木星氷衛星探査計画JUICEの概要と日本からの参加

斎藤 義文 [1]; 佐々木 晶 [2]; 東原 和行 [3]; 藤本 正樹 [4]; JUICE-JAPAN 齋藤　義文 [5]
[1] 宇宙研; [2] 阪大・理・宇宙地球; [3] 宇宙研; [4] 宇宙研; [5] -

Current Status of Japanese Participation to Jupiter Icy Moons Explorer JUICE

Yoshifumi Saito[1]; Sho Sasaki[2]; Kazuyuki Tohara[3]; Masaki Fujimoto[4]; Yoshifumi Saito JUICE-JAPAN[5]
[1] ISAS; [2] Earth and Space Science, Osaska Univ.; [3] ISAS/JAXA; [4] ISAS, JAXA; [5] -

JUICE is an ESAs L-class mission to Explore Jupiter Icy Moons. JUICE was mission adopted in November 2014. It will be launched in 2022, arrive at Jupiter in 2030 and be inserted into Ganymede orbit in 2032. The science objectives of JUICE is to understand (1) emergence of habitable worlds around gas giants and (2) Jupiter system as an archetype for gas giants. Three Japanese groups were selected to provide part of the three science instruments RPWI, GALA, and PEP/JNA. Two Japanese groups were also selected as science Co-I of two instrument groups JANUS and J-MAG.

JUICE is the first mission for ISAS/JAXA to participate to foreign large science mission as a junior partner who will provide part of the science instruments.

JUICE will observe Jupiter system from Jupiter orbit in order to understand Jupiter system as an archetype for gas giants. JUICE will make observation of 3 of the 4 Galilean satellites, Europa, Ganymede, and Callisto in order to understand the emergence of habitable worlds around gas giants.

JUICE will be launched by Arian-5. The Dry mass of JUICE is about 1800kg and the fuel is about 2900kg. The required Delta-V is about 2700m/s. JUICE is a three-axis stabilized spacecraft with solar cell paddle of about 70m2 that will generate approximately 700W power. The mass and power allocated to science instrument is 104kg and 150W, respectively. X band and Ka band are used for satellite-ground communications.

After 7.5 years of interplanetary transfer and Earth-Venus-Earth-Earth gravity assists JUICE will be inserted into an orbit around Jupiter in January 2030. JUICE will make observation of all the three Jupiter icy Moons that potentially have subsurface ocean under the icy crust. After inserted into Ganymede orbit in 2032, JUICE will make detailed observation of the largest Icy Moon in the solar system.

Taking into account all the data to be obtained by 5 instruments that JUICE-JAPAN will participate, Japanese team will be able to contribute to most of the major science objectives relating with planet Jupiter (JANUS), Jupiter magnetosphere (PEP/JNA, RPWI, and J-MAG), and Icy Moons (GALA, J-MAG, and JANUS).

JUICE-JAPAN Working Group (WG) was established in September 2013. JUICE-JAPAN WG submitted a proposal for ISAS/JAXA small project in February 2014. JUICE-JAPAN WG passed the MDR in September 2014. Although ISAS SRR and ISAS project preparation review were held in February 2015, JUICE-JAPAN failed to pass those reviews. JUICE-JAPAN passed the Delta ISAS SRR that was held in April and also passed the Delta ISAS project preparation review that was held in May with some action items. Currently JUICE-JAPAN is in transition from Working Group to ISAS pre-project. In the future, SDR is scheduled in the end of 2015, PDR is scheduled in 2016 and CDR is scheduled in 2017.

JUICE とは、ESA が 2012 年 5 月に選定した L クラス計画であり、2022 年打ち上げ，2030 年木星系到着，2032 年ガニメデ周回軌道投入の予定である。木星到着後、まずは木星周回軌道から木星系の観測を実施し、ガニメデ周回軌道投入後はガニメデという太陽系最大の氷衛星の精査を行う。AO とその後の選定を経て決まった JUICE に搭載される 11 観測機器提供チームのうち、３つの機器 (RPWI, GALA,　PEP/JNA) については ISAS/JAXA から JUICE-JAPAN がハードウェアの一部を提供する事になり、2 つの機器 (JANUS, J-MAG) についてハードウェアの提供は無いがサイエンス Co-I として参加することとなった。海外が主体となる極めて魅力的な大型計画へ日本から機器提供という形で参加することは今後とも活用されるべきである「海外計画への参加」という枠組みであり JUICE-JAPAN はその先駆けとなる。

JUICE の科学的課題は　(1) 系外惑星を意識した，巨大ガス惑星の世界の理解，および、(2) アストロバイオロジーを意識した，氷衛星（ガニメデ，エウロパ，カリスト）の探査である。木星周回軌道から木星系の観測（磁気圏，木星大気，エウロパ・カリスト・ガニメデのフライバイ観測）を実施し、巨大ガス惑星の原型としての木星系探査を行うことで、「巨大ガス惑星系の起源と進化」を解明する事、４つのガリレオ衛星のうち、エウロパ・カリストのフライバイ観測、太陽系最大の氷衛星ガニメデの周回観測による精査を実施し、生命居住可能領域の探査を行うことで、「生命存在可能領域としての氷衛星地下海の形成条件」を解明する事、そして巨大な木星磁気圏と、磁気圏中に存在する氷衛星との相互作用を明らかにすることで、「太陽系最強の加速器木星磁気圏」を解明することである。

JUICE の打ち上げは、アリアン５で行われる。打ち上げ後は、地球・金星・地球・地球というスウイングバイを経て木星に到着する。ガニメデ周回軌道投入後は、ガニメデという太陽系最大の氷衛星の精査を目的とする。ガニメデ高度 500km での周回観測を実施し、最後はガニメデに衝突してミッション終了となる。ISAS/JAXA から JUICE-JAPAN として参加するハードウェア提供３機器 (RPWI, GALA,　PEP/JNA) とサイエンス参加 2 機器 (JANUS, J-MAG) を足し合わせると、木星本体（JANUS）、木星磁気圏（PEP/JNA,RPWI,J-MAG）、氷衛星（GALA,J-MAG,JANUS）といった JUICE のサイエンス・テーマのすべてに、日本からバランス良く貢献が可能であることがわかる。

2013 年 9 月に正式に JUICE-JAPAN WG が設立された後、JUICE-JAPAN WG は、平成 26 年 2 月に小規模プロジェクトの募集に対して応募し、9 月に理学委員会による MDR/SRR を通過した。平成 27 年 2 月に宇宙研の所内 SRR、所内

プロジェクト準備審査を受けたものの不合格となり、その後平成27年4月末に実施された所内SRRの再審査を通過、翌月５月下旬に実施された所内プロジェクト準備審査の再審査も条件付きながら通過し現在に至っている。現在は、WGからプリプロジェクトへの移行時期である。今後、プリプロジェクト、プロジェクトと進み、平成２８年度にはPDR、平成２９年度にCDRと進んでいく予定である。JUICEはプロジェクト終了までまだ約２０年かかる長期間に渡るプロジェクトである。適宜世代交替を進めながら是非ともこの魅力ある大型ミッションへの参加を成功させたいと考えている。

JUICE-GALA ガニメデレーザ高度計の目指すサイエンス

竝木 則行 [1]; 塩谷 圭吾 [2]; 小林 正規 [3]; 木村 淳 [4]; 荒木 博志 [1]; 野田 寛大 [1]; 鹿島 伸悟 [1]; 宇都宮 真 [5]; 石橋 高 [6]; 押上 祥子 [7]; 小林 進悟 [8]; 藤井 雅之 [9]; Hussmann Hauke[10]; Lingenbauber Kay[10]; Oberst Juergen[11]
[1] 国立天文台; [2] 宇宙研; [3] 千葉工大; [4] 東工大 ELSI; [5] JAXA; [6] 千葉工大; [7] 名大; [8] 放医研; [9] ファムサイエンス; [10] DLR; [11] DLR Institute of Planetary Research

Scientific Objectives of JUICE/Ganymede Laser Altimeter (GALA)

Noriyuki Namiki[1]; Keigo Enya[2]; Masanori Kobayashi[3]; Jun Kimura[4]; Hiroshi Araki[1]; Hirotomo Noda[1]; Shingo Kashima[1]; Shin Utsunomiya[5]; Ko Ishibashi[6]; Shoko Oshigami[7]; Shingo Kobayashi[8]; Masayuki Fujii[9]; Hauke Hussmann[10]; Kay Lingenbauber[10]; Juergen Oberst[11]
[1] NAOJ; [2] JAXA/ISAS; [3] Chiba Institute of Technology/PERC; [4] Tokyo Institute of Technology/ELSI; [5] JAXA; [6] Chitech/PERC; [7] Nogoya Univ.; [8] NIRS; [9] Famscience Inc.; [10] DLR Institute of Planetary Research; [11] DLR Institute of Planetary Research

http://www.miz.nao.ac.jp/rise/

'Is there a life elsewhere in the universe?' It is a fundamental question deeply rooted on intelligence of human beings. And a clue of this question may be found on Ganymede. After magnificent achievements of Galileo and Voyager missions, an existence of thick liquid water layer has been implied for three icy satellites of Jupiter, Ganymede, Europa, and Callisto. This layer is now understood as subsurface oceans under icy crust. The evidence of ocean, however, is not widely accepted, because it depends on an inference of electromagnetic observation and surface morphology. Looking for new evidences and clues for these important issues, a new mission to Jupiter system is planned by European Space Agency. It is the Jupiter Icy Moon Explorer (JUICE). JUICE will be launched in 2022, and will arrive at Jupiter in 2030. After several fly-bys to Europa and Callisto, JUICE will be inserted into an orbit around Ganymede in 2032 and will continue scientific observations for eight months until the end of nominal mission in 2033.

The Ganymede Laser Altimeter (GALA) is one of the instruments selected for JUICE. A fundamental goal of any exploratory space mission is to characterize and measure the shape, topography, and rotation of the target bodies. A state of the art tool for this task is laser altimetry because it can provide absolute topographic height and position with respect to a body centered reference system. The GALA data are particularly important for confirming the global subsurface ocean and further characterization of the water-ice/liquid shell. If the ocean exists beneath icy crust, dynamic response of the ice shell to tidal forces is so large that temporal variation of the topography as great as several meters is expected. In addition, small eccentricity of orbit of Ganymede causes the forced physical librations and spin-axis obliquity that will be observed as lateral shifts of footprint of laser beam at the surface. Further, improved determination of spacecraft orbits by cross-over analysis contributes to precise estimate of low degree harmonics of gravity field. We thus aim to estimate accurate tidal Love numbers, h_2 and k_2, to infer internal density structure of the satellite.

Global topographic data derived by GALA are also important for the study of tectonic history at the surface, elastic and viscous structure of ice crust, and thermal evolution of interior of the icy satellite. For example, linear structures such as ridges and grabens reveal extensional stresses in the past. Such stress variation is closely related with thermal history of Ganymede. As well, possible cryo-volcanic features may indicate partial melting of the crust and consequent subsurface lake. These observations on various geologic activities lead to new understanding of transport of heat and materials from the inside to the surface. Further, a comparison of styles of tectonics of ice crust and that of silicate lithosphere will likely shed a new light on theory of plate tectonics of the Earth.

GALA uses the 'direct-detection' (classical) approach of laser altimetry. Laser pulses are emitted at a wavelength of 1064 nm by using an actively Q-switched Nd:Yag laser. The pulse energy and pulse repetition frequency are 17 mJ at 30 Hz, respectively. The emission time of each pulse is measured by the detector. The beam is reflected from the surface and received at a 25 cm diameter F/1 telescope. The returning laser pulse is refocused onto a silicon avalanche photodiode (APD) through back-end optics including a narrow bandpass interference filter for isolating the 1064 nm wavelength. The APD-signal is then amplified, sampled and fed to a digital range finder. The minimum acceptable SNR is approx. 1.2. This system determines the time of flight, pulse intensity, width and full shape. The GALA instrument is developed in collaboration of institutes and industry from Germany, Japan, Switzerland and Spain.

"地球以外に生命を宿す天体は存在するのか"という問いは，人類の知的好奇心の究極に位置する科学的命題である．木星系の大氷衛星であるガニメデやエウロパ，カリストでは，H_2O 主体の氷に覆われた表層の下に全球的な液体層，いわゆる"地下海"の存在が示唆されている．液体水の存在はすなわち生命生存の可能性に直結し，地球生物学の他天体への拡がりは「アストロバイオロジー」としてその重要性がこれまでも広く認識されている．しかし，地下海の存在は電磁気的観測や表面地形の解釈から導き出された"可能性"に過ぎない．ESA が主導する木星系探査計画 JUICE ではこの存否を確認することが最重要課題である．

JUICE の主ターゲットであるガニメデは，地球型惑星に比肩するサイズであり，金属核起源の固有磁場を持っている．

氷衛星は地球型惑星と並ぶもうひとつの固体惑星の代表的な様式と言えるが，ガニメデに対してはこれまで数回のフライバイ探査にとどまっており，その知見は極めて限定的である．JUICE は史上初めての衛星周回探査によってガニメデの全容を把握する．期待される起源と進化の描像は太陽系内天体の多様性の起源を紐解く鍵となるだけでなく，太陽系内天体の認識に根ざした従来の概念を覆す多様な系外惑星の理解にも大きな寄与を果たす.

太陽系固体惑星の主要構成成分は岩石と氷であり，固体惑星のサブカテゴリのひとつである地球型惑星は，雪線の内側で形成したために岩石主体となった．一方で木星系以遠に存在する固体天体は，主構成成分のひとつに氷を持っている．その中でもガニメデは岩石と氷をほぼ等量の割合で保持し水星以上のサイズを持っていることから，地球型惑星と並ぶ固体惑星のもうひとつのサブカテゴリというべき存在である．近年発見が続いている多様な太陽系外惑星の中で，ガニメデのように岩石と氷からなる天体は現在発見されてはいないが存在が十分に予想されることからも，ガニメデの理解は重要である．

JUICE の搭載機器であるレーザ高度計 GALA はレーザ光の往復飛行時間を測定することによって探査機と天体表面までの距離を測定する．探査機と天体重心の位置情報をもとに，測定距離から地形が求められる．これにより地形の平均場としての全球地形モデルが得られるのと同時に，木星からの潮汐力により生じる固体潮汐の振幅（地形の時間変化）の大きさを測定することで，地下海の存否が推定できる．また，地下海の存在によって引き起こされると予測される回転変動（秤動）も，レーザのフットプリント位置のずれとして条件さえ整えば観測可能であろう．さらに，クロスオーバー解析によって，高度計データは探査機の軌道改良にも役に立ち，その結果，天体の重力場係数，慣性能率比，潮汐ラブ数の精度向上につながり，内部構造が制約できる．

一方，レーザ高度計によって全球的に得られる地形情報は，氷衛星の構造変動履歴をうかがう窓となり，様々な地形の形態とその分布の把握を通して氷地殻構造と内部進化の理解に大きな寄与をもたらす．具体的には，過去に発生した伸張応力が作り出したと考えられる溝構造や，氷地殻が局所的に融解している，あるいは薄くなっている場所に存在すると予想される内部湖などを検出しその形態を解明することが期待できる．こうした情報は氷衛星が示す多様な地質活動（熱・物質輸送様式）の理解につながるだけでなく，氷という揮発性（低融点）物質主体のテクトニクス様式をケイ酸塩鉱物でのそれと対比することによって他の固体惑星の地質活動や地球のプレート・テクトニクスを再考察することにも寄与する．

GALA は，ドイツ，スイス，スペイン，日本の国際共同チームにより開発される．基本設計は水星探査機 BepiColombo 搭載のレーザ高度計 BELA をベースにしており，トランシーバユニット（TRU），制御（制御・時間計測・インターフェース）ユニット（ELU），レーザ電子回路ユニット（LEU）の 3 つのユニットで構成されている．このうち，日本チームは TRU の中の反射光受信部（受信光学系および検出器）を担当する．検出器バックエンドのエレクトロニクスは，測距データ処理系を担当するスイスのベルン大学が担当する．また，レーザ発振・送信部と全体のインテグレーションは，PI である Hauke Hussmann の所属する DLR（ドイツ航空宇宙センター）が担当する．

JUICE搭載サブミリ波分光計SWI

笠井 康子 [1]; 関根 康人 [2]; 黒田 剛史 [3]; 佐川 英夫 [4]; 西堀 俊幸 [5]; 真鍋 武嗣 [6]; JUICE/SWI 日本チーム 笠井康子 [7]
[1] NICT; [2] 東大・理・地惑; [3] 東北大・理; [4] 京都産業大学; [5] なし; [6] 大阪府大・工・航空宇宙; [7] -

Current development status of JUICE/SWI Japanese team

Yasuko Kasai[1]; Yasuhito Sekine[2]; Takeshi Kuroda[3]; Hideo Sagawa[4]; Toshiyuki Nishibori[5]; Takeshi Manabe[6]; KASAI Yasko SWI[7]
[1] NICT; [2] Earth & Planetary Sci., Univ. of Tokyo; [3] Tohoku Univ.; [4] Kyoto Sangyo University; [5] JAXA; [6] Aerospace Engineering, Osaka Prefecture Univ.; [7] -

http://smiles.nict.go.jp/index-e.html

The Submillimetre-Wave Instrument (SWI) is one of the 10 scientific payloads on the JUpiter ICy moon Explorer (JUICE). The primary scientific objective of SWI is to investigate the structure, compositions and dynamics of the middle atmosphere of Jupiter and the 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 plans to performed limb and nadir passive observations with frequency 530–600 and 1075–1275 GHz regions. Japanese contributions are the development of main– and sub–reflectors, actuators for the instruments, feasibility studies for observation performance, data processing, and scientific contributions. In this paper, the current status of development in Japan will be presented.

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、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。本講演では、SWIが拓く科学，それを達成するための観測装置，そして測器開発などの進捗状況を述べる

R009-04 **会場: C** **時間: 11月1日 14:45-15:00**

The Radio and Plasma Wave Investigation (RPWI) for JUICE: Contributions from Japan

Yasumasa Kasaba[1]; Hiroaki Misawa[2]; Fuminori Tsuchiya[3]; Yoshiya Kasahara[4]; Tomohiko Imachi[4]; Tomoki Kimura[5]; Yuto Katoh[6]; Atsushi Kumamoto[7]; Hirotsugu Kojima[8]; Satoshi Yagitani[4]; Keigo Ishisaka[9]; Yoshizumi Miyoshi[10]
[1] Tohoku Univ.; [2] PPARC, Tohoku Univ.; [3] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [4] Kanazawa Univ.; [5] RIKEN; [6] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [7] Dept. Geophys, Tohoku Univ.; [8] RISH, Kyoto Univ.; [9] Toyama Pref. Univ.; [10] STEL, Nagoya Univ.

RPWI [PI: J.-E. Wahlund (IRF-Uppsala, Sweden)] on the ESA JUICE mission to Jupiter (launch: 2022) consists of Langmuir probe and electromagnetic wave measurements. It will provide the basic information of the exospheres, surfaces, and conducting subsurface oceans of Ganymede, Europa and Callisto and their interactions with surrounding Jovian magnetosphere.

RPWI has put special efforts into the design in order to have the following capabilities: (1) First to determine the properties, dynamics and the electrically conducting state of the cold plasma (<100 eV, and possibly dusty) that originates from the ionization of the dense exospheres of the icy Galilean moons, and its effect on these moons icy surfaces; (2) First to determine the electro-dynamic coupling via electric currents, Alfven waves, electric acceleration structures and plasma waves that transfer energy and momentum between different particle populations in Ganymede's magnetosphere as well as in the induced induced fields coupling to their conducting subsurface Oceans; (3) First to determine the state and dynamics of the Jovian magnetosphere, and how this variable and rotating magnetosphere transfer energy and momentum to the space environments around the icy Galilean moons, with special emphasis on the mechanisms of the electro-dynamic coupling in this interaction; (4) First to determine the location of source regions of the radio emissions within the Jovian domain and to determine the properties of those emissions, such as polarization, to characterize the source regions;

We also do possible sciences coordinated with others for the possible access to the subsurface ocean. (5) RPWI first provide the precise density and temperature of cold plasma and electric fields in Jovian system. Exhaust plumes from cracks on icy moons will also be detected, as well as micron sized dust migrating in these plumes and their interactions. It can provide the global conductivity and current estimations of icy satellite ionospheres, which contributes to the estimation of those characteristics of the conductive subsurface oceans below the non-conductive icy crust. (6) RPWI also first provides the highly resolved information of Jovian radiation emitted from Ganymede and Jupiter including lightning activity, by the first 3-axis E-filed measurement. As a byproduct, reflected Jovian emission can be expected from the boundary of crust (ice) and subsurface ocean (conductive water). It could observed by RPWI like the Lunar surface reflection in terrestrial auroral kilometric radiation seen by Kaguya Lunar Radar Sounder. RIME (Radar for Icy Moons Exploration) on JUICE uses 9 MHz radar pulse by 16 m tip-to-tip antenna and tries to detect the ocean under ~10 km icy crust. Since the frequency of Jovian radiation is wider, from several 100 kHz to several 10s MHz, RPWI can potentially provide complementary information of RIME, including the vertical distributions of conductivity and permittivity in the icy crust.

RPWI sensors consist of 4 Langmuir probes (LP-PWI) for determination of the vector electric field up to 1.6 MHz and cold plasma properties (including active measurements by LP sweeps and mutual impedance sounding) up to 1.6 MHz, a tri-axial search coil magnetometer (SCM) for determination of the vector magnetic field up to 20 kHz, and a tri-dipole antenna system (RWI) for monitoring of radio emissions (80 kHz - 45 MHz). From Japan, we will provide the RWI preamp and its High Frequency receiver with the onboard software, modifying from the BepiColombo PWI and ERG PWE developments. We will also provide Software Wave-Particle Interaction Analyzer (SWPIA) function to RPWI DPU, for the onboard quantitative detection of electromagnetic field - ion interactions, modifying from the ERG SWPIA developments. We are now developping the first hardware for the preliminary integration test by all members from Jan to March 2016. Long voyage starts till the end of this mission.

宇宙望遠鏡群による木星オーロラの多波長観測：極冠領域における X 線発光

木村 智樹 [1]; 垰 千尋 [2]; 吉岡 和夫 [3]; 村上 豪 [4]; 山崎 敦 [5]; 土屋 史紀 [6]; 江副 祐一郎 [7]
[1] RIKEN; [2] LPP, Ecole Polytechnique; [3] 立教大; [4] ISAS/JAXA; [5] JAXA・宇宙研; [6] 東北大・理・惑星プラズマ大気; [7] 首都大・理工・物理

Multi-wavelength observations of Jupiter's aurora with Hisaki and other space telescopes: X-ray aurora in the polar cap region

Tomoki Kimura[1]; Chihiro Tao[2]; Kazuo Yoshioka[3]; Go Murakami[4]; Atsushi Yamazaki[5]; Fuminori Tsuchiya[6]; Yuichiro Ezoe[7]
[1] RIKEN; [2] LPP, Ecole Polytechnique; [3] Rikkyo Univ.; [4] ISAS/JAXA; [5] ISAS/JAXA; [6] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [7] Tokyo Metropolitan University

From January to April 2014, two observing campaigns by multi-wavelength remote sensing from X-ray to radio were performed to uncover energy transport process in Jupiter's plasma environment using space telescopes and ground-based facilities. These campaigns were triggered by the new Hisaki spacecraft launched in September 2013, which is an extremely ultraviolet (EUV) space telescope of JAXA designed for planetary observations. In the first campaign in January, Hubble Space Telescope (HST) made imaging of far ultraviolet (FUV) aurora with a high special resolution (0.08 arcsec) through two weeks while Hisaki continuously monitored aurora and plasma torus emissions in EUV wavelength with a high temporal resolution (10 min or less). We discovered the internally-driven auroral brightening associated during the solar wind quiet period. The second campaign in April was performed by Chandra X-ray Observatory (CXO), XMM newton, and Suzaku satellite simultaneously with Hisaki. Relativistic auroral accelerations in the polar region and hot plasma in the inner magnetosphere were measured in both X-ray and EUV wavelengths. Driving mechanisms for the relativistic accelerations are discussed mainly based on daily variations and source location of X-ray aurora.

Enhancement of Io's volcanic activity and its influence on local electron heating in the Io plasma torus

Fuminori Tsuchiya[1]; Masato Kagitani[2]; Ryoichi Koga[3]; Hiromasa Nozawa[4]; Mizuki Yoneda[1]; Kazuo Yoshioka[5]; Tomoki Kimura[6]; Go Murakami[7]; Takeshi Sakanoi[8]; Yasumasa Kasaba[9]; Atsushi Yamazaki[10]; Ichiro Yoshikawa[11]
[1] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [2] PPARC, Tohoku Univ; [3] Geophysics, Tohoku Univ.; [4] Kagoshima NCT; [5] Rikkyo Univ.; [6] RIKEN; [7] ISAS/JAXA; [8] Grad. School of Science, Tohoku Univ.; [9] Tohoku Univ.; [10] ISAS/JAXA; [11] EPS, Univ. of Tokyo

http://pparc.gp.tohoku.ac.jp/

Io continuously supplies volcanic gases to the Jovian magnetosphere with typical rate of 1 ton/sec and is a primary source of plasmas in the magnetosphere. The supply of neutral atoms and molecules from Io produces pickup ions and causes significant inputs of mass and energy to the inner magnetosphere. 10-20% of the energy is immediately converted to produce hot electron population downstream of Io while the electrons quickly lose their energy by radiation of ions in the extreme ultraviolet (EUV) range with a time scale shorter than the rotation period of Jupiter. Due to these processes, longitudinal distribution of electron temperature has a maximum downstream of Io. This phenomenon was discovered by EUV spectroscopic observation of the Voyager spacecraft and confirmed by the HISAKI satellite observation in 2014. Based on the HISAKI observation, the Io phase dependence is accompanied by the 5-hour periodicity which is a half of Jupiter's rotation period. This means that the energy production rate at Io depends on the local plasma density since Io crosses the center of the torus twice during one Jovian rotation (10h). However, the Io phase dependence has not been detected by the similar EUV observations by EUVE and Cassini and the origin of the local electron heating is still open question. This study examines unresolved problems on the Io phase dependence using the HISAKI observation data in 2015. The EUV spectroscope, EXCEED, onboard HISAKI measures ion and atomic emission lines in EUV range. The 2nd campaign of Io plasma torus observations has been done from the end of Nov. 2014 to middle of May 2015. On middle of Jan. 2015, EXCEED observed gradual increase in S^{+} brightness. The brightness showed a maximum at the end of Feb. and S^{2+} and S^{3+} intensities also showed maxima subsequently. Ground based observation of the sodium nebula showed increase in the emission intensity from the middle of Jan. to the beginning of Mar. These observations suggest that enhancement of the volcanic activity began at the middle of Jan. The brightness of ions returned to the pre-increase level by the middle of May 2015. These are the first complete data set which shows influence of Io's volcanic activity change to the Io plasma torus from start to finish. Characteristics of the Io phase dependence also changed during the volcanic event. Before the volcanic enhancement, ion brightness shows the Io phase dependence with the similar amplitude as the 2014 data. It kept appearing during the increasing phase but amplitude became large. In the declining phase the amplitude of the Io phase dependence reduced significantly. Periodogram analysis of ion brightness showed significant peaks at Io's orbital period, around Jupiter's rotation period (system III and IV periods), and at a half of it (5-h) and confirmed that the significance of the Io orbital periodicity became small during the declining phase. It is also found that the 5-h periodicity was significant before and during the increasing phase but it disappeared during the declining phase. Hypotheses to account for them is change in the latitudinal distribution of plasmas and longitudinal extend of neutral cloud in the Io torus. If the neutral cloud is primary source of the pickup ions, the longitudinal extend of the cloud cause the extension of the mass and energy production region. This could cause reduction of both the Io phase dependence and 5-h periodicity. The increase of pickup ion causes to increase in ion temperature along the magnetic field line and extend latitudinal distribution of ions. This could reduce local plasma density change at Io and is responsible for decreasing the Io phase dependence. The latitudinal distribution of ion and longitudinal extend of neutral cloud could be derived from EXCEED and ground based observations and will be compared with the Io phase dependence to validate the hypotheses.

