOR MARS EXPLORATION

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The Martian ionosphere and thermosphere are powered by energy that originates from the Sun in the form of direct solar radiation as well as imposed electric fields and precipitating charged particles. Solar irradiance at extreme ultraviolet (0.01-0.1 keV) and X-ray (0.1–12 keV) regime produces ions and photoelectrons that heat the thermosphere and drive thermospheric chemistry. Though in great debate but the solar wind interaction with Mars atmosphere is believed to be one of the causes to taking away these ions and photoelectrons to higher altitudes of more than several hundreds to thousands of kilometers. This issue motivates to fly more plasma experiments to Mars. Further, Mars currently does not possess an appreciable magnetic field of internal origin (dynamo) and it has a comparatively small gravitational acceleration leading all known atmospheric loss processes to be active. Therefore several important constituents such as O^+, O_2^+, CO^+, N^+, N_2^+, H^+, CO_2^+ ions with energies between 0.01- 25 keV are being lost to space. The escape rates of atmospheric constituents including water from Mars indicate that the red planet could have lost an atmosphere of at least 1 bar to space during the past 3.5 Gyr. We propose to develop a Lab model of the "Plasma and Current Experiment (PACE)" in expectation to get an opportunity to fly onboard future mission to Mars. PACE aims to study the atmospheric escape processes in the Martian atmosphere and the structure of the Martian tail. PACE is a plasma imaging instrument in the energy range of 0.001-30 keV by employing an electrostatic analyzer (ESA) along with a time-of-flight technique, coupled with multi-channel plate (MCP) detectors. The instrument will be comprised of two top-hat ESAs: one forward directed for electrons, and other reverse directed for ions, which, however is coupled with time-of-flight (TOF) package. The TOF package will measure mass spectra of ions. The instrument will provide energy spectrum with energy resolution of about 19%. We propose to achieve an angular resolution of $5^o \times 22.5^0$ with $90^0 \times 360^0$ field of view throughout spacecraft orbit. Proposed instrument will provide mass-per-charge, speed, density, spatial distribution, direction and energy spectra of ions and electrons along the spacecraft orbit. These parameters will enable us to improve our current understanding of physical processes taking place in the Martian atmosphere, magnetotail as well as along the orbit of the spacecraft.

Effects of latitudinally heterogeneous buoyancy flux conditions at the inner boundary on MHD dynamos in a rotating spherical shell

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Outer core flows, contributing to generation and maintenance of the intrinsic magnetic field of the earth, is considered to be driven by buoyancy caused by the light elements released at the inner core boundary (ICB) through selective condensation of iron and nickel along with the inner core growth. On the other hand, existence of inner core flows has come to be studied as a candidate of the origin of the anisotropy of seismic velocity in the inner core. The typical flow pattern expected in the inner core is axisymmetric and flows are directed from the equatorial region to the polar regions or vice versa. Since such a flow accompanies mass flux through the ICB, it affects the condensation process of iron and nickel, and as a result, latitudinal heterogeneity of the buoyancy (light elements) flux is expected to occur at the ICB.

Therefore, in the present study, numerical experiments of MHD dynamo in a rotating spherical shell are performed in order to examine the effects of latitudinally heterogeneous buoyancy flux condition at the ICB on the establishment of dynamo solutions. The Ekman number, the Prandtl number, and the ratio of inner to outer radii are fixed as 10^{-3}, 1, and 0.35, respectively. The magnetic Prandtl number is varied from 1 to 10, and the modified Rayleigh number is increased from 100 to 500. The electrically-conducting inner sphere is allowed to be rigidly rotating around the rotation axis of the outer sphere in a different angular velocity. It is found that self-sustained dynamo solutions are obtained at certain parameters when the buoyancy flux at the ICB is uniform or an equatorially-strong type, whereas magnetic field does not develop spontaneously in all cases when strong buoyancy flux is given around the polar regions.

Comparison of convection with Arrhenius viscosity and exponential viscosity: application to initiation of plate tectonics

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February 5, 2012

A common approach to model initiation of plate tectonics is to use pseudo-plastic rheology and impose a yield stress as defined by Byerlees law to simulate brittle behavior. One of the difficulties is that the viscosity of rocks is an Arrhenius function of temperature. This gives extremely high viscosity contrasts and cannot be used in convection models. Thus instead of the Arrhenius viscosity, researchers use various approximations such as the exponential function of temperature (Frank-Kamenetskii approximation). The viscosity contrast calculated from the exponential viscosity function is many orders of magnitude smaller than that calculated from the Arrhenius viscosity, making it computationally tractable. This approximation was shown to be sufficiently accurate for the interior of the convective layer with large viscosity contrasts (in the stagnant lid convection regime). Here we address the question of how well the exponential function approximates the Arrhenius viscosity in simulating plate tectonics initiation. We compare the values of the critical yield stress for plate tectonics initiation for Arrhenius and exponential viscosity. To do so, we consider one-cell steady-state convection in a rectangular 2D box with variable aspect ratio, Rayleigh number and viscosity contrast. This type of flow allows a better control of the solutions and a relatively simple theoretical analysis. Then we apply a constant yield stress and gradually reduce its value. When the yield stress is sufficiently low the stagnant lid fails and some form of lid mobilization occurs. We find that the critical yield stress for the Arrhenius viscosity is smaller than that for the exponential viscosity but the two values are getting closer as Frank-Kamenetskii parameter increases. For planets with large viscosity contrasts across the lithosphere, the value of yield stress predicted by models with exponential viscosity seems to be close to that with the Arrhenius viscosity. We conclude that Frank-Kamenetskii approximation is acceptable for plate tectonics initiation modeling in a broad viscosity range.

