Japan Geoscience Union Meeting 2013
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PCG10-01 会場:102A 時間:5 月 24 日 09:00-09:20

超小型衛星向け観測機器開発に関する衛星システム側からの要求
Requirements for Observation Equipment Development on Small Satellite from Bus Side

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1: Introduction

Artificial satellites are getting larger and larger every year and reached to several tons. This induces satellite high cost, long term development and high reliability requirements and large satellite development stalled. In this situation small satellite which weighs 1 to 100kg become conspicuous in astronautics. Especially, Japan is leading 1kg nano-satellite class in the world since we have developed and verify them first in the world. Mission at first stage was simple satellite bus performance check. Now there are technical demonstrations and high-level science observation missions similar to large satellites are taken place. This time, requirements from satellite side to observation equipment developers are reported.

2: Nano-satellite specifications

In this paper, nano-satellite means 1-50kg, 10-50 cm cubic size and it generates 1-50W power. (Common large satellite is several meter size.) Nano-satellite can provide 30 to 50 % resource for mission side.

In Japan, university one laboratory is a major player for nano-satellite development. And this means students are main force.

As referred in the above, usually nano-satellite has a single mission because of limited resources. And that means observers can use the satellite exclusively.

3: Requests for observation equipment developers

3-1: Interface and use of resources

Nano-satellite developers are not bureaucratic. Interface can be determined based on discussion between bus and mission side and it can be changed it is needed.

3-2: Information and motivation

For precise interface draw up, both sides should exchange design and development information each other. Since we work in a different area, we will start from understanding of terms of other side. Announcement of observation purpose, method and achievements are strongly welcome, it help to raise motivation. Main members of bus side are students, they are curious in science. When the explanation is enough, bus side will start to develop observation equipment part. This helps further mutual understanding and union of organization and knowledge speeds up.

3-4: Development strategy

Ambition for precise observation deserves to be acclaimed. There is performance limit for nano-satellite. Future plan should be considered. Successive small satellite project or combination use of large satellite (high low mix) will be easy rather than on extremely high specification satellite.

3-5: Redundancy

Since nano-satellite bus has little redundancy, too much careful design in mission side is useless.

3-6: Launch delay

Small satellites are often launched as a piggy-back of large satellite. So launch will postpone in many cases by irresistible force. Prepare for launch delay on ahead.

3-7: Ground test

The equipment tests are difficult since it will be used in vacuum and zero-gravity environment. But we can’t fix them after the satellite in on the orbit. Verification for validation must be done before the launch no matter how hard it is.

4: Conclusion

Requirements for mission side from bus side are described in this paper. In recent years, many universities star satellite projects. You can contact UNISEC (University Space Engineering Consortium) for introducing satellite projects.

キーワード: 小型衛星
Keywords: nano-satellite

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PCG10-02 会場:102A 時間:5 月 24 日 09:20-09:35

ピコ・ナノ衛星搭載用電子温度密度測定器
Compact Instrument to measure Te and Ne for Pico /Nano satellite

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電子温度、密度を同時に測定するプローブがピコ, ナノ衛星用搭載用に開発された。約４０年前に開発された電子温度測定器の固定周波数発振部を周波数掃引回路に変えることにより、インピーダンスプローブとしての役割を果たさせることができ、電子温度とともに電子密度を測定することができる。

キーワード: ピコナノ衛星, 上部電離圏, 電子温度, 電子密度
Keywords: Pico.Nanosatellte, Topside ionopshere, Electron density, Electron temperature

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PCG10-03 会場:102A 時間:5 月 24 日 09:35-09:50

Detecting Electrons and Ions with a Single Detector in Miniaturised Low Energy Particle Analysers
Detecting Electrons and Ions with a Single Detector in Miniaturised Low Energy Particle Analysers

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Electrostatic energy analysers for eV to low keV particles typically analyse either electrons or positive ions. Instruments that do study both usually use separate detectors. Using a single detector for both electrons and ions potentially enables more compact instruments with reduced spacecraft resource requirements.

