R009-01
Zoom meeting D ：11/1 AM1 (9:00-10:30)
9:00〜9:15

Initial results and updated plans of the BepiColombo mission during interplanetary cruise

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The ESA-JAXA joint mission BepiColombo is now on the track to Mercury. After the successful launch of the two spacecraft for BepiColombo, Mio (Mercury Magnetospheric Orbiter: MMO) and Mercury Planetary Orbiter (MPO), commissioning operations of the spacecraft and their science payloads were completed. BepiColombo will arrive at Mercury in the end of 2025, and it has 7-years cruise with the heliocentric distance range of 0.3-1.2 AU. The long cruise phase also includes 9 planetary flybys: once at the Earth, twice at Venus, and 6 times at Mercury. Even during the interplanetary cruise phase, the BepiColombo mission can contribute to the heliospheric physics and planetary space weather in the inner solar system. In addition, NASA's Parker Solar Probe was launched in 2018 and it is orbiting around Sun (˜0.05 AU at perihelion). ESA's Solar Orbiter was launched in February 2020 and will have a highly elliptic orbit between 1.2 AU at aphelion and 0.28AU at perihelion. Up to now we have performed several science observation campaigns with other missions and successfully obtained science data during cruise. These multi spacecraft observations provide us great opportunities to investigate the inner heliosphere. In 2021 the second Venus flyby and the first Mercury flyby will happen on 10 August 2021 and on 1 October 2021, respectively. Here we present the updated status of BepiColombo mission, initial results of the science observations during the interplanetary cruise and planetary flybys, and the upcoming observation plans.

R009-02
Zoom meeting D ：11/1 AM1 (9:00-10:30)
9:15～9:30

BepiColombo Mio 搭載イオンエネルギー分析器 MPPE-MIA による金星・水星フライバイ観測

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Venus and Mercury fly-by observations by MPPE-MIA on BepiColombo/Mio

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BepiColombo Mio was successfully launched by Ariane 5 from Kourou, French Guiana on 20 October 2018. The Mercury Plasma/Particle Experiment (MPPE) is a comprehensive instrument package on Mio spacecraft for plasma, high-energy particle and energetic neutral atom measurements. It consists of 7 sensors: two Mercury Electron Analyzers (MEA1 and MEA2), Mercury Ion Analyzer (MIA), Mass Spectrum Analyzer (MSA), High Energy Particle instrument for electron (HEP-ele), High Energy Particle instrument for ion (HEP-ion), and Energetic Neutrals Analyzer (ENA). MIA that measures 3D phase space density of low energy ions between 15eV/q and 29keV/q was developed for understanding (1) structure of the Mercury magnetosphere, (2) plasma dynamics of the Mercury magnetosphere, (3) Mercury - solar wind interaction, (4) atmospheric abundances, structure, and generation/loss process, and (5) solar wind between 0.3 and 0.47 AU. In order to achieve these science objectives, MIA was designed to measure the three-dimensional distribution function of both solar wind ions around Mercury, and Mercury magnetospheric ions.

After experiencing Earth fly-by in April 2020 and 1st Venus fly-by in October 2020, the necessity of modifying the MIA flight software in MDP (Mission Data Processor) was identified. Although the output range of the onboard calculated ion velocity moment is limited, the definition of the output range was not optimum. The optimum output range and the software modification to implement the new output range were decided by using the MIA simulator that outputs the count rate obtained by MIA taking into account the analyzer characteristics determined by the pre-flight calibration and the MDP MIA software simulator that generates exactly the same velocity moment as flight MDP MIA software. The new software was successfully uploaded on 22 June 2021.

The 2nd Venus fly-by is scheduled in August 2021 and the 1st Mercury fly-by is scheduled in October 2021.During the Venus and Mercury fly-bys most of the MPPE analyzers including MIA will be turned on and will make observation of Venus induced magnetosphere and Mercury Magnetosphere though most of the field of view of the MPPE analyzers are blocked by MOSIF (MMO Sunshield and Interface Structure) before arriving at Mercury in December 2025. During the 1st Venus flyby, MIA succeeded in observing energy spectra of low energy ions around the bow shock of Venus and in the Venus plasma sheet. Since the closest distance to Venus during the 2nd Venus flyby is shorter than the 1st Venus fly-by, we are expecting another interesting data set that can be analyzed together with other instruments on Mio not to mention other analyzers of MPPE instrument suits.

We are planning to turn on most of the MPPE analyzers including MIA during the future Mercury fly-bys scheduled in June 2022, June 2023, September 2024, December 2024 and January 2025. The observation with full performance of MIA will start after Mio’s arrival at Mercury in December 2025.

BepiColombo Mio は 2018 年 10 月 20 日にフランス領ギアナのクールーからアリアン 5 によって打ち上げられた。MPPE（Mercury Plasma/Particle Experiment）は Mio 衛星に搭載された、プラズマ・高エネルギー粒子・高速中性粒子の計測を行う観測装置で、7 台の観測装置で構成されている。２台の電子計測センサー：Mercury Electron Analyzers (MEA1 and MEA2), イオン計測センサー：Mercury Ion Analyzer (MIA), イオン質量分析器：Mass Spectrum Analyzer (MSA), 高エネルギー粒子計測装置：High Energy Particle instrument for electron (HEP-ele) 及び High Energy Particle instrument for ion (HEP-ion) と、高速中性粒子計測装置　Energetic Neutrals Analyzer (ENA) である。このうち、MIA は、15eV/q から 29keV/q の低エネルギーイオンの三次元分布関数の計測を行うことで (1) 水星磁気圏の構造 (2) 水星磁気圏におけるプラズマのダイナミクス (3) 水星と太陽風の相互作用 (4) 水星希薄大気の組成、構造、生成・消滅過程 (5) 0.3AU　から 0.47 AU における太陽風の理解を目指す。これらの科学目的を達成するために、MIA は水星周辺の太陽風イオンと、水星磁気圏イオン両方の三次元分布関数を計測できるように設計した。

2020 年 4 月の地球フライバイと、2020 年 10 月の金星フライバイの際のデータを調べたところ、MDP(Mission Data Processor) 内の MIA のフライトソフトを一部変更すべきであることが明らかになった。機上で計算する速度モーメントの出力範囲には制限があるが、その範囲の設定が最適化された値になっていなかったためである。最適な速度モーメントの出力範囲とその変更に必要なソフトウェアの改訂方法については、地上の較正試験結果を取り入れた、MIA のシミュレータと、機上速度モーメント計算の結果を再現することのできる MDP　MIA ソフトシミュレータを用いて決定したが、新しいソフトウェアは、2021 年 6 月に無事アップロードすることができた。

２回目の金星フライバイが 2021 年 8 月に、１回目の水星フライバイが 2021 年 10 月に予定されている。金星フライバイ、水星フライバイの際には、MIA を含む MPPE の殆どのセンサーを観測状態にして、金星の誘導磁気圏と、

水星磁気圏の観測を行う予定である。2025 年 12 月に Mio 衛星が水星に到着するまでの間は、MPPE の視野の殆どは MOSIF (MMO Sunshield and Interface Structure) に隠されてしまっていることには注意を要する。1 回目の金星フライバイの際には、MIA は金星バウショック周辺の低エネルギーイオンや、金星プラズマシートイオンのエネルギースペクトルの観測に成功した。2 回目の金星フライバイ時の最接近距離は、1 回目よりも短いことから、MPPE の他のアナライザーは言うまでもなく、Mio や MPO に搭載された他の観測装置のデータと一緒に解析すべき新しいデータが得られることを期待している。

　その後 2022 年 6 月、2023 年 6 月、2024 年 9 月、2024 年 12 月に予定されている水星フライバイの際にも MIA は観測を行う予定であるが本格的な観測を開始するのは、2025 年 12 月に Mio 衛星が水星に到着してからになる予定である。

R009-03
Zoom meeting D ：11/1 AM1 (9:00-10:30)
9:30〜9:45

ARTEMIS による昼側月面から放出される Auger 電子と光電子ビームの観測

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ARTEMIS observations of Auger electrons and photoelectron beams emitted from the dayside surface

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Since the Moon does not possess an dense intrinsic atmosphere, the lunar surface is exposed to its ambient plasma environment. Surface charging is one of the phenomena resulting from interactions of the lunar surface with ambient charged particles and solar radiation. An observable indicator of lunar surface charging has been provided by a cold beam of electrons accelerated upward from the surface. On the dayside of the Moon, the beam energy is thought to be determined by a negative potential minimum possibly formed above the photo-emitting surface (i.e., non-monotonic potentials), suggesting that the upward beam energy does not necessarily provide direct and definitive evidence for the postulated negative potential at the surface level.

When an inner shell electron is emitted from an atom by an incident energetic photon or particle, the ion relaxes to a lower energy state by releasing an X-ray photon or an outer shell electron. This ejected electron is called an ‘Auger electron’. Auger electrons have intrinsic energies characteristic of the emitting element (e.g., ˜500 eV for O).

Xu et al. (2021) reported first Auger electron observations by ARTEMIS at the Moon. As the Auger electrons are emitted from the surface with a fixed, characteristic energy, we can expect that observations of energy shift of the Auger electron line enable us to infer the electrostatic potential at the surface level, as opposed to the non-monotonic potential minimum probed by the upward electron beam. In this study, we analyzed electron data from ARTEMIS, and have found a number of Auger electron events indicative of the expected energy shift. We will compare the observed energies of Auger electrons and those of cold electron beams, thereby discussing electrostatic potentials at and above the lunar surface and the relationship between the two.

月には濃密な大気がないため、月面は周辺のプラズマ環境に曝されている。表面帯電は、月面と周囲の荷電粒子、そして太陽放射との相互作用によって生じる現象の一つである。月面帯電を示唆する観測結果としては、月面から上向きに加速された電子ビームが挙げられる。月の昼側では、このビームのエネルギーは光電子の放出により月面上空に形成される負の電位極小値によって決まると考えられる。つまり、上昇ビームのエネルギーが必ずしも表面での負の電位を反映しているとは限らない。

エネルギーの高い入射光子・粒子によって原子の内殻から電子が放出されると、イオンが基底状態に脱励起する際に特性 X 線または外殻から別の電子を放出する。この放出される電子は「Auger 電子」と呼ばれる。Auger 電子は、放出する原子の種類によって固有の特性エネルギーを持っている (例えば、O 原子については˜500 eV である)。

Xu et al. (2021) は、ARTEMIS による月での Auger 電子の観測を初めて報告した。Auger 電子は月面から、特徴的な固有エネルギーによって放出されるため、Auger 電子のエネルギー変化を観測することで、表面の電位を推定できると期待できる。本研究では、ARTEMIS による電子のデータを解析し、Auger 電子のエネルギー変化を示す事例を発見した。この観測された Auger 電子のエネルギーと、上昇向き電子ビームのエネルギーを比較することにより、月面上空での電位構造と、観測される 2 つのエネルギーの関係について議論する。

R009-04
Zoom meeting D ：11/1 AM1 (9:00-10:30)
9:45〜10:00

地球磁気圏内の月面上低高度で観測されたULF波の偏波について

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Polarization of ultra-low frequency waves observed by Kaguya at low altitude above the Moon in the earth's magnetosphere

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At altitudes lower than 20km from the lunar surface, Kaguya MAP-LMAG detected ultra-low frequency wave of 0.02 Hz with clear circular polarization when the Moon was in the Earth's magnetosphere. The polarization was clearly left-handed with respect to the background magnetic field, negative Bx in the southern lobe of the Earth's magnetosphere. It reversed to be right-handed in a short period of positive Bx in an excursion of the Moon to the northern tail lobe. It suggests that the sense of rotation of the magnetic field vector was fixed at the generation site. The magnetic field rotation sometimes switched to another rotation around a new center, as if the spacecraft transferred to another new wave packet.

かぐや衛星のミッション終了直前の 2009 年 6 月 9 日、月が地球磁気圏尾部の南側ローブ中にあったとき、月面から 20km 以下の低高度において、背景磁場に対し左回り円偏波の低周波磁場変動が繰り返し観測された。高度 40km 以上ではこのようなはっきりした円偏波は見られないことから、この波は月の低高度領域で発生したものと考えられる。同様の現象は 2009 年 5 月 7 − 10 日、6 月 7 − 10 日にも見られた。このときイオン、電子とも低エネルギー成分が見えなくなっており、電子の加速を伴うこともあることから、固有磁場による分極電場のある領域で磁気圏プラズマの固有磁場との相互作用によって発生した可能性が高い。この磁場変動の周期は約 50 秒であるが、磁場ベクトルの回転の途中で、突然それまでとは異なる中心の周りに磁場が回り始めるような波形が見られた。まるで衛星が別の波束に乗り換えたかのようにみえる。また、月が地球磁気圏北側ローブに出張し磁場 x 成分が反転したときは、そこだけ背景磁場に対する偏波が右回りとなっていた。これは、波の回転方向が発生の時点で決まっており伝搬途中では変わらないことを示唆すると考えられる。プロトンサイクロトロン周波数よりかなり低い周波数であることから、より重いイオンが月の固有磁場との相互作用で生成した波ではないかと推定される。

R009-05
Zoom meeting D ：11/1 AM1 (9:00-10:30)
10:00〜10:15

Possibility of water-ion parallel acceleration in the comet 67P/Churyumov ? Gerasimenko: observation by the Rosetta spacecraft

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Acceleration of the comet-origin water ions is considered mainly by the bipolar electric field and by the solar wind electric field perpendicular to the magnetic field. The ESA/Rosetta observations of the comet 67P/Churyumov-Gerasimenko over two years revealed that the acceleration of these water ions is more complicated than previously thought. Rosetta Plasma Consortium's Ion Composition Analyzer (RPC/ICA) detected comet-origin water ions that are accelerated to $>$100 eV [1]. The majority of them are ordinary pick-up acceleration during low comet activity [2,3]. During the high comet activity near the perihelion when a comet magnetosphere is formed where solar winds cannot reach and solar wind electric field is strongly deformed.

When the Rosetta is located inside the magnetosphere but marginal location, we sometimes observed water-ion acceleration to $>$1keV and some of them are flowing along the magnetic field [4]. In this meeting, we show one of these observations and discuss possible acceleration scenarios.

References

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R009-06
Zoom meeting D ：11/1 AM2 (10:45-12:30)
10:45〜11:00

太陽系天体の宇宙風化再現実験に向けた汎用プラズマ照射装置の開発・評価の現状

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Generic Plasma Irradiation System for Modeling of Space Weathering at Solar System Bodies: Current Status of Commissioning

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Surface and atmosphere of solar system bodies are continuously irradiated with the space plasma, solar photon, cosmic ray, and micrometeorite, which are responsible for long-term alteration of the planetary surface and atmospheric materials on timescales up to the geological scale (Giga years). This is known as the 'space weathering'. The space weathering accompanies physical and chemical changes in the materials (see e.g., Johnson et al., in Jupiter textbook, 2004). For example, organic compounds like tholins are likely created and destroyed via the space weathering at Titan's upper atmosphere and icy moon's surfaces at Jupiter and Saturn (e.g., Waite et al., 2007; Lopez-Puertas et al. 2013). This suggests that the newly created/destroyed compounds are accumulated on the surface over the geological time scale. These are likely essential energy and material sources for the surface, atmosphere, and possibly interior. However, the physical and chemical changes by the geological timescale weathering is still not unveiled because they have not been exactly reproduced by any experimental methods. Here we develop a new laboratory experiment system that reproduces the geological timescale weathering driven by the space plasma irradiation. We successfully completed the irradiation system with the world-highest fluence (<1e+22 particles/cm2) of ions and electrons at 1-30 keV. This corresponds to e.g., the irradiation time of 100s Mega years at Jupiter's icy moons. In this talk, we report the current status of irradiation system commissioning and the upcoming experiment plans.

R009-07
Zoom meeting D ：11/1 AM2 (10:45-12:30)
11:00〜11:15

望遠鏡観測による木星衛星エウロパ表面NaClの起源の検討

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Examination of the origin of NaCl on the surface of Jupiter's moon Europa by telescope observation

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A mantle plume geyser, believed to have originated in the inner sea, has been observed by the Hubble Space Telescope (HST) on Jupiter's moon Europa [Roth et al., 2014]. If the material of the inner sea is deposited on the ground surface, examining its composition will lead to the estimation of the composition of the inner sea. So far, observations by the Hubble Space Telescope (HST) have observed the absorption of specific light (color center) that appears near 460 nm on the surface of Europa due to the exposure of NaCl to radiation, called the F center. [Samantha et al., 2019], suggesting the presence of NaCl in the inner sea. However, absorption near 720 nm, which is expected to occur by the same mechanism, has not been confirmed. In addition, HST observations are limited to four times in a specific four months, and long-term fluctuations on a yearly basis, which indicate temporal fluctuations in mantle plumes, have not been investigated. In this study, continuous observation was performed in a wide band (maximum 400-1,100 nm) using the spectrum imager MSI mounted on the Pirka telescope with a primary mirror diameter of 1.6 m owned by Hokkaido University. Clarify time fluctuations. Using the results of electron beam irradiation experiments [Poston et al., 2017] on NaCl in an environment that reproduces the surface of Europa, NaCl began to be irradiated to electron beams from the observed attenuation rates of 460 nm and 720 nm. Back-calculate how long has passed. From this, it is determined whether NaCl is derived from the inner sea, meteorite, or present from the time of Europa formation.

We started observing Europa in August 2020, and between 400-550 nm and 650-800 nm, the bandwidth is 3.90-10.2 nm for 400-550 nm, 4.17-7.62 nm for 650-800 nm, and the center wavelength. The image is taken at an interval of 10 nm. As a result of analyzing the spectra acquired on August 17, 20, September 28, and October 20, 2020, absorption was confirmed around 430 nm. Although this is a wavelength close to 460 nm reported in previous studies, it may be a Fraunhofer line 430 nm absorption line, and we are carefully examining it. In addition, no absorption was confirmed near 720 nm.
In the future, in order to remove the spectrum of sunlight, we will acquire the spectrum of the moon that is also reflecting sunlight, and confirm the fluctuation of the spectrum by continuing the Europa observation. In addition, we are considering conducting an electron beam irradiation experiment in order to investigate the time variation of the salt that may be present in Europa when it is irradiated with an electron beam.