The Initial State of the Moon Forming Disk and the Mantle of the Earth

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The Moon is thought to be formed by a giant impact between the proto-Earth and an impactor [1]. According to this hypothesis, the impact generates a debris disk around the Earth, from which the Moon is accreted [2]. The disk has a high temperature and is partially vaporized. This scenario can explain the large Earth-Moon angular momentum, the Moon iron depletion, and the similarity of oxygen isotope ratios in the mantles of the Earth and the Moon.

However, the state of the disk and the Earth's mantle right after the giant impact is not well known. This causes several major problems. First, the Moon accretion process is not well understood because it highly depends on the thermal profile of the initial disk. For example, the disk vapor mass fraction affects the disk cooling and the Moon forming time scale, and hence the final Moon mass [3]. Secondly, the mixing process between the Earth's mantle and the disk is not well understood. It has been expected that there is an isotope mixing between the Moon forming disk and the Earth's mantle, given that the proto-Earth and the impactor have difference isotope ratios. The isotope mixing can occur due to rainout, turbulence, and liquid-vapor exchange in the disk-Earth system [4]. This requires a detailed disk thermal model. The initial mechanical mixing of the materials from the two different origins, the proto-Earth and the impactor, within the Earth's mantle is also important. If the impactor-origin materials cover the Earth's surface and experience isotope mixing with the disk, the isotope ratios of the whole mantle and those of the Moon may be different if the mantle convection is not efficient over the Moon forming time scale.

We have performed Smoothed Particle Hydrodynamics (SPH) simulations to investigate the disk and the mantle state right after a giant impact. SPH is a Lagrangian method for fluid simulation. 10^5 particles are used. ANEOS and SESAME equations of state are chosen for forsterite (mantle) and iron (core). SPH outputs give the disk size, mass, angular momentum and entropy distributions. The typical disk sizes are 10 Earth radii. The entropy is nearly uniform in the disk. Based on the SPH outputs and the assumption that the disk is in a hydrostatic equilibrium, we have derived the disk pressure, the density and the temperature distributions as functions of the distance from the Earth's spin axis, r, and the height from the midplane, z. The disk temperature ranges from 4500K (inner disk) to 2500K (outer disk). Typical vapor mass fractions of the disk are 0.1-0.2. For the Earth's mantle, most of the materials from the impactor are distributed on the Earth's surface and are not mechanically well mixed with the materials from the proto-Earth. The entropy is higher outside, which means the system is convectively stable. The Earth reaches rigid body rotation within several hours, although the artificial viscosity is facilitating the process. These results show that smoothing the rotational shear velocities in the mantle does not mix the mantle materials. However, calculations based on a Richardson number criterion for shear mixing suggest that the mantle materials from the two different origins will mix by a Kelvin-Helmholtz instability. This requires further study.

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Implications of the lopsided growth for the viscosity of the Earth's inner core

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Two main seismic features characterize Earth's inner core: a North-South polar anisotropy and an East-West dichotomy of P-wave propagation properties (velocity and attenuation). Anisotropy is expected if shear deformation is induced by convective motions. However, translation has recently been put forward as the dominant mode of convection of the inner core (1, 2). Combined with a simple diffusive grain growth model, this mechanism is able to explain the observed seismic dichotomy, but not the bulk anisotropy. The source of anisotropy has therefore to be sought in the shear motions caused by higher modes of convection. Using a hybrid finite-difference spherical harmonics Navier-Stokes solver, this study investigates the interplay between translation and convection in a 3D spherical model. Three parameters act independently: viscosity, internal heating and outer core convection speed at the surface of the inner core. Particular attention has been paid to the implementation of realistic thermodynamic exchanges and permeable conditions at the inner core boundary. Our numerical simulations show the dominance of pure translation for viscosities higher than 10^{20} Pas. Translation is almost completely hampered by convective motions for viscosities lower than 10^{18} Pas. Between these bounds, translation and convection develop, but convective downwellings are restricted to the coldest hemisphere where crystallization occurs. On the opposite side, shear is almost absent, thereby allowing grain growth. We propose that the coexistence of translation and convection observed in our numerical models leads to a seismic asymmetry but localizes deformation only in one hemisphere.

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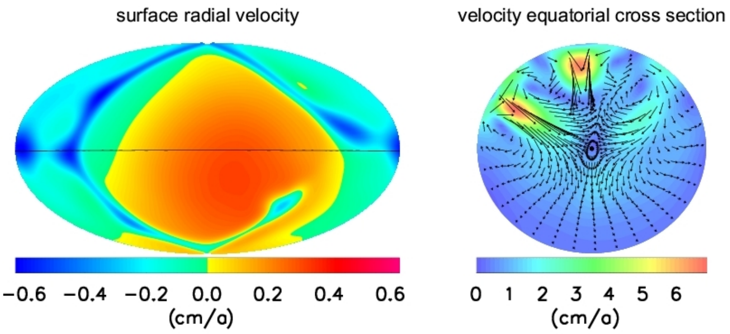

An equatorial cross-section of the simulation for a viscosity set to 10^{18} Pas shows that convective structures only develop in the hemisphere where iron enters the inner core. The thickness of the thermal boundary layer (TBL) depends on the orientation of the radial velocity at the ICB: inward (outward) motion tends to thicken (thin) the TBL. Where the TBL is thin it remains sub-critical which explains the absence of convective structure in one hemisphere. In the convecting hemisphere, crystals are deformed and remain small, whereas on the opposite hemisphere, the small strain rate would allow them to grow, thereby erasing their texture.

