Akatsuki returns to Venus

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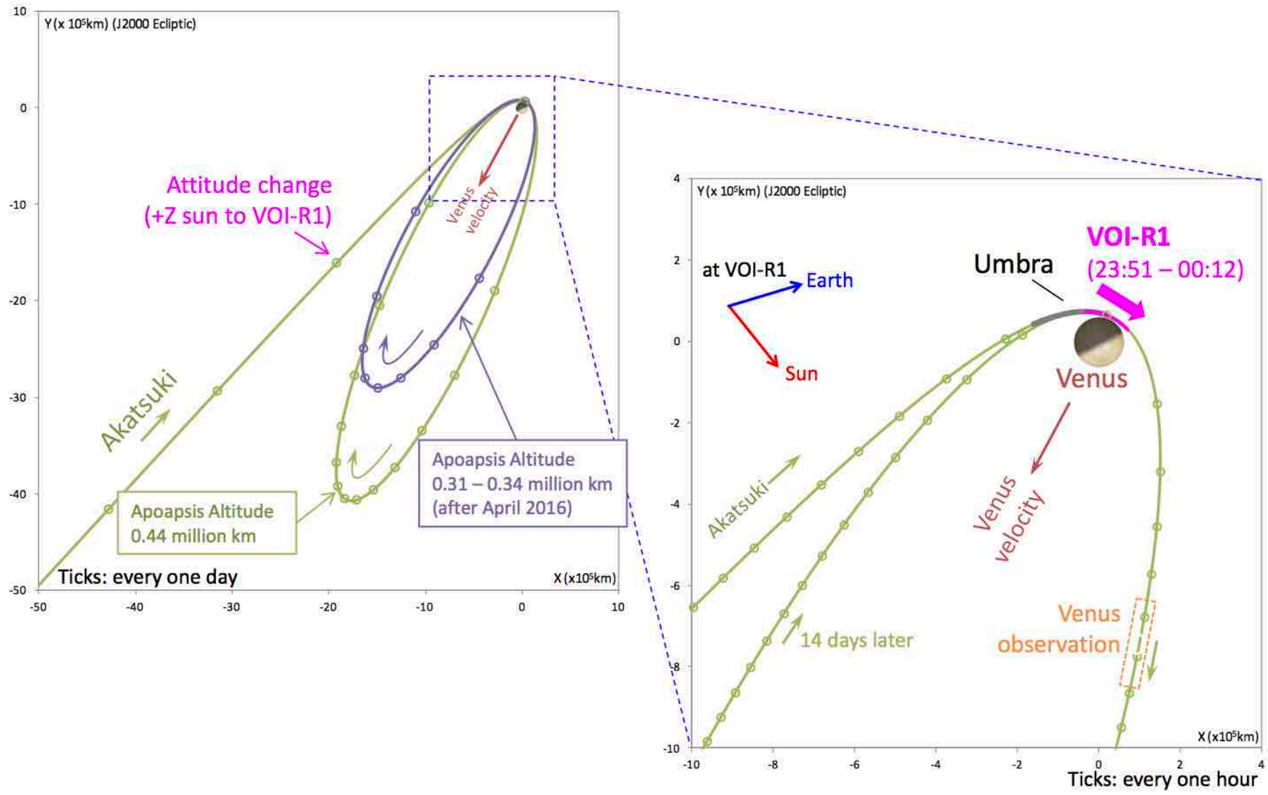
ISAS successfully launched Akatsuki at 06:58:22JST on May 21st 2010, by H-IIA F17. After a half year successful cruise from the earth to Venus, the malfunction happened on the propulsion system during the Venus orbit insertion (VOI) on December 7th, 2010. The engine shut down at 158 sec during the VOI, while we planned 12 min operation. The spacecraft did not enter the Venus orbit but entered an orbit around the Sun with a period of 203 days. The orbital maneuvering engine (OME) was found to be broken and unusable, but most of the fuel still remained. ISAS’s engineers decide to use the reaction control system (RSC) for orbital maneuver and three minor maneuvers in November 2011 were successfully done so that Akatsuki would meet Venus in 2015.
The Akatsuki spacecraft was rotating about the sun with a period of 199 days and was on the trajectory to meet Venus on 22nd of November, 2015 after the orbital maneuvers in November 2011. The date, November 22nd, 2015, was chosen as the shortest encounter timing with consideration of spacecraft's lifetime. Trajectory analysis done later revealed that the orbit around Venus after insertion on 22nd of November, 2015 is unstable. We decided to perform another orbital maneuver in July 2015 to let the spacecraft to meet Venus on 7th of December, 2015 with this date the orbit around Venus would be more stable.
On 7th of December, 2015, the spacecraft approached from outside of Venus orbit and captured by Venus. For the Venus orbit insertion in 2015, termed VOI-R1, four 23 Newton-class thrusters were used as opposed to 500 Newton-class OME used at the 1st VOI in 2010. VOI-R1 burn (1228 seconds) was successfully achieved from 23:51:29 on 6th of December through 00:11:57 on 7th of December (UTC, on-board time).
Akatsuki became the first satellite of a planet in Japan. After VOI-R1, the apoapsis altitude is 0.44 million km with the inclination of 3 degrees. The orbital period is 13 days and 14 hours. The figure shows the VOI-R1 geometry depicted with the Venus center coordinate. For two purposes, to decrease the apoapsis altitude and to avoid long eclipse during the orbiter, we performed a trim maneuver at the first periapsis. The apoapsis altitude is now 0.36 million km with periapsis altitude of 1,000 km - 8,000 km (varying) and the period is 10 days and 12 hours.
Akatsuki will send data over two years to us, and it means that our exploration enters the new era when Japan deliver the continuously changing planet’s data to the whole world.

Keywords: Akatsuki, Venus, Exploration

VOI-R1 Geometry (Venus center)



