# Orbital evolution of solid bodies in circumplanetary gas disks

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In the late stage of the formation of giant planets, sufficiently massive proto-giant planets capture gas and solids from the protoplanetary disk and form circumplanetary disks. Regular satellites of the giant planets such as the Galilean satellites of Jupiter are orbiting in the prograde direction in approximately circular and co-planer orbits, thus they are thought to be formed in the circumplanetary disks. Orbital decay of solid bodies is caused by different mechanisms depending on their sizes. When the solid bodies are small, aerodynamic gas drag is dominant (Adachi et al. 1976). Sufficiently small bodies are coupled to the gas and would be supplied to the circumplanetary disks with the inflowing gas (e.g., Canup & Ward 2002). Planetesimals that are large enough to become decoupled from the motion of the gas can be captured by gas drag from the circumplanetary gas disk (Fujita et al. 2013). It has been recently shown that the efficiency of capture of planetesimals from their heliocentric orbits by gas drag from the circumplanetary disk is the highest for planetesimals with radii of 10-100m (Tanigawa et al. 2014). While the so-called type-I migration is important in the late stage of satellite formation, orbital evolution by aerodynamic gas drag governs the orbital evolution of small solid bodies, and dynamical evolution of such small bodies in the circumplanetary gas disks is important for the growth of protosatellites. In the present work, we examine orbital evolution of planetesimals in circumplanetary gas disks, and the probability of capture of such small bodies by a growing protosatellite (Shimizu & Ohtsuki, in preparation).

We numerically evaluate the probability of collision of migrating planetesimals with the protosatellite, and its dependence on the size of planetesimals. We find that the collision probability has a peak at a certain size. This is because the time scale of the orbital decay varies depending on the size of planetesimals. We also examined cases of various masses and semi-major axes of the protosatellite, and obtained similar results. Finally, we will also discuss effects of gravitational interaction between planetesimals (Kawamura, Ohtsuki, Suetsugu, this meeting).

キーワード：衛星形成
Keywords: Satellite formation

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# レーザー衝撃圧縮実験による氷惑星内部物質探査

# Insulator to electronic conductor transition of synthetic planetary ices at interior conditions of icy giants compressed by laser-driven shock wave

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Ices in the universe are consisting of hydrogen, oxygen, carbon, and nitrogen. These elements coalesced to develop into icy giant planets such as Uranus and Neptune in the solar system, as well as some water planets occurring in extrasolar planetary systems. Properties of such planetary ices at elevated pressures and temperatures are essential clues for understanding the layering structures and material circulations inside these giants. Here by using high-power nanosecond laser pulses from GEKKO-XII glass laser at Institute of Laser Engineering at Osaka University, such ices of several compositional types are dynamically compressed, where their equation-of-state (P-V-T) and optical reflectivity (R) are measured at in situ conditions using fast optical diagnostics (Figure). We have successfully observed the transition from insulator to electronic conductor state of the planetary ices which include carbon and/or nitrogen components, as well as that transition of pure H2O ice observed by our previous work [1]. We have also observed the transition at off-Hugoniot conditions using a sample-precompression technique with a diamond anvil cell, which was effectively coupled with laser-driven shock to increase the shock-pressure and to decrease the shock-temperature. These results provide us a new insight about the nature of conducting media inside the icy giants and about the origin of magnetic fields from deep inside of them.

[1] T. Kimura, N. Ozaki, T. Sano, T. Okuchi, et al., J. Chem. Phys., 142, 164504 (2015).

キーワード：氷惑星、レーザー衝撃圧縮、オフユゴニオ条件、惑星磁場
Keywords: icy giant planets, laser-driven shock compression, off-Hugoniot conditions, planetary magnetic field

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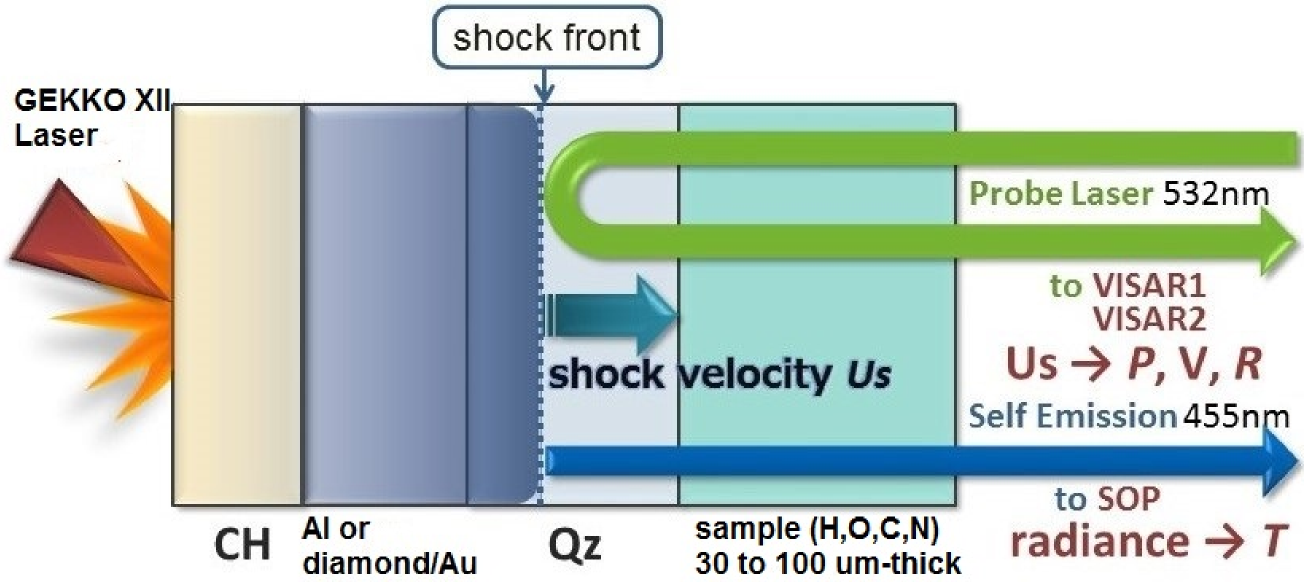


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A massive primordial-atmosphere on proto-Titan formed in a gas-starved disk
A massive primordial-atmosphere on proto-Titan formed in a gas-starved disk

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Titan is a known as a satellite with a thick atmosphere (1.5 bar at the surface) mainly composed of nitrogen. Although several hypotheses about the origin of atmosphere have been proposed, it remains an open question how and when such a thick atmosphere was generated. According to the recent satellite formation theory [e.g., Canup and Ward 2002], Titan formed within low temperature and pressure disk. We numerically investigate the property of the primordial atmosphere of Titan that grew in such a circum-planetary disk, especially in terms of the atmospheric mass and the blanketing effect. In spite of such a disk condition, Titan could capture a thick atmosphere strongly bounded by gravity, which is mainly composed of nebula gas components. This would cause a significant blanketing effect inducing differentiation of this satellite, and result in keeping the surface temperature high relatively (~200 K). This suggests that an ammonia-rich proto atmosphere could be kept on Titan even after the disk was dissipated. Titan’s current nitrogen would be generated from ammonia in the proto atmosphere by photochemical reaction [Atreya et al., 1978]