CATS (Cylindrical And Tiny Spectrometer) is one such approach to this challenge. It is a prototype highly miniaturised instrument that uses a concentric cylindrical geometry to measure multiple energies of electron and ion simultaneously. It has been demonstrated experimentally with 0.5-8 keV electrons using an ion-implanted CCD for a detector. It is being adapted for use in PoleCATS: a student-led experiment on the REXUS (Rocket EXperiments for University Students) European sounding rocket programme. The current geometry has ˜7% energy resolution and ˜7 degree by ˜3 degree angular resolutions. Conceptually the design can be adjusted to tune the instrument parameters for a range of applications.

An alternative approach to the challenge is to adapt a conventional top hat geometry instrument so that it can sample alternately electrons and ions in continuous positive to negative inner hemisphere electrode voltage sweeps. While, unlike CATS, the electron and ion measurements would not be made simultaneously, the elegant focussing properties of the powerful and well-understood top hat geometry are preserved and existing, well-evolved instrument designs can be leveraged. By placing suitable dynodes (secondary electron emitters) at the exit of the analyser it is intended that a single MCP can be used to study electrons and ions over a wide range of energies. Initial simulations and development work on this project will be discussed.

キーワード: plasma analyser, miniaturised instrumentation, direct detection of low energy electrons with a CCD, SIMION simulations, low energy electron and ion spectrometer, CATS Cylindrical And Tiny Spectrometer
Keywords: plasma analyser, miniaturised instrumentation, direct detection of low energy electrons with a CCD, SIMION simulations, low energy electron and ion spectrometer, CATS Cylindrical And Tiny Spectrometer

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PCG10-04 会場:102A 時間:5 月 24 日 09:50-10:10

The Fast Auroral Imager Experiment to Investigate the Dynamics of Nighttime Optical Aurora

The Fast Auroral Imager Experiment to Investigate the Dynamics of Nighttime Optical Aurora

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The Fast Auroral Imager (FAI) consists of two CCD cameras: one to measure the 630 nm emission of atomic oxygen in aurora and enhanced night airglow; and the other to observe the prompt auroral emissions in the 650 to 1100 nm range. Good optical throughput (etendue) will be realized through the combination of fast lens systems (f/0.8) with CCDs of high quantum efficiency. Both cameras have a common 27 degrees field-of-view, to provide circular images of about 650 km diameter from apogee at 1500 km.

In the nadir viewing mode, the near infrared camera will provide multiple images per second at a spatial resolution of a few kilometres, for studies of dynamic phenomena such as substorm onset, vortices and multiple narrow arcs, and for monitoring the auroral context for the complementary *in situ* measurements onboard. The 630-nm camera will produce images once per minute with an exposure time of 0.5 sec, which is compatible with the radiative lifetime of the O(^{1}D) atom in the atmosphere. Not only will this camera image auroral forms such as discrete arcs that are produced by soft electrons, it will also measure the locations of the auroral oval and polar cap boundaries. With on-chip pixel binning it will be possible to investigate weak emission phenomena such as polar arcs and patches, midlatitude SAR arcs and detached arcs, and enhanced airglow from artificial ionospheric heating. Overall, the FAI instrument represents a major advance in the application of new technology to the study of nighttime auroral phenomena.

キーワード: auroral imaging, nighttime optical aurora, night airglow, CASSIOPE/ePOP Mission, Fast Auroral Imager (FAI), discrete aurora
Keywords: auroral imaging, nighttime optical aurora, night airglow, CASSIOPE/ePOP Mission, Fast Auroral Imager (FAI), discrete aurora

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PCG10-05 会場:102A 時間:5 月 24 日 10:10-10:25

ロケット搭載単色カメラによるパルセーティングオーロラ観測計画
Observation plan of pulsating aurora with a monochromatic camera on a rocket experiment

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To understand the small-scale variation of pulsating aurora and its cross-scale coupling to large-scale feature, we plan a S520 sounding rocket experiment to carry out the high-time resolution wave-particle measurements as well as optical imaging. This rocket experiment is characterized by the simultaneous measurement among plasma particle in the wide energy range up to more than 200 keV, VLF and high-frequency plasma waves, magnetic field, electron temperatures and monochromatic auroral image at the N2 1st positive band. Ground-based instruments, such as EISCAT radar, optical imager, and SuperDARN radar, will join this experiment. The rocket will be launched into pulsating auroras from Andoya, Norway during a new moon period in winter of 2017 to achieve the conjugate measurement with the ERG satellite. The launch window is 01-06 MLT, and the apex altitude of rocket will be more than 300 km in altitude. The total mass, electric power and data rate are estimated to be 48 kg, 110 W, and 3.1 Mbps, respectively.

