

超小型深宇宙探査機「エクレウス」搭載，月面衝突閃光観測カメラ「デルフィヌス」の開発

Development of Lunar Impact Flash Observing Camera "DELPHINUS" on deep-space 6U spacecraft "EQUULEUS"

*阿部 新助¹、柳澤 正久²、矢野 創⁴、船瀬 龍³

*Shinsuke Abe¹, Masahisa Yanagisawa², Hajime Yano⁴, Ryu Funase³

1. 日本大学、2. 電気通信大学、3. 東京大学、4. JAXA

1. Nihon University, 2. The University of Electro-Communications, 3. The University of Tokyo, Japan, 4. JAXA

EQUULEUS (EQUilibrUM Lunar-Earth point 6U Spacecraft) will be the world's smallest spacecraft to explore the Earth-Moon Lagrange2 point (EML2). The spacecraft will be jointly developed by the University of Tokyo and JAXA which will be launched by NASA's SLS (Space Launch System) EM-1 (Exploration Mission-1) in 2018. The spacecraft will fly to a libration orbit around the EML2 point and demonstrate trajectory control techniques within the Sun-Earth-Moon region.

DELPHINUS (DEtection camera for Lunar impact PHenomena IN 6U Spacecraft) is one of the onboard scientific instruments onboard EQUULEUS to observe meteoroids by using imaging of lunar impact flashes and near-Earth asteroids. Meteoroid are a small rocky bodies traveling through interplanetary space. When a meteoroid impacts the moon at several 10s of km/s, a brilliant flash at the point of impact can be observed as a lunar impact flash. The influx rate of interplanetary dusts onto the Earth-Moon surface are essential for understanding solar system evolution and are useful information for the future human space activities in the Cis-Lunar space that is the volume within the Moon's orbit. Thus, it is very important to investigate size distributions, influx rate and daily variation of meteoroids. Ground-based meteor observations by using all-sky cameras are limited to the roughly 10,000 km² of upper-atmosphere visible from their location. On the other, Lunar impact monitoring enables to monitor the more than 10⁶ km² collecting area. Lunar impact monitoring has a great advantage to detect large meteoroids in the mass range between 10s of grams and few kilograms corresponding to centimeters and tens of centimeters, which is as a bridge between small asteroids, larger than few meters size, and meteors, smaller than millimeter size, observed mainly from the ground.

This paper describes newly developed DELPHINUS camera system.

キーワード：超小型衛星、月面衝突閃光、メテオロイド、流星、小惑星

Keywords: CubeSat, Lunar Impact Flash, Meteoroids, Meteors, Asteroids



月回轉變動の観測を目的とした小型望遠鏡の開発と実験結果のまとめ、および将来展望

Summary of development a telescope for ILOM (In-situ Lunar Orientation Measurements) and results of experiments, and future prospects

*花田 英夫^{1,2}、鶴田 誠逸¹、浅利 一善¹、荒木 博志^{1,2}、野田 寛大^{1,2}、鹿島 伸悟^{1,4}、船崎 健一³、佐藤 淳³、谷口 英夫³、加藤 大雅³、菊池 護³、佐々木 宏和³、長谷川 知恭³、矢野 太平⁴、郷田 直輝⁴、小林 行泰⁴、山田 良透⁵、岩田 隆浩⁶

*Hideo Hanada^{1,2}, Seiitsu Tsuruta¹, Kazuyoshi Asari¹, Hiroshi Araki^{1,2}, Hiroto Noda^{1,2}, Shingo Kashima^{1,4}, Ken-ichi Funazaki³, Atsushi Sato³, Hideo Taniguchi³, Hiromasa Kato³, Mamoru Kikuchi³, Hirokazu Sasaki³, Tomoyasu Hasegawa³, Taihei Yano⁴, Naoteru Goda⁴, Yukiyasu Kobayashi⁴, Yoshiyuki Yamada⁵, Takahiro Iwata⁶

1. 国立天文台RISE月惑星探査検討室、2. 総研大天文科学専攻、3. 岩手大学工学研究科、4. 国立天文台JASMINE検討室、5. 京都大学理学系研究科、6. 宇宙航空研究開発機構宇宙科学研究所

1. RISE Project, National Astronomical Observatory, 2. Department of Astronomical Science, SOKENDAI, 3. Graduate School of Engineering, Iwate University, 4. JASMINE Project, National Astronomical Observatory, 5. Graduate School of Science, Kyoto University, 6. Institute of Space and Astronautical Science, JAXA

月の形成過程と内部構造を理解するためには、コアの大きさ、密度、化学組成、熱の流れは本質的なパラメータである。月面上に小型望遠鏡を設置して、1ミリ秒角の精度の位置天文観測を1年以上行くと、コアの密度等を制約できる月回転パラメータを、数10ミリ秒角から1ミリ秒角以下の精度で決定できるというシミュレーション結果を受けて、将来の月面着陸ミッションを念頭に、PZT（写真天頂筒）型小型望遠鏡を開発してきた。2014年から実験観測用地上モデルを用いて、実験室、野外で測定実験を行ったので、その結果をまとめて報告する。