キーワード：タイタン、大気
Keywords: Titan, Atmosphere

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# UMISTデータベースを用いた化学反応ネットワーク計算によるタイタン成層圏の未発見分子の予測
# Predicting undiscovered species in Titan’s stratosphere with chemical reaction network based on UMIST database

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Titan, the largest moon of Saturn, is the only satellite that has a dense atmosphere in the solar system. It is known that Titan's atmosphere contains a wide variety of chemical species which mainly generated from the dissociation of two main components, molecular nitrogen and methane. Fractional abundances of these species have been studied well by the Voyager and Cassini-Huygens probes. Also, ALMA now starts to detect global distribution of some species in the Titan’s atmosphere. In this study, we applied chemical reaction network based on UMIST database, which has been used in the studies of interstellar medium, to calculate the chemical evolution of Titan’s upper stratosphere around 200 km from the satellite surface, where most of the observation data of molecular abundances heretofore located. In this chemical network calculation, 375 species are included, which are three times more than previous studies (Wilson et al. 2004 & Loison et al. 2015). We note that the effects of turbulent diffusion and three-body reactions are not included in the calculation. By comparing results of calculations with the observational data, a physical parameter set with moderate FUV flux, effect of cosmic ray and self-shielding of molecular nitrogen and methane is recommended. As a result, 17 nitrogen compounds (e.g. NH2CN CH3C5N HC7N) are abundant and could be detectable in the future observations of ALMA.

キーワード：タイタン大気、化学反応ネットワーク計算、アルマ観測
Keywords: Titan's atmosphere, chemical reaction network, ALMA observations

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# 冥王星地下海の安定性
# Stability of subsurface ocean in Pluto

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NASA's New Horizons spacecraft made its close flyby of the dwarf planet Pluto on July 14, 2015. The LORRI imaging system aboard spacecraft has acquired global images and unveiled a diverse range of landforms, from rugged mountainous region to extremely smooth plains, indicating geological processes that have substantially and recently modified the surface. Combining that accurate determinations of the mean radii of Pluto suggests that Pluto is a sphere, Pluto had or has a relatively warm interior (maybe an ocean) for the most part of its history.

Nitrogen ($N_2$) ice, higher volatility (melting point of 63 K in vacuum) than water ice, has been known from ground-based spectroscopy and the New Horizons has confirmed that $N_2$ (and $CH_4$) ice is enriched in the bright smooth plains, e.g., Sputnik Planum (SP). The ALICE, ultraviolet imaging spectrograph, has observed Pluto’s nitrogen-rich atmosphere as far as 1,600 kilometers above the surface of the planet, demonstrating that nitrogen is volumetrically dominant on Pluto. In parallel, water ice is widely distributed on Pluto, in particular, on rugged mountainous region having relatively older age than SP. It implies that Pluto is covered by huge amount of water ice and few-km thickness nitrogen presents above water ice “bedrock” based on the molecular abundances in the Solar System. High volatility of nitrogen ice can lead to melting and rapid thinning of the ice shell (and forming an internal nitrogen ocean) and can drive tectonics on Pluto even if radiogenic heating is expected to be rather low at present and tidal heating is not efficient.

Here we are going to show the results of numerical simulation for the thermal history in Pluto, and this dwarf planet far away from the Sun has a potential to harbor an ocean and thin solid nitrogen crust might be able to support 2-3 km height ragged mountains even few-km thickness.

キーワード：冥王星、地下海、内部構造、宇宙生命学
Keywords: Pluto, Subsurface ocean, Interior, Astrobiology

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# The Effect of Surface Ice and Topography on the Atmospheric Circulation and Distribution of Nitrogen Ice on Pluto

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A newly developed general circulation model (GCM) for Pluto is used to investigate the unexpected and highly heterogeneous distribution of nitrogen surface ice imaged by the New Horizons spacecraft on the surface of Pluto. The GCM is based on the GFDL Flexible Modeling System (FMS) dynamical core, solved on a discretized latitude/longitude horizontal grid and a pressure-based hybrid vertical coordinate. Model physics include a 3-band radiative scheme, molecular thermal conduction within the atmosphere, subsurface thermal conduction, and a nitrogen volatile cycle. The radiative-conductive model takes into account the 2.3, 3.3 and 7.8 mm bands of $CH_4$, including non-local thermodynamic equilibrium effects. The subsurface conduction model assumes a water ice regolith. In the case of nitrogen surface ice deposition, additional super-surface layers are added above the water ice regolith to properly account for conductive energy flow through the nitrogen ice. The nitrogen volatile cycle is based on a vapor pressure equilibrium assumption between the atmosphere and surface. Prior to the arrival of the New Horizons spacecraft, the expectation was that the volatile surface ice distribution on the surface of Pluto would be strongly controlled by the latitudinal temperature gradient resulting primarily from the slow seasonal variations of radiative-conductive equilibrium. If this were the case, then Pluto would have broad latitudinal bands of both ice covered surface and ice free surface, as dictated by the season. Furthermore, the circulation, and thus the transport of volatiles, was thought to be driven almost exclusively by sublimation and deposition flows (so-called “condensation flows”) associated with the volatile cycle. In contrast to expectations, images from New Horizon showed an extremely complex, heterogeneous distribution of surface ices draped over topography of substantial geologic diversity. To maintain such an ice distribution, the atmospheric circulation and volatile transport must be more complex than previously envisioned. Topography, the distribution of nitrogen ice itself, and an overall large-scale atmospheric circulation at least partially independent of the condensation flows must play a role. Simulations where topography, surface ice distributions, and volatile cycle physics are added individually and in various combinations are used to individually quantify the importance of the general circulation, topography, surface ice distributions and condensation flows. It is shown that even regional patches of ice or large craters, much like that of Tombaugh Regio, can have global impacts on the atmospheric circulation, the volatile cycle, and hence, the distribution of surface ices. This work demonstrates that explaining Pluto’s volatile cycle and the expression of that cycle in the surface ice distribution requires consideration of atmospheric processes beyond simple vapor pressure equilibrium arguments.

Keywords: Plluto, Atmosphere, Dynamics

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# Neutral pH of water on early Ceres

Neutral pH of water on early Ceres

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Ceres, the ice-rich dwarf planet in the asteroid belt, would provide a clue to understand formation processes of the planets in the solar system, as it is considered as one of a few proto-planets remaining today (Castillo-Rogez and McCord, 2010). Ceres' surface reflectance spectra show a unique absorption at 3.06 μm, which is recently found to be caused by the presence of NH4-bearing hydrated silicates (e.g., mica) (De Sanctis et al., 2015). This in turn means that a large amount of NH3 should have been contained in Ceres' interior ocean formed in the early stage of its evolution, and that Ceres' building materials would have been originated from the outer solar system beyond the snowline of NH3 (De Sanctis et al., 2015). However, the formation of NH4-bearing hydrated silicates would depend on not only the presence of NH3 in the ocean but also the chemical compositions and pH of the interior ocean where the hydrated silicates were formed. Here, we performed hydrothermal experiments to constrain pH of the water on early Ceres. Based on the chemical analysis and comparisons of infrared spectra of the produced hydrated silicates, together with the findings of carbonates on Ceres, we show that pH of water on early Ceres should be near neutral. This is because NH4+ ions are incorporated into hydrated silicates under neutral pH conditions. To achieve neutral pH in the water, the rock compositions of Ceres would be different from that of carbonaceous chondrites. As sulfate salts were found on Ceres (Nathues et al., 2015), large amounts of sulfate ions may have worked as a major anion to keep the water pH as neutral. This further suggests that reducing sulfur in the core would have been oxidized by igneous activity on early Ceres sustained by short-lived radiogenic heating upon its early formation (within 3-5 Mys after CAIs).