We are developing a monochromatic camera for this project. The auroral imaging data at the N2 1st positive band (670 nm) is useful since the time response of N2 emission to the precipitating electrons is prompt, and its emission intensity is proposal to the total energy flux of electrons that cause the pulsating aurora. The optical and electrical designing is still in progress. At the present design, the field-of-view (FOV) is 45 degrees covering the ontological to downward directions, time resolution is several frame-per-second, and spatial resolution is 1 to a few km. Using successive image data in the vicinity of pulsating auroral emission layer, we expect to estimate the thickness of emission layer. In addition, we will achieve simultaneous image-particle measurement using the data when the FOV of camera is pointed to the magnetic footprint threading the rocket during the apex period. In this presentation, we give the current status of optical and electrical design of monochromatic camera, its detailed specifications and operation plan.

キーワード: パルセーティングオーロラ, ロケット, カメラ, 光学, 開発, ERG
Keywords: pulsating aurora, rocket, camera, optical, development, ERG

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PCG10-06 会場:102A 時間:5 月 24 日 10:25-10:45

Discussions of Electrode Contamination Effects on a Retarding Potential Analyzer on-board Sounding Rocket
Discussions of Electrode Contamination Effects on a Retarding Potential Analyzer on-board Sounding Rocket

Hui-Kuan Fang[1*], Koichiro Oyama[1], Chio Z. Cheng[1]
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Electrode contamination of a Langmuir probe in space is a serious problem even now although laboratory experimenters were aware of this problem for a long time. Surface contamination layer form extra capacitances and leads to a I-V curve distortion, which leads erroneous measurements, especially of electron temperature. Similar effects exist on electro-static analyzers, such as a retarding potential analyzer (RPA). Error caused by contaminations of a RPA is considered small for satellite experiments because satellite velocity is high (7 km/sec), and plasma density is low. While for sounding rocket experiments, error caused by contamination gets larger when we try to measure low ion temperature of 200-300K. We discussed several contamination effects on a RPA based on the experiments performed in a space plasma chamber. And development of a contamination-free RPA for rocket missions is also demonstrated.

キーワード: Retarding Potential Analyzer, Electrode Contamination, Sounding Rocket, Ion Temperature
Keywords: Retarding Potential Analyzer, Electrode Contamination, Sounding Rocket, Ion Temperature

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PCG10-07 会場:102A 時間:5 月 24 日 11:00-11:20

Study of Space Storms using Next Generation Small Satellite of Korea
Study of Space Storms using Next Generation Small Satellite of Korea

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[1]Korea Advanced Institute of Science and Technology

Korea Advanced Institute of Science and Technology (KAIST) is developing its 8th satellite as the first of the Next Generation Small Satellite series. The satellite will be launched in early 2016 into a polar orbit with an altitude of ~700 km. While the main mission of the satellite is to test engineering payloads, scientific instruments were also selected for space science and astrophysical investigations. The scientific goal of the space science payloads is to understand the behavior of the radiation belt and the ionosphere during space storms. Two of the space science payloads, Medium Energy Particle Detector (MEPD) and High Energy Particle Detector (HEPD), will be operated in the polar region to observe precipitating and trapped energetic particles, in the energy range from ~40 keV to ~1 MeV. Electrostatic deflectors will be employed in these instruments to reduce the cross-contamination between electrons and protons. A Langmuir Probe (LP), a Retarding Potential Analyzer (RPA), and an Ion Drift Meter (IDM) will also be on board the satellite for the operation in the mid- and low-latitude regions by sharing the orbits with the infrared astrophysics mission. Instruments and their operation scenarios will be discussed.