木星の衛星のエウロパには内部海起源と考えられる、マントルプルームによる間欠泉がハッブル宇宙望遠鏡 (HST) によって観測されている [Roth et al., 2014]。もし内部海の物質が地表面に堆積していれば、その組成を調べることで、内部海の組成を推定することにつながる。これまで、ハッブル宇宙望遠鏡（HST）の観測によって、エウロパ表面には NaCl が放射線を受けることによって生じる、特定の光の吸収（カラーセンター）のうち、460 nm 付近に現れる F センターと呼ばれる吸収が観測されており [Samantha et al., 2019]、内部海に NaCl が存在することを示唆している。しかし、同様のメカニズムで起きると予想される 720nm 付近の吸収は確認されていない。また HST による観測は特定の 4 か月間に 4 回と限られており、マントルプルームの時間変動を示すような、年単位の長期的な変動は調べられていない。本研究では、北海道大学が所有する主鏡口径 1.6 m のピリカ望遠鏡に搭載されているスペクトル撮像装置 MSI を用い、広帯域（最大で 400 ー 1,100 nm）における継続観測を行い、エウロパの反射スペクトルの、時間変動を明らかにする。方法はエウロパ表面を再現した環境での NaCl への電子線照射実験 [Poston et al., 2017] の結果を用いて、観測した 460 nm と 720 nm の減衰率から NaCl が電子線に照射され始めてどのくらいの期間が経過しているかを逆算する。これにより NaCl が内部海起源か隕石由来かエウロパ形成時から存在するかを判別する。

2020 年 8 月からエウロパの観測を開始し、400 ー 550 nm および 650 ー 800 nm の間を、バンド幅が 400 ー 550 nm は 3.90 ー 10.2 nm、650 ー 800 nm は 4.17 ー 7.62 nm、中心波長の間隔 10 nm で撮像している。2020 年 8 月 17 日、20 日、9 月 28 日、10 月 20 日に取得したスペクトルかを解析した結果、430 nm 付近に吸収が確認された。これは先行研究で報告された 460nm に近い波長であるものの、フラウンホーファー線の 430 nm 吸収線の可能性があり、慎重に検討を進めている。また、720 nm 付近に吸収は確認されなかった。
今後、太陽光のスペクトルを除去するために同じく太陽光を反射している月のスペクトルを取得するとともに、エウロパ観測を継続することでスペクトルの変動を確認する。また、エウロパに存在する可能性のある塩が電子線照射を受けたときの時間変動を調べるために、電子線照射実験を行うことを検討している。

R009-08
Zoom meeting D ：11/1 AM2 (10:45-12:30)
11:15〜11:30

Numerical radar simulation for the explorations of the ionosphere at Jupiter’s icy moons

#Rikuto Yasuda[1)],Tomoki Kimura[2)],Hiroaki Misawa[3)],Fuminori Tsuchiya[4)],Atsushi Kumamoto[4)],Yasumasa Kasaba[5)]
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Jupiter’s icy moons such as Europa and Ganymede may harbor subsurface liquid water oceans and have ionospheres and plumes created from the oceanic water materials. While only Earth has the ocean on the surface in the current solar system, multiple icy bodies like the icy moons of giant planets have oceans in their subsurface under the icy crust. The icy bodies’ oceans are potentially more universal habitable environment than the Earth-type surface ocean. Structures of the ocean and the ionosphere of the icy moos are essential information for understanding the universality of habitable environments. However, the structures of the oceans are unknown because in-situ or lander explorations on the surface of icy objects, the most effective method for exploring the structures, are still at technically conceptional level at present. The structures of ionospheres are still unclear as well because the ionospheric radio occultation and other effective explorations have difficulties of limited observing opportunities. Here we are going to uncover the structures of the ocean and the ionosphere of Jupiter’s icy moons by the radar exploration with the Radio & Plasma Wave Investigation (RPWI) and the Radar for Icy Moon Exploration (RIME) onboard the JUpiter ICy moons Explorer (JUICE) launched in 2022. For the investigations of radio wave sounding in and around the icy moons with RPWI and RIME ranging in tens KHz to tens MHz, we are now developing a numerical simulation code that models the propagation of electromagnetic (EM) waves in the ionospheres of the icy moons. As the first step, we emulate occultation of the Jovian radio waves by the icy moon’s ionospheric structures during the flybys of the Galileo spacecraft to Jupiter’s icy moons. In this presentation, we are going to propose the vertical ionospheric profiles at the altitude below the orbiter where only remote observations can reach. So far (July 2021) we have found that the EM wave rays are significantly refracted in the ionosphere and have demonstrated that the structures are detectable by the comparison between the observed dynamic spectra and simulated ones. As the next step, we will also simulate the reflection and transmission of the EM waves in the icy crust and underlying ocean. After completing these studies, we will be able to elucidate icy moon’s ionospheric and subsurface structures by combining our model with the JUICE radar explorations. The combination of our model and the JUICE radar explorations would also constrain the pressure and temperature of the subsurface, which finally lead to deep understandings of the icy moon’s habitability.

R009-09
Zoom meeting D ：11/1 AM2 (10:45-12:30)
11:30〜11:45

Variability of Io plasma torus based on ground-based observation during 2015 through 2021

#Masato Kagitani[1),Fuminori Tsuchiya[1),Takeshi Sakanoi[1)
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Volcanic gases (mainly composed of SO2, SO and S) originated from jovian satellite Io are ionized by interaction with magnetospheric plasma and then form a donut-shaped region called Io plasma torus. Ion pickup is the most significant energy source on the plasma torus though, distribution of pick-up region and its variability is still unclear. Density profiles of ions along the magnetic field line are determined under condition of diffusive equilibrium. Based on the equilibrium, plasma equator is close to the centrifugal equator though, higher ion anisotropy moves the plasma equator toward the magnetic equator. Measuring ion distribution with enough special resolution enables us to derive ion anisotropy which is tightly related to the amount of fresh pickup ion. On this study, we focus on variability of latitudinal structure of Io plasma torus as well as its radial structure using ground-based observation starting from 2018 through 2020.

The ground-based observation of sulfur ion emission, [SII] 671.6 nm and 673.1 nm was made at Haleakala Observatory in Hawaii during December 2014 through July 2021 using Tohoku 60-cm telescope. A monochromatic imager with coronagraph attached onto the telescope enables to measure distribution of singly charged sulfur ion with spatial resolution of 0.03 jovian radii. A digital micro-mirror device DMD was employed to block light from Jupiter disk and Galilean moons. Typical integration time of each frame was 20 minutes and total number of reduced images is about 1500. We also made observation of neutral sodium cloud extending up to several hundred of RJ as a proxy of supply of neutral particles from Io (Yoneda et al., 2015).

From the monitoring observation in 2020, [SII] brightness increases from DOY 120 through 160, then gradually decreases though DOY 230, whereas the brightness scaleheight indicating ion temperatures increased gradually from 0.9 RJ to 1.2 RJ during DOY 150 through 220. Given that the primary source of S+ in the Io plasma torus is the electron impact ionization of S, SO and SO2, the [SII] brightening suggests increase in the neutral densities, presumably associated with volcanic active events.

Over the past six years, we identified three prominent peaks of [SII] brightness in February 2015, August 2019 and June 2020. In the three cases, [SII] ribbon scaleheight started to increase just after [SII] brightness peaks suggesting increase of ion temperature due to volcanic outbursts.

R009-10
Zoom meeting D ：11/1 AM2 (10:45-12:30)
11:45〜12:00

Long-term monitoring of Jupiter’s aurora and Io torus by Hisaki EXCEED

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Hisaki is an Earth-orbiting spacecraft equipped with a UV spectroscope that primarily observes planetary atmospheres and magnetospheres. The spectrometer EXCEED (Extreme Ultraviolet Spectroscope for Exospheric Dynamics) has a unique dumbbell-shaped slit for observing the Io plasma torus and Jovian aurora simultaneously. Hisaki EXCEED can continuously observe the Jovian system along the 106 min orbit for several months, which is a feature never available for large facilities such as Hubble Space Telescope. Hisaki EXCEED began its monitoring of the Jovian aurora and Io plasma torus in December 2013 with the dumbbell slit. Because of the degradation of the Hisaki EXCEED field of view camera, it is more difficult to track the target with the guide camera after mid-2016. The location of Jupiter was set to in the narrow slit region, however, sometimes aurora moved away from the narrow slit region. Therefore, we use two observing modes, torus mode and aurora mode since 2017. The Jovian disk is located in the wide-slit region for the aurora mode. Both north and south auroras are observed, and only one side of the torus can be seen. For the torus mode, we set the location of Jupiter to the narrow slit region, and the torus fit within the wide-slit region. We have been developing a pipeline to correct the center position of the Jovian disk and derive the time series of the aurora over 900-1480 A and torus power over 650-780 A. Several transient and solar wind induced brightenings were observed after 2016. The optical observation of the torus showed that sulfur ribbon brightness increased in mid-2019 and mid-2020, however, the UV torus brightness did not show a notable change during this period. In this study, we will show the time series of the total auroral power as well as the torus emission.

R009-11
Zoom meeting D ：11/1 AM2 (10:45-12:30)
12:00〜12:15

KOSEN-1 Jupiter radio observation campaign with ground-based radio telescopes

#Masafumi Imai[1)],Kazumasa Imai[2)],Nobuto Hirakoso[3)],Yusuke Ito[3)],Tatsuya Sugawara[3)],Sota Suzuki[3)],Masanori Nishio[4)], Taku Takada[5)],Kentarou Kitamura[6)],Jun Nakaya[7)],Yukikazu Murakami[8)],Masahiro Tokumitsu[9)],Tracy E. Clarke[10)],Charles A. Higgins[11)],Joseph F. Helmboldt[10)],KOSEN-1 Team[12)]
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Jupiter produces auroral radio emissions at frequencies below 40 MHz from both north and south polar regions of the planet. The highest frequency radio component is called decametric (DAM) radiation covering in a broad frequency range of a few through 40 MHz. Jovian DAM radiation is partially controlled by the Jovian moon Io, thereby being called Io-related DAM (Io-DAM) emissions. The Io-DAM comprises of millisecond-varying bursts called short-bursts or S-bursts. Because the ground-based radio reception is sensitive down to 10 MHz, there are several long-baseline interferometer studies for Jovian S-bursts in understanding the radio beaming structures with thickness of beaming. According to the previous studies, the minimum thickness of the DAM emissions is estimated at least larger than a 2.75” east-west size (Imai et al., 2016, 2019) and a 1.8” north-south size (Lynch et al., 1976) using several radio telescopes (including LWA1). However, the length of the baseline in a usable pair on the ground is physically limited by the diameter of Earth and the U-V coverage is biased due to a sparse low-frequency radio telescope network. Expanding the baseline provides a benefit to further constrain the size of the S-burst beam thickness.

KOSEN-1 is the first 2U CubeSat developed by 10 colleges of the National Institute of Technology (NIT) in Japan. This CubeSat is equipped with a software-defined radio (SDR) receiver that can monitor the electric fields of the waves around 20 MHz by means of a 7-m long dipole antenna. The SDR receiver can provide both waveforms and spectra in a 2-MHz bandwidth depending upon the available telemetry to the ground, while the timing of the records is synchronized with the GPS 1 Pulse-Per-Second. Since its launch in 2021 fiscal year, KOSEN-1 will have maintained its polar orbit around Earth, freely observing Jovian DAM radiation. We propose to observe a total of 16 Io-DAM S-burst events with KOSEN-1 and ground-based radio telescopes, including LWA1 and LWA-Sevilleta. Also, additional ground-based support is planned with the Deployable Low-band Ionosphere and Transient Experiment (DLITE; Helmboldt et al., 2021) in New Mexico, Maryland, and Florida, as well as, Radio JOVE citizen scientist observers. These multi-baseline observations would give a new way of probing the Jovian S-burst beam thickness. In this presentation, we will review the radio observation system onboard KOSEN-1 and show the plan of KOSEN-1 Jupiter radio observation campaign with the ground-based radio telescopes in 2021 fiscal year.

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R009-12
Zoom meeting D ：11/1 PM1 (13:45-15:30)
13:45〜14:00

木星氷衛星探査計画 JUICE：JUICE-Japan の目指すサイエンス

#関根 康人 [1), 齋藤 義文 [2), 浅村 和史 [3), 塩谷 圭吾 [4), 笠井 康子 [5), 笠羽 康正 [6), 春山 純一 [7), 松岡 彩子 [8)
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Jupiter Icy Moons Explorer JUICE: Science goals of JUICE-Japan team

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JUpiter ICy moons Explorer (JUICE) is the ESA's first L-class mission to Jupiter and its satellite system. The launch is scheduled in 2022 and the spacecraft will arrival at Jupiter in 2029. The spacecraft will spend at least three years making detailed observations of Jupiter and three of its largest moons, Ganymede, Callisto and Europa. Among the eleven instruments of JUICE spacecraft, parts of four instruments (SWI, GALA, PEP, and RPWI) are provided from Japan. The JUICE mission will provide an opportunity not only for the Japanese science communities of space physics and planetary geophysics, but also those of cosmo/geochemistry, planetary formation, and astrobiology. To maximize potential value of the JUICE mission, interdisciplinary collaborations and cooperation are required for understanding the origin, evolution, and habitability of the Jovian system. In the present talk, we will discuss science goals of the JUICE-Japan team, especially focusing on interdisciplinary sciences. We discuss key observations by the JUICE spacecraft for understanding the formation mechanism of the Jovian system and potential biomarkers on Europa.

R009-13
Zoom meeting D ：11/1 PM1 (13:45-15:30)
14:00〜14:15

Radio & Plasma Wave Investigation (RPWI) aboard JUICE: 木星および氷衛星への科学目標およびその実現性

#笠羽 康正 [1), 三澤 浩昭 [1), 土屋 史紀 [1), 熊本 篤志 [1), 木村 智樹 [2), 北 元 [3), 安田 陸人 [1), 加藤 雄人 [1), 三好 由純 [4), 笠原 禎也 [5), 八木谷 聡 [5), 小嶋 浩嗣 [6),Cecconi B.[7),Wahlund Jan-Erik[8)
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Radio & Plasma Wave Investigation (RPWI) aboard JUICE: Sciences and their feasibilities for Jupiter and Icy Moons

#Yasumasa Kasaba[1),Hiroaki Misawa[1),Fuminori Tsuchiya[1),Atsushi Kumamoto[1),Tomoki Kimura[2),Hajime Kita[3),Rikuto Yasuda[1),Yuto Katoh[1),Yoshizumi Miyoshi[4),Yoshiya Kasahara[5),Satoshi Yagitani[5),Hirotsugu Kojima[6),B. Cecconi[7),Jan-Erik Wahlund[8)
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Outer solar system is one of the key area of future sciences. JUpiter ICy moons Explorer (JUICE) is ESA's first L-class mission which will aims the largest target in this area, Jupiter and its large icy moons. Now, JUICE is during the final test campaign before the launch planned in 2022, and showing the good capability to perform the outer solar system explorations in early 2030s. This talk shows a view of Radio & Plasma Wave Investigation (RPWI) aboard JUICE which provides a unique and first opportunity in this huge mission.

Japan contributes this mission by the participation to the development of four instruments (PEP, RPWI, GALA, and SWI) and the science teams of six instruments (the above four plus JANUS and J-MAG). RPWI provides an elaborate suite for electromagnetic fields and plasma environment around Jupiter and icy moons, with 4 Langmuir probes (LP-PWI; 3-axis E-field -1.6 MHz, and cold plasmas), a search coil magnetometer (SCM; 3-axis B-field -20 kHz), and a tri-dipole antenna system (RWI; 3-axis E-field 0.08-45 MHz, 2.5-m tip-to-tip length). The RPWI Japan team provides the high frequency part of this system, i.e., Preamp of RWI and its High Frequency Receiver (HF), under with the collaboration of Japan, France, Poland and Sweden. In this paper, we provide the performance and operation concepts with their feasibilities, including the test and emulation results on the ground, planned activities in commissioning and cruise phases, and the full observations around Jupiter and icy moon system. Those are the basis of the observation and telemetry plans which are now heavily discussed in the JUICE SWT including RPWI.

We have confirmed that this system has high sensitivity reaching close to the galactic background enough for the detection of Jovian radio emissions from magnetosphere (aurora etc.), atmosphere (lightning), and icy moons. Direction and polarization capabilities are first enabled in the Jovian system, to identify their source locations and characteristics. RPWI with other instruments covers the survey of harsh environment around Jupiter, environments and interaction with icy moons, and their surface and subsurface characteristics. The most key parts is the sensing of the ionospheres, surface, and subsurface of icy moons during the flybys and on the orbit around Ganymede. Our 'High frequency part of RPWI' can do unique remote observations of the ionospheres below the spacecraft orbit by the radio occultation and reflection of Jovian radio signals, It has a capability to detect the highest ionospheric density not only in usual status but also episodic plume ejections triggered by expected crustal activities. The sensing of surface and subsurfaces are more challenging topics, based on the passive subsurface radar (PSSR) concept which sounds the icy crusts of Galilean satellites by the reflections of penetrated Jovian radio emissions (HOM/DAM). We introduce their possibility and the status of developing simulation system for the evaluation.

R009-14
Zoom meeting D ：11/1 PM1 (13:45-15:30)
14:15〜14:30

JUpiter ICy moons Explorer(JUICE)に搭載のSubmillimetre-wave Instrument(SWI)

#笠井 康子 [1)],Hartogh Paul[2)],SWI ミッションチーム [3)]
[(1]NICT,[(2]Max Planck Institute for Solar System Research,[(3]SWI Mission Team

The Submillimetre-wave Instrument(SWI) on JUpiter ICy moons Explorer(JUICE)

#Yasuko Kasai[1)],Paul Hartogh[2)],SWI Mission Team[3)]
[(1]NICT,[(2]Max Planck Institute for Solar System Research,[(3]SWI Mission Team

The Submillimetre-Wave Instrument (SWI) is one of the 10 scientific payloads on the JUpiter ICy moon Explorer (JUICE). The main scientific objectives of SWI is to investigate the atmospheric structure, compositions and dynamics of the middle atmosphere of Jupiter and exosphere of its moons, as well as thermophysical properties of the satellite surfaces. SWI observations will provide pioneering direct measurements of atmospheric compositions in Jupiter system. SWI will performed limb and nadir observations in the frequency region 530-600 and 1075-1275 GHz. Japanese contribution is the development of main- and sub- reflectors, actuators for the instruments, feasibility studies, data processing, and scientific contributions. We present current status of the JUICE/SWI.

JUICE 搭載装置の一つにサブミリ波分光計 Submillimetre- Wave-Instrument（SWI）がある．深宇宙探査機の歴史の中で，サブミリ波テラヘルツ波を用いた惑星観測はこれまで例がなく SWI が初めての提案となる．SWI の主な目的は木星中層大気の力学的挙動、衛星希薄大気の構造や成分、表面熱力学的性質を調べることである．サブミリ波テラヘルツ波帯における放射を大気周縁と直下方向から受信する。周波数帯は 530-600 と 1075-1275 GHz である．　本講演では、SWI が拓く科学や測器について述べる．

R009-15
Zoom meeting D ：11/1 PM1 (13:45-15:30)
14:30～14:45

高コントラスト望遠鏡 PLANETS の開発状況と惑星・衛星近傍の希薄ガス発光の検出可能性

#坂野井 健[1), 鍵谷 将人[1), 中川 広務[1), 寺田 直樹[1), 笠羽 康正[1), 平原 靖大[2), 栗田 光樹夫[3)
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Current status of the development of high-contrast telescope PLANETS and detection feasibility of scientific targets

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We are carrying out a 1.8-m aperture off-axis telescope project PLANETS (Polarized Light from Atmospheres of Nearby ExtraTerestrial Systems). In this presentation, we give the detection feasibility of scientific targets, such as volcanic and plume activities on Jovian satellites Io and Europa, and escaping gases surrounding Mars, taking advantages of high-contrast performance of the PLANETS telescope. The high-contrast performance of PLANETS telescope optics is provided by low-scattering off-axis mirror system, adaptive-optics (AO), and stable atmospheric conditions of an observatory site at a high-altitude. In particular, the off-axis system brings us no cross-shaped diffraction pattern caused by the secondary mirror support in the optical path, and thus the scattering light of PLANETS is estimated to be more than 10 times better than that of a normal large telescope.