Initial Results and Radiometric Properties of Ultraviolet Imager on AKATSUKI

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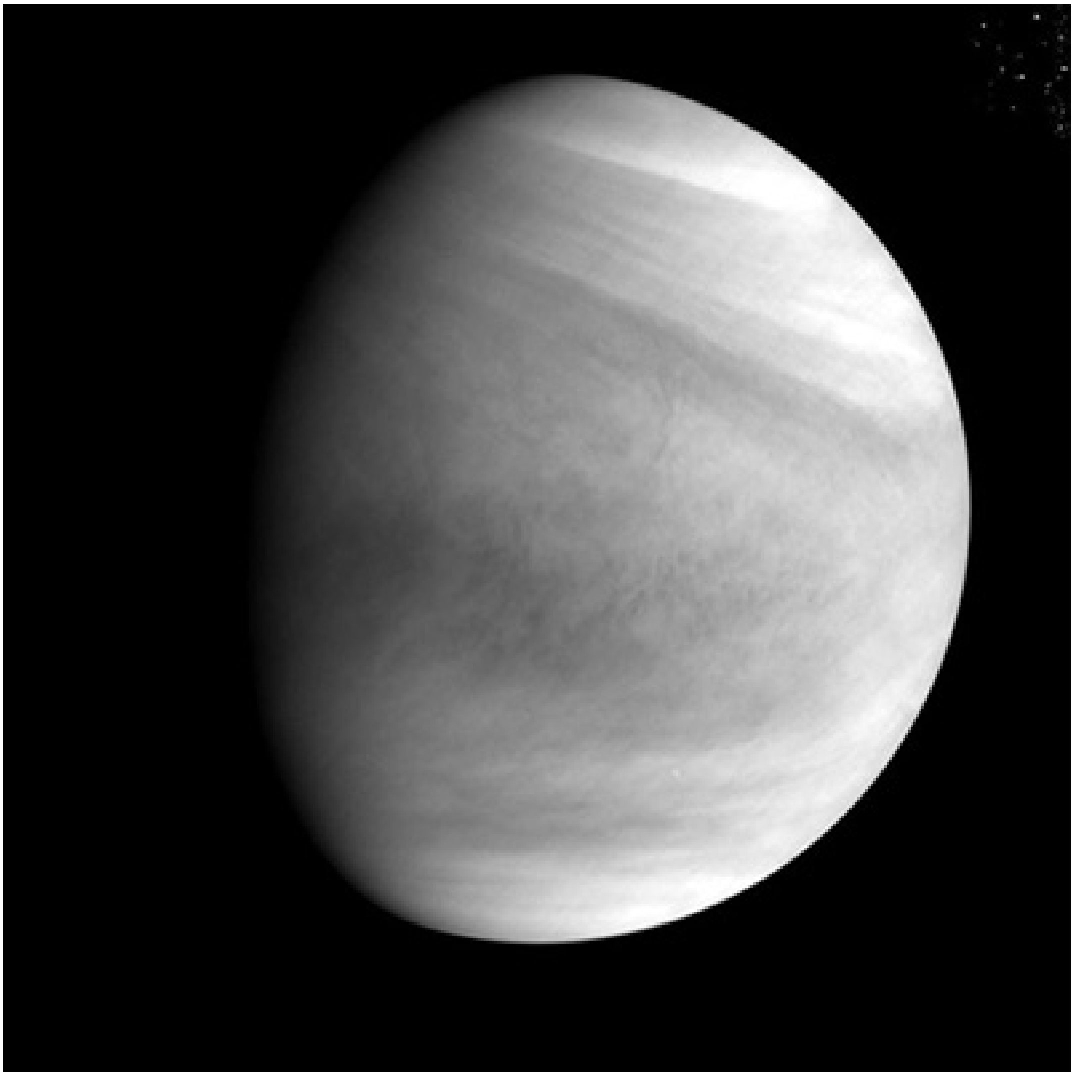
Introduction:
The beautiful UV images of the Venusian cloud top were previously performed by several spacecraft such as Mariner 10 [Bruce et al., 1974], Pioneer Venus [Travis et al., 1979; Rossow et al., 1980], Galileo [Belton et al., 1991], Venus Express [Markiewicz et al., 2007a, 2007b; Titov et al., 2008]. These previous instruments have taken images at the wavelength around 365-nm, but what material distribution reflects the contrasting density has been unknown yet. Under wavelength of 320nm, SO_2 absorption consistent with Pioneer Venus measurements [Pollack et al., 1979], and images in this wave length can clarify the distribution of SO_2.
The ultraviolet imager (UVI) on the AKATUSKI satellite takes ultraviolet images of the solar radiation scattered at the Venusian cloud top level at the both 283- and 365-nm wavelengths. There are absorption bands of SO_2 and unknown absorber in these wave-length regions. UVI result into measurements of the SO_2 and the unknown absorber distributions, and the sequential images lead to understand the velocity vector of the wind at the cloud top altitude.
First Image of Venus:
UVI has taken the two UV wavelength images of Venus immediately after the operation of the Venus orbit insertion last year. The first memorial images by the AKATSUKI “satellite” of Venus were taken at the positions of ~72,000 km far from the Venus center. The solar phase angle at the sub-observer point was ~45 degrees with the evening terminator. The UVI image at a wavelength of 283 nm presents solar radiation attenuated by SO_2 absorption near the cloud top altitudes. This is the first time to capture the snapshot of Venus with this wavelength. Together with the 365-nm images, the continuous UVI images will be used to derive horizontal cloud-tracked velocities near the cloud top altitudes (62–70 km) [e.g., Ogohara et al., 2012; Kouyama et al., 2013].
Although UVI had experienced under interplanetary radiation environment for an unexpected long time, the performance of UVI is fortunately very high because CCD is strongly shielded. Estimated radiance from the first image is from 50 to 200 $W/m^2/sr/\mu m$. It is very reasonable for brightness of the Venusian cloud top. The image quality is very comfortable suite to study scientific objectives before launch. We expect the interesting results from the UVI images of Venus.

Keywords: Venus, AKATSUKI, Ultraviolet Imager



INITIAL RESULTS OF THE VENUSIAN CLOUD-TOP TEMPERATURE OBSERVATION BY AKATSUKI/LIR

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The Longwave Infrared Camera (LIR) onboard Akatsuki took Venus images just after the first challenge in Venus orbit insertion (VOI) in December 2010[1)]. They showed several interesting features in the brightness temperature distribution at the cloud top, however, quality and quantity of the data were far insufficient for studies in details. Akatsuki was finally thrown into a Venus orbit at the second attempt at VOI (VOI-R1) in December 2015 after the unwilling five year cruise around the Sun. It had been confirmed before VOI-R1 that LIR as well as the other cameras onboard Akatsuki was still very good in health. Observations of Venus were started immediately after the VOI-R1 operation. More than 20 Venus images in thermal infrared have been acquired by LIR so far, and observations are continuing to accumulate Venus images day by day.
This presentation will introduce initial results of observation of Venus by LIR, and also show a perspective in future studies in the atmospheric dynamics using brightness temperature and wind distributions derived from the LIR data.
LIR is a small light-weighted thermal infrared camera using an uncooled micro-bolometer array with 320 x 240 effective pixels as an image sensor, and acquires a snapshot of thermal radiation emitted from the cloud top of Venus in the wavelength region of 8 to 12 μm[2)]. The FOV of LIR is designed to fit the full Venus disk to it from the distance of 4.8 R_V from the center of Venus. Since Akatsuki is orbiting in a far elongated elliptical orbit compared to the originally planned orbit, LIR can capture the full Venus disk in most of an orbiting period. The pixel field-of-view is 0.05°, which is four times larger than those of UVI, IR1 and IR2.
LIR has an internal image accumulation function to improve noise-equivalent temperature difference (NETD). This function is called as primary accumulation, which is performed during each exposure. Image data are sent to DE, and up to 32 images can be accumulated. This is called as secondary accumulation. In the nominal observation sequences both primary and secondary accumulation numbers are set to be 32 which gives the best NETD according to the pre-launch test results, and an image acquisition sequence takes about two minutes. An image acquisition sequence without accumulation is also equipped to take an image with a very short exposure time of 1/30 sec, and used when the ground speed of spacecraft is large.
In the first orbiting period LIR took 19 images from Dec. 7 to Dec. 11. The shortest time separation between successive images was two hours. This is chosen so that a wind vector field can be properly derived by a cloud-tracking method. From Dec. 12 to Jan. 14 observation was suspended due to important operations on spacecraft which did not allow the observations in parallel. Observation restarted on Jan. 15.
As a matter of course data amount that can be transferred from spacecraft to ground is limited by bit rate of telecommunication. In the nominal observation plan time interval of image acquisition by LIR is two hours, and it can be shortened to be one hour in a special observation period.
In the first shot by LIR after VOI-R1 several amazing features which have never been seen before are identified at a glance. A huge bow-shape high temperature region extending from the northern high-latitudes across the equator to the southern high-latitudes exists around the evening

terminator. The temperature in the southern polar region seems to be the highest in the snapshot. Dark filament-like streaks aligned north-south direction are found in the low latitudes. They are also identified in the UV image. Interpretation of these interesting features will be discussed in the presentation.

