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.

Keywords: exoplanet, polarization, Haleakala

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

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The objectives of this study is to study the plasma environment of a weakly magnetized small body with heavy ion emission immersed in the solar wind by performing three-dimensional particle simulation. The BepiColombo Mercury mission will observe various plasma phenomena occurring in the small-scale magnetosphere of Mercury. Based on the previous observations, it is reported that the intrinsic magnetic field of Mercury is weak and the magnetic dipole moment is approximately 1/2000 of that of the Earth, which causes a small magnetosphere whose size is 1/20 of that of the Earth. In addition, Mercury owns no ionosphere but an exosphere. The small magnetosphere has a large proportion of Mercury’s body and the structures of magnetospheric regions, particularly at the dayside and in the cusp region, may have spatial scale almost equal to the ion Lamor radius of the solar wind. In such a situation, it is important to consider the plasma kinetics in the analysis of plasma phenomena in the association with the small-scale magnetosphere. In this study, we started investigating the kinetic phenomena in the small magnetosphere by performing full particle simulations. In the simulation model, we have a small body with a small magnetic dipole moment immersed in a plasma flow representing the solar wind. In the vicinity of the surface of the small body, we keep emitting heavy ions as well as photoelectrons. We define L as the distance between the dipole center and a position where the solar wind dynamic pressure balances the magnetic pressure at the dayside. In this study, we set the ratio of the ion Larmor radius to L is between unity and 0.1. In Mercury case, the ratio will be 0.01 which implies the ion Lamor radius is 1/100 smaller than L. However, as stated earlier, it is highly possible that the kinetic effect can play an important role for the dayside physics. Therefore, we emphasize the kinetic effect by adopting larger ion Lamor radius in the simulation. Other important parameters in the simulation are the ratio of the body’s radius to L, the density, and the velocity of the heavy ions and photoelectrons emitted from the surface. In the preliminary simulation results, we could confirm the fundamental physics in the small magnetosphere such as the formation of a small-scale magnetosphere with asymmetric density profile between the dawn and dusk regions, circular current around the body in the magnetic equator and the electric field enhancement near the surface due to the charge separation between heavy ions and photoelectrons emitted from the surface. We would like to investigate the dependency of these phenomena on the parameters stated above. We are also interested in the formation of exoionosphere which can be represented by the spatial distribution of the heavy ions.

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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Keywords: Jupiter, radio emission, Io volcanic activity

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).

Keywords: Saturn, Enceladus, Pitch angle scattering

DSMC simulations of internal gravity waves propagating and dissipating in the Martian upper thermosphere and exosphere

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The effects of internal gravity wave propagation and dissipation in the Martian upper thermosphere and exosphere on the density, circulation, and temperature of the background atmosphere have been studied using a multi-species Direct Simulation Monte Carlo (DSMC) model of Terada et al. (2016). This paper shows results of local simulations of a vertically propagating gravity wave mode in the Martian dayside upper thermosphere and exosphere under the conditions of the observation period of the Mars Atmosphere and Volatile EvolutioN (MAVEN) satellite. The results reveal that gravity waves which produce wave-like density perturbations around the exobase observed by Neutral Gas Ion Mass Spectrometer (NGIMS) instrument onboard the MAVEN satellite [e.g. Yigit et al., 2015; Terada et al., 2017] must have a vertical wavelength of at least 200 km, if they are propagated from the lower and middle atmosphere. We also find that a gravity wave harmonic with a 200 km vertical wavelength significantly heats and accelerates the upper thermosphere and the exosphere, increasing the mixing ratio of CO_2 above 150 km. The calculated horizontal acceleration rate is ~1200 m/s/sol, and the calculated heating rate is ~100 K/sol. The calculated rate of increase in CO_2 mixing ratio is ~80 %/sol around the ionopause, which can probably cause an increase in the escape flux ratios of CO_2^+/O^+ and O_2^+/O^+.

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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.

