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).

Keywords: Satellite formation

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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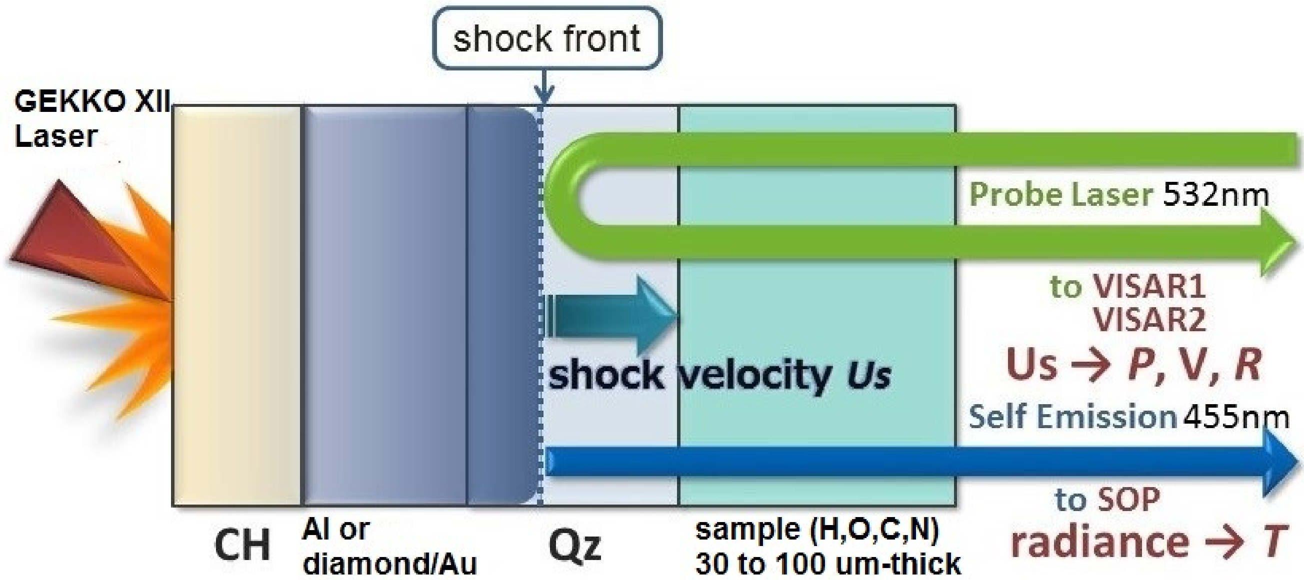
Ices in the universe are consisting of hydrogen, oxygen, carbon, and nitrogen. These elements coalesced to develop into icy giant planets such as Uranus and Neptune in the solar system, as well as some water planets occurring in extrasolar planetary systems. Properties of such planetary ices at elevated 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).

Keywords: icy giant planets, laser-driven shock compression, off-Hugoniot conditions, planetary magnetic field



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]

Keywords: Titan, Atmosphere

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.

Keywords: Titan's atmosphere, chemical reaction network, ALMA observations

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.

Keywords: Pluto, Subsurface ocean, Interior, Astrobiology

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

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).

Keywords: Ceres, hydrothermal reactions, water

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.

Keywords: Ocean Worlds, Enceladus, Titan, Europa

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

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

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

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

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.

Keywords: Hisaki, Jupiter's magnetosphere, 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.

Keywords: Jupiter, Aurora, EXCEED/Hisaki

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.

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.

Keywords: Io plasma torus, sulfur, oxygen

