

Bright spot aurorae and magnetic fields at Uranus

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One of the two ice giants in our solar system, Uranus, is as far as ~20 astronomical units away from the Earth and has been flown by Spacecraft Voyager 2 alone.

The unique spacecraft provided legendary vector magnetic data of the planet to reveal that Uranus has a strong magnetic field of its own. However, it was also found that its dipolar magnetic field, if any, is peculiar in the sense that it is not only offset from the centre of the planet but also tilted from the rotation axis as large as 60 degrees (Ness et al., 1986). Since discovery of the peculiar intrinsic magnetic field, a couple of higher-degree magnetic field models than Ness et al's (1986) offset and tilted dipole model have been proposed by analyzing the vector magnetic data precisely (Connerney et al., 1987) or adding other kind of data such as auroral ultraviolet emission observed by Voyager 2 (Herbert, 2009).

The peculiar magnetic fields at Uranus may tell us what dynamics takes place inside the ice giants, if fully understood. Which part of the Uranus' interior is responsible for its dynamo actions? What kind of conductive fluid is the major constituent of that part? Is that part a globally distributed shell? Why is the planet's magnetic field different from the dipolar magnetic fields like the one that the Earth bears? Doesn't the fast rotation of the planet as fast as a slightly longer rotation period than 17 hrs influence the dynamo regime?

Lamy et al. (2012) recently reported the very first detection of the Uranus' aurorae by Hubble Space Telescope. Their far-ultraviolet images captured two bright spot aurorae occurred in November, 2011, both of which were results of a pair of large CME events traced all the way from the Sun to the region of outer planets by the authors. The estimated latitudes of the aurorae on Uranus are between 5 degrees S and 15 degrees S, which overlaps the larger northern auroral oval of either Q3 Model (Connerney et al., 1987) or AH5 Model (Herbert, 2009) of the planet's magnetic field. Because Lamy et al. (2012) conclude that the bright spot aurorae were results of dayside reconnections, it is possible to use the far-ultraviolet images as constraints of the magnetic field at Uranus by assuming L-values of the reconnection locations and utilizing the knowledge of the interplanetary magnetic field provided by the mSWiM simulation code (Zieger and Hansen, 2008).

This paper reports the attempt of the magnetic field modelling at Uranus using the new constraints.

キーワード：磁場、昼側磁気リコネクション、宇宙望遠鏡、天王星、輝点オーロラ、L値

Keywords: magnetic fields, dayside reconnection, space telescope, Uranus, bright spot aurorae, L-value

Small Next-generation Atmospheric Probe Concept (SNAP)

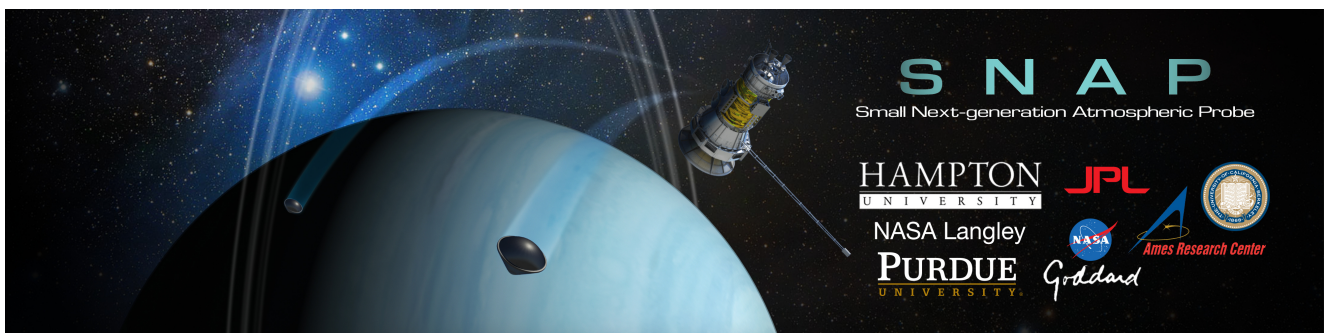
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We present a concept for a small atmospheric probe that could be flexibly added to future missions that orbit or fly-by a giant planet as a secondary payload, which we call the Small Next-generation Atmospheric Probe (SNAP). SNAP's main scientific objectives are to determine the vertical distribution of clouds and cloud-forming chemical species, thermal stratification, and wind speed as a function of depth. As a case study, we present the advantages, cost and risk of adding SNAP to the future Uranus Orbiter and Probe flagship mission; in combination with the mission's main probe, SNAP would perform atmospheric in-situ measurements at a second location, and thus enable and enhance the scientific objectives recommended by the 2013 Planetary Science Decadal Survey and the 2014 NASA Science Plan to determine atmospheric spatial variabilities.

