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


PPS01-01 Room:201B Time:May 21 14:15-14:30

# Formation, Evolution, and Future Exploration of the Giant Planets

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The giant planets are key to the mystery of the origin and evolution of the solar system and, by extension, extrasolar systems. Prevailing hypotheses of the giant planet formation include the core accretion model and the gravitational instability model, while the former is conventionally favored. At the heart of the classic core accretion model is the formation of a solid core of a critical mass of 10-15 Earth masses, followed by gravitational collapse of surrounding protoplanetary nebula that completes the formation of the planet. The core forms from agglomeration of grains of dust, refractory material, metals and ices and the volatiles they trap. The most volatile of the gases, hydrogen, helium and neon are captured last, gravitationally during the collapse phase. The atmosphere results from these gases and the volatiles initially trapped in and subsequently released from the core during accretional heating, and presumably mixed uniformly. The above formation scenario demonstrates that the core is critical to the formation of the giant planets, and that the well-mixed atmosphere is expected to reflect the composition of original elements. Since heavy elements (>4He) comprise much of the core mass, their determination is crucial to any model of the giant planet formation. The core accretion model predicts solar abundances of heavy elements, all relative to H. The Galileo probe measurements at Jupiter in 1995 changed all that. The probe revealed that the heavy noble gases, argon, krypton and xenon, were each enriched relative to solar by roughly a factor of two, whereas the enrichment factor was 4-6 for carbon and nitrogen and about 2.5 for sulfur. Thus, these heavy elements were found to be enriched relative to solar by a factor of 4(+/-2), and the enrichment factor is non-uniform. One missing element is oxygen, which is crucial since water ? the principal reservoir of oxygen in Jupiter ? was presumably the original carrier of the core-forming heavy elements and could make half of the core mass, or greater. The Galileo probe entered a five-micron hotspot ? the Sahara Desert of Jupiter ? where water vapor was severely depleted. O/H was measured to be 0.4x solar in this site. It is unknown whether water is depleted everywhere on Jupiter or enriched like the other heavy elements. The Juno microwave radiometers will measure and map water to deep tropospheric levels in Jupiter in July 2016. It is only then one could assess whether Jupiter is indeed carbon rich and oxygen poor like the exoplanet hot Jupiter WASP-12b, or not. Even after the inventory of key heavy elements has been completed for Jupiter, comparison with the other gas giant, Saturn, is essential. However, with the exception of carbon, no reliable data exist on other heavy elements for this planet or, for that matter, the icy giant planets, Uranus and Neptune. Considering the fundamental importance of this science, which only entry probes can deliver, the US NRC Planetary Decadal Survey (Visions and Voyages, NRC, 2011) has recommended a Saturn probe as one of four candidate missions in the New Frontiers class and a Uranus orbiter and probe as one of four candidate missions in the flagship class for the 2013-2023 decade. Relevant publications may be downloaded from www.umich.edu/~atreya for personal use.

Keywords: Giant Planets, Jupiter, Saturn, Juno, Entry Probes, Extrasolar Planets

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# Exploration of Jovian System by ESA-JUICE Mission: Participation of Japanese Team

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Jupiter is the largest planet in the solar system with mass more than 300 times as large as that of the Earth. It is a rapidly rotating hydrogen-helium gaseous body with strong magnetic field and associated magnetosphere. Recent discoveries of exoplanets suggest that Jupiter should represent a body not only in the solar system but also in the universe. Four large satellites, Io, Europa, Ganymede, and Callisto, were discovered by Galileo 400 years ago. Three of them except Io are icy satellites. Europa and Ganymede are considered to have the interior ocean, which might foster extraterrestrial life. Ganymede has own magnetic field.

The Jupiter system was observed by several flyby missions such as Pioneer 10 and 11, Voyager 1 and 2, Cassini, New Horizons and investigated by Galileo orbiter and its atmospheric entry probe. Galileo spacecraft data were very limited due to the malfunction of its high-gain antenna. JUNO mission will start observation of Jupiter in 2016. But since the main target of JUNO taking polar orbits is structure and composition of Jupiter, observation of satellites would be limited.