2014年8月に実験室で人工光源を用いて測定実験を行い、星像中心位置の変動をビデオカメラで撮影した。室内実験で得られた星像の連続記録には、地盤振動や水銀面振動の影響と思われる0.5Hz以下と約5.5Hzの変動が見られたが、同じ視野内の4星にも同様な変動が見られたので、4星の平均変動をそれぞれの記録から差し引いた結果、それらの変動をほとんど消すことができた。残りの細かい変動が星像中心位置決定誤差によるものと思われる。

同年9月に行った野外観測では実際の星を受光し、天体観測専用のCCDカメラを用いて約2秒間隔で星像を撮影した。CCDカメラの視野の中に7~8等級の星が最大6個観測された。室内実験の結果と同様に、同一視野内の星像中心位置の変動には共通の成分が見られるが、記録間隔が長いこともあり、室内実験ほど顕著ではない。同一視野内の星の平均変動をそれぞれの星の変動から差し引いた結果、ばらつきは少し小さくなったが、室内実験の結果ほど小さくはならなかった。

星像の光度分布を調べたところ、星像の最大光度と、星像以外の部分の光度のばらつき（背景ノイズ）の比（ここでは星像のSN比と呼ぶ）が、室内実験の場合が野外観測に比べて約1桁大きかった。そこで、星像中心位置の変動のばらつきと星像のSN比との関係を調べたところ、図に示すように、両者の間に負の相関が見られた。焦点距離50cmの地上モデルでは、焦点面上での5 μ mの変位が約1秒角に相当するので、1ミリ秒角の精度を達成するためには、CCD上で5nm以下の精度で星像中心位置を決定する必要がある、図3から、星像のSN比は約1000以上が必要であると推定できる。

以上を要約すると、

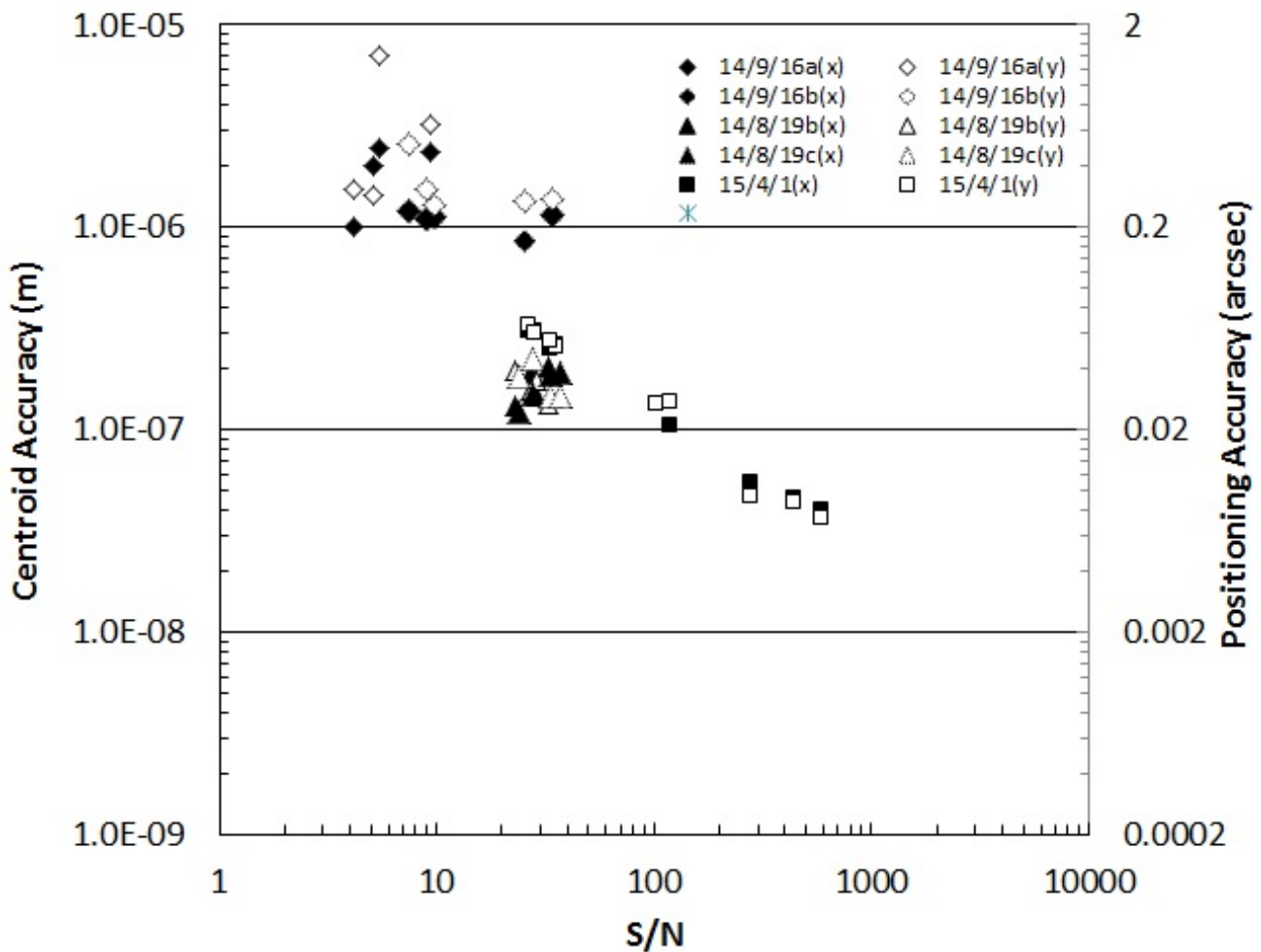
- 1) 実験結果は、SNRが十分に大きければ（1000以上）、1ミリ秒角の精度の観測が可能であることを示す。
- 2) 野外観測において数秒角の観測精度は達成できた。
- 3) 観測精度は、おもに星像のSN比の違いによることがわかった。
- 4) 星像中心位置の変動は、おもに水銀面の振動からきて、それらの影響は同一視野内の星ではほぼ共通である。