Does Saturn have a solid core? Evidence from its intrinsic magnetic field

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The gas giant planets in our solar system, Jupiter and Saturn, are far from been well understood. Understanding the intrinsic magnetic field is an essential step towards understanding the host planet. The intrinsic magnetic field of Saturn shows many peculiar properties, such as the long observed extreme axisymmetry and the recently inferred strong poleward flux concentration at the dynamo surface (Cao et al., 2012). The poleward flux concentration is truly surprising: this feature has never been observed at any other planet before and has never been reproduced in classical convection-driven dynamo simulations. The magnetic fields at the core surface of the Earth and in convection-driven dynamo simulations are characterized by weak field regions near the spin-poles and strong field regions at mid-latitude. Here we propose that the absence of a solid core inside Saturn is responsible for the poleward magnetic flux concentration. The simple physical picture underlying this hypothesis is the concentration of convection columns near the spin axis after the solid inner core as an obstacle is removed. The heat source is the secular cooling of the planet. To verify our hypothesis, we conduct a series of three dimensional magnetohydrodynamics (MHD) numerical simulations based on the community dynamo code MagIC version 3.44 (Christensen & Wicht, 2007). A wide range of the solid core size has been tested in our simulations. Two types of outer boundary heat flow pattern have been investigated: the uniform heat flow pattern and the pattern with high heat flow at the poles and low heat flow at the equator. The investigation of the outer boundary heat flow pattern is to test the possible growing influence it has as the solid core size decreases. A verification of our hypothesis will strongly indicate that there exists no or no significant solid core at Saturn at present. This will impose a strong constraint on the interior model of this planet, and further on the formation and evolution of this planet.

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P-17

Outcomes and Duration of Tidal Evolution in a Star-Planet-Moon System

Takashi Sasaki

Abstract

We formulated tidal decay lifetimes for hypothetical moons orbiting extrasolar planets with both lunar and stellar tides. Previous work neglected the efect of lunar tides on planet rotation, and are therefore applicable only to systems in which the moon's mass is much less than that of the planet. This work, in contrast, can be applied to the relatively large moons that might be detected around newly-discovered Neptune-mass and super-Earth planets. We conclude that moons are more stable when the planet/moon systems are further from the parent star, the planets are heavier, or the parent stars are lighter.

P-18

Enceladus' tidal heating from ice rheology

Daigo Shoji

In spite of its small radius (252 km), Enceladus is active satellite radiating high heat and emanating water plume. As a conventional heat source, tidal heating is thought to be the main mechanism to invoke such a large activity. However, Maxwell response with completely differentiated is insufficient to generate large heat as observed (around 10 GW). Other rheological model than Maxwell is proposed for the research of Iapetus, which results in appropriate response of Iapetus. Although we cannot say, of course, that Enceladus has the same rheology to Iapetus, analogy between Enceladus and Iapetus is a good approach because they both are Saturnian icy satellite. In addition to that, recent gravity measurement implies that Enceladus' core is not completely but partially differentiated, which means thickness of the ice mantle is relatively thin compared to former research. In this work, as ice alternative rheology, Burgers and Andrade body is applied to calculate heating rate in Enceladus by constructing new structure model consistent with latest observational results. While, in the case of Maxwell body, only small amount of heat was generated even though the new structure model, a few giga watt of heat was produced at Burgers and Andrade body when ocean exists. With a lack of ocean magnitude of tidal heat reduced by two of order.

How Does Nonhydrostaticity Affect the Determination of Icy Satellites' Moment of Inertia?

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Current models of icy satellite formation and evolution depend on the accuracy with which we determine their interior structures. These can be inferred from their moments of inertia (MOI), which can be estimated from *in situ* gravitational field measurements by spacecraft. The primary method of estimation is the Radau-Darwin approximation (RDA) [1], which relates the MOI to the degree 2 response of the body to rotation and tides (gravitational coefficient) J_2 and C_{22}. This method makes the assumption that the body is in hydrostatic equilibrium. It has been applied to several large icy satellites in the outer Solar System, including Titan [2], Callisto [3], and Ganymede [4]. Interpretations of the correlation between their MOIs and orbital distances lend credence to the "gas starved disk" model [5]. However, hydrostatic equilibrium is not guaranteed ([2], [3], [4], [5]), so it is prudent to assess the impact of nonhydrostatic structures on the accuracy of RDA. To this end, we consider a model icy satellite consisting of a layer of water ice with density 1g/cc overlaying a rock core with density 3g/cc. This simple arrangement allows us to isolate the essential physics of the problem. We further assume that the only departure from sphericity is a rotational bulge, since the (larger) tidal distortion involves the same physics and can be readily superimposed.

The RDA predicts a one-to-one correspondence between MOI and J_2 for a specific rotation. Nonhydrostatic structure destroys this one-to-one correspondence. RDA can also fail if there are large density variations, but we found this effect to be negligible even for the factor of three difference between core and mantle densities in our model. The nonhydrostatic effect can be quantified by introducing a small change in the hydrostatic figures of the satellite and core surfaces (e.g. make them slightly more oblate); we then relate these to the amount of stress these imply for the satellite and evaluate their feasibility.