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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Keywords: Mars, Ion escape, Atmospheric escape

Observation project of the Martian atmosphere by THz-band heterodyne spectroscopic remote sensing with Mars micro-satellite/landers

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Recently the possible source of Methane on Mars discovered with the NASA’s infrared telescope and Curiosity rover is hot issue for discussion. In 2010 the heterodyne instrument for the far infrared band on board Herschel space observatory revealed that molecular oxygen may increase at the lower atmosphere of Mars. For understanding of the behaviors of biomarkers on exoplanets, it is crucial to reveal the related chemical reaction networks of the Martian atmosphere as well as the presence or absence of life as sources of these species.
Currently the team in department of aeronautics and astronautics, the University of Tokyo is planning to launch Mars micro- satellites and landers. We have plans to install 0.4 and 0.7 THz band heterodyne spectroscopic systems on the micro-satellites and landers for the simultaneous remote sensing of the minor constituents such as O2, H2O, O3, and their isotopes related to oxidation reaction networks of the Martian atmosphere. Grand-based telescopes on the earth cannot observe these species on Mars because of the strong absorption of the earth’s atmosphere
For the frontend and backend Schottky barrier diode mixer detectors implemented with frequency multiplying local oscillators (Virginia diode Inc.) and high-resolution chirp transform spectrometers (1 GHz bandwidth) developed in Max Planck Institutes will be equipped, respectively. The equivalent system noise temperature is about 4000 K, which enables us to observe the spectral lines of above species with high signal-to-noise ratio according to the radiative transfer model. In case of a Mars landing mission with look-up observations so-called standard chopper wheel method is not applicable for spectral calibration. Therefore we will prepare the frequency tunable local oscillators for frequency switching mode and two blackbody calibrators with different temperatures. Planetary protection of the system is also an important task. In this conference the current status of this mission will be reported.

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

Study of THz-band heterodyne spectroscopy system on board Mars micro-satellite/lander

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Recently the heterodyne instrument for the far infrared band on board Herschel space observatory revealed that molecular oxygen in the Martian atmosphere may increase at the lower atmosphere. The NASA's infrared telescope and rover, Curiosity have also discovered the concentration of Methane on Mars. For understanding of the sources of these species, it is crucial to reveal the chemical reaction network of the Martian atmosphere as well as the presence or absence of life. We have just started to study the development of 0.4 and 0.7 THz band heterodyne spectroscopic systems for the remote sensing of the minor constituents such as O2, H2O, O3, CO, and their isotopes in the Martian atmosphere. At present we are planning to install this THz system on the Mars micro-satellite/lander under consideration by Nakasuka group of the University of Tokyo. For the frontend Schottky barrier diode mixer devices implemented with frequency multiplying local oscillators (Virginia diode Inc.) are used. For the backend high-resolution chirp transform spectrometers (1 GHz bandwidth) developed in Max Planck Institutes will be utilized. Due to the budget limitations of the weight, space, and electric power, it's vital to optimize the thermal and structural design and components of the system. The candidate landing sites in the low latitude plains range in temperature from 190 - 280 K according to the Mars Climate Database. With this in mind thermo-fluid simulations of the system were performed for the thermal design. In this conference we present the spectral lines expected to be observed at the landing sites on Mars and the preliminary design studies of the THz band heterodyne system.

Keywords: Mars, Micro-satellite/lander, THz-band remote sensing, Planetary atmosphere, Heterodyne spectroscopy

Observation plan of Venus cloud tops with new developed fiber IFU

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Venus is covered with thick clouds made of sulfuric acid on the whole planet, and in visible light it has poor features like ping-pong balls. On the other hand, in ultraviolet light of the wavelength from 200 to 500 nm, it has clear features showing high speed wind blowing so called "super rotation". From 200 nm to 320 nm, absorption can be well explained by SO2 existence, but absorber have not yet identified at wavelengths longer than 320 nm. Although previous observations were carried out by using only one band with a center wavelength of 365 nm, it may be possible to clarify the nature and number of this unknown absorber by comparing the difference of the spatial structure between different wavelengths. Ultraviolet camera (UVI) mounted on Akatsuki has continued to take two different band images with wavelengths of 283 nm and 365 nm, and there are clear spatial structure difference in two bands. Since the band width of UVI is about 15 nm, it is not possible to know what kind of change is occurring between two wavelengths of UVI. The purpose of this study is to clear that from what wavelength the difference exists.

We are developing a spectrum imaging instrument using fiber array. Spectrum imaging can take several images of different wavelength at same time, and it is suitable for studying the unknown UV absorber of Venus. We thought a new manufacturing method of a fiber array with several hundred of fiber with diameter of ~100 μm, and improvement has been added to the method for practical use.

In this presentation, we will report 1) the new method of tracing each fiber in the fiber array, 2) performance of our instrument and 3) plan to observation of Venus using the fiber array are designed for Haleakala 60-cm.

Keywords: Fiber integral field units, Ultraviolet observation, Venus atmosphere