Global structure and heavy ion distribution in Mercury's magnetosphere

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From Mariner 10 and MESSENGER observations, Mercury’s magnetosphere is thought to be a miniature of the Earth’s magnetosphere. While these two magnetospheres have several characteristics in common, some critical differences are also evident. First, there is no atmospheric layer, but only tenuous exosphere. Second, center of dipole field is shifted to northward about 485km, which is equivalent to 0.2 Mercury's radius. Kinetic effects of heavy ions will also be important in Mercury's magnetosphere, because Mercury’s magnetosphere is relatively small compared to the large Larmor radii. Trajectory tracings is one of the dominant methods to estimate the kinetic effect of heavy ions which originate from the exosphere, though the results of the simulation are quite sensitive to the electric and magnetic field. Hence, it is important to provide a realistic field model in the trajectory tracings. In order to construct a large scale structure, we developed a MHD simulation code, and adopted it to the global simulation of Mercury’s magnetosphere. In this study, first we performed several cases of MHD simulation to investigate the interaction between solar wind plasma and offset dipole of Mercury. Solar wind densities are given 35cm^{-3}, and velocity for 400km/s which is typical value in the Mercury's orbit. IMF conditions comes from Parker Spiral which has strong Bx and By component at the Mercury's orbit, and fluctuations are added in By and Bz components. In the results of MHD simulations, global configuration of magnetosphere shows strong north-south asymmetry due to dipole offset and IMF-Bx in addition to dawn-dusk asymmetry which comes from IMF-By. IMF Bx also affects to the intensity ratio of north and south cusp pressure, while IMF By component “twist” the cusp region to longitudinal direction. The identification of global structures especially the cusp region is important not only for the understanding of magnetospheric physics itself, but also making a proposal to the observational plan of spacecraft such as Bepi-Colombo. In the presentation, we will also discuss the heavy ion distribution and precipitation on Mercury obtained by trajectory tracings of test particles.

キーワード：水星磁気圏、MHDシミュレーション
Keywords: Mercury's magnetosphere, MHD simulation

LWA1 Jupiter radio monitoring during the Hisaki observation campaign

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The Long Wavelength Array (LWA) is a low-frequency radio telescope designed to produce high-sensitivity, high-resolution spectra in the frequency range of 10-88 MHz. The Long Wavelength Array Station 1 (LWA1) is the first LWA station completed in April 2011, and is located near the VLA site in New Mexico, USA. LWA1 consists of a 256 element array operating as a single-station telescope. The sensitivity of the LWA1, combined with the low radio frequency interference environment, allows us to observe the fine spectral structure of Jupiter's decametric modulation lanes.
During the Hisaki observation campaign from January 1 to 15 in 2014 we made a series of observations to monitor Jupiter's decametric radio emissions by using LWA1. During this period we used 91 hours of total machine time of LWA1. We selected the LWA1 spectrograph observing mode (time resolution: 40ms, frequency resolution: 20kHz). The total volume size of the collected data was about 117GB.
During this observing period 14 non-Io-related events of Jupiter radio emissions were observed: 7 for the non-Io-A source, 6 for non-Io-B, and 1 for non-Io-C. We developed a system of semi-automatic data analysis in the study of Jupiter's decametric modulation lanes. By using this system we analyzed the 14 non-Io-related Jupiter radio emissions.
By the modulation lane method [Imai et al., 1997, 2002, 2006], the source parameters of the non-Io-related sources were analyzed. The source L-shell parameter in the case of non-Io-related sources is not well known; therefore, we assumed the fixed L-shell value. One non-Io-A event shows the different cone half-angle parameters between two groups of arc structures on the dynamic spectrum. All other non-Io-A events show almost the same value of cone half-angles based on the fixed L-shell value. The results of all non-Io-related data analysis will be discussed.

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キーワード：木星電波、デカメートル波、モジュレーションレーン、電波源のパラメータ
Keywords: Jupiter radio, decametric emissions, modulation lanes, radio source parameters

Juno observations of Jupiter's dawnside magnetopause boundary layer

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Using recent observations obtained by particles and fields instrumentation on the Juno spacecraft, we present the properties of Jupiter's dawnside magnetopause in unprecedented detail. Through magnetic reconnection and viscous mixing (e.g., the Kelvin-Helmholtz instability) processes, Jupiter's dawnside magnetopause provides a pathway for solar wind plasmas to enter the Jovian magnetosphere. On 14 July 2016, we identify an extended magnetopause boundary layer (MPBL) indicative of significant mass transport across the magnetopause. For this event, minimum variance analysis revealed an open magnetopause with a sunward-tilted boundary normal, indicative of significant magnetospheric compression. Furthermore, we identify ~2 h increases in the total magnetospheric pressure adjacent to two magnetopause crossings. These structures are of an order of magnitude longer duration than typical magnetospheric transits (e.g., plasmoids, reconnection fronts) and may provide evidence of focused energy transport into the magnetosphere via magnetohydrodynamic waves.