We envision that the science objectives can be achieved with a 30-kg entry probe ~0.5m in diameter (less than half the diameter of the Galileo probe) that reaches 5-bar pressure-altitude and returns data to Earth via the carrier spacecraft. As the baseline instruments, the probe will carry an Atmospheric Structure Instrument (ASI) that measures the temperature, pressure and acceleration, a carbon nanotube-based NanoChem atmospheric composition sensor, and an Ultra-Stable Oscillator (USO) to conduct a Doppler Wind Experiment (DWE). While SNAP is applicable to multiple planets, we examine the feasibility, benefits and impacts of adding SNAP to the Uranus Orbiter and Probe flagship mission.

Keywords: Giant Planets, Planetary Mission, Atmospheric Probe



電離圏ポテンシャルソルバーによる木星内部磁気圏電場の太陽風応答の研究

Study of the solar wind influence on the Jovian inner magnetosphere using an ionospheric potential solver

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木星内部磁気圏はプラズマ共回転が対流を支配する領域で、この領域のプラズマ対流には太陽風の影響が及びにくいとする考え方が一般的である。しかし最近、ひさき衛星搭載の極端紫外線分光器EXCEEDによって、イオプラズマトーラス発光分布が朝側・夕側で非対称に変動し、この変動が太陽風の動圧の急激な増加に伴っていることが確認された。このイオプラズマトーラスの発光分布の非対称な変動はイオ軌道上にかかる $\sim 4\text{-}9\text{[mV/m]}$ の朝夕電場により生じると見積もられている[Murakami et al., 2016]。朝夕電場があることでイオプラズマトーラスが朝側に $\sim 0.1\text{-}0.3\text{RJ}$ ほどシフトし、トーラス内プラズマが夕側で断熱加熱を、朝側で冷却を受ける。その結果、イオプラズマトーラスの発光の朝夕非対称変動が生じるとされる。ここで、朝夕電場の起源として以下の太陽風影響プロセスが示唆されている。まず太陽風が木星磁気圏に衝突して磁気圏を圧縮する。これにより磁気圏-電離圏結合電流系が変調され、高緯度電離圏へ流入する沿磁力線電流が増大する。その結果、沿磁力線電流によって形成された電離圏電場が増大し、低緯度領域へと拡大侵入する。これが磁力線を介して磁気圏赤道面に投影されることで、内部磁気圏深部に位置するイオ軌道近傍($\sim 6 R_J$)に朝夕電場が生成される、というものである。このプロセスの内、沿磁力線電流の分布および電流密度は、Galileo衛星観測に基づく赤道面上のリングカレントの発散値として見積もられている[Khurana, 2001]。

