Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

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Scientific exploration of Jovian System by JUICE Mission: Participation of Japanese team

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The largest planet in the solar system, Jupiter, is a rapidly rotating hydrogen-helium gaseous body with strong magnetic field and associated magnetosphere. Recent discoveries of exoplanets suggest that Jupiter should represent a body not only in the solar system but also in the universe. Jupiter has various satellites: four large satellites, Io, Europa, Ganymede, and Callisto, were discovered by Galileo 400 years ago. Three of them except Io are icy moons.

The Jupiter system was observed by several flyby missions such as Pioneer 10 and 11, Voyager 1 and 2, Cassini, New Horizons and investigated by Galileo orbiter and its atmospheric entry probe. Galileo spacecraft data was very limited without capability of its high-gain antenna. So far we knew about Jovian system much less than the Saturnian System, where Cassini spacecraft has been continuously observing. JUNO mission will start observation of Jupiter in 2016. But since the main target of JUNO taking polar orbits is structure and composition of Jupiter, observation of satellites would be limited.

JUICE (Jupiter Icy Moon Explorer) is the ESA first Large-class mission of Cosmic Vision 2015-2025 program. The emergence of habitable worlds around gas giants, and the focus is to characterise the conditions of habitable environments among the Jovian icy satellites, with special emphasis on the Ganymede, Europa, and Callisto. JUICE will be launched in 2022, and will arrive at Jupiter in 2030. After several fly-bys to Europa and Callisto, JUICE will be inserted into an orbit around Ganymede in 2032 and will continue scientific observations for eight months until the end of nominal mission in 2033.

The discussion for the international collaboration for Jupiter mission between ESA and Japan (JAXA) started in 2006. Initially JAXA proposed a magnetospheric orbiter whereas ESA and NASA proposed Ganymede and Europa orbiters, respectively. After the selection of JUICE by ESA in May 2012, six Japanese groups were invited to participate in the mission as Co-Is with instrument development for model payloads. Finally through the selection process of instrument development teams, four of Japanese team partners were selected for the official JUICE instruments. These are GALA (Laser altimeter), SWI (Sub-millimeter wave instrument), PEP (Particle environment package), and RPWI (Radio & Plasma Wave Investigation). Moreover three Japanese scientists are invited to participate in the initial scientific analysis as Co-Is of JANUS (Optical cameras) and J-MAG (Magnetometer). And it is proposed that a longer Mast (for J-MAG) could be supplied from Japan.

Keywords: Jovian System, Subsurface Ocean, Habitable zone, Icy satellites

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Development of JUICE/Ganymede Laser Altimeter (GALA)

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

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

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

GALA is developed by international collaboration of scientists and engineers in Germany, Switzerland, Spain, and Japan. The conceptual design is based on the laser altimeter on board of BepiColombo consisting of transceiver unit (TRU) with laser optics and appropriate electronics, electronic unit (ELU) with digital range finder module, digital processing module and power converter module, and laser electronic unit (LEU) with laser control electronics. Japanese team takes receiver telescope, its back-end optics, detector, and analogue electronics of TRU. The transmission optics of TRU and LEU are developed at DLR in Germany, and ELU is developed at Bern University in Switzerland. Assembly and integration are conducted at DLR.

The initial designs of analogue electronics and receiver telescope including back-end optics have been examined. A main mirror of the telescope will be 300 mm in diameter and be made of aluminum with gold coat. The same detector as those of BELA, Hayabusa, and Kaguya will be taken. Structural and thermal analyses are currently undertaken.

Keywords: Ganymede, Icy satellite, Planetary exploration, Laser altimeter

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JUICE-GALA : Concept of Focal Plane Assembly and Analog Electronics Module

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Ganymede Laser Altimeter (GALA) is scheduled on board JUICE mission by ESA to be launched in 2022. GALA will be developed and manufactured jointly by teams of Germany, Japan, Switzerland, and Spain. Japanese team is responsible for a receiver unit out of GALA instrument; a receiver telescope, a backend optics (BEO), a focal plane assembly (FPA) accommodating an APD sensor module and an analog electronic module (AEM).