A major scientific target is to detect faint emissions of gasses erupted from Jovian satellites Io and Europa. These emissions are so faint (10ˆ-3 to 10ˆ-6 to the brightness of planetary or satellite body) close to the main disk (less than a few arcsec). We will elucidate the spatial and time variations of Io volcanoes and its influence on Jupiter's magnetosphere by monitoring volcanic activities on Io's surface with infrared AO imaging at 1-4 um, and neutral emissions (O 630 nm and Na 589 nm) distributed in the atmosphere surrounding Io, plasma torus emission in the inner magnetosphere (S+ 672 nm, S++ 631nm, O+ 733nm, O++ 501nm), and Jupiter infrared aurora emission (H3+ 3.4um, 3.9um). We also observe visible emission (O 630 nm and 558 nm) caused by the dissociation of water molecules suddenly released by Europa's water ejection activity, and clarify the relationship between tidal action and eruption activity, and between surface topography and eruption location.

Another major scientific target is the escaping gases surrounding planets. We are examining the detection possibility of Martian ionospheric gases and ion tail using the PLANETS telescope. The target is solar resonance emissions of N2+ at 391.4 nm/427.8 nm and CO+ at 505 nm. From the quantitative estimation with number density obtained with MAVEN (Benna+, 2015), the N2+ emission intensity is seems to be greater than detection limit and the time variation may be able to detect during a CME event.

The telescope optics has a Gregorian focus with a FOV of 6 arcsec(F/13). The main mirror is Clearceram Z-HS with a diameter of 1850 mm and thickness of 100 mm. So far, the glass blank of main mirror was made in 2010, the rough grinding was carried out by Harris/Excelis in 2012. In December 2019, the mirror was shipped from Hawaii to Japan for the final polishing. We glued 36 metal adapters on the backside of mirror to connect the mirror support. We adopted the mirror support with warping harness which is similar to that of TMT and the Seimei telescope. We made the elemental test of the whiffletree system, and confirmed that the performance for stress input is as expected by the structure model with a finite element method (FEM), and the repeatability (hysteresis) for stress change is in the acceptable range. We are now carrying out final polishing using a dragging three probe method with a robot-arm system at LogistLab and will complete it within a year. We expect to obtain the accuracy of main mirror better than 20 RMS nm by the final polishing. In addition, we will fabricate the telescope mount and structures using the proto-type mount Seimei telescope. We will assemble the whole PLANETS telescope system, and achieve the first light and technical demonstration, particularly on the high-contrast and low-scattering capability, in Japan within a few years. Further, we already have the construction permit at the summit of Haleakala (CDUP) from the State of Hawaii, and we plan to install PLANETS there as soon as we get the funding for the observatory construction.

R009-16
Zoom meeting D ：11/1 PM1 (13:45-15:30)
14:45～15:00

次世代紫外線宇宙望遠鏡によるエウロパプルーム検出可能性の検討

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Feasibility study of Earth-orbiting UV telescope required to detect the Europa plume signatures

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Inside Jupiter's moon Europa, Ganymede, and Saturn's moon Enceladus, the global putative oceans under the ice shells could be sustained. In the previous study of Roth et al (2014), Hubble Space Telescope (HST) observed the enhancement of HI 121.6 nm and OI 130.4 nm emissions near the Europa south pole. They considered the electron impact of H_2O in the plume yields HI and OI emissions. Geological conditions of ejecting gas and dust form Europa plumes are not understood because the number of observations which succeed to detect Europa plume signatures is very small. Although the water vapor in the plumes do not necessarily pass through the underground ocean, it may include important information to consider the habitable environment of the icy moons.

LAPYUTA (Life-environmentology, Astronomy, and PlanetarY Ultraviolet Telescope Assembly) is the future Earth-orbiting UV telescope project. One of the main goals of LAPYUTA is to observe icy moon's atmosphere continuously, and confine the occurrence conditions such as locations and frequencies of the plume events. In case of spatial resolution of 0.1, 0.2, 0.4 and 0.8 arcsec, we considered the detectability of the Europa plume by UV space telescope with integration time of 10 hours and apparent area of ~350 cm^2. We calculated the signal of OI 130.4 nm and HI 121.6 nm counts from the plume, and the noise from Europa atmosphere (OI only), solar reflection, Earth geocorona and interplanetary medium. Two-dimensional symmetric Lorentzian function is applied as the point spread function whose FWHM corresponds to the spatial resolution. The emission due to solar reflection at the limb is estimated to be a few percentages of that at the center of the disk when the subsolar point is at the disk center. Therefore, the plume position and region of interest in this study are assumed to be near the south pole in the limb. The space telescope is assumed to orbit at 1000 km from the Earth ground. The calculation shows that a spatial resolution of 0.1 arcsec should be needed to detect both OI 130.4 nm and HI 121.6 nm emission originated from the Europa plume under the conditions of an apparent area of about 350 cm^2 and an integration time of 10 hours.

R009-17
Zoom meeting D ：11/1 PM1 (13:45-15:30)
15:00～15:15

系外惑星高層大気観測に向けた国際紫外線天文衛星 WSO-UV 計画の状況

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Current status of WSO-UV for exoplanetary exospheres

#Shingo Kameda[1)],Go Murakami[2)],Akifumi Nakayama[3)],Takanori Kodama[3)],Masahiro Ikoma[4)],Naoki Terada[5)],Norio Narita[3)],
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Many Earth-sized planets have already been discovered, and several Earth-sized planets were recently detected in the habitable zone around low-temperature stars near the solar system. However, it is still difficult to characterize them as Earth-like or Venus-like. Transit spectroscopy requires very high accuracy for small Earth-like planets. Earth's exosphere is extended to ˜38 Earth radii. On the other hand, Venus' and Mars' hydrogen exosphere is not so much extended because of the low temperature of their upper atmosphere. This is caused by the difference in the mixing ratio of CO2 in the upper atmosphere. On Earth, CO2 was removed from its atmosphere by a carbon cycle with its ocean and tectonics. Translating these arguments to exoplanets in a habitable zone presents a possible marker to distinguish an Earth-like planet from a Mars-like or Venus-like planet. The expanded exospheres can be observed in UV during the exoplanet transit event in a primary eclipse. It reduces the stellar flux when an exoplanet is orbiting in front of the host star.

We performed a preliminary design of Ultraviolet Spectrograph for Exoplanet (UVSPEX) for World Space Observatory Ultraviolet (WSO-UV), which is a 1.7-m UV space telescope prepared by Russia. The dominant engineering requirements for the UVSPEX are following. The spectral resolution is better than 0.5 nm to separate O I line from other spectral lines. The spectral range is to exceed the wavelengths from 115 nm to 135 nm to detect at least H Lyman alpha 121.6nm to O I 130 nm. The throughput is better than 0.3%. We propose a simple spectrograph design to achieve these requirements, containing the slit, the concave (toroidal) grating as a dispersing element, and the imaging photo-detector. This optical concept is conventional and used in other space missions for UV spectroscopy. In this presentation, we show the configuration of the UVSPEX instrument and its science objectives.

これまでに地球サイズの惑星が多数発見されており、最近では太陽系近傍の低温恒星のハビタブルゾーンにも惑星が検出されている。しかし、それらの惑星が地球類似型か金星類似型かを判別ことは困難である。トランジット分光法で小さい地球型惑星大気の観測を行う際には、非常に高い精度が要求される。地球の外圏水素は 38 地球半径以上まで広がっているが、金星や火星では上層大気の温度が低いため、あまり広がっていない。これは、上層大気中の CO2 の混合比の違いによっている。地球では、炭素循環によって、大気中の CO2 が除去されている。このことから、上層大気の広がりを観測することで地球類似大気と火星金星類似大気を見分けられる可能性がある。

我々はロシアが打ち上げ予定の 1.7m 紫外宇宙望遠鏡である国際紫外線天文衛星 WSO-UV 搭載用紫外分光器（UVSPEX）の予備設計を行った。UVSPEX に求められる主な技術的要件を以下に示す。(1)O I 線を他のスペクトル線から分離するために、0.5nm 以上のスペクトル分解能を持つこと (2) 少なくとも H Lyman Alpha 121.6nm から O I 130nm までを検出できるように、波長 115nm から 135nm を超えるスペクトル範囲を確保すること (3) スループットは 0.3%以上であること。これらの要求を達成するために、スリット、分散素子としての凹型（トロイダル）回折格子、および検出器を含む、シンプルな設計を採用する。この方式は、他の宇宙での紫外分光観測にも使用されている。本発表では、UVSPEX の装置構成とその科学的目標を紹介する。

R009-18
Zoom meeting D ：11/1 PM2 (15:45-18:15)
15:45～16:00

月極域探査計画 LUPEX に搭載する複数回反射型質量分析器 TRITON の開発

#山本 直輝 [1], 齋藤 義文 [2], 笠原 慧 [3], 横田 勝一郎 [4], 浅村 和史 [5], 西野 真木 [6]
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Development of a Time of Flight Mass Spectrometer (TRITON) for Lunar Polar Exploration (LUPEX)

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Investigation of the amount and the chemical form of volatiles including water on the lunar surface is important not only in understanding the evolution of the lunar surface, but also in understanding the origin of lunar and terrestrial water and the transportation of materials in the solar system. In addition, if the quantity of volatiles on the Moon is substantial, space exploration based on the Moon may be possible converting them into fuels. Therefore, exploration of the lunar poles is important in both planetary science and advancement of space exploration.

Although remote observations suggest the presence of water on the lunar surface, it is still unclear that how much water exists. In LCROSS, one of the examples of the remote observations, water and small amount of hydroxyl were observed. A small abundance of other volatiles was also detected. Since the mass spectrometer should be able to distinguish large amount of water and small abundance of other volatiles, high mass resolution is required in order to achieve scientific goals such as measuring the abundance of volatiles on the lunar surface.

JAXA is planning LUPEX (LUnar Polar Exploration) mission. REIWA (REsource Investigation Water Analyzer) is one of the instruments for investigating volatiles including water. REIWA consists of a heater with a weight scaler, which measures weight of the heated samples, and mass analyzers which analyze desorbed volatiles from the samples. We are developing triple-reflection reflectron (TRITON), which is a time-of-flight mass spectrometer (TOFMS). TRITON is composed of an ion source that generates ion beam with large area and a triple-reflection reflectron which is a compact mass spectrometer with high mass resolution. TRITON is operated mainly in two different modes, single reflection mode which has high sensitivity and low mass resolution and triple reflection mode which has lower sensitivity and higher mass resolution. The two operation modes can be switched by adjusting the voltage applied to the analyzer.

Pulsed high voltage is applied to the analyzer plate. The applied pulsed high voltage has a square wave form. We have replaced the previously used commercial pulsed high voltage module with a pulsed high voltage BBM under development, which is proved to have sufficient performance. In addition, we have investigated that how the rising time influences on the mass spectrum. We have changed the rising time by inserting a resistor in the output line of the pulsed high voltage. The upper limit of the rising time of the pulsed high voltage to satisfy requirements of mass resolution and the quantitative influence on the mass spectrum will be presented. So far, we have been using a commercially available ion source that is not for flight. We will also show the performance of the test model of TRITON whose all components are under development for flight.

月の極域に存在する水などの揮発性物質の量およびその形態を調べることは、月の表層の進化の過程や月表面でのイオンの動きの理解だけでなく、月ないしは地球の水の起源や太陽系内の物質の輸送過程を理解するのに重要である。また、月に利用可能な形で十分な量の揮発性物質が存在した場合、それを燃料に変えることで月を拠点に宇宙探査を行うことができるかもしれない。月の極域探査には惑星科学的意義だけでなく、宇宙探査の発展にとっても重大な意義がある。

これまで遠隔観測から水の存在を示唆する結果は出てきているが、水がどのような状態でどれだけ存在するかについてははっきりしていない。遠隔観測の一つの LCROSS では水だけでなく水酸基も観測されている [1]。また、水や水酸基以外にも様々な揮発性物質が微量ながら観測されている。したがって、揮発性物質の存在量の同定等の科学的目標を達成するためには、存在量の多い水とその他の揮発性物質を質量スペクトル上で区別しなければならず、高い質量分解能が必要となる。

そこで JAXA は月極域探査 (LUnar Polar EXploration mission) を計画している。この探査において水を含めた揮発性物質の調査を行うのが水資源分析計 (REsource Investigation Water Analyzer) である。これは試料の質量を測定し加熱する熱重量測定装置と加熱によって発生した揮発性物質を分析する質量分析器からなる。我々はこのうち、飛行時間型質量分析計 (Time Of Fight Mass Spectrometer) である TRITON(TRIple-reflection reflecTrON) の開発を行っている。TRITON は高い検出効率を実現するためにシート状のイオン流を生成するイオン源と、小型かつ高い質量分解能を確保できる複数回反射型のリフレクトロンから成る。TRITON は印加する電圧を調整することによって、質量分解能は高いが感度は低い 3 回反射モードと質量分解能は低いが感度は高い 1 回反射モード主にの 2 つのモード で質量スペクトルを測定することができる。

加速部にかかる電圧は矩形波によって立ち上がり、この立ち上がりに要する時間は使用するパルス高圧電源によっ

て決まる。これまでは市販のパルス高圧モジュールを使用していたが、開発中の搭載用パルス高圧 BBM に変更して実験を行った結果、パルス高圧 BBM は搭載するのに十分な性能を有していることが確認できた。さらに、パルス高圧の出力ラインに抵抗を挟むことにより、意図的に立ち上がり時間を延ばすことができるため、矩形波の立ち上がり時間を延ばすことによってマススペクトルがどのように変化するのかを調査した。分解能の要求を満たすために必要な立ち上がり時間の上限や、マススペクトルに与える影響に関して得られた定量的な結果について紹介する予定である。また、これまでの実験では、イオン源も搭載には使用できない市販のものを用いていたが、開発中の搭載可能なものに取り換えることで、すべてのコンポーネントを搭載に向けて開発中のものにした試験結果についても紹介する予定である。

[1] A. Colaprete, et al, Science, 330, 6003, (2010)

R009-19
Zoom meeting D ：11/1 PM2 (15:45-18:15)
16:00〜16:15

Oxygen ion modulation by magnetosonic waves in the upper ionosphere of Mars

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It is critically important to characterize the transport of energy and mass in the near-Mars space if we are to understand the current and past ion escape from Mars driven by the solar wind interaction with the Martian upper atmosphere. Among possible ion energization processes, it has been suggested that magnetosonic waves generated upstream of the Martian bow shock propagate through the magnetosheath into the upper ionosphere of Mars, heat oxygen ions of ionospheric origin via wave-particle interactions, and facilitate ion escape to space. However, mechanisms of energy transfer from the magnetosonic waves to oxygen ions remain elusive. In this study, we investigate the interaction between magnetosonic waves and oxygen ions by analyzing ion velocity distribution functions and time-varying magnetic fields measured by MAVEN. We identified a number of cases in which the oxygen ion velocity is modulated by magnetosonic waves around the local oxygen ion cyclotron frequency. Based on case studies and statistical results, we explore mechanisms of wave-particle interactions capable of explaining the observed properties.

R009-20
Zoom meeting D ：11/1 PM2 (15:45-18:15)
16:15～16:30

MAVEN および MGS 観測データを用いた火星地殻残留磁化近傍での周期的電子注入現象の発生機構についての研究

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On the generation mechanisms of periodic electron injection observed in Martian crustal remanent magnetic fields by MAVEN and MGS

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Mars has no global intrinsic magnetic field like the Earth, but it has inhomogeneously distributed crustal remanent magnetic fields. In such an environment, a complex magnetosphere is formed by the solar wind interaction with these localized crustal magnetic fields and with the upper atmosphere of Mars. It is known that closed magnetic field lines are formed above the strongly magnetized regions, as indicated by trapped electrons observed on closed magnetic field lines. Provided that electrons with broad energies are locally and impulsively injected onto closed magnetic field lines, the energy-dependent gradient and curvature drift motions will lead to energy-time dispersed electrons at a fixed observer distant from the source. The local and impulsive electron injection was measured by the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission, and it has been reported that the energy-time dispersed electron signatures sometimes occur periodically for multiple times in succession. However, the characteristics and generation mechanisms of periodic electron injection have not been fully clarified yet. In this sturdy, we investigate characteristics of these periodic electron injection observed in the crustal remanent magnetic fields of Mars using the solar wind electron analyzer (SWEA) and magnetometer (MAG) onboard MAVEN, and the electron reflectometer (ER) and magnetometer (MAG) onboard the Mars Global Surveyor (MGS). At the time of writing, we have identified hundreds of cases of the periodic electron energy-time dispersion events from the MAVEN and MGS data. We will discuss upstream solar wind conditions, seasonal dependence, and geographic dependence based on statistical results derived from a large amount of the MAVEN and MGS data, thereby gaining insight into their generation mechanisms.

火星は地球のような全球的な固有磁場を持たず、偏在した地殻残留磁化を持つのみである。そのような環境で地殻残留磁化や上層大気が太陽風と直接相互作用することで複雑な磁気圏を形成している。地殻残留磁化が強い地域では閉じた磁力線が形成されることが知られており、閉じた磁力線への電子捕捉も確認されている。閉じた磁力線上に電子が局所的かつ瞬間的に電子が注入された場合、ミラー点間をバウンス運動しながら磁力線と垂直にエネルギー依存を伴うドリフト運動をするために、電子のエネルギー分散が見られることが予測される。そのような局所的かつ瞬間的な電子注入イベントはこれまでの MAVEN(Mars Atmosphere and Volatile EvolutioN) による観測において確認されており、また、そのような電子注入イベントの中で複数回の電子エネルギー分散が準周期的に発生する例も同時に報告されている。ただし、その周期性の発生機構や特性については未だ解明されていない。本研究では、火星探査機 MAVEN に搭載された太陽風電子分析器 (SWEA) と磁力計 (MAG)、および MGS(Mars Global Surveyor) に搭載された電子反射率計 (ER) と磁力計 (MAG) を用いて、火星地殻残留磁化付近で観測される周期的電子注入現象の特性を調査し、発生機構について議論する。これまでに MAVEN および MGS データから、計数百例の周期的電子エネルギー分散イベントを同定している。本発表では、MAVEN、MGS による大量のデータを用いた統計解析から、周期的電子注入現象の上流太陽風条件・季節依存性・地理依存性を包括的に議論し、その発生機構について考察する。

R009-21
Zoom meeting D ：11/1 PM2 (15:45-18:15)
16:30〜16:45

A technique for retrieving the Martian hot oxygen exosphere from O+ pickup ion measurements in the magnetosheath

#Kei Masunaga[1)],Naoki Terada[2)],Shotaro Sakai[2)],Shoichiro Yokota[3)],Tomohiro Usui[1)]
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Mars has lost its atmosphere to space over billions of years. The atmospheric escape takes place above exobase where collisions are not important (i.e., exosphere). Studying the atmospheric escape processes leads to expand our understanding on the atmospheric evolution of Mars and to understand why present Mars possesses such a dry environment. However, measuring tenuous atmospheric particles in the exosphere is challenging due to their small density and flux.