Variation characteristics of Jupiter's hectometric radiation during the HISAKI observation campaign in 2015

Hiroaki Misawa[1]; Fuminori Tsuchiya[2]; Tomoki Kimura[3]; Yasumasa Kasaba[4]; Atsushi Kumamoto[5]
[1] PPARC, Tohoku Univ.; [2] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [3] RIKEN; [4] Tohoku Univ.; [5] Dept. Geophys, Tohoku Univ.

http://pparc.gp.tohoku.ac.jp/

Around Jupiter's opposition to the earth in 2015, a remote observation for Jupiter had been made continuously by the HISAKI satellite. In the period, sudden enhancement of Iogenic plasma emissions occurred in the middle of Jan., 2015 and the enhancement had lasted for more than two months. This phenomena would give important clues for investigation of drivers of Jupiter's magnetospheric activities.

We have analyzed Jupiter's hectometric radiations (HOM) by using the WIND spacecraft data for the period. HOM is known to be one of indicators reflecting Jupiter's global magnetospheric activities (Louarn et al., 2014 etc.), and to have some correlation with solar wind variations (Nakagawa et al., 2000 etc.). The preliminary analysis indicates that occurrence of HOM enhanced after the middle of Feb. and showed intermittent feature roughly correlating with activities of UV aurora detected with HISAKI. In the presentation, we will introduce results of comparison analyses among HOM, optical intensities of UV aurora and torus plasma, and solar wind properties, and will discuss variation characteristics of Jupiter's magnetosphere.

Acknowledgements: We would greatly appreciate M. Kaiser, J.-L. Bougeret and the WIND/WAVES team for providing the radio wave data.

Solar wind influence on the Jovian inner magnetosphere derived from EUV spectroscopy

Go Murakami[1]; Kazuo Yoshioka[2]; Tomoki Kimura[3]; Atsushi Yamazaki[4]; Fuminori Tsuchiya[5]; Masato Kagitani[6]; Chihiro Tao[7]; Yasumasa Kasaba[8]; Ichiro Yoshikawa[9]; Masaki Fujimoto[10]
[1] ISAS/JAXA; [2] Rikkyo Univ.; [3] RIKEN; [4] ISAS/JAXA; [5] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [6] PPARC, Tohoku Univ; [7] LPP, Ecole Polytechnique; [8] Tohoku Univ.; [9] EPS, Univ. of Tokyo; [10] ISAS, JAXA

The dawn-dusk asymmetry of the Io plasma torus has been seen by several observations [e.g., Sandel and Broadfoot, 1982; Steffl et al., 2004]. Ip and Goertz [1983] explained this asymmetry can be caused by a dawn-to-dusk electric field in the Jovian inner magnetosphere. However, the question what physical process can impose such an electric field deep inside the strong magnetosphere still remains. The long-term monitoring of the Io plasma torus is a key observation to answer this question. The extreme ultraviolet (EUV) spectrometer EXCEED onboard the Hisaki satellite observed the Io plasma torus continuously during the two periods: from December 2013 to March 2014 and from November 2014 to May 2015. We found clear responses of the dawn-dusk asymmetry to rapid increases of the solar wind dynamic pressure. Our results suggest that the solar wind can effect on the dawn-to-dusk electric field in the Jovian inner magnetosphere. We statistically analyzed the relations between solar wind and IPT response. Furthermore, we investigated the influence of volcanic activity of Io, detected by Hisaki in January 2015, on the solar wind response of Jovian inner magnetosphere. We will report the initial results of this study.

Test-particle simulation of elastic collisions of 500eV-keV electrons with neutral H2O molecule originated from Enceladus

Hiroyasu Tadokoro[1]; Yuto Katoh[2]
[1] none; [2] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.

Water group neutrals (H2O, OH, and O) in Saturn's inner magnetosphere play the dominant role in loss of energetic electrons and ions because of abundance of the neutral particles [e.g., Paranicas et al., 2007; Sittler et al., 2008]. The observations of injected electrons and ions in the inner magnetosphere suggest that these particles do not survive very long time due to the neutral cloud originated from Enceladus [e.g., Paranicas et al., 2007; 2008]. Thus, the previous study suggested that the neutral cloud contributes to loss processes of plasma in the inner magnetosphere. However, little has been reported on a quantitative study of the electron loss process due to electron-neutral collisions. In this study, we focus on the variation of energetic electron pitch angle distribution at the magnetic equator and loss rate of precipitated electrons into Saturn's atmosphere through pitch angle scattering due to elastic collisions with neutral H2O along Saturn's dipole magnetic field line around Enceladus. Conducting one dimensional test-particle simulation for monoenergetic electrons along Saturn's dipole magnetic field line around Enceladus when the co-rotating electron flux tube passes the dense H2O region in the vicinity of Enceladus (˜6.4 minutes), Tadokoro et al., [2014] showed, in case of 1 keV electron, that

1. the equatorial electron pitch angle distribution near the loss cone (<20 degrees and >160 degrees) decreases with time through pitch angle scattering due to elastic collisions and that the distribution around 90 degrees shows significant scattering due to the dense region of H2O,

2. It is found that the electrons of ˜19 % to the total number of equatorial electrons at the initial condition are lost in ˜380 seconds.

3. The calculated loss time is fourth faster than the loss time under the strong diffusion.

We also show the loss rates through pitch angle scattering of electrons with not only 1 keV but also several hundreds eV to several tens of keV.

Plasma dynamics in Saturn's middle-latitude ionosphere and implications for magnetosphere-ionosphere coupling

Shotaro Sakai[1]; # Shigeto Watanabe[2]
[1] University of Kansas; [2] Cosmosciences, Hokkaido Univ.

Saturn's magnetosphere-ionosphere (MI) coupling is active in the auroral regions at high latitudes. The coupling process in the inner magnetosphere at less than 10 R_S (R_S: Saturn radius = 60268 km) is not well understood. However, the interaction between the ionosphere and Saturn's ring particles was recently studied by using measured depletion of $H_3{}^+$ ions in the ionosphere, called "ring rain". Ring rain ions are probably generated by photoionization of the ring surface. A similar phenomenon is expected to occur in the inner magnetosphere covering the E ring since it also contains mainly water group ions and water ice dust from Saturn's moon Enceladus. Sakai et al. (2013) showed that the magnetospheric electric field generated by the ion-dust collisions slows down the ion velocity from the co-rotation speed in Saturn's inner magnetosphere, and suggested that the dust-plasma interaction occurs via MI coupling. This magnetospheric electric field also strongly depends on the ionospheric Pedersen conductivity. A magneto-hydrodynamics (MHD) model is used to investigate the magnetosphere effect on Saturn's ionosphere. The model includes a magnetospheric plasma temperature of 2 eV as a boundary condition. The main results are (1) H^+ ions are accelerated along magnetic field lines by ambipolar electric fields and centrifugal force, and have upward velocity of about 10 km/s at 8000 km; (2) the ionospheric plasma temperature is 10000 K at 5000 km, since it is significantly affected by heat flow from the magnetosphere at high altitudes; (3) model electron densities agree with densities from occultation observations when the maximum neutral temperature at the latitude of 54 deg. is about 900 K or electrons are heated more around 2500 km; and (4) the ion temperature is high at altitudes above 4000 km and it is almost the same as the electron temperature. The ionospheric Pedersen conductivity which affects the magnetospheric plasma velocity varies with local time between 0.4 and 9 S. We suggest that the subcorotating ion velocity in the inner magnetosphere depends on the local time, because the conductivity generated by dust-plasma interaction in the inner magnetosphere is almost comparable to the ionospheric conductivity. This indicates that magnetosphere-ionosphere coupling is highly important in the Saturn system.

LWA1モジュレーションレーンデータによる木星電波源の位置の測定について

今井 一雅 [1]; 今井 雅文 [2]; Higgins Charles A.[3]; Clarke Tracy[4]
[1] 高知高専・電気情報工学科; [2] 京大・理・地惑; [3] Middle Tennessee State University; [4] Naval Research Laboratory

Source locations of Jupiter's decametric emissions measured by LWA1 modulation lane data

Kazumasa Imai[1]; Masafumi Imai[2]; Charles A. Higgins[3]; Tracy Clarke[4]
[1] Kochi National College of Technology; [2] Department of Geophysics, Kyoto University; [3] Middle Tennesee State University; [4] Naval Research Laboratory

Jupiter is one of the most powerful radio sources at decametric wavelengths. The radio emitting frequency range is from about 3 to 40 MHz. These emissions originate along magnetic field lines within auroral zones as well as field lines that pass through Io and the Io plasma torus. The radio waves at Jupiter are amplified by particle-field interactions and are generated in both the X-mode and O-mode. Due to the emission source parameters, right-hand (RH) polarized waves are generated from northern hemisphere sources (Io-A and Io-B sources) while left-hand (LH) polarized waves come from the southern hemisphere (Io-C and Io-D sources).

The modulation lanes in the dynamic spectra of Jupiter's decametric emission were discovered by Riihimaa in 1968. We developed a model to explain the production of the modulation lanes [Imai et al., 1992a, 1992b, 1997, 2001, 2002]. By using our model the precise Jupiter's radio source locations and beam parameters can be measured. This new remote sensing tool is called as the modulation lane method.

The Long Wavelength Array (LWA) is a low-frequency radio telescope designed to produce high-sensitivity, high-resolution images in the frequency range of 10-88 MHz. The Long Wavelength Array Station 1 (LWA1) is the first LWA station completed in April 2011, and is located near the VLA site in New Mexico, USA. LWA1 consists of a 256 element array, operating as a single-station telescope. The sensitivity of the LWA1 combined with the low radio frequency interference environment allow us to observe the fine structure of Jupiter's decametric modulation lanes.

Using newly available wide band modulation lane data observed by LWA1, we measured source locations and beam parameters. The LWA1 wideband data provides the opportunity to verify the accuracy of the model in fitting the modulation lane curvature. From this modulation lane curvature fitting method for the wideband data, we can establish that the longitude of the intersection of the active magnetic flux tube with the equatorial plane. The results of LWA1 data analysis indicate that the radio emitting sources are located along the restricted range of longitude. We only receive one of the individual sources which has a very thin beam thickness (probably less than few degrees) at a given time. We show the measured locations of Io-related sources based on the modulation lanes observed by LWA1.

改良レイトレーシングによる Cassini 探査機で観測された減衰レーンの研究

今井 雅文 [1]; Lecacheux Alain[2]
[1] 京大・理・地惑; [2] なし

Jovian hectometric attenuation lanes during the Cassini flyby of Jupiter: Enhanced ray tracing study

Masafumi Imai[1]; Alain Lecacheux[2]
[1] Department of Geophysics, Kyoto University; [2] CNRS - Observatoire de Paris, LESIA, Meudon, France

Cassini spacecraft during Jupiter's flyby monitored persistent properties of Jovian hectometric (HOM) radiation, which emanates from radio sources along auroral magnetic field lines in the polar regions. In the HOM dynamic spectrum, the modulated low-intensity property, surrounded by regions of enhancement, is rotationally appeared. This feature is called attenuation lanes, whose cause may be a ray refraction from a high-density medium: either (1) enhanced density in the magnetic L-shell connected Io's orbit or (2) in the Io plasma torus. Recently, Imai et al. [2015] have, by means of a standard ray tracing technique, surveyed the HOM ray trajectories of 0.5-3.0 MHz emissions as the cone half-angles in the continuous radio longitudes vary for northern and southern hemisphere radio emissions. After comparing the attenuation lanes with observations and ray-tracing computations, they pointed out that the main contribution to the attenuation lanes is from a medium (1), in which the reasonable flux shell density n_0 is estimated as 100 cm^{-3} with the half-width 5.0 Io radii. However, a difficult part of the interpretation for the standard ray tracing results is implicitly to treat total ray numbers as being proportional to physical intensity. In overcoming this problem, in addition to the standard ray tracing, we have applied the concept of tracing a family of neighboring rays to the attenuation lanes (i.e., this technique is named as an enhanced ray tracing), thereby comparing the more realistic intensity with the Cassini observations.

木星フライバイ時に Cassini 探査機は木星極域におけるオーロラ磁力線沿いに位置する電波源から放射された木星ヘクトメートル (HOM) 波を継続的に観測した。観測された HOM 波のダイナミックスペクトラムでは、電波強度が高くなった領域に囲まれて、その内側で強度が低くなっている特徴が木星磁場回転毎に出現している。この特徴を減衰レーンと呼び、生成過程は木星 HOM 波が高密度プラズマを通過する際に、電波が屈折することで電波の強弱が生じるためであるとされている。先行研究から、高密度プラズマの候補としては (1) 木星イオの軌道を貫く磁気 L-shell に沿った高密度プラズマ、もしくは (2) イオプラズマトーラスが挙げられる。最近、Imai et al. [2015] では 0.5 MHz から 3.0 MHz までの木星 HOM 波に対して、一般的なレイトレーシングをもとに木星両極の経度方向に存在する電波源から観測者 (Cassini 探査機) に到達するまでの光線軌道を計算した。そして、その計算結果と Cassini 探査機で得られた解析結果とを比較したところ、プラズマ (1) の寄与が減衰レーンの生成に重要な役割を果たすことを見出した。さらに、最適なプラズマ密度は 5.0 イオ半径に広がった 100 cm^3 であることも見積もった。しかしながら、一般的なレイトレーシングで得られる解釈の問題点は観測者に到達した光線の数が物理的な強度に比例していることを暗示している。その問題を解決する一つの方法として、一般的なレイトレーシングを拡張した改良レイトレーシングと呼ばれる、近隣の光線を一つのグループとして扱い、その軌道を追跡する考えを適用することが考えられる。それによって、近隣の光線のグループの軌道の広がりが変化することで物理的な強度に対応することから、Cassini 探査機で観測された電波強度と比較することが初めて可能となる。本発表では、改良レイトレーシングによる計算結果と Cassini 探査機で得られた結果を比較することで、減衰レーンの生成メカニズムの再考を行い、その結果を報告する。

宇宙デカメータ電波源観測における宇宙空間蜃気楼現象

大家 寛 [1]
[1] 東北大・理・地物

Space Mirage Phenomena in the Case of Observations of Cosmic Decameter Radio Waves

Hiroshi Oya[1]
[1] Geophysics, Tohoku Univ.

We are observing the decameter radio waves, from the center part of our Galaxy ,from which we can detect arriving pulse signals that are attributed to be from rotating black holes. During analyses of the data from our Galaxy center using the long baseline decameter radio wave interferometer of Tohoku University, we have met phenomena which could be considered as space mirage. Analyses had been made for detection of decameter signal at 21.865MHzfrom the possible black hole binary that show two kinds of pulse periods of 130 sec and 110 sec ; these periods are modulated by sinusoidal variation with a period of 2300sec reflecting the period of orbital motion of the binary black holes Gaa and Gab system. For the case of analyses of data observed from 22 JST on Feb 27 to 02:30 JST on Feb 28 in 2014 when no Galaxy center observed in the direct sight of observation station, we detected the signal of Gaa and Gab. Because the pulse signals from these black holes are restricted with a given frequency modulation on detected pulse periods, we cannot be mixed the results as contamination of trivial noises from unidentified sources. The possibility of the space mirage has been found after investigation of the ray trace of the decameter radio waves at 21.865MHz using three layers model ionosphere that is constructed being based on data of real time ionosphere sounding at Kokubunji station. The rays from Galaxy center entering into the topside ionosphere eventually arrive at a earth's surface passing through the F2 and F1 layers; at this surface the rays are further reflected into the ionosphere. When one of the reflected ray satisfies the condition of the secant law of the reflection in a layer in the ionosphere ranging from F1 to F2 layers, the ray is reflected to the observation point with large enough rates of power. The numerical solution for this processes indicate that we can detect the signals from radio wave origin even the longitude of the observation point is apart by 45 degree to 60 degree from the limiting longitude of direct observations. That is, we can observe the decameter radio wave source in a form of mirage. We may call the phenomena the space mirage which may occur also in the cases of observations of cosmic decameter radio waves such as from Jupiter , and Cassiopeia-A not being restricted in the case of the present studies of the decameter radio wave pulses from the Galaxy center.

木星デカメータ波源や、カシオペア A 電波源のように 20MHz から 30MHz 帯の宇宙電波源観測は広く行われているが、本研究では銀河中心部からくる特異なデカメータ電波パルス群の電波源位置の決定を目指し 100km 級長距離基線をもつ東北大学デカメータ電波長距離干渉計システムを用いて観測、解析を行っている。今回、その解析研究を通じ電離層蜃気楼現象が存在することが判明したので報告する。

ここで観測対象となるデカメタ電波は 21.86MHz で帯域 100Hz で周期 30sec から 140sec の間にあるパルスを探索している。パルス・レベルは背景放射の 0.1-0.8%程度で非常に S/N 比が小さく、特殊な解析法を必要とする。即ち、パルス周期を探索し、非常に多数回信号を重ねる Box-Car 法にて信号検出を行っている。解析結果は対をなす二種のパルスの周期は正弦的に変動することを示す。　これを、本研究では公転するバイナリ―・ブラックホールからの信号と捉え、検出されるパルスはカー・ブラックホールの自転周期と同期し、周期の正弦的な変化は対をなすブラック・ホールの公転にともなう Doppler 効果と結論している。今回、周期 130sec 及び 110sec でその周期変動 2300sec の Gaa-Gab ブラックホールバイナリ―からのパルスに対し電波源方位を決定する解析作業に伴い電離層効果による蜃気楼によると判定する現象が表れた。

解析対象は 2014 年 2 月 27 日 22 時から 28 日 02 時 30 分に観測されたデータで、この時間帯は銀河中心部が直視範囲にないが、問題の Gaa-Gab 信号が継続的に検出された。

対象となるパルス信号は公転周期 2300 秒で周波数変調を受けはっきりした制約条件があり、単なる異質雑音の混入として結論することは不可能で、その直視条件を超えて銀河中心部より信号が到来するか否か、その可能性を検討した。

検討では実観測時刻における国分寺の電離層垂直打ち上げ観測データを基に、電離層をトップサイド、F2 層、及び F1 層の３層にモデル化し、Ray-Theory によって銀河系中心方向から到来する 21.86MHz の電波伝搬方向を追跡した。対象となる Ray は一旦、地表面（海面）に到来した後、その反射成分が F1 層に向かって再突入する。ここで、F1 層から-F2 層の間でセカント則を満たす反射条件がとれる様に入射した Ray は全反射して観測点に到来するといった解を与える。その結果観測点位置が直視経度を 45 度から 60 度以上も離れた時刻にあっても信号は十分な強度で観測点に到来することが出来る。その到来方位は Azimuth 方向には銀河中心の視経度と対応した一点となり観測時刻とともに移動するが、仰角方向には対応するすべての時間帯で 4 度から 25 度と広がって観測される。

以上直視時間を超えて観測される現象を本研究では宇宙空間蜃気楼と呼ぶことにした。

MHD simulation of Mercury's magnetosphere in extreme solar wind condition

Manabu Yagi[1]; Kanako Seki[2]; Yosuke Matsumoto[3]; Dominique Delcourt[4]; Francois Leblanc[5]
[1] PPARC, Tohoku Univ.; [2] STEL, Nagoya Univ.; [3] Chiba University; [4] LPP, Ecole Polytechnique, CNRS; [5] LATMOS-IPSL, CNRS

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

水星ナトリウム大気の長期時間変動

安田 竜矢 [1]; 亀田 真吾 [1]; 鍵谷 将人 [2]; 米田 瑞生 [3]; 岡野 章一 [4]
[1] 立教大; [2] 東北大・理・惑星プラズマ大気研究センター; [3] 東北大・理・惑星プラズマ大気; [4] 東北大・理・PPARC

Long-term temporal variation of Mercury's sodium exosphere

Tatsuya Yasuda[1]; Shingo Kameda[1]; Masato Kagitani[2]; Mizuki Yoneda[3]; Shoichi Okano[4]
[1] Rikkyo Univ.; [2] PPARC, Tohoku Univ; [3] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [4] PPARC, Tohoku Univ.

The very thin atmosphere of Mercury contains hydrogen, helium, oxygen, sodium, potassium, and calcium atoms, as observed by space probes Mariner 10 and MESSENGER and ground-based observations. These atoms emit light, with resonance scattering caused by energy from sunlight. Because of its high intensity, the emission of sodium atoms is well suited for studies by ground-based observations. The source processes of Mercury's exosphere are considered to be solar-photon-stimulated desorption, sputtering by impacting solar wind particles crashing into Mercury's surface and releasing atoms, and interplanetary dust vaporization. A combination of these three processes has been considered, although the primary process among them is unknown.

In the present study, daily variation in Mercury's sodium exosphere was observed at the Haleakala Observatory in Hawaii by using a 40 cm Schmidt Cassegrain telescope, a high-dispersion spectrograph, and a charge coupled device (CCD) camera. During observation seasons, elongation between Mercury and the Sun was more than 15 deg, and the observation time varied from 30 min to 1 h before sunrise or after sunset. We estimated the averaged column density of sodium atoms by using the exospheric model and assuming constant exospheric temperature.

The observation of this study confirmed that the column density of sodium atoms over the dawn side differs from that over the dusk side. We originally focused on column density over the dawn side, which had been observed until January 2015. However, our observational data of March 2015 confirmed significant variation over the dusk side. In addition, we examined the ratio between the dawn and dusk sides. Although the ratio is roughly 1 at the true anomaly angle (TAA) of more than 180 deg, the maximum of the ratio is greater than 2 at the TAA of less than 180 deg.

In the observational data of the dawn side, the local maximums of the column density of sodium atoms were at the TAAs of approximately 140 deg and 320 deg, which indicates contribution by interplanetary dust impact. Interplanetary dust is known to be distributed densely in the dust symmetry plane; however, its detailed distribution in the vicinity of Mercury is unknown. By applying the dust distribution model by Kelsall et al. [1998], these TAAs show the points at which Mercury passes through the dust symmetry plane. To verify the contribution of interplanetary dust to exospheric yield over the dawn side, model parameters that maximize the correlation coefficient were derived, revealing a value of 0.822. Therefore, the column density of sodium atoms may correlate highly with the interplanetary dust density.

However, the variation in column density over the dusk side showed a local maximum near the TAA of 180 deg. Therefore, such variation cannot be explained by the consideration applied to the dawn side. Thus, it is necessary to examine factors indicating the differences in variation between the dawn and dusk sides.

水星は極めて希薄な大気を持つ。水星大気に対してこれまでに、水星探査機 Mariner 10 と MESSENGER による観測、および地上観測が行われてきた。これらの観測により、大気中に H、He、O、Na、Mg、K、Ca が存在することが知られている。これらの原子は太陽光のエネルギーを受けて共鳴散乱により発光する。これらの中でもナトリウムは発光強度が高く、地上観測に適しているため多くの観測が行われてきた。水星のナトリウム大気の生成過程は、太陽光による表面原子の脱離、太陽風イオンによるスパッタリング、微小隕石の衝突による水星表面や隕石中の原子の気化などが考えられている。これらの過程は複合して起こると考えられているが、主な生成過程は未だ明らかにされていない。

本研究ではハワイ・ハレアカラ観測所の口径 40cm のシュミット・カセグレン式望遠鏡、高分散エシェル分光器、および CCD カメラを使用して水星ナトリウム大気光の分光観測を行い、水星大気中のナトリウム原子数の日ごとの変動を調べた。水星は太陽に最も近い惑星であるため、観測に適した時間は限られている。私たちは水星と太陽の離角が 15 度以上の時期に、日の出前または日没後の 30 分から 1 時間程度の時間内に観測を行った。地上から観測できる大気光は昼側全体ではなく一部であり、観測できる大気光の割合は位相角によって変化する。そのため一定の大気温度を仮定した大気モデルをもとに、位相角ごとに観測可能な大気光の割合を計算し、平均のナトリウム原子密度を推定した。

本研究の観測により、ナトリウム原子密度は水星の明け方側と夕方側で異なる変動を示すことが確認されている。私たちは 2015 年 1 月までの観測データに対して、より顕著な変動が見られる明け方側の観測データに注目していた。しかし、私たちの 2015 年 3 月の観測により、夕方側のデータにも軽視できない変動が確認された。また、明け方側と夕方側の比を調べると、真近点離角（TAA）180 度以降ではおおよそ朝夕比が 1 であるのに対し、180 度以前では朝夕比が最大で 2 以上になる。

明け方側のデータに注目すると、TAA 140 度付近と TAA 320 度付近でナトリウム原子密度の極大が見られる。このことから、私たちは微小隕石衝突が寄与すると予想した。惑星間空間の微小隕石はある平面（ダスト対称面）に集中して対称に分布することが知られているが、水星近傍における詳細な分布は知られていない。Kelsall et al. [1998] による隕石分布モデルを適用すると、これらの TAA は水星がダスト対称面を通過するときの値である。私たちは明け方側のナトリウ

ム大気生成に対する微小隕石衝突の寄与を検証するために、隕石分布モデルを用いて相関が最大になるときのモデルのパラメータを求めた。その結果、相関係数は最大でr=0.822 となり、微小隕石の分布と強く相関する可能性が示された。

一方で、夕方側の観測データに注目すると、TAA 140 度付近と TAA 320 度付近には極大が見られず、TAA 180 度付近に極大が見られる。したがって、夕方側におけるナトリウム原子密度の変動については、明け方側と同様の考察では説明することができない。今後、明け方側と夕方側で異なる変動を示す要因について検討が必要である。

金星日面通過時の太陽観測衛星の画像を用いた金星大気研究 (2)

金尾 美穂 [1]; 中村 正人 [2]; 今村 剛 [3]
[1] 宇宙科学研究所; [2] 宇宙研; [3] JAXA 宇宙科学研究所

A study on the atmosphere of Venus with the Hinode observation during the transit of Venus (2)

Miho Kanao[1]; Masato Nakamura[2]; Takeshi Imamura[3]
[1] ISAS; [2] ISAS,JAXA; [3] ISAS/JAXA

The transit is one of the chances to observe the atmosphere of Venus. The round arc is observed along the limb of Venus disk at the beginning and the end on the transit of Venus. The SOT onboard HINODE captured the arc spreading from the equator to the northern pole of Venus in 109 x 109 arcsec images, on July 2012.

The bending angle smaller than 1.0 degree due to the atmosphere above 60 km of Venus make us enable to observe the refracted solar light. The intensity at the arc (~100 DN $pixel^{-1}$ sec^{-1}) is 1 to 2 orders weaker than that of the solar photosphere.

We aimed to interpret the vertical profile of the intensity observed during the transit of Venus. The intensity was estimated following the four steps; 1) The bending angle of the solar light in the geometry of the transit of Venus using the temperature and the density of the VIRA (Seiff et al., 1985). 2). The modeled transmittance in the atmosphere of Venus referring the spectroscopic observation by Wilquet et al. (2009). 3) The intensity profile convolved by the point spread function of the Gaussian with 0.16 arc sec FWHM (Suematsu et al., 2009).

The altitude defined as the peak intensity of the observation is higher than the estimated intensity profile by 10 km. We tried the some atmospheric temperature based on VIRA and the transmittance due to the cloud scattering to reproduce the observed intensity profile. We could show the atmospheric temperature and the transmittance model in the wide latitudinal range with the images had taken during the transit. Thank you.