また、本文の内容には含まれませんが、将来に向けて、

- 5) 月惑星探査機への搭載の機会を増やすためには望遠鏡の小型化は重要である。
- 6) 上記のために、鏡筒を鉛直に保持する新方式の開発を始めた。

キーワード：月回転、小型望遠鏡、写真天頂筒、星像中心位置

Keywords: Lunar rotation, Small telescope, PZT, centroid



Laser-Induced Fluorescence Spectroscopy of Martian mineral analogues

*椎野 朱里¹、藪田 ひかる²、押鐘 寧³

*Akari Shiino¹, Hikaru Yabuta², Yasushi Oshikane³

1. 大阪大学理学研究科、2. 広島大学理学研究科、3. 大阪大学工学研究科

1. Department of Earth and Space Science, Osaka University, 2. Department of Earth and Planetary Systems Science, Hiroshima University, 3. Department of Engineering, Osaka University

Identification of methane (Freissinet et al. 2015) and hydrated salts (Ojha et al. 2015) on Mars by NASA have improved our understanding of Martian habitability. A miniaturized fluorescence microscope for detecting extraterrestrial life cell using fluorescence pigments have been under consideration in the Japanese future Mars exploration project (Yamagishi 2011). However, the application of this instrument is limited for the detection of fluorescently-labeled cells and/or organic compounds. This issue would be improved if Laser Induced Fluorescence Spectroscopy (LIFS) is combined with the fluorescence microscope, and planetary geological survey with a high spatial resolution would become possible. This study aims to understand LIFS spectral characteristics of the Martian surface mineral analogues.

We used 14 kinds of minerals. YAG laser was used in the LIFS experiment (wavelength: 355 nm, Laser power: 8 mJ/pulse, pulth width: 5 ns, laser spot size: 8 mm, oscillation frequency: 10Hz). LIFS spectra were measured with a wavelength range of 375-525 nm. Delay time from laser irradiation was 0 ns (gate 150 ns). Streak camera was used for the measurement of fluorescence life time.

Four silicate minerals showed broad spectra with a peak around at 400-550 nm. Five hydrated salts, boric acid, calcium oxide showed a developed peak around 405 nm, which are possibly derived from hydroxyl radicals. Calcium carbonate showed two characteristic peaks at 435 and 458 nm, and sodium tetraborate showed a peak at 435 nm. On the other hand, no fluorescence was detected from iron oxide, that is one of the major components of Martian surface.

The fluorescence lifetimes of the silicates were in decreasing order of talc > kaolinite, zeolite > montmorillonite. The fluorescence lifetime of sodium tetraborate was the shortest, which was distinct from the other minerals. All the hydrated salts had similar fluorescence lifetime.

キーワード：レーザー誘起蛍光、鉱物

Keywords: Laser-Induced Fluorescence, mineral

NIRS4/MacrOmega: a near-infrared hyper-spectral imaging camera for the Martian moon's sample return mission

*坂野井 健¹、中川 広務¹、岩田 隆浩²、中村 智樹¹、Jean-Pierre Bibring³、Cedric Pilorget³、Vincent Hamm³、笠羽 康正¹、今村 剛⁴、青木 翔平⁵、佐藤 隆雄²、田口 真⁶、山崎 敦²

*Takeshi Sakanoi¹, Hiromu Nakagawa¹, Takahiro Iwata², Tomoki Nakamura¹, Jean-Pierre Bibring³, Cedric Pilorget³, Vincent Hamm³, Yasumasa Kasaba¹, Takeshi Imamura⁴, Shohei Aoki⁵, Takao M. Sato², Makoto Taguchi⁶, Atsushi Yamazaki²

1. 東北大学大学院理学研究科、2. JAXA宇宙科学研究所、3. パリ南大学、4. 東京大学、5. ブリュッセル航空宇宙研究所、6. 立教大学

1. Graduate School of Science, Tohoku University, Japan, 2. JASA/ISAS, Japan, 3. University of Paris-Sud, France, 4. The University of Tokyo, Japan, 5. Institut d'Aéronomie Spatiale de Belgique, Belgium, 6. Rikkyo University