Mars does not have a global intrinsic magnetic field, and thus its exosphere is directly exposed to the solar wind. Once the exospheric particles are ionized by the solar UV radiation, charge exchange, or electron impact, they are accelerated by the solar wind motional electric field. The “ion pickup” by the solar wind is known as a common ion escape process from Mars. Pickup ions are widely observed in the solar system and their nature is well studied (e.g., Coates, 2010; Cravens et al., 2002).

In the collisionless plasma, pickup ions exhibit cycloid trajectories (i.e., the E x B drift). In the velocity space, the E x B drift is described as the ring distribution. Because ring distributions potentially own information of ionization locations and densities of exopheric neutral particles, they are a useful tool to probe the Martian exosphere. Recent studies have shown that very tenuous hydrogen and oxygen exospheres (altitude of $>$3000 km) can be retrieved by H^+ and O^+ pickup ion ring distributions observed in the solar wind (Rahmati et al., 2015, 2017, 2018).

In this study, we have established another method to retrieve hot oxygen exosphere around Mars, using the O^+ pickup ion ring distributions in the magnetosheath observed by the SupraThermal And Thermal Ion Composition (STATIC) instrument aboard the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft. In the magnetosheath, although the shocked solar wind has fluctuations in velocity and magnetic field, the motional electric field typically points outward or planetward depending on the interplanetary magnetic field orientation. Because O^+ pickup ion gyroradii are typically much larger than the Mars radius, pickup ions in the magnetosheath are nearly accelerated along the motional electric field of the magnetosheath, meaning that they are typically on the initial phase of the ring distribution. Using measured ion fluxes in the first quadrant phase of the O^+ ring distribution, we successfully retrieved ionization locations and densities of hot oxygen atoms in ˜1000-5000 km altitude range. In this presentation, we will show typical oxygen exosphere profiles in different local times and their dependences on the solar wind, solar EUV radiation, and seasons.

In near future, the Martian Moons eXploration (MMX) spacecraft will carry multiple scientific instruments to investigate Mars and Martian moon environments and return samples from Phobos. One of the instruments is the Mass Spectrum Analyzer (MSA) instrument that measures ion velocity distributions and magnetic fields. The high mass resolution ($M/\Delta M>100$) of MSA will allow us to study ion isotopes such as $^{18}O^+$ and $^{13}C^+$ as well as their major ion elements ($^{16}O^+$ and $^{12}C^+$). Using our retrieval method in the future observations of MMX/MSA, we aim to retrieve Martian exospheric density profiles of multiple components, including isotopes, with the MSA's pickup ion measurements around Mars. Such information will be crucial for understanding the evolution history of Mars through atmospheric escape.

R009-22
Zoom meeting D ：11/1 PM2 (15:45-18:15)
16:45〜17:00

MAVENおよびMars Expressによる火星電離圏不規則構造の遠隔・直接同時観測

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Simultaneous remote and in-situ observations of ionospheric irregularities at Mars by MAVEN and Mars Express

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It is known that the ionosphere of Mars contains a variety of irregularities. Gurnett et al., [2008] reported that "diffuse echoes", the traces of which appear unusually diffuse in an ionogram, are sometimes observed by topside ionospheric sounding of Mars Express. These echoes are proposed to be caused by irregularities in the Martian ionosphere. However, the spatial scale lengths and generation mechanisms of ionospheric irregularities that cause diffuse echoes are still unknown, partly because comparative studies utilizing remote and in-situ measurements of ionospheric irregularities are yet to be conducted at Mars.

In this study, we surveyed conjunction events in which Mars Express and MAVEN observed the topside ionosphere of Mars at almost the same time and the same location, searching for cases with diffuse echoes apparent in the Mars Express data. We then investigated variations of the electron, ion, and neutral densities, magnetic fields, and the presence or absence of the hot electron precipitation from MAVEN data. Based on the analysis, events with clear diffuse echoes were detected in 3 out of 77 simultaneous observations. It is suggested that the spatial scale lengths of irregularities causing diffuse echoes range from tens to hundreds of kilometers. Additionally, case studies of intense diffuse echo events suggest that there could be multiple drivers causing ionospheric irregularities, such as dynamic pressure of the solar wind, ion-neutral coupling, and interaction between solar wind and crustal magnetic fields. In this presentation, we are going to discuss characteristics, occurrence frequency, and generation processes of diffuse echoes caused by each driver.

本研究では、火星電離圏に見られる不規則構造について、Mars Express 衛星のトップサイドレーダー観測と、MAVEN 衛星の電子密度等の直接観測による準同時・同地域を観測しているデータを解析し、不規則構造の性質について考察を行なった。

火星電離圏には様々な不規則構造が存在すると考えられている。Gurnett et al. [2008] では、Mars Express のトップサイドサウンディングによって得られたイオノグラム中に、通常の電離圏から返ってくるエコーよりも広がって見えるエコー（diffuse エコー）が見られることがあると報告している。これは電離圏中の不規則構造に起因していると考えられている。しかし、diffuse エコーの原因となる火星電離圏不規則構造に関して、遠隔観測（エコー観測）と直接観測（電離圏の密度計測）を比較した研究はこれまでになく、その空間スケールや発生機構はいまだに不明であった。

そこで本研究では、Mars Express と MAVEN の電離圏観測が時間的・空間的に比較的近いイベントを探し、diffuse エコーが見られる時の電子密度・中性大気密度の変動、磁場の特性、電子の降り込みの有無等を調べた。結果として、はっきりとした diffuse エコーが見られるイベントは同時観測 77 例中 3 例見つかり、diffuse エコーをつくる不規則構造の空間スケールが数十〜数百 km であることが示唆された。また、diffuse エコーの原因となる不規則構造を作る駆動源として、太陽風動圧、中性大気由来の波動、強く開いた地殻磁場と太陽風の相互作用などが考えられるような観測結果がみられた。本発表では、それぞれの駆動源による diffuse エコーの性質や発生頻度の傾向、発生プロセス等について議論する。

On plasmasphere formation around terrestrial exoplanets: Possible evidence of exoplanetary intrinsic magnetic field and atmosphere

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There have been discovered many exoplanets and the number of terrestrial exoplanet detection increases rapidly in recent ten years. Many terrestrial exoplanets or super-Earth are found around low mass stars such as M dwarfs. A red dwarf (M type star) has comparatively narrow habitable zone, which is very close to the host star, and exoplanets are considered to be exposed to extreme levels of X-ray and ultraviolet (UV) radiation. Classic equilibrium tide theories predicts that K or M-type stars induce strong tidal effects on potentially habitable exoplanets, and tidal locking is possible for most planets in the habitable zones of K and M dwarf stars [e.g., Barnes, 2017].

When a planet has dipole magnetic field and rapid rotation, superposition of the stellar wind induced and corotation electric fields results in the tear-drop-shaped region of the closed drift, where planetary ionized atmosphere can fill the magnetic flux tubes along the field lines. The region is characterized with cold dense planetary plasma and called as the plasmasphere. In this study, a simple estimation method of the size of terrestrial exoplanetary plasmasphere is shown based on the knowledge of the solar system planets. We considered the role of rapid rotation of the atmosphere (superrotation) in the formation of the plasmasphere of tidally-locked exoplanets. Many GCMs of exoplanets show that the circulations of typical tidally locked terrestrial exoplanets can become superrotation [e.g., Showman+, 2013]. However, the horizontal circulation in the thermosphere is far from understood [e.g., Machado+, 2017].

The results indicate that Earth-like magnetized exoplanet can have a plasmasphere with a size of 4-6 times of the planetary radius. The size of the plasmasphere depends on the superrotation speed of the thermosphere, ionospheric conductance, stellar wind dynamic pressure, and IMF cone angle. If the exoplanet has a CO_2-rich atmosphere, the results suggest the FUV absorption of plasmaspheric C+ ions might be observable by space telescopes. Since the plasmasphere formation requires the existence of both the thick atmosphere and global intrinsic magnetic field, the observation of plasmasphere can provide possible evidence and clues of the exoplanetary atmosphere and intrinsic magnetic field.

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R009-24
Zoom meeting D ：11/2 AM1 (9:00-10:30)
9:15〜9:30

Numerical experiments of exospheric retrieval for isotope ratio measurements by MSA onboard MMX

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Mars has experienced a massive atmospheric escape and climate change over the past 4.6 Gyr. The main component of Martian atmosphere is carbon dioxide (CO_2) and how much CO_2 has escaped to space is significant for understanding the climate change on Mars. The isotope ratio is one of the important key parameters to understand the atmospheric evolution. Jakosky et al. (2017) suggested from measurements of argon isotope ratio ($^{38}Ar/^{36}Ar$) based on observations by the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft that one bar or more of oxygen (O) has been lost to space, assuming that the lost O comes primarily from CO_2, but these estimations were not based on direct observations of CO_2. Evolution of O and carbon (C) isotope ratios ($^{16}O/^{18}O$ and $^{12}C/^{13}C$) between the surface and upper atmosphere are suitable for understanding the CO_2 loss process, but no observational constraints on these isotope ratios in the upper atmosphere have been made until this point. Note that Curiosity identified the isotope ratios of $^{16}O/^{18}O$ ˜476 and $^{12}C/^{13}C$ ˜85 near the surface (e.g., Mahaffy et al., 2013), and the Atmospheric Chemistry Suite onboard Trace Gas Orbiter (TGO) found the isotope ratio of $^{16}O/^{18}O$ ˜420 in the middle atmosphere below 60 km altitude (Alday et al., 2019). Japanese future sample return mission ”Martian Moons eXploration (MMX)” is a candidate of this observation. Mass Spectrum Analyzer (MSA) onboard MMX can measure the escaping ions with a high mass resolution of $M/dM > 100$. MSA enables us to measure isotope ratios in the escaping atmosphere for the first time, and in addition, it can estimate isotope ratios in the exosphere by retrieving the neutral atmosphere of each isotope from the ion observations. As a first step toward future MMX observations, this study investigates the distribution and energy of ions ($^{16}O^+$ and $^{18}O^+$) seen at midnight around the Phobos’ orbit, as well as their sources, using test particle simulations under electric and magnetic fields obtained from magnetohydrodynamic simulations (e.g., Sakai et al., 2021). The particle simulations are conducted under certain interplanetary magnetic field conditions. The ions that reach Phobos’ orbit at midnight are picked up in the induced magnetosphere or the solar wind region. Most of the ions come from the induced magnetosphere around 2000 km altitude, and the energy is as low as several eV. The ions coming from the solar wind reach several keV because of the acceleration by the solar wind electric field. The simulations also show that there is a proportional relationship between the energy and the distance from the Phobos’ orbit to the pickup position, and that the gradient significantly depends on the electric field. Establishing a retrieval method would enable us to determine the pickup position from the ion energy around the Phobos’ orbit in MMX. Finally, the radial $^{16}O^+$ and $^{18}O^+$ fluxes around the Phobos’ orbit are 10^5 - 10^7 cm^{-2} s^{-1} and 10^3 - 10^4 cm^{-2} s^{-1}, respectively. The $^{16}O^+$ flux from the simulations is consistent with the previous study (Curry et al., 2013). Multiple measurements of isotope ratios at different altitudes by MMX, Curiosity, and TGO would lead to a better understanding of atmospheric evolution on Mars, and this simulation aims to help measurements by MMX.

R009-25
Zoom meeting D ：11/2 AM1 (9:00-10:30)
9:30〜9:45

Development of an engineering model (EM) of the Mass spectrum Analyzer (MSA) for Mars Moons eXploration (MMX)

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The Mass Spectrum Analyzer (MSA) will conduct in-situ observations of ions and magnetic fields around Phobos as part of the Martian Moons eXploration (MMX) mission, in which remote-sensing and in-situ measurements and sample return will be performed. The MMX project has two primary science goals: 1) Reveal the origin of Martian moons and 2) Understand physical processes in the Martian environment for investigating co-evolution of the Martian-moons system. The MSA instrument is composed of an ion energy mass spectrometer, two magnetometers, and electronics. The ion analyzer measures distribution functions and mass distributions of low-energy (<˜10s keV) ions. The magnetometers measure the magnetic field of the solar wind which is sometimes perturbed by Mars and possibly by Phobos. The combination of ion and magnetic field sensors will allow us to measure ions emitted from Phobos and its torus as well as escaping ions from the Martian atmosphere with monitoring the solar wind to address the MMX science goals.

The MSA is now being developed from previous instruments for space plasma missions such as Kaguya, Arase, and BepiColombo/Mio to contribute to the MMX scientific objectives. The preliminary design review (PDR) was completed last fall and we have started the development of the engineering model (EM) since then. We present the results of the EM design and performance tests to show the current status of the development.

R009-26
Zoom meeting D ：11/2 AM1 (9:00-10:30)
9:45～10:00

TGO/NOMAD からリトリーバルした火星中間圏・下部熱圏の CO/CO2 分布の変動

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Variation of CO/CO2 profiles in the Marian mesosphere and lower thermosphere retrieved from TGO/NOMAD

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CO is produced by the photodissociation of CO_2 and recycled to CO_2 by the catalytic cycle involving HOx in the Martian atmosphere [e.g., McElroy & Donahue, 1972]. In the mesosphere and lower thermosphere (MLT) region of Mars, the number density of CO is determined by the photodissociation, eddy diffusion, and atmospheric circulation. The increase in the CO mixing ratio in the MLT region and further enhancement in the polar region due to the transport of CO-enriched air via meridional circulation are predicted in 3D models [Daerden et al., 2018; Holmes et al., 2019]. On the other hand, the decrease in the CO mixing ratio in the MLT region during a global dust storm is discovered by the Atmospheric Chemistry Suite (ACS) aboard Trace Gas Orbiter (TGO), which suggests that the increase in the hygropause altitude due to the global dust storm leads to the increase in the vertical range over which OH becomes available to convert into CO_2 [Olsen et al., 2021]. Additionally, a substantial variation in the homopause altitude has been found by recent studies [Slipski et al., 2018; Jakosky et al., 2017; Yoshida et al., 2020], which suggests that the order of magnitude changes in the eddy diffusion coefficient at the homopause altitude [Slipski et al., 2018]. It implies variations in the profile of CO mixing ratio in the MLT region. However, the effects of change in the eddy diffusion coefficient on the profile of CO mixing ratio have not been investigated.

To clarify the contributions of photochemistry, eddy diffusion, and atmospheric circulation to the CO/CO_2 profiles in the MLT region, we use the Nadir and Occultation for MArs Discovery (NOMAD) instrument aboard TGO. NOMAD solar occultation is designed as the combination of the Acousto Optical Turnable Filter and echelle grating [Neefs et al., 2015; Thomas et al., 2016]. NOMAD solar occultation operates in the wavelength range of 2.2 - 4.3 μm (2320 to 4350 cm^{-1}) with a high spectral resolution ($\lambda/d\lambda$ = 20000) [Vandaele et al., 2018]. It provides us CO and CO_2 spectra below 100 km and 180 km altitudes, respectively.

In this study, we applied the equivalent width technique [Chamberlain and Hunten, 1987; Krasnopolsky, 1986] to derive a new set of CO and CO_2 column densities with the observed atmospheric transmittance spectra by NOMAD solar occultation. The absorption lines at 4285.0, 4288.2, and 4291.5 cm^{-1} for CO (2-0) band and 3358.7, 3364.9, and 3366.4 cm^{-1} for CO_2 (21102-00001) band are carefully selected for retrievals to avoid the contamination of absorption lines from the nearby diffraction orders [cf. Liuzzi et al., 2019]. It is noted that the line strengths of the selected CO_2 have high sensitivity to the background temperature. We assumed the vertical profiles of temperature simulated in the GEM-Mars model [Neary et al., 2018; Daerden et al., 2019]. We retrieve the CO and CO_2 slant column densities between 60 and ~100 km altitudes because those slant opacities are saturated below 60 km altitude. The CO and CO_2 spectra observed from April 2018 to September 2020, corresponding to from MY 34 L_s ~150 to MY 35 L_s ~280, are investigated.

We found that the retrieved CO/CO_2 ratio between 60 and ~100 km increases with altitude. The decrease in the CO/CO_2 ratio over the whole altitude range during the global dust storm corresponds to the previous observations [Olsen et al., 2021]. In addition, we found that the CO/CO_2 profiles vary with season and latitude. The slope of CO/CO_2 profiles is about two times larger in L_s = 240 - 270 (southern summer season) than in L_s = 120 - 150 (southern winter season). For interpretation, a 1D photochemical model is compared with newly obtained CO/CO_2 profiles, especially in order to discuss the contributions from the variations in eddy diffusion coefficient and photochemistry in the MLT region of Mars. When we assume a constant eddy diffusion profile of 10^7 cm^2s^{-1}, the CO/CO_2 profile in L_s = 120 - 150 is reproduced. Furthermore, the CO/CO_2 profile in L_s = 240 - 270 is reproduced when we assume a higher eddy diffusion profile by one order of magnitude. The ranges of eddy diffusion coefficient support the recent study by Slipski et al. (2018).

R009-27
Zoom meeting D ：11/2 AM1 (9:00-10:30)
10:00～10:15

CO2 近赤外吸収と渦拡散強度による火星熱圏構造への影響

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Effects of the CO2 near-IR absorption and strength of eddy diffusivity on the Martian thermosphere

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The temperature and compositional structure in the thermosphere have a crucial importance of the evolution of planetary atmosphere via the atmospheric escape because the temperature and composition at the thermosphere would determine the supply rate of gas to the exosphere. On the other hand, CO_2 dominated atmosphere is popular not only for the planets in the Solar system but also for water-rich terrestrial exoplanets in the habitable zone [e.g. Nakayama et al. 2019]. Thus, we discuss uncertainty of numerical modeling and consistency to observations for the CO_2-rich Martian thermosphere because recent MAVEN observations provide enough knowledge of the Martian thermosphere. In generally, the structure of the thermosphere is known to be determined by complex processes, such as photo- and thermo-chemistry, radiative cooling, and mixing and separation via molecular and eddy diffusion. In particular, we have no enough knowledge of the effect of strength of eddy diffusion on the temperature structure, although there are some studies to discuss the effects on compositional structure [e.g., Nier & McElroy 1977]. On the other hand, CO_2 near-IR absorption has an important role to the temperature structure of CO_2-rich atmosphere [e.g., Bougher & Dickinson 1988]. Although previous study adopted the band model, such as k-distribution method, for the radiative transfer [Bougher et al. 2015], we need to determine the absorption and heating profile, using line-revolved method because teneous upper atmosphere only absorb strong absorption lines. In this study, we evaluate effects of the CO_2 near-IR absorption and strength of eddy diffusivity on the structure of the Martian thermosphere.

