あかつき、金星への帰還
Akatsuki returns to Venus

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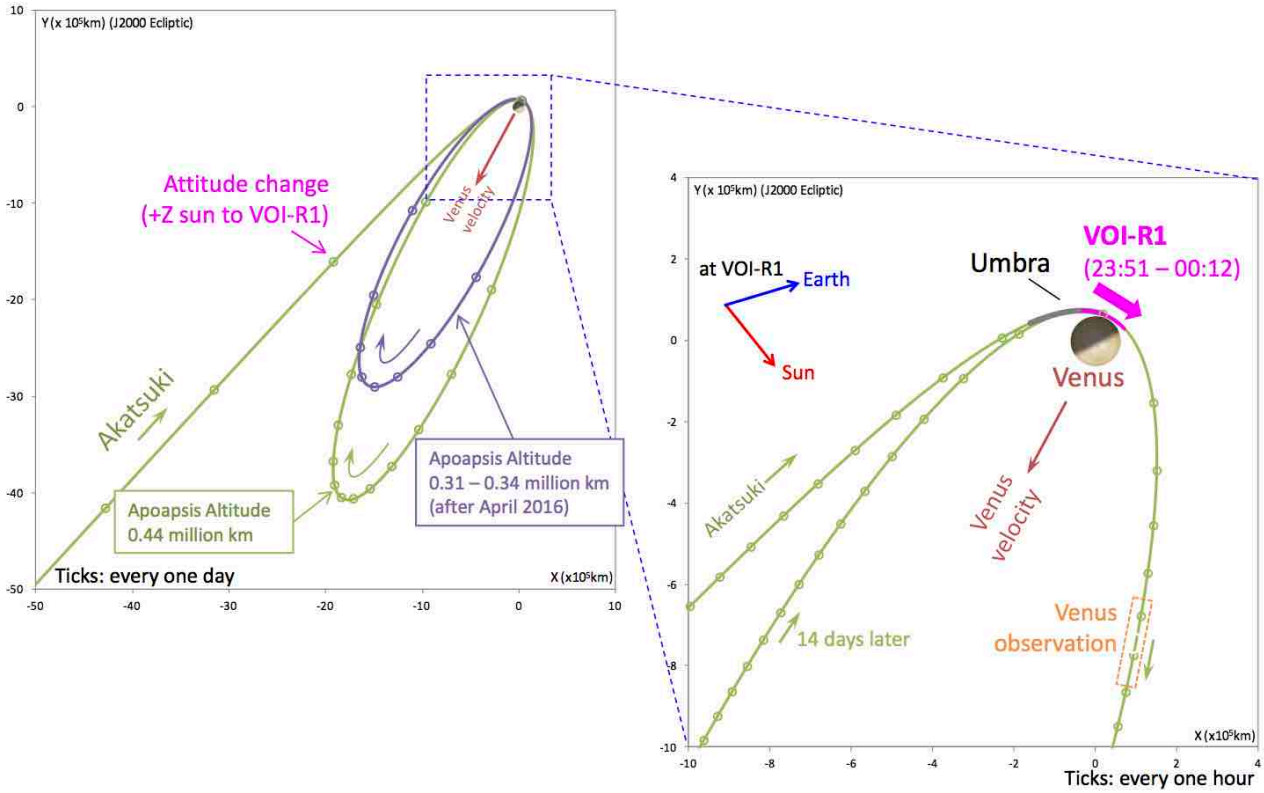
ISAS successfully launched Akatsuki at 06:58:22JST on May 21st 2010, by H-IIA F17. After a half year successful cruise from the earth to Venus, the malfunction happened on the propulsion system during the Venus orbit insertion (VOI) on December 7th, 2010. The engine shut down at 158 sec during the VOI, 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.

キーワード：あかつき、金星、探査
Keywords: Akatsuki, Venus, Exploration

VOI-R1 Geometry (Venus center)



あかつき紫外イメージャ初期報告と感度特性評価
Initial Results and Radiometric Properties of Ultraviolet Imager on AKATSUKI