このシナリオをモデルによって定量評価するため、木星の2次元電離圏ポテンシャルソルバーを開発した。これにより、任意の沿磁力線電流分布に対する全球電離圏ポテンシャル分布の導出を試みた。沿磁力線電流量にはGalileo探査機などの観測結果[Khurana, 2001]を用い、その水平方向分布には地球のモデルで採用されているガウス関数を用いた。また、電離圏の電気伝導度分布は木星超高層領域における荷電粒子の衝突周波数とサイクロトロン周波数と密度の分布から計算した。衝突周波数はイオン- H_2 衝突と電子- H_2 衝突を考慮した[Tao, 2009]。イオ軌道上の朝夕電場の強度は電離圏電気伝導度の空間分布に大きく依存しうするため、電気伝導度の全球的な分布をより正確に与えることが必要である。Galileo探査機やVoyager探査機による電離圏観測は観測領域が限定されていたため、本研究ではTao et al. [2009]の木星熱圏-電離圏-磁気圏結合モデルを用いて熱圏・電離圏の全球的な密度・温度分布を与えた。このモデルは、オーロラ電子の降込みに伴う加熱等を考慮し

ており、沿磁力線電流の流出入領域である極域の電気伝導度分布をより正確に求めることが可能である。

以上の電流・電気伝導度分布を基に木星電離圏電場ポテンシャル分布および磁気圏朝夕電場強度の分布を導出する。上記のシナリオの妥当性を評価するために、イオプラズマトーラスを形成するプラズマが等ポテンシャル線に沿って流れると仮定し、朝夕電場と共回転電場が作るイオ軌道上の等ポテンシャル線の朝側へのシフト量とプラズマの朝夕の発光強度比を求め、ひさき衛星観測による推定値と比較する。今学会では、これらの結果について報告する。

キーワード：木星、イオプラズマトーラス

Keywords: Jupiter, Io plasma torus

ひさき衛星が捉えた火山活動中におけるイオ起源の酸素原子発光の時空間変動

Time and spatial variations in atomic oxygen emission around Io during the volcanic active event observed with Hisaki/EXCEED

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We report time and spatial variations of atomic oxygen supplied from Io during the volcanic active event. The atmosphere of a Jovian satellite Io has been thought to be mainly supplied by volcanism and sublimation of surface frost. Dominant atmospheric gases are sulfur dioxide, and dissociative product such as atomic oxygen and sulfur, which are produced mainly by electron impact dissociation and photolysis. Neutral oxygen and sulfur escape from exobase to neutral cloud (> 5.8 Io radius) mainly by atmospheric sputtering (torus ions collide with several neutrals). However, the characteristics of spatial and time variations of atomic oxygen and sulfur escaping from Io are not well understood.

The brightening event of the Io's extended sodium nebula was reported by the ground imaging observation in the spring of 2015 [Yoneda *et al.*, 2015]. We therefore examined the time variation of atomic oxygen emission at 130.4 nm around Io obtained with Hisaki/EXCEED from 27 November 2014 to 14 May 2015 (from day of year (DOY) -35 to 134) and compare the result with the brightening event of the Io's extended sodium nebula. We accumulated observed counts within 46" centering at Io for one day to obtain enough signal to noise ratio. We found the atomic oxygen emission increased by 2.5 during the volcanically active period of DOY 20-110 of 2015. The time variation of atomic oxygen emission was well correlated with that of sodium emission until the brightness maximum on DOY 50 of 2015. In the meanwhile, the duration of atomic oxygen brightness declining from the maximum to the quiet level (60 days) was longer than that of sodium nebula (40 days).

In addition, we investigated Io phase angle (IPA) dependence of atomic oxygen emission at 130.4 nm averaged for the distance range of 4.5-6.5 Jupiter radius from Jupiter in the dawn and dusk sides, respectively during volcanically quiet period (DOY -35 and -1). Then, we found following two important observation fact. First, weak atomic oxygen emission (4-6 Rayleighs (R)) continuously existed on both dawn and dusk sides not depending on the phase angle. This suggests that small amount of atomic oxygen distributes uniformly along the Io's orbit. Second, the emission averaged between IPA 60-90 degrees (14.0 R) was larger than that between IPA 90-120 degrees (10.5 R) for the dawn side, and the emission between IPA 240-270 degrees (15.8 R) was larger than that between IPA 270-300 degrees (12.3 R) for the dusk side. We can explain this difference if the large amount of atomic oxygen spread inward and ahead of Io's orbit and shape like banana expected by the model of atomic oxygen neutral clouds such as *Smyth and Marconi* [2003]. The emission of this banana-shape neutral oxygen cloud was almost included in the region between the distance of 4.5-6.5 Jupiter radius from Jupiter when IPA 60-90 degrees, but that was partly excluded in the same region when IPA 90-120 degrees. The similar tendency was also seen in the dusk side. In this poster, we also present the IPA dependence of atomic oxygen

emission during volcanically active period (DOY 20-110), and show different and common points between atomic oxygen distribution around the Io's orbit during volcanically quiet period and that during volcanically active period.