キーワード: Space Storms, Next Generation Small Satellite
Keywords: Space Storms, Next Generation Small Satellite

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PCG10-08 会場:102A 時間:5 月 24 日 11:20-11:35

小型衛星群による地震先行現象観測ミッション
Seismo-Electromagnetic Research by Small Satellite Constellation

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Tetsuya Kodama[1*], Koichiro Oyama[2]

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国際協力による小型衛星群を用いた地震先行現象観測ミッションの提案

キーワード: 地震電磁気, 小型衛星群, 地震先行現象, 電離圏
Keywords: Seismo-Electromagnetic, Small Satellite Constellation, Earthquake Precursor, Ionosphere

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PCG10-09 会場:102A 時間:5 月 24 日 11:35-11:50

SPRINT-A 搭載の極端紫外撮像分光器（EXCEED）の現状
The current status of EUV spectroscope, EXCEED on board the SPRINT-A

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EXCEED is the Extreme ultraviolet spectroscope on board the Japanese small scientific satellite, SPRINT-A. The mission will carry out spectroscopic and imaging observation of EUV (50-150 nm) emissions from tenuous plasmas around the planets (such as Venus, Mars, Mercury, and Jupiter) from the Earth orbit at the altitude of around 1000 km. It is essential for EUV observation to put on an observing site outside the Earth's atmosphere in order to avoid the absorption. In addition, because the emissions from the targets are very faint, the effective are should be as large as possible and needs long observation period. Since EXCEED is developed mainly for the planetary science, we can use the observation window as long as possible on the geometrical point of view. In this presentation, the specification and performance of the instrument according to the FM final calibration, and possible observation scenario are discussed.

キーワード: 小型科学衛星, 極端紫外, 木星, 散逸大気, イオプラズマトーラス, 分光
Keywords: SPRINT-A, EUV, Jupiter, Escaping atmosphere, Io plasma torus, Spectroscopy

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PCG10-10 会場:102A 時間:5 月 24 日 11:50-12:05

Development of a Low-Energy Electron Instrument LEP-e for the ERG Mission
Development of a Low-Energy Electron Instrument LEP-e for the ERG Mission

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Plasma and Space Science Center (PSSC) at National Cheng Kung University (NCKU) in Taiwan is now developing a low-energy electron instrument LEP-e for JAXA's radiation belts observation mission ERG (Energization and Radiation in Geospace). The LEP-e instrument measures electrons in the inner magnetosphere with energies from ~10eV to ~20keV to give key information on background plasmas, in which electron accelerations to a MeV range take place. The instrument is a tophat-type electostatic analyzer with multi-channel plates, similar to those on the NOZOMI and REIMEI missions. In the ERG mission, the keypoint of plasma instruments is to suppress effects due to background radiations. LEP-e employs 6mm-thick aluminum shields for the analyzer, and 5mm-thick shields for the electronics. In addition, LEP-e has a background noise channel, and an electron count is estimated by subtracting a noise count. In the presentation, instrument performance, estimated radiation effects and the current status of the development will be discussed.

Keywords: plasma analyzer, ERG mission

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PCG10-11 会場:102A 時間:5 月 24 日 12:05-12:20

Ionosphere Profiling Based on FORMOSAT-3/COSMIC Radio Occultation Experiment
Ionosphere Profiling Based on FORMOSAT-3/COSMIC Radio Occultation Experiment

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FORMOSAT-3/COSMIC (F3/C) is a Taiwan-US collaborative satellite mission for sounding Earth's atmosphere and ionosphere in recent years. The primary payload of each F3/C satellite is a GPS radio-occultation (RO) receiver, which measures the phase delay of radio waves from GPS satellites occulted by the Earth's atmosphere or ionosphere. By estimating the bending angles of radio wave trajectories, accurate and precise vertical profiles of the global troposphere, stratosphere and ionosphere are obtained. This presentation reveals data processing from F3/C RO phase measurements to ionospheric electron density profiles by means of single-difference excess phase estimation, bending angle estimation and ionosphere inversion technique. In addition, related RO experiments on board the next generation of F3/C, FORMOSAT-7, to be launched in 2016 and 2018, will be mentioned.

キーワード: FORMOSAT-3/COSMIC, radio occultation, ionospheric electron density, GPS
Keywords: FORMOSAT-3/COSMIC, radio occultation, ionospheric electron density, GPS

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PCG10-P01 会場:コンベンションホール 時間:5 月 24 日 16:15-17:30

ASIC を用いた磁気圏探査衛星搭載用ディジタル方式フラックスゲート磁力計の小型化
Development of the ASIC for miniaturizing the digital fluxgate magnetometer onboard future magnetospheric satellites

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kyosuke Iguchi[1*], Ayako Matsuoka[2]