JUICE (Jupiter Icy Moon Explorer) is the first Large-class mission of ESA Cosmic Vision 2015-2025 program. It will be launched in 2022 and will reach Jupiter in 2030. JUICE will continuously observe the atmosphere and magnetosphere of Jupiter and the interaction of the Galilean satellites with the gas giant planet. Using multi-flybys with Callisto, JUICE will change orbital inclination. It will twice fly by Europa. It will finally enter orbit around Ganymede in 2032, where it will study the icy surface and internal structure, especially its subsurface ocean. Ganymede would have molten metallic core generating intrinsic magnetic field. JUICE will observe the unique magnetic and plasma interactions of Ganymede with Jupiter's magnetosphere.

After the selection of JUICE in May 2012, several Japanese groups were invited to participate in the mission as Co-Is with instrument development for model payloads. Those includes plasma instruments such as low, middle, high-energy particles and plasma wave detectors, a submillimeter sounder, an UV imager and a laser altimeter. They participates in ESA AO at October 2012. After the selection in February 2013, ISAS/JASA will support but check the progress of instrument developments by Japanese team.

It should be noted that discussion for the international collaboration for Jupiter mission between ESA and Japan (JAXA) started from 2006 and International Jupiter Mission Working Group started at JAXA in 2007. The initial plan was that JAXA will take a role on the magnetosphere spinner JMO (Jupiter Magnetosphere Orbiter) and JMO would be launched and transported together with ESA orbiter. The original plan was similar to the framework of the BepiColombo Mercury mission. Then in the framework of EJSM (Europa Jupiter System Mission), ESA will launch JGO (Jupiter Ganymede Orbiter) and NASA would launch JEO (Jupiter Europa Orbiter), whereas JAXA would launch JMO. Only JGO was selected as JUICE for the first ESA cosmic vision L-class mission. And Russia is considering to launch Ganymede lander which would arrive at the icy surface when JUICE is observing from polar orbits.

Keywords: Jupiter exploration, magnetosphere, Ganymede, Europa, interior ocean, icy satellites

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PPS01-03 Room:201B Time:May 21 14:45-15:00

# Radio and Plasma Wave Investigation around Jupiter

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Future Jovian mission is now planned for 2020s.
One of its major objectives is the investigation of electromagnetic system connected and driven by Jupiter. Under the international collaborations, we have started the development for the small-sized radio sensor for this mission from 2011, by the aid of the Grant-in-aid of JAXA Payload Development etc.
We succeeded to establish the base technical elements for (1) light-weight rigid antenna with simple and reliable extension capability and (2) small-sized radiation-hard preamp with the highest sensitivity.

In any missions related to plasmas, electric field from DC to several 10s MHz has contributed to the remote-sensing and in-situ studies of dynamics and energetic interactions in the electromagnetic system, associated with remote optical measurements and in-situ particle and magnetic field sensors.
For the Jovian project, an Europe-USA-Japan joint team is formed for the plasma and radio wave studies. Especially in Jupiter, its radio wave is important as a remote sensing tool for the direct measurement of Jovian radio source regions distributing around the Jovian system, i.e., polar region, radiation belts, Io torus system, and Galilean satellites with thin atmospheres. We are involved for this team based on the high reputation of Plasma Wave Investigation (PWI) aboard the BepiColombo/MMO, and have developed the small-sized radio sensor package with antenna and preamp within the tightest resource limitations.

We investigated base technologies for (1) a 3-axial antenna with 2m length, extracting at the Earth orbit and can be kept during the long travel till the end of the mission on the orbit around Galilean satellite, and (2) a 3-axial preamp covering 10kHz-100 MHz with the highest sensitivity, enough radiation tolerance in Jovian environment, the hardest in the solar system, within the mass limit less than 200g. For the former, we established a simple extension mechanism based on the self-extracting thin BeCu and CFRP element, which is based on the combination of the key technologies in the SCOPE Z-axis antenna (STEM-type extension mechanism but with a complex motor system) and the sounding rocket antenna (self-extraction but with limited length, only 1 m). For the latter, under the collaboration with the IRF-Uppsala (Sweden) team, we established the key parts of the radiation-hard analogue custom IC technologies, in which the most difficult part was a relay in the package with high-impedance, small-sized, and high-reliability. In parallel, we also tested the high-sensitivity preamp BBM under the radiation hard condition, and proved that even in 200 krad the degradation of the noise level is only the twice, without critical linearity and sensitivity damages. In 2012, we are proceeding to the next phase, including the design of a backend receiver with direct sampling scheme with fast (100-125MHz) rad-hard A/D.