Keywords: juno, jupiter , magnetosphere

金星大気重力波に誘発された弓状構造のALMA/Venus Climate Orbiter「あかつき」衛星連携観測ミッション

Synergetic mission of simultaneous observations toward bow-shaped structures induced by atmospheric gravity wave on Venus with ALMA and Venus Climate Orbiter “Akatsuki”

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本講演では金星「あかつき」衛星と日欧米の国際望遠鏡であるアタカマ大型ミリ波サブミリ波干渉計(ALMA)を用いた金星の同時連携観測について報告する。我々はSolar Planetary Atmosphere Research Telescope(SPART)望遠鏡により太陽系の地球型惑星の大気環境の監視観測を推進しており、短期スケール(数日～数週間)の一酸化炭素(CO)の変動を捉えてきた。その原因解明には、金星の大気化学とダイナミクスの間のリンクを紐解く必要がある。2015年12月、「あかつき」衛星(JAXA)のLIRカメラは、アフロデティ大陸で発生した重力波の影響と思われる弓状構造を捉えることに成功した。この現象を介して、大気ダイナミクスの変化に伴って乱されるCOやH_2O、硫化物などの時空間変化の連動を捉えることができれば、金星の低層から中高層にかけての大気化学反応ネットワークに関する重要な知見が得られる。「あかつき」衛星の赤外域や紫外線のセンサーは雲頂から低層にかけての温度やCO、SO_2などの存在量や分布、速度場の高解像度観測に強力な威力を発揮する。一方、ALMAのミリ・サブミリ波帯のヘテロダイン分光観測では、75 kmから110 kmの高度の微量分子の3D分布（高度方向と緯度経度方向など）を捉えることができる。

現時点で2016年11月20日と12月1日の2回に渡って、ALMAと「あかつき」衛星の連携観測が実施されている。同時に「あかつき」衛星もLIRカメラにより、近金点から次に重力波が発生すると思われるアフロデティ大陸近傍エリアの連続撮像に成功した。この観測期間のALMAはCycle-4のC40-4の配列となっており、50台の12m望遠鏡群と12台の7m望遠鏡群の干渉計システムと、4台の12m単一望遠鏡を用いることでUV空間をカバーし、空間解像度は300 GHz 帯(^{12}CO,^{13}CO,HDO,SO,SO_2)において0.43秒角、200 GHz 帯(^{12}CO,^{13}CO)において0.63秒角となっている。高度方向は吸収スペクトルのVoigt line-shapeをモデルフィットすることで数km程度の分解を得ることができる。また、スペクトルのセンターのドップラーシフトから熱圏下部域の風速場の導出も可能となる。現在、ALMAの3回目の観測をまだ残しており、また上記観測に伴う大規模データのパイプライン処理に時間を要している関係で、まだデータが配信されていない状況にあるが、本講演では、これらの観測の取り組み・進捗について紹介する。

キーワード：アタカマ大型ミリ波・サブミリ波干渉計 (ALMA)、Venus Climate Orbiter 「あかつき」、金星、大気重力波、SPART望遠鏡、惑星大気
Keywords: Atacama Large Millimeter/submillimeter Array (ALMA), Venus Climate Orbiter "AKATSUKI", Venus, Atmospheric Gravity Wave , SPART Telescope, Planetary Atmosphere

Search of CH4 on Mars by SOFIA/EXES

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Discovery of CH4 in the Martian atmosphere has led to much discussion since it could be a signature of biological/geological activities on Mars. However, the presence of CH4 and its temporal and spatial variations are still under discussion. We performed sensitive measurements of Martian CH4 by using the Echelon-Cross-Echelle Spectrograph (EXES) onboard the Stratospheric Observatory for Infrared Astronomy (SOFIA) on 16 March 2016, which corresponds to summer (Ls = 123.2˚) in the northern hemisphere on Mars. The high altitude of SOFIA telescope (~13.7 km) enables us to significantly reduce the effects of terrestrial atmosphere, and the high spectral resolution of EXES (R~90,000) enables us to detect the intrinsically narrow lines of Martian CH4 at the 7.5 μm band. . Mars disk was spatially resolved into 3 x 3 areas, none of the observed region showed the unambiguous detections of CH4. The upper limits on the CH4 volume mixing ratio ranges from 1 to 6 ppb.

キーワード：火星、メタン、SOFIA
Keywords: Mars, Methane, SOFIA

惑星大気大循環モデルのための放射伝達モデルの開発に向けて
Toward development of a radiative transfer model for a planetary atmosphere general circulation model

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1990 年代後半以来, 多数の系外惑星が発見されている. 系外惑星研究における興味深い科学的課題の一つは, 系外惑星において実現される表層環境や循環構造である. 発見されている系外惑星は様々な軌道要素を持っており, また, その大気の組成や質量は太陽系惑星とは大きく異なる可能性があるため, 系外惑星においては非常に幅広い様々な表層環境や循環構造が実現しているだろう.

そのような系外惑星の表層環境と循環構造を調べる上で最も重要かつ難しい点はその大気の放射伝達計算である. そもそも, 系外惑星に限らず, 放射場を正確に求めるための困難の一つは, 放射伝達方程式の波数に対する積分を正確に評価することである. 地球の気候研究のためには, 計算量を削減するために, 多くの場合に相関 k 分布法が用いられているが, 系外惑星大気の研究においてはそれを地球とは異なる大気組成・質量に対して実装できなければならない.

我々は, 系外惑星の表層環境と循環構造の多様性を明らかにすることを目指して, 様々な大気組成・質量を持つ惑星大気の大気循環計算に使用できる放射モデルの構築を目指している. 本研究では, それに向けた最初の一歩として, 地球大気の長波放射モデルの構築を目指す.