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宇宙航空研究開発機構・宇宙科学研究所では 5 機の衛星による地球磁気圏の同時多点、マルチスケール観測計画（SCOPE：cross-Scale COupling in the plasma universE）が進められている。5 機の衛星の総重量や体積は大きく、ロケットへの積載制限により衛星重量や体積は厳しく制限される。そのため、磁気圏探査に搭載されるフラックスゲート磁力計などの科学観測機器も重量等のリソースを削減しなければならない。

フラックスゲート磁力計は簡便な仕組みであり、高精度、省電力であるため、1950 年代から多くの磁気圏探査衛星に搭載されてきた。従来のアナログ方式フラックスゲート磁力計の信号処理回路は、多数の個別のアナログ電子部品で構成されており、小型軽量、省電力化が困難である。一方、アナログ回路による信号処理を FPGA 等のディジタルプロセッサに代替させたディジタル方式フラックスゲート磁力計が 1990 年代に開発された。ディジタル方式は小型軽量、省電力化されたが、アンプやバンドパスフィルタは未だアナログ回路で構成されている。さらに、アナログ・デジタル変換器やデジタル・アナログ変換器も個別の半導体デバイスで構成されている。

市販の半導体デバイスとは異なる Application Specific Integrated Circuit（ASIC）は、用途に合わせて独自に開発する半導体デバイスである。したがって、必要な性能を満たし、回路を小型化できる可能性がある。我々が設計する磁力計では、磁力計のディジタル化とアンプやバンドパスフィルタの ASIC 化により、より一層のリソースの削減を実現させる。

設計した ASIC はそれぞれ 1 種類の増幅回路とバンドパスフィルタ回路で構成されている。ASIC のチップ面積は 5 mm 角であり、実際の使用面積は 5 mm x 1 mm 程度である。増幅回路の増幅率は外部信号により 2 倍から 10 倍まで変更できる。バンドパスフィルタは 2 次型バターワースフィルタを採用し、中心周波数はフラックスゲートセンサの検出信号の周波数である 22 kHz に調整できるようにした。

まず、ASIC の機能や性能について電子回路シミュレータを用いて検証した。さらに、-30 度から 50 度の温度範囲で ASIC の機能や性能が損なわれないことも確認した。設計した回路の消費電流は 1 mA で、消費電力は約 5 mW であった。出力のダイナミックレンジは 0.24 F.S. であり、1.2 V に相当する。増幅回路とバンドパスフィルタで発生するノイズは 600 $nV/Hz^{1/2}$ at 1 Hz（2 $pT/Hz^{1/2}$ に相当）以下と小さく、センサのノイズと同等またはそれ以下である。シミュレーションの結果から設計した ASIC が正しく機能し、要求に対して十分な性能が期待されることを確認した。

今回の発表では、実験により評価した ASIC の性能を中心に報告する。

キーワード: 宇宙プラズマ, 磁気圏, SCOPE, フラックスゲート磁力計, ASIC
Keywords: Space plasma, Magnetosphere, The SCOPE mission, Fluxgate magnetometer, ASIC

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PCG10-P02 会場:コンベンションホール 時間:5 月 24 日 16:15-17:30

アナログ ASIC を用いた宇宙プラズマ波動観測器の小型化に関する研究
Study on Miniaturization of Plasma Wave Receiver Using Analog ASIC

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Plasma filling the space is very rarefied. Ions and electrons in space plasma don’t exchange their kinetic energy through their collision but through plasma waves. Hence observing plasma wave is essential for measuring space electromagnetic environment. The characteristics of plasma waves appear especially in the frequency range below electron plasma frequencies, which are typically a few tens of MHz at maximum in the terrestrial magnetosphere. On the other hand, the signal dynamic range of plasma waves is very wide. There exist plasma waves with their intensities of a few uV/m to a few hundreds of mV/m. Then the plasma observation device should have high sensitivity as well as a wide dynamic range in wide frequency bands. The device of observing plasma waves is so-called plasma wave receiver. In order to achieve the above requirements to the frequency range, the sensitivity, and the dynamic range, typical plasma wave receivers tend to be large because they need large analog circuits such as filters and amplifiers. However, recent space missions require miniaturization of onboard observation device in order to reduce mass and power budgets. Plasma wave receivers cannot run away from the miniaturization of their analogue circuits. In this study, we will try to miniaturize the plasma observation receiver using ASIC(Application Specific Integrate Circuit).