Since the small but reliable extension mechanism and electronics are not so much expensive, we can also consider the implementation to sounding rocket experiments. After the full establishment of this technology, we will be able to adopt it to any space radio and planetary missions in which the resource is very tight.

Keywords: Jupiter, Radio, Receiver, Antenna

PPS01-04 Room:201B Time:May 21 15:00-15:15

# Measurement low-energy energetic neutral atoms around Jupiter's satellite

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We are proposing a measurement of low-energy (10eV-3keV) energetic neutral atoms around Jupiter's satellite especially Ganymede. Ganymede has its own intrinsic magnetic moment. There is considered to be a mini-magnetosphere around Ganymede because of interactions between plasma in Jovian magnetosphere and Ganmede's magnetic field. However, its characteristics will be different from terrstrical one, since Alfven mach number of upstream plasma flow (corotational plasma flow around Jupiter) is small. JNA (Jovian Neutral Analyzer) will reveal characteristics of Ganymede's magnetosphere in terms of measurement of scattered/sputtered particles generated by precipitation of plasma particles onto Ganymede's surface. Measurement of these particles will provide spatial distribution of plasmas in remote sense, since electric/magnetic field do not affect trajectories of neutral particles. JNA is a part of PEP (Particle Environment Package) led by Swedish Institute of Space Physics, which was proposed as potential instruments onboard JUICE mission.

We will discuss current status of JNA.

Keywords: low-energy energetic neutral atoms, Ganymede, magnetosphere, remote observation

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# The EXCEED mission and the next

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An earth-orbiting Extreme Ultraviolet spectroscopic mission, EXtreme ultraviolet spectrosCope for ExosphEric Dynamics explore (EXCEED)

is ready to be launched in 2013 to 800 km x 1200 km orbit and will start the observaion in November.

The EXCEED mission will carry out out-of-atmosphere observations of Extreme Ultraviolet (EUV: 60-145 nm) emissions from tenuous plasmas around the planets (Mercury, Mars, Venus, and Jupiter).

Our operation scenario is that the EXCEED points to Jupiter from November to March(2014), Mercury (mid March to mid April), and later Vunes and Mars.

Most importantly, HST and some important ground-based telescopes will observe Jupiter with EXCEED in the spectral range from UV to IR.

This is precursive for the next exploration to Jupiter.

I will present the overall EXCEED mission (qualification result and observation plan), the cooporative observation with HST in Decemver, and the next Jupiter exploration (JUICE).

Keywords: EUV, Jupiter, JUICE, EXCEED, planetary airglow

PPS01-06 Room:201B Time:May 21 15:30-15:45

# The Submillimetre Wave Instrument (SWI) for JUpiter ICy moons Explorer (JUICE)

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The Submillimetre Wave Instrument (SWI) is an instrument proposed to form part of the scientific payload instruments for the JUpiter Icy Moons Explorer (JUICE) mission of the ESA's Cosmic Vision 2015-2025 program.

SWI is a very high spectral resolution (up to R=107), dual band (600 and 1200 GHz), sub-millimeter heterodyne instrument on the JUICE spacecraft, achieving 1000-2000 km spatial resolution on Jupiter's disk and 0.5-1 km on icy satellites. SWI will determine the composition, structure and dynamics of Io's atmosphere. On Europa, Ganymede and Callisto, SWI measurements will detect active regions, generally determine sources and sinks of the atmospheres, their interaction with magnetospheric plasma; the interaction of Ganymede's magnetosphere with the Jovian magnetosphere will be derived.

SWI has four scientific targets as fellow: 1) the Jovian system with particular emphases on the chemistry, meteorology and structure of Jupiter's middle atmosphere, and atmospheric coupling processes, 2) Characterize the regoliths, icy-crusts, atmospheres, and exospheres of Ganymede, Europa and Callisto, thereby providing important inputs for the exploration of their habitable zones, 3) Study Ganymede as a planetary object and possible habitat; study and explore Europa's young icy crust in recently active zones, 4) Explore the Jovian system as an archetype for gas giants in characterizing the Jovian atmosphere and its satellite and ring systems.