Keywords: cloud morphology

Initial results of IR2 camera on board Akatsuki

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Akatsuki, after its successful orbit insertion on 7 Dec 2015, is under the initial check-out phase. IR2, a 2-um camera on board Akatsuki, is to investigate the Venusian atmospheric dynamics, distribution of the trace gas, aerosol properties and mechanisms of their production and maintenance.
The detector of IR2 is a 1024x1024 pixels PtSi (17-um pixel pitch), combined with the f=84.2 mm lens (F/4, Nikon). The field of view is a square of 12 degrees on a side. To suppress the dark current in PtSi, it is cooled to ~65 K, while the optics including filters are < 190 K to reduce the infrared radiation. Such cooling is achieved by a single-stage Stirling cooler from Sumitomo Heavy Industries, the company responsible to the entire IR2 system.
IR2 has 4 Venus filters: 1.735, 2.26, and 2.32 um are for the night-side of Venus. These "windows" are wavelength regions where CO2 absorption is relatively weak and the thermal emissions originating the lower atmosphere can leak to the space. Therefore, these windows allow imaging of lower clouds as silhouette and enable measurements of atmospheric dynamics in deeper levels. The 2.32-um filter, in CO absorption band, allows to map the distribution of CO in the lower atmosphere. We de-cloud by differentiating 2.32-um image from nearly-simultaneous 2.26-um image. The 2.02-um filter for the day-side allows the cloud top altimetry by utilizing the stron CO2 absorption.
In this paper, we present initial results of data analysis acquired during the check-out phase, and will present the latest data from the orbit.

Keywords: Venus atmosphere, near-infrared, cloud property, CO

Radio occultation observation of Venus atmosphere in Akatsuki mission

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The Radio Science experiment (RS) in the Akatsuki mission of JAXA aims to determine the vertical structure of the Venus atmosphere, thereby complementing the imaging observations by onboard instruments. The physical quantities to be retrieved are the vertical distributions of the atmospheric temperature, the electron density, the H2SO4 vapor density, and small-scale density fluctuations. The uniqueness of Akatsuki RS is quasi-simultaneous observations with multi-band cameras dedicated to meteorological study; the locations probed by RS are observed by the cameras a short time before or after the occultations. An ultra-stable oscillator (USO) provides a stable reference frequency, which is needed to generate the X-band downlink signal used for RS. The USO was switched on and tested successfully in February 2016.

Keywords: Venus, Akatsuki, radio occultation

Cloud top structure of Venus retrieved from Subaru/COMICS mid-infrared spectra

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Venus is completely shrouded by a curtain of dense clouds (50-70 km) with total optical thickness of 20-40 at visible wavelengths. The upper sulfuric acid (H_2SO_4) clouds reflect ~76% of the incident solar radiation back to space [Crisp and Titov, 1997]. Approximately 50% of the solar energy absorbed by Venus is deposited at altitudes higher than 64 km mainly due to unknown UV absorber mixed in the upper clouds [Tomasko et al., 1980]. In addition, infrared radiation from the lower atmosphere is absorbed by the clouds. To elucidate the cloud structure which controls thermal balance of the planet, we analyzed the mid-infrared images obtained by the Cooled Mid-Infrared Camera and Spectrometer (COMICS) mounted on Subaru Telescope [Sato et al., 2014]. We found several important findings near the cloud top altitudes (~70 km), such as the possibility that the westward rotation of the polar features is synchronized between the northern and southern hemispheres, and temporally variable small-amplitude patterns distributed in the entire disk. In order to investigate what atmospheric parameters are responsible for these features seen in the images, we have also analyzed mid-infrared spectra taken on the same date by the same instrument.

A ground-based spectroscopy of Venus was carried out at the solar phase angle of ~90 deg, with the morning terminator in view, using Subaru/COMICS on October 29, 2007 (UT). The entire N-band (8-13 μm) spectra were obtained with a spectral resolving power of R ~ 250, which is equivalent to that of the Fourier Spectrometer onboard Venera 15 [Moroz, 1986]. The slit, which was sufficient to capture the northern and southern limbs of Venus (angular diameter ~25 arcsec), was set to be parallel to the central meridian of Venus just off the nightside limb and Venus was scanned toward the dayside limb. The observed thermal radiation in this wavelength range is emitted mainly from altitudes ~65-70 km.

From slit-scan images composed of a total of 78 spectra, polar hot spots and cold collars in both hemispheres are clearly seen and day-night asymmetry is also found, which are consistent with the characteristics of snapshots at 8.66 μm and 11.34 μm taken by imaging observations on the same date [Sato et al., 2014]. The spectra near 9.6 μm are unavailable due to the contamination of O_3 in the Earth’s atmosphere even after the careful data reduction. There are two identifiable CO_2 bands (12.1 μm and 12.7 μm). For both bands, the spectral features appear in absorption for the equatorial region and in emission for the southern cold collar. This qualitative characteristic is consistent with our knowledge obtained from Venera 15 [Moroz, 1986]. Such information as well as overall spectral shape is useful to retrieve atmospheric parameters, for example, cloud top temperature, cloud top altitude, and cloud scale height.

To estimate how accurately atmospheric temperature can be retrieved from 8-13 μm spectra, as a first step, we performed a sensitivity test with VIRA-2 temperatures [Zasova et al., 2006]. The pseudo observed spectra were calculated from several combinations of VIRA-2 temperatures and a cloud model [Zasova et al., 2007; Eymet et al., 2009], and an inversion technique [Smith, 1970] was applied to these spectra while changing the initial guess of the temperature profile. As a result, we found that the temperature in altitudes ~65-70 km can be retrieved with the uncertainty of ~2 K.

In this presentation, we will show the mid-infrared spectra of Venus obtained by Subaru/COMICS and primitive results of atmospheric parameters retrieved from the observed spectra.

Keywords: Venus, cloud structure, ground-based infrared spectroscopy, radiative transfer

Ground-based observations of the formation and periodical rotation of the global scale UV-feature on Venus cloud top

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On Venus, the atmosphere moves rapidly in the westward direction, reaching velocities 60 times the rotation velocity of the solid globe. This atmospheric ″super-rotation,″ was first detected in the 1960s, however, the mechanism of super-rotation remains mysterious. A planetary-scale bright and dark UV feature, known as the “Y-feature,” rotates around Venus with a period of 4-5 days and has been long-time interpreted as a planetary wave. When assuming this, its rotation period and spatial structure might help to understand the propagation of the planetary-scale waves and find out their role in the acceleration-deceleration of the zonal wind speed, which is essential for understanding the super-rotation of the planet. The rotation period of the UV feature varied over the course of observation by the Pioneer Venus orbiter (PVO). However, last work issuing this crucial topic was made more than 15 years ago, and, since PVO was operated in nearly fixed inertial space, the periodicity variations on sub-yearly timescales (one Venusian year is ~224 Earth days) were obscured by the limitation of continuous dayside observations.

We newly conducted ground-based Venus imaging observations at 365 nm, which consists of six periods covering over half or one month from mid-August 2013 to the end of June 2014 and one continuous periods from mid-April to end of July 2015. Distributions of the relative brightness were obtained from the equatorial to mid-latitudinal regions in both hemispheres, and from the cyclical variations of these distributions we deduced the rotation periods of the UV features of the cloud tops albedo. The relative brightness exhibited periods of 5.2 and 3.5 days above 90% of significance. The relative intensities of these two significant components also seemed subject to temporal variations.

In 2013 and 2014, although the 3.5-day component persisted throughout the observation periods, its dominance over the longer period varied in a cyclic fashion. The prevailing period seems to change from 5.2 to 3.5 days in about nine months, what is clearly not-coincident with the Venusian year (224 days). The amplitude of relative brightness variation is weak during the transition periods of dominant-wave changing. It was indicated that the stability of the planetary scale UV-feature were observed only in the presence of single longer or shorter periodic waves. In 2015, 3.5-days and 5.2-days wave periods could be observed. We success to obtain the change of the first significant mode from 3.5-day wave to 5.2-day wave continuously. As the former observation results, Venus experienced the absence of dominant-wave mode during the transition periods, and the time scale of the transition is estimated about one month in that period.