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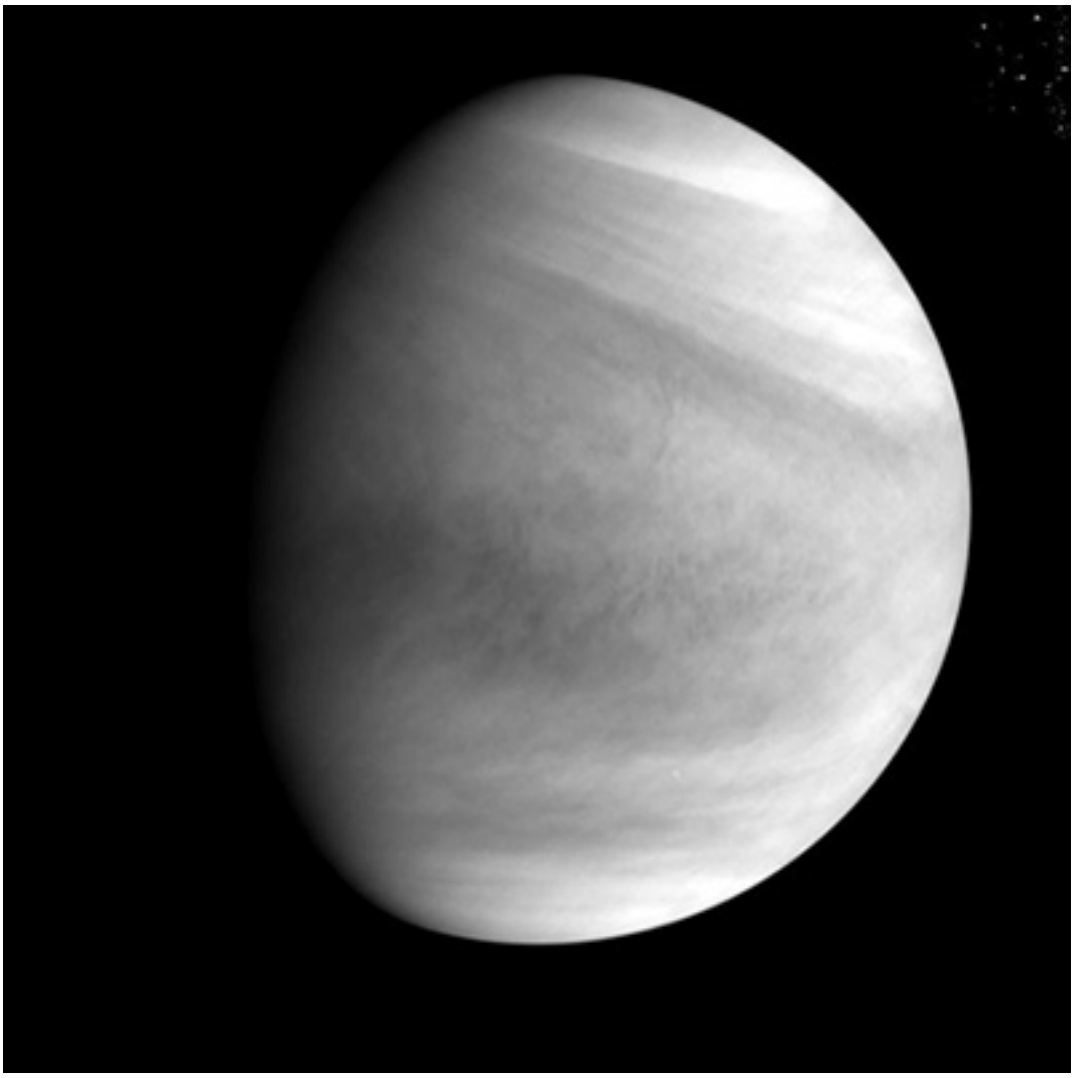
Introduction:
The beautiful UV images of the Venusian cloud top were previously performed by several spacecraft such as Mariner 10 [Bruce et al., 1974], Pioneer Venus [Travis et al., 1979; Rossow et al., 1980], Galileo [Belton et al., 1991], Venus Express [Markiewicz et al., 2007a, 2007b; Titov et al., 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.

キーワード：金星、あかつき、紫外イメージャ
Keywords: Venus, AKATSUKI, Ultraviolet Imager



あかつき搭載中間赤外カメラによる金星雲頂温度観測の初期結果
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.

キーワード：雲形態学
Keywords: cloud morphology

あかつきIR2カメラの初期成果
Initial results of IR2 camera on board Akatsuki

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探査機あかつきが2015年12月7日に金星周回軌道へ投入され、初期チェックアウトが続いている。IR2カメラは波長2um帯で金星大気の運動や微量気体の分布、雲の性質、生成・維持機構の解明などを目指す搭載機器である。
検出器は1024x1024画素のPtSi検出素子（17um画素ピッチ）であり、焦点距離84.2mm/F4のレンズ（ニコン）を組み合わせて12度四方 の視野をもつ。PtSi素子の暗電流を低く抑えるために検出器は65K程度、フィルターを含む光学系は190K以下に冷却して熱雑音を抑える。冷却には一 段スターリング冷凍機を用い、冷凍機の製造およびカメラ全体の組み立ては住友重機械工業が担当した。
金星観測用には4種類のフィルターを搭載している。波長1.735, 2.26, 2.32umは金星の夜面観測用である。これらはCO2大気の「窓」と呼ばれる領域で、相対的に大気吸収が弱く下層からの熱放射が漏れ出てくる。それにより雲のシルエットが見え、中下層大気の運動を可視化する。2.32umはCO吸収帯にあたり、2.26umとの差分により雲の影響を取り除き、CO分布とその時間変化を調べる。
波長2.02umは昼面用、CO2吸収を利用して雲頂の微細な凹凸を調べることができる。
本講演では初期チェックアウト中のデータ解析結果、最新のデータの紹介を行う。