SWI will measure Three-Dimensional of temperatures, winds (with accuracy of ˜10 m/sec) and chemical species (e.g. CO, CS, HCN, H2O, CH4) in Jupiter's stratosphere. The Icy moon measurement will be performed with water vapor, its isotope ratio, and ortho/para ratio in their tenuous atmospheres/exospheres. It will measure thermophysical and electrical properties of satellite surface/subsurfaces and correlate them with atmospheric properties and geological features. SWI will determine key isotopic ratios in Jupiter's and satellite atmospheres, especially the deuterium-to-hydrogen ratio, diagnostic of the formation and evolution of Jupiter's satellite system.

SWI is a instrument with a passive, heterodyne receiver for simultaneous observation in two submillimetre spectral bands, 530-601 GHz and 1082-1271 GHz. In combination with two high-resolution Chirp Transform Spectrometers (CTS), SWI obtains a resolving power v/dv of up to 107. The local oscillator is tunable to observe at any frequency within the bandwidth of the two receivers. SWI is equipped with a movable 30 cm telescope to change its viewing direction independent of the spacecraft orientation. In this presentation, the overview of the SWI mission will be introduced.

Keywords: Jupiter, icey moon, JUICE, SWI, atmospheric dynamics, sub-millimeter sounder

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PPS01-07 Room:201B Time:May 21 15:45-16:00

# Dynamics and material transport of Jupiter's stratosphere as scientific targets of JUICE-SWI

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We will show the overview of atmospheric sciences in Jupiter's stratosphere in connection with the expected contributions of a sub-millimeter instrument proposed for the JUICE mission (JUICE-SWI).

It is very important to investigate the atmosphere of giant planets, for the universal understandings of formation and evolution of planetary atmospheric circulations with different viewpoints from the investigations of terrestrial planets, as well as the clarifications of physical parameters specific to each planet. Moreover, the field of planetary science is broadening beyond our solar system, and gas giants are especially important existences in extra-solar stellar systems as far as our current understandings. Then we need to understand Jupiter, the closest gas giant to us, thoroughly as the first step.

Jupiter's stratosphere extends for more than 350 km above the visible cloud top, with the pressure range of roughly between $10^3$ and $10^{-3}$ hPa. The rotational speed of Jupiter is faster than Earth, dynamical processes are thought to be affected by radiative processes by molecules in stratosphere and eddies enhanced from the troposphere. Belts of fast westerly wind (up to 140 m $s^{-1}$) have been found at 23 N and 5 N, and the oscillations of equatorial zonal wind with periods of about 4 years (quasi-quadrennial oscillation, QQO) are also indicated. As for the minor components, CS, CO and HCN are inserted by collisions of comets (e.g. Shoemaker-Levy 9 in 1994). Water has also been observed, but the origin of it is not determined quantitatively.

JUICE-SWI is a very sensitive instrument to observe some minor species such as $CH_4$, $H_2O$, HCN, CO and CS in Jupiter's stratosphere. We can detect vertical temperature profiles and wind velocities from $CH_4$ molecular lines. CO and CS can be used as tracers for the investigations of atmospheric flows (general circulation and dynamical processes), because they are chemically stable. From these observations, it is expected to help us to understand the dynamical and chemical processes of Jupiter's stratosphere.

Keywords: Jupiter, atmospheric dynamics, atmospheric chemistry, sub-millimeter sounder, JUICE

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# Geophysics of Ganymede as revealed by orbiter missions: application to the JUICE mission

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As indicated by the Voyager and Galileo missions, Ganymede is a very complex world:

(a) Ganymede is highly differentiated. With a dimensionless moment of inertia of 0.3115 [1] it is the most condensed solid-state body of the solar system. The moment-of-inertia value is consistent with interior structure models including an iron-rich core, a silicate layer, high-pressure ice layers, a liquid water layer, and an ice-I layer at the surface. Based on the Galileo gravity field measurements a set of models with different thicknesses of the layers can be constructed (e.g., [2]). The process of differentiation would be accompanied by global extension of the satellite because ice is more compressible than rock.