We report the current status of the MMX (Mars Moon eXploration) mission, particularly on the development of a near-infrared hyper-spectral imaging camera. We also discuss near- and mid-infrared spectroscopy for next generation space-borne planetary missions with advanced imaging technology. MMX spacecraft is scheduled to be launched in the early to mid 2020s, will orbit Phobos and Deimos, and return samples from Phobos back to Earth in the late 2020s. Near-infrared imaging spectroscopy is useful to understand the material distribution on Martian moons (e.g., hydroxide minerals at 2.7–2.8 μm , hydrated minerals at 3.0–3.2 μm , and organics at 3.4–3.4 μm) and dynamics and climatology in the Martian atmosphere (e.g. H₂O at 2.5–2.65 μm , and pressure with CO₂ absorption at 1.2–2.2 μm). We proposed a near-infrared hyper-spectral imaging spectrometer NIRS4/MacrOmega for the MMX mission to observe such properties on Phobos, Deimos as well as in the Martian atmosphere. NIRS4/MacrOmega will adopt an acousto-optic tunable filter (AOTF) as a monochromatic imaging filter. We are now discussing a conceptual design mainly for optics, and currently an AOTF device with a diameter of 15 mm (or 20 mm) is located at the fore-optics which enable us to obtain an image with a field-of-view of 6 x 6 deg. for a wide wavelength range from 1.0 to 3.6 μm with a wavenumber resolution of 20 cm^{-1} . The detector is a Sofradir Neptune SMW HgCdTe 512 x 256 array with a pixel size of 30 x 30 μm with an operational temperature of 110K. Using this optics and detector, we will take a Phobos surface area of 2.1 x 2.1 km with a pixel resolution of 8.2 x 8.2 m in case of a spacecraft altitude of 20 km. Directing its field-of-view to Mars, the Mars surface area of 630 x 630 km will be observed by a single shot. The advantage of AOTF device is high flexibility in wavelength selection which enable us to obtain images efficiently at the wavelengths in which important spectral feature will be expected on Phobos, Deimos and Mars. In the presentation, we will give the current status of optical design of NIRS4/MacrOmega, expected optical performance, and operation plan, and strategy to achieve the scientific goals on Phobos, Deimos and Mars.

キーワード：火星、フォボス、近赤外分光、サンプルリターン、開発

Keywords: Mars, Phobos, Near-infrared spectroscopy, sample return, development

The Venera-D Mission Concept for Exploring Venus

Ludmilla Zasova², David Senske³, *Sanjay S Limaye¹, Thomas Economou⁴, Natan Eismont², M Gerasimov², M Ivanov⁸, Nikolay Ignatiev², Kandi Lea Jessup⁶, I Khatuntsev², Oleg Korablev², Tibor Kremic⁵, I Lomakin⁹, M Martynov⁹, Adriana Ocampo⁷

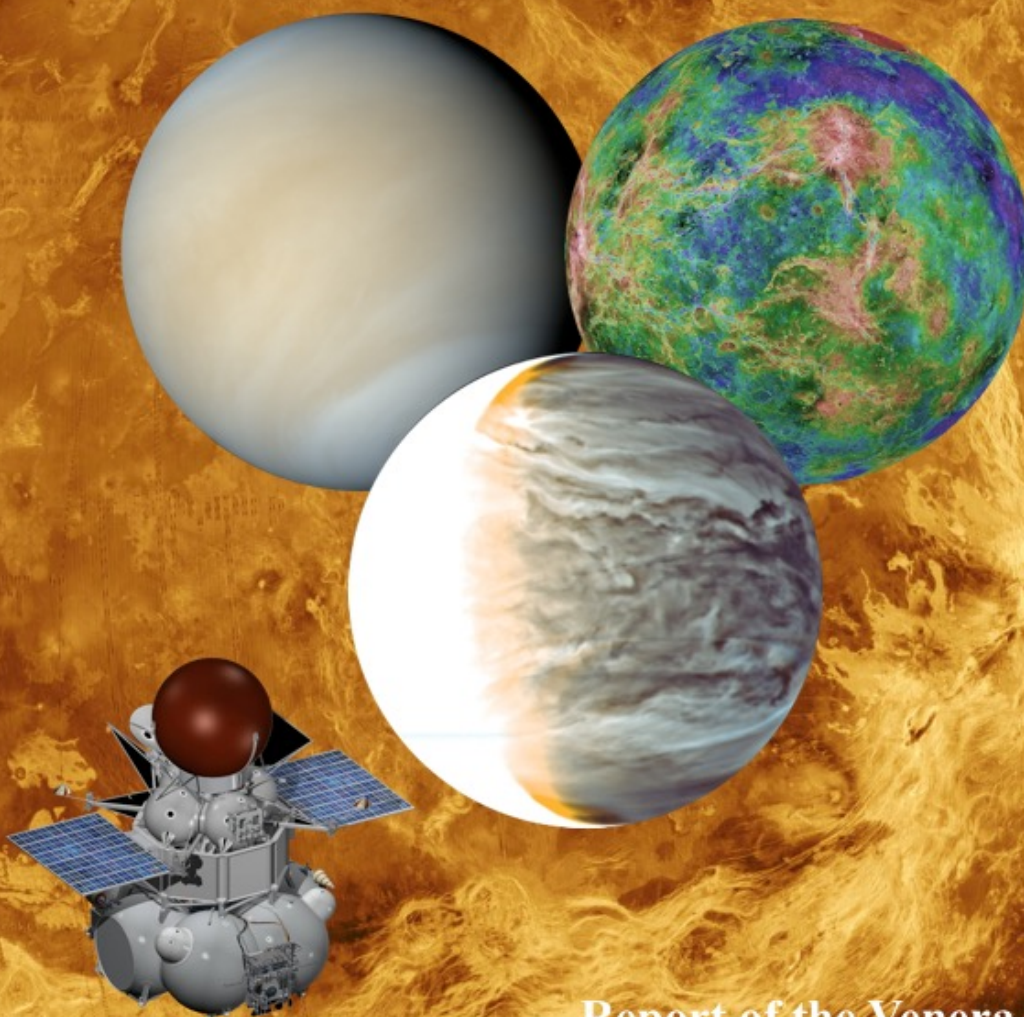
1. University of Wisconsin Madison, Wisconsin, USA, 2. Institute for Space Research, Moscow, Russia, 3. Jet Propulsion Laboratory, Pasadena, California, USA, 4. University of Chicago, Chicago, Illinois, USA, 5. NASA Glenn Research Center, Cleveland, Ohio, 6. Southwest Research Institute, Boulder, Colorado, USA, 7. NASA HQ, Washington, DC, USA, 8. Vernadsky Institute, Moscow, Russia, 9. Lavochkin Associates, Moscow, Russia