Return laser pulse from the target body is collected by the receiver telescope and is fed into the following BEO. The BEO focuses the return light on the surface of an APD sensor contained in an APD module. For APD as optical sensor, we adopted a product of Excelitas Technologies Corporation that has a lot of experiences in space laser altimeter. The APD sensor is mounted on a hybrid IC of the APD module including a trans-impedance amplifier (TIA) for signal readout in a wide band width as 120MHz, a thermos-sensor for measurement of the APD sensor temperature and a thermoelectric (TE) cooler for control of the APD sensor temperature to stabilize the temperature as 25 deg-C or so. The APD sensor has an enhanced quantum efficiency of up to 40% at 1060 nm. APD typically has a large temperature dependency of gain. The APD module is equipped with TE cooler and the TE cooler is capable to control the temperature of APD precisely. Two redundant optical fibers are attached to the FPA so that a part of transmitted laser pulse generated in Laser head Module (LHM) is introduced to the APD sensor.

The TIA in the APD module outputs voltage signals corresponding to the input light pulses. The voltage signals are fed into the AEM. The transmitted pulses introduced from LHM are attained not to overshoot by a programmable amplifier in the AEM because the following part of analogue signal processing circuit in AEM is to be tuned for signals returned from the target body which are much smaller than the introduced laser pulses. Signal waveform from the introduced laser pulse to the received return pulse is converted to digital data by analogue-to-digital conversion (ADC) circuit and digitized waveform are transmitted to a range finder module (RFM). In RFM, the digital waveform with the transmitted pulse and the received pulse are filtered to optimize signal-to-noise ratio by ”matched filter” and the timings of both pulse are detected for ranging and also the width and height of the received pulse can be identified more precisely.

In our poster presentation, the current development status of the optical sensor and analogue module of GALA will be reported.

Keywords: JUICE, GALA, Laser altimeter, APD, Ganymede, analogue signal processing circuit

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JUICE-GALA : Design of receiver telescope and related optics

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Ganymede Laser Altimeter (GALA) is scheduled on board JUICE mission by ESA to be launched in 2022. GALA will be developed and manufactured jointly by teams of Germany, Japan, Switzerland, and Spain. Japanese team is responsible for receiver telescope, backend optics (BEO), APD detector, and analog electronic unit.

Receiver telescope is Cassegrain type reflector whose aperture is 250mm or 300mm, which collects laser echo pulses from Ganymede's surface and guides to APD detector through backend optics (BEO). Telescope's field of view is 450μrad which covers laser beam expansion angle (100μrad.) and reduces noise signal to APD as small as possible. We have designed 300 mm aperture model in which distance between primary and secondary mirror is less than 160mm using Code V software. In parallel we compared two types of BEO using Code V again and confirmed both types satisfy GALA specification; one type of BEO is comprised of 1 folding mirror and 2 convex lenses and the other is comprised of 2 concave mirrors. The narrow band filter for laser echo (wavelength 1064nm; band width 8nm) is also confirmed available from a Japanese optics manufacturer. Primary and secondary mirrors and supporting structures will be fabricated of aluminum to realize athermal property and surfaces of two mirrors will be sputtered of gold to enhance total throughput of telescope. Thermal vacuum and radiation tolerance test of gold sputtered aluminum samples, filter material, and BEO elements is an important issue and will be conducted within 2015. It is also a critical issue how to establish the way to realize accurate alignment between laser transmitting telescope (German side) and receiver telescope (Japanese side).

Practically, GALA optical system cannot be determined by only optical design itself because it is closely related or depending on weight resource management and results of thermal or structural investigation of GALA. In our poster presentation the newest development status of GALA optical system will be reported.

Keywords: JUICE, GALA, telescope, BEO, Ganymede, athermal

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The Radio & Plasma Wave Investigation (RPWI) for JUICE: Contribution plan from Japan

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We present the current status of Radio & Plasma Waves Investigation (RPWI) [PI: J.-E. Wahlund (IRF-Uppsala, Sweden)] on the ESA JUICE mission to Jupiter (launch: 2022). RPWI consists of a highly integrated instrument package that provides a whole set of Langmuir probe and electromagnetic wave measurements, and will study the electro-dynamics of the Jovian magnetosphere and the affected exospheres, surfaces, and conducting subsurface oceans of Ganymede, Europa and Callisto.

RPWI first focuses on cold plasma around Jupiter and its satellites by 4-axis Langmuir probe combined with 3-axis search coil sensor, for the understanding of how the momentum and energy transfer occurs through electro-dynamic and electromagnetic coupling in Jovian environments with icy moons. Exhaust plumes from cracks on icy moons will also be studied, as well as micron sized dust and related dust-plasma surface interaction processes.