(b) Ganymede has a magnetic dipole field. Together with the Earth and Mercury, Ganymede is one of only three solid bodies in the solar system that generate a magnetic field in a liquid (outer) iron core [3]. Therefore present temperatures and heat flows of the core and/or compositional gradients must be sufficient to sustain a dynamo.

(c) The magnetic field data is consistent with induced fields generated in an electrically conducting salty global ocean beneath the ice-I layer [4]. This provides strong evidence for a present subsurface ocean on Ganymede. The latter would have strong implications on the tidal response of the satellite.

(d) Ganymede is locked in the three-body Laplace resonance with Io and Europa. Although the forcing of Ganymedes orbital eccentricity of ef = 0.0006 is weaker as compared to Io and Europa, scenarios of formation of the resonance and its implications for tidal heating must be consistent with the satellites orbital evolution (e.g. [5]) and present state.

(e) Ganymedes icy surface consists of two types of terrain exhibiting differences in albedo, surface age (through crater density), and surface morphology (e.g., [6]). Whereas the dark terrain is several Gyrs old the light terrain can be as young as about ˜400 Myrs. The different types of geologic activity may be a consequence of different energy budgets available from the interior during different regimes of thermal evolution.

(f) Ganymedes bright terrain globally shows intense fracturing and tectonic resurfacing. In addition there is local evidence for cryovolcanic activity.

(g) Ganymede displays a great diversity of impact morphologies. Those are related to the thermal state of the icy crust at time of the impact and temperature dependent relaxation processes.

Starting from various scenarios of Ganymedes evolution that have been discussed in the literature to explain the unique features of the satellite we describe measurements by orbiting spacecraft that could constrain these theories. Application to ESAs JUICE mission will be shown. Emphasis is given on the geophysical aspects, i.e. interior structure and tidal deformation. The models are set into perspective by comparison with the neighboring satellites Europa and Callisto. Prospects to investigate the geophysics of Europa and Callisto with flybys are briefly discussed.

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PPS01-09 Room:201B Time:May 21 16:30-16:45

# Development of JUICE/Ganymede Laser Altimeter (GALA)

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"Is there a life elsewhere in the universe?" It is a fundamental question deeply rooted on intelligence of human beings. And a clue of this question may be found on Ganymede. After magnificent achievements of Galileo and Voyager missions, an existence of thick liquid water layer, namely internal oceans under icy crust, has been implied for icy satellites of Jupiter, Ganymede, Europa, and Callisto. And water in liquid state is thought to be a necessary condition for emergence of life in the field of astrobiology. The evidence of ocean, however, is not widely accepted, because it depends on an inferences of electromagnetic observation and surface morphology. Looking for new evidences and clues for these important issues, a new mission to Jupiter system is palnned by European Space Agency. It is the Jupiter Icy Moon Explorer (JUICE). JUICE will be launched in 2022, and will arrive at Jupiter in 2030. After several fly-bys to Europa and Callisto, JUICE will be inserted into an orbit around Ganymede in 2032 and will continue scientific observations for eight months until the end of nominal mission in 2033.

Ganymede Laser Altimeter, GALA, is one of model payloads ofJUICE and measures distance between the spacecraft and the surface of the satellite from time of flight of a laser pulse. Together with positions of the spacecraft and mass center of the satellite, surface topography of the satellite is calculated from measured distances. The GALA data are particularly important for finding of internal ocean. First, if the ocean exists beneath icy crust, tidal deformation of the satellite is so large that temporal variation of the topography as great as a few tens meter shall be detected. Second, small eccentricity of orbit of Ganymede causes libration that will be observed as lateral shifts of footprint of laser beam at the surface. And third, improved determination of spacecraft orbits by cross over analysis results in precise estimate of low degree harmonics of gravity field. Thus accurate Love number will be calculated to infer internal density structure of the satellite.

Global topographic data derived by GALA are also important for the study of tectonic history at the surface, elastic and viscous structure of ice crust, and thermal evolution of interior of the icy satellite. For example, linear structures such as ridges and grabens reveal extension stresses due to past variation of thermal states. As well, flat surface and thin crust may indicate partial melting of the crust and consequent internal lake. These observations on various geologic activities lead to understanding of transport of heat and materials from interior to the surface. Further, a comparison of styles of tectonics of ice crust and that of silicate lithosphere will likely shed a new light on the theory of plate tectonics of the Earth.