We applied our model to Titan, Callisto, and Ganymede by using their published values of mass, radius, and rotational period in our equations. Iess et al. [2] reported Titan's MOI to be 0.3414 ± 0.0005, suggesting partial differentiation or complete differentiation with a low-density, hydrated core [6]. However, recent work by O'Rourke and Stevenson [7] has shown that a compositional gradient likely existed in early Titan, which would've prohibited convection to the point where the ice near the center would've melted due to long-lived radioactive isotopes, leading to complete differentiation; the trapped radiogenic heat would've likely dehydrated the core as well in the age of the Solar System [6]. Thus, Titan is likely completely differentiated with a rocky core, even if it started out partially differentiated during accretion. The MOI for a completely differentiated Titan is ~0.31. We find in our calculations that, in order to produce a 10% error in the measured MOI (enough to shift it to ~0.31), the degree 2 nonhydrostatic structure, if purely in the form of surface topography, needs to have a maximum amplitude of ~20 m on the satellite surface, or ~30 m on the core surface, corresponding to load stresses of ~0.3 and ~1 bar(s), respectively. Nonhydrostatic geoid variations similar to these values have been observed on Titan [2]. Similar treatment of Callisto revealed the same general values for the aforementioned quantities. In contrast, Anderson et al. [4] reported Ganymede's MOI to be 0.3105 ± 0.0028, suggesting a completely differentiated body. To produce a MOI error of 10% here, the nonhydrostatic structure must have an amplitude of ~100 m on the satellite surface, or ~200 m on the core surface, corresponding to load stresses of ~2 or ~6 bars, respectively. Mass anomalies have also been observed on Ganymede [11].

It is apparent that the same amount of departure from a hydrostatic figure would have a greater effect on Titan and Callisto's MOIs than on Ganymede's. Thus, it is valid to suggest that all three satellites are almost fully-differentiated, but the incorrectly-inferred MOIs for Callisto and Titan are higher at least partially due to invalid assumptions of hydrostatic equilibrium in RDA, the method used to determine them. It should be noted that the error caused by degree-2 nonhydrostatic stress would tend to result in a higher MOI than the real value, rather than lower, due to true polar wander maximizing the polar MOI through reorientation, i.e. the error would shift a true MOI of ~0.31 to ~0.34 rather than ~0.28.

The feasibility of these stresses can be evaluated by comparison with other icy satellites. For example, Iapetus has a fossil bulge corresponding to a 16 hour rotation period even though its current rotation period is ~80 days [8]. This configuration has likely been preserved due to a thick lithosphere holding up the fossil bulge [8]. Stresses of the same order of magnitude as those calculated above can also be produced by ongoing convection ([9], [10]). However, convection will not preferentially affect degree 2, so their presence is potentially revealed in other harmonics.

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Dehydration of primordial hydrous rock in Ganymede: formation of the conductive core and the grooved terrain

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From gravity data, it has been found that Ganymede has a small value of the moment of inertia (MoI) factor (0.3115), which suggests a highly differentiated interior. Combined with its mean density (1,942 kg m^{-3}), a three-layered structure (an outermost H_2O layer, a rocky mantle, and a metallic core) is most consistent with the gravity data. Also, existence of the intrinsic magnetic fiel strongly supports the existence of a (at least partially) liquid, iron core. However, process of the internal differentiation including the core formation is highly unclear, and the size of Ganymede implies that only accretional heat is insufficien to segregate the water, rock, and metallic materials completely. On the other hand, Callisto has similar size to Ganymede but show larger value of the MoI (0.355) implying incomplete differentiation. Although many hypotheses to explain this contrasting characteristic between two moons have proposed, but none of these theories has been sufficientl convinced. Here we suggest another hypothesis for the internal evolution in early stage and focus on a dehydration process of primordial rock-metal-mixed core.

Dehydration of hydrous rock and associated rheological change might be a key to create the dichotomy but its possible influ ence to the thermal histories of these satellites has never been explored. During the stage of accretion, rocky component is possibly hydrated because of the chemical reaction with liquid water generated by accretional heating. The similarity in reflectanc spectra among hydrated carbonaceous chondrites and asteroids near Jovian orbit also implies that the constituent material of the icy moons has already been hydrated prior to their incorporation into circum-Jovian nebula in which the regular satellites accreted. After the end of accretion (and after initial upwelling segregation of excess water due to the accretional heating), hydrous rock-metal-mixed core starts to warm due to the decay of long-lived radioactive elements. The thermal convection occurs efficientl in such mixed core because of low viscosity of hydrated minerals. However, once the temperature within the mixed core reaches the dehydration point then the viscosity would significantl increase and the efficien y of heat transport would decrease. As a result, thermal run-away would occur, that is, the core temperature would increase higher and the dehydration of rock would further proceed. Consequently, the temperature would exceed the melting point of the metallic component, and thereby metal segregation from rocky material could occur, although in mainly depends on the amount of the heat sources. If the trigger of thermal runaway needs sufficien rocky mass near that of Ganymede, it could explain the dichotomy in differentiation state between the two satellites and the metallic core formation of Ganymede.

To test above idea, we performed numerical simulations for the internal thermal evolution taking into account the reaction heat due to dehydration. In a reasonable range of viscosity is assumed for hydrated rocky core, models for Ganymede experience the dehydration of the pristine mixed-core and possibly the metallic component could segregates from the rocky materials in case of the high silicate content and/or higher viscosity of hydrous rock. On the other hand, Callisto does not undergo dehydration because of the smaller amount of radiogenic heat. The difference of radiogenic heat and the dehydration process have potential to create the dichotomy between two moons. Moreover, this may also explain the geological records on Ganymede showing the occurrence of global extension after the period of heavy bombardment. Global mapping with high spatial resolution in future mission on giant icy moons and improvement of accuracy in cratering chronology (e.g., current estimate on Ganymede's bright grooved terrain has uncertainty of an order of Gyr) are needed to examine our hypothesis.

Deep Dense Magma and Radioactive Elements into the Metallic Core

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Abstract

Proto-Earth is supposed to be suffered extensive melting in its violent accretionary stage. Our recent study shows the gravitational stability of deep magma ocean (Labrosse et al., 2007 Nature) against the residual silicate solids at >76 GPa conditions owing to the preferential iron partitioning into the silicate melt (fig. 1) (Nomura et al., 2011 Nature). This gravitational stability may persist at least till the Mg-postperovskite phase breaks down to Fe_2P-type SiO_2 phase and CsCl(B2)-type MgO at >1.05 TPa(Tsuchiya and Tsuchiya, 2011 PNAS) in the super-Earth.