We develop the thermosphere model based on Johnstone et al. (2018). This model estimates steady-state thermospheric structure, considering photo- and thermo-chemistry, molecular and eddy diffusion, non-LTE radiative cooling, and CO_2 near-IR absorption. For the near-IR absorption, we adopt the Line-by-line (LBL) method using HITRAN2012 database [Rothman et al. 2013]. We assume present Martian condition for UV spectrum and temperature and composition at the lower boundary. We adopt the scaling law for eddy diffusivity derived by Krasnopolsky et al. (1986) and vary its strength by an order of magnitude. For the LBL method, we vary wavenumber resolution from 1 to 0.01 cm^{-1} to evaluate the impact on the heating profile.

We found the numerical method of near-IR absorption and eddy diffusivity affect temperature structure in the thermosphere located typically from 100 to 200km. Both give temperature difference of typically 20K at the exobase. In particular, the LBL method provide different absorption and heating profiles from those estimated by k-distribution method. In addition, the higher wavenumber revolution of the radiative transfer, the higher heating rate around exobase is because strong and fine absorption lines are absorbed in the upper part of the thermosphere. Our results indicate the importance of eddy diffusivity and line-resolved near-IR absorption for the CO_2-rich thermosphere with relative weak UV irradiance, like the present Martian thermosphere.

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R009-28
Zoom meeting D ：11/2 AM2 (10:45-12:30)
10:45〜11:00

Observation Capability of a Ground-based Terahertz Radiometer in Martian atmosphere

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We present expected performance for a ground-based Terahertz (THz) radiometer, plan to be launched on the TEREX-1 (TERahertz EXplore-1) Mars exploration micro spacecraft.

The small THz passive radiometer has been developed for the TEREX series of future micro spacecrafts.

This spacecraft is an opportunity for organizations with limited resources and technology to conduct frequent missions to Mars well suited for resource exploration in contrast to all of the current and past Mars missions of large/giant class missions with fully government lead.

The observation frequencies of TEREX-1 radiometer are 474.64 to 475.64 and 486.64 to 487.64GHz with 100 kHz resolution, and the double-sideband noise temperature less than 3000 K.

A theoretical error analysis is performed with the instrument characteristics to assess for the first time up-looking observations of atmospheric Oxygen molecules (O_2) and water vapor (H_2O).

Measurement errors for O_2 and H_2O are 7 to 22% and 14 to25% with 8 to 17 km and 5 to 10 km vertical resolution in the vertical ranges 0 to 55 km and 0 to 25 km, respectively.

TEREX-1 is also capable to measure minor species, O_3 and H_2O_2, with a precision better than 30% within two independent layers.

We used the integration time of 1 hour for all simulations.

Our theoretical simulation showed the instrument characteristics of the TEREX-1 sensor is able to observe vertical profiles of O_2 and H_2O abundances with the same level of the large class missions.

R009-29
Zoom meeting D ：11/2 AM2 (10:45-12:30)
11:00〜11:15

太陽高エネルギー粒子が火星オゾンに与える影響の評価

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Influences of solar energetic particles on the Martian ozone

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Solar energetic particles (SEPs) consist of protons, electrons and heavy ions in the energy range between a few tens of keV and GeV. SEPs are originated from solar flares, shock waves driven by coronal mass ejections.

SEPs penetrate the Earth's atmosphere down to tens of kilometers at high geomagnetic latitudes. The penetrating SEPs can change the composition in the middle atmosphere. During the large solar flare that occurred in October 2003, penetrating SEPs caused NO2 enhancement by several hundred percent, accompanied by ozone depletion of tens of percent between 36 and 60 km altitudes (e.g., Seppala et al., 2004; Rohen et al., 2005).

The SEP penetration imposes a critical influence on deep atmospheres and impacts on surfaces of various planets, as Martian Radiation Environment Experiment (MARIE) onboard Mars Odyssey was disabled in the 2003 event (Zeitlin et al., 2010) and a global diffuse-aurora was reported on the entire Martian night side due to the SEP precipitation associated with a solar flare in September 2017 (Schneider et al., 2018). Considering the increasing human activities in space, such as future international missions to the Moon and Mars, it is important to understand the behavior of SEPs in planetary environments in order to assess their impacts on missions and human bodies. In addition, the ozone layer is essential for understanding how NOx increases in the Martian environment, and the increases in NOx can have implications for aspects of astrobiology and the past Martian greenhouse effect.

In this study, we aim to identify the response of the Martian ozone layer to SEP events. We use vertical profiles of ozone number densities observed by stellar occultation measurements by IUVS onboard MAVEN, and the energy fluxes of electrons and ions monitored by Solar Energetic Particle onboard MAVEN (MAVEN/SEP). MAVEN/IUVS has regularly conducted stellar occultation campaigns (1-2 days per campaign) once every ~2-3 months (Groller et al., 2018). MAVEN/SEP can detect electron's and ion's energy spectra from 20 keV to 1 MeV and from 20 keV to 6 MeV in the differential flux range of 3-3x10^6 eV/cm^2 s sr eV (Larson et al., 2015).

As the first step of this study, we focus on a SEP event at Mars on 3-4 November 2015, when ozone was observed simultaneously by stellar occultation measurements by MAVEN/IUVS. Comparing the data during this SEP event with data during another period of quiet solar activity with similar seasons and latitudes, there was no significant difference in the ozone profile.

We estimated the production rate of CO2+ induced by the SEP flux using a Monte-Carlo model. We then considered the process of ozone depletion by OH increased by SEP, and estimated the amount of ozone depletion using a photochemical model (Nakamura et al., this issue). As a result, no ozone depletion was observed during the November 2015 event. On the other hand, the model suggests that OH increase by a factor of 10-100 at around 40 km compared to the quiescent state, and ozone decrease by a factor of 100 during the large flux SEP event in the September 2017 event. The results of the Monte-Carlo model suggest that particles above 5 MeV for protons and 200 keV for electrons effect on the production rate of CO2+ at below 60 km. The reason for this result is that the SEP flux in that energy band is three to four orders of magnitude larger in September 2017 than in November 2015. However, there is concern about cross contamination in the SEP flux data during the SEP event in September 2017, the estimated ozone variation can be assumed as an upper limit.

Since the MAVEN data are only available after 2014, we analyze the data from Mars Express (MEX). The ozone column densities can be obtained from the observation by nadir observation of Spectroscopy for the Investigation of the Characteristics of the Atmospheric of Mars (SPICAM) and the SEP flux is from the background counts of energetic particles observed by the Analyzer of Space Plasma and Energetic Atoms (ASPERA-3). MEX/SPICAM nadir observations are applied to retrieve the ozone profiles since 2004. MEX/ASPERA-3 can record the penetrating energetic particles through the instrument structure as background counts (Ramstad et al., 2018).

We analyze ozone data observed by SPICAM/MEX during several SEP events identified using ASPERA-3/MEX. We also evaluate the effect of SEPs on atmospheric chemistry on Mars using the aforementioned photochemical model and the Mars Climate Database (MCD).

太陽高エネルギー粒子 (Solar Energetic Particles：SEP) は陽子や電子、重イオンから構成される数十 keV から数 GeV の粒子である。これらはコロナ質量放出や太陽フレアと呼ばれる爆発現象に伴って惑星間空間に大量に放出され伝搬し、また、地球の高磁気緯度領域の高度数十 km にまで侵入し中層大気の大気組成変化を引き起こすことが知られて

いる。例えば、2003 年 10 月の大型フレア時には、太陽高エネルギー粒子到来に伴って地球大気中の NO_2 増加と、それに伴ってオゾン層の半減が報告されている (e.g., Seppälä et al., 2004; Rohen et al., 2005)。同じく 2003 年のイベントでは火星探査機 Mars Odyssey の Martian Radiation Environment Experiment(MARIE) が大規模な太陽嵐で機能を停止し (Zeitlin et al., 2010)、加えて 2017 年 9 月に起きた太陽フレアに伴って放出された太陽高エネルギー粒子は火星に到達し、粒子降り込みに伴って火星夜側全球でオーロラのような発光現象が報告されたことからも (Schneider et al., 2020)、太陽高エネルギー粒子の惑星大気深部への侵入・表層への影響が無視できないことが明らかである。2020 年代の国際宇宙探査到来とともに人類の活動領域が月、そして火星へと急速に広がりつつある中で、太陽高エネルギー粒子の大気・表層環境でのふるまいを解明することは、人体への影響やミッションへの影響を評価する上で非常に重要である。また太陽高エネルギー粒子が火星大気、特にオゾンに与える影響の定量的理解は、火星環境で NOx がどのように増大するのかを理解する上でも重要であり、アストロバイオロジーの観点や過去火星の温室効果の観点において示唆を与えうる。

火星におけるオゾン鉛直分布は、2004 年から Mars Express 搭載の SPICAM が精力的に観測を実施してきた。この先行研究の結果によると、冬の南極では高度約 50 km にオゾン層が約 1.5ppm 程度存在することが分かっている。加えて遠日点では、両半球とも低中緯度で高度 30-40 km でオゾン層が観測されており、季節・緯度によって高度や密度が大きく変動する様子が捉えられている (Montmessin et al., 2013, Maattanen et al., 2019)。近年では、TGO (Trace Gas Orbiter) による観測から Ls = 0, 180 ° において両半球で高緯度 (>± 55 °)、高高度 (40-55km) でのオゾン量の増加が報告されている (Patel et al., 2021)。

本研究で、我々は、火星大気中のオゾン密度の高度分布が、太陽高エネルギー粒子イベントに対してどのように応答するのかを同定することを目指す。まず NASA 火星探査衛星 Mars Atmosphere and Volatile EvolutioN(MAVEN) に搭載された Imaging UltraViolet Spectrograph(IUVS) による星掩蔽観測から得られたオゾン数密度の鉛直分布に加え、同衛星搭載 Solar Energetic Particles(SEP) から火星周回軌道上における太陽高エネルギー粒子の電子・イオンのエネルギーフラックスのデータを用いた。IUVS は 2015 年 3 月から、平均で 2〜3ヶ月ごとに 1 度の頻度で 1-2 日間の星掩蔽観測キャンペーンを継続的に行ってきた (Groller et al., 2018)。この星掩蔽観測は南緯 80 度から北緯 75 度までと、経度全範囲を広くカバーしている。SEP は、電子は 20 keV〜1 MeV、イオンは 20 keV 〜6 MeV のエネルギースペクトルを 3〜3 × 10^6 eV/[cm^2 s sr eV] の範囲で観測することができる (Larson et al., 2015)。

これらの観測データから、まず 2014 年 3 月から 2020 年 1 月までに MAVEN/SEP が観測した太陽高エネルギー粒子のエネルギーフラックスを用い、SEP イベント時に IUVS の星掩蔽観測も同時に行われた 1 つのイベントに着目した。このイベントは 2015 年 11 月 3-4 日に起こったものであり、このデータと季節・緯度が似ている太陽活動静穏時のデータとを比較した結果、オゾン高度分布に優位な違いはみられなかった。

次にモンテカルロモデル (Nakamura et al., this issue) を用いて観測された太陽高エネルギー粒子到来に伴う CO_2^+ の生成率を推定し、それに伴い増加した OH がオゾンを破壊するプロセスを考え、光化学モデル (Nakamura et al., this issue) を用いてオゾンの減少量を見積もった。結果として 2015 年 11 月のイベントではオゾンの減少は見られなかった。しかし、比較的規模の大きな 2017 年 9 月の SEP イベントにおいては、静穏時と比較して高度約 40 km において OH が 10~100 倍増え、それに伴ってオゾンが 1/100 に減少する可能性が示唆された。モンテカルロモデルの結果からは、高度 60 km 以下の CO_2^+ の生成率に効くのは陽子では 5MeV 以上、電子では 200 keV 以上であることが示唆されている。2015 年 11 月と比べて 2017 年 9 月ではそのエネルギー帯のフラックスが 3 桁~4 桁大きいことが今回の結果の要因だと考えられる。しかしながら、2017 年 9 月の SEP イベントでは、高エネルギー粒子のエネルギーフラックスにクロスコンタミネーションの懸念があるため、このイベントにおいて見積もったオゾン変化量は上限値と考えられる。

MAVEN のデータは 2014 年以降に限られるため、我々は、2014 年以前について、ESA 火星探査衛星 Mars Express(MEX) のデータ解析にも着手した。具体的には MEX 搭載の Spectroscopy for the Investigation of the Characteristics of the Atmospheric of Mars(SPICAM) による直下観測から得られたオゾンの気柱密度を用いた。また太陽高エネルギー粒子の到来時刻の同定には、同探査機搭載の Analyzer of Space Plasma and Energetic Atoms(ASPERA-3) による、高エネルギー粒子のバックグラウンドカウントのデータを使用した。SPICAM/MEX は 2004 年以降の長期間において断続的に星掩蔽観測により、オゾン、二酸化炭素、気温、エアロゾルを観測している。また、ASPERA-3/MEX は、非常に大きなエネルギーを持つ粒子は装置の壁や内部構造を貫通してバックグラウンドカウントとして記録される (Ramstad et al., 2018)。

我々は ASPERA-3/MEX のデータを用いて同定したいくつかの SEP イベントについて、SPICAM/MEX から得られたオゾンについて解析を行った。また、前述の光化学モデルや Mars Climate Database(MCD) を用いて、火星における太陽高エネルギー粒子の大気化学への影響を捉えることを試みる。

R009-30
Zoom meeting D ：11/2 AM2 (10:45-12:30)
11:15〜11:30

磁場配置と中性大気密度の効果を検証するための火星ディフューズオーロラモデルの開発

#沖山 太心 [1), 関 華奈子 [1)
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Development of Martian diffuse aurora model to investigate effects of the magnetic field orientation and neutral density profile

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The diffuse aurora at Mars (e.g., Schneider et al. 2015) is thought to be caused by solar energetic particles (SEPs) penetrating into the Martian atmosphere along the interplanetary magnetic field lines draped around the planet. The diffuse aurora emission consists of significant CO_2^+ ultraviolet doublet emission and its peaking around 60-70 km altitude. Schneider et al. (2018) showed that the time variation of the auroral emission does not always correlate with the variation of the SEP flux. The emission correlate also with SEP protons in some events. The cause of the time variations of the auroral emission is far from understood. The horizontal induced magnetic field is developed when interplanetary magnetic field is draped around the Mars, and the structure of the induced magnetic field will change the flux of the penetrating SEPs. Therefore, one of the possibilities is that the change in the magnetic field orientation around Mars affects the auroral altitude profile. In addition, the density profile of Martian atmosphere will change depending on the local time (Slipski et al. 2018), so another possible candidate is the change in the Martian atmospheric density. The purpose of this study is to investigate effects of the possible candidates on the vertical emission profile of Martian diffuse aurora based on a Monte Carlo simulation.

We have developed a one-dimensional (1-D) model that calculates the vertical emission profile of CO_2^+ UVD and the CO Cameron bands, which are typical emission lines of the diffuse aurora. Our model is similar to the Monte Carlo model of Bhardwaj et al. (2009), which calculates the energy degradation of electrons below 1000 eV through collisions between CO_2 and electrons. The energy range of our models is expanded up to hundreds of keV with reference to the cross sections for collisional reactions between electrons and neutral atmosphere used in the model of Gerard et al. (2017), which calculates the electron flux to reproduce the emission profile of Martian diffuse aurora. A difference of our model from the previous models is that we trace the trajectories of each electron in the given magnetic field structure including the cyclotron motion of electrons to investigate the effect of the draped magnetic field structure. The results of our model showed that decreasing elevation angle of the magnetic field from the horizontal direction increased the peak altitude of the emission intensity. Difference of the altitude profile of the neutral atmospheric density also affected the peak altitude. The result suggests that the magnetic field orientation in the vicinity of the planet and the neutral atmospheric density altitude profile are the important factors to change the vertical emission profile of the diffuse aurora.

R009-31
Zoom meeting D ：11/2 AM2 (10:45-12:30)
11:30〜11:45

Numerical prediction of changes in atmospheric compositions during SEP events at Mars

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Solar energetic particles (SEPs) are high-energy particles that consist mainly of electrons and protons with energies from a few tens of keV to GeV ejected from the Sun associated with solar flares and corona mass ejections. SEPs that precipitate into planetary atmospheres experience many types of collisions with atmospheric particles during their entry, causing increased ionization, excitation, dissociation, heating and changes in ion and neutral compositions [e.g. Solomon et al., 1981; Leblanc et al., 2002]. The effects of SEPs on atmospheric compositions are of great importance because SEPs could cause destruction of ozone, and production of hydrogen cyanide that is essential in prebiotic synthesis of amino acid [e.g. Solomon et al., 1981; Airapetian et al., 2016].

The effects of SEPs on ozone concentration at polar region of the Earth has been intensively studied for the past decades. For instance, during the enormous solar flare that occurred in late October 2003, NOx and HOx concentrations were enhanced and ozone concentration was depleted by 40% at the polar lower mesosphere [e.g. Jackman et al., 2005]. Increased ionization and dissociation of atmospheric N2 and O2 molecules led to the production of NOx and HOx, which catalytically destroyed ozone at the polar mesosphere.

Recently, the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft has discovered global diffuse aurora on the nightside of Mars during SEP events, indicating that more energy could be deposited in the deeper atmosphere than previously thought due to the interaction of SEPs with the Martian atmosphere [Schneider et al., 2015]. However, the effects of SEPs on the atmospheric chemistry of Mars has not yet been understood by both observations and models.

We have developed a Monte Carlo model and a photochemical model to investigate the effects of SEPs on the atmospheric compositions at Mars. The Monte Carlo model solves transport of protons, hydrogen atoms and secondary electrons in the Martian atmosphere to calculate ionization rate during SEP events. The photochemical model solves 171 chemical reactions including photoionization, ion chemistry, and neutral chemistry with respect to HOx and ozone.

We have performed a simulation of the effects of a large SEP event on atmospheric compositions on Mars. The proton flux observed at Earth during the enormous solar flare of October 2003 [Mewaldt et al., 2005] was used as input to the Monte Carlo model. We found that concentration of water cluster ions increased up to 10^{10} cm^{-3} below 70 km altitudes, which is in good agreement with the previous study [Sheel et al., 2012] that predicted the SEP effects on the ionosphere of Mars. We found that HOx increased by a factor of 10 and ozone decreased by a factor of 10 in the altitude range from 20 km to 60 km. This is the very first estimation of the effects of SEPs on the atmospheric neutral compositions at Mars, indicating that the similar effects on HOx and ozone could be expected on Mars as on Earth, such as increased ionization leads to the formation of water cluster ions and following production of HOx, which destroy ozone.