キーワード：金星大気、近赤外線、雲特性、一酸化炭素
Keywords: Venus atmosphere, near-infrared, cloud property, CO

金星探査機「あかつき」による電波掩蔽観測
Radio occultation observation of Venus atmosphere in Akatsuki mission

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「あかつき」の電波掩蔽観測は気温の高度分布を精度0.1 K、高度分解能1 km程度で観測し、光学観測を補完する。この観測では普段は探査機と地上局の間の通信に用いている電波を利用する。地上局から見て探査機が金星の背後に隠れる時と背後から出てくる時、探査機から送信される電波は金星大気をかすめるように通過して地上局に届く。このとき電波が金星大気の影響で屈折する結果としてDoppler周波数が変化する。これを分析すると大気の屈折率の高度分布がわかり、そこから気温の高度分布がわかる。高度100 km以上の屈折率からは電離層の電子密度も得られる。受信電波強度の変化からは硫酸雲の下に多く存在する電波吸収体である硫酸蒸気の分布がわかる。

電波掩蔽という手法自体は枯れた技術であり、金星でも実績がある。しかし電波掩蔽はラジオゾンデを放球するようなものであり、いつどこでどのように実施するかによって成果は全く異なるものとなる。「あかつき」の探査においては5台の気象カメラで得られる大気の水平構造の情報と組み合わせることにより3次元の気象場の推定を可能にする。また「あかつき」は赤道周回軌道をとるため従来の極軌道の探査機と異なり中・低緯度を重点的に観測することも特色である。

金星大気の変動がもたらす微小な周波数変化を検出するために、基準周波数に対する周波数変動の割合が10^{-12}以下という超高安定発振器(Ultra-stable oscillator、USO)を搭載した。これまでの金星探査においてこのような安定度のUSOを搭載したのは欧州の金星周回機Venus Expressだけである。「あかつき」から送信されたGHz帯の電波は臼田宇宙空間観測所のアンテナで受信され、ローカル信号のミキシングにより数百KHzの信号に変換されたのち波形ごと記録される。このデータから周波数や電波強度の時系列を抽出する。

「あかつき」の電波掩蔽では撮像観測との連携が重要である。異なる高度の多様な雲の変動が温度場（安定度）のどのような変化に対応するのか、水平発散場と温度場の対応はどうなっているのか、そのような雲中のダイナミクスとその上の中層大気の重力波活動はどう関係するのか。「あかつき」の新たな軌道では軌道周期が10日程度と長く、観測頻度が低いが、撮像観測との有機的な連携により革新的な成果を狙う。

2016年2月、あかつき搭載USOは4年半ぶりに目を覚まし、所定の性能を発揮することが確認された。3月以降にいよいよ観測が始まる。

キーワード：金星、あかつき、電波掩蔽
Keywords: Venus, Akatsuki, radio occultation

Subaru/COMICSの中間赤外分光データで調べる金星雲頂構造
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.

キーワード：金星、雲層、地上赤外分光、放射伝達
Keywords: Venus, cloud structure, ground-based infrared spectroscopy, radiative transfer

金星雲頂での惑星規模模様の形成と循環周期の地上観測

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.

キーワード：金星、Y字模様、地上望遠鏡
Keywords: Venus, Y-feature, Ground-based telescope

Venus Express VMCの雲画像解析による金星雲頂の微細構造の研究
Analysis of fine structures of Venusian clouds using VMC on Venus Express