RPWI also first provides the spatially resolved information of radio sources in auroral regions of Ganymede and Jupiter and possibly lightning activity of Jovian clouds, by the first 3-axis measurement in radio frequency. As a byproduct, reflected Jovian emission can be expected from the boundary of crust (ice) and subsurface ocean (conductive water), which could observed as the Lunar surface reflection in terrestrial auroral kilometric radiation seen by Kaguya Lunar Radar Sounder.

For these objectives, RPWI sensors consist of 4 Langmuir probes (LP-PWI) for determination of the vector electric field up to 1.6 MHz and cold plasma properties (including active measurements by LP sweeps and mutual impedance sounding) up to 1.6 MHz, a tri-axial search coil magnetometer (SCM) for determination of the vector magnetic field up to 20 kHz, and a tri-dipole antenna system (RWI) for monitoring of radio emissions (80 kHz - 45 MHz). From Japan, we will provide the RWI preamp and its High Frequency receiver with the onboard software, modifying from the BepiColombo PWI and ERG PWE developments. We will also provide Software Wave-Particle Interaction Analyzer (SWPIA) function to RPWI DPU, for the onboard quantitative detection of electromagnetic field - ion interactions, modifying from the ERG SWPIA developments.

The RPWI consortium covers all the best international scientists and engineers in this field who have provided a long heritage record in ESA/NASA/JAXA missions and a track record of collaboration with each other. The team also includes the expert members in numerical modeling of all relevant sciences related to RPWI, in order to maximize the science return from the investigation. Followings are the participating organizations: [Sweden] Swedish Inst. Space Physics (IRF); Royal Inst. Technology (KTH). [France] Lab. de Physique des Plasmas (LPP); LESIA - Obs. de Paris; CNRS-LPC2E, Univ. d'Orleans; CNRS-IRAP, Univ. Paul Sabatier 9; Univ. de Versailles Saint-Quentin (LATMOS). [Poland] Space Research Centre of the Polish Academy of Sciences. [Czech] Inst. Atmospheric Physics; Astronomical Inst. [UK] Imperial College London; Univ. Sheffield [Austria] Space Research Inst. [Germany] Univ. Cologne. [Japan] Tohoku Univ.; Toyama Pref. Univ.; Kyoto Univ.; Kanazawa Univ.; ISAS/JAXA; Nagoya Univ. [USA] Space Science Lab., UC Berkeley; Univ. Iowa; Johns Hopkins Univ.; NASA/GSFC; Boston Univ.; Univ. Michigan.

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JUICE-SWI Submillimeter-wave instrument

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In the JUICE mission, we are developing the Submillimetre Wave Instrument(SWI) which is a spectrometer with two frequency bands in 600 GHz and 1.2 THz region to observe submillimeter-wave emission from molecular species in atmospehre such as CH4, H2O, 17-0, 18-O, D/H ratio, CS, HCN and CO, as well as surface emission of satellites and the planet. Japanese contribution is the main- and sub- reflector of the antenna, and moters.

The chemical and isotopic compositions of volatiles on geologically non-active Callisto may preserve information of the composition of icy planetesimals formed in the Jupiter-forming region. Based on the observations of Callisto's atmosphere, the SWI Japan will try to constrain dynamics and chemistry of both the outer solar nebula and circum-Jovian subnebula, using their chemical model of protoplanetary disks and N-body simulations.

Also, the compositions of the atmospheres (and plumes) of Europa and Ganymede would provide information on particular geochemical processes in their subsurface oceans. Using results of the observations, the SWI Japan team will be able to investigate the availability of biogenic elements, conditions of geochemical reactions, and habitability, based on their high-pressure hydrothermal experiments and chemical models of subsurface oceans.

Keywords: Oxygen isotope, Submillimeter-wave, SWI

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Can gap suppress gas capturing growth of giant planets?

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We study the final masses of giant planets growing in a protoplanetary disk by using a toy model, which employs simulation-based two empirical formulae for gap depth and accretion rate of area of protoplanetary disks. This model enables us to calculate time evolution of mass of giant planets. We find that gap opening is not effective to suppress gas capturing growth of giant planets: a Jupiter-mass planet is easily formed in a disk with small viscosity (alpha is 10^{-3}) and a small disk surface density (~1/10 of the minimum mass solar nebula model). Hot jupiters, which are thought to be formed outer region and then move inward by type II migration, could be formed in-situ (at 0.1 AU for example).