SFA(Sweep Frequency Analyzer) and WFC(Wave Form Capture) are used in plasma observation device. The SFA is one type of spectrum analyzer, which has poor time resolution and fine frequency resolution. The SFA is a double super heterodyne receiver and operate frequency conversion two times. In usual SFA, we swept the frequency very finely, so it takes long time to sweep all frequency and time resolution becomes worse. However, SFA which we design operate A/D conversion and FFT after sweeping frequency roughly. By using this method, we can realize both good frequency resolution and good time resolution. Thus we need to implement a frequency synthesizer, mixer, and band pass filter inside an ASIC chip. We developed test circuits of the each component and evaluated their performance. On the other hand, the WFC observes plasma waves in the time domain. It provides phase information of the observed plasma waves. Then the WFC should be calibrated in its phase as well as its gain. The transfer functions of the electric field sensors strongly depend on the surrounding plasma conditions. Because the change of transfer functions affect observed waveforms, we need to measure transfer function by onboard system in space. We realized miniaturization of waveform receiver, measurement system and preamplifier using analog ASIC and developed the miniaturized waveform receiver with the built-in preamplifier and onboard measurement system.

In the present paper, we show our attempts in developing both types of ASIC, i.e., SFA chip and WFC chip.

Keywords: Plasma Wave, Downsizing, Integrate Circuit, ASIC, Sweep Frequency Analizer, Waveform Capture

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赤外エシェル分光・撮像装置用 InSb アレイセンサ駆動系の開発
The development of an InSb array driving electronics for the infrared imager and the echelle spectrometer

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惑星の大気圏・電磁圏は、多様な時間スケールで変動している。その顕著な例は木星をはじめとする 惑星のオーロラ現象である。特に、赤外の木星 H3+、H2 オーロラ発光は、地球大気透過率の高い 2 μ m や 4 μ m といった窓領域の波長帯を通して唯一地上観測が可能であり、長期的な観測に適している。HST 等の宇宙望遠鏡や、SUBARU 望遠鏡等の大型公開望遠鏡では、観測に使えるマシンタイムが短いことから、長期の連続観測は難しい。このことから、惑星オーロラ発光の長期連続観測を行うためには、マシンタイムを確保できる中小型の望遠鏡と、独自の赤外観測装置を用いることが唯一の解である。

そこで本研究グループでは、主として木星赤外オーロラやイオ火山の観測から木星磁気圏のモニタリング行うことを目標として、惑星観測に幅広く利用可能な赤外撮像装置 (高橋, 2005; 小鮒, 2008; 北 見, 2010) および、赤外エシェル分光装置 (宇野, 2009) の開発を進めている。これらの装置はいずれも検出器に 256 × 256 pixel の InSb アレイセンサを用いており、1 から 5 μ m に感度を持つ。赤外撮像装置は 赤外アクロマートレンズを用いた屈折光学系で、赤外 H3+オーロラ観測用に中心波長 3.414 μ m、半値幅約 10nm の狭帯域フィルターがフィルターターレットに搭載されている。赤外エシェル分光装置は、放物面鏡を用いた反射光学系で、波長分解能は約 20,000 である。これらはいずれも、ハワイ・ハレアカラ山頂 (標高 3000m) の 60cm 反射望遠鏡 (2013 年稼働予定)、および「惑星・系外惑星専用 1.8m(PLANETS) 望遠鏡」(2014 年稼働予定) に搭載し、木星、および他惑星の連続観測を行う予定である。我々は、これらの 装置の InSb センサ駆動回路系の開発を中心に行なっている。本研究は、イメージセンサ読み出し回路を詳細に検討し、適切なセンサバイアス、クロックの長さを決定し、赤外撮像試験に成功した。残すところ雑音評価を含めたキャリブレーションのみである。又、センサを載せる fan-out-board の設計、製作も進めている。現在、素子のモデル作成からシミュレーション、試作回路の作成、評価までを行っている。本発表では、開発した駆動系について発表を行う。

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宇宙機での同位体計測を目指したマルチターン・飛行時間計測型質量分析器
A multi-turn time-of-flight isotope analyzer for space application