Keywords: Venus, Y-feature, Ground-based telescope

Analysis of fine structures of Venusian clouds using VMC on Venus Express

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At low latitudes of Venus observed by ultraviolet wavelength range, turbulent-like patterns are observed at the cloud top (Markiewicz *et al.,* 2007). Although it is usually thought that the cloud in the visible wavelength range has little contrasts, structures of clouds are discernible by the observation of Venus Express (Titov *et al.,* 2007). The structures observed by visible wavelength range reflect the horizontal distribution of clouds' thickness because the absorption of sunlight by the "unidentified absorber" which is important in ultraviolet wavelengths is not significant. Since visible light is strongly related to the energy budget of Venus, to study features of clouds in visible wavelength range is important.

In this study, we analyzed the structures of Venusian cloud at low latitude using the data obtained by VMC on Venus Express spacecraft. Using a method of enhancing contrast of the cloud features, which simultaneously eliminates one-dimensional streaky noises fixed to the detector, the contrasts of the cloud features become clear even in the visible wavelength range. We discuss the spatial structures of the Venusian clouds in the visible wavelength range.

Keywords: Venus, visible image, cloud morphology

Detailed temperature structure of the Venusian atmosphere revealed by radio holographic analysis of radio occultation data

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Radio occultation (RO) is one of the most important measurement techniques for studying planetary atmospheres. Radio occultation method relies on the measurement of the frequency shift of the received signal caused by the bending of radio waves in the radial gradient of the refractive index in the atmosphere. The relationship between the impact parameter and the bending angle is retrieved from the observed frequency shift, and this relationship yields the vertical profiles of the refractive index, from which the temperature profile is obtained. The geometrical optics (GO) method has long been used for the analysis of RO data. However, this method cannot disentangle multipath rays, which often occur in the temperature inversion region at high latitudes in the Venusian middle atmosphere. Furthermore, vertical resolution is limited by the size of the Fresnel zone (~1 km for a typical spacecraft-tangential point distance of 2 Venus radii and the wavelength of the radio wave of 3.6 cm).
Radio holographic methods have been proposed for processing of RO signals in multipath regions and obtaining atmospheric profiles with high resolution. One of them is the Full Spectrum Inversion (FSI), which was recently applied to GPS occultation data of the Earth’s atmosphere. By applying the FSI technique to ESA’s Venus Express RO data, we demonstrated the applicability of this technique to Venus’ atmosphere.
The new vertical temperature profiles obtained by FSI technique seem to well repro- duce the temperature structure in the multipath region and achieve high vertical resolution (~150 m). Thin, near-neutral layers were found in the high-resolution static stability pro- files in the high latitude. This feature can be attributed to generation of turbulent layers by breaking gravity waves. The static stability profile in the middle and high latitude tends to show sharp transition from neutral stratification below ~60 km to stable stratification above, suggesting that the convective layer and the overlying stable layer are adjacent to each other with a very thin transition region. Such a condition is favorable to convective generation of gravity waves.

Keywords: Venus, radio occultation, FSI

Two dimensional numerical experiment of the Venusian gravity waves by using a cloud resolving model

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Atmospheric gravity waves influences the atmospheric circulation due to the heat and momentum transports associated with their propagation and breaking. Recently gravity waves are often observed in the Venusian atmosphere by optical and radio occultation measurements (e.g. Peralta et al. 2008; Ando et al. 2015). Convection in the Venusian cloud layer, which is located at 50 to 70 km altitudes, is thought to be one of the main sources of the gravity waves. We have investigated the convective motion and wave generation and propagation due to it by using two dimensional numerical model (Ando et al. JPGU 2014) and found that the reproduced gravity waves satisfy the dispersion relationship, but wave amplitude and energy depend on the resolution and numerical viscosity set in our model. In this presentation, we change the resolution and numerical viscosity and examine the shape of the energy spectrum obtained in each case to determine the appropriate resolution and numerical viscosity to reproduce the gravity waves. Furthermore, we show the energy spectrum distribution and calculate the acceleration rate associated with the momentum convergence in the vertical direction in the case where we use these appropriate values.
We use a cloud resolving numerical model “deepconv” (Sugiyama et al. 2009). The horizontal domain is 500 km, and the vertical domain corresponds to 35 to 135 km altitudes in the Venus atmosphere. There are no stress, vertical flow and potential temperature flux at the upper and lower boundaries. Side boundary is a periodic one. To prevent the wave reflection at the upper and lower boundaries, we introduce Rayleigh friction within 35 km down from top boundary and 5 km up from bottom boundary. To prevent generation of the mean zonal wind we also add <s>the</s> artificial friction to zonal wavenumber 0 component. Newtonian cooling is also introduced in our model on the basis of Crisp (1989). Initial vertical temperature profile is based on Ikeda et al. (2010), who derived the temperature distribution under the radiative-convective equilibrium. This profile has a neutral stable layer within the altitude rage of 48-54 km and a stable layer above and below it. We use net solar heating and infrared radiative cooling profiles based on Ikeda et al. (2010), assuming that they are horizontally uniform and do not change temporally. We assume that the atmosphere is stationary at the initial stage. To generate convective motion potential temperature perturbation with the maximum amplitude of 1 K at 50 km altitude, and we perform the numerical calculation for 15 Earth days. Horizontal resolution is constant of 200 m, and we use three vertical resolution cases (16, 32, 64 m) and four numerical viscosity cases (1×10^{-4}, 3×10^{-4}, 1×10^{-3}, 3×10^{-3}, 1×10^{-2} m s^{-2}).
As a result, in the case where vertical resolution is less than 32 m and numerical viscosity is less than 3×10^{-3} m s^{-2}, all the calculated spectral amplitude are almost equal. Within the altitude region of 66 to 98 km, where gravity waves propagate upward, the spectral amplitude decreases with the altitude. The spectral slope is about -2 within the horizontal wavenumber range of $10^{-4} < k < 10^{-3}$ (1/m) and -3 of $10^{-3} < k$ (1/m). In particular, the spectral slope in the former case is consistent with that empirically suggested on the basis of the observations of gravity waves in the Earth’s atmosphere. Furthermore, the acceleration rate in the horizontal direction associated with the wave dissipation increases with altitude, and it is ~1 m s^{-1} day^{-1} at 90 km altitude.

Keywords: Venus, Atmospheric gravity waves, Numerical calculation

Study of the Venusian cloud formation and distribution in low- and mid-latitudes using a GCM: Effects of atmospheric chemistry and circulation