キーワード：イオ、木星、ひさき衛星

Keywords: Io, Jupiter, Hisaki

地上望遠鏡とHisaki/EXCEEDとによる、木星衛星イオ火山噴火に伴うイオプラズマトラス中のイオンと電子温度の変動

Variation of ion and electron temperature on Io plasma torus during an outburst measured with Hisaki/EXCEED and ground-based telescope

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Volcanic gases (mainly composed of SO₂, SO and S) originated from jovian satellite Io are ionized by interaction with magnetospheric plasma and then form a donut-shaped region called Io plasma torus. Ion pickup is the most significant energy source on the plasma torus thought, additional energy source by hot electron is needed to explain energy balance on the neutral cloud theory (e.g. Daleamere and Bagenal 2003). In fact, *in-situ* measurements by Galileo indicates some injections of energetic particles in the middle magnetosphere. Recent EUV spectroscopy from the space shows fraction of hot electron increases as increase of radial distance in the plasma torus (Yoshioka et al., 2014; Steffl et al., 2004). On this study, we focus on variability of electron temperature derived from EUV diagnostics measured by HISAKI/EXCEED after a volcanic outburst in 2015, as well as ion temperatures parallel and perpendicular to the magnetic field measured from the ground-based spectroscopy.

The ground-based observation of sulfur ion emission, [SII] 671.6nm and 673.1nm from Io plasma torus was made at Haleakala Observatory in Hawaii from November 2014 through May 2015 with the high-dispersion spectrograph (R = 67,000) with an integral field unit (IFU) coupled to a 40-cm Schmidt-Cassegrain telescope. The IFU consist of 96 optical fibers (core/crad/jacket diameter are 50/125/250 micro-meters, respectively). The fibers are arranged in 12 by 8 array at the telescope focus which makes high-resolution spectroscopy over field-of-view of 41" by 61" with a spatial resolution of 5.1" on the sky. Two-dimensional Doppler measurements enables to derive spatial distribution of [SII] emissions as well as their temperatures parallel and perpendicular to the magnetic field. We also made observation of neutral sodium cloud extending up to several hundred of jovian radii as a proxy of supply of neutral particles from Io (Yoneda et al., 2015).

We also employ EUV spectroscopy of Io plasma torus with EUV space telescope Hisaki EXCEED from December 2014 through May 2015. We have made spectral fitting as the following method. First, we made series of EUV spectra averaged over five days. Next, assuming azimuthal homogeneity of Io plasma torus, Abel inversion is made to reduce line-of-sight integration effect. Then, we made fitting of observed EUV spectra (60 - 140 nm) with CHIANTI model spectra by changing electron density and temperature, mixing ratio of ions (S⁺, S⁺⁺, S⁺⁺⁺, O⁺ and O⁺⁺) and fraction of hot electron (Te = 100 eV).

Based on observation of neutral sodium cloud (Yoneda et al., 2015), neutral supply started to increase at around DOY= 10, was at maximum at around DOY = 50, and has backed into the initial levels at around DOY = 120. In contrast, plasma diagnostics indicates that hot electron fraction at 7.0 jovian radii was less than 2 % before DOY = 50, started to increase after DOY = 50, and have reached 8(+/-1) % at DOY = 110. In addition, ion temperatures from ground-based observation started to increase after DOY=50 as similar trend of increase of hot electron fraction. EUV emission from aurora was also activated after DOY =

50 as increase of hot electron fraction on the plasma torus. In the presentation, we will introduce a possible scenario that explain variations of ion and electron temperatures after the outburst in early 2015.