This chemically heterogeneous, incompatible elements-rich dense reservoir will be equilibrated with the metallic core. We investigate the partitioning behaviors of radioactive element potassium between liquid-alloy and liquid-silicate melts under high-pressure and high-temperature conditions (>100 GPa, >4000K) using laser-heated diamond anvil cell apparatus to elucidate the thermal history of the Earth and exo-Earths.

In this presentation, we will show the results of our high-*PT* experiments and some implications for the thermal history of the initial (exo-)Earths.

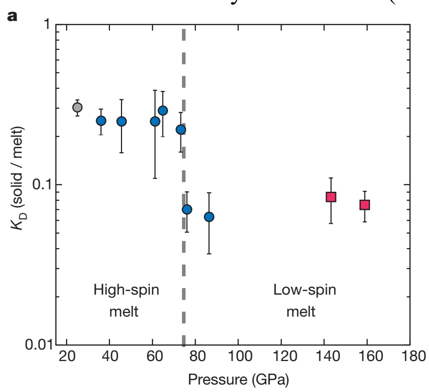

Figure 1. Change in Fe-Mg distribution coefficient (K_D) in the Mg-perovskite, Mg-postperovskite liquidus phase regions. The abrupt change of K_D value was occurred at ~76 GPa, which implies the preferential partition of iron into the silicate melt at high-pressure conditions.

Young Mare Volcanism in the Orientale Region Contemporary with ~2Ga PKT Volcanism Peak Period.

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The crater retention ages of the mare deposits within the Orientale multi-ring impact basin are investigated using 10 m resolution images obtained by Selenological and Engineering Explorer (SELENE, nicknamed Kaguya) spacecraft, in order to constrain the volcanic history of the moon around the nearside-farside boundary. Precise crater-counting analyses reveal that Lacus Veris and Lacus Autumni, maria along the northeastern rings of the basin, are much younger (~2 Ga) than previously thought. This result indicates that peripheral regions of the Orientale basin experienced volcanic activities ~1.8 billion years after the basin-formation impact. The uniform age (~2 Ga) of the mare deposits around the Orientale basin rims, rather far away from PKT, suggests that the suspected peak of volcanic activity at around 2 Ga may not have been confined within the PKT regions but more widespread on the Moon.

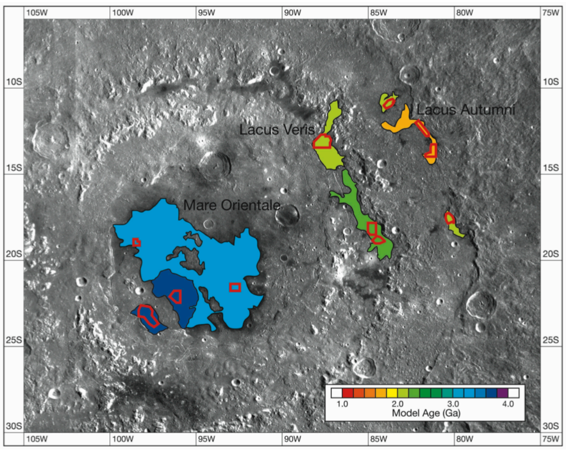

Figure 1. Model age map of the mare deposits in the Orientale basin with count regions highlighted by the red polygons.

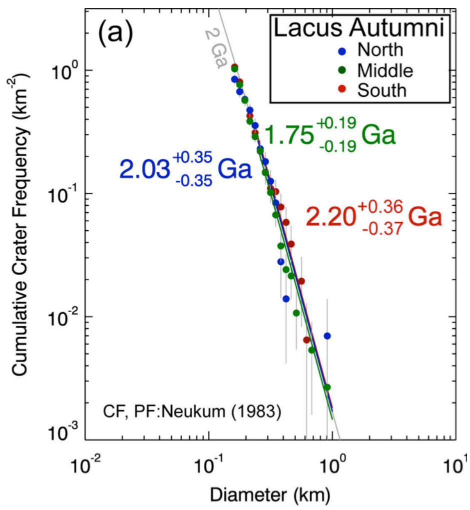

Figure 2. Crater size-frequency distribution plot and cumulative frequency fit of the three distinct parts of Lacus Autumni.

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

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Introduction: In order to understand the impact histories related to the asteroid formation processes, it is very important to study the impact craters found on the surfaces of asteroids. So, we should study the crater formation mechanism and establish the formation theory of the impact crater based on the physical mechanism. The target internal structures changing with time during the crater formation processes have not been studied yet by laboratory experiments because it is difficult to observe the target interior by visible light. In some previous works, impact experiments were conducted by using porous transparent silica aerojel to visualize the target interior [3]. In this study, we tried to visualize the interior of the target during the crater formation process by using a flash X-ray generator and studied the elementary processes of the crater formation, and observed the projectile penetration and the cavity expansion in the target.

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

Results: We found that the crater shape depended on the impact velocity and the projectile type. In the case of low-velocity collisions, the SUS projectile penetrated through the target without deformation and the penetrated hole was formed while the Al projectile collided the target surface and the hemispherical cavity was formed. In the case of high-velocity collisions for SUS projectile, the large projectile deformed and the hemispherical cavity was formed in the target, accompanied with some narrow pits on the cavity front. When the small projectile collided, the hemispherical crater was formed on the surface. We measured the penetration depth (d) to examine the drag coefficient of projectile (C_d). In the case of penetration hole, the d increased with time exponentially. In the cases of hemispherical cavity, the d increased with the time, however, the increase stopped at 20 μs. Beyond 60 μs, the behavior depended on the stainless projectile size. In the case of small projectile, the d continued to stop. In the case of large projectile, the d increased due to the progress of some disrupted projectiles. We examined the C_d by using the deceleration model [3], and found that the C_d for penetration was about 0.9 while that for other cases was about 2-3. This high value might be caused by the deformation of projectiles [4].