キーワード：Ceres、hydrothermal reactions、water
Keywords: Ceres, hydrothermal reactions, water

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# Exploration of Extraterrestrial Ocean Worlds -results from Cassini and perspectives

Exploration of Extraterrestrial Ocean Worlds -results from Cassini and perspectives

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The Cassini mission, which has been in Saturn’s system for more than a decade, has discovered two ocean worlds: Enceladus, a tiny moon 252 km in radius and Titan, a large moon 2575 km in radius which is the only moon in the solar system with a dense atmosphere. For each of these satellites of Saturn, the ocean is located beneath a thick icy crust. Enceladus is characterized by the presence of jets that eject samples of the deep ocean into space. The data gathered by the Cassini instruments suggest the presence of hydrothermal activity (Hsu et al., 2015). Recent measurements of Enceladus’ librations are best explained by a decoupling between the icy crust and the inner core, suggesting the presence of a global ocean. Maintaining a global ocean during billions of years is a challenge for thermal evolution models of a tiny moon in a very cold environment. Titan is characterized by its dense atmosphere where large organic molecules are produced. These heavy molecules eventually form the organic haze that falls on Titan’s surface and may constitute the sand of the equatorial dunes. Titan is also characterized by hydrocarbon seas at the North Pole making Titan, the only other object besides Earth with stable liquid bodies on its surface. Although the organic cycle has been studied by the Cassini missions, there are still major scientific questions such as the molecular and elementary composition of the heavy organics and the processes responsible for the replenishment in methane of Titan’s atmosphere.
Enceladus can be compared with Europa in the sense that the global ocean is in contact with a rocky core where conditions are very similar to those existing on the terrestrial sea-floor. The fact that its ocean is being ejected into space makes measurements into the plume a science priority for future missions to Enceladus. Europa is the target of a planned NASA flagship mission for which the instruments to be mounted on the spacecraft have already been selected. This mission would characterize Europa’s deep ocean. Although the presence of a plume (Roth et al., 2013) that would eject samples of Europa ocean into space is still debated, assets that would analyze this potential plume are being studied.
Titan can be compared to Callisto and Ganymede, Jupiter’s largest moons, which have very similar mass and radius. Interpretation of the magnetic field measurements at Ganymede and Callisto by the Galileo mission suggests that they also have a deep ocean. Similarly, interpretation of (i) the electric signal recorded by the Huygens probe during its descent in Titan’s atmosphere in January 2005 and (ii) the value of the tidal Love number k2, suggest that an ocean is present beneath Titan’s icy crust. On these three large moons, models based on the equation of state of $H_2O$ and values of the moment of inertia, a measure of mass repartition, suggest that this deep ocean would not be in contact with silicates because a high-pressure layer of ice would be present between the ocean and the rocky core. This paper will investigate the conditions under which the liquid water may have been in contact with the silicates in the past. This question is important to assess the habitability potential of these large icy moons. Ganymede and to a lesser degree Callisto will be the targets of the ESA JUICE mission, the first large mission of the ESA “Cosmic Vision” program. The primary goal of the JUICE mission is to characterize the oceans of Ganymede and Callisto.
This work has been performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

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キーワード：Ocean Worlds、Enceladus、Titan、Europa
Keywords: Ocean Worlds, Enceladus, Titan, Europa

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# The Science Case for the Ganymede Laser Altimeter (GALA) on ESA's Jupiter Icy Moons Explorer (JUICE)

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The Ganymede Laser Altimeter (GALA) is one of ten selected instruments for ESA's JUICE mission. Here we will give an overview on the scientific objectives for Europa, Callisto, and in particular, Ganymede to be accomplished by GALA. By obtaining range measurements during flybys at the moons and in orbit around Ganymede, geodetic and geophysical objectives will be addressed. Prime objectives at Ganymede are (1) determining the satellite's topography on global, regional, and local scales and (2) measuring tidal surface deformations. The topography measurements will provide information on the body's shape in relation to hydrostatic equilibrium. It will characterize topographic depressions and elevated regions for impact basins and other large scale features. Local topography will give insight into formation mechanisms for geologic features, e.g. the grooved terrain, cryo-volcanic sites, and impact structures. By obtaining range measurements at different tidal phases along Ganymede's orbit, the radial surface displacement can be measured. The tidal amplitudes are crucial to confirm a subsurface ocean on Ganymede. In addition the tidal phase-lag, if it can be detected, can provide key information on the deep interior of the satellite and the global dissipation inside Ganymede. Geodetic measurements will focus on the rotation state of Ganymede including the orientation of the pole and possible physical librations in longitude. By analyzing the spreading of the return pulse, the surface roughness on the scale of the laser footprint, i.e. approximately 50 m at the nominal 500-km orbit, can be determined. The slopes between individual laser spots along the track provide further information on surface roughness on larger scales, possibly correlated with geological features. The albedo at the laser wavelength of 1064 nm is obtained from each shot. Possible correlations with topographic heights and specific surface features can provide information on geological processes and on the interaction of the surface with the moon's radiation and particle environment. On Callisto, the measurements will be focused on a global shape determination to test whether this satellite which is only partially differentiated, is in a hydrostatic state. In addition impact structures of different sizes and types will be characterized by high-frequency along-track measurements. On Europa, the ground-tracks will focus on recently active sites and chaos regions. Combined with subsurface radar measurements and imaging data, this will provide insight in the formation mechanism of these unique features on Europa that are probably related to liquid water reservoirs near the subsurface. Constraints on the global shape of Europa will be provided by the flyby laser profiles with high spatial resolution. In addition surface roughness and reflectivity will be measured during the Callisto and Europa flybys.

Keywords: Jupiter, Ganymede, Laser Altimetry

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# NASA’s Flagship Mission to Jupiter’s Moon Europa: Exploring a Potentially Habitable World

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It is expected that Jupiter's moon Europa may have the three ingredients thought necessary for life to exist: liquid water, chemical elements from which to build organic molecules, and chemical energy. Europa is hypothesized to have the three ingredients in the form of: (1) an extensive saltwater ocean beneath an ice shell that is geodynamically active and relatively thin (several kilometers to several tens of kilometers thick); (2) key chemical elements derived from the primordial chondritic composition of the Jovian protoplanetary disk, plus delivery by asteroids and comets over time; and (3) a source of chemical energy for life, from the combination of irradiation of its surface to produce oxidants, plus hydrothermal activity and/or serpentinization at its ocean floor to produce reductants.