R009-32
Zoom meeting D ：11/2 AM2 (10:45-12:30)
11:45〜12:00

Water vapor vertical distributions on Mars: Results from three years of TGO/NOMAD science operations

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Nadir and Occultation for Mars Discovery (NOMAD) onboard ExoMars Trace Gas Orbiter (TGO) started science measurements on 21 April, 2018. Here, we present results on the retrievals of water vapor vertical distributions in the Martian atmosphere from three years of TGO/NOMAD science operations.

NOMAD is a spectrometer operating in the spectral ranges between 0.2 and 4.3 um onboard ExoMars TGO. NOMAD has 3 spectral channels: a solar occultation channel (SO - Solar Occultation; 2.3-4.3 um), a second infrared channel capable of nadir, solar occultation, and limb sounding (LNO - Limb Nadir and solar Occultation; 2.3-3.8 um), and an ultraviolet/visible channel (UVIS - Ultraviolet and Visible Spectrometer, 200-650 nm). The infrared channels (SO and LNO) have high spectral resolution (R˜10,000-20,000) provided by an echelle grating used in combination with an Acousto Optic Tunable Filter (AOTF) which selects diffraction orders. The sampling rate for the solar occultation measurement is 1 second, which provides a good vertical sampling step (˜1 km) with higher resolution (˜2 km) from the surface to 200 km. Thanks to the instantaneous change of the observing diffraction orders achieved by the AOTF, the SO channel is able to measure five or six different diffraction orders per second in solar occultation mode. In this study, we analyze the solar occultation measurements at diffraction order 134 (3011-3035 cm-1), order 136 (3056-3080 cm-1), order 168 (3775-3805 cm-1), and order 169 (3798-3828 cm-1) acquired by the SO channel in order to investigate water vapor vertical distributions.

Knowledge of the water vapor vertical profile is important to understand the water cycle and its escape process. Solar occultation measurements by two new spectrometers onboard TGO - NOMAD and Atmospheric Chemistry Suite (ACS) - allows us to daily monitor the water vapor vertical distributions through the whole Martian Year and obtain a good latitudinal coverage for every ˜20 deg of Ls. In 2018, for the first time after 2007, a global dust storm occurred on Mars. It lasted for more than two months (from June to August). Moreover, following the global dust storm, a regional dust storm occurred in January 2019. The NOMAD and ACS observations therefore fully cover the majority of the global and regional dust storms and offer a unique opportunity to study the trace gases distributions during the dust storms. We analyzed those datasets and found a significant increase of water vapor abundances in the middle atmosphere (40-100 km) during the global dust storm from June to mid-September 2018 and the regional dust storm in January 2019. In particular, water vapor reaches very high altitude, at least 100 km, during the global dust storm (Aoki et al., 2019, Journal of Geophysical Research, Volume124, Issue12, Pages 3482-3497, doi:10.1029/2019JE006109). A GCM simulation explained that dust storm related increases of atmospheric temperatures suppress the hygropause, hence reducing ice cloud formation and so allowing water vapor to extend into the middle atmosphere (Neary et al., 2020, Geophysical Research Letters, accepted, Volume47, Issue7, e2019GL084354, doi: 10.1029/2019GL084354). This study presents the results with the extended dataset, which covers a full Mars year. The extended dataset newly includes aphelion season that involves interesting phenomena such as sublimation of water vapor from the northern polar cap and formation of the equatorial cloud belt, which are known as key periods to understand the large north-south hemispheric asymmetries of Mars water vapor. Yet, only a few papers report the water vapor vertical distributions in the aphelion season. The extended dataset also includes the southern summer season (dusty season) in MY 35, which will allow us to compare the water vapor distributions in the global dust storm year with those in the non-global dust storm year. In the presentation, we will discuss the water vapor vertical profiles as well as the aerosols vertical distributions retrieved from the three-year measurements of the TGO/NOMAD.

R009-33
Zoom meeting D ：11/2 AM2 (10:45-12:30)
12:00〜12:15

リム観測による火星大気鉛直構造の解明を目指す新大気リトリーバル技術の検証

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Validation of a new atmospheric retrieval technique for the vertical profiles of Martian atmosphere by limb observations

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In the Martian atmosphere, the vertical distribution of trace gases and aerosols can be observed by orbiters using various geometries, amongst them solar occultation and limb observations. Their spatial-time variability is one of the basic information for Martian atmospheric studies. For example, recent studies have suggested that water vapor is transported from the lower atmosphere to the upper atmosphere, and then can be lost to space through UV photodissociation. Its vertical structure and spatial-temporal variations may be critical for understanding the dynamics and evolution of Martian atmosphere. Aerosols are also important because they can affect the trace gas distribution and their vertical transportation through radiative transfer processes, accumulation, dissipation, and catalytic functions.

The vertical structure has been mainly investigated by solar occultation using the NOMAD instrument on board EMTGO (e.g., Vandaele et al., 2019; Aoki et al., 2019). NOMAD has an excellent S/N and a fine altitude resolution. However, it is not suitable for the investigation of Local Time (LT) variation and horizontal distribution, because the observational geometry is limited on the line-of-slight of the Sun at dusk and dawn. Limb observations, which observe solar scattered light by aerosols, can provide a wide coverage of LT and horizontal distribution. For the retrievals of vertical structures from limb data, comprehensive, accurate, and fast calculations of scattering and absorption features are needed. Because these algorithms imply huge computation cost, few studies by limb observations are found in the literature (e.g., Smith et al., 2013; Clancy et al., 2019).

We use the JACOSPAR package, a fast multiple-scattering retrieval tool originally developed for Earth observations (Iwabuchi et al., 2006), to retrieve Martian limb observations observed by OMEGA on board Mars Express. JACOSPAR is a fast calculation algorithm that (1) computes the multiple scattering components using the backward-propagating Monte Carlo method and (2) uses the dependent sampling approach to simultaneously simulate a radiance spectrum along wavenumbers. JACOSPAR considers a spherical-shell atmosphere to compute the atmospheric refraction, while the code can simultaneously derive the vertical profile of dust and atmospheric components without any specific assumption.

In this work, we compare the results with the conventional retrieval code DISORT, which accounts for multiple scattering and reflection from the lower boundary.

The JACOSPAR calculated radiances are in good agreement with the DISORT results within typically a ˜3% range. We are now evaluating the gas absorptions. As an application, thanks to a non-sun-synchronous orbit of MEx, we will obtain the LT variations of the aerosols and the trace gases in order to investigate the vertical transport mechanisms. In this presentation, we will report on this analysis as well.

This study aims to contribute to the Martian atmospheric limb observations planned by JAXA Martian Moons eXploration (MMX) mission in the mid 2020s. MMX will acquire a unique set of atmospheric spectroscopic data at Mars mid-low latitude regions from nadir and limb geometries with wide field coverages from an equatorial orbit near the Phobos orbit. Our high accuracy and fast retrieval tool will contribute to the MMX atmospheric observation, for the retrieval of the horizontal and vertical profiles of dust and water vapor over a wide range at hourly time scale.

火星大気のシリケイトや水氷等からなるエアロゾルや水蒸気を含む微量成分の高度分布は、周回探査機による太陽掩蔽観測およびリム観測によって観測されうる。これらの地表面近傍から高高度に至る鉛直構造の時空間双方での変動追跡は、火星における地表から上層大気をつなぐ物質の鉛直輸送の解明に欠かせない。特に水は、表層から供給され火星大気全域を循環するだけでなく、上層大気まで輸送された場合には紫外線による光解離を経て宇宙空間へと流出しうることが示唆されてきた。このため、その鉛直構造とその時空間変動は、火星とその大気の現在の変動だけでなく、過去の進化の解明にも重要な情報を提供する可能性がある。またエアロゾルは、ダストストームなどの火星大気の変動要因となるだけでなく、微量大気成分の蓄積・放出や触媒機能を介してこれらの鉛直輸送の質・量にも影響を与えうるため、その鉛直構造とその時空間変動は火星大気の基本情報として重要である。

現在、ExoMars Trace Gas Orbiter による太陽掩蔽観測によって、火星大気の鉛直構造探査が重点的に行われつつある。太陽掩蔽観測は、強い太陽直達光の吸収を用いるため S/N および高度分解能に優れる。しかし、観測ジオメトリが朝・夕に限られ、また太陽の line-of-slight すなわち「1 次元」の観測に限られるため地方時の変化や、現象の水平規模を理解することが難しい。これらの追跡には、太陽散乱光を用いるリム観測の活用が期待されうる。この手法は

エアロゾルによる太陽散乱光を利用した大気を水平によぎる長基線観測であり、広い LT の観測が可能で、また観測装置の視野が許す限り水平方向の情報も取得できる。しかし、太陽からの入射光と地表からの反射光のエアロゾルによる散乱光を観測することになる。リム観測は、約 100 km に及ぶ長光路透過光を観測し、多重散乱を含め広い高度範囲に跨る影響を含む。エアロゾルによる散乱と大気吸収を包括的に高精度・迅速に解くことが、そこから鉛直構造の情報を引き出す要件となる。この制約から、多数の欧米火星探査機群の Limb 観測データはこれまでさほど有効に活用されていない。

我々は、この課題を解決すべく、日欧共同作業で地球静止軌道からの Nadir 観測用に開発された高速リトリーバルツール「JACOSPAR」を Limb 観測用に改造し、欧米火星探査機群の Limb 観測データ群から火星のエアロゾルおよび大気組成の鉛直構造を導出すべく、研究を進めてきた。本ツールは逆モンテカルロ法の適用等による高速性に特長があり、高散乱大気の分光情報からエアロゾル・微量物質量を一括して導出しうるものである。本コードは、特定の仮定に基づくことなく、ダストと微量大気成分の鉛直成分を同時に導出できる機能を有する。低高度の情報や、高度数十 km までダストが覆う全球ストーム中での観測では多重散乱光からの情報抽出を要するため、まさにこの能力が生きることになる。

2021 年夏の段階では、特定ガス、特定エアロゾルのどれか 1 つを、フォワード計算および多重散乱を含まずにリトリーバルし、エアロゾルの低～高高度循環とその LT 依存性の様相が見える段階に到達しつつある。現在、残るバグを解消・確定しつつあるところで、複数ガス種およびダスト・エアロゾルを一括し、多重散乱を含めた高度方向分離も含めて一気に解く、という JACSPAR の本来機能を現実のものとすべく作業中である。散乱のきつい表面近傍を含む手が届きにくかった幅広い高度領域を幅広いローカルタイム・水平方向で導出できることを期待している。

このコードの検証は、欧 Mars Express（MEX）の搭載観測機器 OMEGA による Limb 観測データを活用している。精度はある程度保証されているがより低速な従来方式のリトリーバルツール（DISORT 等）で導出された結果との比較で進めている。この確立後、MEx OMEGA の観測が存在する 2004-2010 の可視・近赤外データを活用した大気下層の鉛直輸送の解明に着手する。MEx は非太陽同期軌道で、多様な LT の観測がなされている。ダスト・水氷などエアロゾルの量・粒径および H2O・CO など微小成分量の広範囲の鉛直・水平分布を一括して精度良く得ることで、これらの鉛直輸送メカニズム等の解明につなげていく。本講演では、この状況を併せて報告の予定である。

本開発は、日本の火星圏探査における大きなステップとなる JAXA Martian Moons eXploration (MMX) 計画による「火星大気リム観測」につなげていく予定である。このデータパイプラインに本開発ツールを仕込み、大気鉛直構造情報を導出するための基盤インフラとしての発展を目指している。MMX は、リムを含む火星中低緯度域の大気分光スナップショットデータを面として取得することができる。このため、リム域を含む大気の水平・鉛直分布を同時データとして一括導出しうるポテンシャルがある。我々が開発中の高精度・高速リトリーバルツールは、この実現の鍵を握るものとなる。

R009-34
Zoom meeting D ：11/2 PM1 (13:45-15:30)
13:45〜14:00

#風間 暁 [1], 笠羽 康正 [2], 中川 広務 [3], 青木 翔平 [4], 黒田 剛史 [2], 小暮 李成 [5], 鈴木 湧平 [2], 村田 功 [6], 吉田 奈央 [7]
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Remote sensing of surface pressure on Mars by CO2 2 μ m absorption band observed by Mars Express/OMEGA

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In the global enhancement of Martian explorations, Japan is developing the Martian Moons eXploration (MMX) mission toward the launch in 2024. MMX will execute the sample return from Phobos, and also do the continuous and global observation of the Martian atmosphere in the low-mid latitudes from the equatorial field of views. Mars has a dilute surface pressure of about 6 hPa, and its solar radiation varies more than 30% per year by a large orbital eccentricity. The large variations of the Martian atmosphere are caused by the condensation and sublimation of CO2 and H2O and the absorption of sunlight by dust. One of the goals of MMX for the Martian atmosphere is understanding the global and mesoscale dynamics and the transfer processes of dust and water vapor. The surface pressure is one of the important key parameters.

In Earth, the distribution of surface pressure can be obtained by many observation points on the ground. In Mars, it is difficult because there are only a few numbers of landers at specific locations.

The estimation of the mesoscale surface pressure distribution was tried by Forget et al. (2007) and Spiga et al. (2007) from orbiter data. They derived the surface pressure using near-infrared CO2 absorption at 2 um in the initial observation data (2004-2005) of OMEGA onboard Mars Express. Since they showed the results only from the ideal data set (e.g. dust-free, etc.), 0.007% of the total data (29 of ˜4000 nadir observations) were utilized. In those data sets, the pressure distribution over 95 x 150 km (2.5 deg in longitude, 4 deg in latitude) could be obtained and succeeded to show the pressure gradients deviating from the geostrophic balance in some regions.

We have tried to apply this method to the planned MMX observations. In this method, surface pressure is estimated using the column density of CO2 derived from the spectral absorption in 2 m. The CO2 mixing ratio in the Martian atmosphere (well known as 0.9532 in early summer obtained by the Viking Lander mass spectrometer) can be regarded as uniform in the lower atmosphere in altitude and can be assumed that the surface pressure is in proportion to the CO2 gas column density when the atmosphere is hydrostatic. As in the previous study, now we are developing the code to derive the surface pressure from the OMEGA SWIR (near-infrared) channel 1.8-2.2 m (25 points, wavelength resolution ˜20 nm). For the conversion from absorption spectra to surface pressure, we need to make about 450,000 spectra by our forward model with a group of physical parameters affecting the absorption spectra (e.g., atmospheric pressure, temperature, surface albedo, dust opacity, solar zenith angle, solar viewing angle, and phase azimuth angle). Using this table, the surface pressure is estimated by selecting the model spectrum closest to the observed one. In July 2021, we are in the process to establish the forward model and to make this spectral table.

In this presentation, we will show the status to apply the method to the entire period (2004-2010) of available OMEGA near-infrared observation data and report the trial of its application to the Martian mesoscale phenomena. We will also discuss the issues to be solved for the application to the MMX data which can cover more wide area and have the potential to investigate the global atmospheric phenomena.

火星探査活動が世界的に活発化するなか、日本では 2024 年の打ち上げを目指した火星衛星サンプルリターン計画 (MMX : Martian Moons eXploration) が開発途上にある。MMX では、フォボスタッチダウンによるサンプルリターンと共に、フォボス近傍の周回軌道上から火星中低緯度大気の広域連続観測が計画されている。火星は表面気圧が 6hPa 程度と希薄で、軌道離心率が大きく太陽輻射量が年間で 30%以上変動する。CO2 と H2O の凝結・昇華に伴う相変化や浮遊ダストによる太陽光の吸収により、火星大気は大きく変動する。MMX による火星大気観測の目標の 1 つは、火星大気中のダスト・水蒸気のグローバル・メソスケールの輸送過程の把握であり、その重要なキーパラメータとしてその表面気圧分布がある。地球では、表面気圧分布は地上に網羅された多数の観測点で求められている。これに対し、火星の表面気圧は特定箇所に降りた限られた着陸機群しか観測点が無い。

メソスケールの地表面気圧分布を周回探査機による観測から取り組んだ事例として、Forget et al. (2007) および Spiga et al. (2007) がある。これらは、Mars Express 探査機搭載 OMEGA 初期観測（2004-2005）時の近赤外 CO2 吸収分光撮像データから、火星表面気圧を導出する手法をとっている。ダストフリー等の理想的な状態でのデータのみを対象としたため、気圧導出は全データの 0.007 %程度 (約 4000 回の nadir 観測中 29 回) に留まるが、これにより 95 × 150 k m（経度幅 2.5 °、緯度幅 4 ° ）の表面圧力分布を求めることに成功し、この地域の平衡状態から逸脱した圧力勾配などが観測可能であることを示した。

我々は、この手法を MMX 観測に適用すべく検討を行なっている。Forget および Spiga の手法では、スペクトル吸収量から CO2 気柱量を導出し、そこから高度補正等を加えて地表面気圧を推定する。火星大気の CO2 混合比（Viking Lander 質量分析計による 0.9532(初夏の値) がよく知られる）は、下層大気中では高度一様とみなせる。このため、大気が静水圧であるとみなせる際には、表面気圧は CO2 気柱量に比例すると仮定できる。この先行研究を再現すべく、OMEGA SWIR(近赤外) チャネル 1.8-2.2 μｍ（25 点、波長分解能 ～20 nm）の 2 μｍ CO2 吸収帯を用いて表面気圧を導出するプログラムを開発中である。吸収スペクトルから表面気圧への変換のため、観測スペクトルに影響しうる物理パラメータ群（気圧、温度、表面アルベド、ダストオパシティ、太陽天頂角、太陽視野角、位相方位角）をフリーパラメーターとして、フォワードモデルによる推定スペクトルを 45 万個程用意する。観測スペクトルに最も近いものをベストフィット法にて選択することで、表面気圧値を決定する。2021 年 7 月現在、このテーブル作成とその検証に向けた作業を進めているところである。

本講演では、OMEGA 近赤外線観測データがある全期間（2004-2010）からの表面気圧導出の試行状況、および火星メソスケール気圧現象への適用可能性について現況を報告する。また、MMX で可能となるより広域のグローバル気圧現象への適用時に予想される課題についても述べる。

R009-35
Zoom meeting D ：11/2 PM1 (13:45-15:30)
14:00～14:15

電波掩蔽データ解析による火星大気の微細構造の抽出と解析手法の改良

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Martian atmospheric structures studied with radio occultation and Improvement of analysis method

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Radio occultation is a method to derive the vertical structure of an atmosphere from the frequency time series of radio waves transmitted from the spacecraft and recorded at the ground station after passing through the planet's atmosphere. The method is effective especially for studies of fine structures in planetary atmospheres. The geometrical optics method has been used to obtain the ray path at each moment from the instantaneous frequency and then determine the atmospheric structure sequentially. In contrast, Full Spectrum Inversion (FSI) proposed by Jensen et al. (2003), one of the radio holographic methods, analyzes the whole time series at once. This method has been applied to the Venusian atmosphere by Imamura et al (2018) to reveal fine vertical structures in the atmosphere that could not be captured by previous analysis.