Many questions remain unanswered regarding the current state of Venus. Its global cloud cover and superrotating winds in the deep atmosphere, as well as the surface morphology and mineralogy remain poorly sampled. A better understanding of the interior structure is also needed in addition to understanding the solar wind interaction with the planet. Venus Express' more than 8 year exploration of the planet' s atmosphere has raised many new questions; likewise, JAXA' s Akatsuki orbiter is revealing new facets of the atmosphere, adding to the complexity of the questions that define the Venus puzzle. Against this background, a Joint Science Definition Team (JSDT) chartered by NASA and IKI/Roscosmos have collaborated for the last year and a half to define the most crucial questions that must be explored in a new mission to Venus, while considering the science in the context of Russia' s Venera-D baseline mission, originally conceived more than a decade ago.

Currently, the JSDT is assessing a mission architecture concept for the comprehensive investigation of Venus that would consist of an orbiter (>3 yr. of operation) and a lander (2 hrs. on the surface). The scientific goals of the concept are tied closely to the key objectives established by VEXAG and the NASA Planetary Decadal Survey, and include: investigation of the thermal structure and chemical composition of the atmosphere and clouds, abundances and isotopic ratios of the light and noble gases; study of the thermal balance, dynamics, and super-rotation of the atmosphere; determination of the surface mineralogy and elemental composition including key radioactive isotopes; study of potential current volcanic and electrical activity; and the study of the plasma environment, magnetosphere, and atmospheric escape. The JSDT is also evaluating technology needs and the potential for innovative flight element augmentations including, free flying aerial platforms, sub-satellites, and small long-lived surface stations. The study is continuing and will refine the mission architecture and potential instrument suite for the different flight elements.

Keywords: Venus , Mission, Orbiter, Lander, Aerial Platform, Surface Station

Venera-D: Expanding our Horizon of Terrestrial Planet Climate and Geology through the Comprehensive Exploration of Venus



Report of the Venera-D
Joint Science Definition
Team

31 January 2017

A Sensor Package for Space Weather Global Monitoring Based on Micro Satellite Constellation

*長妻 努¹、熊本 篤志²、尾崎 光紀³、北村 健太郎⁴、斎藤 義文⁵、高島 健⁵、能勢 正仁⁶、栗原 純一⁷、小嶋 浩嗣⁶、石坂 圭吾⁸、松岡 彩子⁵、野村 麗子⁵、石田 哲朗⁷、高橋 幸弘⁷

*Tsutomu Nagatsuma¹, Atsushi Kumamoto², Mitsunori Ozaki³, Kentarou Kitamura⁴, Yoshifumi Saito⁵, Takeshi Takashima⁵, Masahito Nose⁶, Junichi Kurihara⁷, Hirotsugu Kojima⁶, Keigo Ishisaka⁸, Ayako Matsuoka⁵, Reiko Nomura⁵, Tetsuro Ishida⁷, Yukihiko Takahashi⁷

1. 国立研究開発法人 情報通信研究機構、2. 国立大学法人 東北大学、3. 国立大学法人 金沢大学、4. 独立行政法人 国立高等専門学校機構 徳山工業高等専門学校、5. 国立研究開発法人 宇宙航空研究開発機構、6. 国立大学法人 京都大学、7. 国立大学法人 北海道大学、8. 公立大学法人 富山県立大学

1. National Institute of Information and Communications Technology, 2. Tohoku University, 3. Kanazawa University, 4. National Institute of Technology, Tokuyama College, 5. Japan Aerospace Exploration Agency, 6. Kyoto University, 7. Hokkaido University, 8. Toyama Prefectural University

Geospace is the space around the Earth. The geospace environment is disturbed by the solar wind. Disturbances in geospace are causes of satellite anomalies, radiation hazards of astronauts and aircrews on polar route, problem of HF communications, error of high-precision positioning and navigation, and induction current in long-line power cables. Many kinds of social infrastructure are vulnerable to geospace disturbances. Therefore, research and operation of space weather forecast is very important for understanding the current and future condition of space environment to mitigate the risk of geospace disturbances.