金星に到達する太陽光は蜃気楼のように大気によって 0.1 度前後屈折する。金星日面通過の始まりと終わりの時間帯に、地球方向に屈折した太陽光は金星大気層に相当する細い領域に沿ってアーチ型に観測できる。ひので衛星搭載の SOT は 388.35 nm から赤色連続光 668.40nm までのフィルターを用いて 109 秒角四方の画像を取得し、雲粒による散乱を受けた太陽光を高度およそ 70km 以上に捉えた。2012 年 6 月の金星日面通過の最初では金星朝側子午面の北半球、日面通過の終わりには夕方側子午面の北半球で屈折太陽光の観測を行った。

VIRA モデルと分光計によって観測された大気透過率を基に、ある緯度において観測できる太陽光強度の高度プロファイルを導出した。しかし、実際に画像で得られた屈折光の強度分布とは強度に数 10 DN $pixel^{-1}$ s^{-1} 程度の、高度方向に 10km 程度のずれが見られた。

幾つかの大気温度と透過率を仮定し PSF を考慮して屈折太陽光の強度を予測し、観測されたプロファイル説明できる大気温度と透過率のモデルを決定付ける。太陽リムを光源とする太陽光は、屈折光の強度は高度 110 km 付近でおよそ 100 DN $pixel^{-1}$ s^{-1} とピークに相当し、その高度は時間変化する。ジオメトリーによって決定でき時間変化する屈折角から、大気のスケールハイトを導出できる。これらを合わせて金星日面通過時における大気温度、大気透過率を決定する。惑星北半球全体と広範囲に渡る撮像を行った 2 次元画像から導出される物理量を用いて、雲頂付近の大気と雲粒の鉛直運動について議論する。

電波ホログラフィ法による金星大気の電波掩蔽データの解析

宮本 麻由 [1]; 今村 剛 [2]; 安藤 紘基 [3]; 津田 敏隆 [4]; 青山 雄一 [5]
[1] 東大・理・地惑; [2] JAXA 宇宙科学研究所; [3] ISAS/JAXA; [4] 京大・生存研; [5] 極地研

Radio holographic analysis of Venus' radio occultation data

Mayu Miyamoto[1]; Takeshi Imamura[2]; Hiroki Ando[3]; Toshitaka Tsuda[4]; Yuichi Aoyama[5]
[1] Earth and Planetary Science, The University of Tokyo; [2] ISAS/JAXA; [3] ISAS/JAXA; [4] RISH, Kyoto Univ.; [5] NIPR

The radio occultation is one of the important measurements for studying planetary atmosphere. Temperature profiles of the planetary atmosphere can be derived through the radio occultation technique. The radio occultation method relies on the measurement of the frequency shift of the received signal caused by the bending of radio waves in the radial gradient of the refractive index in the atmosphere. The geometrical optics method has long been used for the analysis of radio occultation data. However, this method cannot disentangle multipath rays and vertical resolution is limited by the size of the Fresnel zone (~1 km). Gravity waves with vertical wavelengths from a few tens of meters to kilometers have been observed in the Earth's atmosphere by radiosondes and radars. Also in the atmospheres of other planets, gravity waves are observed by various methods including radio occultation.

Radio holographic methods have been proposed for processing of radio occultation signals in multipath regions and obtaining atmospheric profiles with high resolution. One of them is the Full Spectrum Inversion (FSI), which was recently applied to GPS occultation data of the Earth's atmosphere. By applying this technique to Venus Express radio occultation data, we derived temperature profiles with high vertical resolution. In this presentation, the FSI technique will be introduced and the high resolution temperature profile and the vertical wave number spectra of gravity waves will be shown.

電波掩蔽とは探査機が地上局から見て惑星の背後を通過した際に、探査機から送信された電波が惑星大気を通過し地上局に届くことを利用した観測である。惑星大気の高度方向の温度分布を測定することができ、惑星探査における重要な観測手法のひとつである。例えば、この温度の鉛直分布から波に伴う温度擾乱を抽出し、大気重力波の性質が議論されている。重力波は浮力を復元力とする波動で、運動量やエネルギーを鉛直輸送して大気大循環を駆動すると考えられている。また上方伝搬と共に波の振幅が大きくなると、対流不安定やシアー不安定といった局所的な不安定を介して砕波し、それに伴う乱流は物質やエネルギーや運動量の拡散に重要な役割を果たすと考えられている。地球大気では、ラジオゾンデやレーダーにより鉛直波長が数十 m〜数 km の重力波が観測され、小スケールの波の構造まで良く理解されている。しかし、惑星大気の観測では従来の電波掩蔽データの解析において電波を 1 本の光線として扱う幾何光学解法が用いられているため、屈折率の勾配が大きい領域を通過した電波は、複数経路 (マルチパス) の電波と重なり地上で同時に受信されてしまうため、分離できない。また、電波の回折効果により鉛直分解能が 1 km 程度に制限されるため、これでは幅広い重力波スペクトルのうちのごく一部分しかとらえておらず、地球以外の惑星における重力波の伝搬・散逸過程はほとんど理解されていない。

そこで我々は、近年の地球大気における GPS 掩蔽観測で用いられている電波ホログラフィ法という、受信信号の振幅と位相の時系列全体を同時にスペクトル解析して分解能を上げる解法を金星大気に応用した。このことにより、鉛直波長 100 m 程度という高分解能な金星大気の温度の鉛直分布が得られ、またマルチパスの影響により今まで正しく求めることができなかった金星の中高緯度に見られる局所的な低温域の温度構造が明らかになった。本発表では新たに用いた解析手法について述べる。また、得られた温度の鉛直分布から重力波に伴う温度擾乱を抽出し、より高波数側まで求まった鉛直波数スペクトルや、より高分解な大気安定度の鉛直分布についても紹介する。

金星雲層高度における温度擾乱の時間・空間的な変動

神山 徹 [1]; 佐藤 隆雄 [2]; 佐川 英夫 [3]
[1] 産総研; [2] 宇宙研; [3] 京都産業大学

Spatial and temporal variations of thermal fluctuations in Venus middle atmosphere as seen by IRTF ground-based observations

Toru Kouyama[1]; Takao Sato[2]; Hideo Sagawa[3]
[1] AIST; [2] ISAS/JAXA; [3] Kyoto Sangyo University

Previous studies on cloud brightness patterns and wind velocity fields have shown the presence of many kinds of transient waves, with various spatial scales, in the Venus atmosphere. On the other hand, there has been less clues of periodical perturbations in cloud thermal structures, and thus the understanding on relationship between thermal fluctuation in the cloud top altitudes and spatial/temporal variations in Venus atmosphere has been poorly revealed. Recently a model research showed Kelvin and Rossby waves can provide thermal perturbations with the amplitude of 1 K based on results of wind speed analysis using images from Venus Monitoring Camera onboard Venus Express. Since the amplitude and the phase of thermal fluctuation are one of key components which represent characteristics of a wave structure and its propagating structure, analyzing thermal fluctuations should provide additional hints for investigating wave activities in Venus atmosphere.

We have conducted ground-based observations at 4.5 um using Infrared Telescope Facility (IRTF) in December 2013, and July 2015. NSFCam2 and SpeX instrument were used for the former and latter period, respectively. At this M-band wavelength, the thermal radiation emitted from the altitude around 70 km is observed at both day and night-side hemispheres of Venus. Relatively small scale features (several hundred km scale) were clearly seen in the high-passed Venus images, and westward motion of these features were confirmed by comparing images taken with ˜1 hr separation. In addition to M-band images, we obtained 2.3 um near-infrared images of Venus at which the spatial distribution of cloud opacity is illuminated as a silhouette against the hot thermal emission from the lower atmosphere. Such 2.3 um images were also taken with ˜1 hr separation so that we can derive the short-term temporal variation (movement) of the cloud opacity. Comparison of propagation velocities between upper and lower cloud regions may provide a hint of existence of thermal connection between both layers.

惑星高層大気の直接観測に向けた中性粒子質量分析器ANAの較正試験

有見 弘毅 [1]; 下山 学 [2]; 石黒 恵介 [1]; 平原 聖文 [1]
[1] 名大・STE研; [2] IRF

Experimental development of Atmospheric Neutral Analyzer (ANA) for in-situ observations of planetary upper atmospheres

Kouki Arimi[1]; Manabu Shimoyama[2]; Keisuke Ishiguro[1]; Masafumi Hirahara[1]
[1] STEL, Nagoya Univ.; [2] IRF

The dynamics in the neutral upper atmosphere of the Earth and the other planets affect the environment of their ionospheres and the thermospheres. Observations in the terrestrial and planetary neutral atmospheres such as the Earth, Mars, and Venus have been mostly carried out by remote sensing, while in-situ observations of neutral atmospheres have been accomplished only few times. The in-situ observations utilizing by spacecraft are needed for understanding atmospheric circulations, heating, and dissipation.

We are newly developing a Bennett-type radio-frequency mass spectrometer, which is called Atmospheric Neutral Analyzer (ANA). The ANA is capable of observing 2-D velocity distributions, from which density, wind velocity and temperature are derived, for each component of neutral species. The ANA consists mainly of five sections: an entrance slit, an ionization section utilizing electron gun, a pre-acceleration section, a Radio Frequency (RF) stage for mass spectrometry, and a detection section which obtains 2-D velocity distributions in combination of MCP with 2-D position-sensitive device. We now concentrate on the development of the whole ion mass spectrometer after the ionization section.

We use a suprathermal ion beam line for the calibration of the ANA. For the calibration, we set the engineering model of the ANA in a vacuum chamber, and emit several types of ion beams, and investigate its responses. Because our beam line facilities are currently under development, it is still difficult to emit suprathermal ion beams stably. In the previous performance verification, we could not obtain adequate beam properties with Ar^+ beams. In order to improve the beam profiles, therefore, we attempt to investigate the responses of the ANA by utilizing heavier ions such as Xe^+ (130amu).

As mentioned above, suprathermal ion beam flux varies according to a particle species. The ion beam which it is easy to irradiate most is Ar^+. In addition, the targeted mass resolution of ANA, i.e. m/(delta m) is equal to 10. Therefore, we are now preparing the calibration to verify whether the mass separation between the Ar^+ (40amu) and $CO_2{}^+$ (44amu) will be possible or not.

In the presentation, we will show the overall design of the ANA regarding the mass spectrometry and the characteristics investigated by the simulation and the beamline experiments.

Design of the suprathermal ion mass spectrometer (STIMS) and experimental study of ion scattering characteristics at foil

Keisuke Ishiguro[1]; Masafumi Hirahara[1]; Kouki Arimi[1]
[1] STEL, Nagoya Univ.

In ionospheres of non-magnetized planets, e.g., Venus and Mars, planetary ions directly interact with the solar wind magnetic field due to the absence of intrinsic magnetic fields. These ions are accelerated up to suprathermal energies and escape from the planetary ionospheres, which is so-called ion pickup that is one of the processes of planetary ion escape. This process is an interesting topic of space physics around the non-magnetized planets. As for major ions such as H^+ and O^+, three-dimensional ion velocity distributions have been successfully obtained by in-situ observations. There is, however, a problem that conventional observation techniques have not been sufficient to derive precisely three-dimensional velocity distributions of heavier molecular ions such as CO^+/$N_2{}^+$ and $CO_2{}^+$. This problem is caused by low mass resolutions of the conventional space-born mass spectrometers. In order to improve the mass resolutions, we have been designing a suprathermal ion mass spectrometer (STIMS) for future in-situ observations of the three-dimensional ion velocity distributions around the planetary ionospheres.

The STIMS consists of (a) a top-hat type electrostatic analyzer (ESA) and (b) a time-of-flight (TOF) analyzer. A field of view of the STIMS is about 4 PI sr per a half spin of spin-stabilized spacecraft. A target energy range is from 0.1 to 300 eV, which corresponds to suprathermal energies, and a mass range is from 1 to 50 amu. We aim to achieve an energy resolution (deltaE/E) that is better than 5%, and a mass resolution (M/deltaM) that is over 10.

(a) An energy analysis of the STIMS is carried out with the top-hat type ESA, which consists of two dome-shaped electrodes: inner and outer dooms. In order to deflect incident positive ions by 90 degrees, a sweeping negative voltage is applied to the inner dome, while the outer dome is grounded. Only ions that drift around a center radius of the two domes can enter the TOF analyzer. Between the ESA and the TOF analyzer, the ions are accelerated by -10kV.

(b) The TOF analyzer of the STIMS is mainly made up of three elements: carbon foils, guiding electrodes and micro-channel plate assemblies (MCP). TOFs are obtained from time differences between start and stop signals. Just as the accelerated ions get through the foil, secondary electrons are emitted. Guided by the electrodes, the emitted electrons arrive at the start MCP and generate the start signals. In the same way, the stop signals are generated when the ions arrive at the stop MCP.

The profiles of TOF in the STIMS are simulated with SIMION. Generally, after penetrating the foil, particle velocities decrease by a few percent and, at the same time, charge exchange and/or dissociation could occur. Whether or not the charge exchange and/or the dissociation occur, it is possible to obtain the particle TOFs when velocities of all particles are equal after penetrating the foil. In this simulation, therefore, it is assumed that the velocities of all particles are equal after penetrating the foil.

This assumption seems to be theoretically valid, but it is necessary to confirm experimentally. Thus, our group are now conducting experimental research so as to investigate following characteristics of the particles after penetrating the foil: (1) particle velocity distributions, (2) angular scattering distributions, (3) charge exchange type and rate, (4) dissociation type and rate. We have been designing an experimental device. In the device, two types of MCPs are applied: one-dimensional position-sensitive MCP for the detection of the particle angular scattering distributions, and high-speed response (TOF) MCP for the identification of the particle velocity distributions. We are planning to utilize our low-energy beam line facility in our laboratory, which is able to emit several types of ion beams such as H^+, N^+, Ar^+, $N_2{}^+$ and $CO_2{}^+$ with 10keV.

Atmospheric escape induced by magnetic reconnection in the dayside ionosphere of an unmagnetized planet

Hitoshi Sakamoto[1]; Naoki Terada[2]; Yasumasa Kasaba[3]
[1] Geophysics, Tohoku Univ; [2] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [3] Tohoku Univ.

The ionospheres of unmagnetized planets such as Venus and Mar directly interact with the solar wind. At an unmagnetized planet, magnetic reconnection can occur in the dayside ionosphere, induced magnetotail, and regions around crustal magnetic fields. We have studied magnetic reconnection caused by the rotation of the interplanetary magnetic field (IMF) in the ionospheres of Venus and Mars by performing local numerical simulations.

At Venus and Mars, some satellites have observed Hall magnetic fields [Eastwood et al., 2008; Halekas et al., 2009], plasmoids and flux ropes [Zhang et al., 2012; Eastwood et al., 2012] generated by magnetic reconnection, but the effects of the magnetic reconnection on the atmospheric escape and the structure of their ionospheres have been unclear. Dreher et al. [1995] suggested that the ejections of ionospheric plasma clouds [Brace et al., 1982] can be caused by magnetic reconnection in the dayside ionosphere based on the result of Pioneer Venus Orbiter observation, which showed a correlation between the rotation of IMF and the cloud ejections [Ong et al., 1991]. However, performing a linear analysis and an MHD simulation, Dreher et al. [1995] estimated only the linear growth time of magnetic reconnection at the Venus ionopause, so its nonlinear stage and the resultant loss rate of ionosphereric ions have yet to be investigated.

In this study, using 2-D multi-species MHD simulations, the spatiotemporal evolutions of magnetic reconnection in the ionospheres of Venus and Mars are examined and the loss rates of the ionosphereric ions are also estimated.

In the case of Venus ionosphere, our simulation result shows that plasmoid instability [Loureiro et al., 2007] occurs in a Sweet-Parker (SP) current sheet above 240 km altitude where Lundquist number exceeds 10^6, and consequently many plasmoids are generated. In the nonlinear stage, some monster plasmoids [Loureiro et al., 2012], which are larger in size than the initial current sheet thickness, are generated through plasomoid coalescences. These monster plasmoids are as large as the giant ropes observed by Venus Express [Zhang et al., 2012], and it is suggested that the giant flux ropes can be generated by the plasmoid instability.

As a result of the acceleration due to the reconnection, ionospheric plasma is ejected to the outside of the current sheets with a local Alfven velocity. According to our simulation results, the loss rate at the Venus ionopause is about 10^{24} [s^{-1}]. This value is smaller than that estimated by Pioneer Venus Orbiter observation ($1.7*10^{26}$ [s^{-1}][Brace et al., 1982], $1*10^{25}$[s^{-1}][Lammer et al., 2006]), but is of the same order as that estimated from Venus Express observation ($2.7*10^{24}$ [s^{-1}] [Fedorov et al., 2011], $4.9*10^{24}$ [s^{-1}] [Masunaga et al., 2013])

The magnetic reconnection in the dayside ionosphere of Mars has been also studied. The estimated Lundquist number in the Mars ionosphere exceeds 10^6 above 200km altitude and it is expected that plasmoid instability can occur also in the Mars ionosphere. In the presentation, the loss rate for the case of the Mars ionosphere will be reported.

金星・火星を始めとする非磁化惑星では、太陽風と電離圏が直接相互作用する環境にあり、昼側電離圏、誘導磁気圏の尾部付近、残留磁場付近で磁気リコネクションが起こると考えられている。我々は、中でも惑星間空間磁場 (IMF) が回転した時に昼側電離圏で起きる磁気リコネクションをローカルシミュレーションによって調査している。

金星および火星では、いくつかの人工衛星により無衝突リコネクションに起因する Hall 磁場 [Eastwood et al., 2008；Halekas et al., 2009] や、リコネクションにより形成されたプラズモイドやフラックスロープが観測されているが [Zhang et al., 2012；Eastwood et al., 2012]、惑星大気の散逸や電離圏の構造に対する磁気リコネクションの影響は、いまだに不明確な点が多い。Dreher et al. [1995] は、Pioneer Venus Orbiter の観測において、IMF の回転と電離圏からプラズマ雲の放出に相関があった [Ong et al., 1991] ことから、昼側電離圏での磁気リコネクションがプラズマ雲の放出 [Brace et al., 1982] に関連する可能性を示唆した。しかしながら、同研究では、線形解析と数値シミュレーションに基づいた金星の電離圏界面における磁気リコネクションの線形成長時間の見積りに留まり、非線形発展ならびにその帰結として生じる電離圏イオンの散逸率は見積もられていない。

本研究では、金星ならびに火星の昼側電離圏で生じる磁気リコネクションを二次元多成分磁気流体力学シミュレーションにより再現し、現象の時空間発展を調査するとともに、電離圏イオンの散逸率の見積もりを行う。

シミュレーションの結果によれば、金星の電離圏について、Lundquist 数が 10^6 を超える高度 240km 以上において、プラズモイド不安定 [Loureiro et al., 2007] が発生し、Sweet-Parker 型電流シート内の多数の点でリコネクションが起こり、多数のプラズモイドが発生することが確認された。非線形段階においては、プラズモイド同士が互いに合体することで初期の電流シートの厚みを超えるモンスタープラズモイド [Loureiro et al., 2012] が形成されることも確認された。このプラズモイドは、Venus Express 衛星で観測された巨大なフラックスロープ [Zhang et al., 2012] に匹敵するサイズであり、プラズモイド不安定と巨大フラックスロープの関係が示唆された。リコネクションによる加速の結果、電離圏のプラズマはアルフベン速度程度で電流シートから放出されることが確認され、金星の電離圏界面付近におけるこの過程による O+の散逸率は 10^{24} [s^{-1}] 程度となることが見積もられた。この値は Pioneer Venus Orbiter の観測で見積もられたプラズマ雲による散逸率 $1.7*10^{26}$ [s^{-1}][Brace et al., 1982]、$1*10^{25}$[s^{-1}][Lammer et al., 2006] よりも小さな値だが、Venus Express の観測による見積もり $4.9*10^{24}$ [s^{-1}] [Masunaga et al., 2013]、 $2.7*10^{24}$ [s^{-1}] [Fedorov et al., 2011] とは同程度の散逸率であった。

現在、火星における昼側電離圏の磁気リコネクションも調査を行っている。火星電離圏における Lundquist 数を調べたところ、高度 200km 以上の領域では Lundquist 数は 10^6 を超えており、火星においても同様にプラズモイド不安定が起こることが予想される。発表においては、火星における電離圏イオン散逸率も報告する予定である。

火星探査機MAVENによって観測された大密度勾配プラズマ境界層の構造とケルビン・ヘルムホルツ不安定性への影響

関 華奈子 [1]; 松本 洋介 [2]; 寺田 直樹 [3]; 原 拓也 [4]; 松永 和成 [1]; 益永 圭 [5]; 藤本 正樹 [6]; Brain David A.[7]; McFadden James P.[4]; Halekas Jasper S.[8]; Mitchell David L.[4]; Andersson Laila[9]; Espley Jared R.[10]; Connerney John E. P.[10]; ベイカー ダニエル [11]; Jakosky Bruce M.[9]
[1] 名大STE研; [2] 千葉大理; [3] 東北大・理・地物; [4] SSL, UC Berkeley; [5] 名古屋大・STEL
; [6] 宇宙研; [7] LASP, Univ. of Colorado at Boulder, USA; [8] Dept. Phys. & Astron., Univ. Iowa; [9] LASP, CU Boulder; [10] NASA GSFC; [11] コロラド大学

Structure of plasma boundaries with a large density gradient observed by MAVEN and its effects on the Kelvin-Helmholtz instability

Kanako Seki[1]; Yosuke Matsumoto[2]; Naoki Terada[3]; Takuya Hara[4]; Kazunari Matsunaga[1]; Kei Masunaga[5]; Masaki Fujimoto[6]; David A. Brain[7]; James P. McFadden[4]; Jasper S. Halekas[8]; David L. Mitchell[4]; Laila Andersson[9]; Jared R. Espley[10]; John E. P. Connerney[10]; Daniel Baker[11]; Bruce M. Jakosky[9]
[1] STEL, Nagoya Univ.; [2] Chiba University; [3] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [4] SSL, UC Berkeley; [5] STEL, Nagoya Univ.; [6] ISAS, JAXA; [7] LASP, Univ. of Colorado at Boulder, USA; [8] Dept. Phys. & Astron., Univ. Iowa; [9] LASP, CU Boulder; [10] NASA GSFC; [11] LASP, Univ. Colorado

In space plasmas, collisions between constituent particles are usually negligible. Moreover, how to cause plasma mixing across different plasma regimes has been one of the fundamental problems in the plasma universe. At a plasma boundary where different plasma regimes are in contact, there often exists a velocity shear and a density gradient. The Kelvin-Helmholtz instability (KHI) has been studied as a promising mechanism to cause the plasma mixing. Although the importance of the density gradient has previously been pointed out, the structure of large-density gradient boundaries remains unknown due to lack of observations. Based on plasma observations at Mars by MAVEN, we show here that the real structure of velocity-sheared boundaries with a 3-order density gradient has a fundamental difference from the traditional input model used in various simulation studies. We propose a new boundary model adopting entropy considerations to agree with the new observations. Comparison of MHD simulation results with the two different initial conditions shows that the change in the initial condition alters the time evolution of KHI and it can potentially affect the escape rate of cold ionospheric ions. The effects on KHI also depend on the magnitude of the density gradient across the boundary. Particularly in high density gradient case with a density ratio of 5000, KHI cannot develop in the traditional boundary model. On the other hand, KHI can be excited in our realistic new model due to the difference in compressibility effects at the velocity shear layer.

赤外ヘテロダイン分光器 MILAHI を用いた火星・金星大気観測

中川 広務 [1]; 青木 翔平 [2]; 佐川 英夫 [3]; 笠羽 康正 [4]; 村田 功 [5]; 高見 康介 [1]; 鍵谷 将人 [6]; 坂野井 健 [7]; 岡野 章一 [8]
[1] 東北大・理・地球物理; [2] IAPS-INAF, Italy; [3] 京都産業大学; [4] 東北大・理; [5] 東北大院・環境; [6] 東北大・理・惑星プラズマ大気研究センター; [7] 東北大・理; [8] 東北大・理・PPARC

IR heterodyne spectrometer MILAHI observations of atmospheres on Mars and Venus

Hiromu Nakagawa[1]; Shohei Aoki[2]; Hideo Sagawa[3]; Yasumasa Kasaba[4]; Isao Murata[5]; Kosuke Takami[1]; Masato Kagitani[6]; Takeshi Sakanoi[7]; Shoichi Okano[8]
[1] Geophysics, Tohoku Univ.; [2] IAPS-INAF, Italy; [3] Kyoto Sangyo University; [4] Tohoku Univ.; [5] Environmental Studies, Tohoku Univ.; [6] PPARC, Tohoku Univ; [7] Grad. School of Science, Tohoku Univ.; [8] PPARC, Tohoku Univ.

Mid-Infrared LAser Heterodyne Instrument (MILAHI) is one of a facility science instruments aboard Tohoku University-60cm dedicated telescope (T60) at the top of Mt. Haleakala (h=3,055m), Hawaii, which is well suited for infrared spectroscopy by low humidity. MILAHI is designed to explore the planetary atmospheres and study its dynamics, thermal structure, and compositions. The instrument with more than million spectral resolution is one of the most powerful spectroscopy in the mid-infrared regime with several key capabilities: (1) fully resolve molecular features to address the atmospheric temperature and abundance vertical profiles, (2) direct measurement of the mesospheric wind and temperature with high precision, (3) sensitive detection of minor trace gases and isotopic ratios without any ambiguity with the strong terrestrial absorptions. In addition, T60 enables us to perform long-term monitor including the support campaign for orbiter missions. Transient events and time-sensitive applications, such as dust storm on Mars and cometary activities can also be measured flexibly.

The IR heterodyne detection is analogous to spectroscopy technique in radio frequency range. An IR source from the plants is combined with a laser local oscillator, and focused onto a MCT photodiode mixer with 3 GHz bandwidth. The resultant intermediate frequency is in the radio region of the electromagnetic spectrum and it preserves the intensity and spectral information of the IR spectrum. Notable successes on Venus, Mars, Jupiter, Titan, and Earth were accomplished by NASA/GSFC, University of Cologne, and Tohoku University so far. Thanks to a wide coverage of combination of quantum cascade lasers (30-100 mW) and a compact CO2 gas laser (400mW), MILAHI derives atmospheric properties through spectroscopic measurements of IR emissions and absorptions of atmospheric gases in 7.69-7.73, 9.54-9.59, 10.28-10.33, and 10.53-10.61 micron. Frequency stabilization could be 1MHz with optical feedback, which corresponds to 10ˆ7 spectral resolution. Specifically, MILAHI will be able to the compositions, dynamics and structure of the atmosphere by measuring:

1. CO2 absorption spectrum in nightside for temperature and wind vertical profiles in the altitude of 0-30km on Mars, and 70-90km on Venus
2. CO2 non-LTE emission in dayside for wind and temperature in the middle atmosphere (in the altitude of 70km on Mars and 110km on Venus (0.15 Pa pressure level))
3. Column abundance maps of O3, H2O2, H2O and CH4 with moderate spatial resolution
4. Isotopologues of water vapor (HDO) and carbon dioxide (17O-C-O, 18O-C-O)

We have currently accomplished the relocation of T60 from Fukushima, Japan to the summit of Mt. Haleakala on September 2014. Although it is a small telescope, MILAHI will provide ˜3”” spatial resolution with 60cm-telescope. T60 can be remotely operated in order to achieve continuous measurements of planetary atmospheres, and have successfully operated with the support of ATRC (IfA, University of Hawaii). First CO2 non-LTE emission on Venus has successfully observed on March 2015 (Nakagawa et al., submitted), which is not possible with other instruments. Typical sensitivity over the full 1 GHz bandwidth reached 2.500 K at 10 micron and 3,500 K at 7.7 micron. These system noise temperature obtained by MILAHI is only 70 % above the quantum limit at 10 micron. This corresponds to a minimal detectable brightness temperature difference of 50 mK for extended source with 1.5 MHz resolution and 10 mininute-integration. For example, 2 VSMOW-determination of water vapor isotope (HDO) on Mars can be obtained by 15 minute-integration. Here we report MILAHI initial results obtained during August-September 2015, and discuss observational plan in 2015-2016 with several spacecraft on flight, i.e., Akatsuki around Venus, Mars Express, MAVEN around Mars. The nature of atmospheric activity on various time-scales will be investigated.

火星衛星サンプルリターン計画とその科学

倉本 圭 [1]; 火星衛星サンプルリターン計画科学検討チーム 倉本　圭 [2]
[1] 北大・理・宇宙; [2] -

Mars satellite(s) sample return mission and its sciences

Kiyoshi Kuramoto[1]; Kiyoshi Kuramoto Mars Satellite Sample Return mission science team[2]
[1] Cosmosciences, Hokkaido Univ.; [2] -

A mars satellite(s) sample return mission has been rapidly crystallized as the next strategic middle class space science mission of ISAS. This mission is planned to approach the Mars system, not yet reached by our country, by extending the heritage of asteroid sample return missions that have brought a unique advantage to Japanese space exploration. Mars has been recognized as a main target of future Japanese space exploration because its Earth-like surface environment provides us irreplaceable research field for the origin and evolution of habitable environment in the solar system. The mars satellite sample return mission has a position as a door for future successive Mars exploration programs to be promoted in our country.

Origin of the Mars satellites Phobos and Deimos is still an enigma. The available surface reflectance spectra of them are similar to those of D-type asteroids, suggesting their capture origin from the outermost population of the main asteroid belt. On the other hand, both bodies have near-circular orbits above the equator of Mars. Such an orbit is difficult to be explained by the capture origin, but favors the formation from a circum-planetary disk created by a giant impact. If the giant impact origin is the case, each satellite is expected to be composed from igneous rocks due to impact shock heating. However, the reflectance spectra lack any signatures supporting such composition.