NASA recently approved the development of a flagship-level mission to explore Europa, with the specific goal of investigating its habitability. The spacecraft will launch some time in the next decade, and will arrive in the Jupiter system between 3 and 7 years later, depending on which launch vehicle and trajectory is selected. In order to survive the harsh Jovian radiation environment, the spacecraft will orbit Jupiter, dipping in and out of its radiation belts, and will encounter Europa at different positions in its orbit for a total of over 40 close flybys. This strategy allows data to be acquired from across most of the moon’s surface and enables particles and fields measurements to be made in the local vicinity.

High-priority science will be accomplished through interrogations of the moon’s ice shell, ocean, composition, geology, and current activity. The payload consists of five remote sensing instruments that cover the wavelength range from ultraviolet through radar and four *in-situ* instruments that measure fields and particles; moreover, gravity science can be achieved via the telecom system, and valuable scientific data could come from the spacecraft’s planned engineering radiation monitoring system. The remote sensing instruments are: an ultraviolet spectrograph (Europa-UVS); a wide-angle and narrow-angle visible camera system (EIS); an infrared spectrometer (MISE); a thermal instrument (E-THEMIS); and an ice-penetrating radar (REASON). The *in-situ* instruments are: a magnetometer suite (ICEMAG); a plasma instrument (PIMS); a time-of-flight mass spectrometer (MASPEX); and a dust analyzer (SUDA). Taken together, the payload has the potential to test hypotheses and make discoveries relevant to the composition, interior, and geology of Europa, in order to address the potential habitability of this intriguing moon.

Keywords: Europa , Mission, Habitability, Spacecraft

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# Deep Plume Interaction with Gas Giant Weather Layers: Preparing for Juno and Cassini Observations

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The weather layers of Jupiter and Saturn receive both solar radiation and heat from the deep interior. Currently, most numerical models fall into two broad categories: Deep, dry and convecting interior models that lack a stably stratified troposphere above, or thin shells that represent only a troposphere, with parameterized heating from the lower boundary. Here we present the results from a new coupled model that allows resolved deep convective plumes to interact with a stable "weather layer". We demonstrate the relative importance of a stable tropospheric lapse rate and the magnitude of bottom heating on the strength and depth of the jets. Studies of this kind will benefit understanding of Jupiter's dynamics, in particular the depth of the cloud-level jets, in advance of Juno's 2016 arrival. Moreover, the difference between Saturn and Jupiter is explored using a parameter sweep of tropospheric stability, which acts as a proxy for tropospheric water abundance.

Keywords: Jupiter, Juno, Atmospheric Dynamics

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# Magnetic Field Observations; at Saturn with CASSINI and at Jupiter with JUICE.

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Some of the highlights of discoveries made utilising magnetic field observations from the Cassini spacecraft at Saturn will be described. These include the planetary period oscillations that fill the Saturnian magnetosphere, that change over time, and that are different between the northern and southern hemisphere. The need to understand these observations is critical for Cassini end of mission science during which time the spacecraft will have 22 close flybys to Saturn, enabling resolution of the planetary dynamo field as well as how long a day is on Saturn. The discovery by the magnetometer team of a dynamic south polar plume on Enceladus, one of Saturn’s icy moons , will also be described. We will also look to the future and the required measurements the magnetometer, onboard the ESA JUICE mission to Jupiter and it’s moons, will need to make. The most difficult measurement as well as the most interesting is that of the induced magnetic field signatures in a liquid subsurface ocean at Ganymede. Resolving these signatures at more than one inducing frequency will allow unambiguous determination of both the depth and conductivity of the ocean and potentially of its global extent.

Keywords: Jupiter, Saturn, Magnetic field, CASSINI, JUICE

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# Synergetic Multi-Wavelength Observation of Jupiter's Magnetosphere Driven by Hisaki: Recent Results and Plans for JUNO Mission

Synergetic Multi-Wavelength Observation of Jupiter's Magnetosphere Driven by Hisaki: Recent Results and Plans for JUNO Mission

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JAXA Hisaki satellite is an EUV space telescope dedicated for continuous monitoring of planetary atmospheric and plasma environments. Synergetic multi-wavelength observing campaigns for Jupiter’s magnetosphere have been carried out by Hisaki with other ground-based and space telescopes from 2014 to the present. Here we report some highlights of the synergetic campaign and present plans for the coordinated observation with NASA JUNO mission in 2016-2017.

キーワード：ひさき、木星磁気圏、JUNO
Keywords: Hisaki, Jupiter's magnetosphere, JUNO

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# Jupiter's auroral observations by Hisaki/EXCEED and expectation toward collaborations with Juno

Jupiter's auroral observations by Hisaki/EXCEED and expectation toward collaborations with Juno

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Ultraviolet (UV) emissions from atmospheric $H_2$ and H reflect powerful polar energetics at outer planets. UV spectra provides information related with the precipitating auroral electron energy. Auroral electron energy and flux relationship shows variety among Jupiter’s auroral regions. The spectrometer EXCEED onboard JAXA’s Earth-orbiting planetary telescope Hisaki monitors extreme UV emissions from Jovian aurora and Io plasma torus continuously. Hisaki succeeded to detect sporadic, large auroral power enhancements lasting both short- (<1 planetary rotation) and long-term (>a few rotations) variations and their modulations by an Io’s volcanic activity over several weeks. The spectral information taken by Hisaki enables us to investigate (1) the time variation of the auroral electron during these emission enhancements, (2) statistical survey for occurrence of polar-dominant events, and (3) associated magnetospheric dynamics for these emission enhancement events using the Knight’s aurora acceleration theory. Expecting collaborative observation with Juno will be discussed.

キーワード：木星、オーロラ、EXCEED/ひさき
Keywords: Jupiter, Aurora, EXCEED/Hisaki

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# 衛星イオ火山活動による木星磁気圏へのプラズマ供給変動と磁気圏への影響：ひさき衛星観測
# Io's volcanic influence on the Jovian magnetosphere: HISAKI observation

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The satellite Io which has many active volcanos supplies volcanic gases to the Jovian magnetosphere with a typical rate of 1 ton/sec and has is a primary source of plasmas in the magnetosphere. Change in the volcanic activity would cause change in plasma supply rate to the magnetosphere and could affect structure of the magnetosphere and dynamics occurring in it. However, responses of the magnetosphere to the plasma supply rate change is still not fully understood. The extreme ultraviolet (EUV) spectroscope, EXCEED, onboard the HISAKI satellite made observations of Io plasma torus and Jovian northern aurora from the end of Nov. 2014 to middle of May 2015 continuously. On middle of Jan. 2015, HISAKI detected gradual increase in intensity of $S^{+}$ emission lines and decrease of $S^{3+}$ ones in the plasma torus. The S+ intensity showed a maximum around the end of Feb. and $S^{2+}$ and $S^{3+}$ intensities also showed maxima subsequently. Simultaneous ground based observation of the sodium nebula showed increase of the emission intensity from the middle of Jan. to Feb. These observations suggest that the volcanic activity enhancement started at the middle of Jan. and increase neutral atom and ion densities in the Io torus. Change in radial structure of the plasma torus was also detected. The intensity of $S^{+}$ ion began to increase around the orbit of Io (6 Jovian radii). The brightened region propagated outward and reached at 8.5 Jovian radii from Jupiter at the beginning of Feb. Further one month later, HISAKI found unusual activity of Jovian EUV aurora intensity. It began at the beginning of Mar. and continued for 1 month. The enhancement of the aurora activity may be caused by the enhanced loading of heavy ion plasma into the middle magnetosphere.