Radio occultation observation has been utilized to study the temperature structure of Martian atmosphere. Various meso-scale structures such as atmospheric gravity waves, convective boundary layer, and thin neutral layers that occur at night have been detected. Such fluid dynamical processes are thought to play important roles in the transport of energy and momentum. However, geometrical optics method has an altitude resolution of about 1 km, which is not sufficient to fully resolve the vertical structures of these phenomena.

We report the following two results. (1) we analyzed the Mars Global Surveyor (MGS) radio occultation data by both the geometrical optics method and FSI, and compared the results. MGS conducted many radio occultations during its mission period from 1997 to 2006, and here we report results from a portion of the data. (2) We have also improved the details of the analysis method. Specifically, we have improved the FSI analysis program that we currently use. In the current program includes several tunable parameters that are determined manually for each data, and thus it takes a long time to analyze a single data. In addition, artificial temperature oscillations appear in the results for specific seasons, latitudes, and local times. The influence of the ionosphere is sometimes seen in the solution of the neutral atmosphere. We are trying to solve these problems.

電波掩蔽観測は、探査機から送信され惑星大気を通過したのち地上局で記録された信号から大気の鉛直構造を導出するものであり、惑星大気中の微細な構造を研究するための効果的な手法の一つである。大気の鉛直構造を導出する手法として、従来は各瞬間の電波経路を算出してから大気構造を求める幾何光学法が用いられてきた。これに対し、近年考案された電波ホログラフィ法の一種である Full Spectrum Inversion（FSI）（Jensen et al.2003）が Imamura et al.（2018）によって金星大気に応用され、幾何光学法と比べて大幅に鉛直分解能が向上することにより、従来の解析では捉えられなかった大気中の細かい構造が見えることが示された。

これまで火星周回機を用いた電波掩蔽観測により、火星大気の温度構造が求められ、そこから大気重力波、対流境界層、夜間に発生する氷の雲による薄い安定層等の様々な微細構造が存在することが明らかにされてきた。そのような流体力学過程はエネルギーと運動量の輸送に重要な役割を果たしていると考えられている。しかし、従来の解析では高度分解能が 1km 程度であり、 これらの現象を十分に分解し解析することができない。

そこで本研究では、以下の二つのことを行った。

(1) 火星探査機マーズ・グローバル・サーベイヤーから得られた電波掩蔽データを従来の解析手法である幾何光学法と新手法である FSI で解析し、結果を比較した。ただし、マーズ・グローバル・サーベイヤーは 1997 年から 2006 年までのミッション期間中に多数回の電波掩蔽を実施したが、ここではその一部のデータについての現段階における結果を報告する。

(2) 解析手法の細部の改良も行った。具体的には現在使用している FSI 解析プログラムの改良を行った。現段階における解析では、解析途中の段階でデータごとに手動で経験的に決めるパラメータがいくつか存在し、それらの影響で一つのデータを解析するまでの時間がかかり過ぎてしまうという問題があった。また、これまでに解析を行ったデータの結果のうち, 特定の季節・緯度・ローカルタイムのデータの結果において周期的な温度振動が検出され、中性大気だけでなく電離層の影響が現れてしまうようなものも含まれた。本研究ではこれらの問題を解決するために現状の FSI 解析プログラムの修正も試みた。

R009-36
Zoom meeting D ：11/2 PM1 (13:45-15:30)
14:15〜14:30

Retrieval of HCl abundance at the cloud top of Venus from IRTF/iSHELL spectra

#Takao M Sato[1],Hideo Sagawa[2]
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The atmosphere of Venus can be vertically divided into three regions with different chemical conditions. Thermodynamic equilibrium reactions are dominant in the lower atmosphere up to 60 km under high temperature and pressure conditions. The middle atmosphere between 60 and 110 km is controlled by photochemistry driven by solar UV radiation. In the upper atmosphere above 110 km, dissociation, ionization, and ionospheric reactions are important processes.

HCl is the primary chlorine reservoir in the Venus' atmosphere below 110 km. Highly reactive chlorine species (ClO_x), which is produced by solar UV photolysis of HCl, has been proposed to play an important role in catalysis of CO and O recombination to CO_2, thereby stabilizing the CO_2 atmosphere. Chlorine chemistry is also linked to the source and sink of SO_2, and its understanding is necessary to explain the observed vertical distribution of SO_2.

Interestingly, there is a large inconsistency between the HCl abundances measured by spacecraft and ground-based telescopes. The SOIR instrument onboard Venus Express measured its abundance as less than ˜50 ppb at the cloud top (˜70 km) increasing with altitude, reaching to 1 ppm in the upper atmosphere (˜110 km) [Mahieux et al., 2015]. Such a vertical trend conflicts with the results obtained by sub-mm ground-based observations which inferred a vertically constant profile (up to ˜80 km) [Sandor and Clancy, 2012]. Near-infrared ground-based observations also showed the HCl abundance at the cloud top as ˜500 ppb [Iwagami et al., 2008; Krasnopolsky, 2010], which are nearly one order of magnitude larger than the SOIR results. The reason for this inconsistency has not been understood yet.

In order to revise the HCl abundance at the cloud top, we carried out a high-resolution spectroscopy of Venus' dayside at wavelengths of 3.580-3.934 μ m with IRTF/iSHELL on August 5-7, 2018 and August 18-20, 2020 (UT). Venus was near its greatest eastern and western elongations, respectively, in the observation periods. Taking the full advantages of iSHELL's high spectral resolution of R ˜75,000 with a high relative Doppler-shift of Venus seen from the Earth, iSHELL resolved individual HCl lines with sufficient separation from terrestrial lines. We analyzed three cross-dispersed echelle orders (orders 141, 142, and 144) which contain retrievable lines of $H^{35}Cl$, $H^{37}Cl$, and $^{16}O^{12}C^{18}O$. With using radiative transfer modeling, $H^{35}Cl$ and $H^{37}Cl$ abundances were derived after cloud top altitude was retrieved from several $^{16}O^{12}C^{18}O$ lines. Our results showed that HCl abundance at the cloud top is larger than 100 ppb and does not vary with the observation period (i.e., no difference between the morning and evening hemispheres). Through the data analysis, we found that differences between the observation and best-fit model are usually larger around absorption lines, which probably results from subpixel level inaccuracy of wavelength calibration. To reduce impact of this mismatch on the retrieval accuracy, we adjusted the HITRAN spectral line transition frequencies to match the observed absorption lines.

In this presentation, we show latitudinal distribution of HCl abundance and its isotopic ($H^{35}Cl/H^{37}Cl$) ratio at the cloud top, retrieved from the iSHELL spectra and compare them with the previous studies.

R009-37
Zoom meeting D ：11/2 PM1 (13:45-15:30)
14:30〜14:45

金星探査機「あかつき」の水平風速を用いた客観解析データ作成の試み

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Attempts to produce Venus first analysis using horizontal wind obtained from Akatsuki observations

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Observations of the Venus Orbiter “Akatsuki” provide us with horizontal distributions of the horizontal wind derived from cloud tracking of the UVI camera and of temperature observed by the LIR camera. However, these observations are very limited with respect to the altitude, local time (day or night side), and frequency. It is difficult to elucidate the general circulation including various temporal and spatial scales only from observations. We have developed the Venus atmospheric data assimilation system ”ALEDAS-V” (Sugimoto et al., 2017) based on the Venus atmospheric general circulation model ”AFES-Venus” (Sugimoto et al., 2014a). In this study, we aim to produce a Venus objective analysis that has high temporal and spatial resolutions by assimilating the Akatsuki observations into a general circulation model using “ALEDAS-V”. At the top of the cloud layer of Venus, there are planetary-scale atmospheric waves that are excited by solar heating and move with the sun, called the thermal tides. In this presentation, we focused on these thermal tides and verified the created analysis data.

We assimilated the horizontal wind obtained from the UVI (365 nm) of Akatsuki using cloud tracking (Ikegawa and Horinouchi, 2016) to the altitude of 70 km of ALEDAS-V for the period from September to December 2018. As a result, for zonal wind, the assimilated result shows that the structure of the zonal wave number 2 near the equator shifted to the morning side for about 2 hours compared to unassimilated result. This structure is close to the Akatsuki observations, namely, the phase shift of the thermal tides in AFES-Venus could be improved. It is also consistent with previous studies (Sugimoto et al., 2019). For the future work, we plan to release these assimilation results as the objective analysis data of Venus for the first time in the world.

金星探査機「あかつき」の観測により、紫外カメラの雲追跡による水平風速、中間赤外カメラによる温度の水平分布のデータ等が蓄積されつつある。しかし、あかつきから得られる観測の多くは、観測高度、観測面（昼側あるいは夜側に偏る）、観測頻度に制約があり、観測データのみから時間・空間的に様々なスケールの全球的な循環場を知ることは難しい。本研究の目的は、我々がこれまでに開発してきた、金星大気大循環モデル「AFES-Venus」（Sugimoto et al., 2014a）を基にした金星大気データ同化システム「ALEDAS-V」（Sugimoto et al., 2017）を用いて、あかつき観測をデータ同化の手法によってモデルに取り込むことで、高時間・空間分解能の金星の客観解析データを作成することである。本講演では、金星の雲層上部における太陽加熱で励起され、太陽とともに移動する惑星規模の大気波動である熱潮汐波に着目して、作成した解析データの検証を行った。

あかつき紫外カメラ (365nm) の雲追跡（Ikegawa and Horinouchi, 2016）により得られる水平風速を 2018 年 9 月から 12 月の期間について雲層上部である高度 70km に同化した結果、同化した結果は、同化なし結果に比べて、東西風速の赤道付近の東西波数 2 の構造が午前側に 2 時間ほどシフトした。この構造はあかつき観測結果と近く、AFES-Venus が持っている熱潮汐波の位相のずれの全球的な改善に成功した。また先行研究 (Sugimoto et al., 2019) とも整合的である。今後は、得られた同化結果を世界で初めての金星の客観解析データとして、公開していく予定である。

R009-38
Zoom meeting D ：11/2 PM1 (13:45-15:30)
14:45〜15:00

Observation and analysis of optical emission by lightning in Jupiter and Venus with high-speed photometer

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The investigating the lightning can be used to understand the atmospheric dynamics on the other planets. Sometimes the lighting is generated by the moist convection in the planetary atmosphere. Jovian lightning has been detected by some spacecraft by night-side optical imaging and radio wave observation. Previous studies (Gierasch et al., 2000; Ingersoll et al., 2000) suggested that zonal jet is driven by the many small-scale eddies which are received their energy from the moist convection. Moist convection is expected to be correlated with the Jovian lightning distribution, like as on Earth. The monitoring of lightning is useful to investigate the local and general circulation, energy transport, and composition of Jupiter and other planets. In the case of Venusian lightning, its existence is controversial for 40 years. The possible generation mechanisms are convection, volcanic, or aeolian triboelectric activity. In the previous study, there are radio wave observations and optical observations with CCD. It is difficult to distinguish between the lightning signal and the electrical noise or cosmic ray, the spacecraft and ground-based observation area are limited, and the CCD's sensitivity is not enough to observe the lightning on disk of Venus. If we can reveal the existence of Venusian lightning, it could be used to promote an understanding of the Venusian atmospheric dynamics.

We have developed the Planetary lightning Detector (PLD) to observe the optical planetary lightning flashes. We use the PLD observed data to understanding the relationship between lightning and atmospheric dynamics by comparing it with other observation data. The PLD is mounted on the 1.6-m Pirka telescope. Using this ground-based telescope, we can obtain an observation period of at least one hour per day for several months, longer than the previous studies. The PLD is the high-speed and high-sensitive photon-counting sensor by using the photomultiplier tube to obtain the light curve of lightning optical flashes. We can obtain it with a sampling rate of over 20 s^{-1} to distinguish the other flashes and decrease the contamination of sky and dayside light variation and improve the Signal-to-Noise ratio. The observed data be used to obtain the distribution of lightning and its frequency. The PLD equips narrowband filters of 777 nm (FWHM = 1nm) and 656 nm (FWHM = 1nm) for Jovian and Venusian lightning. These wavelengths are the strongest emission light of the experienced lightning spectrum (Borucki et al., 1996). We can select the FOV of PLD from some pinholes and a slit to observe appropriate Jovian dayside and Venusian night-side disk. PLD observes the background variation simultaneously by using a second photomultiplier tube with a broadband filter to estimate the variation of background (e.g., sky, dayside light) after finishing our improvement work. We have observed Venus and Jupiter since 2020 while improving. We analyze the data with denoising to remove the shot noise and CR with moving average or wavelet denoising. In our Venus observation, we obtain a few hour observation period. We could find several possible lightning events having large count values above the background level.The estimated peak energy of light-curve is about from 10^6 to 10^8 J. However, we have not yet been able to estimate the frequency of occurrence due to insufficient analytical processing such as noise removal.The estimated event rate is about 10^{-11} [$s^{-1}km^{-2}$], which is larger than result of previous study 2.7x10^{-12} [$s^{-1}km^{-2}$] (Hansell et al., 1995). The LAC onboard AKATSUKI Venus Climate orbiter should record the lightning more frequently if the estimated results are correct. Although, our observation duration is not enough to compare with previous study. It is necessary to increase the observation time up to 3 hr in total.

In this time, we will introduce the developed lightning observation instrument PLD, the analysis method, and present our observation results.

R009-39
Zoom meeting D ：11/2 PM1 (13:45-15:30)
15:00〜15:15

Estimation of the drift rate and intensity of Neptune’s storm in 2018 and 2020

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A storm more than 4,000 km in diameter occasionally occurs in Neptune. In a previous study, Voyager 2 observed Neptune on May 24, 1989, and discovered a storm of 13,000 km in diameter called Great Dark Spot (GDS). GDS was located in the southern hemisphere like the Great Red Spot of Jupiter. But GDS became extinct when the Hubble Space Telescope observed it in 1994 (Hammel et al., 1995). It is unknown whether it is a sudden thing or storms such as GDS always occur in Neptune. In addition, a huge storm of 9,000 km was observed on July 2 and June 26, 2017, by the Keck observatory (Edward et al., 2019). It’s considered that Neptune storms occur at a mid-latitude in the north and south that an ascending air occurs. However, this huge storm occurred near the equator. Neptune’s rotation axis is 29.6 degrees, and the storm possibly occurred near the equator because of seasonal change. Neptune is observed by large telescopes such as the Keck Observatory and the Hubble Space Telescope, but it isn’t easy to always use those telescopes for Neptune observation. Therefore Neptune is not observed for the long term on a short time scale. We developed the technique to estimate the drift rate and intensity of storms by observing Neptune’s whole spectrum in this study. When seeing is bad, it’s possible to observe and acquire Neptune’s observation data for the long term on a short time scale. The purpose is to deepen the understanding of Neptune’s atmosphere convection structure by chasing the detailed change of storms. In this study, we observed Neptune at wavelengths of 890, 855 nm using a 1.6 m Pirka telescope that Hokkaido University owns. The observation time is from October 22, 2018, to November 26, 2018, and from September 3, 2020, to September 8, 2020. Storms look brighter at 890 nm because the altitude of storms is higher than that of other areas. In addition, the apparent size of storms from the observation point changes by the rotation of Neptune, so an 890 nm flux changes by the rotation. We took the ratio of an 890 nm flux and an 855 nm flux to correct the atmosphere’s effect on the earth and calculated the theoretical values of the relative intensity by the rotation. We assumed the storm’s diameter is 4,500 km and fit the observed values with the theoretical values in the method of least squares to estimate the drift rate and the 890 nm albedo inside storms. The theoretical values change with the storm’s latitude. Therefore, we calculated the storm’s latitude from the HST image and used it as a fixed value for fitting. We estimated that the drift rate and the 890 nm albedo are 24.7 degrees/ day and 0.219 in 2018, respectively. In 2018, Simon et al. (2019) discovered a new northern Great Dark Spot (NDS-2018) located at 23 degrees N. NDS2018 drifted westward at 2.46 degrees/hr in November 2018. However, NDS-2018 could not be seen because it was located on the night side during our observation, and it is considered that we observed a different storm. In 2020, we estimated that the drift rate and the 890 nm albedo are 23.5 degrees/ day and 0.136, respectively. We will continue Neptune’s observation and compare with other researchers and amateur observations, and have a discussion in the future.

R009-40
Zoom meeting D ：11/2 PM2 (15:45-18:15)
15:45～16:00

全球非静力学金星大気モデルの開発：簡易金星計算

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Development of a non-hydrostatic global model of the Venus atmosphere: A simplified Venus simulation

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Venus is fully covered by thick clouds of sulfuric acid, and its atmospheric circulation and inherent phenomena are not well understood. However, recent observations by the Venus Climate Orbiter/Akatsuki have revealed a variety of atmospheric phenomena from the planetary-scale bow-shaped structure (Fukuhara et al., 2017) and streak-structure (Kashimura et al., 2019) to a front-like structure to small-scale vortices and waves of several hundred kilometers (Limaye et al., 2018). There have also been active attempts to reproduce these phenomena using Venusian atmospheric general circulation models and to understand the mechanisms involved. In particular, AFES-Venus (Sugimoto et al., 2014), which was developed based on AFES (Ohfuchi et al., 2004; Enomoto et al., 2008), the atmospheric general circulation model highly optimized for the Earth Simulator, has realized high-resolution simulations of the Venus atmosphere, and the planetary-scale streak-structure, thermal tides, gravity waves, meridional circulations, and other structures have been analyzed (e.g., Kashimura et al., 2019; Takagi et al., 2018; Sugimoto et al., 2021; Takagi et al., in prep.). However, AFES is a hydrostatic model, which is not suitable for phenomena whose horizontal scales are of less than several tens of kilometers and cannot explicitly express convections in the cloud layer. The convections in the cloud layer are not only interesting in themselves but are also very important in the Venusian atmosphere because the neutral or low-stability layer resulting from convections is closely related to the formation of the planetary-scale bow-shaped structure and the streak structure. Though non-hydrostatic regional models have been used to study convective activities in the cloud layer and the resulting gravity waves (e.g., Baker et al., 1998; Imamura et al., 2014; Yamamoto 2014, Lefevre et al., 2017), due to the limitation of the domain size, effects of the convective activities on large-scale phenomena have not been investigated.