To improve the accuracy of space weather forecast, introducing numerical forecast scheme is essential. In case of terrestrial weather forecast, numerical forecast scheme with data assimilation technique based on merging between large number of data points and global simulation of atmospheric large circulation have been applied more than 50 years ago. This effort makes continuous improvement of terrestrial weather forecast. On the other hand, insufficient number of space environment data prevent us to introduce numerical forecast scheme for operational space weather forecast. The accuracy improvement of space weather forecast is highly expected if we realize global space weather monitoring based on constellation of several tens of satellites.

The major difficulties of introducing global monitoring by satellite constellation was cost of satellite, and size and power of the sensors. Large number of costs and human resources are needed to realize the global monitoring of space weather based on constellation of several tens of small satellite.

Miniaturization and power saving of satellite and sensor have been investigated for in-situ measurements of advanced scientific project. However, there are some limits of miniaturization of sensor with keeping the high level of specification.

To breakthrough this situation, we are planning to design and develop a space environment sensor package, which can contribute to safety operation of the micro satellite itself, and can realize low-cost global monitoring of space environment based on constellation of micro satellites. Our planned sensor package includes magnetometer, plasma wave receiver with measuring electron density, low and high energy particle detectors. The data obtained from the sensor package will be used not only for monitoring of the global distribution of currents, fields, and particles but also for understanding conditions of satellite such as, the attitude, charging condition, and risk of CPU malfunction, etc. So we will develop the package as one of the satellite bus component. The first priority of our development task is the mountability of the sensor package for every common micro satellite. Thus, the trade-off among optimization of sensor performance, integration of sensors, and miniaturization and power saving of each sensor needs to be

made. Space weather observations by several tens of micro satellite constellation enables us to narrow down the sensor performance of single satellite. This strategy can accelerate miniaturization and power saving of the package. Installing our sensor package on board common microsatellite is beneficial to satellite operator. And this approach enables us to realize space weather global monitoring based on constellation of common microsatellite with low-cost. Then, numerical forecast scheme with data assimilation technique can be introduced for space weather forecast.

キーワード：宇宙天気予報、全球モニタリング、衛星コンステレーション、超小型衛星

Keywords: space weather forecast, global monitoring, satellite constellation, micro satellite

Development of the bistatic radar system for subsurface radar sounding of the satellites and asteroids

*熊本 篤志¹、宮本 英昭²、西堀 俊幸³、岩田 隆浩⁵、土屋 史紀⁴、石山 謙⁵

*Atsushi Kumamoto¹, Hideaki Miyamoto², Toshiyuki Nishibori³, Takahiro Iwata⁵, Fuminori Tsuchiya⁴, Ken Ishiyama⁵

1. 東北大学大学院理学研究科地球物理学専攻、2. 東京大学総合研究博物館、3. 宇宙航空研究開発機構、4. 東北大学大学院理学研究科惑星プラズマ・大気研究センター、5. 宇宙航空研究開発機構宇宙科学研究所

1. Department of Geophysics, Graduate School of Science, Tohoku University, 2. The University Museum, The University of Tokyo, 3. Japan Aerospace Exploration Agency, 4. Planetary Plasma and Atmospheric Research Center, Graduate School of Science, Tohoku University, 5. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

Recent explorations clarified that the surfaces of the terrestrial planets, satellites and small bodies in the solar system are covered by regolith, and that the composition of the internal material is not always the same with the composition of the regolith on the surface. For example, the mass density of 21 Lutetia is as high as that of metallic meteorites, while its surface is covered by regolith with stony composition. The surfaces of Saturn's moons Helene and Atlas are contaminated by the ring particles. Disagreement between the chemical map measured by gamma-ray spectrometer and geological features on the Martian surface suggests that the Mars is covered by thin regolith layer with homogeneous composition. It makes difficult to estimate the amount of the carbonate rocks under the ground, and discuss the presence of the ancient humid subtropical climate on the Mars. Even if we can obtain numerous data on the surface of the planets, satellites, and small bodies in our future solar system exploration, we can not avoid the difficulty that the information on the surface doesn't always show the information bedrocks. In order to solve the problem, we consider that it is essential to acquire the technique of subsurface radar sounding of the planets, satellites, and small bodies with enough accuracy and resolution.

In 2000s, global subsurface radar sounding of the Mars and the Moon was performed by radar sounders onboard the Mars Express, MRO, and SELENE [Picardi et al, 2005; Seu et al., 2007; Ono et al., 2009]. Their resolution was several to several ten meters. In Chang'E-3 mission in 2013-2014, ground penetrating radar onboard the rover was operated in a local area on the Moon, and observed subsurface structures at a resolution of 0.33 m [Xiao et al., 2015]. In Rosetta mission, the bistatic radar system was installed on the orbiter and lander of the 67P/Churyumov-Gerasimenko. The bistatic radar observations was performed in 2014, and reported permittivity of the ice including some voids below the surface [Kofman et al., 2015]. In this study, we focus on the development of the spaceborne bistatic radar sounder system for small satellites and asteroids because Japan has strength in the exploration of the asteroids, and we can expect penetration of radar pulse through such small bodies, which is important in the bistatic radar observation.