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# 「ひさき」観測から求める木星内部磁気圏の硫黄・酸素イオン空間分布
# Radial distribution of sulfur and oxygen ions in the Io plasma torus observed by Hisaki spacecraft

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The imaging spectrum of Io plasma torus in extreme ultraviolet (50-150nm) has been observed by EXCEED on Hisaki. We analyzed them using the spectrum diagnosis method and deduced the column averaged plasma parameters (such as S+, S++, S+++, O+, etc.) from the radial distance of 6 to 8 Jovian radii. The local densities of those ions are deduced and the clear increase of S+ (about 3 times) after the Io’s outburst event in 2015 are seen.

キーワード：イオプラズマトーラス、硫黄、酸素
Keywords: Io plasma torus, sulfur, oxygen

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# 高分解能画像に基づくガリレオ衛星の傾斜、ラフネス特徴
# Slope and roughness characteristics derived from high-resolution images of Galilean satellites

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Topographic data is fundamental information to investigate geology at various scales. The Galileo spacecraft has obtained high-resolution images of the Galilean satellites at a scale up to approximately ten meters per pixel, which provide an insight into diverse geologies and surface materials associated with tectonics, cratering, and sublimation. Putative subsurface oceans on Europa, Ganymede, and Callisto indicated by inductive magnetic fields and aurorae shifting are top priority for the next planetary exploration. Measuring topography at a scale of ten-meter also could be essential for designing radar sounder, laser altimeter, and lander. These instruments are expected to detect putative subsurface oceans on Jovian icy satellites. Nevertheless, no quantitative topographic data at the scale has yet been obtained, except for the surface of Europa. This is mainly consequence of previous digital elevation models (DEMs) with spatial resolutions higher than 50 m being only available for the southeast region of the Tyre crater of Europa (33 m/pixel). Current knowledge of topographic features of the Galilean satellites is only derived from stereo image (SI) analysis or photoclinometry (PC) because of the absence of laser altimetry data. The slopes and roughness strongly depend on the spatial resolution of topographic data. In general, higher spatial resolution provides steeper slope histograms. We reexamined high-resolution images obtained by the SSI camera onboard the Galileo spacecraft using SI analysis and PC.
As for SI analysis, we used Integrated Software for Imagers and Spectrometers (ISIS3) produced by USGS to calibrate the SSI raw images radiometrically and perform bundle adjustment. Then we applied NASA’s Ames Stereo Pipeline software (ASP) to compute DEMs. ASP is a suite of automated SI analysis tools developed by NASA and designed for processing planetary images. To compute the slope, we i) selected a pixel from a DEM, ii) computed a least squares plane in a seven-pixel square centered around the selected pixel, iii) obtained the gradient of the least squares plane (the slope is defined as the gradient), and iv) performed (i) to (iii) over the entire DEM. Then, the total surface area of each DEM was normalized to 1. To compute roughness, we defined the roughness as the Allan deviation of differences in height (i.e. RMS deviation). In detail, we i) measured the difference in height between two points separated by a given distance (i.e. window length) along lines of constant longitude, ii) performed (i) over the entire DEM and collected differences in height over the entire DEM, and (iii) computed the Allan deviation of all differences in height obtained in (ii).
PC uses apparent brightness to estimated slope at each pixel, assuming a photometric function. We applied a photometric function that fits lunar-like surface. In order to compute roughness, we converted the slopes into height differences for each pixel. Then we integrated the height differences along the line of sight to construct one-dimensional topographic cross-section from line to line. Here roughness is defined as the Allan deviation of differences in height between two points separated by a given distance along the line of sight. We showed an average of the Allan deviation values for each window length among the all one-dimensional topographic profiles.
As a result, we obtained the slope histograms and roughness from SI analysis and PC. We found that most of Ganymede and the region of Callisto showing abundant knobs appear to be very rough surfaces

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as steep as 10 to 30º, while Europa and the region of Callisto without knobs mostly appear to be smoother than 10º. These results are far from previous estimates based on topographic data with the lower resolution. Also, this implies that instrument performances are expected to be strongly affected by the steep slopes in the former areas.

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# ガニメデ地下海の安定性
# Stability of subsurface oceam in Ganymede

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The outer solar system provides potential habitats for extra-terrestrial life. Past spacecraft's and telescopic observations support that the Jovian icy moons may harbor water oceans beneath the icy crusts. However evidence for oceans is not definitive and awaits confirmation measurements. Also their depth and composition remain unclear, as do their stability and variability with time. Here we focus on Ganymede, the largest moon in the Solar System and the primary target the Jupiter Icy Moons Explorer (JUICE). To investigate the stability of an ocean (structural, thermal and compositional change through time) assumed to be initially in an entirely liquid state, we performed numerical simulations for the internal thermal evolution using an one-dimensional spherically symmetric model for the convective and conductive heat transfer, with radial dependence of viscosity, heat source distribution, and other material properties. We take into account the energy due to decay of long-lived radioactive elements and also evaluate the effect of tidal heating. To see the temporal change of the boundary position between solid ice layers including ice shell and high-pressure ice mantle, we also evaluate the energy balance at the phase boundaries between the solid and liquid $H_2O$ layer, and the movements of the positions of these boundaries are calculated by evaluating the heat balance between incoming and outgoing flux at the boundaries considering with latent heat (classically known as a Stefan problem).

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# Feasibility of the exploration of the subsurface structures of Jupiter’s icy moons by Jovian hectometric radiation

Feasibility of the exploration of the subsurface structures of Jupiter’s icy moons by Jovian hectometric radiation

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A new method for detection of the subsurface structures in the ice crust of Jupiter’s moons by using interference patterns found in the spectrogram of the Jovian hectometric radio emissions (HOM) have been proposed. In Jupiter icy moon explorer (JUICE) mission, plasma wave observation around icy moons are planned by using radio and plasma wave instrument (RPWI). In this observations, we will be able to obtain spectrograms of the HOM propagating from Jupiter. Because the emissions directly from Jupiter can be interfered with the emissions reflected at the icy moon’s surface and subsurface boundaries, we will find interference patterns in the measured spectrograms. In case of the Earth's Moon, the lunar orbiter SELENE detected the interference patters in the spectrograms of auroral kilometric radiation (AKR) [Ono et al., 2010; Goto et al., 2011]. Because the interference occurs between AKR directly from the earth and AKR reflected at the lunar surface, the amplitude of the interference patterns are almost constant. In case of Jupiter’s icy moons, HOM directly from Jupiter, HOM reflected at the icy crust surface, and HOM reflected at the fully-freezed/partial-melted or high/low-porosity boundary in the ice crust. Due to slight phase difference between HOM emissions reflected at the surface and subsurface boundaries, the amplitude of the interference patterns will be modulated. The depth of the liquid ocean can be determined the frequency width of the modulation. Assuming that the frequency of HOM is ~10 MHz, the permittivity of the icy crust is 3, permittivity of the melted ice is 87, loss rate in the icy crust is 2-9 dB/km, and spacecraft height is 500 km, the maximum detection depth is estimated to be 6-23 km, which is less than the estimated ice thickness of the Ganymede, 150 km [Kivelson et al., 2002]. On the other hand, we can also expect lower attenuation rate than 2-9 dB/km in a depth range where the ice temperature is much lower than 240 K. The receiver’s specifications needed for measurement of the interference patterns in the spectrogram are as follows: (1) Frequency resolution: 100 Hz, and (2) The interval of spectrum measurements: 30 sec. In addition, the following two issues have to be considered in actual application: (a) HOM itself has band structures in the spectrogram due to anisotropy of the emission at the source. (b) The roughness of the surface and subsurface boundaries has to be within the half wavelength (~15 m). (c) The delay by inhomogeneity of TEC of the moon’s ionosphere has to be less than the half of the period of the HOM (~0.05msec), which corresponds to the dTEC ~ $9.3 \times 10^{12}$ $m^{-2}$.