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Sulfuric acid clouds cover the Venusian atmosphere in 48-70 km, and are important in the Venusian climate through their radiative processes. The clouds are the main objective of the JAXA Akatsuki orbiter for the investigations of atmospheric dynamics, so the modeling study of the formation and advection of them using a Venusian General Circulation Model (VGCM) is of significance also for the help of the mission. We have implemented the sulfuric acid cloud formations and related chemical processes into a VGCM, and investigated their distribution and the formation systems.
We used the VGCM modified from the CCSR/NIES/FRCGC AGCM [Ikeda, 2011], with the horizontal resolution of T21 (longitude and latitude grids of about 5.6 degrees) and 52 levels in vertical with the sigma (equivalent to the pressure) coordinate (the top altitude of ~95 km). For the cloud condensation and evaporation processes, the effects of supersaturation are not considered and the radius of cloud aerosol is artificially distributed into 4 modes by ratios based on the vertical profiles shown by Haus and Arnold [2010]. Note that our model at the moment does not include the growth or reduce of the particle size, and only traces the advection of produced clouds. Also note that the cloud distributions should modulate the thermal distributions through radiative effects, but the current model still assumes constant heat input profile (as well as the former code by Ikeda [2011]).
Our model includes the chemical processes related to the production and loss of H_2SO_4 vapor (SO_3, SO_2 and H_2O) in order to reproduce the realistic maintenance processes of cloud distributions. In the model with those chemical processes (hereafter WC model), the simulated latitudinal distributions of the optical thickness of clouds agree with the observational results by the Visible and InfraRed Thermal Imaging Spectrometer (VIRTIS) onboard Venus Express (VEX), and also the simulated vertical profiles of H_2SO_4 vapor agree with the Magellan radio occultation data, in low- and mid-latitudes (0-70^o N). On the other hand, in the model without the chemical processes (hereafter NC model), the cloud opacity distributions become less than half of the observed ones, and also the abundance of H_2SO_4 vapor around 48 km becomes less than half in comparison with the WC model. Clouds are formed above ~50 km in both models, but the abundances in the WC model are larger than those in the NC model. The difference of the WC model is caused by the production of H_2SO_4 vapor due to the chemical processes and the condensation of it into the clouds in the upper cloud region (60-80 km). We conclude that our VGCM reproduces the observed features with a good reliability in low- and mid-latitudes with chemical processes.
With this VGCM, we investigated the maintenance and circulation processes of the sulfuric acid clouds and vapor in low- and mid-latitudes. Our model indicated that, in the upper cloud region, the clouds are produced centered at ~65 km altitude, and flow upward and poleward by the meridional circulation and vertical diffusion. Meanwhile, in the lower cloud region (50-60 km), H_2SO_4 vapor transported by the upward advection and vertical diffusion condenses into the cloud in the equatorial region at the altitude of 50-54 km, and the formed clouds are transported poleward along the meridional circulation. These cycles are consistent with those simulated in a 2-D latitude-altitude cloud formation model by Imamura and Hashimoto [1998] with a given meridional circulation, and we first reproduced the cycle in a VGCM. Using this new VGCM, we showed that the diurnal tide mainly contributed to drive the meridional circulation through the wave-zonal mean

flow interaction in low- and mid- latitudes.

Keywords: Venus, Sulfuric acid clouds, Atmospheric chemistry, General circulation model, Akatsuki

Small-scale disturbances reproduced by AFES for Venus (Atmospheric general circulation model For the Earth Simulator)

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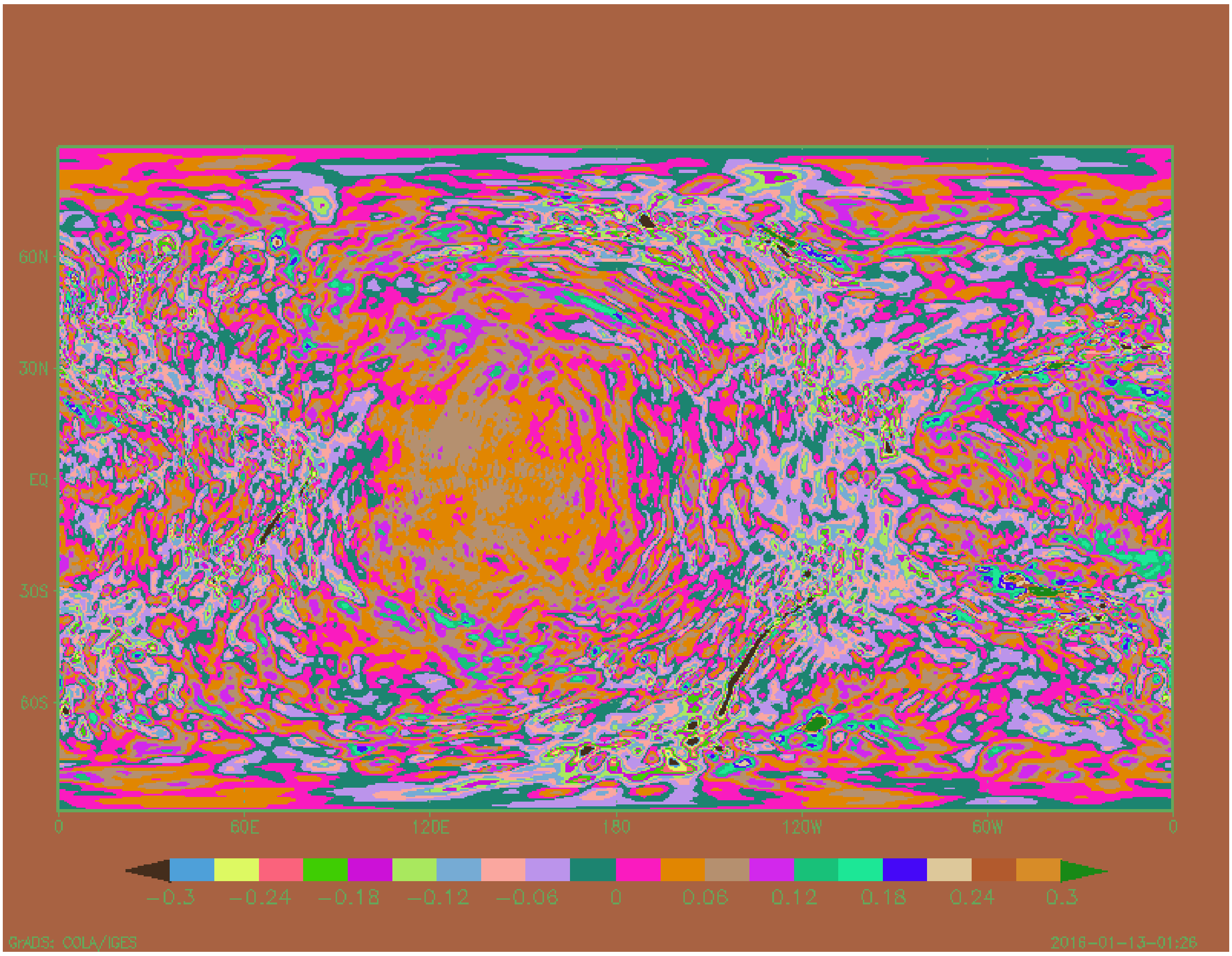
An atmospheric general circulation model (AGCM) for Venus on the basis of AFES (AGCM For the Earth Simulator) have been developed to perform a very high-resolution simulation (e.g., Sugimoto et al., 2014a). The highest resolution is T319L120, namely, there are 960 times 480 horizontal grids (grid intervals are about 40 km) with 120 vertical layers (layer intervals are about 1 km). In the model, the atmosphere is dry and forced by the solar heating with the diurnal and semi-diurnal change. The infrared radiative process is simplified by the Newtonian cooling. Then the temperature is relaxed to a prescribed horizontally uniform temperature distribution which has a virtual static stability of Venus with almost neutral layers. We set a fast zonal wind in a solid-body rotation as the initial state.
Starting from this idealized superrotation, the model atmosphere reaches a quasi-equilibrium state within 1 Earth year. This state is stably maintained for more than 10 Earth years. The zonal-mean zonal flow with weak midlatitude jets has almost constant velocity of 120 m/s in latitudes between 45°S and 45°N at the cloud top levels, which agrees very well with observations. We have investigated small-scale disturbances reproduced in the model. In the cloud layer, baroclinic waves develop continuously at midlatitudes and generate Rossby-type waves at the cloud top (Sugimoto et al., 2014b). At the polar region, warm polar vortex zonally surrounded by a cold latitude band (cold collar) appears successfully (Ando et al., 2016). As for horizontal kinetic energy spectra, divergent component is broadly ($k > 10$) larger than rotational component compared with that on Earth (Kashimura et al., in preparation). In the presentation, the relation between small-scale gravity waves and large-scale thermal tides will be also shown.

Keywords: Venus, GCM, Waves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Status of Millimeter-wave Band Ground-based 10m-SPART Telescope for Monitoring Observations of the Middle Atmospheres of Terrestrial Planets in the Solar System.