大気循環計算に用いる放射モデルの構築では, まず, ラインバイラインの放射伝達モデルを構築する. 次に, そのラインバイラインモデルを参照解として, 相関 k 分布法に基づくモデルを構築する. ラインバイラインの放射伝達モデルでは, Humlicek (1982) の計算方法による Voigt 線形と HITRAN2012 (Rothman et al., 2013) の吸収線データを用いる. 連続吸収は, MT_CKD モデル (Mlawer et al., 2012) を用いて考慮する. このラインバイラインモデルは, 長波放射モデルの相互比較実験

(Ellingson et al., 1991) に基づいて検証することにする. 相関 k 分布法を用いた放射モデルの構築においては, ここでは,

地球大気の放射伝達モデルとして実績のある RRTM (Mlawer et al., 2012) と同じバンド設定および k 分布のビンの設定を用いることにする. 構築した相関 k 分布放射モデルは, 上に述べたラインバイラインモデルと比べることで検証する. 講演では, 本研究で構築したラインバイラインモデルと相関 k 分布放射モデルの詳細, および, 両モデルの計算結果を示す予定である.

キーワード：惑星大気、放射伝達、地球
Keywords: Planetary atmosphere, Radiative transfer, Earth

Global distribution of gravity waves activity in Mars' lower thermosphere derived from MAVEN/IUVS stellar occultations and analyzed using two Martian General Circulation Models

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Small-scale gravity waves (GWs) are recognized as an important part of the terrestrial climate system. They affect the dynamics, composition, and thermal structure of the terrestrial middle atmosphere and thermosphere. On Mars, most of information about GWs at altitudes 0-40 km has been obtained with radio occultation techniques and temperature profiles by MCS/MRO, while GW activity in the upper atmosphere was quantified using aerobraking measurements. Since previous studies did not establish a correlation between the GW activity in the lower and upper atmosphere, questions about thermospheric sources of the perturbations still remain to be addressed. Since October 2014, comprehensive studies of the Martian atmosphere have been performed with NASA's Mars Atmosphere EvolutioN (MAVEN) mission. In-situ measurement of the upper atmosphere, down to 130 km, revealed substantial wave structures in ions and neutrals. Wave structures have also been detected by remote sensing with Imaging Ultraviolet Spectrograph (IUVS) at altitudes between 30 and 150 km. IUVS measurement provide opportunities for investigating possible links between GWs in the Martian troposphere and thermosphere.
In this paper, we use the IUVS stellar occultation measurements to characterize a global distribution of GW activity in the lower thermosphere. We focus on the data obtained between March 2015 and March 2016. Two comprehensive general circulation models (MGCMs), a GWs resolving MGCM and the Max Planck Institute MGCM incorporating a state-of-the-art GW parameterization have been used to interpret the observations. The main results of this study are as follows.
(1) The observed perturbations demonstrate GW signatures with vertical wavelengths of 10-20 km and amplitudes of up to 10 % of the mean temperature (~13 K) and 15-20 % of the mean density.
(2) The observed wave potential energy in the lower thermosphere has larger values at middle latitudes. This is contrary to the distribution of GW activity in the lower thermosphere, whose maximum is located in low latitudes, but is consistent with simulations using the two MGCMs.
(3) Our MGCM simulations demonstrate that the background winds play a major role in vertical propagation of GWs generated in the lower atmosphere, which can explain the latitudinal distribution of

the GW activity. High-resolution as well as parameterization GW simulations demonstrate a consistent picture of GW-induced temperature perturbations.
(4) The observed perturbations in the lower thermosphere are most likely caused by GWs of tropospheric origin penetrated from below.
We must emphasize that the spatial coverage of the existing MAVEN/IUVS occultation data is still poor to unambiguously establish the global distribution of the GW activity in the lower thermosphere. This should be a subject of further observations. However, the presented data, at least, do not contradict the model predictions pointing to the lower atmospheric origin of these waves.

キーワード：火星、重力波、熱圏、MAVEN
Keywords: Mars, gravity wave, thermosphere, MAVEN

MAVEN/NGIMS observations and full-particle DSMC modeling of gravity waves in the Martian upper thermosphere

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Global distribution and parameter dependences of gravity wave activity in the Martian upper thermosphere have been analyzed using density profiles obtained by the Neutral Gas Ion Mass Spectrometer (NGIMS) onboard the MAVEN spacecraft. The average amplitude of gravity waves around the Martian exobase is ~10% on the dayside and ~20% on the nightside, which is about two and ten times larger than those on Venus and in the low latitude region of Earth, respectively. The amplitudes are inversely proportional to the background atmospheric temperature, suggesting saturation due to convective instability in the Martian upper thermosphere. After removing the dependence on the background temperature, dependences of the average amplitude on the geographic latitude and longitude and solar wind parameters are found to be not larger than a few percent. These results suggest that the amplitudes of gravity waves are mainly determined by convective breaking/saturation in the upper thermosphere on Mars, unlike those on Venus and Earth. We have also performed numerical simulations of propagation, saturation, and dissipation processes of gravity waves in the Martian upper thermosphere using a full-particle Direct Simulation Monte-Carlo (DSMC) model. The modeling results are compared to the NGIMS observations with a particular emphasis on the vertical profiles of the wave amplitudes and their day-night variations to constrain the vertical and horizontal wavelengths of the observed waves.