ひさき衛星/EXCEED ならびに地上観測による火山活動に伴うイオフトラスマトーラス中の硫黄イオン温度の時間変動

Temperature variation of sulfur ions in the Io plasma torus associated with a volcanic event with the Hisaki/EXCEED and ground-based observations

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We report the time and spatial variation of sulfur ion emission lines from the Io plasma torus to understand the dynamical process in the torus associated with Io's volcanic event during the period from December 2014 to March 2015, using the data obtained with Hisaki/EXCEED (Extreme Ultraviolet Spectroscopy for Exospheric Dynamics).

A large quantity of gas is ejected from Io's volcanoes, principally oxygen and sulfur atoms and their compounds. Once they are ionized through electron impact or charge exchange, the ions are accelerated to the nearly corotational speed of the ambient plasma to form a torus of ions (the Io plasma torus, about 6 R_J from the center of Jupiter) surrounding Jupiter. The fresh ions lose their pickup energy to the ambient electrons through Coulomb collisions. Ultimately, the torus electrons lose energy by transiting electron energy state of ions into higher states, leading to the prodigious extreme ultraviolet (EUV), ultraviolet, and visible emissions from the torus.

During the period from December 2014 to March 2015, Io's outburst was observed by EXCEED, and the increase in the pickup ions were anticipated along with the increase in the neutral gas. To investigate energy flow from ions to electrons during the Io's outburst period, we derived sulfur ion temperatures parallel to magnetic field lines from the brightness scale height of the ion along the field line. From the spectral images of sulfur ion emission at 76.5 nm (SII), 68.0 nm (SIII) and 65.7 nm (SIV) observed by EXCEED, we identified the time variation of sulfur ion temperature increasing associated with enhanced volcanic activities, and interpreted that this was due to increase in the fresh ions by ion-pickup process. We also carried out the measurement of SII 671.6 nm emission with a monochromatic imager on the T60 telescope at Haleakala, Hawaii, which has a high spatial resolution capability, and found similar variation in ion temperature. We also evaluated the spatial resolution of EXCEED by comparing the brightness scale heights which were derived from EXCEED and T60, and then corrected the value of broadened scale height by EXCEED.

Furthermore, in order to interpret how electrons and ions exchange their energy, we reproduced the observation result (i.e., time variations of sulfur ion temperature, hot electron fraction, core electron temperature, and ion composition in the torus) using the zero-dimensional time evolution model based on *Delamere and Bagenal* [2003]. From the model we found that increase of hot electron fraction causes increase of core electron temperature, and makes the subsequent increase of new ion pickup via electron

impact due to the increase of core electron temperature. Concerning the difference in the magnitude relationship among the sulfur ion temperature of SII, SIII, and SIV obtained from observed data and modeled value, we reproduced the spatial distribution of the Io torus along the magnetic field and found that the brightness scale height of roughly decreases by 60 % under conditions of the temperature anisotropy (T_{S+perp} / T_{S+para}) of 5. Related to the decrease in the brightness scale height of SII, the magnitude relationship among three of ion species obtained with our model significantly approached to that in the observed EXCEED data.

キーワード：木星、イオ、ひさき

Keywords: Jupiter, Io, Hisaki

2015年イオ火山イベントにおけるイオトラス中硫黄イオンのSystem IV周期の変動

Variations of System IV period of the sulfur ions in the Io torus for the volcanic event in 2015

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Previous ground-based and probe observations of Io plasma torus (IPT) in visible, near-infrared and extreme ultraviolet (EUV) wavelengths have detected a periodic time variation whose period is longer than System III Jupiter's rotation period (9.925 h). It has been called System IV period (~10.21 h). The "dual hot electron model" in which hot electron populations has two azimuthal variations corotating at System III period and sub-corotating at System IV period is proposed to account for the System IV period measured by the Cassini UVIS observation (Steffl et al., 2008). However, little progress has been made in explaining an origin of the System IV period.