キーワード：Passive subsurface radar、Jupiter Icy Moon Explorer (JUICE)、Radio and plasma wave instrument (RPWI)
Keywords: Passive subsurface radar, Jupiter Icy Moon Explorer (JUICE), Radio and plasma wave instrument (RPWI)

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# Software-type Wave-Particle Interaction Analyzer (SWPIA) by RPWI for JUICE: Science objectives and implementation

Software-type Wave-Particle Interaction Analyzer (SWPIA) by RPWI for JUICE: Science objectives and implementation

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We present science objectives of Software-type Wave-Particle Interaction Analyzer (SWPIA), which will be realized as a software function of Low-Frequency receiver (LF) running on the DPU of RPWI (Radio and Plasma Waves Investigation; PI: J.-E. Wahlund, IRF-Uppsala, Sweden) for the ESA JUICE mission. SWPIA conducts onboard computations of physical quantities indicating the energy exchange between plasma waves and energetic ions. Onboard inter-instruments communications are necessary to realize SWPIA, which will be implemented by efforts of RPWI, PEP (Particle Environment Package; PI: Stas Barabash, IR-Kiruna, Sweden) and J-MAG (JUICE Magnetometer; PI: M. Dougherty, ICL, UK). By providing the direct evidence of ion energization processes by plasma waves around Jovian satellites, SWPIA contributes scientific output of JUICE as much as possible with keeping its impact on the telemetry data size to a minimum.

SWPIA measures the energy transfer process between energetic particles and electromagnetic plasma waves [Fukuhara et al., EPS 2009; Katoh et al., AnGeo 2013]. SWPIA will be firstly realized in the ERG satellite mission of JAXA to measure interactions between relativistic electrons and whistler-mode chorus in the Earth's inner magnetosphere. We will apply SWPIA to ion-scale wave-particle interactions occurring in the Jovian magnetosphere. SWPIA clarifies where/when/how heavy ions are energized by waves in the region close to Ganymede and other Jovian satellites. In SWPIA of RPWI for JUICE, we focus on the interactions between energetic ions (a few to tens of keV) and ion cyclotron waves (typically less than 1 Hz). SWPIA uses wave electromagnetic field and ion velocity vectors provided by RPWI sensors and PEP, respectively, with referring three-components of the background magnetic field detected by J-MAG. SWPIA measures a relative phase angle between the velocity vector vi of i-th particle of charge qi and the wave electric field vector at the timing of particle's detection (E(ti)) and computes an inner product of W(ti) = qiE(ti) dot vi, where W(ti) corresponds to the variation of the kinetic energy of the i-th energetic particle. We accumulate W for detected particles to obtain Wint = Sigma_i W(ti), and we expect statistically significant values of Wint for the case of the measurement at the site of efficient wave-particle interactions. In this presentation, we discuss details of the implementation of SWPIA of RPWI and

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inter-instruments communications among RPWI-PEP-J-MAG of JUICE.

キーワード：木星磁気圏、木星衛星、波動粒子相互作用
Keywords: Jovian magnetosphere, Jovian satellite, wave-particle interactions

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# JUICE衛星搭載用非熱的中性粒子観測器の開発
evelopment of a low-energy energetic neutral atom analyzer (PEP/JNA) for JUICE

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We are developping a low-energy (10eV-3keV) energetic neutral atom analyser (PEP/JNA) which is to be onboard European JUICE spacecraft. 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. We will discuss current status of JNA.

キーワード：非熱的中性粒子、JUICE
Keywords: Energetic neutral atom, JUICE

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# 木星の中間磁気圏の擾乱に対するイオプラズマトーラスの応答
Responses of Io Plasma Torus to middle magnetosphere of Jupiter

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木星の衛星イオには火山活動があり、硫黄や酸素を含むガスが内部磁気圏に放出されている。この火山ガス起源のプラズマがイオの公転軌道に沿ってトーラス状に分布していることが光学観測で明らかにされており、イオプラズマトーラス（IPT）と呼ばれている。また、木星極域にオーロラが常時発生していることも観測されている。2000年、カッシーニ探査機が木星のフライバイをする際に、IPTと木星オーロラを同時に観測し、両者が非常に短い時間差で突発的に増光していることを発見した。IPTの発光は内部磁気圏の状態を反映し、木星オーロラの発光は中間磁気圏の活動度の指標となるため、内部・中間磁気圏間に未知のエネルギー輸送プロセスが存在することの証拠であると考えられた。しかし、カッシーニ探査機の観測では観測休止時間が増光現象の継続時間に比べて長く，両者の相関関係や時間差の決定が困難であり、エネルギー輸送機構の特定にはいたらなかった。2013年9月にイプシロンロケットにより地球周回軌道に打ち上げられたHISAKI/EXCEEDは惑星専用の宇宙望遠鏡であり、木星磁気圏を高い時間分解能（約1時間）で、長期的かつ継続的に観測を行っている。EXCEEDのデータを使用したIPT・オーロラ増光イベントの詳細な解析により、IPTの増光は高温電子の増加に起因する現象であることが分かった。また、オーロラとIPTの増光の時間差は約11時間であり、これは中間磁気圏からIPTへの高温電子の輸送のタイムスケールを示していると考えられる。本発表では、EXCEEDの観測によって明らかになったIPT・オーロラ増光イベントの時間的、空間的な特徴を示し、木星磁気圏におけるエネルギー輸送の謎を解き明かしていく。

キーワード：木星、磁気圏、オーロラ、イオプラズマトーラス
Keywords: Jupiter, magnetosphere, aurora, Io plasma torus

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Horizontal and vertical structures of the Jovian IR aurora from plasma and neutral atmospheres: Observation by SUBARU/IRCS with Adaptive Optics
Horizontal and vertical structures of the Jovian IR aurora from plasma and neutral atmospheres: Observation by SUBARU/IRCS with Adaptive Optics