キーワード：Gravity waves、Upper thermosphere、Mars
Keywords: Gravity waves, Upper thermosphere, Mars

Solar energetic electron penetration into the Martian upper atmosphere observed by MAVEN

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Discovery of diffuse aurora at Mars caused by the SEP (solar energetic particle) electrons [Schneider et al., Science, 2015] sheds a new light on the high-energy particle environment at Mars. Since Mars has no global intrinsic magnetic field, direct interaction between the solar wind and Martian upper atmosphere results in the draping of the interplanetary magnetic field (IMF) around Mars and forms the induced magnetosphere. The diffuse aurora observation in the northern hemisphere, where the crustal field is absent, indicates penetration of the high-energy electrons of ~100 keV down to the altitudes around 70 km most likely along the draped IMF around the planet. However, to what extent the draped magnetic field configuration around Mars controls the SEP electron penetration to the atmosphere is far from understood.
In this study, we investigated three SEP events observed by MAVEN from December 2014 to March 2015. The pitch angle (PA) distributions of the high-energy (30-210 keV) electrons observed in the Martian ionosphere are analyzed in details. In order to achieve a good coverage in the 2-D (PA-energy) phase space, data obtained during a SEP event is accumulated and binned. Using the elevation angle of the local magnetic field, we also sorted the data so as to investigate the SEP electron loss below the MAVEN periapsis (~150 km altitude). The obtained PA distributions in the ionosphere are compared with the distributions of the source electrons in the magnetosheath. The results show that the field-aligned component is pronounced for the penetrating electrons and it does not significantly depend on the initial PA distributions in the magnetosheath. The observation also indicates that the highest energy of the SEP electrons lost into the Martian atmosphere depends on the magnetic field configuration draped around the planet. During the aurora event reported by Schneider et al. [2015], electrons with energy less than ~130 keV were lost into the atmosphere. These SEP observations thus support the scenario that the solar energetic electrons penetrate into the ionosphere along the draped magnetic field and the altitude to which they can penetrate depends on the magnetic field configuration.

キーワード：太陽高エネルギー粒子、オーロラ、火星、コロナ質量放出、MAVEN
Keywords: SEP, aurora, Mars, CME, MAVEN

Planetary SpaceWeather Services for the Europlanet 2020 Research Infrastructure

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Under Horizon 2020, the Europlanet 2020 Research Infrastructure (EPN2020-RI, http://www.europlanet-2020-ri.eu) includes an entirely new Virtual Access Service, “Planetary Space Weather Services” (PSWS) that will extend the concepts of space weather and space situational awareness to other planets in our Solar System and in particular to spacecraft that voyage through it. PSWS will provide at the end of 2017 12 services distributed over 4 different service domains –1) Prediction, 2) Detection, 3) Modelling, 4) Alerts. These services include **1.1) A 1D MHD solar wind prediction tool**, **1.2) Extensions of a Propagation Tool**, **1.3) A meteor showers prediction tool**, 1.4) A cometary tail crossing prediction tool, 2.1) Detection of lunar impacts, **2.2) Detection of giant planet fireballs**, 2.3) Detection of cometary tail events, **3.1) A Transplanet model of magnetosphere-ionosphere coupling**, 3.2) A model of the Mars radiation environment, 3.3.) A model of giant planet magnetodisc, 3.4) A model of Jupiter’s thermosphere, 4) A VO-event based alert system. We will detail in the present paper some of these services with a particular emphasis on **those already operational** at the time of the presentation.
The proposed Planetary Space Weather Services will be accessible to the research community, amateur astronomers as well as to industrial partners planning for space missions dedicated in particular to the following key planetary environments: Mars, in support of ESA’s ExoMars missions; comets, building on the success of the ESA Rosetta mission; and outer planets, in preparation for the ESA JUpiter ICy moon Explorer (JUICE). These services will also be augmented by the future Solar Orbiter and BepiColombo observations. This new facility will not only have an impact on planetary space missions but will also allow the hardness of spacecraft and their components to be evaluated under variety of known conditions, particularly radiation conditions, extending their knownflight-worthiness for terrestrial applications.
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Keywords: Planets, Space Weather, Services

ハレアカラ観測所T60/DIPOL-2を用いた系外惑星の偏光観測
Polarimetry of exoplanets using T60/DIPOL-2 at the Haleakala observatory