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In order to study terrestrial or planetary plasma environment in situ low-energy ion measurements are indispensable and thus have been done by a variety of ion analyzers. Detailed studies of plasma characteristics demand mass analyses as well as energy analyses. In case of measuring a variety of ions originating from planetary atmospheres, we need to measure the ion composition with high mass resolution. Although we have achieved the measurements of the ion composition by mass analyzers around planetary environment, higher mass resolution is now needed in order to distinguish heavy species and isotopes. For the future isotope measurements around moons, planets and asteroids, we are developing a high-mass-resolution mass analyzer. One of our scientific objects is to measure the Martian atmospheric escape and evolution. Mass resolution (m/dm) of 100 is generally needed for the isotope analysis of planetary particles. However the Martian atmospheric escape and evolution science requires m/dm>3,000 to discriminate N2 from CO.

Low-energy particle measurement group of ISAS has developed a time-of-flight(TOF) ion mass analyzer with mass resolution of about 20 for KAGUYA, which succeeded in measuring ions originating from the lunar exosphere and surface. It is also preparing a TOF mass analyzer with mass resolution of 40 for the BepiColombo mission. Multi-turn TOF mass spectrometers(MULTUM), where ions are stored in a fixed orbit within electrostatic sectors and allowed to propagate the same orbit numerous times, have been developed by Osaka Univ. mass spectrometry group. One of the MULTUM series achieves the mass resolution over 30000 with the size of 20cm x 20cm. We have prepared a test model of the ion optics of the isotope analyzer which employs the MULTUM technique. We are also developing a pulsive high voltage power supply(HVPS) for the test model of the ion optics. We will report test results of the MULTUM optics and the HVPS performance.

キーワード: 質量分析, 同位体, 惑星探査
Keywords: mass analysis, isotope, planetary exploration

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中性粒子分析器における高周波電場型イオン質量分析部の検出効率と質量分解能の特性
Detailed design and performances on radio frequency mass spectrometer for development of Atmospheric Neutral Analyzer

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Neutral Mass Spectrometer (NMS) has been onboard several satellites and sounding rockets to observe neutral upper atmosphere of the Earth and other planets. However physical processes of neutral atmosphere are not fully understood because of limitations of observation time and NMS capabilities to observe neutral particle motion such as wind or temperature. Since in almost NMSs quadrupole mass spectrometer was applied to analyze particle species, it is difficult to obtain information on detailed velocity distributions for specific species. Neutral particles interact with plasma through collisions with ions in the upper atmosphere. Behavior of neutral particle motion thus varies by conditions in the ionosphere or the magnetosphere. In order to understand physical processes of neutral atmosphere response to the ionosphere and magnetosphere variation, it is necessary to achieve velocity distribution function for each atmosphere species.

We are developing new NMS which is called Atmospheric Neutral Analyzer (ANA). In ANA, radio frequency (RF) electric field is applied for mass analysis. After ionization of incident neutral particles, the particles are uniformed in a certain energy perpendicular to the entrance plane and then the particles through RF fields in three times. While passing through RF sections, the velocity perpendicular to the entrance slit plane is accelerated or decelerated by RF fields, and only particles with specific mass which have the resonant velocity can gain maximum energy in comparison with other particles. The particles which gained maximum energy can pass through the retarding potential analyzer (RPA) which is placed after the exit of the RF section to detection section. Counts and locations of the accelerated particles are detected by combination of MCP with fluorescent plate and CCD as a 2D image. The image represents 2D velocity distribution parallel to the plane of entrance slit and winds and temperatures are derived.

The detection efficiency and mass resolution of ANA depends on the potential on RPA and characteristics of energy gain. We improve mass resolution and detection efficiency by optimizing the geometry of RF analyzer. We will show performances of the RF analyzer estimated from numerical simulation.