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In the rotational driven magnetosphere of Jupiter, the momentum and energy transfers between thermosphere and ionosphere is the key part of the magnetosphere, ionosphere and thermosphere (MIT) coupling. Jovian aurora, emitted from this region through this process, does not only shows the strength of magnetospheric activities but also affects to the ion-neutral interactions.
Previous observations have shown the morphological difference between plasma ($H_3^+$) and neutral (IR $H_2$) emissions. It suggests the difference between strong electron precipitating area exciting the plasma emissions and the heated area exciting the neutral emissions. In order to investigate their emission mechanisms and relationships to the energy injection processes, the comparison between $H_3^+$ fundamental (v2=1→0) and overtone (v2=2→0) lines is also important. The different emission altitude of both emissions is caused by their different sensitivity to surrounding atmospheric temperature and density.
We first executed the quasi-simultaneous comparisons of the horizontal and vertical emission profiles in $H_3^+$ fundamental, $H_3^+$ overtone, and $H_2$ polar emissions, by the near infrared spectroscopy of Jovian polar emissions using SUBARU/IRCS on 31 January 2015. $H_2$ IR emission and $H_3^+$ overtone emissions are seen simultaneously in K-band spectra (2.03-2.22 μm), and $H_3^+$ fundamental emission in L-band (3.31-3.98 μm) is quasi-simultaneously taken by short interval, ~5 min. We also simulateounly took the slit viewer image of the $H_3^+$ fundamental line or K-band filter. During these observations, we used the adaptive optics system (AO188) when Galilean satellites could be used as a guide star, and achieved high spatial resolution, ~0.2 arcsec (~320 km of Jupiter). The slit was set along the rotational axis when AO188 could be used.
First, we compared the horizontal flux profiles. The morphological difference between $H_3^+$ fundamental and overtone emissions are small. Both have clear main oval emissions like the averaged UV aurora profile. On the other hand, IR $H_2$ emission does not show clear enhancement at the main oval. We also derived the horizontal profiles of temperature and column density from those emissions. $H_3^+$ fundamental lines have a better correlation with column density. $H_3^+$ overtone lines are more related to temperature. On the other hand, IR $H_2$ emission intensity does not show clear correlations.
Next, we derived the vertical structures of their volume emissivity profiles by “onion peeling” method. We confirm the result of Uno et al. (2014), the similar emission peak altitude between IR $H_2$ and $H_3^+$ overtone emissions in K-band. We also found that the peak altitude of $H_3^+$ fundamental emission was lower than them. Although the derived $H_3^+$ vertical emission profiles are not contradict to the theoretical models, and their derived temperatures represent those of emission peak altitudes, it is hard to explain the vertical profiles of IR $H_2$ volume emissivity by a simple ‘thermal excitation model’. It is also hard to explain the fact that the derived temperature from $H_2$ emissions from higher altitude (~700 K) is lower than that from $H_3^+$ fundamental emission in lower altitude (~1,000 K). We are now investigating possible scenarios for those points.
In May 2016, we will observe Jovian IR emission again, simultaneously with UV aurora by Hubble

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Space Telescope, EUV aurora and Io torus by Hisaki/EXCEED, and the upstream solar wind by NASA Juno spacecraft approaching to Jupiter. It will be the chance to solve the problems raised in this study.

キーワード：木星、赤外線オーロラ、水平構造、垂直構造
Keywords: Jupiter, infrared aurora, horizontal profiles, vertical profiles

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# ひさき衛星を用いた木星紫外オーロラの太陽風応答に関する統計解析

# Statistical study of the response of Jovian EUV aurora to the solar wind from Hisaki observations

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In order to reveal the solar wind response of Jovian extreme ultraviolet (EUV) auroral activity, we made a statistical analysis of Jovian EUV aurora obtained from long term Hisaki observation.
The EUV emission from hydrogen molecule is excited by collision with high energy electron. The main oval is one of the components of Jovian EUV aurora where the auroral particle precipitations are caused by the rotationally driven field-aligned current system. It is theoretically expected that angular velocity of magnetospheric plasma increases when the Jovian magnetosphere is compressed by enhanced solar wind pressure, which decreases the field-aligned current. Regarding this scenario, increase of the solar wind dynamic pressure is expected to be anti-correlated with the intensity of the EUV aurora. A previous observation such as that by International Ultraviolet Explorer (IUE) or Hubble Space Telescope (HST) showed the time variability of the EUV aurora, while their data still limited in continuity over solar wind variation with good time resolution. On the other hand, Hisaki satellite is an earth-orbiting EUV spectroscope launched in 2013 which has been continuously monitoring Jovian EUV auroral activity. Therefore, the Hisaki data sets are effective for investigating the solar wind response of Jovian aurora.
The purpose of this study is to investigate the solar wind response of Jovian EUV aurora observed by Hisaki. We used the EUV data set obtained from Dec. 2013 to Feb. 2014 and from Dec. 2014 to Feb. 2015. We compare the total EUV power over 900-1480 A and solar wind dynamic pressure which is extrapolated at Jupiter using a one-dimensional magnetohydrodynamic (MHD) model.
Superposed epoch analysis indicated that Jovian EUV aurora increases with the enhancement of the solar wind dynamic pressure. We also found a correlation between the total power of EUV aurora and the duration of the rarefaction region of the solar wind before the enhancement of the dynamic pressure. The similar trend could also be found in the thermal current, i.e., incoming electron flux increased with the duration of rarefaction region.
One possible scenario is that mass loading from Io increases the electron density in the Jovian middle magnetosphere and it also increases seed electron of the thermal current whose energy is several keV. The solar wind compression causes adiabatic acceleration of thermal current and then EUV aurora increases. However, it is still unclear how the angular velocity distribution and brightness distribution vary during the solar wind compression.

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キーワード：木星、オーロラ、太陽風応答
Keywords: Jupiter, Aurora, Solar wind response

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# ひさき衛星極端紫外光観測と地上可視光観測による木星衛星イオの硫黄イオントー ラスの時空間変動

# Variation in SII and SIII brightness distribution of Io plasma torus based on Hisaki/EXCEED and ground based observation data

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木星の衛星イオの軌道(6R$_J$)には、イオの火山ガスに起因するプラズマトーラスが形成される。このトーラス中の硫黄・酸素イオンは、電子(5eV-1keV)との衝突励起により極端紫外から可視に渡る広い波長範囲で発光する。常に明るく光るプラズマトーラスの発光を維持するには電子の温度を5eV程度に加熱し続ける必要があり、その主要な加熱源の一つとして火山ガスの電離により生じる数100eVのピックアップイオンから電子へのクーロン衝突が考えられている。「ひさき」衛星に搭載された極端紫外線分光撮像装置 EXCEED により、2014年12月から2015年3月にかけて、イオ火山噴火に伴うとみられるイオトーラス増光現象が観測された。本研究は、EXCEED と地上からの可視光イメージング観測データを用いて、トーラス増光現象期間（2014年 12 月-2015 年 3 月）におけるイオン温度と電子温度の時間変化の特徴とこの変化が生じた領域を調べることにより、電子の加熱機構を検証することを目的とする。可視イメージング観測が1価の硫黄イオンの発光分布を約1秒角の高空間分解能で撮像できるのに対し、EXCEEDは広い波長域のスペクトル観測から、多価の硫黄イオンと電子温度の情報を得ることができる。EXCEEDが観測したトーラス増光現象期間(2014年12月-2015年3月）における1価と2価の硫黄イオン([SII]76.5nm及び[SIII]68nm)の2次元発光分布から動径幅2R$_J$（dawn側、dusk側ともに6R$_J$－8R$_J$）の南北方向発光プロファイルを得、そのスケールハイトと赤道面での最大値を導出したところ、トーラス増光現象を跨いだスケールハイトの増大が確認された。可視光イメージング観測からも同様に、1価の硫黄イオンのスケールハイトと発光強度の最大値を導出した。EXCEEDの観測から導出されるスケールハイトは空間分解能の影響を受けているため、EXCEEDとT60から導出された1価の硫黄イオンのスケールハイトとの比較から空間分解能を評価し、EXCEEDの観測から得られた硫黄イオンのスケールハイトを補正することが可能である。今後は補正後のスケールハイトと発光強度の最大値から、イオンの温度と赤道面での密度の変動を定量的に評価する予定である。発表では、このような手順で得られた硫黄イオンの温度と、EXCEEDの観測から得られた電子温度の時間変化の特徴をプラズマトーラスの増光期間を跨ぐ期間で比較した結果を報告する。