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金星の雲の紫外線観測では低緯度に、数十から数百kmの空間スケールの不規則な乱流のような模様が観察される(Markiewicz *et al.*, 2007)。従来、輝度の変化が小さく雲の模様の変化が見にくいとされてきた可視波長でも、Venus Expressの観測により低コントラストながら模様が存在することが明らかとなった(Titov *et al.*, 2007)。可視波長領域は雲の吸収物質による影響が少ないため、雲の厚さの水平分布上層雲の水平分布をよく表していると考えられ、さらに太陽放射の大半は可視波長領域にある。そのため雲の反射率の変化が金星大気におよぼす影響を考える上で可視波長を用いた研究は重要である。可視波長での観測により得られる、金星の雲そのものの形態を手がかりに、どのような物理が金星大気に働いているか理解することに意義がある。
本研究では、欧州の金星探査機Venus Expressに搭載されていた撮像装置VMC（Venus Monitoring Camera）により得られた可視画像を用いて金星の雲の低緯度にある微細な構造の抽出を試みた。輝度の微細な空間変化を強調するために空間差分を行う際に、同時に検出器の読み出しに伴う筋状の固定ノイズを取り除くよう工夫することにより、低コントラストの模様までとりだすことができ、雲が背景風に流される様が観察できた。本発表では、可視波長でみた金星の雲の空間構造について議論する。

キーワード：金星、可視画像、雲の形態学
Keywords: Venus, visible image, cloud morphology

電波掩蔽データの電波ホログラフィ解析で明らかになった金星大気温度の微細構造
Detailed temperature structure of the Venusian atmosphere revealed by radio holographic analysis of radio occultation data

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電波掩蔽とは探査機が地上局から見て惑星の背後を通過した際に、探査機から送信された電波が惑星大気を通過し地上局に届くことを利用した観測である。惑星大気の高度方向の温度分布を測定することができ、惑星探査における重要な観測手法のひとつである。電波掩蔽データの解析においては長年、電波を１本の光線として扱う幾何光学解法が用いられている。しかし、この解法では複数経路(マルチパス)の電波が重なり地上で同時に受信されると分離できない。マルチパスは金星では高緯度に見られる温度逆転領域でしばしば生じる。また、この解法では鉛直分解能がフレネルゾーンの大きさ(典型的な探査機と電波の接点の距離を金星半径の2倍、電波の波長3.6cmのとき~1 km)で制限される。
本研究では上記の欠点を補うために新たに提案されている電波ホログラフィ法を用いて金星大気の構造を決定した。この法はマルチパス領域の処理と高分解能で大気構造を得るために提案された手法であり、そのうちの一つがFull Spectrum Inversion (FSI)で、近年の地球大気におけるGPS掩蔽観測で用いられている。本研究では、このFSIをESA Venus Expressの電波掩蔽データに適用し金星大気の鉛直温度分布を新たに求め、惑星大気観測におけるFSIの有効性を実証した。
FSIにより求まった金星大気の鉛直温度分布はマルチパスを分離し、高鉛直分解能（~150m）を達成した。これにより金星大気の温度構造について新たに次のことを述べた。(1)中高緯度で従来知られていたよりもシャープな温度極小構造が見られ、温度極小の直下が断熱温度勾配になっていること、およびこの中立層(対流層)は従来知られていたよりも高高度まで到達しており、その上の安定層と薄い遷移領域で隣り合っている。これは雲頂付近における放射冷却だけではなく、対流プルームがより高高度まで到達し温度極小の構造を作っていることを示唆している。また対流層がその上の安定層と薄い遷移領域で隣り合っている状況は、対流プルームが安定層をたたき重力波を生成するのに好都合な条件である。さらに、(2)対流層の上の安定層で厚さ数百m程度の薄い中立層が中高緯度で数多く捉えられた。これは重力波の砕波によって生成された乱流の層が捉えられた可能性がある。