Since the composition of building material of a satellite depends on its source and satellite formation mechanism, compositional analyses of samples originated from bed rock may clarify the satellite origin. If a satellite is captured asteroid origin, it can be regarded as a survivor of building blocks of Mars, allowing us to deduce cosmochemical constraints for the starting condition of Mars through sample analysis. If giant impact origin is correct, satellite material likely contains components not only from the impactor but also from the crust and mantle of proto-Mars, which would provide geochemical constraints for the initial condition of Mars evolution. Application of isotopic chronology would reveal the timing of satellite formation, which would shed light also on the large scale evolution of the early solar system. The inner satellite Phobos is possibly contaminated by ejecta from large impact craters on Mars. If such materials are picked up from the returned sample, they may provide geochemical constraints for the evolution of the Martian surface environment.

In-situ observations are also important to constrain the origin of both satellites. If abundant structural water and/or organics are identified on fresh outcrops or boulders, captured origin becomes very favorable. Since both satellites are trapped by Mars, they have been kept cold enough to possibly preserve abundant water ice in their interiors. The presence of ice is likely if they are captured asteroids originated from the outer main belt. Such an ice rich satellite possibly has density profile concentrated with depth and also releases a small flux of water vapor. Thus measurements of density and compositional profile and also those of gas density, composition and motion around the satellite orbit are clue to diagnose the internal ice. Those gas measurements may also reveal the influence of gas flux to the satellite surface material and also the outflow mechanism of the Martian upper atmosphere.

Observations of the Martian atmosphere from the vicinity of a satellite are also valuable. Successive full disk imaging from the equatorial orbit at multiple wavelengths may provide unique data to clarify the global transport of water vapor and dust in the Martian atmosphere.

This mission covers broad scientific areas and is significant as the step toward the successive future Mars missions. We hope that many researchers, especially of young generations, will participate this attractive mission.

宇宙科学研究所の次期戦略的中型科学探査として、火星衛星サンプルリターン計画が急速に具体化しつつある。この計画は、小惑星サンプルリターンという日本の太陽系探査科学の強みを伸ばしつつ、我が国では未踏の惑星火星に、ユニークなアプローチを試みる。地球に最も類似した表層環境を持つ火星は、生命保有可能環境の形成と進化に迫ることのできる格好の研究対象であり、我が国の将来の太陽圏探査の主目標天体の一つとみなすことができる。この火星衛星サンプルリターン探査は、将来的に我が国が独自の火星探査を展開してゆくための布石と位置付けられる。

火星の衛星フォボスとダイモスの起源は今のところ謎に包まれている。表面の反射スペクトルの特徴は D 型小惑星に似ており、ここからは衛星の起源としてメインベルト外側に由来する小惑星の捕獲が支持される。他方、両衛星は火星赤道上をほぼ円軌道で公転しており、このような軌道は一般に捕獲では説明しにくい。軌道を説明するには、地球の月同様に、火星への巨大衝突とそれによる放出破片円盤からの衛星集積のほうがより考えやすい。この場合は、衛星材料物質は高温を経験し、火成岩的な組成になることが期待される。しかしこれまでに獲得されている表面スペクトルにはそのような兆候は見いだされていない。

起源によって衛星の材料物質は異なるので、代表的なサンプルを持ち帰って組成分析を行えば、衛星の起源を解明できる。もしも衛星が捕獲小惑星起源であった場合、それは火星を作り得た材料物質の生き残りとみなすことができ、火星形成の宇宙化学的な境界条件について制約できると考えられる。反対に巨大衝突起源であった場合には、そこに衝突

天体だけでなく火星岩石圏の成分も混在していることが期待され、火星進化の地球化学的初期状態について制約できる可能性がある。またいずれの起源説であっても、同位体年代学を適用すれば、衛星形成のタイミングや、初期火星への物質輸送のタイムスケールが制約でき、木星など巨大惑星の大移動とそれによる小天体の散乱を伴ったとされる初期太陽系の構造進化に対して、一定の証拠を提示できる可能性がある。また特に内側を公転するフォボスには、火星上の衝突クレータからの放出物が混入している可能性があり、これらを選別して多角分析できれば、揮発性物質の同位体組成進化など、火星表層環境の変遷に迫ることも期待できる。

他方、両衛星への接近観測からも両衛星の起源に迫ることができる。新鮮な露頭や岩体について適切なリモートセンシング調査を行えば、例えば構造水や有機炭素の濃度が制約でき、これらがある程度の濃度で検出されれば捕獲説が有利になる。さらに両衛星は、火星重力圏に捕まり、近地球小惑星のように太陽に接近することなく、低温の状態に保持されている。したがって衛星が捕獲起源であれば内部に現在も氷が存在し、深部ほど質量集中した密度構造を持つと同時に、いまなお微量の水蒸気を放出している可能性がある。重力や電磁波探査から衛星内部の密度分布を制約することに加え、衛星周辺空間でのガスの濃度、組成、運動などを測定することで、衛星内部の水の有無に手がかりを得ることができる。一方、こうしたデータは、衛星表面物質の外来ガス成分による改質や、火星大気の流出を捉える意味でも有益と考えられる。

両衛星が火星赤道上を公転することから、衛星軌道からの火星大気観測も有益である。従来の火星探査機の多くは極軌道を取っており、全球像を得ることが難しかった。赤道軌道から火星フルディスク画像を連続的に得ることで、地方時に依存したダストや水の循環過程の解明が期待できる。火星大気の流出に迫るデータの取得と併せて、これを火星大気進化の駆動機構として位置付ける視点が、この探査計画を有機的なものとするために重要であろう。

現時点では、科学目標とシステム要求のすり合わせが開始されたところであり、機体・機器の構成や探査シナリオには自由度が残されている。ちなみに、火星衛星を目指した探査計画には、ロシアと旧ソ連による複数のフォボス探査の試みがあったが、いずれも失敗に終わってきた．いまのところ火星衛星のサンプルリターン探査を目指す計画が現実性を持っているのは我が国のみである。この計画は幅広い分野の研究者が集うことのできる魅力を持っており、またその先の火星探査の先鞭としての役割も大きい。ぜひ多くの方々、特に若手の参入をお願いしたい。

火星衛星サンプルリターン計画：火星衛星から探る火星圏の科学目的

寺田 直樹 [1]; 関 華奈子 [2]; 二穴 喜文 [3]; Leblanc Francois[4]; 松岡 彩子 [5]; 横田 勝一郎 [6]; 齋藤 義文 [6]; 山崎 敦 [7]; 亀田 真吾 [8]; 長 勇一郎 [9]; 火星衛星サンプルリターン計画科学検討チーム 倉本 圭 [10]
[1] 東北大・理・地物; [2] 名大 STE 研; [3] IRF; [4] LATMOS-IPSL, CNRS; [5] JAXA 宇宙研; [6] 宇宙研; [7] JAXA・宇宙研; [8] 立教大; [9] 立教・理; [10] -

Exploration of Mars-satellite system from a Mars satellite sample return mission

Naoki Terada[1]; Kanako Seki[2]; Yoshifumi Futaana[3]; Francois Leblanc[4]; Ayako Matsuoka[5]; Shoichiro Yokota[6]; Yoshifumi Saito[6]; Atsushi Yamazaki[7]; Shingo Kameda[8]; Yuichiro Cho[9]; Kiyoshi Kuramoto Mars Satellite Sample Return mission science team[10]
[1] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [2] STEL, Nagoya Univ.; [3] IRF; [4] LATMOS-IPSL, CNRS; [5] ISAS/JAXA; [6] ISAS; [7] ISAS/JAXA; [8] Rikkyo Univ.; [9] Rikkyo Univ.; [10] -

In this presentation, we will present science objectives of the Mars-satellite system awaiting exploration from a Mars satellite sample return mission.

火星衛星（フォボスおよびダイモス）は、数十億年前から現在までの超長期にわたり火星起源物質と相互作用し、火星と共進化して来た。火星大気から散逸する重イオンは数百 eV から数 keV 以上に加速されて火星衛星の表面を叩き、表面物質を風化・変質させるとともに、衛星軌道周辺に分布するガストーラスの形成に寄与する。また、火星物質は衝突に伴う放出物としてもたらされ、衛星表層に蓄積していると推測されている。

火星-衛星の相互作用と共進化は現在も進行中であり、現在進行形のプロセスをその場観測や火星起源粒子の捕獲によって調査が可能である。本発表では、火星衛星サンプルリターン計画において検討が進められている、火星圏の科学目的について発表する。

火星衛星サンプルリターン機による火星大気観測の可能性

今村 剛 [1]; 小郷原 一智 [2]; 田口 真 [3]; 山本 真行 [4]; 笠羽 康正 [5]; 青木 翔平 [6]; 坂野井 健 [7]; 黒田 剛史 [5]; 笠井 康子 [8]; 高橋 芳幸 [9]; 野口 克行 [10]; 火星衛星サンプルリターン計画科学検討チーム 倉本　圭 [11]
[1] JAXA 宇宙科学研究所; [2] 宇宙研; [3] 立教大・理・物理; [4] 高知工科大; [5] 東北大・理; [6] IAPS-INAF, Italy; [7] 東北大・理; [8] NICT; [9] 神戸大・理・惑星; [10] 奈良女大・理・情報; [11] -

Atmospheric observations in the Mars satellite sample return mission

Takeshi Imamura[1]; Kazunori Ogohara[2]; Makoto Taguchi[3]; Masa-yuki Yamamoto[4]; Yasumasa Kasaba[5]; Shohei Aoki[6]; Takeshi Sakanoi[7]; Takeshi Kuroda[5]; Yasuko Kasai[8]; Yoshiyuki O. Takahashi[9]; Katsuyuki Noguchi[10]; Kiyoshi Kuramoto Mars Satellite Sample Return mission science team[11]
[1] ISAS/JAXA; [2] JAXA/ISAS; [3] Rikkyo Univ.; [4] Kochi Univ. of Tech.; [5] Tohoku Univ.; [6] IAPS-INAF, Italy; [7] Grad. School of Science, Tohoku Univ.; [8] NICT; [9] Department of Planetology, Kobe Univ.; [10] Nara Women's Univ.; [11] -

We are studying possibilities of remote sensing observations of the Martian atmosphere in the Mars satellite sample return mission, which is under study as one of the possible future planetary missions of Japan. The main goal of the atmospheric observations is to understand the transport processes of dust and water. Observations of hydrogen escape and detection of meteorite/lightning flashes are also planned. The spacecraft's equatorial high orbit, which enables encounter with the Martian satellites, is advantageous for continuous global mapping.

本構想では、火星衛星サンプルリターン機が周回軌道にとどまる期間中に火星大気と地表面のリモートセンシングを行い、大気-表層のダスト輸送と水循環の理解を目指す。赤道周回というユニークな軌道からはあらゆる地方時でグローバルかつ継続的に観測することが可能であり、この特徴を生かして従来観測できなかった現象をとらえることができる。観測装置の選択は今後の議論による。

火星の希薄大気では主成分である二酸化炭素の温室効果はほとんど働かないが、代わって大気中に浮遊する微細鉱物粒子（ダスト）が太陽光を吸収することにより加熱源となり、大気の熱構造や地表面温度を支配する。地表ダストの移動はアルベドや熱慣性の変化をもたらす。ダストの巻き上げを担う可能性のある流体現象の多くが顕著な地方時依存性や日変化を伴うと想像されており、これらは従来の太陽同期軌道の火星周回機によって得られる 1 太陽日に 1 枚の可視光画像ではほとんどとらえられなかった。とくにダストプルームや斜面風といった特定の地方時において短時間で発達するメソスケールの現象は、近年発見された高高度でのダスト混合比の極大をもたらす可能性も指摘されているが、観測的手がかりがない。そこで本計画では、幅広いローカルタイムで解像度 5-10 km、時間間隔 1 時間程度の連続撮像観測を行い、このようなダストストームの背後にある流体現象を特定することを目指す。可視光撮像に加え、夜間も観測可能な熱赤外撮像が重要な役割を果たす。

ダストと並ぶ火星気候理解の鍵は水循環である。地下氷や水和鉱物の分布は火星気候の長期変動の履歴を反映すると考えられており、また氷雲や極冠の消長はアルベドの変化をもたらす。ダストを核とする氷雲生成は大気からのダスト除去を促進する。このような火星の水の多様な姿は、水の相変化を介した大気-地表間の水交換と、様々な流体力学現象に伴う大気中の水蒸気輸送に支配されているはずである。しかしその実態、なかでも大規模地形の影響を受けた地域気象の寄与や、数十 K に達する気温の日変化に伴う大規模な相変化に関しては、これまでの観測では時空間分解能が乏しかったことから理解が進んでいない。たとえば低緯度での氷雲形成が water equivalent hydrogen の赤道域の特定地域での極大を説明する可能性も指摘されているが、仮説の域を出ない。そこで本計画では、大気中の水輸送の時空間構造を、個々の気団における水蒸気変動と相変化を空間分解能 100 km 程度、時間間隔 1 時間程度で幅広いローカルタイムで追跡することにより明らかにしたい。とくに氷雲が大規模に蒸発・凝結する朝・夕の数時間が重要である。可視光撮像に加えて近赤外分光マッピングによる水蒸気観測が主たる手段となる。

火星の環境の変遷に関わる水素の宇宙空間への流出をリモートセンシングで捉えることも目指す。火星周辺の水素コロナの変動を Ly-α 線を用いてモニターし、水素の熱的・非熱的散逸量を推定するとともに、水素コロナ形成メカニズムを明らかにしたい。過去に行われた水素コロナ観測は発光強度しか観測しなかったため、密度と温度の寄与を分離できなかったが、吸収セル法を用いてこれらを分離することができる。同じ観測手法によって衛星内部の氷から蒸発した水が起源の水素原子の検出も試みる。

可視カメラで火星や衛星の夜側の短時間の発光をモニターし、微小隕石の降り込みや大気放電をとらえることも検討中である。このような観測により、隕石の供給量や放電現象の有無を制約することができる。

JUICE-PEP/JNA 高速中性粒子計測装置の開発

浅村 和史 [1]; 齋藤 義文 [2]; 下山 学 [3]; 二穴 喜文 [3]; 三好 由純 [4]; 坂野井 健 [5]
[1] 宇宙研; [2] 宇宙研; [3] IRF; [4] 名大 STE 研; [5] 東北大・理

JUICE-PEP/JNA Jovian energetic neutral atom analyzer

Kazushi Asamura[1]; Yoshifumi Saito[2]; Manabu Shimoyama[3]; Yoshifumi Futaana[3]; Yoshizumi Miyoshi[4]; Takeshi Sakanoi[5]
[1] ISAS/JAXA; [2] ISAS; [3] IRF; [4] STEL, Nagoya Univ.; [5] Grad. School of Science, Tohoku Univ.

We are developping a low-energy (10eV-3keV) energetic neutral atom analyser (PEP/JNA) which is to be onboard European JUICE spacecraft. There is considered to be a mini-magnetosphere around Ganymede because of interactions between plasma in Jovian magnetosphere and Ganmede's intrinsic magnetic field. However, its characteristics will be different from terrstrical one, since Alfven mach number of upstream plasma flow (corotational plasma flow around Jupiter) is small. JNA (Jovian Neutral Analyzer) will reveal characteristics of Ganymede's magnetosphere in terms of measurement of scattered/sputtered particles generated by precipitation of plasma particles onto Ganymede's surface. Measurement of these particles will provide spatial distribution of plasmas in remote sense, since electric/magnetic field do not affect trajectories of neutral particles. We will discuss current status of PEP/JNA.

月・惑星探査用飛行時間型質量分析装置の開発

大石 峻裕 [1]; 齋藤 義文 [2]; 齋藤 直昭 [3]; 藤原 幸雄 [3]; 長 勇一郎 [4]
[1] 東大・理・地惑; [2] 宇宙研; [3] 産総研; [4] 立教・理

Development of a TOF-MS for the future planetary missions

Takahiro Oishi[1]; Yoshifumi Saito[2]; Naoaki Saito[3]; Yukio Fujiwara[3]; Yuichiro Cho[4]
[1] Dept. Earth & Planet. Sci, Univ. Tokyo; [2] ISAS; [3] AIST; [4] Rikkyo Univ.

In-situ measurement of planetary material is quite important in understanding evolution of the planets. NASA's Curiosity rover performed in-situ Potassium-Argon (K-Ar) isochron dating experiment on Martian rock by a quadrupole mass spectrometer (QMS) and an alpha particle X-ray spectrometer (APXS). On the other hand, the ESA's Rosetta spacecraft performed direct in-situ measurement of the D/H ratio and N^2/CO ratio in the Jupiter family comet 67P/Churyumov-Gerasimenko by the ROSINA mass spectrometer on ROSETTA. Furthermore, Philae lander on ROSETTA discovered 16 organic compounds on comet 67P/Churyumov-Gerasimenko.

In ISAS, IMA (Ion Mass Analyzer) measured the lunar plasma aboard the ISAS's Kaguya spacecraft. IMA is an linear electric field time-of-flight (LEF-TOF) energy mass spectrometer. However, ISAS has never developed a time-of-flight mass spectrometer (TOF-MS) for the future planetary missions. Therefore, we are developing a new instrument for in-situ K-Ar isochron dating.

K-Ar isochron dating is a radiometric dating method and it is based on the measurement of the product of radioactive decay of ^{40}K into ^{40}Ar. This instrument is the combination of laser-induced breakdown spectroscopy (LIBS) and TOF-MS. ^{40}K is measured using LIBS and ^{40}Ar is measured using TOF-MS. One of the purposes of this mission is to understand climate change of ancient Mars by determination of the absolute age of the Noachian-Hesperian transition. We are developing a small size TOF-MS that has a length of 180mm and a diameter of 100mm in order to install the instrument on a rover. We confirmed that the mass resolution of the TOF-MS is 160 (at m=40 amu) by using SIMION charged particle simulation software. We also manufactured a test model TOF-MS in order to confirm its performance.

Furthermore, we are considering experiments to measure organic compounds and planetary atmosphere by using the TOF-MS. In this presentation, we report the current development status of the TOF-MS and what the TOF-MS can detect based on the results of the first experiment of the test model TOF-MS.

月・惑星探査において、その場の質量分析によって得られる情報には、天体の起源と進化を理解するための手がかりになることが期待される。近年の探査において、NASA の火星探査機「Curiosity」による年代計測や、ESA の彗星探査機「Rosetta」によるチュリュモフ・ゲラシメンコ彗星の D/H 比計測や N^2/CO 比計測が質量分析器により行われた。さらに着陸機「Philae」に搭載された質量分析器は、16 種類の彗星の有機物を検出した。このようにその場の質量分析は、年代計測、同位体計測、揮発性物質計測など多岐にわたる太陽系探査に貢献している。

また、ISAS ではこれまで天体周辺空間のイオンを質量分析により計測する TOF(Time-Of-Flight) 型質量分析器が開発され、「かぐや」では月周辺プラズマのイオン質量分析を行った。しかしながら、ISAS では月・惑星の岩石を構成する主要元素や揮発性物質の測定を目的とした質量分析器は未開発であり、その開発が望まれている。また、TOF 型質量分析器はこれらの物質計測に加えて、その場 K-Ar 年代計測のための質量分析部としても応用できる。そこで我々は将来の月・惑星探査を想定した、その場 K-Ar 年代計測のための TOF-MS(Time-Of-Flight Mass Spectrometer:飛行時間型質量分析器) の開発を進めている。

我々が検討している年代計測システムでは LIBS(Laser-Induced Breakdown Spectroscopy:レーザ誘起絶縁破壊分光法) による K 濃度測定と TOF-MS による Ar 同位体測定から K-Ar 年代を求めるものである。その場 K-Ar 年代測定が可能となれば、火星のノアキス代からヘスペリア代に起きた気候変動や、月の進化の過程について制約を課すことができる可能性がある。そこで我々は、着陸機に搭載可能な直径 10[cm]、全長 18[cm] 程度の TOF-MS を開発し、イオンを約 4keV まで加速することで、質量数 40 のピークにおいて 160 程度の質量分解能を得ることを計算機シミュレーションにより確認した。これまでにイオン源と TOF-MS で構成される K-Ar 年代計測のための試験モデルの製作を行った。TOF-MS では、イオンを加速もしくは反射させるためのリング状の電極をインシュレーターで結合し、イオンを自由飛行させるドリフトチューブに取り付けた。また、この試験モデルでは部品を組み替えることにより、イオンを直線的に飛行させるリニアモードと、イオンを反射させるリフレクターモードを切り替え、ミッションに合わせた最適な形状を選ぶことができる。

さらに、我々はこの試験モデルを用いて、質量分析器の開発目的である岩石を構成する主要元素や揮発性物質の測定、さらには惑星大気の同位体比計測のための試験の実施も検討している。岩石を構成する主要元素測定では、レーザーイオン化法により生じたガスを試験モデルにより計測する。本発表では試験モデルを用いた初期性能結果と、岩石を構成する主要元素や揮発性物質の測定等の K-Ar 年代計測以外の応用法についても報告する。

EXCEED/HISAKI によるイオプラズマトーラスの発光の輝線の同定

疋田 伶奈 [1]; 吉岡 和夫 [2]; 村上 豪 [3]; 木村 智樹 [4]; 土屋 史紀 [5]; 桑原 正輝 [6]; 鈴木 文晴 [7]; 吉川 一朗 [8]
[1] 東大・新領域・複雑理工; [2] 立教大; [3] ISAS/JAXA; [4] RIKEN; [5] 東北大・理・惑星プラズマ大気; [6] 東大・新領域・複雑理工; [7] 東大・理・地惑; [8] 東大・理・地惑

The EUV Spectrum of Io Plasma Torus Observed by EXCEED/HISAKI

Reina Hikida[1]; Kazuo Yoshioka[2]; Go Murakami[3]; Tomoki Kimura[4]; Fuminori Tsuchiya[5]; Masaki Kuwabara[6]; Fumiharu Suzuki[7]; Ichiro Yoshikawa[8]
[1] Frontier Sciences, Tokyo Univ.; [2] Rikkyo Univ.; [3] ISAS/JAXA; [4] RIKEN; [5] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [6] Univ. of Tokyo; [7] Earth and planetary science, Univ.Tokyo; [8] EPS, Univ. of Tokyo

The volcanic ejecta from Io are ionized in space and trapped in Jupiter's magnetic field, and form Io Plasma Torus (IPT) along Io's orbit around the planet. In early 2015 the ground-based optical observation of sodium clouds captured the signature of increase in volcanic activity on Io.

We determine the origin of EUV spectral emissions of IPT using the spectral image in the range from 50 nm to 150 nm taken by the earth-orbiting satellite, EXCEED/HISAKI. In this study, we had used the consecutive data by the wide slit and the data with high spectral resolution.

イオ火山からの噴出物は、宇宙空間で電離して木星磁場にとらわれ、イオ公転軌道の付近にトーラス状に漂っている。地上望遠鏡でのＤ線の観測から、イオの火山活動は２０１５年初頭に活発化したことが明らかになっている。

本研究では、50nm〜150nm の観測波長域をもつ地球周回衛星 EXCEED/HISAKI による分光観測データを用いて、イオプラズマトーラスの発光の輝線の同定を行った。視野の広いスリットによる連続的な観測と高い波長分解能のスリットによる観測を活かし、イオ火山が活発化した時期の各輝線の変動を比較することや、変動周期を用いて地球大気の発光を区別することにより、発光源の特定を試みた。

ひさき衛星を用いたイオ周辺の酸素原子極端紫外発光の変動

古賀 亮一 [1]; 土屋 史紀 [2]; 鍵谷 将人 [3]; 坂野井 健 [4]; 吉川 一朗 [5]; 村上 豪 [6]; 山崎 敦 [7]; 木村 智樹 [8]; 吉岡 和夫 [9]; 米田 瑞生 [2]
[1] 東北大・理・地物; [2] 東北大・理・惑星プラズマ大気; [3] 東北大・理・惑星プラズマ大気研究センター; [4] 東北大・理; [5] 東大・理・地惑; [6] ISAS/JAXA; [7] JAXA・宇宙研; [8] RIKEN; [9] 立教大

Atomic oxygen EUV emission near Io using Hisaki

Ryoichi Koga[1]; Fuminori Tsuchiya[2]; Masato Kagitani[3]; Takeshi Sakanoi[4]; Ichiro Yoshikawa[5]; Go Murakami[6]; Atsushi Yamazaki[7]; Tomoki Kimura[8]; Kazuo Yoshioka[9]; Mizuki Yoneda[2]
[1] Geophysics, Tohoku Univ.; [2] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [3] PPARC, Tohoku Univ; [4] Grad. School of Science, Tohoku Univ.; [5] EPS, Univ. of Tokyo; [6] ISAS/JAXA; [7] ISAS/JAXA; [8] RIKEN; [9] Rikkyo Univ.

http://www.sgepss.org/

We focus on the time and spatial variation of neutral oxygen emission in the EUV range at 130.4nm associated with the enhancement of volcanic activity on Io during the period from December 2014 to March 2015 using the data obtained with hisaki/EXCEED. Past studies showed that main origin of Io's atmosphere is sublimation of SO_2 (Retherford et al., 2007). However, it is under controversy how much volcanic eruption directly contributes to making atmosphere compared to sublimation. Recently, Hisaki/EXCEED observed the enhancement of Io plasma torus emission (e.g., trivalent sulfur at 68nm) and auroral emission probably due to volcanic activities (Tsuchiya et al., 2015). In addition, ground-based data showed that neutral sodium emission at 589nm increased simultaneously surrounding Jupiter (Yoneda et al., 2015). Continuous Hisaki/EXCEED measurement data is useful to detect neutral gas behavior associated with the volcanic event, and one candidate target is neutral oxygen atom emission at 130.4nm.

Using the hisaki/EXCEED data for the several month after November 27 2014, we estimated the atomic oxygen emission at 130.4nm within a range of 1 Jupiter radius near Io every 10 days. When Io was in the dawn side (Io's phase angle 45 ˜135) and in dawn side (Io's phase angle 225 ˜315), we overlapped the data whose center corresponds to the Io's location within a range of +-60 arcsec. We carefully selected data when the local time of Hisaki were in the range of 20-4 to avoid the contamination of geocorona.

We found the atomic oxygen emission at 130.4nm started to increase in the middle January, which is consistent with the sodium emission. The intensity showed the maximum up to 25 Rayleigh around January 26 to February 4, which was almost two times greater than the normal intensity. We also confirmed that the emission in the dusk side was more intense than that in the dawn side throughout the period. To validate the atomic oxygen emission intensity, the electron density and temperature are required. In this talk, we give the time variation and dawn-dusk asymmetry of atomic oxygen emission at 130.4nm during the volcanic activity event.