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To understand the influence of activities of central stars on the atmospheres of terrestrial planets in the solar system and of exoplanets, we are performing monitoring observations of millimeter-waveband spectral lines of carbon monoxide, ^{12}CO(J = 1-0, J=2-1) and ^{13}CO(J = 2-1) of the Martian and Venusian atmosphere with a 10-m telescope, Solar Planetary Atmosphere Research Telescope (SPART). Heterodyne spectroscopy with high frequency resolution is a powerful tool to trace the weak and narrow spectral lines of minor constituents in the middle atmosphere of planets.

The results obtained with SPART suggest that the disk-averaged mixing ratio of carbon monoxide derived at an altitude of 80 km in Venus was about 60 ppmv during 2012 and 2015. This observing period corresponds to the solar cycle 24 maximum phase. The mixing ratios of CO seem to be lower than those observed during the solar cycle 22 maximum phase. These may suggest that the abundance variations of CO are related to solar activities. For understanding of the CO production induced by solar energetic particles (SEP) events, we performed a numerical model on the basis of the Bethe–Bloch formula under conditions of typically great solar-proton events with incident-proton energies of less than 1 GeV. The obtained results suggest that the ionization rate reaches its maximum at an altitude of 80–90 km in the Venusian atmosphere. However it was found that the production rate of CO is smaller than that induced by incident ultraviolet radiation at the altitude. Although currently the operation environment of the SPART telescope is renewed for opening to the general public at Nobeyama Radio Observatory, we will restart the monitoring observations soon after the construction within this year in anticipation of integrated researches with the AKATSUKI.
In this conference, we will present the current status of the SPART project briefly.

Keywords: Venusian atmosphere, Radio Telescope, Solar Activity

Radiative Transfer Simulations for 1.9 THz Band Remote Sensing Observations of the Martian Atmosphere with SMILES-2

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For better understanding of global warming and space weather predictions, recovery of Ozone layer, physics and dynamics such as planetary and gravity waves, and chemical reaction networks of the Earth’s middle atmosphere, the Submillimeter Wave Limb Emission Sounder 2 (SMILES-2) mission is currently being studied. The target species of the SMILES-2 are H_2O, N_2O, NO_2, NO, CO, H_2CO, OH and O-atom, and so on, which are also key species to study the CO_2 stability problem on the terrestrial planets of the solar system and the formations/sources and destruction processes of CH_4 on Mars. The SMILES-2 will employ 4 K-cooled superconductor/insulator/superconductor mixer detectors and superconducting hot-electron bolometer mixer (HEBM) detectors for the frequency bands below 600 GHz and above 1.8 THz, respectively.
Currently we are developing a superconducting NbTiN HEBM detector integrated with a waveguide slot and a horn antenna for 1.8-2.0 THz band remote sensing observations. We also carried out the feasibility studies of the spectral lines of HO_x, CO, NO_x, and their isotopes in the Martian atmosphere observed with SMILES-2 equipped with the HEBM by performing the radiative transfer simulations. In this conference, we will present the results of these simulations.

Keywords: SMILES-2, THz, Remote Sensing, Mars

Effects of ion-ion collisions on vertical CO_2^+ profiles in Martian ionosphere under magnetic field penetration: Multi-fluid MHD

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The escape of the planetary atmosphere is an important phenomenon related to evolution of the atmosphere, and numerical simulations are an effective method to understand the global atmospheric escape processes. The escape of CO_2^+ from Mars observed by Mars Express is presumed that the origin of CO_2^+ escape flux is result of the ionospheric outflow. In this process, the escape of massive amounts of CO_2^+ requires relatively high density of CO_2^+ at high altitude ionosphere. Ionospheric model developed by Fox and Hac [2010] presumed chemical reaction and velocity difference for each ion fluxes in ionosphere to reproduce the density disturbance of CO_2^+ in high altitude ionosphere. This result suggests velocity difference is important to reproduce the high CO_2^+ density in high altitude ionosphere. Multi-fluid MHD, it is the model allows ion fluxes to take individual velocities, has developed Najib et al,. [JGR, 2011], but the model has not include the effects of the collisions between ions. In our previous research, we developed Multi-fluid MHD and reproduced Martian ionosphere. To investigate effects of collisions, we conducted 5 cases of the simulation. Case1: Multi-fluid MHD includes electron-neutral and ion-ion collisions, Case2: Multi-fluid MHD without electron-neutral collision, Case3: Multi-fluid MHD without ion-ion collisions. Case4: Multi-fluid MHD without electron-neutral and ion-ion collisions. Case5: Multi-fluid MHD. From this previous study, we obtained the effects of velocity differences between ion fluxes and collision for CO_2^+ vertical density distribution. Our recent study is the effect of solar wind magnetic field on Martian ionosphere using under developing Multi-fluid model. Mars has no intrinsic magnetic field. So that, solar wind magnetic field penetrates into Martian ionosphere when the solar wind magnetic field is in active state. When solar wind magnetic field penetrates, Martian ionosphere is contracted, and ion-fluids are accelerated by magnetic field. Our Multi-fluid MHD code can describe individual velocity of ion fluxes, ion-ion collisions, electron-neutral collision, and effects of magnetic field for ion fluxes with different speeds. In this presentation, we report the dependence of ionospheric condition on magnetic field strength and ion velocity in the upper boundary.

Keywords: Mars, Ionosphere, Multi-Fluid MHD

An MHD simulation study of the Kelvin-Helmholtz instability at the Martian ionopause with a day-to-night density gradient

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The effect of a day-to-night density gradient on the evolution of the Kelvin-Helmholtz instability (KHI) at the Martian ionopause is investigated using 2-D extended-local MHD simulations. The KHI is expected to play a major role in transporting mass, momentum and energy across the ionopause between the sheath flow and the Martian ionospheric plasmas, and is thus regarded as one of the candidate processes that have removed a huge amount of ions from Mars through its long history. Recent local MHD simulation studies have pointed out that a density gradient in the vertical direction significantly reduces its linear growth rate and its maximum growing wavelength mode becomes longer. A Longer wavelength mode makes KH vortices more inhomogeneous during the nonlinear phase [*Amerstorfer et al.*, 2010]. However, the actual ionopause has a density gradient not only in vertical but also in the horizontal (day-to-night) direction. In order to investigate the effects of a day-to-night density gradient, we have developed two extended-local MHD models by incorporating two elements of a global model, i.e., an aperiodic boundary condition and the day-to-night density gradient, into a local model.
Comparing the results of the aperiodic case (extended-local model without a day-to-night density gradient) with those of the periodic case (local model), we find two notable differences in the evolution of the KHI. Firstly, while the evolution of the main vortices group is mostly the same in both cases, that of the leading vortex is quite different[YK1] .[AS2] The main vortices group rises and its intrusion into two regions is symmetrical with the ionopause but the leading vortex does not enter the sheath region in the linear growth phase. On the other hand, the leading vortex seems to be squeezed by the sheath region while the main vortices group does not show such a squeezing like structure. Secondly, the ionospheric plasma in the aperiodic case is excavated about 1.5 times deeper. We find that these two differences are caused by the asymmetry in the structure of both sides of each vortex. When there is another vortex with a larger amplitude just downstream of a vortex, this structure behaves like a wall, the sheath flow will be stagnated by this wall-like structure. This stagnated sheath flow induces an enhanced vortex return flow, resulting in a deeper excavation of the ionospheric plasma. Previously, it has been thought that the mixing area will spread widely over time. The Deeper excavation of the leading vortex enhances mixing of ions. In addition, we also find the elongated filament structure is caused by the asymmetry in the structure of both sides of the vortex. A wall-like structure downstream side which mentioned above and an insufficient vortex motion on the leading (upstream) side of a KH vortex leads to vortex return flow and an imbalance between the pressure gradient force and the centrifugal force associated with the vortex motion. The vortex cannot keep its structure and will be an elongated filament. These asymmetries in the vortex structure are responsible for making two differences between the aperiodic and the periodic cases.
We also add the day-to-night density gradient to the aperiodic case by reference to MEX observation results [*Duru et al.*, 2008]. We find that the KHI is quickly excited in the downstream (low density) region. It has been thought that the KH wave propagates from upstream to downstream, i.e., one-way propagation. This excitation in the downstream indicates that the perturbations associated with the KH wave propagate not only to the downstream but also toward the opposite direction, with highly elongated filamentary structures in downstream.
In those simulations, we evaluate the effect of the day-to-night density gradient on the loss rate

of the ionospheric ions. We find that the day-to-night density gradient reduces the ions loss efficiency with 30-40%.