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

Title: The Rotational Period and the Surface Properties of Phaethon

Author: Sherry Kang-Shian Pan (Graduate Institute of Astronomy, National Central Universiy) and Shinsuke Abe (Graduate Institute of Astronomy, National Central Universiy)

Apollo asteroid (3200) Phaethon (1983 TB) is thought to be a dormant or an extinct cometary nuclei because this object has been known as the parent of the Geminid meteor stream (e.g. Whipple 1983; Ryabova 2001). The rotation period of Phaethon (~3.6 hours by Meech et al. 1996, ~7.2 hours by Kinoshita et al. 2002) is still under debate. Since Phaethon is one of the most important target for the future space missions in order to explore a cometary object in the near Earth space. In addition, it was suggested that the Apollo asteroid 2005 UD was likely candidate of a slitted asteroid that generate a large member of the Phaethon-Geminid stream Complex (Ohtsuka et al. 2006).

During 2011 November and 2012 February Time-resolved visible photometric of Phaethon were carried out using 0.81-m and 1-m telescopes at Tenagra observatory in US and Lulin observatory in Taiwan, respectively. The rotational period and the surface properties of Phaethon which is classified as F/B-type asteroid are investigated by using obtained color lightcurves over the full rotation phase.

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

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Shin-Ichi Takehiro, Research Inst. for Math. Sci., Kyoto University, Kyoto, Japan.
Ken-suke Nakajima, Faculty of Science, Kyushu University, Fukuoka, Japan
Kiyoshi Kuramoto, Department of Cosmoscience, Hokkaido University, Sapporo, Japan.
Yoshi-Yuki Hayashi, Faculty of Science, Kobe University, Kobe, Japan

The problem of convection in rotating spherical shells has been studied vigorously as a fundamental model of global convection presumably emerging in celestial bodies, such as stars, gas and icy giant planets, and terrestrial planetary interiors. Recently, according to development of numerical computational abilities, fundamental aspects and characteristics of convection has been revealed and knowledge about this issue is increased under the assumption of Boussinesq approximation, which ignores compressibility of the fluid. However, 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 and gas and icy planets, since thickness of their convection layers is several times larger than the scale height. Not only for these celestial bodies but also for extra-solar gas giant planets, which have been so many discovered with recent sophisticated technologies of astronomical observation, 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.

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

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

The Effect of Lower Mantle Metallisation on the Dynamo Generated Magnetic Fields of Super Earths

Ryan Vilim, Sabine Stanley, Linda Elkins-Tanton

Recent work has shown that a host of materials commonly thought to be present in terrestrial planet mantles (e.g. $CaSiO_3$[1], Al_2SO_3[2], FeO[3]) will conduct electricity at the conditions present in the lower mantles of large, terrestrial exoplanets.

A solid, electrically conducting lower mantle layer should have a significant effect on any dynamo present in the planet, as magnetic field lines should be simultaneously anchored in the convecting fluid core, and the solid mantle. This should create a new source of shear for the dynamo to generate magnetic fields.

We use a numerical dynamo model to simulate the dynamo of terrestrial exoplanets and incorporate a conducting mantle layer. We study the effect the conductivity of the layer, and the inner core size has on observable field.

In all cases, a conducting lower mantle increases the internal field strength significantly, due to the presence of a new way to shear magnetic fields in the core.

We find that the observable effects of a conducting mantle layer are most pronounced in planets with a large solid inner core, where the observable magnetic field becomes weaker as the conductivity of the mantle is increased. Conversely, we find that in models with a small solid inner core the observed magnetic field becomes modestly stronger in the conducting mantle layer models.

We will present the results of our models as well as a detailed explanation of the mechanism behind the observed effects.

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RHEOLOGICAL STRUCTURE OF EARTH AND VENUS INFERRED FROM STRENGTH CONTRAST BETWEEN PLAGIOCLASE AND OLIVINE

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Introduction:

Venus has been regarded as a twin planet to the Earth, because of density, mass, size and distance from the Sun [1]. However, the Magellan mission revealed that plate tectonics does not work on the Venus [2]. The plate tectonics is one of the most important mechanism of heat transport and material circulation of the Earth, consequently, its absence might cause the different tectonic evolution between Earth and Venus. Rheological structure is very important on considering about tectonics of planets because rheology shows us strength and deformation of planet's interior. In previous study, the behavior of venusian lithosphere has been inferred by one-phase deformation experiments of dry diabase [3]. In this study, we conduct two-phase deformation experiments to directly investigate strength contrast between plagioclase (crust) and olivine (mantle) utilizing modified Griggs and try to discuss the difference between these planets in terms of rheology from experimental results.

Experimental:

In this study, we performed experiment to directly determine the relative strength between plagioclase and olivine without any extrapolating of flow law; the crustal materials consist predominantly of plagioclase that largely control deformation of the crust, whereas deformation of the upper mantle is largely controlled by olivine. These samples are together sandwiched between alumina pistons in a simple shear geometry and we used the hot-pressed samples and performed deformation experiments using solid-medium deformation apparatus. The experimental conditions were ranging 1GPa and 600-1000 °C, corresponding conditions approximately to Moho of the Venus under dry conditions.