木星の衛星イオは他のガリレオ衛星と比べて木星との距離が近く潮汐力を大きく受けるため地質活動が活発である。そのため、火山噴火による SO_2 を主成分としたガスの排出が頻繁に起こっている。現在イオの大気の起源は表面の SO_2 の昇華が主成分とされ (Retherford et al. 2007)、火山噴火が昇華と比べてどのくらい大気生成に寄与しているか活発に議論されている。本研究ではイオ周辺（1 木星半径程度）の 130.4nm の酸素原子発光強度がどのように時間変動するかを明らかにすることで、大気生成プロセスの理解に寄与することを目的とする。

2015 年の 1 月から 3 月にかけて火山活動が活発化したことに伴うイオプラズマトーラス（e.g., 硫黄イオン 68nm 発光）やオーロラの発光強度の増大が観測された (Tsuchiya et al., 2015)。同時期に、地上観測により木星系全体（〜100 木星半径）で中性ナトリウムの 589nm 可視光の発光の増大も明らかになった (Yoneda et al., 2015)。同様に火山噴出ガスを起源とするイオ近傍の中性酸素原子についても発光の増大が期待される。

本研究では 2014 年 11 月 27 日から 2015 年 4 月 25 日にわたってイオの 1 木星半径周辺の酸素原子 130.4nm 発光強度を解析した。解析では、十分な S/N を得るために、朝側 (イオ位相角 45 度˜135 度) と夕方側 (イオ位相角 225 度˜315 度) の露出時間 1 分間のデータをイオを中心に前後 60 秒角の範囲で数百枚重ね合わせた。また、地球近傍の水素原子や酸素原子発光であるジオコロナの影響が無視できるように、ひさき衛星の地方時 20˜4 時の観測データのみを使った。

その結果、酸素原子発光は 1 月 16 日から増光を開始し、1 月 26 日〜2 月 4 日に火山活動が平穏な時 (11Rayleigh 程度) に比べて約 2 倍程度の明るさを示した。これは地上観測によるナトリウム発光との時間変動と整合的である。また、期間全体を通して朝側より夕方側の方が約 1.1 倍明るく発光していた。講演では 2015 年 4 月までの観測期間中の酸素原子発光強度の変化示し、どれくらいの速さで通常の発光強度に戻るかを明らかにする。また、電子衝突励起によって発光する中性酸素原子の発光強度から、酸素原子の柱密度を導出し、より火山活動の変動を定量的に議論するためには、イオ周辺での電子密度と電子温度の情報が必要である。今後の研究ではこれら電子密度と電子温度の導出方法についての検討も紹介する。

R009-P05 **会場: Poster** **時間: 11月3日**

Variation of plasma parameters of Io torus observed by Hisaki/EXCEED

Kazuo Yoshioka[1]; Go Murakami[2]; Tomoki Kimura[3]; Atsushi Yamazaki[4]; Fuminori Tsuchiya[5]; Masato Kagitani[6]; Ichiro Yoshikawa[7]; Masaki Fujimoto[8]
[1] Rikkyo Univ.; [2] ISAS/JAXA; [3] RIKEN; [4] ISAS/JAXA; [5] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [6] PPARC, Tohoku Univ; [7] EPS, Univ. of Tokyo; [8] ISAS, JAXA

The EUV spectroscope "EXCEED" on board the Hisaki spacecraft is observing the planets in our solar system since the end of November 2013 [Yoshikawa et al. 2014]. Since then, EXCEED is continuously observe the Io plasma torus with wide width slit. Using those EUV spectra, we have deduced the plasma conditions around there through the spectral diagnosis method. Especially, the variation during the Io’s volcanic activity is detected. In this presentation, we will show the whole results of Io plasma torus observation through the EXCEED, and we will also explain the way of our approach for the Jovian plasma dynamics.

ひさき衛星極端紫外光観測と地上可視光観測による木星衛星イオの硫黄イオントーラスの時空間変動

宍戸 美日 [1]; 坂野井 健 [2]; 鍵谷 将人 [3]; 土屋 史紀 [4]; 吉川 一朗 [5]; 山崎 敦 [6]; 吉岡 和夫 [7]; 村上 豪 [8]; 木村 智樹 [9]
[1] 東北大・理・地物; [2] 東北大・理; [3] 東北大・理・惑星プラズマ大気研究センター; [4] 東北大・理・惑星プラズマ大気; [5] 東大・理・地惑; [6] JAXA・宇宙研; [7] 立教大; [8] ISAS/JAXA; [9] 理研

Variation in SIII torus of Jovian satellite Io based on Hisaki/EXCEED and ground based observation data

Mika Shishido[1]; Takeshi Sakanoi[2]; Masato Kagitani[3]; Fuminori Tsuchiya[4]; Ichiro Yoshikawa[5]; Atsushi Yamazaki[6]; Kazuo Yoshioka[7]; Go Murakami[8]; Tomoki Kimura[9]
[1] PPARC, Tohoku Univ.; [2] Grad. School of Science, Tohoku Univ.; [3] PPARC, Tohoku Univ; [4] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [5] EPS, Univ. of Tokyo; [6] ISAS/JAXA; [7] Rikkyo Univ.; [8] ISAS/JAXA; [9] RIKEN

We report the time and spatial variation of sulfur ion emission line (SIII, 68nm) to understand the dynamical process in the torus associated with Io's volcanic event during the period from December 2014 to March 2015, using the data obtained by Hisaki/EXCEED. Io is one of the moons of Jupiter, distinguished as a rocky moon and is the most volcanically active object in the solar system. The large quantities of gas were ejected by its volcanoes, principally oxygen and sulfur atoms and their compounds. Once they are ionized through electron impact and charge exchange, the ions are accelerated to the nearly corotational flow of the ambient plasma to form a torus of ions (the Io plasma torus, about 6R_J from the center of Jupiter) surrounding Jupiter. Since the intensity of these emissions is determined by the ion density and electron temperature in the torus, past studies revealed the mechanism of energy transportation by measuring the emission intensity.

Hisaki/EXCEED is an EUV spectrograph launched in September 2013 into the orbit with the height of 954 km-1157 km and the period of 106 min. With an effective area of more than 1cm^2 and well-calibrated sensitivity in space, the EUV spectrometer will produce spectral images (52-148nm). Continuous measurement for Io's plasma torus and Jupiter's aurora in the EUV range give us a unique opportunity to witness the sporadic and sudden brightening events occurring on one or both regions.

We identified the spatial and time variation of sulfur ion torus associated with enhanced volcanic activities from successive 800 images of sulfur ion (SIII) emission at 68nm (an integration time for each image is 30 min) during the period from December 2014 to January 2015. During this period, in addition, we carried out the measurement of SII 673 nm emission with visible spectrograph on T60 telescope at Haleakala, Hawaii.

In this talk we give the results on the scale height and ion temperature of sulfur torus derived from spatial distribution of Io torus with EXCEED associated with the Io's volcanic event, and the comparison with ground-based visible data obtained with T60.

木星衛星イオの軌道 (6R_J) には、イオの火山ガスに起因するプラズマトーラスが形成される。このトーラス中の硫黄・酸素イオンは、電子 (5eV-1keV) との衝突励起により極端紫外から可視に渡る広い波長範囲で発光する。「ひさき」衛星に搭載された極端紫外線分光撮像装置 EXCEED により、2014 年 12 月から 2015 年 3 月にかけて、イオ火山噴火に伴うとみられるイオトーラス増光現象が観測された。また同時期に，東北大学がハワイ・ハレアカラ観測所に所有する望遠鏡 T60 の可視光イメージング観測装置を用いて，イオトーラス観測 (SII 673nm) が高い空間分解能で行われた。本研究は、この増光現象に伴う硫黄イオン輝線 (SIII、68nm) の発光 2 次元分布の時間変動を EXCEED の観測データを用いて詳細に解析し、可視光イメージング観測と組み合わせて、イオの火山活動が活発な時期のトーラスの動径方向及びそれと垂直方向の発光プロファイル変動を明らかにする。

「ひさき」衛星搭載 EXCEED は、イオトーラスのプラズマが発する輝線が集中して存在する極端紫外光領域 (55nm-145nm) を波長分解能 0.3-1nm、空間分解能 17 秒角で連続的に分光撮像する。「ひさき」軌道は高度 950km-1150km、軌道傾斜角 30 度の地球周回軌道で、軌道周期は約 106 分である (1 日当たり 13 周回)。10 秒角、60 秒角、140 秒角幅の 3 種類のスリットが選択可能で、木星オーロラ及びイオトーラスの観測時には、イオトーラス全体の発光を分光撮像し、且つ視野ガイドカメラによる指向制御を行うために、主に 140 秒角幅のスリットを用いる。トーラスの硫黄イオンの輝線は、それぞれ数 10R - 数 100R の明るさがあり、1 周回中の積分時間 (約 50 分) で十分な信号強度が得られる。視野ガイドカメラは可視光に感度をもち、280 秒角四方の視野をもつ。分光器のスリット周縁で反射された光を視野ガイドカメラに導き、オンボード姿勢制御が行われている。

本研究では、EXCEED の観測データを用いて、トーラス増光現象期間 (2014 年 12 月-2015 年 3 月) における硫黄イオン (SIII、68nm) の 2 次元分布画像を得、さらに動径方向及びそれに垂直方向の発光プロファイルを導出した。特に、垂直方向の発光プロファイルから、硫黄イオンのスケールハイト並びに温度を推定することができる。加えて、可視光イメージング観測装置は、電子温度の低い cold torus とプラズマ密度が最大となる ribbon 領域の硫黄イオン発光 (SII、673nm) により高い空間分解能 (約 1 秒角) で撮像できるため、EXCEED と T60 の観測データ比較により、トーラスの増光現象の相補的な解析が可能である。発表では、この解析から得られたイオトーラスの 2 次元時空間変動やイオ位相角依存性について報告する。

中性子星にオーロラは光るか？: 中性子星-磁化降着円盤間電磁結合過程の検証

木村 智樹 [1]; 岩切 渉 [1]; 榎戸 輝揚 [2]; 垰 千尋 [3]; 和田 智秀 [1]
[1] RIKEN; [2] 京大・白眉; [3] LPP, Ecole Polytechnique

Can neutron stars have auroras ? : electromagnetic coupling process between neutron star and magnetized accretion disk

Tomoki Kimura[1]; Wataru Iwakiri[1]; Teruaki Enoto[2]; Chihiro Tao[3]; Tomohide Wada[1]
[1] RIKEN; [2] Kyoto Univ.; [3] LPP, Ecole Polytechnique

Angular momentum transfer from accretion disk to a star is essential process for spin-up/down of stars. The angular momentum transfer has been well formulated for the accretion disk strongly magnetized by the neutron star [e.g., Ghosh and Lamb, 1978, 1979a, b]. However, the electromagnetic (EM) coupling between the neutron star and accretion disk has not been self-consistently addressed in the previous studies although the magnetic field lines from the star are strongly tied with the accretion disk. In this study, we applied the planet-magnetosphere coupling process established for Jupiter [Hill, 1979] to the neutron star and magnetized accretion disk. Angular momentum distribution is solved based on the torque balance between the neutron star's surface and accretion disk coupled by the magnetic field tensions. We found the EM coupling can transfer significantly larger fraction of the angular momentum from the magnetized accretion disk to the star than the unmagnetized case. The resultant spin-up rate is estimated to ˜10ˆ-14 [sec/sec] for the nominal binary system parameters, which is comparable with or larger than the other common spin-down/up processes: e.g., the magnetic dipole radiation spin-down. The Joule heating energy dissipated in the EM coupling is estimated to be up to ˜10ˆ36 [erg/sec] for the nominal binary system parameters. The release is comparable to that of gravitation energy directly caused by the matters accreting onto the neutron star. This suggests the EM coupling at the neutron star can accompany the observable radiation as auroras with a similar manner to those at the rotating planetary magnetospheres like Jupiter, Saturn, and other gas giants.

イオプラズマトーラスと木星オーロラの同時増光イベントの解析

鈴木 文晴 [1]; 吉岡 和夫 [2]; 村上 豪 [3]; 土屋 史紀 [4]; 木村 智樹 [5]; 北 元 [4]; 桑原 正輝 [6]; 疋田 伶奈 [7]; 吉川 一朗 [8]
[1] 東大・理・地惑; [2] 立教大; [3] ISAS/JAXA; [4] 東北大・理・惑星プラズマ大気; [5] RIKEN; [6] 東大・新領域・複雑理工; [7] 東大・新領域・複雑理工; [8] 東大・理・地惑

Analysis of simultaneous brightening of the Io Plasma Torus and Jupiter's Aurorae

Fumiharu Suzuki[1]; Kazuo Yoshioka[2]; Go Murakami[3]; Fuminori Tsuchiya[4]; Tomoki Kimura[5]; Hajime Kita[4]; Masaki Kuwabara[6]; Reina Hikida[7]; Ichiro Yoshikawa[8]
[1] Earth and planetary science, Univ.Tokyo; [2] Rikkyo Univ.; [3] ISAS/JAXA; [4] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [5] RIKEN; [6] Univ. of Tokyo; [7] Frontier Sciences, Tokyo Univ.; [8] EPS, Univ. of Tokyo

The satellite of Jupiter, Io, is a volcanically active moon that ejects ionized gas such as sulfur and oxygen into space. This gas forms a torus encircling Jupiter along the orbit of Io, and called Io Plasma Torus (IPT). Jupiter has by far the most energetic and brightest aurorae in the solar system. During the Cassini spacecraft's flyby of Jupiter (October, 2000-March, 2001), the UV spectrometer witnessed a puzzling phenomenon. Both of IPT and Jupiter's aurorae were sometimes brightened almost simultaneously. The torus emissions reflect the state of the inner magnetosphere while the aurora emissions are an index of activity in the middle magnetosphere. This fact might suggest an energy transport process from the middle to inner magnetosphere, but it has not been understood yet. But due to low-temporal resolution of Cassini observation, the dataset of Cassini was insufficient to identify the process.

The EXCEED/HISAKI was launched in September 2013 by the Epsilon rocket. Now it is orbiting around the Earth. EXCEED is the world's first observatory in space observing planets and has an advantage of long-term and continuous monitoring of the aurorae and IPT at the same time. In this presentation, we investigate the energy transport process in the Jovian magnetosphere by analyzing of the EXCEED observation.

木星の衛星イオには火山活動があり、硫黄や酸素を含むガスが内部磁気圏に放出されている。この火山ガス起源のプラズマがイオの公転軌道に沿ってドーナツ状に分布していることが光学観測で明らかにされており、イオプラズマトーラス（IPT）と呼ばれている。また、木星極域にオーロラが常時発生していることも観測されている。2000年、カッシーニ探査機が木星のフライバイをする際に、IPTと木星オーロラを同時に観測し、両者が非常に短い時間差で突発的に増光していることを発見した。IPTの発光は内部磁気圏の状態を反映し、木星オーロラの発光は中間磁気圏の活動度の指標となるため、内部・中間磁気圏間に未知のエネルギー輸送プロセスが存在することの証拠であると考えられた。しかし、カッシーニ探査機の観測では観測休止時間が増光現象の継続時間に比べて長く，両者の相関関係や時間差の決定が困難であり、エネルギー輸送プロセスの特定にはいたらなかった。

2013年9月にイプシロンロケットにより地球周回軌道に打ち上げられたHISAKI/EXCEEDは惑星専用の宇宙望遠鏡であり、木星磁気圏の長期的かつ継続的な観測を、約1時間という高時間分解能で可能にした。本研究では、HISAKI/EXCEEDのデータを使用したIPT・オーロラ増光イベントの詳細な解析により、増光の時間差や空間的な特徴を明らかにして、木星磁気圏におけるエネルギー輸送の謎を解き明かしていく。

ひさき衛星を用いた木星紫外オーロラの太陽風応答に関する研究

北 元 [1]; 木村 智樹 [2]; 垰 千尋 [3]; 土屋 史紀 [1]; 吉川 一朗 [4]; 坂野井 健 [5]
[1] 東北大・理・惑星プラズマ大気; [2] RIKEN; [3] LPP, Ecole Polytechnique; [4] 東大・理・地惑; [5] 東北大・理

Solar wind response of Jovian EUV aurora from HISAKI observations

Hajime Kita[1]; Tomoki Kimura[2]; Chihiro Tao[3]; Fuminori Tsuchiya[1]; Ichiro Yoshikawa[4]; Takeshi Sakanoi[5]
[1] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [2] RIKEN; [3] LPP, Ecole Polytechnique; [4] EPS, Univ. of Tokyo; [5] Grad. School of Science, Tohoku Univ.

In order to reveal solar wind response of Jovian extreme ultraviolet (EUV) auroral activity, we made statistical analysis of Jovian EUV aurora obtained from long term HISAKI observation.

The EUV emission from hydrogen molecule is excited by collision with high energy electron. Main oval is one of the components of Jovian EUV aurora where the auroral particle precipitations are caused by rotationally driven field-aligned current system. It is theoretically expected that angular velocity of magnetospheric plasma increases when the Jovian magnetosphere is compressed by enhanced solar wind pressure, which decreases the field-aligned current. Regarding to this scenario, increase of the solar wind dynamic pressure is expected to be anti-correlated with the intensity of the EUV aurora. Jovian UV aurora has been observed by such as International Ultraviolet Explorer (IUE) or Hubble Space Telescope (HST). They have investigated the time variability of the EUV aurora, while their data still limited in continuity over solar wind variation with good time resolution. On the other hand, HISAKI satellite is an earth-orbiting EUV spectroscope launched in 2013 which has been continuously monitoring Jovian EUV auroral activity. Therefore, the HISAKI data sets are effective for investigating solar wind response of Jovian aurora.

The purpose of this study is to investigate solar wind response of Jovian EUV aurora which is obtained from long term HISAKI observation. The analyzed data was obtained from Dec. 2013 to Feb. 2014 and from Dec. 2014 to Feb. 2015. We compare the EUV emission intensity over 900-1480 A and solar wind dynamic pressure which is extrapolated at Jupiter using a one-dimensional magnetohydrodynamic (MHD) model.

A preliminary analysis showed the correlation between the EUV intensity variation and the solar wind dynamic pressure. This character is also expected from previous UV and IR observation results. These results contradict the theoretical expectation. In addition to that, we also found that the time duration of rarefaction region of the solar wind have correlation with the intensity variation, which had never been reported. We will discuss possible mechanism to explain these characteristics.

R009-P10 会場: Poster 時間: 11月3日

Oxygen torus in the inner magnetosphere of Saturn observed by Hisaki

Hiroyasu Tadokoro[1]; Fuminori Tsuchiya[2]; Tomoki Kimura[3]; Chihiro Tao[4]; Atsushi Yamazaki[5]; Go Murakami[6]; Kazuo Yoshioka[7]; Ichiro Yoshikawa[8]
[1] none; [2] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [3] RIKEN; [4] LPP, Ecole Polytechnique; [5] ISAS/JAXA; [6] ISAS/JAXA; [7] Rikkyo Univ.; [8] EPS, Univ. of Tokyo

The water group neutrals are dominated by Saturn’s magnetosphere. In this study, we focus on oxygen dynamics in the inner magnetosphere of Saturn. Understanding of the temporal and spatial distributions of oxygen is required to understand the water group neutral dynamics in Saturn. The atomic oxygen was discovered by UVIS onboard Cassini [Esposito et al., 2005]. The spatial and temporal with time scale of several days – several tens of days distributions of oxygen are revealed by Melin et al., [2009]. "Hisaki" has been launched in September 2013. Using the EUV spectra by the EXCEED onboard Hisaki, we show the daily variation and spatial distribution of oxygen.

Observation of ion temperature and corotation deviation on Io plasma torus during an outburst in early 2015

Masato Kagitani[1]; Mizuki Yoneda[2]; Yoshikawa Ichiro Exceed mission team[3]
[1] PPARC, Tohoku Univ; [2] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [3] -

Atoms and molecules originated from volcanic eruption on Jovian satellite Io are ionized and form a donut-shaped region along Io's orbit which is called Io plasma torus. Although creation of pick-up ion in the plasma torus is expected to make high anisotropy ($T_{perpendicular} > T_{parallel}$) of ion temperature as well as deviation from corotation, the value of anisotropy and corotation deviation as well as their variability during an outburst from Io has not been clear yet. Tsuchiya et al.(2015) and Yoneda et al.(2015) have reported that the outburst from Io occurred during January through April 2015. Subsequent increase of EUV radiation from Io plasma torus was also observed by EUV space telescope, HISAKI.

We report the latest observation results of variability on the ion temperatures and the corotation deviation of Io plasma torus caused by the mass-loading during the outburst from Io in early 2015. The observation of sulfur ion emissions, [SII] 671.6nm and 673.1nm, was made at Haleakala Observatory in Hawaii during December 2014 during April 2015 including period of an outburst from Io. We employed a high-dispersion spectrograph (R = 67,000) with an integral field unit (IFU) coupled to a 40-cm Schmidt-Cassegrain telescope. A high-dispersion spectroscopy with an imaging capability enables to derive line-of-sight velocity of ion which is associate with deviation from corotation, as well as its temperatures parallel and perpendicular to the magnetic field. The IFU consist of 132 optical fibers (core/crad/jacket diameter are 50/125/250 micro-meters, respectively). The fibers are arranged in 11 by 12 array at a telescope focus, and are lined up at an entrance slit of the spectrograph. This layout enables to make 2-dimentional spectroscopy over field-of-view of 55" by 61" with a spatial resolution of 5.1" on the sky. The IFU was developed in collaboration with the Institute for Astronomy, University of Hawaii.

Based on a preliminary result from the observation that produced more than 100 spectral datasets, there is an increase of ion temperature after the outburst from Io. Using an 1-dimensional time evolution model of Io plasma torus composition, the observed increase of ion temperature is expected to be associated with the mass-loading from Io. More accurate analysis including deviation of corotation after the outburst is ongoing, the result will also be presented at the meeting.

木星電離・中性オーロラ発光の水平・鉛直構造比較：SUBARU/IRCS による補償光学観測

藤澤 翔太 [1]; 笠羽 康正 [2]; 垰 千尋 [3]; 北 元 [4]; 鍵谷 将人 [5]; 坂野井 健 [6]
[1] 東北大・理・地物; [2] 東北大・理; [3] LPP, Ecole Polytechnique; [4] 東北大・理・惑星プラズマ大気; [5] 東北大・理・惑星プラズマ大気研究センター; [6] 東北大・理

Horizontal and vertical structures of Jovian IR aurora emission observed by SUBARU / IRCS with Adoptive Optics

Shota Fujisawa[1]; Yasumasa Kasaba[2]; Chihiro Tao[3]; Hajime Kita[4]; Masato Kagitani[5]; Takeshi Sakanoi[6]
[1] Tohoku Univ; [2] Tohoku Univ.; [3] LPP, Ecole Polytechnique; [4] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [5] PPARC, Tohoku Univ; [6] Grad. School of Science, Tohoku Univ.

In the Jovian magnetosphere, planetary rotational angular momentum is transported from Jupiter to its magnetosphere and drives magnetospheric plasmas through magnetosphere-ionosphere-thermosphere (MIT) coupling. Magnetospheric energy returns to the polar upper atmosphere by auroral current and precipitating electrons, and heats and ionizes this region. The heated atmosphere excites H3+ and H2 IR aurora. Since H3+ is generated by the ionization of H2 through the collisions with auroral electrons, the emission intensity of H3+ can correlate with both the ionization rate and atmospheric temperature, whereas that of H2 should mainly be controlled by the atmospheric temperature. For these reasons, horizontal and vertical structures of H2 and H3+ IR emissions enable us to separate and compare the horizontal / vertical distributions of ionization and heating in the polar atmosphere associated with MIT coupling processes.

Past K-band (2.0-2.4 um) spectroscopic observations, which obtained H2 and H3+ aurora quasi-simultaneously, shows the difference between H2 and H3+ emission distributions [Raynaud et al., 2004; Uno, 2013]. It could be originated from the different source altitudes, i.e., H3+ emission is from higher altitude where atmosphere is more ionized by auroral electrons and H2 emission is from lower altitude where Joule heating by ionospheric current works more. However, our IR aurora observations by IRCS (Infrared Camera and Spectrograph) attached to SUBARU on Dec. 2011, the first Jovian IR spectroscopy with Adaptive Optics (AO), showed that H3+ and H2 emissions in the northern aurora have similar peak altitude (H2 at 590-720 km, and H3+ at 680-900 km)[Uno et al., 2014]. In our study, the motive is to assess this result by new datasets and also evaluate the horizontal and vertical structures of emission profiles, temperature, and density of the neutral (H2) and ionized (H3+) atmosphere.

The observation was conducted in K-band and L-band (3.2-4.0um) by SUBARU/IRCS on 30 Jan 2015. We used AO which provides high spatial resolution of ˜0.1 arcsec (˜165km). We obtained H3+ overtone lines (v=2-0), hot overtone lines (v=3-1) and H2 emission lines simultaneously in K-band and H3+ fundamental lines (v=1-0) in L-band. While AO could be used, we set the slit along the rotational axis (crossing the aurora oval vertically). While AO could not be used, we set the slit along and over the aurora oval. At the same time, we took the slit viewer image of the H3+ fundamental line with similar spatial resolution.

We compared the horizontal and vertical structures of H2 and H3+ emission intensities. In horizontal distribution, the emission intensities of both H3+ K-band lines and L-band lines showed clear peak on the aurora oval where electron precipitation is the most active and strong UV aurora is often observed in Jovian disk. However, H2 lines emission intensity does not show similar characteristics, i.e., its flux decreases from limb to lower latitude without clear enhancement at the auroral oval. We also derived the vertical distribution of auroral intensity by onion peeling method. We reconfirmed that the peak altitude of ionized H3+ and neutral H2 emissions are similar (H2 at 600-800 km, and H3+ at 800-1000 km), as the result shown in Uno et al. [2014]. This supports that the observed altitudes of H3+ and H2 are not largely different, and both emissions are from ionosphere-thermosphere coupling region is just where neutral atmosphere are heated and ionized strongly.

We are also deriving the horizontal and vertical distribution of H2 and H3+ temperature and column density. In this paper, we will summarize the horizontal and vertical distributions of emissivity, temperature, and densities of H3+ and H2. Based on this result, we will search the possible scenarios for both the common and difference points of these distributions, and evaluate the ionosphere-thermosphere interactions at the height around the IR aurora emission regions.

Time and wavelength variation of wave structure in Jupiter's south polar region observed with ground-based telescope

Yuya Gouda[1]; Yukihiro Takahashi[1]; Makoto Watanabe[1]
[1] Cosmosciences, Hokkaido Univ.

The south polar wave at about 67^o S in Jupiter is considered as one of signatures of Rossby wave. Previous observations, such as by Cassini ISS in 2000 or the Hubble Space Telescope (HST) from 1994 to 1999 [*Barrado-Izagirre at al.,* 2008], show that the polar region is covered by bright diffuse haze and its edge has a wave structure spreading in longitudinal direction with wavenumber of 12-14 at 67^o S, which travels westward with a phase velocity of 0-10 m/s in SystemIII. These observations suggested that this wave structure is caused by a planetary Rossby wave. However, these observations had been carried out only every other year and the variance of short time scale (about month and less than) is not clear.

Using a deep methane absorption band filter at 889 nm installed at Multi-Spectral Imager (MSI) of the 1.6 m Pirka telescope, we investigated the meridional and vertical wavenumbers and phase velocity of the observed wave structure and zonal wind speed.

In this presentation, we introduce the observational results of time variation of the wave structure at 889 nm in Jupiter's south polar region in 2011 to 2015 by the ground-based telescope. Each result is separated by two weeks to a few months in the periods that we can observe Jupiter. Our results show the wave structure is very different between 2011 and 2015. In 2011, longitude between 0^o and 150^o in SystemIII are also similar, however other longitudes are very different. Large changes in the wave structure of within a few days are observed even in 2015. This point is different from previous studies. Moreover, we compare this structure with the wave structure at a middle methane band filter at 727 and 619 nm. Using another wavelength filter, we can get information of wave structure in troposphere. We can get vertical variation of wave structure between pressure altitude of about 361 mbar and 750 mbar. However, we cannot use the same method which selected images as in the 889 nm. Because the brightness ratio of Jupiter to Galileo satellite used by estimate of atmospheric seeing differ about thirty times between 889 nm and another methane band. We also introduce result of wave structure using new method of selection of Jupiter image which using only brightness of Jupiter itself. This is a new point of my study. Using frequency analysis of latitudinal direction of Jupiter, we can get wave structure by every wavelength.

高専連携 CubeSat による木星電波観測プロジェクトについて

今井 一雅 [1]; 高田 拓 [2]; 北村 健太郎 [3]; 平社 信人 [4]; 高専スペース連携 グループ [5]
[1] 高知高専・電気情報工学科; [2] 高知高専・電気; [3] 徳山高専; [4] 群馬高専; [5] -

KOSEN-Renkei CubeSat Project for the observation of Jupiter's decametric radio emissions

Kazumasa Imai[1]; Taku Takada[2]; Kentarou Kitamura[3]; Nobuto Hirakoso[4]; Group KOSEN Space Renkei[5]
[1] Kochi National College of Technology; [2] Kochi-CT; [3] NIT,Tokuyama.; [4] NIT,Gunma; [5] -

The development of a micro satellite (CubeSat) for Jupiter radio observation is made by the collaboration with 8 colleges which belong to National Institute of Technology (KOSEN-Space-Renkei). The KOSEN-Space-Renkei students and teachers have been collaborating to develop the 2U-size CubeSat from this year. This CubeSat is being considered to be ejected from the International Space Station (ISS). The duration of the possible observation is estimated to be more than 50 days. During this period we are considering measurement of the delay time between CubeSat and ground observatories for the detection of Jovian S-bursts. The measured delay time reveals very important information for determining the beam model of Jupiter's radio emissions. We show the current status of the design of CubeSat including Jupiter's radio receiving antenna, receiver, and data acquisition system synchronized with GPS.