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# ひさき衛星によるイオ周辺の130.4nm酸素原子発光の時間変動解析
time variation of 130.4nm atomic oxygen emission near Io observed by hisaki/EXCEED

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木星の衛星イオは他のガリレオ衛星と比べて木星との距離が近く、潮汐力を受けるため地質活動が活発である。イオ大気の主成分はSO2や解離してできた酸素や硫黄原子などで、残りの数パーセントが中性ナトリウムやカリウムである。この大気の起源は火山活動によるガスの噴出と表面に堆積された SO2frostの昇華が考えられ、どちらが支配的かはまだ決着が着いていない。本研究ではイオ周辺(1木星半径程度)の130.4nmの酸素原子発光強度の時間変動を明らかにすることで、大気生成プロセスの理解に寄与することを目的とする。
2014年の12月から2015年の5月にかけて地上狭帯域イメージング観測により広域ナトリウム雲の発光の増大が観測された(Yoneda et al., 2015)。この期間に火山噴出ガスの主成分である酸素原子のイオ周辺での振る舞いを明らかにするため、本研究では同時期のひさき衛星観測データを用いて、イオの1木星半径周辺の酸素原子130.4nm発光強度の時間変動を解析した。解析では、十分なS/Nを得るために、イオが朝側(イオ位相角45~135度)と夕方側(イオ位相角225~315度)にいる時の観測データをイオを中心とした60"の空間範囲について一日ごとに積算した。また、ジオコロナ起源の酸素原子発光の影響を回避するため、ひさき衛星が地方時20時から4時の観測データのみを使用した。その結果、酸素原子発光は1月上旬は11R程度であったが、1月中旬から増光を開始し、二月中旬には発光のピーク(32R)に達した後、4月末まで減光して平穏時の明るさ(10R)に戻った。また、dawn側よりdusk側の明るさが全体を通して1.2倍程度明るかった。
この解析結果から、イオ火山活動が活発になることでイオ周辺の酸素原子の量が増大することが明らかになった。より定量的に火山活動が大気生成の関係性を議論するためには、ひさき衛星の130.4nm発光強度データから酸素原子柱密度の変動に変換する必要がある。130.4nm酸素原子発光には太陽光の共鳴散乱とイオプラズマトーラスの電子衝突励起の両方が寄与しているが、寄与の大きさを見積もったところ電子衝突励起の方が共鳴散乱より数百倍大きい。プラズマトーラスの電子温度はdusk側が高いことが知られており、酸素原子のdawn-dusk非対称性を説明する上で電子衝突励起が優勢であるという見積もりの結果は整合的である。発表ではこの見積もりの結果から酸素原子柱密度を導出し火山活動の変化によりイオ大気が受けた影響を推定する。

キーワード：木星、イオ、ひさき衛星、火山活動
Keywords: Jupiter, Io, hisaki/EXCEED, volcanic activity

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# Science Experiments with the Trojan Asteroid Lander in the Solar Powered Sail Mission

Science Experiments with the Trojan Asteroid Lander in the Solar Powered Sail Mission

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Scientific exploration on the Jupiter Trojan asteroid is under study for the solar-powered sail (SPS) mission. This mission includes a scientific lander jointly studied by Japanese and European engineers and scientists [1]. We present the objectives and the strawman payloads for this mission. The SPS is a candidate as the next medium class space science mission in Japan. This engineering mission is based on the technologies such as the solar sail and the ion engine system inherited from Ikaros and Hayabusa missions, respectively. With this hybrid propulsion system, the spacecraft will cruise to the Jupiter and beyond, even if a radioisotope thermoelectric generator (RTG) is not used. A Trojan asteroid will be investigated by remote sensing after rendezvous, and then a small lander will be deployed from the mothership to conduct *in situ* experiments on the asteroid. As an option, sample will be returned to the Earth. Mission duration is typically 15 years to arrive at the Trojan asteroid, and 30 years in total for Earth return. The shortest one way trip to the asteroid is less than 12 years. The lander should be designed within 100 kg wet mass. Total mission payloads should be within 20 kg, including all the science payloads, sampling and sample return systems [2].

Jupiter Trojan asteroids are located around the Sun-Jupiter Lagrange points. Most of them are volatile-rich D- or P-type asteroids, and their origin and evolution, composition and physical conditions still remain unknown. In a classical model of solar system evolution, they formed around the Jupiter orbit and survive until now. But in a recent model such as Nice model [3], they formed at the far end of the solar system and transferred inward due to dynamical migration of giant planets. Physical, mineralogical, and isotopic studies of surface materials could solve their origin and evolution processes, as well as the solar system formation [4]. To achieve these goals, *in situ* observations using the lander is planned, as well as the asteroid global characterization with a near-infrared hyperspectral imager.

Geological, mineralogical, and geophysical observations will be conducted to characterize the landing site, by using a panoramic camera, an infrared hyperspectral imager, a magnetometer, and a thermal radiometer. The surface conditions and composition will be investigated with a close-up imager and a Raman spectrometry. The imager is also used to check the conditions whether the

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sampling could be done or not. If the configuration is unsuitable for sampling, the lander must relocate and change the configuration. The surface and subsurface materials will be collected into a carousel by bullet-type and pneumatic drill type samplers, respectively. Samples in the each case of carousel will be viewed by infrared microscope to identify them. Those samples will be transferred for evaporation of volatiles for high resolution mass spectrometry (HRMS). Some samples will be heated for pyrolysis for isotopic analysis. Mass resolution $m/\Delta m > 30,000$ is required to investigate isotopic ratios of D/H, $^{15}N/^{14}N$, and $^{18}O/^{16}O$, as well as molecules from organic matters (M = 30 to 1000).The MULTUM type in Japan and the Cosmorbitrap type in France are being investigated for the HRMS. A set of strawman payloads are now considered to meet the science, mission, and system requirements and constraints (total mass < 20kg, and total energy consumption < 600 WHr). They will be finally determined by the international announce of opportunity.

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キーワード：トロヤ群小惑星、ソーラーセイル、着陸機、高精度質量分析、ソーラー電力セイル、地下サンプル

Keywords: Trojan asteroid, Solar Sail, Lander, High Resolution Mass Spectrometry, Solar-Powered Sail, Subsurface sample

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