GALA is developed by international collaboration of scientists and engineers in Germany, Switzerland, and Japan. Its conceptual design is based on the laser altimeter on board of Mercury orbiter, BepiColombo, and consists of transceiver unit (TRU) with laser optics and appropriate electronics, electronic unit (ELU) with digital range finder module, digital processing module and power converter module, and laser electronic unit (LEU) with laser control electronics. Japanese team provides receiver telescope, backend optics, detector, and analogue electronics of TRU. The transmission optics of TRU and entire LEU are developed at DLR in Germany, and ELU is developed at Bern University in Switzerland. Assembly and integration are conducted at DLR under a supervision of the principal investigator of GALA. We therefore need to pay special caution on interfaces between analogue electronics and range finder, low-temperature environment, and radiation environment that Japanese space scientists have never experienced before.

Keywords: Jupiter, Ganymede, Laser altimeter

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# Evolution and diversity of the large icy moons

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Large icy moons in the solar system, Ganymede, Callisto, and Titan, have a similar size of Mercury but smaller bulk density (~2.0 g/cc) than the terrestrial planets, which indicates that the bulk composition is half water ice and half rocky material. However, there are quite different state on its surface and interior at present among these moons. Ganymede has globally-tectonic surface and completely differentiated interior having the central metallic core which generates the intrinsic magnetic field, while Callisto's surface is saturated by the impact craters, suggestive of an old age, and its interior seems to be incompletely differentiated which is implied by a large value of the moment of inertia factor. Titan has an intermediate size, density, and moment of inertia between Ganymede and Callisto, and has experienced some internally driven geology. Although many studies have proposed hypotheses explaining this contrasting states between the two moons, none of these theories has been sufficiently convinced.

We construct a new model for the evolution of large icy moons, especially in order to explain the origin of surface tectonics and strongly differentiated interior on Ganymede and the different current state and history between Ganymede and Callisto. That is, "Dehydration model" of primordial hydrous silicate and metal-mixed core so that only Ganymede undergoes significant temperature rise inside allowing the separation of a conductive core and the global tectonics during its history. This model assumes that 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 reflectance 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 than their incorporation into circum-Jovian nebula in which the regular satellites accreted. After the end of accretion, primordial core starts to warm due to only the decay heating of long-lived radioactive elements. Once the dehydration starts to occur, the temperature of rocky core would increase more rapidly and exceed the melting point of the metallic component, and thereby metal segregates from rocky material. The difference of radiogenic heat and moon's size between Ganymede and Callisto may have potential to create the dichotomy between two moons.

In addition, applicability of this model is not limited to Ganymede and Callisto but extends to other similar-sized icy moons, e.g., Europa and Titan, and an implication for the "Super-Ganymede" exoplanets will be addressed. If extrasolar planetary systems are analogous to our own, then icy moons could be the most common habitats in the universe, probably much more abundant than Earth-like environments which require highly specialized conditions that permit surface oceans.

Finally, we will propose a possible contribution to the JUICE (Jupiter Icy Moon Explorer) mission, which is planned by ESA (European Space Agency) to visit the Jovian system and will launch in June 2022 on an 11-year mission to explore the giant planet and three of Jupiter's moons; Ganymede, Callisto, and Europa.

Keywords: satellite, thermal history, interior, tectonics, evolution, exploration

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# Formation Processes of Regular Satellites around Giant Planets

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Satellite systems around the giant planets in our solar system are commonly seen. They are thought to have formed in circum-planetary disks, which are believed to have existed around giant planets during their gas capturing growing stage.

In earlier works, the formation process of satellite systems has been considered based on a minimum mass subnebula (MMSN) model, in which satellites form from a disk that contains sufficient solid mass with solar composition for reproducing the current satellite systems (e.g., Lunine and Stevenson 1982), as an analog of the minimum mass solar nebula model (Hayashi 1981). However, it was suggested that the MMSN model has difficulty in reproducing current satellite systems around Jupiter and Saturn (Canup and Ward 2002). One of the severe problems is that the model leads to much higher temperature than that of H2O ice sublimation at the current regular satellite region, which means that ice, which is the main component of the satellites, cannot be used as building material of the satellites.