キーワード：金星、電波掩蔽、FSI
Keywords: Venus, radio occultation, FSI

雲解像モデルを用いた金星大気重力波の２次元数値実験

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

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大気中の重力波は、その伝播と砕波に伴う熱と運動量の輸送を介して、大気循環に影響を与える。近年、金星大気においても重力波が光学機器や電波掩蔽観測により盛んに観測されている（e.g. Peralta et al. 2008; Ando et al. 2015）。金星大気中を鉛直伝播する重力波の励起源の一つとして、雲層内（高度50-70 km）に存在すると思われる鉛直対流がある。これまで我々は、金星雲層内の対流運動とそれによる波の励起と伝播を２次元の数値モデルを用いて調べてきた（安藤 他, JPGU 2014）。その結果、再現された重力波は分散関係式を良く満たすが、波の振幅やエネルギー密度がモデルの解像度や数値粘性に強く依存することが分かった。本発表では、モデルの解像度と数値粘性を変えて、それに伴うエネルギースペクトルの形状の変化を調べることにより、鉛直対流起源の重力波の生成と伝播を計算するのに適切な解像度と数値粘性を探索する。さらに、それらの値を用いた場合の重力波のエネルギースペクトル分布、重力波による鉛直方向の運動量フラックス収束に伴う加速率を調べる。
用いた数値モデルは雲解像モデルdeepconv（Sugiyama et al. 2009）である。計算水平領域は500 km、鉛直領域は金星の高度35-135 kmとした。境界条件は上下端にて応力なし、鉛直流・温位フラックスなしとし、側面は周期境界とする。また、上下端からの波の反射を抑えるために、上端から35 kmと下端から5 kmの範囲にレイリー摩擦とニュートン冷却を加えた。また運動の結果として平均流が生成されないように人工的な摩擦を波数０成分に対して加える。初期に与える温度の鉛直分布は、放射対流平衡の下での温度分布（Ikeda et al. 2010）を用いた。この時の静的安定度は、高度48-54 kmで中立、その上下の領域で安定である。放射過程は陽に計算せずに、水平一様かつ時間変化しない熱強制として与え、正味の加熱・冷却の鉛直分布はIkeda et al. (2010) の計算結果に準ずる。初期に大気は静止しているとし、対流運動を励起するために最大振幅1 Kの温位擾乱を高度50 kmに与え、そこから15日間の計算を行う。モデルの水平解像度は200 mに固定し、鉛直解像度を16, 32, 62 mと変化させ、また数値粘性も1×10^{-4}, 3×10^{-4}, 1×10^{-3}, 3×10^{-3}, 1×10^{-2} m s^{-2} と変えた。
その結果、数値粘性3×10^{-3}以下、鉛直解像度32 m以下の計算では、スペクトル密度の大きさと水平波数に対する依存性はおおむね一致することが分かった。重力波の鉛直伝播が生じる高度66-98 kmでは、スペクトル密度の振幅は高度と共に減少する。そして、スペクトルの傾きは水平波数領域$10^{-4} < k < 10^{-3}$ (1/m) では -2 に比例し、$10^{-3} < k$ (1/m) の領域では -3 であった。特に、$10^{-4} < k < 10^{-4}$ (1/m) におけるスペクトルの傾きは、地球大気の観測に基づいて提唱された経験的な重力波の水平波数スペクトルの傾きに一致する。また、波の減衰に伴う水平方向の加速率は高度と共に増大し、高度90 kmでおよそ 1 m s^{-1} day^{-1} であった。

キーワード：金星、大気重力波、数値計算
Keywords: Venus, Atmospheric gravity waves, Numerical calculation

GCMを用いた金星低・中緯度の雲生成と分布の研究：化学と循環の影響

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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硫酸雲は金星の高度48～70kmを覆い、その放射効果は金星の気候に大きな影響を与える。また硫酸雲はJAXAの金星探査機「あかつき」の主要な観測対象であり、雲観測を通しての大気力学の研究が予定されているため、金星大気大循環モデル(VGCM)を用いた硫酸雲の生成・移流過程の研究はあかつきミッションに対しても資するものとなる。我々はVGCMに硫酸雲生成過程とそれに関連する大気化学過程を導入し、雲の分布および生成に絡む過程の研究を行った。
本研究に用いたVGCM [Ikeda, 2011]はCCSR/NIES/FRCGC AGCMをもとに開発されたもので、水平分解能はT21(緯度・経度のグリッド間隔ともに約5.6°)、鉛直シグマレベル52層で地表面から高度約95kmまでをカバーしている。雲の凝縮・蒸発過程については過飽和の効果は考慮せず、飽和蒸気圧を超えた分の硫酸を雲として取り扱い、雲の半径はHaus and Arnold [2010]で示された4つのモードに、各高度におけるモード別雲量の比に応じて分配し設定している。すなわち現在のところは雲粒の成長過程は導入されておらず、生成された雲の移流のみを考慮している。また放射コードはIkeda [2011]に導入されているものをそのまま用いており、すなわち今回のモデルで得られる雲分布の変化は放射には反映されず、水平一様の雲分布を仮定した放射を与えている。
本研究のモデルには硫酸(H_2SO_4)蒸気の生成・消滅に係る大気化学過程(SO_3, SO_2, H_2Oとの反応を含む)が導入されており、それによって現実的な雲分布の維持機構が再現された。これらの大気化学過程を含むモデル(WCモデル)では、低・中緯度(緯度0～70 °)において、雲の光学的厚さの緯度分布はVenus Express搭載のVIRTISによる近赤外分光観測と整合し、また硫酸蒸気の鉛直分布もMagellan電波掩蔽観測と整合していた。一方で大気化学過程を含まないモデル(NCモデル)では、低・中緯度における雲の光学的厚さは観測と比べて半分以下の値となり、また高度48km付近の硫酸蒸気量もWCモデルと比べて半分以下の量となった。WCモデル、NCモデルとも雲は高度50km以上で生成されているが、雲量には大きな違いがあり、WCモデルの方が雲量は多い。この違いはWCモデルでは上部雲領域(高度60～80km)で大気化学過程により硫酸蒸気が生成され、またそれが凝結して雲が生成されていることによる。このことより本研究にて用いるVGCMは、大気化学過程の導入により、低・中緯度における硫酸雲および硫酸蒸気の観測事実を精度よく再現するものになったといえる。
我々はこのVGCMを用いて、硫酸雲と硫酸蒸気分布の維持および循環プロセスの研究を行った。このモデルの結果によると、上部雲領域では高度65km付近を中心に雲が生成され、子午面循環と鉛直拡散によって上方および極方向へと輸送されている。一方で下部雲領域(高度50～60km)では、赤道域の高度50～54kmにおいて移流と鉛直拡散により下方から輸送された硫酸蒸気が凝結して雲になり、それが子午面循環によって極方向へ輸送されている。このような硫酸雲の循環メカニズムは子午面循環を外的に与えたImamura and Hashimoto [1998]による緯度―高度2次元モデルによって示されたものと一致し、VGCMでこれを再現したのは本研究が初めてである。このVGCMはさらに、主に1金星日周期の熱潮汐が東西平均流加速と絡んで低・中緯度の子午面循環を駆動していることを示した。