In spaceborne bistatic radar system, it will be difficult to provide the same clock to the two radar units (e.g. transmitter and receivers) at different locations in space. So, we install transmitter and receiver into one radar unit (Unit-A, hereafter), and transponder into another unit (Unit-B, hereafter). In the observation, radar pulse is transmitted from Unit-A, propagates through the asteroid, and reaches Unit B. Transponder in Unit-B receives radar pulse, and transmits another radar pulse immediately. The radar pulse from Unit-B propagate back through the asteroid, reaches receiver in Unit-A. The same clock can be provided to the transmitter and receiver in Unit-A. From the delay time between transmitting radar pulse and receiving radar pulse, we can determine the round trip time of the radar pulse. In bistatic radar observation, we have to discriminate the radar pulses with different history of propagation path and relay

at transponder in Unit-B. So we are planning to use coded signal for radar pulse and add information of transmission and relay history on radar pulses.

キーワード：地下探査レーダ、バイスタティックレーダ、小惑星探査

Keywords: Subsurface radar, Bistatic radar, Asteroid exploration

SS-520-3号機観測ロケット実験に向けたASIC回路搭載磁場観測器の開発研究

Development of the magnetometer with on-board ASIC circuit for SS-520-3 sounding rocket

*野村 麗子¹、松岡 彩子¹、池田 博一¹、小嶋 浩嗣²

*Reiko Nomura¹, Ayako Matsuoka¹, Kazuhiro Ikeda¹, Hirotsugu Kojima²

1. 宇宙航空研究開発機構宇宙科学研究所、2. 京都大学生存圏研究所

1. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 2. Research institute for sustainable humanosphere, Kyoto University

本研究では、ソーラーセイルミッション（木星トロヤ群小惑星探査）の大規模な（一辺~50m）薄膜太陽電池パネルの4隅に磁力計を搭載し、波数を計測することを目指して、センサ部と信号処理部一体型の超小型・軽量、省電力かつ低ノイズの磁場観測器を開発している。大型薄膜太陽電池パネルに搭載するためには、従来の磁場観測器のままでは信号処理回路部が大きく重すぎることが問題とのひとつとなる。そこで、センサ部と信号処理回路で構成されているフラックスゲート磁力計のうち、信号処理回路のアナログ回路部全体を5mm角の集積回路(ASIC; Application Specific Integrated Circuit)に納めることにより軽量化及び1/3以下に小型化をおこなった。この磁場観測器は、2017年冬季に欧州より打ち上げ予定のSS-520-3号機観測ロケット実験において、フライト実証を実施する予定である。本発表では、ASIC回路搭載磁場観測器の環境試験の結果と、柿岡地磁気観測所で実施した較正試験によって導出された感度、オフセットやノイズ、タイミング試験によって導出された観測器が持つ時間遅れについて報告する。

Low-energy ion and electron spectrometers for the sounding rocket of SS520-3

*横田 勝一郎¹、斎藤 義文¹

*Shoichiro Yokota¹, Yoshifumi Saito¹

1. 宇宙航空開発研究機構・宇宙科学研究所

1. Japan Aerospace Exploration Agency Institute of Space and Astronautical Science

In-situ low-energy charged particle measurement in terrestrial or planetary plasma environment has been done with a variety of analyzers onboard spacecraft. Detailed studies of plasma characteristics demand measurement of a three-dimensional distribution function with adequate energy and angular resolution, a wide energy range, full coverage of space, and a high sampling rate. For three-dimensional energy analysis of low-energy charged particles, the top-hat electrostatic method using spherical deflectors or toroidal deflectors has usually been applied because of its large geometric factor and uniform angular response while requiring relatively few resources.

Since the in-situ plasma measurements have advanced and matured, today multi-spacecraft observation is indispensable to resolve not only the small-scale but also large-scale structures in the plasma environment. In addition, to achieve high-time resolution, one spacecraft is equipped with a dozen of identical electron and ion spectrometers, such as the MMS mission. Therefore, the reduction in size and weight is more and more important for following plasma observation missions. On the other hand, in the case of deep space exploration, since a variety of science instruments are mounted on the spacecraft for the comprehensive planetary science, there is left a small space for the charged particle instruments. We have designed and fabricated a low-energy charged particle spectrometer, which is capable of measuring ions and electrons alternately by switching the polarity of high-voltage power supplies. For the sounding rocket of SS520-3 which will launch in the end of this year, we are preparing low-energy ion and electron spectrometers. The two analyzers consist of two identical sensors/optics and two sorts of high-voltage power supplies for ion and electron measurements. We present the design and characteristics of the analyzers.

キーワード：低エネルギー粒子、プラズマ計測、SS520-3

Keywords: Low-energy charged particle, Plasma measurements, SS520-3

High speed MCP anodes for high time-resolution low-energy charged particle spectrometers

*齋藤 義文¹、横田 勝一郎¹、浅村 和史¹

*Yoshifumi Saito¹, Shoichiro Yokota¹, Kazushi Asamura¹

1. 宇宙航空研究開発機構・宇宙科学研究所・太陽系科学研究系

1. Solar System Science Division, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

Time resolution required for the low energy charged particle measurements is becoming higher and higher due to the demand for resolving electron scale phenomena. There exist several items that should be developed in order to realize time resolution to acquire 3-D phase space density higher than 10 msec. The 3-D phase space density measurement should be made independent of the spacecraft spin motion. The sensitivity of the analyzer should be high in order to secure good enough counting statistics with short sampling time especially for measuring tenuous plasmas, for example, in the Earth's magnetotail. The charged particle detector should be fast enough to accept high count rate generated by high sensitivity analyzer.