Keywords: Mars, Kelvin-Helmholtz instability, MHD simulation

Comparison of Martian Magnetic Pileup Boundary with Ion Composition Boundary Observed by MAVEN

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The Martian upper atmosphere directly interacts with the solar wind, since Mars does not possess the intrinsic global magnetic field. This interaction forms a transition region between the shocked solar wind (magnetosheath) and the ionosphere, in which characteristic boundary structures are embedded. In this transition region, the neutral atmospheric heavy atoms can be ionized and involved into the solar wind flow. This is called the mass loading process [e.g., Dubinin and Lundin, 1995]. The loaded heavy ions form a dense layer which called “ion composition boundary” (ICB). ICB separates the solar wind protons dominant region from the planetary heavy ions dominant one [e.g., Erkaev et al., 2007]. Since the interplanetary magnetic field (IMF) frozen-in the solar wind plasma, IMF also drape around the transition region. Due to the draping IMF piles up in the front of the Martian upper atmosphere, the magnetic pileup boundary (MPB) is formed [e.g., Luhmann et al., 2004].
Previous studies have shown existence of the magnetic pileup region or the induced magnetosphere in the transition region. Mars Global Surveyor (MGS) observed MPB, a boundary between the magnetosheath and the Martian magnetic pileup region by its magnetometer and electron reflectometer [e.g., Vignes et al., 2000, Trotignon et al., 2006]. ICB was also observed by the ion mass analyzer of Phobos 2 and Mars Express (MEX) [e.g., Breus et al., 1991, Dubinin et al., 2006]. Due to the lack of continuous simultaneous observations of the magnetic field and ion composition, however, relations between MPB and ICB are far from understood. In this study, we investigate relative locations and characteristics of MPB and ICB, and their dependence on solar wind parameters, utilizing a full package of plasma instruments onboard Mars Atmosphere and Volatile EvolutioN (MAVEN).
We conducted a statistical analysis of the ion, electron, and magnetic field data obtained by MAVEN from November 2014 to March 2015 in order to investigate relations between MPB and ICB. We identified MPB from the electron and magnetic field data by inspection based on criteria of Trotignon et al. [2006]. We calculated the density ratio between the planetary heavy ions and the solar wind protons to investigate the ion composition around MPB. Results show that there is a north-south asymmetry in locations of MPB and ICB. Observations also indicate that the relative location of MPB and ICB has deference between dayside and nightside. Moreover, the southern crustal magnetic fields seem to play a role of the north-south asymmetry in locations of MPB and ICB. However, dependences of MPB and ICB on the solar wind dynamic pressure, density, and velocity are not clear. The solar wind induced magnetic field direction also has no clear effects on ICB and MPB locations.

Keywords: Mars, Induced magnetosphere, Magnetic Pileup Boundary, Ion Composition Boundary, Unmagnetized planet, MAVEN

O^+ ion beams reflected below the Martian bow shock

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We investigate a generation mechanism of O^+ ion beams observed above the Martian bow shock by analyzing ion velocity distribution functions (VDFs) measured by the Superthermal and Thermal Ion Composition (STATIC) instrument on the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft. In the solar wind near Mars, MAVEN often observes energetic O^+ ion beams (~10 keV or higher). Accompanied with the O^+ ion beam events, we sometimes observe characteristic ion VDFs in the magnetosheath: a partial ring distribution or a hook-like distribution. The partial ring distribution corresponds to pickup ions with a finite initial velocity (i.e. not newborn pickup ions). Thus the partial ring distribution is most likely to be produced by the reflection of the precipitating O^+ ions below the bow shock. After being injected into the magnetosheath from the solar wind, the precipitating O^+ ions are subject to the significantly enhanced magnetic field in this region, and consequently, a part of precipitating O^+ ions are reflected back to the solar wind, generating O^+ beams in the solar wind. The hook-like distribution contains two ion populations: a mixture of local O^+ pickup ions and O^+ pickup ions precipitating from the solar wind right above the bow shock, and O^+ pickup ions precipitating from the upstream solar wind and being reflected below the bow shock. The latter population also generates the O^+ ion beams in the solar wind. The reflected O^+ beams are reaccelerated by the convection electric field in the solar wind and may escape Mars.

Keywords: Mars, ion reflection, MAVEN

Global structure of Mercury's magnetosphere : Dependence on solar wind parameters

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Based on observations by MESSENGER, Mercury's magnetosphere is thought to be a miniature of the Earth's magnetosphere. These two magnetospheres have several characteristics in common, however, some critical differences are also evident. First, there is no atmospheric layer, but only tenuous exosphere. Second, the kinetic effects of heavy ions might not be negligible because Mercury magnetosphere is relatively small compared to the large Larmor radii. Recent observation by MESSENGER also found that the center of dipole is shifted to northward about 485km from the center of Mercury. Trajectory tracings is one of the dominant methods to estimate the kinetic effect of heavy ions which originate the exosphere, though the results of the simulation are quite sensitive to the electric and magnetic field. Therefore, 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 to the global simulation of Mercury magnetosphere. In this study, first we performed two cases of simulation, low and high solar wind density cases(35cm^{-3}, 70cm^{-3}, and 140cm^{-3}) with velocity for 400km/s and northward IMF condition. When solar wind density is low, magnetopause is formed at 1.4R_{M}, and the global structure has weak north-south asymmetry in the MHD simulation. One of the important characteristics is open field line from south pole even in the northward IMF condition without Bx and By components. When solar wind dynamic pressure is high, Mercury's magnetosphere is compressed to the scale of Mercury itself. In this case, planetary surface disturbs the magnetospheric convection, and the north-south symmetry as well as similarity to Earth's magnetosphere are strongly violated. Trajectory trancings in the MHD fields show that there are enough space for energetic (~ few keV) sodium ions which are the main component of 'sodium ring' at the vicinity of the planet to go through the dayside magnetosphere in the low density case. In the high density case, dayside is too compressed and there are no space for sodium ions to go through. As a result, 'sodium ring' became not isotropic ring but formed only at nightside. In the next step, we performed higher dynamic pressure of the solar wind condition, it is, density for 140cm^{-3} and velocity for 800km/s. This parameter is rarely occurred except for the extreme case such as CME events. The result of MHD simulation shows that most of magnetic filed lines are opened, and continuous tail reconnection occurred by extremely high dynamic pressure. These structure and phenomenon partly correspond to that of magnetosphere with southward IMF, while magnetospheric convections are largely different because no magnetic reconnection occurs at the dayside magnetosphere. Another characteristics is secondary compression region in the magnetosheath at flank side of the planet. First compression is occurred by planetary surface at the front side and formed what we call bow shock. Second compression is caused by magnetopause at the flank side which lies at the direction of sheath flow. In the presentation, we will also report the ongoing simulation result of trajectory tracings in this extreme case.