キーワード：金星、硫酸雲、大気化学、大気大循環モデル、あかつき
Keywords: Venus, Sulfuric acid clouds, Atmospheric chemistry, General circulation model, Akatsuki

金星GCM(AFES)で再現された小規模擾乱の解析

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

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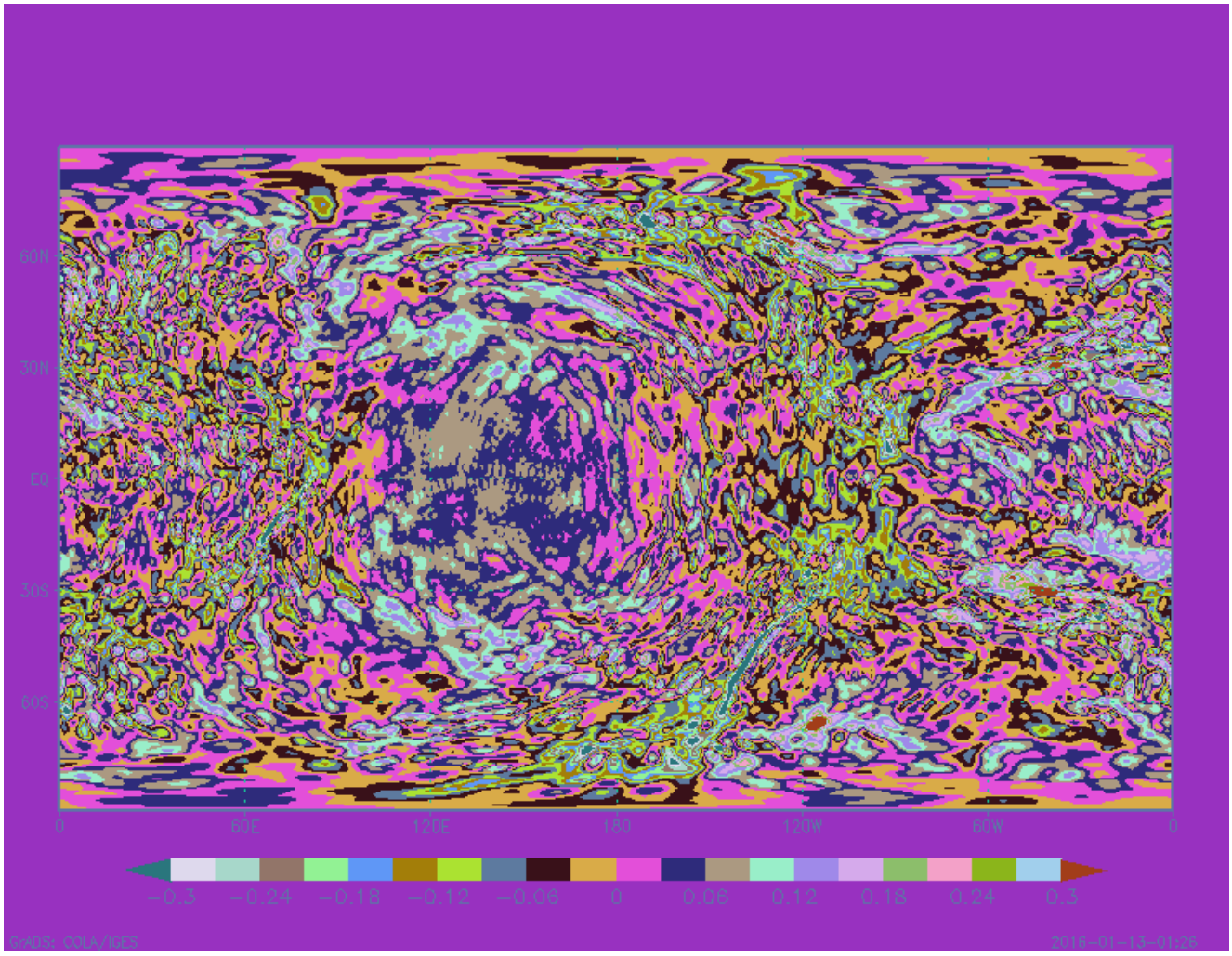
An atmospheric general circulation model (AGCM) for Venus on the basis of AFES (AGCM For the Earth Simulator) have been developed to perform a very high-resolution simulation (e.g., Sugimoto et al., 2014a). The highest resolution is T319L120, namely, there are 960 times 480 horizontal grids (grid intervals 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.