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Many exoplanets have been found since the first discovery of exoplanet in 1995, and observation methods have been developed so far. In this study we particularly focus on polarimetry of the exoplanets. Light scattered at exoplanetary atmosphere is polarized with a periodic variation of it's revolution. Thus, we expect to obtain exoplanetary orbital element and exoplanetary atmosphere information from phase, amplitude, wavelength dependence of polarization. The measurement of exoplanetary polarization is characterized by photon noise limited, which enable us to observe with a small-sized telescope.
Since 2000, several groups attempted to detect the polarimetry of exoplanets. Some groups suggested that the polarization degree less than 10^-4 exists, however other groups reported that there is no significant variation in exoplanetary polarization. In this study, we purpose to establish the measurement method of exoplanetary polarization using DIPOL-2 installed on the Tohoku 60 cm telescope(T60) at Haleakala, Hawaii, and also aim to develop the data analysis method which is required to estimate the exoplanetary polarization very accurately.
DIPOL-2 observation data involve exoplanetary polarization as well as instrumental polarization. Thus, we need to subtract the instrumental polarization precisely from the observed data. In case that the instrumental polarization is too large compared with exoplanetary polarization, it might be impossible to detect exoplanet polarization. To verify the stability of instrumental polarization, we carried out two kinds of observations of non-polarized standard stars as follows. One is the observation of 44 non-polarized standard stars, and the other is the continuous observation of a non-polarized standard star HD142373. Observations of 44 non-polarized standard stars were performed on 90 nights during the period from May 2015 to October 2016. From the useful dataset for 39 stars, we estimated Stokes Q and U of instrumental polarization are 1.20 x 10^-5 and 2.63 x 10^-6, respectively. From continuous observation of a non-polarized standard star HD142373 in August 2016, we also estimated the lower limits of variabilities in Stokes Q (sigma_Q) and U (sigma_U) of the instrumental polarization as 1.0 x 10^-5 and 8.8 x 10^-6, respectively. These variabilities in instrumental polarization defines the estimation limit of exoplanetary polarization.
On the exoplanetary observation, we first estimated the expected amplitude of stokes parameter and observation S/N based on previously known parameters of exoplanet, such as the distance between exoplanet and main star, and brightness of main star. From this estimation, we selected three target exoplanets, HD189733 b, τ Boo b, υ And b.
From the data analysis of HD189733 b, we could not obtain significant periodic variation in stokes parameters obtained in past observation by Berdyugina et al. [2011]. Standard deviations in observed stokes parameters were close to the those of instrumental polarization, and therefore it seems further accurate observation is required to evaluate the polarization parameters for HD18933 b. On exoplanet τ Boo b and υ And b, the standard deviation in observed data was larger than expected estimation errors including photon shot noise and uncertainty of instrumental polarization (Stokes Q=65%, and Stokes U=128% for τ Boo b, and Stokes Q=20%, and Stokes U=39% for υ And b). Therefore, we conclude that

the data should show exoplanetary polarization although any significant orbital phase dependence in exoplanetary polarization was not seen. This may be due to insufficient accuracy of estimated instrumental polarization parameters, and thus we suggest further accurate calibration of instrumental polarization and its dependence on telescope environment, such as temperature, air pressure, viewing angle and seasonal dependence, should be needed in future study.

キーワード：系外惑星、偏光、ハレアカラ
Keywords: exoplanet, polarization, Haleakala

重イオン放出弱磁場小型天体のプラズマ環境に関する粒子シミュレーション

PIC simulation on the plasma environment of a weakly magnetized small body with heavy ion emission

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本研究の目的は、外圏(exosphere)起源の重イオンを放出する、弱い固有磁場を持つ小型天体と太陽風との相互作用を3次元電磁粒子シミュレーションにより再現し、小型天体のプラズマ環境を理解することである。

日欧共同で進められているBepiColombo水星探査ミッションにより水星磁気圏における様々なプラズマ現象の観測が期待されている。これまでの観測から、水星の固有磁場を形成する磁気モーメントは地球のものよりも約2000倍程度小さく、地球磁気圏の約1/20のサイズの小型磁気圏が形成されると予想されている。また水星には電離圏が存在せず、希薄な外圏大気が存在する。明確な電離圏がない磁気圏の電流構造において外圏起源のイオン（Na+など）がどのような役割を果たすかは興味深い。また、水星本体が磁気圏の中に占める割合が大きいことも特徴の一つである。このような特異な水星磁気圏の巨視的構造については、磁気流体力学(MHD)シミュレーションを用いたモデル化も試みられている。しかし、水星表面近傍から放出される重イオンや光電子と太陽風・磁気圏との運動論的な相互作用の理解は進んでいない。特に昼間側やカスプにおいて、イオンラーマ半径と同程度のスケール長でしかないプラズマ構造が予想されている。そこで、本研究では、全粒子シミュレーションを用いて、重イオン放出弱磁場小型天体のプラズマ環境を運動論的観点から再現する。

モデルでは、弱い磁気ダイポールを持つ小型球体をプラズマ流の中に置き、その表面近傍からNa+に相当する重イオンと光電子を同量放出し続ける。昼間側において、ダイポール中心から磁気圧と太陽風動圧が釣り合う点までの距離を代表長Lとすると、今回のモデルでは、Lに対するL地点でのイオンラーマ半径の比が1から1/10程度となるような磁気ダイポールを球体に与える。水星環境ではイオンラーマ半径はLに対して1/100程度であるが、あえてプラズマの運動論的効果を強調させるためにラーマ半径を大きくしたモデルを採用する。パラメータとしては、Lに対する球体半径rの比、放出重イオンと光電子の密度、速度がある。

これまでに実施した準備的なシミュレーション結果により、小型磁気圏の形成、朝方夕方の磁気圏構造の非対称性、重イオンと光電子放出起源の赤道面での天体近傍環状電流、重イオンと光電子の電荷分離による地表面近くでの強い電界形成などの基本的な物理は確認できた。これらの基本物理現象が上に述べたパラメータに対してどのように依存しているのかを解析する。

キーワード：プラズマ粒子シミュレーション、弱磁場惑星、水星磁気圏、外圏
Keywords: plasma particle simulation, weakly magnetized planet, Mercury's magnetosphere, exosphere

Reconsideration of the relation between Jupiter's auroral radio activities and Io's volcanic variations