Then, we have started developing a non-hydrostatic Venusian atmospheric general circulation model to realize a global simulation of the Venusian atmosphere that explicitly represents convective activities in the cloud layer. We utilize SCALE-GM (http://r-ccs-climate.riken.jp/scale/) for the dynamical core, which determines the coordinate system and calculates atmospheric motions. As a first step in the development, the various planetary and atmospheric constants are changed to Venusian values, and the solar heating and Newtonian cooling functions used in AFES-Venus (Tomasko et al., 1980; Crisp et al., 1986; Sugimoto et al., 2014) are imported to SCALE-GM. We then tried a simplified Venus simulation similar to AFES-Venus in various resolutions to explore the necessary numerical properties such as time-step intervals and strength of the numerical diffusion and the sponge layer. The planetary-scale streak-structure are represented in the same way as in AFES-Venus, in case of the resolution of a horizontal grid spacing of dx ~52 km and 120 layers (dz = 1 km) in vertical with a second-order Laplacian for the horizontal diffusion whose e-folding time for the minimum scale is 100 s. However, in SCALE-GM, a strong sponge layer that dumps not only the eddies but also the mean flow is necessary for computational stability. Therefore, the superrotation strength and the angular momentum budget of the atmosphere are influenced by the artificial sponge layer, and we need to seek better ways to keep computational stability. We are attempting to calculate in higher horizontal resolution, and we will also present these results.

金星は全球が濃硫酸の分厚い雲で覆われており、その大気の循環構造や内在する諸現象の全貌は明らかになっていない。しかし近年、金星探査機「あかつき」の観測によって、惑星規模の弓状構造 (Fukuhara et al., 2017) や筋状構造 (Kashimura et al., 2019)、前線のような構造、数百 km 程度の小規模な渦や波 (Limaye et al., 2018) などといった様々な大気現象が発見されている。また、これらの現象を大気大循環モデルで再現し、そのメカニズムに迫る試みも活発に行われている。なかでも、地球シミュレータに最適化された大気大循環モデル「AFES」(Ohfuchi et al., 2004; Enomoto et al., 2008) をもとに開発された AFES-Venus (Sugimoto et al., 2014) によって、高解像度のシミュレーションが実現され、惑星規模の筋状構造や熱潮汐波、重力波、子午面循環などの構造が解析されてきた (e.g., Kashimura et al., 2019;

Takagi et al., 2018; Sugimoto et al., 2021; Takagi et al., in prep.)。しかし、AFES は静力学平衡を仮定した大気モデルであり、水平数十 km 規模以下の現象には適しておらず、雲層の対流活動を陽に扱うこともできない。雲層の対流活動は、それ自身が興味深いだけでなく、対流の結果として生じる中立あるいは低安定度の層が、惑星規模の弓状構造や筋状構造の成因に深く関わっており、金星大気において非常に重要だと考えられる。これまでに、非静力学の領域モデルによって雲層の対流活動やそこから生じる重力波などが研究されてきた (e.g., Baker et al., 1998; Imamura et al., 2014; Yamamoto 2014, Lefèvre et al., 2017) が、計算領域が限定されるがゆえに、大規模現象に対する影響を調べることは出来ていない。

そこで我々は、雲層の対流活動を陽に表現した金星大気の全球シミュレーションを実現すべく、非静力学の金星大気大循環モデルの開発を始めている。大気運動や座標系を担う力学コアには「SCALE-GM」(http://r-ccs-climate.riken.jp/scale/) を利用する。SCALE-GM は、完全圧縮方程式系を正 20 面体準一様格子 (Tomita et al., 2001, 2002) 上で有限体積法で解く力学コアである。開発の最初の一歩として、惑星・大気の諸定数を金星の値に変更し、AFES-Venus で使われていた加熱強制・ニュートン冷却 (Tomasko et al., 1980; Crisp et al., 1986; Sugimoto et al., 2014) を与えられるようにした。そして、AFES-Venus と同様の簡易金星計算を様々な解像度で試行し、必要な時間刻み幅や数値拡散やスポンジ層の強さなどを探った。水平格子間隔 dx ~52 km、鉛直 120 層 (dz = 1 km) の解像度において、水平拡散として 2 次のラプラシアン、最小スケールに対する緩和時間を 100 s とした場合に、惑星規模の筋状構造が、AFES-Venus と同様に表現されることが確認できた。一方 SCALE-GM では、計算安定のためには平均東西風も減速させる強いスポンジ層をモデル上部に導入する必要があった。このため、スーパーローテーションの強度や大気の角運動量収支に、人工的なスポンジ層が影響を与えてしまっており、さらなる工夫が必要である。また、より高解像度の計算も試行しており、本発表ではこれらの結果も紹介したい。

R009-41
Zoom meeting D ：11/2 PM2 (15:45-18:15)
16:00〜16:15

金星の微細な雲形態の統計的解析

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Statistical analysis of the morphology of Venusian fine clouds

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[(1The university of Tokyo

Venus is entirely covered with clouds composed mainly of sulfuric acid. By observing the clouds of Venus at low latitudes in the ultraviolet wavelength, we can see the light and dark contrast on the planetary scale, while some parts of Venus show fine structures in the contrast. The factors that cause such cloud patterns have not yet been clarified. It may be related to planetary scale waves, but this has not been investigated, too.

So, we performed statistical analysis of cloud images in order to research the formation process of small-scale structures. For the analysis, we used the images continuously taken by Venus orbiter Akatsuki at the ultraviolet wavelength of 283nm. The ultraviolet absorber at 283nm on Venus is mainly SO_2, and we can observe horizontal distribution of the clouds around 65 km.

As analysis methods, we first compared the radiance variance of the high-pass images, which retains structures below about 1200 km, with the mean radiance value, from which the effect of the incidence and emission angle has been removed. The results show that the variance changes significantly by about one order of magnitude over a time scale of about 4 days. As for the phase difference between the variance and the mean radiance, both of which change with a period of about 4 days, we need to analyze more data.

Furthermore, we also extract the data near the equator, which is our current focus, and performed wavelet analysis and fractal analysis. The results of the wavelet analysis suggest that the components with wavelengths of about 10 degrees or more in longitude have large amplitudes, while smaller scale components have little structures.

Such analyses are expected to clarify the relationship between the large-scale brightness contrast of clouds and the small-scale structure.

金星は惑星全体が, 硫酸が主成分の雲に覆われている. 低緯度付近の雲を紫外波長で観察すると, 惑星規模の明暗のコントラストが見られる一方で, 一部分ではそのコントラストの中に細胞状の細かい構造がしばしば確認できる. このような雲形態が生じる要因は未だ解明されておらず, 惑星規模の波動との関連も考えられるが未だ調べられていない.

そこで我々は雲形態の小規模な構造の形成過程を調べるために, 雲画像の統計的解析を行った. 解析には, 金星探査機あかつきが 283nm の紫外波長で連続的に撮影した画像を用いた. 金星での 283m の紫外吸収物質は主に SO_2 であり, 紫外画像から高度 65km 付近の雲の水平分布を観測することができる.

解析方法として, まず大規模な明暗のコントラストと細かい構造の関連性を見るために太陽光入射角・出射角の影響を除いた輝度値の平均値と, 約 1200km 以下の構造を残すハイパスフィルターをかけた画像の輝度値の分散の時間変化を比較した. 計算結果より, ハイパス処理を行った画像の分散は約 4 日の時間スケールで約 1 桁にわたる大きな変化をすることが分かった. 約 4 日周期で変化する輝度値の平均値と分散の値の位相差等については更なる解析を行う必要がある.

また, 注目している赤道付近のデータを切り出し, wavelet 解析やフラクタル解析を行った. wavelet 解析の結果から, 波長にして約 10 ° 以上の成分が大きな振幅を持ち, それよりも小さなスケールでは構造が乏しいことが示唆される.

このような解析は, 雲形態の大規模な明暗と小規模な構造との関連性についての解明に繋がることが期待できる.

R009-42
Zoom meeting D ：11/2 PM2 (15:45-18:15)
16:15〜16:30

Longitudinal variation in the Venusian cloud optical thickness associated with a Kelvin wave

#Hiroki Karyu[1),Takeshi Kuroda[2),Naoki Terada[3),Yasumasa Kasaba[2),Masaru Yamamoto[7),Masaaki Takahashi[4),Kohei Ikeda[5), Norihiko Sugimoto[6)
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Longitudinal variation in the Venusian cloud optical thickness associated with a Kelvin wave

We have investigated, using a Venus Global Climate Model (VGCM), a large-scale longitudinal variation in the optical thickness of the Venusian cloud caused by a Kelvin wave and its relation to a sharp disruption feature reported by Peralta et al. (2020) [1]. They suggested that optically thick region is generated by vertical wind caused by a nonlinear Kelvin wave, making small particles abundant there. On the other hand, Ando et al. (2021) [2] showed that temperature fluctuation by a Kelvin-like gravity wave generates cloud thickness contrast using the AFES VGCM coupled with cloud physics. In addition, they argued cloud particle size should be larger in the thick cloud region.

Our VGCM is based on MIROC [3]. The model resolution is T21L52, the altitude range is from the surface up to 95 km, and topography is included. The radiation scheme and horizontal and vertical eddy diffusion for momentum and heat are based on Yamamoto et al. (2019) [4]. Our VGCM calculates the space and time evolution of cloud size distribution, which was not taken into account in the previous study [2]. Another difference is cloud particle modes [5] considered in the cloud physics parameterization. Although Ando et al. (2021) took into account Mode 1 and Mode 2, our VGCM takes into account Mode 3 and Mode 2' particles in addition to Mode 1 and Mode 2.

We calculated the optical thickness at 2.26 microns with the simulated cloud distribution to compare our results with IR images taken by Akatsuki. In the low latitudes, optical thickness sometimes changes sharply in the west-east direction, which is similar to that reported by the observation [1]. In general, the optical thickness variation has a wavenumber-1 structure and moves in the same direction as the super-rotation. Fourier analysis showed that a wavenumber-1 Kelvin wave structure is synchronized with the optical thickness variation. We also investigated a phase relationship among the variation of temperature, the vertical wind caused by the Kelvin wave, and cloud production rate. Cloud production rate is more in phase with the vertical wind than temperature. Therefore, contrary to Ando et al. (2021), our results suggest that vertical wind is the main cause of cloud optical thickness variation. Moreover, the simulated particle size is smaller in the optically thick region. It is expected that vertical wind transports sulfuric acid vapor from the sub-cloud region and small particles are generated there, which is consistent with the observation [1].

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R009-43
Zoom meeting D ：11/2 PM2 (15:45-18:15)
16:30〜16:45

金星探査機あかつきによる電波掩蔽観測で得られた硫酸蒸気混合比

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Sulfuric acid vapor in the Venus atmosphere observed by the Akatsuki radio occultation measurement

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On Venus, clouds exist at the altitudes of 45 to 70 km, covering the entire planet. The knowledge of the clouds will provide clues to estimate the heat budget and atmospheric circulation of the Venus atmosphere.

In particular, sulfuric acid vapor, which is the main material of sulfuric acid clouds, is essential for understanding the microphysics and distribution of clouds.

We derived the vertical profiles of sulfuric acid vapor mixing ratio using the time series of the signal intensity during radio occultation by the Akatsuki spacecraft. We found a zonal structure with a wavenumber 2 in sulfuric acid vapor mixing ratio, which suggested that thermal tidal waves affected the distribution of sulfuric acid vapor in the lower latitudes.

金星の高度 45〜70km には硫酸からなる雲が存在し、惑星全体を覆っている。この雲は、太陽光入射の約 78%を宇宙空間に反射する一方で、地表面や下層大気からの赤外線を吸収・放射することで温室効果を引き起こす。そのため、金星の雲に関する知見は大気の熱収支や大気循環を知る手掛かりとなる。特に硫酸雲の材料である硫酸蒸気に関する情報は、雲の物理や分布を理解する上で必要不可欠である。

大気中の微量物質の分布を調べる一つの手段として電波掩蔽観測が挙げられ、金星においては硫酸蒸気混合比を導出することが可能である。過去の金星探査では、探査機が極軌道であったため主に中・高緯度の硫酸蒸気の分布が調べられているが、低緯度の観測は少ない。本研究では、赤道周回軌道である「あかつき」の電波掩蔽観測にて取得された受信強度の時系列データを用いて、緯度 0-40 度における硫酸蒸気混合比の高度分布を導出した。2016 年から 2020 年までのデータを用いて地方時-高度分布を調べたところ、高度 50km 付近の硫酸蒸気混合比に東西波数 2 の構造が見られた。このような分布は、地方時に固定された構造を持つ熱潮汐波の影響を受けていることを示唆する。本発表では、数値シミュレーションとの比較も行いながら、硫酸蒸気分布と熱潮汐波をはじめとする力学との関連性について議論する。

R009-44
Zoom meeting D ：11/2 PM2 (15:45-18:15)
16:45〜17:00

Study of SO2 transport using Akatsuki UVI images and radiative transfer calculation

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The cloud layer which covers the entire Venus has a great influence on the Venus climate system. The clouds are composed of H_2SO_4 aerosols, and the mechanism of its formation involves sulfur cycle; SO_2, which is abundant in the lower part of the cloud layer, is transported to the cloud tops, where SO_2 is photochemically converted to H_2SO_4. H_2SO_4 forms cloud particles and is transported downward by sedimentation and the meridional circulation, and is thermally decomposed into SO_2 (Mills, Esposito and Yung, 2007). However, the mechanism of SO_2 transport is not understood well.

Akatsuki has been continuously observing Venus. One of its objective is to observe the spatial distribution of SO_2 in the Venus atmosphere (Nakamura et al., 2016). UVI onboard Akatsuki takes images at the wavelength of 283 nm, which is close to the center of the absorption band of SO_2 (Yamazaki et al., 2018). These images reflect the spatial distribution of SO_2, which should be strongly affected by atmospheric circulation. The horizontal wind velocity distribution has been obtained by tracking small-scale patterns in the UV images (Ikegawa and Horinouchi, 2016).

In our recent study, the mechanism of SO_2 transport was qualitatively examined by comparing the horizontal divergence calculated from the wind velocity distribution and the change in the UV reflectance along the movement of each air parcel. The horizontal divergence is used as an index of upward flow, and the reflectance and its temporal variation along the movement of the air parcel were used as indices of SO_2 abundance and its supply rate, respectively. As a result of comparison of these distributions, it is suggested that SO_2 is transported by convection which changes temporally and spatially. Furthermore, an analysis of the UV reflectance and the wind field averaged on the local solar time-latitude coordinate suggested a SO_2 supply process by thermal tides of wavenumber 2 (semi-diurnal tide). However, these analyses are only qualitative. In order to evaluate the roles of those SO_2 transport in cloud formation quantitatively, the mixing ratio of SO_2 at the cloud top and its variation need to be investigated.

In this study, we developed a radiative transport model for the estimation of the abundance of SO_2 at cloud tops. We used the Adding-Doubling method (van de Hulst, 1980), which can calculate the effect of multiple scattering, to calculate the radiative transport in UV region. We adopted the Lebedev quadrature (Lebedev, 1976), which is a kind of quadrature method of the spherical integration, to achieve a uniform resolution with respect to the solid angle. Under the geometrical conditions of observations by Akatsuki UVI, radiative transfer calculations were performed with various SO_2 mixing ratios. By comparing the observed reflectance and the radiative transfer calculations, we can estimate the SO_2 mixing ratio that agrees with the observed reflectance. In this presentation, we show the results of these calculations.

R009-45
Zoom meeting D ：11/2 PM2 (15:45-18:15)
17:00〜17:15

多波長撮像観測で探る金星極渦の立体構造

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3-dimensional structure of Venus' polar vortex as probed with multi-color imaging observations

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The polar vortex of Venus was discovered by Pioneer Venus Orbiter (PVO) and its detail was later observed by ESA's Venus Express (VEx). While both PVO and VEx were in polar orbit, Japan's Akatsuki chose to orbit near the equatorial plane of Venus, making it less favored to observe polar regions of Venus. Only when the sub-spacecraft latitude happens to offset from the equator (~10 degrees or so), one pole can be seen relatively better. We analyzed the data acquired on 7 May 2016 as an example case of such a viewing condition.

Images by the thermal-IR camera LIR show the "relatively high-temperature" polar vortex surrounded by the low-temperature cold collar. On the other hand, images by the 2-micron camera IR2 (2.02um filter) visualize the drop of cloud-top altitude in the polar region (higher than 60 degrees latitude). The "enhanced" IR2 images show complex features in the polar region.

We will report comparison of these data, will discuss the probing technique with observations in other wavelengths (not done by Akatsuki). These (the instruments and the observing techniques) will be proposed for the Venera-D mission being planned by Russia.

金星の極渦はパイオニア・ヴィーナス周回機（PVO）により発見され、欧州のヴィーナス・エクスプレス（VEx）により詳細に観測された。PVO, VEx はともに極軌道の周回機であったが、日本のあかつきは金星赤道面に近い軌道を採用したため、極域の観測は得意ではない。それでも、ときに衛星直下点の緯度が 10°程度になるときは片側の極が比較的によく見える。本研究ではそのような観測機会のものとして、2016 年 5 月 7 日のデータを解析した。

熱赤外線カメラ LIR では、周囲より高温の極渦が低温の cold collar に取り囲まれている様子がとらえられている。一方、2 ミクロンカメラ IR2（波長 2.02um フィルター）では、緯度 60°より高緯度で雲長高度が顕著に低くなっていることが分かる。さらに強調処理を施すと、その中に複雑な構造が多数存在している。

本講演ではそれらの比較を報告するとともに、あかつきでは実現していないもののこれら以外の波長を組み合わせた場合に探ることのできる構造を論じる。ロシアが計画中の Venera-D 金星探査に測器＋観測手法として提案することを検討している。

R009-46
Zoom meeting D ：11/2 PM2 (15:45-18:15)
17:15〜17:30

次世代金星探査の検討

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Toward the next generation Venus exploration

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The next phase of Venus exploration is going to start, given the successful completion of Venus Express and the continuous accumulation of results from Akatsuki. Three Venus missions were newly approved by ESA and NASA this year, and India and Russia are also promoting their Venus missions. Venus science is gaining momentum again toward around 2030. In Japan, discussions on the scientific objectives of the next Venus mission are progressing, and several Venus orbiter concepts are being studied. Exploration by entry probes is also discussed. Based on this situation, we are considering to establish a Venus exploration research group (RG) to study the roadmap of Venus exploration from both science and engineering perspectives. In this presentation, we will report the status of the study.

世界における金星探査は、Venus Express の成果がほぼ出揃い、あかつきが粛々と成果を積み上げるフェーズに入り、次の展開を図る時期に来ている。今年になって欧州と米国で合わせて 3 つの金星ミッションが採択され、さらにインドとロシアの金星ミッションも推進されており、海外では 2030 年前後に向けて改めて金星の科学が盛り上がりつつある。日本においては、次期金星探査の科学目的の議論が進むとともに、複数の金星オービター構想の検討が実施され、直接探査プローブを考える機運もある。このような状況を踏まえ、理学と工学の両面から金星探査のロードマップを検討するために、宇宙科学研究所の宇宙理工学委員会に金星探査検討 RG（リサーチグループ）を設置することを考えている。本講演では検討状況について報告する。