高専スペース連携は、全国高専の宇宙関係の研究者を中心とした、連携教育研究プロジェクトで、文部科学省の平成 26 年度宇宙航空科学技術推進委託費・実践的若手宇宙人材育成プログラムに採択された「国立高専超小型衛星実現に向けての全国高専連携宇宙人材育成事業」(http://space.kochi-ct.jp/) を中心に活動を行っている。この全国高専連携宇宙人材育成事業の一環として、高知高専と徳山高専を中心として 8 高専が連携し、2 機の超小型衛星 (CubeSat) の開発が、教育プロジェクトとして学生を中心に行われている。本発表では、高知高専を中心として進められている木星電波観測用 CubeSat の開発について報告する。

この高専連携 CubeSat 開発のターゲットとして選ばれた木星電波は、木星からのデカメートル帯での自然電波放射である。木星電波は、1955 年に発見されて以来、観測・研究が進んでいるが、その放射機構の全貌はまだ明らかとなっていない。この木星電波は、木星のオーロラ現象と密接に関連し、木星磁気圏内のプラズマと磁場との相互作用により発生するもので、地球でも観測が可能であることから、その電波放射エネルギーは極めて大きい。この木星電波放射機構を解明するためには、様々な研究項目があるが、その中でも木星電波のビーム構造の研究が重要であると考えられている。この木星電波のビーム構造の研究のための観測は、主に地上の観測点で行われており、地上の 2 地点間で木星電波の同時観測を行って、木星電波の短時間の変動である S バースト波形の相関解析から遅延時間が測定されている。しかしながら、遅延時間測定の精度をあげるためには、東西方向の 2 地点間の距離（基線長）を長くする必要があるが、地上の観測点では基線長に限界がある。そこで、この限界を打破するために、衛星と地上の 2 カ所で同時観測を行うことにより、従来にない基線長を確保した観測を行い、測定精度の向上を目指すことを考えている。

ミッションとしては、木星電波観測用 CubeSat を、国際宇宙ステーション (ISS) より放出することを想定している。ISS から放出された後、木星電波受信用アンテナとアップリンク・ダウンリンク用アンテナを展開し、搭載した GPS モジュールの正秒パルスを用いて、受信した木星電波のアナログ信号を A/D コンバータによりデジタル信号へ変換し、Linux マイコンボードの Raspberry Pi のプログラムによってデータを地上局へ送信する。最終的には、地上での同時観測データとの相関解析より木星電波 S バーストの到達遅延時間をミリ秒レベルの精度で求める。この到達遅延時間の測定から、木星電波のビーム特性に起因する木星電波のビーム構造が木星磁場と一緒に共回転しているかどうかについての検証を行うことが可能となる。本発表では、木星電波観測用の超小型衛星 (2U の CubeSat) の開発状況について、木星電波観測用アンテナ、受信機、GPS 同期型のデータ収集システムを中心に報告する。

東北大地上観測にもとづく木星デカメータ電波データアーカイブ

熊本 篤志 [1]; 佐々木 悠朝 [2]; 加藤 雄人 [3]; 八木 学 [4]; 土屋 史紀 [5]; 三澤 浩昭 [6]
[1] 東北大・理・地球物理; [2] 東北大・理・地球物理; [3] 東北大・理・地球物理; [4] 東北大 PPARC; [5] 東北大・理・惑星プラズマ大気; [6] 東北大・理・惑星プラズマ大気研究センター

Data archive of Jovian decametric radiation based on ground based observation at Tohoku University

Atsushi Kumamoto[1]; Yuasa Sasaki[2]; Yuto Katoh[3]; Manabu Yagi[4]; Fuminori Tsuchiya[5]; Hiroaki Misawa[6]
[1] Dept. Geophys, Tohoku Univ.; [2] Geophysics, Tohoku Univ.; [3] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [4] PPARC, Tohoku Univ.; [5] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [6] PPARC, Tohoku Univ.

We are developing integrated data archives for Jovian decametric radiation (DAM) datasets obtained at Nancay station of Paris Observatory and Iitate station of Tohoku University in order to provide data which covers >16 hours (˜2 Jovian days) for the support of JUNO's initial observation. As a first step, we prepared metadata server at Tohoku University in July 2015 for integrated data access via Virtual Observatory (VO) with support of Paris Observatory team. This server with other VO's repository servers enable us to search and access Nancay and Iitate datasets using the same tools.

In addition to the integrated metadata repository, we are developing high-time-resolution (˜1 msec) data archive of Jovian decametric radiation (DAM) obtained at the observatories of Tohoku University in order to provide them as open data for investigation of S-burst of Jovian DAM. High-time-resolution observation of Jovian DAM at Tohoku University has been performed since 1982 with updating receiver system. So the frequency range and time resolution of the data varied among different periods: 2 MHz in 20-40 MHz and 2 msec in 1982-2004 (Period-1), 3.2 MHz in 21-28 MHz and 0.51 msec in 2006-2009 (Period-2), 20-40MHz and 0.8 msec since 2012 (Period-3). Because the size of the entire dataset is too large to store in the storage of the data server, meta data and reduced-resolution data will be provided by the data server, and main body of data will be provided manually on request of the users. In the presentation, we are going to show the progress of the studies based on the high time resolution dataset of Jovian DAM.

Verification of Jovian ionospheric Alfven resonator by event analyses of ground-base observation

Yuasa Sasaki[1]; Atsushi Kumamoto[2]; Yuto Katoh[3]; Hiroaki Misawa[4]
[1] Geophysics, Tohoku Univ.; [2] Dept. Geophys, Tohoku Univ.; [3] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [4] PPARC, Tohoku Univ.

Jovian decametric (DAM) radiation has been studied based on event analyses of a simultaneous S-burst event in multiple frequency bands and continuous occurrence of S and L bursts obtained by ground-based observation in order to verify Jovian ionospheric Alfven resonator (IAR) hypothesis.

Ergun et al. [2006] and Su et al. [2006] proposed Jovian IAR model. According to these previous studies, eigenfrequencies of Jovian IAR are also expected to determine the repetition rate of S-burst of Jovian DAM radiation. This Jovian IAR hypothesis was based on the theory and observations of the Earth's IAR. However, due to lack of the observational evidences, Jovian IAR hypothesis has been controversial since its proposal. In order to verify the Jovian IAR hypothesis, we have observed Jovian DAM radiation with a logperiodic antenna at Yoneyama observatory and a wideband receiver, whose frequency range is from 20 MHz to 40MHz. Previous studies reported that intense S-burst events increase were often found in Io-B source condition. So, we have scheduled observation in Io-B source condition.

In this study, we focus on following two events: The first one is a simultaneous S-burst event in two different frequency bands (~23.5 MHz and ~27 MHz) found around 15:56 UT on 24 November, 2014. Assuming that the emission frequency is equal to the electron cyclotron frequency at the source, the geometric distance of the emission sources at 23.5 MHz and 27 MHz are estimated to be 82500 km and 74800 km. The estimated Alfven wave length in Jovian IAR is from 7200 km to 12000 km by using Alfven speed of 0.80 c and 0.52 c, and the eigenmodes is ~20 Hz [Ergun et al., 2006; Su et al., 2006]. The distance between the two sources is about 7700 km, which is as large as Alfven wave length trapped at Jovian IAR.

The second one is continuous occurrence of S-burst and L-burst of Jovian DAM for ~30 minutes found in 12:00-12:30 UT on 2 January, 2015. At first there were L bursts. Then S bursts emissions overlapped came with L busts. Finally, L bursts faded away and there were only S bursts. When the both S-burst and L-burst occurred, complex structures called inverted tilted-V events [Riihima and Carr, 1981; Oya et al., 2002] were found in the spectrogram. The event suggests that there are upward-moving plasma which cause shadowing of background emissions.

In the presentation, we will show some results of further analyses of observation data for verification of Jovian IAR.

土星電波活動の南北非対称性及び季節変動

佐々木 歩 [1]; 笠羽 康正 [1]; 木村 智樹 [2]
[1] 東北大・理; [2] RIKEN

North-south asymmetry and seasonal variation of Saturn's radio activities

Ayumu Sasaki[1]; Yasumasa Kasaba[1]; Tomoki Kimura[2]
[1] Tohoku Univ.; [2] RIKEN

Saturn emits intense radio emissions, Saturn Kilometric Radiation (SKR), from the northern and southern polar region in 3-1200kHz. SKR is generated by field-aligned energetic auroral electrons via Cyclotron Maser Instability (CMI) [Wu and Lee, 1979] at local cyclotron frequency. In the Saturn's magnetic field directions (similar to the Earth's), the CMI theory predicts the right-handed circularly polarization (RH) emissions are from north and the left-handed circularly polarization (LH) ones are from south, respectively. Cassini observations in the southern summer (2004-2009) showed that the SKR intensity shows daily variation [Kurth et al., 2008]. Its period is slightly longer in the southern SKR than the northern one [Gurnett et al., 2009], and it was reversed near the equinox (September in 2009) [Gurnett et al., 2010]. Related to this, we studied other trend in 2004-2010, and showed that the averaged intensity of LH component (summer, south) is stronger than that of RH component (winter, north) [Kimura et al., 2013]. . Those characteristics suggested that the auroral activities are controlled by the north-south asymmetry of the polar ionospheric conductivities, which are related to the seasonal variations of the solar EUV flux. However, the scenario that can totally explain all observed features has not been yet established. For example, in the observations after 2010 (the Northern summer), both northern and southern SKR periods are not clearly different [Provan et al., 2014; Fischer et al., 2015]. This fact is contrary to the simple idea based on the polar ionospheric conductivities.

In this study, we extend the seasonable variation study in Kimura et al. (2013) covering the northern (summer) in 2010-2015. First we try to study the north-south ratio of the SKR intensity. We note that a simple extension of this analysis has a problem, caused by the Cassini orbit bias. Since the SKR are stronger in the dawn side, Kimura et al. (2013) adopted the detection criteria that Cassini is at the dawn side, (2h to 10h LT) and in the latitude and distance where SKR propagation is outside of the radio-invisible zone (latitude: -5 to +30deg (RH), +5 to -30 (LH); radius: 10 to 100 Rs). However, because of Cassini's orbital transition, apokrone after 2010 has shifted to the dusk side, and it becomes hard to get a large number of observations with the same data selection criteria.

At the moment, we removed the LT constraints and roughly investigated the SKR intensity ratio at all LT experimentally. In 2004-2007 the intensity of LH component (south, summer) was stronger by 7dB than RH (north, winter). In 2009-2011, the both SKR intensity became similar. After 2012, RH (north, summer) was stronger by 4dB than LH (south, winter). For further study, we will establish the new selection criteria based on additional analysis of the latitude - LT relationships in southern and northern SKR in overall periods.

We also note that the solar activity was minimum in 2008-2010, near Saturn's equinox. It means that solar EUV variation and Saturn's seasonal variation were not decoupled. We will also check this point as the investigation of the EUV influence on the SKR in 2004-2010 included in the work of Kimura et al. [2013].

土星は、Saturn Kilometric Radiation（SKR）と呼ばれる強力な電波放射を 3-1200kHz で南北両極から放射している。SKR は沿磁力線加速されたオーロラ電子からサイクロトロンメーザー不安定性によって励起され、サイクロトロン周波数で放射される。土星磁場の配位 (地球と同様) から、北側からは右旋円偏波（RH）、南側からは左旋円偏波（LH）で放射されるため、円偏波度を用いて南北要素を分離可能である。この性質を利用した Cassini 探査機による土星南半球夏季の観測 (2004-2010) から、自転に伴う SKR 日変動周期が時間変動すること [Kurth et al., 2008]、日変動周期が南半球でより長いこと [Gurnett et al., 2009]、春分点（2009 年 9 月）付近で南北周期の逆転が見られること [Gurnett et al., 2010] 等、ユニークな土星の電磁圏活動特性が発見された。この南北非対称・季節変動に絡んで、Kimura et al. (2013) では、南北 SKR 強度の長期変動を追跡し、南半球夏季では LH 成分（南半球・夏側）が RH 成分（北半球・冬側）よりも平均的に強いことを見出している。これらの統一的な原因として、土星の極域沿磁力線電流量・降下電子量・オーロラ活動量が、極電離圏の電気伝導度の南北非対称（夏側が冬側より高い）およびその季節変動・太陽 EUV フラックス応答により制御されるシナリオが示唆されているものの、決定的な結論は未だ確立されていない。特に、春分点を過ぎた 2010 年以降の観測（北半球夏季）において、南半球夏季に見られた南北日変動周期の相違が見出せなくなっている [Provan et al., 2014; Fischer et al., 2015]。この事実は、極域電離圏伝導度の相違に原因を委ねる簡易なアイディアに反している。

本講演では、SKR 南北強度比の季節変動について、Kimura et al. (2013) で提示された南半球夏˜春分点 (2004-2010) の追跡を北半球夏 (2015 春) まで拡張した結果を速報の予定である。なお、この解析の単純延長には、Cassini の軌道の偏りに起因する問題があることがわかっている。土星 SKR の放射は、朝側領域でより強いことが確認されているため、Kimura et al. (2013) では、Cassini がこの朝側領域を観測可能で（ローカルタイム：2˜10h）、かつ放射域近傍の高密度域に電波伝搬が阻害されない位置（緯度：RH（北側）で -5˜+30deg、LH（南側）で +5˜-30deg、距離：10-100Rs）に絞って解析を行った。しかし、Cassini は軌道遷移のため 2010 年以降には遠土点が夕方側へ移行しており、同様な制限を設けると適用可能データが著しく減少してしまう。このため、まずローカルタイム制約を外して、試験的に観測可能な全ローカ

ルタイムにおける SKR の南北強度を比較調査した。この結果、2004˜2007 年は LH 成分（南半球・夏側）が平均約 7dB 電波強度が大きく（先の結果と矛盾せず）、春分点直前から 2 年後に至る 2009˜2011 年では両極の SKR 強度はほぼ同程度、2012 年以降には RH 成分（北半球：夏側）が約 4dB 大きくなる様子が見られた。この結果は「夏側半球の側でオーロラ活動がより増大する」という予測と整合はする結果である。この解析の正当性を確立するため、各ローカルタイム毎の観測緯度-電波強度（周波数依存性含む）を確認し、南半球夏季（朝側から観測）と北半球夏季（夕側から観測）の接続がどういう前提のもとで可能か、確認しつつある。

なお、太陽活動は 2008-2010 に極小期を迎えていた。このため、太陽 EUV 放射量は土星の春分点近傍で最も下がっており、太陽 EUV 強度変動と季節変動とは同期してしまっている。Kimura et al. (2013) では、太陽 EUV 放射強度と SKR 強度との相関をとってこの影響を季節変動とは独立に評価したが、2010-2015 年についても同様な追跡を行う必要がある。特に、2011 年まで SKR 南北比がはっきり見えなかったという我々の暫定結果と太陽 EUV 放射量との関係確認は重要な視点となりうる。さらに、2010 年以降の Cassini 軌道は、遠土点が Magnetopause よりも上流側に位置するため、太陽風磁場・密度と SKR 活動量との相関を直接比較可能となっている可能性がある。これは過去の解析期間では追跡不可能だった視点であり、この解析にも随時発展させたい。

Dependence of the Vorticity in Kronian Magnetosphere on the IMF

Keiichiro Fukazawa[1]; Raymond J. Walker[2]
[1] ACCMS, Kyoto Univ.; [2] IGPP/UCLA

In a series of simulation studies we have found turbulent convection and vortices formed at Saturn's dawn and dusk magnetopause in simulations when IMF was northward. We interpreted these vortices as resulting from the Kelvin Helmholtz (K-H) instability. The resolution of simulation is an important parameter for the formation of vortices and turbulent convection as it is necessary to capture the small changes in convection which can trigger of vortex formation. Recent developments in computer technology have enabled us to run simulations with much higher resolution (0.06RS) then was previously possible. In this study we perform simulations of the Kronian magnetosphere for various IMF orientations to determine the conditions under which vortices form.

In this study we determine the minimum component of BZ for vortex formation and present a physical model showing how the combination of the IMF, Saturn's rotating flows and reconnection determine when vortices form. From the detailed analysis of plasma convection in the magnetosheath and magnetosphere, there are important differences in the flow due to the tail reconnection and it affects the condition for K-H instability and vorticity in the overall magnetosphere.

BepiColombo 日欧共同水星探査ミッション：MMO プロジェクト最新状況報告

早川 基 [1]; 前島 弘則 [2]; BepiColombo MMO プロジェクトチーム 早川　基 [3]
[1] 宇宙研; [2] JAXA/ISAS; [3] -

BepiColombo Euro-Japan Joint mission to Mercury: MMO Project Status update

Hajime Hayakawa[1]; Hironori Maejima[2]; HAYAKAWA, Hajime BepiColombo MMO Project team[3]
[1] ISAS/JAXA; [2] ISAS/JAXA; [3] -

http://www.stp.isas.jaxa.jp/mercury/

BepiColombo is a ESA-JAXA joint mission to Mercury with the aim to understand the process of planetary formation and evolution in the hottest part of the proto-planetary nebula as well as to understand similarities and differences between the magnetospheres of Mercury and Earth.

The baseline mission consists of two spacecraft, i.e. the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO). The two orbiters will be launched in 2016 by an Ariane-5 and arrive at Mercury in 2024. JAXA is responsible for the development and operation of MMO, while ESA is responsible for the development and operation of MPO as well as the launch, transport, and the insertion of two spacecraft into their dedicated orbits.

MMO is designed as a spin-stabilized spacecraft to be placed in approx. 600 km x 11400 km polar orbit. The spacecraft will accommodate instruments mostly dedicated to the study of the magnetic field, waves, and particles near Mercury.

Selection of the PI responsible instruments was finished on 2004. MMO final AIV in JAXA was completed in this March. MMO was transported to ESA/ESTEC in April and is waiting for the Mercury Cruise System level final AIV. Mission CDR for whole BepiColombo was closed in this March.

11th BepiColombo science working team (SWT) meeting, which discusses science related matters, will be held on Sep. 2015 at Chicheley Hall, in Buckinghamshire, UK. In this paper, we will report the latest information of MMO project status.

紀元前から知られる水星は、「太陽に近い灼熱環境」と「軌道投入に要する多大な燃料」から周回探査は困難であった。米国マリナー 10 号による３回のフライバイ観測 (1974-5) は、この小さな惑星にはあり得ないと考えられていた磁場と磁気圏活動の予想外の発見をもたらしたが、その究明は 30 年以上続く夢に留まってきた。これらの探査耐熱技術の進展に代表される技術革新が、ようやく大きな壁を取り除きつつあり、2011 年 3 月からは米国 MESSENGER の周回軌道からの観測を行っている。「ベピ・コロンボ（BepiColombo）」は、欧州宇宙機関（以下、ESA）との国際分担・協力によりこの惑星の磁場、磁気圏、内部、表層を初めて多角的・総合的に観測しようとするプロジェクトである。固有磁場と磁気圏を持つ地球型惑星は地球と水星だけで、初の水星の詳細探査＝「初の惑星磁場・磁気圏の詳細比較」は、「惑星の磁場・磁気圏の普遍性と特異性」 の知見に大きな飛躍をもたらすし、磁場の存在と関係すると見られる巨大な中心核など水星の特異な内部・表層の全球観測は、太陽系形成、特に「地球型惑星の起源と進化」の解明に貢献する。また、MESSENGER によってなされた数多くの発見は BepiColombo によって解き明かされる事が期待されている。

本計画は、観測目標に最適化された２つの周回探査機、すなわち表面・内部の観測に最適化された「水星表面探査機 (MPO)」（３軸制御、低高度極軌道）、磁場・磁気圏の観測に最適化された「水星磁気圏探査機 (MMO)」（スピン制御、楕円極軌道）から構成される。ISAS ／ JAXA は、日本の得意分野である磁場・磁気圏の観測を主目標とする MMO 探査機の開発と水星周回軌道における運用を担当し、ESA が残りの全て、すなわち、打ち上げから惑星間空間の巡航、水星周回軌道への投入、MPO の開発と運用を担当する。

両探査機に搭載する数々の科学観測装置は、2004 年の搭載機器選定以降開発は着々と進行し、日本側は 2012 年 9 月より FM の総合試験を実施しており、本年 3 月に終了した。また ESA 側開発のモジュール（MPO,MTM) も各々の NFM 総合試験を実施しており、本年度中に終了する予定である。MMO FM は 4 月に ESA/ESTEC に輸送され、スタックレベル (MCS:Mercury Cruise System) の総合試験の開始を待っているところである。MCS 試験の終了後射場へと輸送され 2017 年 1 月に予定されている打ち上げに備える事になる。なお、BepiColombo 全体のミッション CDR は本年 3 月に終了した。

水星到着後の観測は、選ばれた装置開発チームに留まらず、広く日欧研究者で構成する「BepiColombo 科学ワーキングチーム」(年 1 回程度開催) で立案・実施される。本講演では、これら科学観測に関連した状況、日本側が製作を担当する MMO の状況並びに ESA 側進捗状況について最新状況を報告する。

2015 年 12 月における ”あかつき ”の金星軌道投入

あかつきプロジェクト 中村 正人 [1]
[1] -

Venus Orbit Insertion of Akatsuki in December, 2015

Masato Nakamura Akatsuki Project[1]
[1] -

Japan launched Venus Climate Orbiter Akatsuki to observe the dynamics of the Venus atmosphere globally and clarify the mechanism of the atmospheric circulation. The cruise to Venus was smooth, however, the first Venus Orbit Insertion (VOI) trial on December 7th, 2010 tuned out to be a failure. Fortunately we keep the spacecraft in a healthy condition and surprisingly we have found another chance to let this spacecraft to meet Venus in 2015. Next VOI trial will be done on December 7th, 2015.

This mission is planed to answer the question described below. The radius of the Earth and Venus are almost the same. In addition the radiation from the sun is also almost the same. The climates of these planets, however, are much different. For example, the strong zonal wind is observed on Venus with the period of 4 days, where Venus rotates westward with the period of 243 days. This is called super rotation. We will investigate from data from Akatsuki what attributes to the difference of the climates between Earth and Venus. AKATSUKI was designed for remote sensing from an equatorial, elliptical orbit to tract the atmospheric motion at different altitudes using 5 cameras (3xIR, UV, Visible) and by the radio occultation technique.

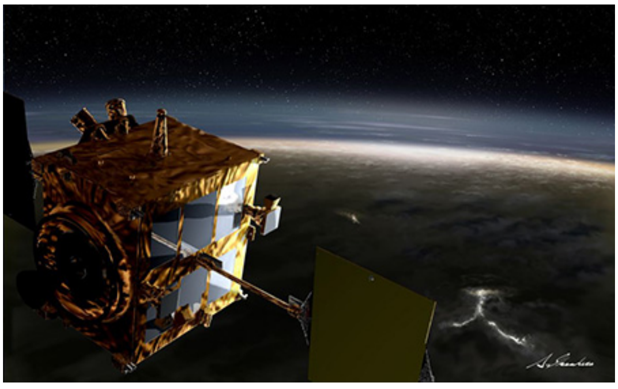
We decide to use RCS thrusters for Trajectory Control Maneuvers (TCMs) and Venus Orbit Insertion. Total thrust force of 4 RCS thrusters is 20% of that of the main thruster and the orbit after VOI-R becomes a larger ellipse (apoapsis altitude will be finally 3.2x10^6km) than the original plan in 2010. We have already done major 6 TCMs before July 31st, 2015 to let the spacecraft to meet Venus in December.

金星の大気のダイナミクスをグローバルに観察し、大気大循環のメカニズムを解明するために日本は金星探査機「あかつき」（コード名：PLANET-C）を打ち上げました。打ち上げは種子島宇宙センターから 5 月 21 日、2010 年に行われました。金星へのクルーズは順調でしたが 12 月 7 日最初の金星軌道投入（VOI）は失敗に終わり「あかつき」は、現在太陽を周回しています。探査機の状態は良好に維持され、さらに幸いなことに、我々は「あかつき」を２０１５年に金星に再び巡り合わせる軌道を発見しました。次の VOI は本年 12 月 7 日に行われます。

「あかつき」ミッションは、以下の疑問に答を与えるために計画されました。地球と金星の半径はほぼ同じであり、また、太陽からの熱量もほぼ同様です。ところが 2 つの惑星の気候は全く異なっています。金星の自転周期は 243 日ですが、一報 4 日間で金星をめぐる風系が観測されます。これをスーパーローテーションと呼びます。「あかつき」は、5 台のカメラ（３台の IR カメラ、UV カメラ、可視カメラ）と電波掩蔽法を用いて、異なる高度における大気の動きをリモートセンシングします。

主エンジンが壊れているためプロジェクトは姿勢制御の為に備わっているスラスタ（ＲＣＳスラスター）を使用し、軌道制御を行う事にしました。４つの RCS スラスタの総推力は、主エンジンの 20 %でしかないため、当初の計画よりも大きな楕円軌道（遠点高度 3.2x10^6km）に入ることになります。今年 7 月末までに 6 回の大きな軌道制御を行った後、１２月に軌道投入に挑みます。

講演では投入後の探査機の軌道および観測計画について話す予定です。



地上赤外分光観測による金星大気波動解析：1.7umCO2吸収・5.04um放射比較

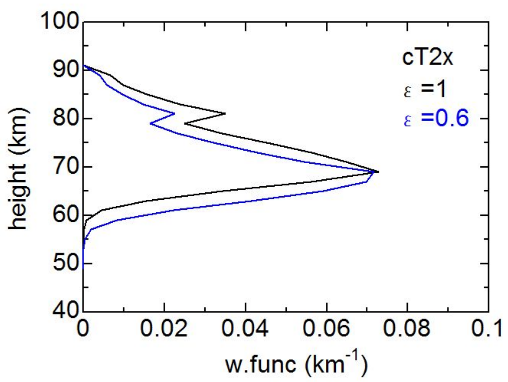
狩野 咲美 [1]; 細内 麻悠 [2]; 大月 祥子 [3]; 岩上 直幹 [1]
[1] 東大・理; [2] 東大・理・地惑; [3] 専修大

Study of Venusian atmospheric waves by the ground-based IR spectroscopy:Comparison of 1.7um and 5.04um.

Sakimi Kano[1]; Mayu Hosouchi[2]; Shoko Ohtsuki[3]; Naomoto Iwagami[1]
[1] U Tokyo; [2] Earth & Planetary Science, Univ. of Tokyo; [3] Senshu Univ.

Investigation of Venusian atmospheric waves has been made at only limited heights; they are the cloud-top height at 70km by scattered solar UV and the night side 50km by IR transmission.We have developed a new method to find out waves at 60km (Hosouchi et al, ICARUS 2012).During the observation at IRTF in May 2014 for 10 days, we requested VEX/VMC to have simultaneous observation. However, such plan could not be realized because of VEX's life. Instead we plan to use 5um observation by rselves.Since 5um emission will give us information at 70km, and we can get information at 60km in the 1.7um.We can investigate the waves at 60 and 70km; this may give us insight into the formation mechanism of the Super Rotation. Figure:5um weighting function.

金星雲高度域での大気波動に関する検討は、意外なことに限られ高度でしかなされてこなかった。つまり昼面太陽 UV 散乱光による雲頂高度 70km と、夜面 IR 透過光による 50km に限られていた。この状況を打破すべく、我々は昼面高度 60km での波検出方法を考案し（細内ほか ICARUS 2012）全雲域における大気波動の伝播を研究しようとしている。2014 年 5 月にハワイ・マウナケア・IRTF・CSHELL に 10 日間の観測時間を得たため欧州 Venus Express の UV センサ VMC(Venus Monitoring Cam　昼面 70km 情報）との同時観測を提案し承諾を得た。ところが、この目論見は VEX の寿命終了のため実現しなかったため、我々は代替として 5um での熱放射測定で 70km 情報を得ることを考えた。波長 3um 以長では雲が黒くなるので 5um では雲頂 70km の熱放射がみえる。1.7um 昼面 60km 情報との比較により雲域での大気波動消長の検討より大気超回転問題の解決に迫りたい。図：5um 荷重関数



極端紫外線領域の金星大気光の輝線の同定

奈良 佑亮 [1]; 吉川 一朗 [1]; 岩上 直幹 [2]; 吉岡 和夫 [3]; 村上 豪 [4]; 木村 智樹 [5]; 山崎 敦 [6]; 土屋 史紀 [7]; 藤原 空人 [1]; 桑原 正輝 [8]
[1] 東大・理・地惑; [2] 東大・理; [3] 立教大; [4] ISAS/JAXA; [5] RIKEN; [6] JAXA・宇宙研; [7] 東北大・理・惑星プラズマ大気; [8] 東大・新領域・複雑理工

Extreme Ultraviolet Spectroscopy of Venusian Atmosphere Observed by EXCEED

Yusuke Nara[1]; Ichiro Yoshikawa[1]; Naomoto Iwagami[2]; Kazuo Yoshioka[3]; Go Murakami[4]; Tomoki Kimura[5]; Atsushi Yamazaki[6]; Fuminori Tsuchiya[7]; kuto Fujiwara[1]; Masaki Kuwabara[8]
[1] EPS, Univ. of Tokyo; [2] U Tokyo; [3] Rikkyo Univ.; [4] ISAS/JAXA; [5] RIKEN; [6] ISAS/JAXA; [7] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [8] Univ. of Tokyo

Planetary upper atmosphere glows due to transition of atoms, ions and molecules excited by solar photons. Investigating these emissions leads to realizing constitution and chemistry in the upper atmosphere.