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It has been discussed for a long time how the Iogenic heavy plasma affects to Jupiter's magnetic activities. Kronberg et al. (JGR, 2007) proposed a conceptual model for periodic magnetospheric variations by assuming that magnetospheric reconfigurations are caused by ion mass loading from the internal plasma sources. This proposal implies that enhancement of Iogenic plasma enhances internal magnetic variations. On the other hand, Shay and Swisdak (PRL, 2004) indicated that magnetotail reconnection rate is reduced when heavy ions (O+) are contained larger. This idea implies the opposite response of Jupiter's magnetosphere to plasma enhancement.
Tohoku University has conducted campaign-base optical observations for Iogenic gas around the opposition period of Jupiter since 1999. From the observations, significant variations of Iogenic gas have been identified several times in 1999, 2003, 2007 and 2015 (Nozawa et al., JGR, 2004; Yoneda et al.,GRL, 2010; GRL, 2013; Icarus, 2015). These phenomena give good opportunities to examine how magnetospheric activities respond to the Iogenic plasma enhancement.
We have analyzed Jupiter's auroral radio emission in hectometer to decameter wave ranges by using the WIND/WAVES data to investigate relation between Jupiter's magnetospheric variations and Io's volcanic events. So far, a negative correlation was reported for the event in 2007 (Yoneda et al., GRL, 2013), while we suggested a positive correlation for the recent event in 2015. To clarify more precise characteristic of the mutual relation, we have extended the analysis for the other volcanic events by evaluating variations of the emission power. In the presentation, we will show the results and reconsider causalities for the variability of magnetospheric response to Io's volcanic variations.

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キーワード：木星、電波、イオ火山活動
Keywords: Jupiter, radio emission, Io volcanic activity

磁気圏keV電子とEnceladus衛星起源H_2O分子の弾性衝突によるピッチ角散乱

Pitch angle scattering due to elastic collisions between magnetospheric keV electrons and neutral H_2O molecules originated from Enceladus

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The observations of injected plasmas in the inner magnetosphere suggest that these particles do not survive very long time due to the neutral cloud originated from Enceladus [e.g., Paranicas et al., 2007; 2008]. These neutrals in the inner magnetosphere play the dominant role in a loss process of energetic electrons and ions [e.g., *Paranicas et al.,* 2007; *Sittler et al.,* 2008]. However, little has been reported on a quantitative study of the electron loss process due to electron-neutral collisions. In this study, we focus on the elastic collisional loss process with neutrals. Conducting one dimensional test-particle simulation, *Tadokoro et al.* [2014] examined the time variations of equatorial pitch angle distribution and electrons within loss cone through 1 keV electron pitch angle scattering due to electron-H_2O elastic collisions around Enceladus when the electron flux tube passes the region of the dense H_2O molecules in the vicinity of Enceladus (~380 sec). The result showed that the electrons of 11.4 % are lost in ~380 sec. Next remaining issue is loss rate of electrons with other energy. In this study, we show a preliminary result of the loss rate of electrons with 500eV-50keV. We also show the comparison of the loss rate between the high H_2O density region (in the vicinity of Enceladus) and the low H_2O density region (in the Enceladus torus).

キーワード：土星、エンケラドス、ピッチ角散乱
Keywords: Saturn, Enceladus, Pitch angle scattering

火星上部熱圏・外圏を伝搬し散逸する内部重力波のDSMCシミュレーション
DSMC simulations of internal gravity waves propagating and dissipating in the Martian upper thermosphere and exosphere

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多成分火星上部熱圏・外圏 Direct Simulation Monte Carlo (DSMC) モデル [Terada et al., 2016] を用いて外圏にまで到達する内部重力波の数値シミュレーションを行い、内部重力波が上部熱圏・外圏の密度・流速・温度構造に及ぼす影響を研究した。Mars Atmosphere and Volatile EvolutioN (MAVEN) の観測期間と同等のコンディションの下、複数のモードの重力波の昼側上部熱圏・外圏における鉛直伝播のローカルシミュレーションを行った。その結果、MAVEN に搭載されているNeutral Gas Ion Mass Spectrometer (NGIMS) が観測したような、外圏底における大きな振幅の密度擾乱 [e.g. Yigit et al., 2015; Terada et al., 2017] を、下層・中層大気から伝播してきた重力波によって生じさせるには、200 km 以上の鉛直波長が必要であることが分かった。また鉛直波長 200 km の重力波は、高度 150 km より高高度の上部熱圏から外圏を強く加速・加熱し、CO_2 の混合比を増加させることが分かった。その加速は水平方向に約 1200 m/s/sol、加熱は約 100 K/sol に達する。イオノポーズ近傍の CO_2 の混合比の増加は約 80 %/sol であり、外圏にまで達する内部重力波は CO_2^+/O^+ と O_2^+/O^+ の流出フラックス比を増加させると推測される。

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キーワード：Gravity waves、Upper thermosphere、Mars
Keywords: Gravity waves, Upper thermosphere, Mars