Keywords: gap, protoplanetary disk, giant planet

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Origins of stresses in the lithosphere of icy satellites

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Surface geological features on the Moon, terrestrial planets and icy satellites reflect past interior activity which effects surface stress.

Most geologic features on icy satellites suggest a possibility that the surface have fractured and extended due to tensional stress. In case of large icy satellites such as Europa and Ganymede, it also well-recognized that the surface stresses were directly generated from the past interior activity. On these surfaces, elastic lithosphere is divided from asthenosphere due to the large viscosity contrast between the base of icy shell and the surface. Therefore we assume that surface features have been formed by the stress of elastic lithosphere that directly affected by the current and past interior activity.

We will discuss origins of stresses of elastic lithosphere of icy satellites. On surfaces of Europa and Ganymede, we can see many extensional features, stripes, bands and ridges, which have been interpreted as a sign of past interior activity, especially global volume expansion (Greenberg *et al*., 1998). In previous studies, various origins of such extensional features have been suggested.

In case of Europa, stress associated with icy convection (McKinnon (1998)) and tidal deformation (Greenberg *et al.*, 1998) discussed but the resultant of amplitude of surface stress is too small to create the observed extensional features. Therefore we thus focus on global expansion as important source of surface feature. The growth of the surface Ice-I layer is proposed for the expansion quantitatively (Kimura et al., 2007). Hillier and Squyres (1991) discussed thermal stress on small satellites of Saturn and Uranus including contribution of the phase transition of water ice, and they suggested that thermal stress is another source of surface features. Although they included an effect of temperature change due to phase transition, they neglected a contribution of volume change due to the phase transition and thermal history. Kimura *et al*. (2007) discussed surface stress on surface of Europa, and they considered stress due to temperature change and volume change of phase transition. Furthermore they also simulated interior thermal history coupling with stress calculation. Surface stress due to temperature change associated with the temperature evolution in the lithosphere and the stress raised by the excess pressure in the asthenosphere are coupled. Therefore this method is consistent with the physical process of phase transition.

In the case of Ganymede though the amount of the expansion seems significant the origin is still enigmatic. Therefore in this report we try to formulate a kind of Stefan problem which takes into account of the self-consistent adaptation of pressure build-up by phase change of Ganymede. We consider the heat transfer in the lithosphere by temperature-dependent rheology in the scheme of MLT(Kimura *et al*., 2009) and the elastic lithosphere which accumulate stress is estimated by estimated the thermal history of Ganymede.

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Keywords: Icy Satellites, The Mixing Length Theory, The Thermal Stress, Phase Transition, surface feature

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Horizontal and vertical structures of Jovian IR aurora emission observed by SUBARU / IRCS

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We will report the horizontal and vertical structures of Jovian infrared (IR) aurora observed by SUBARU 8.2m telescope in Feb. 2014 and Jan. 2015. In these observations, we used Adaptive Optics (AO) and achieved high spatial resolution (˜170km). This makes it possible to analyze not only horizontal profile but also vertical one (scale height: ˜200-400km) of Jovian IR aurora. These observations were held in a framework of Jupiter observation campaign simultaneous with Hisaki/EXCEED.

Jovian magnetosphere, ionosphere and thermosphere are coupled (MIT coupling system) by electric current that generated by fast Jovian rotation. Upper atmosphere extracts the dynamical energy to the magnetosphere through the collisions of neutral and plasma atmospheres and it drives magnetospheric plasma. Such magnetospheric energy is back to the upper atmosphere as electrical current and aurora electrons that causes UV aurora. By these interactions, upper atmosphere is heated and thermally excited H3+ and H2 emit IR aurora. Past K-band spectroscopy showed the different horizontal distributions of H3+ and H2 aurora [Raynaud et al., 2004; Uno, 2013]. In previous emission models of H3+ and H2 lines, it could be originated from the different source altitudes (H3+ from higher and H2 from lower). But our SUBARU/IRCS observation on Dec. 2011, the first Jovian IR spectroscopy with AO, found that H3+ and H2 emissions have similar altitude profile (H2 peaks at 590-720km, H3+ peaks at 680-900km)[Uno et al., 2014]. This is not agreed with past explanations by the altitude difference.