In this study, we analyze spectrum of Venus obtained by EXCEED on HISAKI spacecraft, which was launched on September 2013. The data we use were obtained between 9th and 29th March 2014. In the past, Venusian atmosphere was observed in the EUV wavelength range by Marinar-10 (1974), Venera-11,12 (1978), Cassini (1999), etc. and emissions of H, C, O, N and CO were identified by these observations. Because of HISAKI's high temporal resolution, the weak atomic and ionic emissions and N_2 Lyman-Birge-Hopfield band, Tanaka band etc. are newly identified.

惑星の大気上層は主に太陽光により励起された原子やイオン、分子が脱励起することによって発光している。発光現象を調べることは、大気上層の組成や光化学の理解へとつながる。ここでは 2013 年 9 月に打ち上げられた「ひさき」衛星に搭載されている極端紫外線分光器 EXCEED の観測結果を用いて、金星大気の発光による輝線の同定を行った。

地球周回軌道上で惑星を EUV 波長領域で観測している「ひさき」は 2014 年 3 月 9 日から 29 日の間、金星の観測を行った。過去に金星の EUV 波長領域の観測を行ったものとして、水星探査機マリナー 10 号 (1974 年) 、土星探査機カッシーニ (1999 年) の金星遷移軌道中の観測、金星探査機ヴェネラ 11, 12 号 (1978 年) などがあり、H, C, N, O, CO が同定された。ひさきの高時間分解能の観測により、これまで見つからなかった強度の弱い原子、イオンの輝線や N_2 Lyman-Birge-Hopfield band, Tanaka band などの発光帯が新たに同定できた。

金星 GCM への硫酸雲の導入及びその循環、分布に関する研究

伊藤 一成 [1]; 黒田 剛史 [2]; 笠羽 康正 [2]; 寺田 直樹 [3]; 池田 恒平 [4]; 高橋 正明 [5]
[1] 東北大院理; [2] 東北大・理; [3] 東北大・理・地物; [4] 環境研; [5] 東大・大気海洋研

Implementation of sulfuric acid clouds into a Venus GCM and study of their distributions and cycle

Kazunari Itoh[1]; Takeshi Kuroda[2]; Yasumasa Kasaba[2]; Naoki Terada[3]; Kohei Ikeda[4]; Masaaki Takahashi[5]
[1] Pat, Tohoku Univ.; [2] Tohoku Univ.; [3] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [4] NIES; [5] AORI, Univ. of Tokyo

We have implemented H_2SO_4 clouds into our VGCM (Venusian General Circulation Model) to reproduce their cycle and distributions comparable with observations. Venus is covered by global sulfuric acid (H_2SO_4) cloud deck in the altitude of 50-70 km. Past trials for such cloud reproductions in VGCMs used cloud parameterization (condensation / evaporation and sedimentation processes) (Lee et al., 2010; Kato, 2014). However, they did not include chemical processes related to the cloud cycle, and did not reproduce the cloud on the realistic processes.

We have implemented the chemical processes related to the production and loss of H_2SO_4 clouds for the reproduction of realistic cloud cycle in the model. We used a VGCM based on the CCSR/NIES/FRCGC AGCM [Ikeda, 2011], with the horizontal resolution of T21 (longitude and latitude grids of about 5.6 degrees) and 52 levels in vertical with the sigma (equivalent to the pressure) coordinate (the top altitude of about 95 km). For cloud condensation and evaporation processes, we assumed that the H_2SO_4 clouds are generated when the H_2SO_4 vapor is saturated, i.e., the forecasted mixing ratio of total H_2SO_4 (sum of vapor and cloud) is larger than the calculated saturated level. And all H_2SO_4 clouds evaporate to the vapor if not, without the effects of supersaturation. The radius of cloud aerozol is artificailly distributed into 4 modes by ratios based on the vertical profiles shown by Haus and Arnold[2010]. (Our model at the moment does not include the growth or reduce of the particle size, and only traces the advection of produced clouds.) We also note that the cloud distributions should modulate the thermal distributions through radiative effects, but current our model assumes constant heat input profile (as well as the former code by Ikeda [2011]).

After the run for 20 Venus days (2340 earth days), the cloud distribution in this model reaches an equilibrium status. In the result, the simulated cloud cycle are reproduced; the formation of H_2SO_4 cloud particles in the upper cloud region (about 70 km altitude) of lower latitudes (about 0 - 30 degrees) due to the chemical processes, advection of clouds to the higher latitudes (about 70 degrees) by the meridional circulation, and evaporation of clouds and formation of SO_2 in the lower cloud region (about 50km altitude) of higher latitudes. This is consistent with the formation and extinction processes suggested by a two-dimensional model [Imamura and Hashimoto, 1998], though the meridional transport of the clouds is weaker in our model. In the presentation we will also show further analyses of the simulated results and their comparisons with the global distribution of cloud characteristics derived by Venus Express observations.

This model will contribute to the study of qualitative and quantitative global cloud distributions and variations observed by the Akatsuki mission from 2016.

我々は、観測と定性的・定量的比較が可能な金星雲の循環・分布の再現を目指す金星大気大循環モデル（Venus General Circulation Model, VGCM）の開発を進めている。金星は高度 50-70km を硫酸雲に覆われ、その化学過程と太陽光吸収が金星大気の大循環に大きく寄与している。VGCM における硫酸雲の生成・循環・消滅過程の導入は、Lee et al. [2010] と我々のグループ（e.g. 加藤, 2014）においてなされてきた。これらでは、硫酸雲の凝縮・蒸発過程と沈降過程はパラメタリゼーションによって取り扱われたが、これらに伴う関連物質間の化学過程が導入されておらず、Knollenberg and Hunten [1980] で提唱されている金星硫酸雲サイクルが成り立っていない。このため、観測されている雲の高度・緯度分布の再現には未だ至っていない。

本研究では、硫酸蒸気の生成・消滅に絡む SO_2、H_2O などを含む化学過程を導入することで、未だ下記に示す一定の簡略化を前提とするものの、現実的な金星硫酸雲の生成・消滅を VGCM 上で再現することに成功した。ベースモデルは CCSR/NIES/FRCGC AGCM をもとに開発された VGCM [Ikeda, 2011] である。現モデルでは、水平分解能 T21（グリッド間隔：緯度経度双方で約 5.6 度）、鉛直 52 層（大気上端高度：約 95km）に設定した。雲の生成・消滅は、各タイムステップで硫酸飽和蒸気量を上回る分の硫酸蒸気を凝縮させて硫酸雲としている（過飽和の効果は取り入れていない）。生成される雲粒径は、Haus and Arnold [2010] に基づく 4 種類のモード比の高度分布に従って配分される（この粒径高度分布は、全緯度・経度にわたり水平方向一定と仮定している）。生成後の雲粒子径の拡大・縮小の再現は取り入れておらず、各粒子の移流を追跡するに留まる。また、得られる雲分布は大気の熱放射・吸収の量・空間分布に影響を与えるが、現モデルにおいてはまだ「一定量・一定高度」としている。

この化学過程を導入した VGCM を用いて、20 金星日間（2340 地球日）の計算を行った。この結果、平衡状態に達した雲循環は、主に低緯度域（0-30 度）の高度約 70km で化学反応によって SO_2 と H_2O から硫酸雲が生成され、子午面循環によって高緯度域 (約 70 度) へ移流、そこで下降し高度 50km 付近で蒸発という過程で構成された。これは金星雲循環 [Knollenberg and Hunten, 1980; Imamura and Hashimoto, 1998] と整合する。ただし、我々のモデルでは子午面方向への雲の輸送は上記の雲循環に比べて弱い結果となった。本発表では、再現された雲の光学的厚さや雲頂高度の緯度分布に

ついて、Venus Express の観測結果との比較を行った結果について報告するとともに、現在簡略化しているパラメータに対する問題点と今後の開発方向の整理を行う。

2016 年早期に開始される予定の「あかつき」による雲の大規模分布や昼夜間変動の観測にあたり、本モデルはそれらを定性的・定量的に考察することが可能な重要なツールとなることが期待される。

金星重力波の 2 次元数値実験

安藤 紘基 [1]; 杉山 耕一朗 [2]; 小高 正嗣 [3]; 中島 健介 [4]; 今村 剛 [5]; 林 祥介 [6]
[1] ISAS/JAXA; [2] JAXA 宇宙科学研究所; [3] 北大・理・宇宙; [4] 九大・理・地惑; [5] JAXA 宇宙科学研究所; [6] 神戸大・理・地惑

Venusian gravity waves simulated by a two dimensional numerical model

Hiroki Ando[1]; Ko-ichiro Sugiyama[2]; Masatsugu Odaka[3]; Kensuke Nakajima[4]; Takeshi Imamura[5]; Yoshi-Yuki Hayashi[6]
[1] ISAS/JAXA; [2] ISAS/JAXA; [3] Cosmosciences, Hokkaido University; [4] Earth and Planetary Sciences, Kyushu University; [5] ISAS/JAXA; [6] Earth and Planetary Sciences, Kobe University

Recently, gravity waves are often observed by a lot of optical and radio occultation measurements in the Venusian atmosphere. For example, wavy structure having the horizontal wavelength of 60-150 km is observed at the cloud top altitude by UV cameras. However, these optical measurements can observe the atmosphere at the specific altitude, then it is difficult to investigate the vertical propagation characteristic and estimate the momentum flux. On the other hand, the vertical distribution of the temperature fluctuation associated with the wave is obtained from 65 to 90 km altitudes by radio occultation measurements, and its vertical wavenumber spectrum shows that the wave having the vertical wavelength of 5-10 km is predominant. However, small scale gravity waves cannot be detected because of its long distance averaging in the horizontal direction. In addition, horizontal wavelength and phase speed cannot be calculated. Therefore, it is difficult to investigate how gravity waves influence the atmospheric dynamics in the Venusian atmosphere only by observational studies.

In this study, we perform a two-dimensional numerical simulation of the gravity waves, which are generated by the convection in the Venusian cloud layer, to investigate the wave propagation characteristic and calculate the phase speed and acceleration rate. There are some theoretical studies which investigate how gravity waves influence the atmospheric dynamics in the Venusian atmosphere, but they include the empirical wave spectrum based on the observations in the Earth's atmospheric in these models. Imamura et al. (2014) has already investigated theoretically the behavior of the convection in the Venusian atmosphere, but they do not study the characteristic of the waves above 60 km altitude. Therefore, our study is the first one which includes both the generation and propagation of the gravity waves.

We use the semi-compression equations (Klemp and Wilhelmson 1978). The horizontal domain is 0-500 km, and the vertical one is corresponding to 35-135 km in the Venus atmosphere. Top and bottom boundary conditions are that there are no stress, vertical flow and potential temperature fluxes. Side ones are periodic. To prevent the wave reflection, sponge layer is put from 35-40 km altitudes and 100-135 km ones. Initial vertical temperature profiles is that in the radiative-convective equilibrium temperature based on Ikeda et al. (2010), which has a neutral stable layer from 48 to 54 km altitudes and stable ones above and below it. Vertical distribution of the net heating rate is based on Ikeda et al. (2010). It is horizontally uniform and does not change temporally. The atmosphere is rest in the initial stage, and the artificial damping is given to the wavenubmer 0 component to prevent generating the mean flow. We give the potential temperature perturbation with the maximum amplitude of 1 K at 50 km altitude randomly to drive the convection and run the calculation for 15 Earth days.

We examined the dependence of the calculation results on the vertical resolution and numerical viscosity by calculating the horizontal spectral densities. Horizontal resolution is fixed to 200 m, and vertical one is set to 16, 32 and 62 m. Numerical viscosity is set to 1x10^{-4}, 3x10^{-4}, 1x10^{-3}, 3x10^{-3}, 1x10^{-2}. As a result, there are little differences of the spectral densities in the case of vertical resolution $<$32 m and numerical viscosity $<$3.0x10^{-3}. Furthermore, we referred to the modeled zonal wavenumber spectrum of the gravity waves constructed in the Earth's meteorology and concluded that the optimal case is vertical resolution = 32 m and numerical viscosity = 1.0x10^{-3}.

大気中の重力波は, その伝播と砕波にともなう熱と運動量の輸送を介して, 大規模循環に影響を与えている. 近年、金星でも重力波が光学機器や電波掩蔽観測により盛んに観測されている。例えば, 前者による観測例として, 紫外光カメラの撮像観測により、雲頂 (高度 70 km) で水平波長が 60-150 km の重力波が確認されている (e.g. Peralta et al. 2008)。しかしこの観測では、ある特定高度での重力波しか観測できず、波の鉛直伝播特性を考察することや運動量フラックスを見積もることが難しい。一方、後者により高度 65-90 km の範囲で得られた鉛直温度分布から重力波に伴う温度擾乱が検出され、そのスペクトル解析から鉛直波長 5-10 km の波が卓越することが示されている (Ando et al. 2015)。しかしこの観測では水平方向に物理量を積分するので、上記の様な小規模な重力波は捉えられず、また水平波長や水平位相速度について知ることができない。このように、現段階では重力波が金星大気の運動に与える影響を観測のみから理解することは難しい。一方、過去にも重力波が金星大気の運動に及ぼす影響に関する理論研究は行なわれているが、いずれも地球の重力波観測に基づいた経験的なスペクトルをモデルに組み込んでいる。波の励起源となる運動と波の生成, 伝播を陽に計算した研究はこれまであまり行なわれていない.

金星大気中を鉛直伝播する重力波の励起源の一つとして、雲層内 (高度 50-70 km) に存在すると思われる鉛直対流がある. これまで我々は、金星雲層内の対流運動とそれによる波の励起と伝播を, 2 次元の数値モデルを用いて調べてきた (安藤他 JPGU 2014)。その結果, 再現された重力波は分散関係式を良く満たしているが、波の振幅やエネルギー密度がモデルの解像度や数値粘性に強く依存していることが分かった. そこで本発表では, モデルの解像度と数値粘性をさまざまに

変え, それにともなうエネルギースペクトルの形状の変化を調べることにより, 鉛直対流起源の重力波の生成と伝播を計算するのに適切な解像度と数値粘性を探索する.

モデル方程式として準圧縮系方程式 (Klemp and Wilhelmson, 1978) を用いる。計算の水平領域は 500 km、鉛直領域は金星の高度 35-135 km とした。境界条件は上・下端にて、 応力なし・鉛直流なし・温位フラックスなしとし、側面は周期境界とする。また波の反射を抑えるため、上端から 35 km と下端から 5 km の範囲でそれぞれスポンジ層を設けた。初期に与える温度の鉛直分布は、放射対流平衡の下での温度分布 (Ikeda et al. 2010) を用いた。この時の静的安定度は、高度 48-54 km で中立層、その上下に安定層を持つように分布している。放射過程は陽に計算せず、水平一様かつ時間変化しない熱強制を与え、正味の放射加熱・冷却の鉛直分布は Ikeda et al. (2010) に準ずる。初期では大気は静止しているとし、波によって平均流が生成しないように人工的な摩擦を波数 0 成分に対して与えている。そして対流運動を駆動するために最大振幅 1 K の温位擾乱を高度 50 km に与え、そこから 15 日分の計算を行う。そしてモデルの水平解像度は 200 m に固定し、 鉛直解像度を 16, 32, 62 m と変化させ、また数値粘性も $1x10^{-4}$, $3x10^{-4}$, $1x10^{-3}$, $3x10^{-3}$, $1x10^{-2}$ と変える.

各解像度と数値粘性を与えた計算結果を比較した結果、数値粘性 $3.0x10^{-3}$ 以下、鉛直解像度 32 m 以下の計算では、スペクトル密度の大きさと水平波数に対する依存性はおおむね一致することがわかった. このとき, スペクトル密度は波数領域 $10^{-4} <k <10^{-3}$ において k^{-2} の傾きをもち, $10^{-3} <k$ では k^{-3} の傾きを持つ。波数領域 $10^{-4} <k <10^{-3}$ のスペクトルの傾きは, 地球気象で提唱された経験的な重力波の水平波数スペクトルに一致する. 以上の結果から、数値粘性 = $1x10^{-3}$, 鉛直解像度 = 32 m とすることが, 鉛直対流起源の重力波の生成と伝播を計算するのに適切な値であると判断した. 本発表では、それの結果を示すと共に、今後の展望・研究方針についても論じる.

金星雲層を想定した鉛直対流の 3 次元数値計算

杉山 耕一朗 [1]; 川畑 拓也 [2]; 小高 正嗣 [3]; 中島 健介 [4]; 石渡 正樹 [3]; 今村 剛 [5]; 林 祥介 [6]
[1] JAXA 宇宙科学研究所; [2] 株) テクノスジャパン; [3] 北大・理・宇宙; [4] 九大・理・地惑; [5] JAXA 宇宙科学研究所; [6] 神戸大・理・地惑

A Three-dimensional Numerical Simulation of Venus' Cloud-level Convection

Ko-ichiro Sugiyama[1]; Takuya Kawabata[2]; Masatsugu Odaka[3]; Kensuke Nakajima[4]; Masaki Ishiwatari[3]; Takeshi Imamura[5]; Yoshi-Yuki Hayashi[6]
[1] ISAS/JAXA; [2] Tecnos Japan Inc.; [3] Cosmosciences, Hokkaido University; [4] Earth and Planetary Sciences, Kyushu University; [5] ISAS/JAXA; [6] Earth and Planetary Sciences, Kobe University

Although convection has been suggested to occur in the lower part of Venus' cloud layer by some observational evidences, its structure remains to be clarified. To date, a few numerical studies try to simulate Venus' cloud-level convection (Baker et al., 1998, 2000; Imamura et al., 2014), but the model they utilized is two-dimensional. It is difficult to attempt direct comparison between the results of their simulations and the observations. Here we report on the results of our numerical simulations performed in order to investigate a possible three-dimensional structure of Venus' cloud-level convection.

We use the convection resolving model developed by Sugiyama et al. (2009). The model is based on the quasi-compressible system (Klemp and Wilhelmson, 1978), and is used in the simulations of the atmospheric convections of Jupiter (Sugiyama et al., 2011,2014) and Mars (Yamashita et al., submitted). We perform two experiments. The first one, which we call Ext.B, is based on Baker et al. (1998). A constant turbulent mixing coefficient is used in the whole computational domain, and a constant heat flux is given at the upper and lower boundaries as a substitute for radiative forcing. The second one, which we call Exp.I, is based on Imamura et al. (2014). The sub-grid turbulence process is implemented by Klemp and Wilhelmson (1989), and an infrared heating profile obtained in a radiative-convective equilibrium calculation (Ikeda, 2011) is used. In both of the experiments, the temporally averaged solar heating profile is used. The spatial resolution is 200 m in the horizontal direction and 125 m in the vertical direction. The domain covers 128 km x 128 km horizontally and altitudes from 40 km to 60 km.

Obtained structures of convection moderately differ in the two experiments. Although the depth of convection layer is almost the same, the horizontal cell size of Exp.B is larger than that of Exp.I; the cell sizes in Exp.B and Exp.I are about 40 km and 25 km, respectively. The vertical motion in Exp.B is asymmetric; updrafts are widespread and weak (~3m/s), whereas downdrafts are narrow and strong (~10m/s). On the other hand, the vertical motion in Exp.I is nearly symmetric and weaker (~2m/s) compared with those in Exp.B. The difference of convective structure results from the different vertical distributions of implemented infrared heating. Namely, the intense downdrafts in Exp.B are forced by the strong cooling concentrated near the top of the convection layer. In Exp.I, the heating is distributed in a thick layer; the net heating is positive from 47 km to 49 km altitudes, and is negative from 49 km to 56 km altitudes. This profile of net heating makes vertical motion relatively symmetric.

赤外レーザーヘテロダイン分光による金星中間圏の風速場/温度場計測

高見 康介 [1]; 中川 広務 [1]; 佐川 英夫 [2]; 青木 翔平 [3]; 笠羽 康正 [4]; 村田 功 [5]
[1] 東北大・理・地球物理; [2] 京都産業大学; [3] IAPS-INAF, Italy; [4] 東北大・理; [5] 東北大院・環境

Mesospheric wind/temperature measurements in Venusian atmosphere using infrared laser heterodyne spectrometer

Kosuke Takami[1]; Hiromu Nakagawa[1]; Hideo Sagawa[2]; Shohei Aoki[3]; Yasumasa Kasaba[4]; Isao Murata[5]
[1] Geophysics, Tohoku Univ.; [2] Kyoto Sangyo University; [3] IAPS-INAF, Italy; [4] Tohoku Univ.; [5] Environmental Studies, Tohoku Univ.

Mesosphere in the terrestrial planet is the transition region between the lower atmosphere and the upper atmosphere. The altitude region of mesosphere is 50-90km on Mars and 70-120km on Venus. In this transition region, atmospheric waves potentially play a major role through the effects of momentum transport and eddy mixing. Disturbances by atmospheric waves have significant effects on its variable nature and complicate the picture. The study of the planetary mesosphere is important to understand the coupling between the upper and lower atmosphere.

In this study, we observe temporal variations and global distributions of wind velocity and temperature in Venusian mesosphere using infrared high spectral resolution spectrometer. Infrared laser heterodyne spectrometer MILAHI (Mid-Infrared LAser Heterodyne Instrument) that has been developed in Tohoku University is currently installed to 60cm telescope (T60) of Tohoku University at the summit of Mt. Haleakala, Hawaii, which achieves ~3.5 arcsec of spatial resolution and ~10^7 of spectral resolution.

We can derive temperature and wind velocity at the altitude region of 100-120km from CO_2 non-local thermodynamic equilibrium (LTE) emission at a wavelength of 10 micron. We can directly detect temperature from Doppler width and wind velocity from Doppler shift of the peak of the emission line whose profile is Doppler line shape in this region. The wavelength resolution is required ~10^7 and higher. This resolution makes it possible to detect with accuracies of about ± 10K for temperature and ± 10m/s for wind velocity. Reliable direct wind detections can be accomplished from CO line in millimeter and submillimeter region [e.g., Clancy et al., 2008]. Early submillimeter/millimeter observations had an essentially low spatial resolution due to their large beam footprints. MILAHI with T60 can achieve higher spatial resolution and the integration time of 20 minutes is enough to achieve sufficient S/N at a certain point of Venus disk. The accuracies were estimated using observed spectra obtained by another heterodyne spectrometer, Cologne Tuneable Heterodyne Infrared Spectroscopy (THIS), which conducted at the McMath Pierce Solar Telescope on Kitt Peak, Arizona, USA in 2009. Estimated accuracies were ± 12K for temperature and ± 8m/s for wind, respectively [Sonnabend et al.,2010, Sornig et al.,2013]. Additionally, we acquire constant and long-term variation using T60 of the exclusive possession.

Temperature field at cloud top altitudes between 70-95km is also observable by CO_2 absorption line at 10 micron in nightside. It is necessary to observe absorption line profile at so high resolution that temperature distribution is retrieved by absorption line. The required integration time to obtain CO_2 absorption spectrum are 160 minutes. We will analyze the spectra by Advanced Model for Atmospheric TeraHertz Radiation Analaysis and SimUlation (AMATERASU) [Baron et al., 2008] which performs forward (line-by-line radiative transfer and numerical modeling of instrumental characteristics) and inversion calculations.

Venus orbiter Akatsuki which will reinsert to Venus orbit in December of this year will observe the atmospheric circulation to study dynamics globally in the region between the surface and the altitude of 90km using infrared and ultraviolet camera and radio occultation. The orbiter observes constantly temperature distribution near the cloud top (altitude of about 70km) by the middle infrared camera LIR (wavelength range: 7-11micron). Moreover, vertical temperature profile is derived by radio occultation (altitude range: 35-90km) twice in every orbital period (8-9 Earth days). Observation by MILAHI complimentarily obtains dynamical information at higher altitude region above them. It provides vertical information of temperature field from the cloud top to mesosphere.

地球型惑星の中間圏は、地表に接し対流する下層大気と宇宙へ散逸しうる上層大気の接続領域である。中間圏の高度は火星で 50-90km、金星で 70-120km とされている。下層から伝搬してくる重力波がこの領域で砕波し、運動量とエネルギーが中間圏の大気に受け渡されることで、風速や温度の擾乱や加熱を引き起こすため、下層大気-上層大気間の結合を理解するのに不可欠な領域である。

本研究では、金星をターゲットとし、この中間圏の風速・温度場の時間変動を継続的な地上赤外線高分散分光観測によって捉える。観測は、ハワイ/ハレアカラ山頂の東北大 60cm 望遠鏡（T60）に実装された本学開発の赤外レーザーヘテロダイン分光器 MILAHI (Mid-Infrared LAser Heterodyne Instrument) を用いて行う。MILAHI は、空間分解能~3.5 秒角、波長分解能~10^7 を達成可能であることがここまでに実証されており、今夏からの金星観測に着手すべく準備を進めている。

高度 100-120km の温度・風速は、この高度で発光する 10 μ m 帯の CO_2 非局所熱力学平衡 (LTE) の放射輝線から求めることができる。この高度からの輝線の線形はドップラー線形となるので、温度はドップラー幅から、風速は輝線のピークのドップラーシフトか直接的に導出される。必要な波長分解能は、10^7 以上であり、この分解能から導出精度は温度・

風速それぞれ± 10K、± 10m/s 程度を達成できる。サブミリ波・ミリ波域でのヘテロダイン分光による CO 観測から風速・温度を導出する先行研究が報告されている [e.g., Clancy et al.,2008] が、観測波長が長いために空間分解能が最も高い場合でも ~15 秒角程度という制約が生じる．この問題は，干渉計を利用した観測によって改善されるが，一方で，干渉計の観測では金星のように大きく広がった面光源の大規模構造のフラックスを観測することは技術的に困難であり，結果として，従来の干渉計観測では視直径が比較的小さい時期の金星観測が主に行なわれている。MILAHI+T60 による観測は，こうした先行研究と比較しても，より高い空間分解が可能で、また観測点一箇所あたり積分時間 20 分で必要 S/N を達成できる想定である。なお、MILAHI と同様の観測装置での先行研究として、同様の性能空間分解能を持つケルン大学の赤外線ヘテロダイン観測器 THIS が挙げられる。2009 年アリゾナ州キットピークでの THIS の観測は、温度・風速誤差それぞれ± 12K、± 8m/s が達成されている [Sonnabend et al.,2010, Sornig et al.,2013]。更に，専有利用が可能な望遠鏡 T60 を利用することで，さらなる連続・長期間の変動追跡の実現を目指す。

また、夜面雲頂上方の高度 70-95km における温度場・風速場は、夜面の 10 μ m LTE CO_2 吸収線から導出が可能である。吸収線から気温分布をリトリーバルするには吸収線のプロファイルを十分高い精度で観測する必要がある。観測点一箇所あたり積分時間 160 分で必要 S/N を達成できる想定である。解析準備として、放射伝達および反転解析計算モデル AMATERASU [Baron et al., 2008] を用いたデータ解析手法の整備を進めつつある。

今年の 12 月に金星軌道に再投入される金星探査機あかつきは、赤外・紫外カメラ、電波観測により、地表から高度 90km までの大気運動をグローバルに観測し大気循環メカニズムを解明しようとする衛星である。この衛星に搭載されている中間赤外カメラ LIR（観測波長域: 7-11 μ m）による雲頂付近（高度:約 70km）の温度分布、軌道周期（8-9 日）毎に二回行われる電波掩蔽観測（高度範囲:35-90km）による温度鉛直プロファイル（高度範囲:35-90km）が定常的に導出される予定である。我々の地上観測はこれらの高度分布情報をさらに上方へ伸ばすため、雲頂から中間圏までの温度場が断続的ではあるが，鉛直方向にカバー可能となりうる。あかつきの観測開始後、我々は MILAHI で金星の赤道域、中緯度帯、極域の 3 つの領域の昼面、夜面を観測予定である。これにより、昼面ではあかつきによる雲頂温度分布情報を踏まえた中間圏の温度・速度変動の評価、夜面では同じく雲頂温度分布情報を踏まえたより高高度の鉛直温度プロファイル変動の評価を行うことが初めて継続的に可能となる。2016 年からのこの共同支援観測の実現を目指し、手法の確立を進めていく。

Variability of the propagation periods of the Y-feature on Venus in one Venus year

Masataka Imai[1]; Yukihiro Takahashi[1]; Shigeto Watanabe[1]; Makoto Watanabe[1]; Toru Kouyama[2]
[1] Cosmosciences, Hokkaido Univ.; [2] AIST

The fast atmospheric circulation named the super-rotation is one of the great mysteries on Venus. Planetary scale bright and dark UV feature, which is called the Y-feature, circulate around the planet about 4-days or 5-days associated with the super-rotation. Until now, Venus exploration spacecraft such as Pioneer Venus and Venus Express have monitored the circulation of this Y-feature for many years. Variation of the circulation period of the Y-feature was observed (e.g. 5-10 Earth years [Del Genio and Rossw, 1990]) and it was suggested that the dynamical state of Venusian atmosphere changes on a time scale of one Venus year (˜224 Earth days) or more. However, orbital planes of past spacecraft were nearly fixed in the internal frame of reference, and there were some difficulties to investigate the variation of periods in one Venus year without interruption. There are several numerical models reconstructing the steady super-rotation, however we have not been able to explain the mechanism of the super-rotation especially at the point of its long-term variability.