キーワード：金星、大気大循環モデル、波動
Keywords: Venus, GCM, Waves



太陽系地球型惑星大気観測専用ミリ波望遠鏡によるSPARTプロジェクトの現状報告
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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近年、系外惑星の探査研究が活発に展開されている。我々は、中心星が周囲の惑星の中層大気の物理・化学的環境に与える影響を理解するため、まずG型星である太陽の活動が地球型惑星の中層大気に与える影響について理解を深めるべく、国立天文台野辺山宇宙電波観測所の口径10 mの単一鏡を惑星大気監視専用ミリ波望遠鏡として運用し、太陽系惑星大気監視プロジェクト(SPART：Solar Planetary Atmosphere Research Telescope）を推進している。これまでにSPART 望遠鏡は、主として、金星や火星の一酸化炭素 (^{12}CO J=1-0 230.538 GHz, J=2-1 115.2712018 GHz, ^{13}CO J=2-1 230.3986765 GHz)の回転遷移によるスペクトル線のモニタリングを実施してきた。2011-2015年 の観測期間において、金星の高度80 km 付近のCO 混合比の全球平均は約60 ppmv であった。野辺山宇宙電波観測所の太陽電波偏波計1 GHz 帯の電波強度データによると、この観測期間中、太陽はほぼ極大期を維持していた。Cycle-22における過去の先行研究によるCO混合比(高度80 km)と比べて、このCycle-24におけるCO混合比は半減している。このことは近年の太陽活動の低下傾向との関連を示唆している可能性がある。固有磁場を持たない金星や火星に対して、太陽からの高エネルギ粒子の降込みが、ＣＯの生成にどのような影響を与えるかを理解するため、ベーテ・ブロッホの解析式を用いた数値モデル計算を実施したところ、COの生成を誘発するCO_2の高エネルギ粒子(protonなど)によるイオン化率はちょうど高度80-90 km付近で極大となったが、その効果は紫外線よりも小さいことも分かった。太陽はこれから極小期を迎えるため、金星のCOが今後減少に転じるのか、観測を継続していく予定である。現在SPART望遠鏡の観測棟は、一般の来訪者が運用の様子を見学できる博物資料館へと改良工事が進められている。この間に、モーターやGM-JT冷凍機のメンテナンス、旧計算機群のLinux化などを平行して実施しており、現在はシャットダウン中であるが、AKATSUKI衛星との連携研究を見据え2016年3月には運用を再開する計画である。本講演では、これらSPARTプロジェクトの一連の取り組みと現状について報告する。

キーワード：金星大気、電波望遠鏡、太陽活動
Keywords: Venusian atmosphere, Radio Telescope, Solar Activity

SMILES-2を用いた火星大気の1.9 THz帯リモートセンシングを見据えた放射輸送シミュレーション
Radiative Transfer Simulations for 1.9 THz Band Remote Sensing Observations of the Martian Atmosphere with SMILES-2