For further pursuit, we performed Jovian IR aurora observation on 13-14 Feb. 2014 and on 30-31 Jan. 2015 by the SUBARU/IRCS (R˜10,000) with AO. The former, we observed southern hemisphere and the latter, we observed both hemispheres. While AO was active, we set the slit along the rotational axis to cross the aurora oval vertically. While AO was not active (when Galilean satellites were not at suitable positions), we set the slit along and over the aurora oval to avoid the effect of sliding off of the FOV. At the same time, we took the image of the H3+ in fundamental (v=1-0) line. We acquired the emission lines of H3+ fundamental in L-band (3.2-4.0 um) and H3+ overtone (v=2-0), hot overtone (v=3-1) and H2 (S1) in K-band (2.0-2.4 um) at the same time each in good weather condition. Those enable us to discuss compare spatial distribution, relative intensity and spatial-temporal variations with high accuracy. During this observation, Hisaki/EXCEED tracked Jovian UV aurora emission from the north pole and acquires the information of the flux and energy of precipitating electrons. We try to analyze considering this information.

We have been analyzing the observation data in Feb. 2014 and get follow results (1) H2 emission has lower contrast than H3+ emission at the main oval, (2) the peaks of H2 and H3+ exist similar altitudes. Recently, we try to find out the cause of structures problems by comparison of the horizontal and vertical temperature profiles derived from H2 and H3+ emission.

And we try to H3+ L-band / K-band comparisons about the emission structures and intensities of those for the first time using the fine datasets in Jan. 2015. H3+ is generated through the collisions of precipitating electrons and H2. Since the highly energetic electron can penetrate deeper into the atmosphere, H3+ density and emission intensity may include the information of precipitating electron energy. A theory says that the L-band lines from lower energy states come from lower altitude at lower temperature region than K-band lines from higher altitude at higher temperature region. Using our observation data and Hisaki/EXCEED data, we examine the L-band / K-band emission intensity ratio and response to the precipitating electron energy.

Keywords: Jupiter, aurora, Infrared, spectroscopy

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Coordinated observation of Io plasma torus using Hisaki/EXCEED and gourd-based telescopes

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EXCEED is an EUV spectrograph onboard an earth-orbiting space telescope, SPRINT-A(Hisaki). One of the primal mission goal of Hisaki/EXCEED is to reveal radial transport of mass and energy in the Jovian magnetosphere. An intense campaign observations of Jovian aurora and Io plasma torus were made using Hisaki/EXCEED and ground-based telescopes from December 2014 through February 2015. We will present results from [SII] 671.6/673.1nm observation of Io plasma torus using a 60-cm telescope at the Haleakala observatory feeding to a monochromatic imager.

The monochromatic imager consists of a coronagraph and a narrow-band filter (FWHM=0.9nm). The coronagraph has an occulting mask and a Lyot stop to reduce contamination by diffraction from Jupiter. Field-of-view, 8 arc minutes, is wide enough to cover both sides of the plasma torus. A platescale and integration time are 1arcsecond/pixel and 20 minutes respectively. We could get 280 images from the observation during December 2014 through January 2015.

Based on a preliminary analysis of the Haleakala 60-cm, we have found variability of dawn-dusk shift of plasma torus which is believed to be related to dawn-dusk asymmetry in EUV brightness as well as sudden brightening of plasma torus. Latest result will be presented at the meeting.

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Observations of neutral oxygen torus in the inner magnetosphere of Saturn by Hisaki

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Water group neutrals in Saturn's inner magnetosphere play the dominant role in loss of energetic electrons and ions because of abundance of the neutral particles Enceladus [e.g., Paranicas et al., 2007; Sittler et al., 2008]. Understanding of the temporal and spatial distribution of the neutrals is required to understand the plasma-neutral dynamics in the inner magnetosphere of Saturn. Water molecules mainly originating from Enceladus lead to the productions of hydroxyl radicals and oxygen atoms through dissociation reactions. In this study, we focus on oxygen dynamics in the inner magnetosphere of Saturn. The atomic oxygen in the magnetosphere of Saturn was discovered by UVIS/Cassini [Esposito et al., 2005]. Melin et al., [2009] reported the spatial distribution of oxygen and the variation of the total number of oxygen with time scale of several days — several tens of days. In this study, we examine the time and spatial distributions of neutral oxygen in the inner magnetosphere of Saturn observed by Hisaki. The daily variation of oxygen is first detected by the EXCEED onboard Japanease Earth orbiting satellite Hisaki. We also show the daily variation of spatial distribution such as dawn-dusk distribution and Enceladus phase angle observed by Hisaki.

Keywords: Hisaki, Saturn, neutral oxygen, Enceladus neutral torus