Results and Discussion: The experimental results under experimental conditions show that olivine is expected to always be stronger than plagioclase. The rheological structures of Venus are inferred from our experimental results and draw a comparison between Earth and Venus. (Fig. 1). In case of the Earth, rheological structure of oceanic lithosphere is constrained well by Byerlee's law and power-law creep. The moho of oceanic lithosphere is still brittle deformation range owing to lower temperature. The oceanic crust and mantle lithosphere are strongly coupled mechanically, so that they could move and subduct together into the deep. The temperature of moho, which strongly influences the coupling strength, depends on crustal thickness. The crustal thickness of Venus is, however, not constrained by the observation. In this study, crustal thickness of Venus is assumed to be 7km because of comparison with oceanic lithosphere of the Earth. Our experimental results imply that large strength contrast exists between lower crust and upper mantle in Venus. Decoupling of the motion between the crust and mantle lithospheres is expected to occur because the weak lower crust acts as a lubricant. Moreover, the soft crust cannot subduct into the hard mantle. The strength contrast between the crust and the mantle is supposed to prevent from recycling the crust into the mantle as Earth's plate tectonics. To quantitatively examine the effects of the soft lower crust on the Venusian tectonics, we are conducting numerical simulation using the rheology obtained from our experiments.

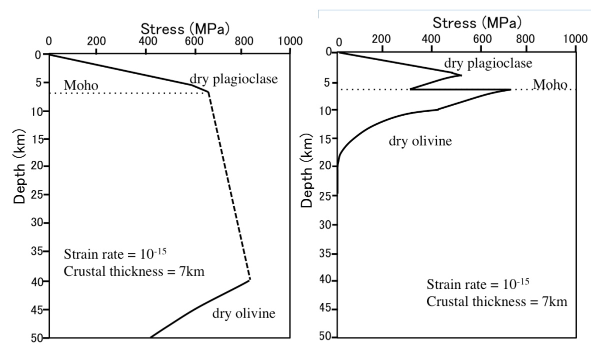

Fig. 1 *Strength profile: (a) Rheological structure of the oceanic lithosphere of the earth. (b) Rheological structure of the Venus (crustal thickness = 7km).*

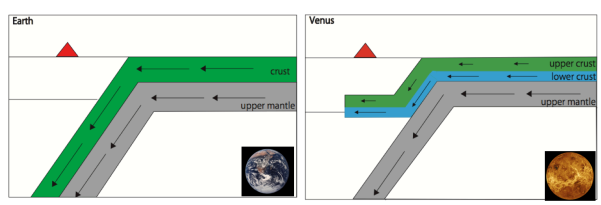

Fig. 2 *Tectonics model: (a) Subduction of the oceanic lithosphere (b) Tectonics of model that expected from our experimental results.*

References: [1] Taylor, S. R. and McLennan, S. (2008) Planetary Crusts. Cambridge University Press, New York. pp.181, [2] D. L. Turcotte, G. Morein, D. Roberts, and B. D. Malamud, *Icarus,* **139**, 49–54 (1999). [3] S. J. Mackwell, M. E. Zimmermanand, D. L. Kohlstedt, *JGR,* **103,** 975-984 (1998)

Sound velocity of CaSiO3 perovskite under ultrahigh-pressures

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Abstract

$CaSiO_3$ perovskite is one of the major constituent minerals in the Earth's lower mantle, and expected to be in the other terrestrial planets including the Super-earth. The elastic behavior under high-pressure and temperature condition is very important to imply the seismic observation, especially to discuss lateral heterogeneities of temperature and matter in the Earth's lower mantle, or the mantles of the other terrestrial planets in the future, which could be a fundamental data to discuss convections.

In this presentation, we will show the results of our recent experiments and some implications of seismic observations.

CPS 9th International School of Planetary Science

Poster of Fabien Patru (European Southern Observatory, ESO Chile)

Title: High contrast imaging techniques for exoplanets detection

Abstract:
My intention is to give a brief overview of the observational techniques and instrumental concepts dedicated to high contrast imaging, allowing direct detection and spectroscopic characterization of Earth-like exoplanets.

Direct imaging is one of the most promising techniques to search for a habitable exoplanet, so as to study its atmophere and its surface. Both the scientific objectives and the technical requirements to image nearby exoplanets are challenging, due to the low contrast (>1e10 in the visible) and the small angular separation between the compagnion and the star (~1 AU). Thus, the improvement of the observational planetary science, to study the predictions of the astrophysical models of exo-Earths, requires the development of effective and complexe instruments.

Extreme adaptive optics (ExAO) on large telescopes will soon enable the exploitation of novel coronographic approaches, including amplitude and phase apodization as well as continuous pupil redistribution (PIAA, Guyon et al. 2003). Interferometric techniques and spatial filtering can also be used not only with a large array of telescopes, but also with a single aperture telescope, such as the project of pupil single-mode filtering and remapping (FIRST, Perrin et al. 2006) or the project of dense aperture mapping (DAM, Patru et al. 2011, 2012).

In is essential, DAM is a filtered multi-pupil sampler, composed of two consecutive micro-lens arrays to subdivide the telescope aperture in many sub-pupils, which are spatially filtered and then re-imaged downstream. DAM can be exploited both for interferometric imaging as for AO filtering. In practice, coupled with an AO system it provides diffraction limited images, even with a residual piston, up to λ/8, in long exposure mode. Such images get the requested level of high-angular resolution to explore the inner region of sub-stellar systems. DAM is a simple, stable and passive optics, easy to mount on any telescope equipped with AO.

Hence, DAM represents a novel and smart opportunity to enlarge the use of interferometry to a broader community working on high-angular resolution. Finally, DAM is complementary either with other focus instruments such as a coronograph, an apodizer or an IFU spectrograph, or with differential imaging techniques such as Angular Differential Imaging ADI (Marois et al. 2006).