Keywords: Mercury's magnetosphere, MHD

Ionic composition in the Io plasma torus measured using Hisaki/EXCEED and gourd-based telescope

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Volcanic gases (mainly composed of SO_2, SO and S) originated from jovian satellite Io are ionized by interaction with magnetosphere plasma and then form a donut-shaped region called the plasma torus. Ion composition in the plasma torus is a key issue to investigate a source region and production mechanisms of magnetospheric plasma. A coordinated observation of EUV spectroscopy by Hisaki/EXCEED with a ground-based spectroscopy by Kitt Peak 4-m telescope enables to measure composition of most of ions (S^+, S^{++}, S^{+++}, O^+ and O^{++}) in the plasma torus.
At the begging of January 2014, intense campaign observations of Jovian aurora and Io plasma torus were made using Hisaki/EXCEED, Hubble Space Telescope and other ground-based telescopes covering wavelength range from EUV through IR. The 4-meter R.C. Spectrograph was set up covering 550nm through 800nm which could successfully detect NaD (589nm), [S III] 631.2nm, [S II] 671.6/673.1nm, and [O II] 731.9/733.0nm as well. A field-of-view was 98 arc-seconds along the slit and the slit center was pointed at the dawn or dusk edge of the centrifugal equator. We could get 54 spectra from the observation during January 4th through 10th, 2014.
Based on analysis of visible spectrum from Kitt-Peak 4-meter, typical emission intensity of [S II] 671.6+673.1nm, [S III] 631.2nm and [O II] 731.9+733.0nm were 700R, 100R and 60R, respectively. Combining the visible spectrum with EUV spectrum measured by EXCEED/Hisaki, plasma diagnostics can be made on the plasma torus. According to the atomic database, CHIANTI version 8.0, the best fit ion composition was $S^+:S^{++}:S^{+++}:O^+:O^{++}$ = 4:27:11:13:40. The result shows that the average ionization state was higher than that at Cassini era in 2004. More accurate analysis including errors and uncertainty is ongoing, the recent result will be presented at the meeting.

Keywords: Io plasma torus

Variations of Io's volcanism seen in Jupiter's sodium nebula

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Io, which is one of Jupiter's remarkable moons, is the most volcanically active body in the solar system. Io's volcanic gas forms its atmosphere, but it cannot stay on Io stable. It is ionized due to the solar radiation or impacts by Jupiter's magnetospheric energetic particles, then escapes and forms the Io plasma torus. Sodium chloride molecules included in Io's volcanic gas are also ionized, then picked up by Jupiter's co-rotating magnetic fields and going to the Io plasma torus. In the torus, these molecular ions collide with the torus electron, then they distract and neutral fast sodium atoms are produced. These sodium atoms have velocity of Jupiter's co-rotation at an orbit of Io that corresponds to 74 km/s. This is enough to escape from Jupiter's gravitational-sphere. The sodium atoms whose origin is Io's volcano form a extend cloud around Jupiter, and this is called Jupiter's sodium nebula. This nebula can be seen at sodium D-line wavelengths from the ground. The brightness in the sodium nebula is changing with respect to volcanic activity on Io. We have been making the observations of this sodium nebula from an observatory on Mt. Haleakala in a conjunction with the HISAKI spacecraft whose one of main targets is Jupiter's magnetosphere. The sodium nebula shows a distinct enhancement in its brightness in January-April 2015. In this presentation, volcanic activity on Io in a period of the HISAKI observations will be shown.

Keywords: Io, Jupiter, Volcanism, magnetosphere

The wave structure in Jupiter's polar region and the asymmetric distribution of the polar cup haze

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In the Jupiter stratosphere, the polar cup hazes exist in the both hemispheres whose edges show the wave structure. Previous observations, such as by Cassini ISS in 2000 or the Hubble Space Telescope (HST) from 1994 to 1999 [*Barrado-Izagirre at al.*, 2008], show that the polar region is covered by bright diffuse haze and its edge has a wavy structure spreading in longitudinal direction with wavenumber of 12 –14 at 67° S, which travels westward with a phase velocity of 0- 10 m/s. These observations suggested that this wave structure is caused by a planetary Rossby wave. However, these observations had been carried out only every other year and the variance of short time scale (about month) is not clear. The spatial range of this wave structure have not been investigated.
The aim of this study is to clear dynamics of the wave structure which vary within few days or few weeks. This is achieved by the continual observation using a methane absorption band filter at 889 nm installed at Multi-Spectral Imager (MSI) of the 1.6 m Pirka telescope. To investigate spatial structure of this wave, we measure the boundary of the low-latitude side of the wave. We also clear the vertical structure in polar region using observation at wavelengths that absorption by methan are different. In addition, identify of distribution of the haze structure is also purpose of this study.
In this presentation, we introduce the observational results of time variation of the wave structure in Jupiter’s south polar region in 2011 to 2015 by the ground-based telescope. Each result is separated by few days to few weeks. Our results show the variation of the wave structure within few weeks for the first time. It is found that disappearance of wavy positive peak at longitude 100° in 18 days by the time variation of the wave structure. The wave structure change locally in a short period. The longitudinal difference of the vertical wave propagation is found by observation at some wavelength that observational altitude are different. It is possible that which is different from Rossby wave. It was suggested that not only Rossby wave but also locally and short-period wave structure exist in the polar region. It is cleared that the wave structure at 67° S is only seen at 56° S by the latitudinal variation of the wave structure. Thus, the spatial distribution of the wave structure is constrained.
In addition, the spatial distribution of polar cup haze in the north hemisphere is asymmetry for the north pole. This corresponds with a sharp of auroral oval at some longitude. It is suggested the relationship haze structure and auroral oval.

Keywords: haze, wave structure

Measurements of Jupiter's decametric source locations by LWA1 modulation lane data

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Jupiter's decametric emissions originate along magnetic field lines within auroral zones as well as field lines that pass through Io and the Io plasma torus. The radio waves at Jupiter are amplified by particle-field interactions and are generated in both the X-mode and O-mode. Due to the emission source parameters, right-hand (RH) polarized waves are generated from northern hemisphere sources (Io-A and Io-B sources) while left-hand (LH) polarized waves come from the southern hemisphere (Io-C and Io-D sources).
The modulation lanes in Jupiter’s decametric radiation, which were discovered by Riihimaa [1968], are groups of sloping parallel strips of alternately increased and decreased intensity in the dynamic spectra. Extensive systematic observations of modulation lanes have been made in the frequency range 21 to 23 MHz by Riihimaa [1970, 1974, 1978]. The frequency-time slopes of the lanes can be either positive or negative, depending on which of the Jovian sources is being observed.
In the Imai et al. model for the production of modulation lanes, the lanes are assumed to be a manifestation of interference fringes from the line source consisting of the points along the axis of the Io-activated flux tube that are emitting at the different local values of fc. The fringes are produced as a result of the passage of the multi-frequency radiation through an interference grating. This grating is a planar grid of almost equally spaced field-aligned columns of enhanced plasma density, perpendicular to the ray-paths toward Earth, located near the sub-Earth point on Io’s orbit. Radiation from each of the frequencies emitted by the line source produces a set of interference fringes when it is scattered by the plasma-enhanced columns. These sets of fringes are inclined with respect to the Jovian equator. The rotation of Jupiter sweeps the inclined interference patterns for the different frequencies across Earth, producing the modulation lanes in the observed dynamic spectra. We developed a model to explain the production of the modulation lanes [Imai et al., 1992a, 1992b, 1997, 2001, 2002]. By using our model the precise Jupiter's radio source locations and beam parameters can be measured. This new remote sensing tool is called as the modulation lane method.
The Long Wavelength Array (LWA) is a low-frequency radio telescope designed to produce high-sensitivity, high-resolution images 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 allow us to observe the fine structure of Jupiter's decametric modulation lanes. Using newly available wide band modulation lane data observed by LWA1, we measured source locations and beam parameters. The results of LWA1 data analysis indicate that the radio emitting sources are located along the restricted range of longitude. We only receive one of the individual sources which has a very thin beam thickness (probably less than few degrees) at a given time. We show the measured locations of Io-related sources based on the modulation lanes observed by LWA1. The new components of Io-C and Io-B sources are discussed.

Keywords: Jupiter radio, modulation lane, radio source locations