Dense cold ion outflow observed in the Martian induced magnetotail by MAVEN

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Geological studies have suggested that Mars had a warm climate and liquid water on surface about 4 billion years ago. Now, Mars has a cold surface temperature and little water on surface. Escape of greenhouse gases such as CO_2 to space is considered as the plausible reason to cause the drastic climate change. On one hand, mechanisms enabled the large amount of the CO_2 loss is far from understood. The planetary ion escape through interaction between the solar wind and the Martian upper atmosphere is one of the candidate mechanisms to achieve the atmospheric escape. To understand atmospheric loss from Mars, MAVEN (Mars Atmosphere Volatile EvolutioN) has observed the ion escape from Mars as well as space environment around Mars since November 2014. In this study, we investigate detailed characteristics of a dense cold ion outflow event observed in the Martian induced magnetotail based on the MAVEN observations.
From 14:55 to 15:35 UT on December 4, 2014, MAVEN traversed the wake region and observed cold ions in the induced magnetotail of Mars. Around 15:01 UT, it crossed the current sheet from the dusk-southern to dawn-northern quadrants of the magnetotail. The former (latter) corresponds to the downward (upward) electric field (E) hemisphere in the MSE (Mars-Sun-Electric field) coordinates, since the direction of the solar wind electric field was directed roughly to Z axis of the MSO coordinates. In the wake region, the negative spacecraft charging enable us to detect ambient cold ions. The observation shows a clear asymmetry both in the cold ion density and composition against the current sheet crossing: In the southern downward-E hemisphere, the density is high (>100 1/cc) and heavy ion rich, where the main component is O_2^+ with O_2^+/O^+ ratio of ~2.6. However, in the northern upward-E hemisphere, the heavy ion density drops more than 1 order of magnitude and proton becomes the main component. It should be noted that the high heavy ion density was observed also at high altitudes (>2000km).
At the time of the cold dense heavy ion observation, the strong crustal magnetic fields located on the dayside of Mars. Therefore, the MAVEN observed the cold dense heavy ion outflow in the magnetotail region which corresponds to the downward-E hemisphere as well as most likely the downstream of the mini-magnetosphere formed by interaction between the solar wind and the strong crustal magnetic fields. The result might mean that the combination of the mini-magnetosphere and the downward-E hemisphere facilitates the cold ion escape from Mars. We also tried to precisely estimate the number density of CO_2^+ ions by eliminating the O_2^+ contamination using a fitting method based on the data from The Supra-Thermal And Thermal Ion Composition (STATIC) instrument onboard MAVEN. The preliminary result of the CO_2^+ density estimation will be shown.

キーワード：火星、大気流出、MAVEN
Keywords: Mars, Atmospheric escape, MAVEN

Variations of ion escape from the past to present at Mars

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The present Mars has thin atmosphere consisting mainly of CO_2 and does not have liquid water at the surface. The recent space missions gave some evidences for existence of liquid water in the past Mars. It suggests that Mars have experienced atmospheric loss from the past through present. One of the important mechanisms of atmospheric escape is the ion loss. The ion escape is largely controlled by the magnetic configuration, solar wind and solar XUV (X-ray and extreme ultraviolet) irradiances. Terada et al. (2009) showed that the ion escape rate was at most five orders of magnitude higher under the past active solar condition than under the present ones.

The magnetic field is also an important factor in determining the ion escape rate. The present Mars does not have intrinsic global magnetic field, but is leaving the magnetism in its crust, which is known as the crustal magnetic field. The existence of crustal field suggests that Mars had a global magnetic field of interior origin in the past and the different escape mechanism from the present. The magnitude was perhaps about 0.1 G which is corresponding to the strength of the present magnetic field of the Earth's surface (Curtis and Ness, 1988).

We present the ion escape rates calculated by different magnetic configurations and solar conditions, and compare the results with the Terada et al. (2009) ones. The three-dimension and multi-species magnetohydrodynamics (MHD) modeling are used for the simulation. We will discuss the variation of escape rate due to the differences of magnitude of magnetic field, solar XUV irradiances, and solar wind density.

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キーワード：火星、イオン流失、大気散逸
Keywords: Mars, Ion escape, Atmospheric escape

超小型火星探査機のTHz帯ヘテロダイン分光リモートセンシングによる火星大気観測プロジェクト
Observation project of the Martian atmosphere by THz-band heterodyne spectroscopic remote sensing with Mars micro-satellite/landers

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近年、火星では赤外望遠鏡やキュリオシティなどによりメタンが検出され、その起源については、生物の可能性も含めた活発な議論が展開されている。また、2010年には、ハーシェル宇宙望遠鏡に搭載されたHeterodyne Instrument for the Far Infrared(HIFI)により、低高度で酸素分子の濃度が増加する様子が捉えられ謎を呼んでいる。系外惑星のバイオマーカーの挙動を探る上でも、こうした分子の変動を大気化学反応ネットワークの観点から詳細理解することが喫緊の課題となっている。

現在、東京大学航空工学研究科の中須賀研究チームが火星への超小型深宇宙探査機/着陸機の検討を進めており、我々はこれに搭載可能な簡易なTHz帯のヘテロダイン分光システムの開発検討を進めている。火星大気の突入速度とのトレードオフの関係から超小型衛星に搭載できる重量に制限があるため、現時点で観測周波数帯は450 GHz帯、750 GHz帯の2系統で検討しており、地球の地上望遠鏡からでは地球大気のコンタミにより観測が難しいO_2やH_2O，O_3や関連分子、それらの同位体の同時観測を見据えている。これにより、昼夜や季節変動に伴う大気の酸化反応素過程に迫る予定である。これらの分子の放射輸送計算も実施し、バージニアダイオード社の常温のショットキーバリアダイオードミクサ受信機(等価雑音温度:4000 K)、分光計にはマックスプランク研究所が開発したチャープ型分光計(帯域1GHz)を採用することで、火星の地上から十分なS/Nのスペクトルが得られる見込みである。重量制限から追尾アンテナなどは搭載せず、ランダーではホーンアンテナによる直上観測を想定している。着陸はメタン発生地域近傍の低緯度の平原を検討中であるが、現時点ではまだランダーとオービターの両方の可能性が残されている。ランダーによる観測の場合は、off点が存在しないため、通常のChopper wheel法による強度較正が行えない。そこで、局部発振源による周波数スイッチと、2つの温度の黒体/calibratorを用いた較正手法を検討している。システムを開発していく上でPlanetary protectionも慎重に進めていく必要がある。本講演では、これら一連のミッションの検討状況について報告する。システムや熱設計の詳細は、本学会において松本他がポスターにて検討状況を報告する。