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現在、国際宇宙ステーションJEM/SMILESの後継となるSMILES-2のワーキンググループが立ち上がり、地球の中間圏・下部熱圏のサブミリ・テラヘルツ波帯の衛星観測が提案されている。このミッションでは、地球におけるO_3層回復や温暖化などの予測や重力波/Planetary波などの総括的理解を目指しており、H_2O,N_2O,NO_2,NO,CH_3Cl,CO,H_2CO,OH and O-atomなどの分子種をターゲットとし、400 GHzから2.5 THz帯までをカバーする複数バンドの観測を見据えている(Suzuki et al Proc. of SPIE, 2015)。この受信機には、SIS接合やHEB細線などを実装した、4 Kの冷却による超伝導ヘテロダイン検出素子の搭載なども検討されている。
THz帯は未開拓な波長領域であり、我々は現在、SMILES-2にも搭載可能な、超伝導NbTiN細線を集積した1.8-2.0 THz帯ホーン集光型ホットエレクトロンボロメータ(HEB)ミクサの開発を進めている。太陽系の地球型惑星では、CO_2の安定問題や、最近では火星においてCH_4が観測されており、惑星大気における酸化反応素過程の解明が急務の課題となっている。これには1.8-2.0 THz帯に分布するCOや、地上観測からは不可能であったOHやH_2O,O-atomなどの衛星観測が鍵を握り、系内外の惑星大気科学へと理解を拡張する上でも重要な役割を担う。そこで、本研究では、火星の中層大気の放射輸送モデル計算を実施し、SMILES-2にHEB検出素子を搭載し、火星大気のリモートセンシングを実施した場合の観測スペクトルを検証した。本講演ではこれらの放射輸送計算の結果について報告する。

キーワード：SMILES-2、THz、リモートセンシング、火星
Keywords: SMILES-2, THz, Remote Sensing, Mars

多流体MHDシミュレーションに基づく太陽風磁場進入時の火星電離圏CO_2^+鉛直分布にイオン種間衝突が及ぼす影響の研究

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.

キーワード：火星、電離圏、多流体MHD
Keywords: Mars, Ionosphere, Multi-Fluid MHD

火星電離圏界面における昼夜間密度勾配を考慮したケルビン-ヘルムホルツ不安定のMHDシミュレーション

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%.

キーワード：火星、ケルビン-ヘルムホルツ不安定、MHD シミュレーション
Keywords: Mars, Kelvin-Helmholtz instability, MHD simulation

火星探査機MAVENの観測データを使用したMagnetic Pileup BoundaryとIon Composition Boundaryの比較

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.

キーワード：火星、誘導磁気圏、Magnetic Pileup Boundary、Ion Composition Boundary、非磁化惑星、MAVEN
Keywords: Mars, Induced magnetosphere, Magnetic Pileup Boundary, Ion Composition Boundary, Unmagnetized planet, MAVEN

火星磁気圏周辺における酸素イオン反射
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.

キーワード：火星、イオン反射、MAVEN
Keywords: Mars, ion reflection, MAVEN

水星磁気圏の大規模構造：太陽風依存性
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.

キーワード：水星磁気圏、磁気流体

Keywords: Mercury's magnetosphere, MHD

地上望遠鏡とHisaki/EXCEEDとによるイオプラズマトーラスのイオン組成の計測
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.

キーワード：イオプラズマトーラス
Keywords: Io plasma torus

木星ナトリウム雲に観測されるイオの火山活動変動
Variations of Io's volcanism seen in Jupiter's sodium nebula

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木星の衛星、イオは太陽系で最も活発な火山活動を有する。この火山から生じるガスがイオの大気を構成するが、この大気は太陽光や木星磁気圏高エネルギー粒子などにより、電離・プラズマ化する。火山性プラズマは、木星の共回転する磁場にピックアップされ、木星内部磁気圏へと流出し、イオ・プラズマ・トーラスという環状の構造を形成する。トーラスプラズマには、同じくイオの火山を起源とした、$NaCl^+$分子イオンが含まれている。この分子イオンが、電子と衝突し、解離することで共回転速度(74km/s)を達成している高速中性ナトリウム原子が生成される。これら高速ナトリウム原子は、木星の磁気圏・重力圏を超えて分布し、木星ナトリウム雲と呼ばれる巨大構造を形成している。木星ナトリウム雲は、太陽光を共鳴産卵することで、ナトリウムD線の波長で発光していて、地上から観測することができる。また、木星ナトリウム雲の発光強度はイオの火山活動に応じて変化していることが知られている。木星磁気圏プラズマの供給源でもあるイオの火山活動を監視することは、木星磁気圏の研究にも貢献する。木星磁気圏を主観測ターゲットとしている、ひさき衛星の観測期間も含め、我々は木星ナトリウム雲の観測を行ってきた。特に、2015年前半にはイオでの火山性爆発の検出に成功している。本発表では、この数年のイオ火山活動の状況の詳細を報告する。

キーワード：イオ、木星、火山、磁気圏
Keywords: Io, Jupiter, Volcanism, magnetosphere

木星極域ヘイズの外縁部波構造及び非対称分布

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.

キーワード：ヘイズ、波構造
Keywords: haze, wave structure

LWA1モジュレーションレーンデータによる木星デカメートル波電波源の位置測定について
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.

キーワード：木星電波、モジュレーションレーン、電波源の位置
Keywords: Jupiter radio, modulation lane, radio source locations