One of the solutions for the 3-D phase space density measurement independent of the spacecraft spin motion is to use two analyzers with hemispherical field of view installed on a spacecraft back to back. An example of such an analyzer is ASKY-ESA (All SKY-ElectroStatic Analyzer) originally developed for the 3-D phase space density measurement on 3-axis stabilized spacecraft. ASKY-ESA consists of FOV (Field Of View) scanning deflectors at the entrance and spherical/toroidal electrostatic deflectors inside. The FOV is electrically scanned between ± 45 degrees around the center of the FOV, which is 45 degrees inclined from the axis of symmetry. ASKY-ESA was flight verified as MAP-PACE sensors on Japanese lunar orbiter Kaguya.

In order to realize high sensitivity, an electron energy analyzer FESA (Fast Electron energy Spectrum Analyzer) was developed. FESA consists of two electrostatic analyzers that are composed of three nested hemispherical deflectors. Single FESA functions as four top-hat type electrostatic analyzers that can measure electrons with four different energies simultaneously. By measuring the characteristics of the test model FESA, the validity of the design concept of FESA was proved.

The charged particle detector should be fast enough to accept high count rate generated by high sensitivity analyzer. 1D circular delay line anode and MCP anode with ASIC have been developed as high-speed MCP anodes. The 1D circular delay line anode has zigzag patterns on the front side and a microstrip line with a characteristic impedance of $\sim 50\Omega$ is formed with a ground plane on the back of the anode. The maximum count rate of the 1D circular delay line anode is around 1×10^7 /sec/360deg., which is much higher than the widely used resistive anode, whose maximum count rate is around 1×10^6 /sec/360deg.. In order to achieve much higher speeds, an MCP anode with ASIC has been developed. We decided to adopt an anode configuration in which a discrete anode is formed on a ceramic substrate, and a bare ASIC chip is installed on the back of the ceramic. The ASIC contains 64-channel fast amplifiers and counters that enable the 5.625deg. angular resolution necessary for measuring solar wind ions. The whole ceramic substrate, except for the discrete anode pads that collect charged particles, is coated with parylene in order to protect the ASIC and the bonding wires from humidity and dust and to prevent electric discharge. It has been found that the anode can detect at a high count rate of 25 MHz/channel (1.6×10^9 /sec/360deg.). The ASIC anode has been successfully flight verified by three Norwegian sounding rocket experiments ICI-2, ICI-3, and ICI-4 (Launched from Ny Alesund, Svalbard, Norway in Dec. 2008 and 2011, and from Andoya, Norway in Feb. 2015). In the near future, this anode will be used for detecting low energy ions with Mercury Ion Analyzer (MIA) on BepiColombo/MMO. The ASIC chip and its

implementation will be widely used for the future missions that require lightweight low power consumption, high time resolution charged particle measurements.

キーワード：荷電粒子計測、MCP アノード、検出器

Keywords: charged particle measurements, MCP anode, detector

Bayesian Evaluation Technique for Direction Finding Method using Spectral Matrix

*太田 守¹、笠原 禎也¹、後藤 由貴¹

*Mamoru Ota¹, Yoshiya Kasahara¹, Yoshitaka Goto¹

1. 金沢大学大学院自然科学研究科

1. Graduate School of Natural Science and Technology, Kanazawa University

The plasma waves propagating in the Earth's magnetosphere are influenced by plasma on the propagation path in the generation and propagation process. In order to deeply understand the space plasma environment, in situ plasma wave observations by scientific satellites are indispensable. Spectral matrices which consist of cross spectra of electromagnetic field components are generally used for polarization analysis and direction finding of plasma waves. On the plasma wave experiment (PWE) aboard the ERG mission, power spectra and spectral matrices of VLF waves are generated onboard and transmitted continuously to the ground. These data are used in order to select the high-resolution waveform data to be downlinked, because they are generated intermittently and once stored on the onboard data recorder.

Conventional methods of direction-finding of VLF waves using a spectral matrix are classified as follows. One is based on the plane-wave approximation such as Means method and SVD method, and the other is the wave distribution function (WDF) method which regards observed signals as random waves. The methods for plane wave give a unique solution, and these methods have lower complexity than the WDF method. However, we must assess the validity of the approximation in advance. On the other hand, the WDF method estimates direction of arrival for multiple waves included in observed signals, and the number of the model parameters is generally more than the number of the input data components. To determine the solution uniquely, some additional assumption (model) is therefore required. So far many models have been proposed, and the estimated images are well known to be sensitive to the models.

By applying the Bayesian inference, reliability of the estimation methods can be evaluated under very weak assumption without determining the unique solution. In addition, the validity of the plane-wave approximation can be verified on the basis of the information of an observed spectral matrix. In this presentation, we introduce such evaluation techniques and tendencies of the solutions of direction finding methods.

キーワード：プラズマ波動、伝搬方向推定、不良設定問題、ベイズ推定

Keywords: Waves in plasma, Direction finding, Ill-posed Problem, Bayesian inference