An Effective Temperature Scale for a Sample of M Dwarfs

Ikechukwu Obi

Abstract

In this paper, we present a quantitative comparison of low-resolution observed spectra of 40 nearby M-dwarfs with spectral types between M0 to M9.5 in the optical wavelength region with synthetic spectra obtained with the most current PHOENIX stellar atmosphere models. Our goal is to derive the effective temperature of the 40 M-dwarfs through this comparison between observations and models and also obtain a correlation between our derived effective temperature and spectral type to those of other works. We found a perfect agreement between the slope of the optical to near Infrared(IR) spectra to that of the models as well as some discrepancies in the strength of the absorption bands.

Keywords: Effective temperature, Infrared, Optical, Spectra, Absorption band, M-Dwarf

On the Accretion of Atmospheres Onto Super-Earths

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National Astronomical Observatory of Japan
(Division of Theoretical Astronomy)

Low-mass planets with several Earth-masses and orbital periods of a few days have been discovered via radial-velocity measurements and transit surveys. Although some super-Earths have density comparable to that of water, many of them have density comparable to or larger than that of Mercury and the Earth. We show that if these super-Earths migrated to inner regions or were assembled in a protostellar disk close to their present location, some of them may have accreted and then lost an envelope several times more massive than their cores. In contrast, the envelope accreted by planetary embryos at several AU from their host stars is mostly retained. Based on these results, we suggest that 1) most of low-density super-Earths were probably formed out of refractory material beyond the ice line, 2) very few, if any short-period super-Earths have evolved into hot Jupiters through gas accretion near their present location. We also show that it is possible to form super-Neptune mass planets through accretion of metal-rich disk gas.

The Asymmetry Relationship between the Winter NAO and Precipitation in Southwest China

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Abstract The relationship between the winter North Atlantic Oscillation (NAO) and the winter precipitation in Southwest China is investigated using the NCAR/NCEP reanalysis dataset and 160 stations monthly rainfall in China during 1951 ~ 2010. The result shows there is a significantly positive correlation between boreal winter NAOI and the winter precipitation in Southwest China, and the positive correlation is asymmetry. During winter of the weak NAO years, the circulation pattern in East Asian is not favorable for precipitation in Southwest China. Contrastingly, during the winters of strong NAO years, the relationship between them is not significant. Further analysis shows that the main circulation pattern which influences the precipitation in Southwest China is a teleconnection pattern existed in the Caspian Sea-Arabian Sea-Tibetan Plateau and the downstream area (CAT teleconnection). We find that the CAT teleconnection pattern has an asymmetric relationship with winter NAO, and the relationship is significant only in the winter of NAO negative phase. The results from the composite of wave ray and wave-activity flux during strong and weak winter NAO years shows that in weak winter NAO years the wave rays which aroused by the wave source in the Mediterranean could consistent with the route of CAT teleconnection pattern, and the wave-activity flux shows that the stationary wave could spread to the downstream along the Caspian Sea-Arabian Sea-Tibetan Plateau and South of China, while in strong winter NAO years, the wave rays are to the north of the CAT teleconnection and the stationary wave could spread only to Peninsular India. These results indicate the asymmetric relationship between winter NAO and Southwest China winter rainfall maybe determined by the asymmetric influence of NAO on the CAT teleconnection.

Key Words North Atlantic Oscillation (NAO), southwest China winter rainfall, Caspian Sea-Arabian Sea-Tibetan Plateau (CAT) Teleconnection, asymmetry

Viscoelastic deformation of major lunar impact basins: Implications for concentrations of heat-producing elements in the lunar crust

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Although remote-sensing observation suggests strong heterogeneity in the early thermal evolution, quantitative differences in thermal structures among different regions are not constrained well. One of the few geologic record for the ancient thermal structure of the Moon is the viscoelastic state of lunar impact basins. In this study, we constrain the paleo-thermal state for impact basins using recent global geodetic data and viscoelastic calculations. We found that the upper limit of surface temperature gradient is significantly different for each region (Figure 1). We also found that the lunar lower crust on the farside needs to be depleted in heat-producing elements, such as thorium, suggesting strongly region-dependent radioactive element concentration in the lunar crust.

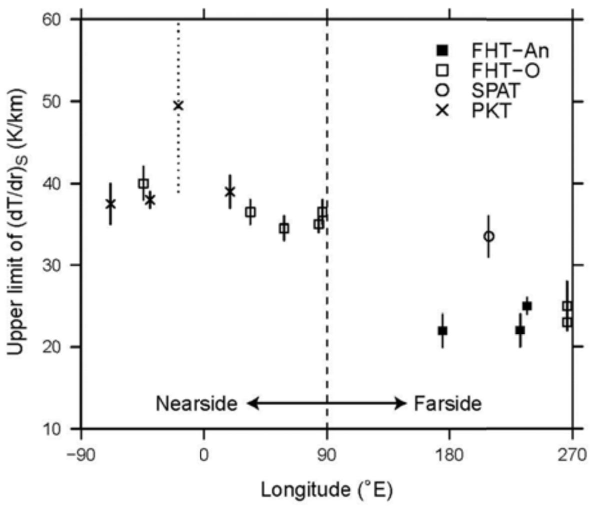

Figure 1: Regional dependence of the upper limit of surface temperature gradient. The FHT, the SPAT, and the PKT indicate the Feldspathic Highlands Terrane, the South Pole-Aitken Terrane, and the Procellarum KREEP Terrane, respectively. The FHT-An and the FHT-O indicate the central anorthositic region and the outer region of the FHT, respectively.