In order to overcome the difficulties of the MMSN-type models which assume a closed and static disk, alternative models have been developed. Canup and Ward (2002) proposed a model in which an accretion disk with a continuous supply of gas and solid is considered as a proto-satellite disk. This model reproduces ratio of total satellite mass to the parent planets' mass for Jupiter, Saturn, and Uranus.

Recently, Crida and Charnoz (2012) showed that if a massive ring around a giant planet exists, it spreads outward by radial diffusion, which could produce regular satellites. This model can reproduce satellite masses and orbital radius simultaneously for Saturn, Uranus, and Neptune.

In this talk, satellite formation processes mainly of the two major hypotheses will be reviewed.

Keywords: satellite, moon, Jupiter, giant planets

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# Planetary tectonics: A new tool to judge the presence or absence of life on planets

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Concept of habitable planet has been suggested around 1965 to discuss the possibility of presence of life on planets, because liquid water is major component of life, which has a tight stability field of T$<$100 degrees depending on pressure. Discovery of icy satellites of Jupiter, which may contain water under the icy surface, pointed to the possibility of presence of life there. Titan has a landmass, which is partly occupied by methane lakes, enveloped by CH4-rich atmosphere. If the landmass comprises rocky materials and an energy circulation system, such discoveries would certainly change the original definition of habitable planet.

Here, we propose a new tool of planetary tectonics as an index for the presence of life on planets. The phenomenon of life is possible only where there is a steady-state supply of nutrients, as well as water circulation and thermal energy. If these conditions are not satisfied, life will terminate. Considering these conditions, the Earth has only two life-sustaining places: (1) the surface of the Earth fed by a climate driven by the Sun, and (2) endogenic-influenced aqueous environments, best exemplified by both continental lake environments, which interact with basement structures such as rift systems and associated hydrothermal systems (the structures serve as conduits for the migration of volatiles and heat energy often related to magma), and deep-sea hydrothermal systems driven by MORB magma (though the biomass at mid-oceanic ridge is 10-6 times smaller than that of the surface of the Earth; negligibly small when compared to the continental lake environments). Understanding planetary tectonic systems that can generate such environments is significantly important in the search for life beyond Earth, including providing an index not only for finding life in our Solar System but also extrasolar planets.

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# Planetary Tectonic System (#1) and the Search for Life

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For life to initiate, diversify, and flourish, it requires a continuous nutrient supply, metabolism with continuous reactions to gain energy, and self-duplication. These conditions can be optimally met through a planetary tectonic system (PTS) that is composed of a nutrient-enriched continental landmass, an ocean, tectonic structures such as rift systems that act as conduits for the migration of volatiles and heat energy, and a sunlit planetary surface. This is realized through the evolution of the Earth, particularly in the case of the Cambrian explosion [1; also see Shingenori Maruyama, this conference]. The Cambrian explosion included a dramatic increase in the supply of nutrients and oxygen and resultant organic matter, including macroscopic hard-shelled animals that reached dimensions 1 million times larger than the Precambrian Eukaryotes.

The PTS to explain the Cambrian explosion is as follows [1, also see Shigenori Maruyama, this conference]: (1) the appearance of a landmass of nurtrient-enriched materials resulting from a drop in sea-level related to plate tectonism including subduction of hydrated slabs into the mantle, (2) the global distribution of the nutrient-enriched continental materials into the ocean through wind (aeolian erosion and deposition) and water (e.g., fluvial erosion and transport along river systems); winds, for example, transported fine-grained materials from desert regions to the oceans, feeding the plankton life along the surface of the open oceans, and (3) the interaction among deep-seated basement structures, magma, and continental lakes which collectively yield life-thriving, hydrothermal systems (considered prime habitable environments on Earth and Mars; [1,2]).

The delivery of enormous amounts of nutrients drove the burst of photosynthesis which resulted in an increase of free oxygen in the atmosphere and a rapid increase of organic matter. Knowledge of PTS provides the road map for the search for life beyond Earth [also see Dohm and Maruyama?Planetary tectonic system #2, this conference].

References

[1] Maruyama, S et al., (2013?in press), Geoscience Frontiers 171.

[2] Dohm, J.M., et al. (2011) GSA Special Paper 483, 317?347, doi:10.1130/2011.2483(21).