The Cassini UVIS observation of IPT was made just after Io's volcanic eruption in 2000. It is reported that the System IV period derived from the Cassini observation was 10.07 h, which was shorter than the typical System IV period of 10.21h (Steffl et al., 2006). The causal relationship between plasma source enhancement due to the volcanic event and change in the System IV period is not clear from the Cassini observation. Here, we analyzed time variations in EUV emissions from IPT obtained by the HISAKI satellite to understand the mechanism responsible for the System IV period and the influence of Io volcanic activity on IPT.

The observation period used in this study is from December 2014 to the middle of May 2015. During this period, enhancement of Io volcanic activity from January to March 2015 was reported from the observation of logenic sodium emission (Yoneda et al., 2015). To find variations of the System IV period in the EUV brightness, the System III longitude at peak EUV intensity was derived by the following procedure: (1) Extracting the time variations of sulfur ion emission intensity at S II 76.5 nm + 126 nm, S III 68 nm, and S IV 65.7 nm + 140.5 nm every 10 days (data window) from the HISAKI Level-2 data. (2) Selecting the data of Io phase angle range from 0-45 degrees (180-225 degrees) in dawn (dusk) side, which corresponds to the downstream region of Io, to remove the dependence of EUV brightness on Io's position. (3) Plot the data as a function of the System III longitude. (4) Fitting a second order sinusoidal curve to the data, where the first and second order terms correspond to the System III period and the half of System III period, respectively. The half of the System III period is produced because the rate of electron impact ionization of sulfur ions increases at the intersection of the centrifugal and rotational equator. The time variation in the phase of the component of the first order term indicates the System IV modulation. From the analysis, the System IV periods of SII 68 nm before and after the volcanic event (Dec. 1, 2014 - Jan. 20, 2015 and April. 20 - May 14, 2015, respectively) were roughly 10.10 h and 10.07

h, respectively. During the volcanic event, the System IV period was 9.97 h. This is the first observational evidence which shows that the System IV period has shortened after the enhancement of Io volcanic activity.

Origin of the System IV period has been discussed with sub-corotation of plasma in IPT; since the sub-corotation occurs due to mass loading of newly picked-up ions into IPT, it is expected that the System IV period becomes long during the Io volcanic event. However, the result derived from the HISAKI observation shows the opposite feature and will give important information to constrain the origin of the System IV period.

We plan to derive the ion composition, electron density, electron temperature, and hot electron fraction in IPT by EUV spectral diagnosis analysis. Comparing the plasma parameters with the change in the System IV period presented here, we try to understand the influence of Io volcanic activity on the Jovian magnetosphere in detail.

キーワード : イオプラズマトーラス、イオ火山噴火、System IV周期

Keywords: Io plasma torus, Io volcanic eruption, System IV period

Short-term variation of Jupiter's synchrotron radiation associated with solar-wind-driven electric field: a simulation study

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Radiation belt is a layer of energetic particles (~few tens MeV) held by geomagnetic fields, ranging up to several planetary Radii in distance. Jovian Radiation Belt, where in-situ measurement is limited, Jupiter's synchrotron radiation (JSR) observation is a key tool for determining physical process therein, and various diffusion models have been proposed to account for observed JSR's short-term and long-term variations as well as the steady profile of it. As for the short-term variation, where the total JSR flux density varies by a few % over a few days or weeks, it is theoretically backed by fluctuating dynamo electric field at Jupiter's upper atmosphere correlated with solar UV/EUV flux [Brice and Mcdonough, 1973], supported by a number of researches. Amid the situation, Extreme ultraviolet spectroscopy HISAKI has found evidence of another type of electric field - solar-wind-driven convection electric field inside Jupiter's magnetosphere [G. Murakami et al. 2016], from which one can expect enhanced radial diffusion inside the magnetosphere too.