Since the Venus-Earth synodic period is 584 days, the ground-based telescope has great potential to monitor the circulation of Y-feature continuously over one Venus year except for the conjunction seasons. We conducted Venus imaging observation using 365 nm UV filter for six times at one or two months intervals from mid-August 2013 to the end of June 2014, and each observational periods has a half or one months. We analyze the UV brightness variation from equatorial to mid-latitudinal regions in both hemispheres and investigate the periodicity of the propagation of the Y-feature. Our data has good correlations with the one from Venus Monitoring Camera (VMC) on-board Venus Express spacecraft observing southern hemispheres in 2013.

Here we found the variation of the propagation period of the Y-feature with a few months or more time scale. Faster and slower periodical brightness variations were obtained and it was shown that the period was changed from ˜5.2 days to ˜3.5 days perhaps in eight months. In the middle observational period, two periodical components were obtained in the brightness variation and the Y-feature considered not maintaining in this season. On the other hand, it was confirmed that the ˜3.5 days periodical component, which was apparently faster than the one ever reported, exists in all observational periods with a substantial significance. Our study suggests that the planetary scale wave activities with ˜3.5 days periods contribute to the change of dynamical states on Venus. We will add our new observation results taken from April to July 2015 and discuss about the annual variability of the super-rotation.

火星探査機MAVENの観測データを使用したmagnetic pileup boundaryとion composition boundaryの比較

松永 和成 [1]; 関 華奈子 [1]; Brain David A.[2]; 原 拓也 [3]; 益永 圭 [4]; McFadden James P.[3]; Halekas Jasper S.[5]; Mitchell David L.[3]; Mazelle Christian[6]; Connerney John E. P.[7]; Jakosky Bruce M.[8]
[1] 名大STE研; [2] LASP, Univ. of Colorado at Boulder, USA; [3] SSL, UC Berkeley; [4] 名古屋大・STEL ; [5] Dept. Phys. & Astron., Univ. Iowa; [6] CNRS,IRAP; [7] NASA GSFC; [8] LASP, CU Boulder

Comparison of Martian magnetic pileup boundary with ion composition boundary observed by MAVEN

Kazunari Matsunaga[1]; Kanako Seki[1]; David A. Brain[2]; Takuya Hara[3]; Kei Masunaga[4]; James P. McFadden[3]; Jasper S. Halekas[5]; David L. Mitchell[3]; Christian Mazelle[6]; John E. P. Connerney[7]; Bruce M. Jakosky[8]
[1] STEL, Nagoya Univ.; [2] LASP, Univ. of Colorado at Boulder, USA; [3] SSL, UC Berkeley; [4] STEL, Nagoya Univ.; [5] Dept. Phys. & Astron., Univ. Iowa; [6] CNRS,IRAP; [7] NASA GSFC; [8] LASP, CU Boulder

Martian upper atmosphere directly interacts with the solar wind, since Mars does not possess the intrinsic global magnetic field. This interaction forms a transition region between the shocked solar wind (magnetosheath) and the ionosphere, in which characteristic boundary structures are embedded. Previous studies have shown existence of the induced magnetosphere or magnetic pileup region in the transition region. Mars Global Surveyor (MGS) observed the magnetic pileup boundary (MPB), a boundary between the magnetosheath and the magnetic pileup region by its magnetometer and electron reflectometer [e.g., Vignes et al., 2000, Trotignon et al., 2006]. On one hand, Phobos 2 and Mars Express (MEX) observed the ion composition boundary (ICB) by their ion mass analyzer [e.g., Breus et al., 1991, Dubinin et al., 2006], where the ion composition changes from the solar wind origin to planetary origin dominant. Due to the lack of continuous simultaneous observations of the magnetic field and ion composition, however, relations between MPB and ICB are far from understood. In this study, we investigate relative locations and characteristics of MPB and ICB and their dependence on solar wind parameters, utilizing a full package of plasma instruments onboard Mars Atmosphere and Volatile EvolutioN (MAVEN).

We conducted a statistical analysis of the ion, electron, and magnetic field data obtained by MAVEN from November 2014 to March 2015 in order to investigate relations between MPB and ICB. We identified MPB from the electron and magnetic field data by inspection based on Trotignon et al. [2006]. We calculated the density ratio between the planetary heavy ions and the solar wind protons to investigate the ion composition around MPB. Results show that there is a north-south asymmetry in locations of MPB and ICB. Observations also indicate that the relative location of MPB and ICB has deference between dayside and nightside. The MPB locations also depend on the solar wind parameters. We will also report on the dependence of MPB and ICB on the solar wind velocity, density, and dynamic pressure.

Reference:
Vignes et al., 2000, GRL, DOI: 10.1029/1999GL010703
Trotignon et al., 2006, PSS, DOI: 10.1016/j.pss.2006.01.003
Breus et al., 1991, JGR, DOI: 10.1029/91JA0113
Dubinin et al., 2006, SSR, DOI: 10.1007/978-0-387-70943-7_8

火星電離圏界面におけるケルビン-ヘルムホルツ不安定のMHDシミュレーションの研究

相澤 紗絵 [1]; 寺田 直樹 [2]; 笠羽 康正 [3]; 八木 学 [4]
[1] 東北大・理・地物; [2] 東北大・理・地物; [3] 東北大・理; [4] 東北大 PPARC

An MHD simulation study of the Kelvin-Helmholtz instability at the Martian ionopause

Sae Aizawa[1]; Naoki Terada[2]; Yasumasa Kasaba[3]; Manabu Yagi[4]
[1] Geophysics, Tohoku Univ; [2] Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.; [3] Tohoku Univ.; [4] PPARC, Tohoku Univ.

Because Mars has no intrinsic magnetic filed, the solar wind directly interacts with the planetary ionosphere. Under this circumstance, the planetary ionopause represents a density discontinuity surface and a velocity shear surface between the magnetized solar wind flow and the planetary ionosphere. The ionopause is subject to the Kelvin-Helmholtz (KH) instability [Amerstorfer et al., 2010], which is expected to play a role in removing ionospheric materials from the planet. In addition, the KH instability may cause a dawn-dusk asymmetry at the magnetopause because of the finite Larmor radius (FLR) effect of ions [Nagano, 1978]. At an ionopause, for the same reason, the KH instability may cause an asymmetry in the direction of the solar wind motional electric field.

Terada et al. [2002] pointed out using a global hybrid simulation that the KH instability at the Venusian ionopause develops asymmetrically through the acceleration of ionospheric ions in the direction of the solar wind motional electric field. It is known that the ion FLR effect, the gravitational stabilizing effect, the effect of the thickness of the boundary layer, etc. determine the initial growth of the KH instability. However, it was difficult to separately evaluate each contribution of these effects with the global hybrid simulation. At the Martian ionopause, the ion FLR effect is expected to be four times larger than that at Venus, because gyroviscous coefficient is two times larger and the obstacle size is about half that of Venus. The gravitational stabilizing effect, which prevents the KH instability from growing at low solar zenith angles (SZAs), is also one of the important effects to estimate the escape rate of the Martian atmosphere, but quantitative evaluations of these competing effects at the Martian ionopause have not yet been done.

In this study, we estimate the escape rate of the Martian atmosphere by the KH instability considering the ion FLR effect and the gravitational stabilizing effect. We have investigated contribution of each effect to the linear growth rate and non-linear evolution of the KH instability using parameters at the Martian ionopause. The preliminary results of our simulation show that the KH instability can grow sufficiently before reaching the terminator of Mars, suggesting that the non-linear saturation phase rather than the linear growth phase affects the escape rate of the Martian atmosphere. Considering the fact that the previous studies concentrated on the linear growth phase in estimating the escape rate, we have estimated it with a particular emphasis placed on the saturation phase of the KH instability.

What is more, to model a more realistic condition of Mars, we have performed simulation runs with a density gradient in the direction of the velocity shear (horizontal direction) in the Martian ionosphere. Our past simulations, which used a periodic boundary condition, had a peak of momentum at the ionopause in the initial condition, so that the growth rate of the KH instability can be over-estimated. This problem is partly resolved by employing this realistic condition. Accordingly, it is expected that the growth rate of the KH instability decreases near the subsolar point, but increases at high SZAs due to the horizontal density gradient compared to our previous results, resulting in a different atmospheric escape rate. In this presentation, initial results obtained from the numerical simulation that considers the horizontal density gradient will be presented.

火星は全球的な固有磁場を持たないため、太陽風と惑星電離圏が直接相互作用をする環境にある。このような環境下において、惑星電離圏界面では惑星電離圏と磁化太陽風プラズマの間に密度不連続と速度シアーが形成される。これに伴い、電離圏界面にケルビン-ヘルムホルツ (KH) 不安定が励起されうる [Amerstorfer et al., 2010] が、これが電離圏イオンの流出過程の一端を担っている可能性が指摘されている。さらに KH 不安定は惑星磁気圏界面においてその速度シアーの向きとイオンの旋回方向の関係から、朝夕非対称を引き起こすと考えられている [Nagano, 1978]。非磁化惑星においては同様の理由から太陽風対流電場方向に非対称を引き起こすと考えられている。

非磁化惑星の電離圏界面での KH 不安定は、グローバルハイブリッドシミュレーションによって研究された [Terada et al., 2002]。KH 不安定はイオンの有限ラーマー半径 (FLR) 効果や電離圏界面の境界層の厚みを考慮して扱われる [Huba,1996] が、グローバルハイブリッドシミュレーションではその手法のために様々な効果の寄与がまとめて計算されるため、各々の効果がどの程度寄与するかといった点を見積もることは困難であった。特に、イオンの FLR 効果はイオンラーマー半径と惑星半径の比によって寄与の大きさが異なることが予想され、火星電離圏界面におけるパラメータでは、金星よりも約 4 倍強い FLR 効果が見込まれる。また、重力安定化効果は太陽天頂角が小さい領域で KH 不安定の成長を妨げるため、火星大気の散逸率を見積もる上で重要な効果の一つであるが、火星電離圏界面における各々の寄与とその競合の定量的な評価は未だ行われていなかった。

本研究では、理想 MHD シミュレーションにイオンの FLR 効果や重力安定化効果を加えることで、各々の効果がどれほど KH 不安定の成長に寄与するか、また火星からの大気散逸率にどれほど寄与するかを見積もった。我々のシミュレーションの初期結果から、KH 不安定は火星の昼夜境界線に到達するまでに十分成長することが示唆され、火星からの

大気散逸には線形段階よりもむしろ非線形段階が寄与する可能性が指摘された。先行研究による大気散逸率の見積もりが KH 不安定の線形成長段階を主に考慮していた点を踏まえ、本研究では KH 不安定の非線形段階に注目して大気散逸率を見積もった。

さらに、より現実的な系を模擬すべく、火星電離圏の速度シアー方向（水平方向）の密度勾配を考慮したシミュレーションを行った。これまでの周期境界系におけるシミュレーションでは初期状態において運動量が電離圏界面でピークを持ち、KH 不安定の成長が過剰見積もりされているという危惧があったが、現実的な系を模擬することでこの問題を改善することができるという利点がある。これに伴い、太陽直下点近傍における KH 不安定の成長は、先の結果と比較して遅くなることが示唆されるが、その一方で太陽天頂角が大きな領域において、速度シアー方向（水平方向）の密度減少に伴う KH 波の振幅増加が期待されるため、大気散逸率が変化することが予想される。本学会においては、この速度シアー方向の密度勾配を考慮したシミュレーションについての初期結果を発表する予定である。

惑星大気大循環モデル DCPAM を用いた火星大気中の水蒸気分布の計算

高橋 芳幸 [1]; 林 祥介 [2]
[1] 神戸大・理・惑星; [2] 神戸大・理・地惑

A numerical simulation of water vapor distribution in the Martian atmosphere by the use of the DCPAM

Yoshiyuki O. Takahashi[1]; Yoshi-Yuki Hayashi[2]
[1] Department of Planetology, Kobe Univ.; [2] Earth and Planetary Sciences, Kobe University

Distributions of minor constituents have been observed not only in the Earth's atmosphere, but also in the other planetary atmospheres, since they have important information on the strucutures of atmospheric circulations as well as on photochemical reactions. For example, a distribution of water vapor in the Martian atmosphere was observed by Viking orbiter in 1970s. From 1997 to 2006, Mars Global Surveyor conducted a long term observation of water vapor in the Martian atmosphere, and provided information on atmospheric transport and mixing.

Our group has been working on development of a general circulation model for planetary atmospheres, DCPAM. Up to now, we performed simulations of the Earth's atmosphere and Earth-like ideal atmospheres which include water vapor. However, we have not intensively worked on simulations of minor constituent distributions in other planetary atmospheres. In this study, we perform a simulation of the water vapor distribution in the Martian atmosphere, since it has been observed for a long time and the observed result can be used for validation of the model.

The general circulation model used in this study is composed of dynamical process and physical processes. The dynamics is based on a primitive equation system. Almost all equations are solved by the use of the spectral method, while the continuity equations for minor constituents are solved by a semi-Lagrangian method. The semi-Lagrangian method used in the model incorporates interpolation method by Enomoto (2008). In addition, an arcsine transformation proposed by Kashimura et al. (2013) is used to avoid negative values. The physics includes radiation, turbulent mixing, and surface processes. By the use of this model, we have performed a simulation of the water vapor distribution in the Martian atmosphere. Following the similar simulations performed previously by other groups, a large amount of water ice is placed on the northern high latitudes. In addition, surface temperature is fixed at 145 K at south pole to mimic southern permanent CO_2 ice cap. The resolution of the simulation is T21L36, which corresponds to about 5.6 degrees longitude-latitude grid, and 36 vertical layers. The model is integrated for 10 Mars years from an isothermal and motionless initial condition.

The result of our simulation shows existence of large amount of water vapor at two locations at two seasons. One is the northern high latitudes around northern summer and the other is the southern high latitudes around southern summer. However, the amount of water vapor at the low latitudes is small compared to the observed one. This implies insufficient transport of water vapor from high latitude to low latitude in our model.

In order to check sensitivity of the transport behavior on the choice of atmospheric transport scheme, another simulation is performed without using arcsine transformation in our transport method. The result shows an increase of water vapor amount in the low latitudes by about a factor of 4. This result shows that water vapor transport represented in our model is very sensitive to transport schemes. In the presentation, we will discuss the difference between results by two schemes and address possible causes of the difference.

MRO-MCS データを利用した火星大気のダスト、気温、水氷雲の間に見られる関係の解析

野口 克行 [1]; 黒田 剛史 [2]; 林 寛生 [3]
[1] 奈良女大・理・情報; [2] 東北大・理; [3] 富士通 FIP

Relationship among water ice clouds, dust and temperature in the Martian atmosphere revealed by the MRO-MCS data analysis

Katsuyuki Noguchi[1]; Takeshi Kuroda[2]; Hiroo Hayashi[3]
[1] Nara Women's Univ.; [2] Tohoku Univ.; [3] Fujitsu FIP

Focusing on the longitudinal distributions of water ice clouds, dust and temperature and their correlations in the Martian atmosphere, we analyzed Mars Reconnaissance Orbiter Mars Climate Sounder (MRO-MCS) data. The data covers Mars Year (MY) 28 to 30, which enables us to conduct interannual analyses.

Results show that the concentration of water ice clouds around Hellas Planitia (30-60S, 50-100E) largely decreases in the southern winter (Ls=70-110 deg), while temperature and the concentration of dust in the same region increase simultaneously. The decrease of water ice clouds and the corresponding behaviors of temperature and dust were clearly observed every year during MY29-31, suggesting a strong interannual repeatability. We also compared the observations with Martian general circulation model (MGCM), but we could not find very clear agreement. We extracted the wave components by fitting the data to stationary zonal harmonics through wave number 4. The wave number 1 component is dominant and its typical amplitude in the southern winter is about 6 K. This may be attributed to thermal tides in the Martian atmosphere.

In this study, we compiled a gridded data set in the netCDF format from the original text-based data in order to make data handling much easier. We are planning to make the gridded data available to researchers near future.

磁気嵐に呼応する地球外気圏の水素原子の密度変動

桑原 正輝 [1]; 吉岡 和夫 [2]; 村上 豪 [3]; 土屋 史紀 [4]; 木村 智樹 [5]; 鈴木 文晴 [6]; 疋田 伶奈 [7]; 吉川 一朗 [8]
[1] 東大・新領域・複雑理工; [2] 立教大; [3] ISAS/JAXA; [4] 東北大・理・惑星プラズマ大気; [5] RIKEN; [6] 東大・理・地惑; [7] 東大・新領域・複雑理工; [8] 東大・理・地惑

The geocoronal responses to the geomagnetic storms

Masaki Kuwabara[1]; Kazuo Yoshioka[2]; Go Murakami[3]; Fuminori Tsuchiya[4]; Tomoki Kimura[5]; Fumiharu Suzuki[6]; Reina Hikida[7]; Ichiro Yoshikawa[8]
[1] Univ. of Tokyo; [2] Rikkyo Univ.; [3] ISAS/JAXA; [4] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.; [5] RIKEN; [6] Earth and planetary science, Univ.Tokyo; [7] Frontier Sciences, Tokyo Univ.; [8] EPS, Univ. of Tokyo

The dominant neutral constituent in the Earth's exosphere, atomic hydrogen, resonantly scatters solar Lyman-alpha (121.6 nm) radiation, observed as the geocorona.

The past observations of the geocorona were conducted mainly by the Earth-orbiting satellites. Recently, the abrupt temporary increases of the Lyman-alpha emission in the range of 3 to 8 Earth radii by approximately 10% during the period of geomagnetic storms have been observed. However, the physical process of the responses of the geocoronal brightness to the geomagnetic storms is unknown.

We report here observations of an exospheric response to geomagnetic storms obtained using measurements of the geocorona by EXtreme ultraviolet spectrosCope for ExosphEric Dynamics (EXCEED) onboard HISAKI satellite. It is orbiting around the Earth and observing the geocorona. Several geomagnetic storms observed in February 2014 are accompanied by abrupt temporary increases of the Lyman-alpha emission. These events seem to show some correlation with the minimum Dst index reached during the peak of each storm.

地球外気圏を構成する中性原子の中で最も密度の高い水素原子は、太陽光を共鳴散乱することでジオコロナを形成する。これまでのジオコロナの観測は地球周回衛星によるものが主であり、近年では磁気嵐が発生した期間に地球半径の3~8 倍の高度で水素ライマンα線の発光量が 10%程度増加するという現象が確認された。しかし、この増光を引き起こす物理過程は未だよく理解されていない。

「ひさき」衛星は、太陽系惑星の外気圏の観測を主な目的とした地球周回衛星（軌道高度約 1000 km）である。それと同時に、「ひさき」衛星はジオコロナを内側から観測していることになる。2014 年 2 月に磁気嵐が数回確認されており、その間水素ライマンα線の増光が確認された

本研究では、「ひさき」による観測結果をもとに、磁気嵐発生時におけるジオコロナの水素ライマンα線の増光過程を探る。

ハワイ・ハレアカラ山頂の惑星／系外惑星専用望遠鏡：40cm・60cm 活動状況および 1.8m 新設計画

笠羽 康正 [1]; 坂野井 健 [2]; 鍵谷 将人 [3]; 中川 広務 [4]; 村田 功 [5]; 小原 隆博 [6]; 岡野 章一 [7]; 米田 瑞生 [8]
[1] 東北大・理; [2] 東北大・理; [3] 東北大・理・惑星プラズマ大気研究センター; [4] 東北大・理・地球物理; [5] 東北大院・環境; [6] 東北大・惑星プラズマセンター; [7] 東北大・理・PPARC; [8] 東北大・理・惑星プラズマ大気

Telescopes Dedicated to Planets and Exoplanets at Haleakala, Hawaii: Activity of 40cm and 60cm and Development of 1.8m telescopes

Yasumasa Kasaba[1]; Takeshi Sakanoi[2]; Masato Kagitani[3]; Hiromu Nakagawa[4]; Isao Murata[5]; Takahiro Obara[6]; Shoichi Okano[7]; Mizuki Yoneda[8]
[1] Tohoku Univ.; [2] Grad. School of Science, Tohoku Univ.; [3] PPARC, Tohoku Univ; [4] Geophysics, Tohoku Univ.; [5] Environmental Studies, Tohoku Univ.; [6] PPARC, Tohoku University; [7] PPARC, Tohoku Univ.; [8] Planet. Plasma Atmos. Res. Cent., Tohoku Univ.

In this paper, activity reports and development status of the University-sized small but unique telescopes extracted at the summit of Mt. Haleakala of Maui Island, Hawaii by Tohoku University with domestic and international collaborations.

Clear sky and good seeing condition are important for any ground-based observations. The Haleakala High Altitude Observatories at the summit of Mt. Haleakala is not the highest place (3050m) but one of the best sites with clear sky, good seeing, and low humidity conditions. Operation is relatively easy because we can access to the airport, major towns, and a good engineering facility, ATRC (Advanced Technology Research Center) of IfA/UH within 1-2 hour drive from summit.

On the summit, our group is now operating a 40 cm Schmidt-Cassegrain (T40) and 60 cm Cassegrain (T60) telescopes. The T40 telescope is mainly observing faint atmospheric features such as Io torus, Mercury, Lunar sodium tail, and so on. From fall 2013, ISAS Hisaki/Exceed EUV space telescope run on the orbit. It has uniquely provided long-term Io torus activities for this project, including the identification of Io volcanic enhancement in January - March 2015. The T60 telescope was moved from Iitate Observatory and started the operation from Sep. 2014. This telescope is now observing planetary atmospheres in infrared with newly developed Infrared heterodyne spectrometer (MIRAHI). And with other instruments including a high-dispersion spectrometer with coronagraph and an optical polarimeter, we have observed Jupiter and exoplanets in 2014-2015.

These activities are open to any possible collaborators. Recent days, guest observers visited for Jupiter (Dr. Asada, Kyushu Inst. Univ.), Mercury (Dr. Kameda and colleagues, Rikkyo Univ.)) and Exoplanets (Univ. Turk, Finland, and KIS, Germany) observations. Our and guest investigators' observations are also linked to Venus (Akatsuki), Mars (Mars Express, MAVEN) and Jupiter (Juno) in 2015-2016 observation terms.

We are also running a new telescope development plan dedicated to planets and exoplanets. This 1.8m off-axis telescope named PLANETS (Polarized Light from Atmospheres of Nearby Extra Terrestrial Planets)is under the international consortium mainly formed with IfA/UH and KIS (Germany). Although the schedule is delayed by the mirror forming etc., in the earliest case, we will see the first light in the late 2016.

It is welcomed to any planet and exoplanet observation scientists who have interest to use our facility or expect to attach their own instruments for specific objectives. For promoting such activities, M. Kagitani, H. Nakagawa, and M. Yoneda stay in or visit frequently to Maui, and are contributing to the telescope/instrumental operations and developments.

紫外線望遠鏡による系外惑星観測の検討

堀越 寛己 [1]; 池澤 祥太 [1]; 桑原 正輝 [2]; 村上 豪 [3]; 亀田 真吾 [1]; 吉川 一朗 [4]; 田口 真 [5]
[1] 立教大; [2] 東大・新領域・複雑理工; [3] ISAS/JAXA; [4] 東大・理・地惑; [5] 立教大・理・物理

UV space telescope for exoplanetary systems

Hiroki Horikoshi[1]; Shota Ikezawa[1]; Masaki Kuwabara[2]; Go Murakami[3]; Shingo Kameda[1]; Ichiro Yoshikawa[4]; Makoto Taguchi[5]
[1] Rikkyo Univ.; [2] Univ. of Tokyo; [3] ISAS/JAXA; [4] EPS, Univ. of Tokyo; [5] Rikkyo Univ.

Many observations have been carried out for exoplanets since they were first discovered in 1995. To date, the number of detected exoplanets is more than 1800. Furthermore, the detection of many Earth-sized exoplanets in the vicinity of low-temperature stars is expected in the near future.

The habitable zones of low-temperature M type stars are inward of the orbit of Mercury [1]. However, if the planets are close to the host star, stellar UV radiation dissociates or ionizes molecules in the planetary atmosphere; in particular, EUV radiation drives atmospheric heating [2]. It is not possible to measure the stellar EUV flux because of interstellar absorption. However, it can be estimated from the stellar Lyman alpha flux (121.6 nm) [3]. Since the Lyman alpha emission is very bright, it could be measured using the small space telescope. We can use Lyman alpha observations in discussion about exoplanet atmospheres.

There are 50 low-temperature stars within 5 pc of Earth. However, the Lyman alpha emission line has been observed for only 25 of them. NASA and ESA are planning to launch space telescopes dedicated to exoplanets; however, their spectral ranges are limited to the visible and infrared regions. Russia is planning to launch a large multipurpose UV space telescope, but the launch year has not been determined. Currently, the Hubble Space Telescope is the only telescope for the UV range, although its operation will be stopped in the near future because of aging. Therefore we are planning to develop a small UV space telescope dedicated to exoplanetary systems. In this presentation, we introduce the scientific objectives and our plan for a small UV space telescope.

1995 年に系外惑星が発見されてから数多くの観測が行われ、現在では 1800 個以上の惑星が検出されている。今後は、低温度星周りに地球と同程度の大きさの惑星が数多く発見されることが期待されている。

低温度星周りのハビタブルゾーンは、太陽系における水星軌道よりも内側だが [1]、惑星が主星の近くに存在する場合、主星が発する強い紫外線が惑星大気中の分子を解離・電離させ、特に極端紫外線は大気の加熱源となる。極端紫外線は、星間空間の水素によって吸収・散乱されてしまうので、観測はできないが、恒星の極端紫外線と水素ライマン α 線（波長 121.6 nm）の間には相関関係があると考えられている [3]。また、この輝線は、低温度星の近紫外線では圧倒的に強く、測定にも向いている。従って、水素ライマン α 線を測定すれば、惑星大気を左右する主星の情報が得られる。

しかし、低温度星の水素ライマン α 線は、地球から 5 pc 以内に限っても、50 個中 25 個しか測定されていない。また、NASA や ESA で提案されている将来計画における、観測波長域は可視—赤外であり、ロシアが多目的の大型紫外宇宙望遠鏡の開発を進めているが、打ち上げ年度は未定である。現時点で紫外線観測を行えるのは、ハッブル宇宙望遠鏡だけであるが、老朽化が進んでおり、修復の予定は無い。そこで我々は、超小型深宇宙探査機 PROCYON 搭載の LAICA を開発した経験を活かし、系外惑星観測に特化した紫外線宇宙望遠鏡の検討を進めている。本発表では、本研究の科学目標と検討している観測装置について発表する。

[1] Kaltenegger & Traub 2009
[2] France et al., 2014
[3] Linsky et al., 2014