キーワード：テラヘルツ、超小型探査機/着陸機、惑星大気、テロダインリモートセンシング、バイオマーカー、火星

Keywords: Terahertz, Micro-satellite/lander, Planetary Atmosphere, Heterodyne Remote Sensing, Biomarker, Mars

超小型衛星による火星着陸機搭載THzヘテロダイン分光装置の開発検討
Study of THz-band heterodyne spectroscopy system on board Mars micro-satellite/lander

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近年、ハーシェル衛星(ESA)のサブミリ波帯観測により、酸素分子が低高度において増加する傾向が捉えられた。火星では、局所的なメタンの発生も観測されているが、これらはいずれも、まだその起源がよく分かっておらず、生物起源の可能性も含め、火星大気における基本的な化学反応ネットワークの理解が重要な課題となっている。 我々は、東京大学工学系研究科の中須賀研究チームが検討を進めている超小型火星周回機や着陸機により、火星大気中のO2、H2O、O3、COや同位体分子などの昼夜・四季を通じたリモートセンシングを実現すべく、0.4, 0.7 THzヘテロダイン分光装置の開発検討を進めている。検出部には衛星搭載用に開発されたショットキーバリアダイオードミクサと局部発振信号に逓倍型の固体発振器を内蔵したヘテロダイン受信機を、分光計にはチャープ型分光計を採用する計画である。超小型のため、現在の検討段階では搭載できるバジェットは6kg程度以下の制限があるため、システムの熱設計が１つ重要な課題となる。着陸候補の１つである火星の低緯度地域の平原の温度は、1公転周期の季節変動と日照変化によって外気は、190 Kから280 K程度まで変動する(Mars Climate Databaseより)。火星の大気圧程度の熱流体も考慮した熱解析シミュレーションを実施したところ、熱伝導と輻射を効果的に利用すれば、少なくとも夜間にはシステムの昇温を抑えて(80度程度以内)、オペレーションが可能であることを確認できた。日中での観測も実現させるべく、高温時は熱伝導をより効果的に使えるようにするなどのさらなる検討を進めている。本講演では、火星の地上からの観測を想定した放射輸送モデルの計算結果や、これらのTHzヘテロダイン分光装置の開発検討状況について報告する。

キーワード：火星、超小型着陸機、THzリモートセンシング、惑星大気、ヘテロダイン分光
Keywords: Mars, Micro-satellite/lander, THz-band remote sensing, Planetary atmosphere, Heterodyne spectroscopy

新規開発ファイバ面分光ユニットを用いた金星雲観測計画
Observation plan of Venus cloud tops with new developed fiber IFU

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金星は全球が分厚い硫酸の雲におおわれており、可視光で見る金星はピンポン玉のように特徴に乏しい。一方、金星の上層雲には太陽放射のうち200nmから500nmの波長を吸収する物質が含まれており、高速の風が吹き荒れているさまを見せる雲の模様を作り出す。200nm から320nm はSO2による吸収で良く説明できるが、320nm より長い波長での吸収を担う物質はいまだ同定されていない。これまで実施された観測は主に365nmを中心波長とする単バンドしか使っていなかったが、異なる波長の空間構造の違いを比較することでこの非同定吸収物質の性質や数を明らかにできる可能性がある。2015年12月に金星周回軌道に投入されたあかつきに搭載された紫外カメラ(UVI)は、非同定中心波長283nm と 365nm のバンド分光による連続観測を続けており、これら波長の違いによる空間構造の違いと相似があることが判明しつつある。UVIのバンド幅は15nm程度であり、UVIの二波長の間でどのような変化をしているのか知ることはできない。本研究は、この波長間を埋める波長・空間構造を地上より観測することで、365nm付近で見える非同定吸収といわれるものが、いったい何を観測していることになるのかの考察を可能にすることを目的とする。

我々はファイバアレイを用いた分光イメージャを開発してきた。分光イメージングは同時に複数の波長で二次元の画像を取得でき、金星の非同定吸収物質を観測するのに適している。百数十μm程度の細いファイバを数百本用いたファイバアレイの新しい製造方法を考案し、実用化に向けて改良を加えてきた。これをもちいて地上から金星の雲を面分光する光学系を検討している。

本発表では、新しく考案した、ファイバアレイ内の個々のファイバ素線の入射、出射の対応付けを決める新しい方法の紹介のほか、開発中の光学系の性能と、2017年6月頃の金星西方最大離隔をターゲットとしたハレアカラ観測所の望遠鏡をもちいた観測計画を報告する。

キーワード：ファイバ面分光、紫外観測、金星大気
Keywords: Fiber integral field units, Ultraviolet observation, Venus atmosphere