In this research, I show the result of my numerical calculation on radial diffusion driven by the estimated convection electric field correlated with solar wind dynamic pressure and synchrotron radiation variation resulted therefrom and suggest that observed short-term variation in the past can be explained by solar-wind-driven convection electric field as well.

キーワード：木星、シンクロトロン、ひさき

Keywords: Jupiter, Synchrotron, HISAKI

Thermal evolution and 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 surface images and unveiled a diverse range of landforms, from rugged mountainous region to extremely smooth plains, indicating geological processes that have modified the surface substantially and recently. Accurate determinations of Pluto's radius from different images suggest that Pluto is almost perfectly spherical and had or has a relatively warm interior (maybe an ocean) for the most part of its history.

The New Horizons spacecraft has confirmed that N₂, CH₄ and CO ices are enriched in the heart-shaped bright smooth plains, e.g., Sputnik Planitia (SP). In parallel, water ice is widely distributed on Pluto, in particular, on rugged mountainous region and normal faults 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.

Assuming the Pluto's interior consists of two components, water and rock, and completely differentiated state, we find that a high-pressure ice layer could appear at the bottom of the water layer in case of a denser (smaller) rock core according to the Pluto's bulk density. Here we are going to show the results of numerical simulation for the thermal history in Pluto considering various interior structures and initial thermal states, and to discuss this dwarf planet far away from the Sun could have a potential to harbor an ocean.

クラスレートハイドレート形成がエンセラダス内部海のアンモニア及びアンモニウムイオン濃度に与える影響

The effect of clathrate formation on concentrations of ammonia and ammonium ion in a subsurface ocean of Enceladus

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The Saturn's icy moon Enceladus could have a global subsurface ocean beneath the icy shell. Cassini spacecraft has found water plumes near the south pole and investigated those components. The Cassini INMS (Ion and Neutral Mass Spectrometer) data showed that the plume includes H₂O, CH₄, CO₂, NH₃, and many other organic materials. Basically, these components reflect those of subsurface ocean but it might be affected by clathrate formation in the ocean and its decomposition process through the pluming activity. Clathrate hydrates are crystalline inclusion compounds, in which hydrogen-bonded water molecules form cages containing hydrophobic gases called guest molecules. Bouquet et al. (2015) suggests that clathrate hydrate should be stable in the icy shell deeper than 22 km in Enceladus. To understand the chemical environment of the subsurface ocean, we need to evaluate the effect of clathrate formation on chemical concentrations in the seawater and/or the plume. We considered an inclusion of ammonium ion into clathrate hydrate. Cassini INMS data showed that a mixing ratio of ammonia in the plume is 0.8%. Ammonia does not form clathrate hydrate, while ammonium ion can be replaced with a part of water cages of clathrate hydrate. The inclusion of ammonium ion into clathrate hydrate could affect the concentration of ammonium ion in the subsurface ocean, therefore, we experimentally investigated the amount of ammonium ions that can be included into clathrate hydrate and evaluated the concentration of ammonium ions and ammonia in Enceladus's subsurface ocean.

Clathrate hydrate was crystallized in the ammonium salts solution and the concentration of ammonium ion in the hydrate and that in the residual solution were measured. As a guest molecule of clathrate hydrate, we used tetrahydrofuran (THF) as an analogue for CH₄ and CO₂. And we used ammonium chloride as an ammonium salts because chloride has been detected in the Enceladus plume. Finally, we measured the concentration of ammonium ion in THF hydrate (C_s) and the concentration of ammonium ion in residual solution (C_L) and determined the partition coefficient, the ratio of C_s to C_L ($K_D=C_s/C_L$). From the partition coefficient and the ammonia concentration observed by Cassini, we calculated a change of concentration of ammonium ion in the plume with time and estimated a possible range of concentration of ammonium ion and that of ammonia in the present subsurface ocean.

キーワード：エンセラダス、クラスレートハイドレート、アンモニア、アンモニウムイオン

Keywords: Enceladus, clathrate hydrate, ammonia, ammonium ion