キーワード: 超高層大気, その場観測, 中性粒子, 高周波, イオン質量分析器
Keywords: Upper atmosphere, In-situ observation, Neutral particle, Radio frequency, Ion mass analyzer

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地球・惑星電磁気圏探査を目指した高質量分解能 ToF 型イオン質量分析器の設計
Design of a ToF type ion mass spectrometer with high mass resolution for future planetary in-situ observations

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Many investigations of ion three-dimensional velocity distribution functions (VDFs) have been conducted with spacecraft-borne ion mass spectrometers (IMSs) to clarify plasma dynamics around terrestrial/planetary ionospheres and magnetospheres. According to numerical simulations, it has been considered that molecular ions exist around ionospheres of non-magnetized planets (e.g. Kransnopolsky et al., JGR, 2002). But there is a problem that conventional time-of-flight (ToF) type IMSs applying carbon foils (CFs) require high acceleration voltages to measure molecular ion VDFs with high mass resolution. Generally, acceleration voltages are limited due to sizes of power supplies which can be applied to spacecraft. A limitation of acceleration voltages is critical for this problem because mass resolution depends on the acceleration voltages. Therefore, developments of IMSs that can also measure VDFs of the molecular ions without high acceleration voltages are necessary for future investigations of plasma dynamics around the ionospheres of non-magnetized planets.

Our ToF type IMS is supposed to installed on spin-stabilized spacecraft. It consists of two analyzers: a top-hat type electrostatic analyzer (ESA) and a ToF analyzer. Firstly, the ESA discriminates kinetic energy per charge (E/q) of incident ions by applying sweep voltages to spherical electrodes. Secondly, information of ion velocities (v) can be derived from ToFs of accelerated ions with a high uniform energy (Eacc) at the ToF analyzer. Finally, from a relationship between Eacc/q and v, we can get information of incident ion mass per charge (M/q).

In this study, we designed the ToF analyzer by adopting new applications, conversion surfaces (CSs), instead of the conventional applications, the CFs, to realize measurement of the molecular ion VDFs with high mass resolution. A particle ToF is defined as a time difference between a START signal and a STOP signal. In the case of our ToF analyzer, secondary electrons emitted by collisions of the incident positive ions with the CSs, are treated as the START signals. The STOP signals can be generated by only reflected particles which can pass through a slit. Due to the collisions, charge-exchange reaction occurs, and most of the incident positive ions are converted into neutral particles. Electrode structures which produce linear electric fields (LEFs) are adopted to make it possible to analyze ToFs of reflected positive and negative ions with high accuracy. In the case of molecular ion collisions, dissociative reaction occurs with high probability, and the molecular ions split up into positive, negative, and neutral particles. Thus, three types of STOP signals may be generated in response to one START signal. Our ToF analyzer can also identify positions where the incident ions collide with the CSs by detecting incident positions of secondary electrons on START micro-channel plate (MCP). We firstly designed simple electrode model of the ToF analyzer with SIMION. Secondly, we analyzed a specification of the ToF analyzer with numerical simulations. As a result, we finally concluded that mass resolutions of the reflected positive ions are high enough to identify CO_2^+ and HCO_2^+ respectively at full width half maximum.

In this presentation, we will show numerical simulation results of the ToF analyzer, and will describe its total specification.

キーワード: 超熱的イオン, イオン質量分析器, 静電分析器, Ｔｏ Ｆ分析器, カーボンフォイル, コンバージョンサーフェス
Keywords: Suprathermal ion, Ion mass spectrometer, Electrostatic analyzer, ToF analyzer, Carbon-foil, Conversion surface

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ERG 衛星搭載用 0.01-25keV/q イオン質量分析器の開発
Development of 0.01-25keV/q ion mass spectrometer (LEPi) for ERG spacecraft

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We are developing a low-energy ion mass spectrometer (0.01-25keV/q) to be onboard ERG spacecraft. Measurements of plasma partciles with energies lower than 100keV is not easy in the terrestrial inner magnetosphere, since fluxes of high-energy particles are large. High-energy particles can penetrate through, or kick out the secondary particles when they hit materials. This means they can be detected by a detector inside an instrument without any analysis, namely, noise. In order to reduce the noise generated by the high-energy particles, we apply a time-of-flight (TOF) technique. In addition, we try to minimize size of the detector. We will discuss how an instrument in the current design can survive under severe environment under terrestrial inner magnetosphere.
Keywords: low-energy plasma analyzer, mass spectrometer, ERG

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ERG 衛星搭載 MEP-e と MEP-i の設計および検証計画
Design and verification plan of MEP-e and MEP-i onboard ERG

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We have been developing instruments for the observations of the medium-energy electrons (10-80 keV) and ions (10-180 keV/q) in our coming radiation belt mission ERG (Exploration of energization and Radiation in Geospace). The mission goal is to understand the radiation belt dynamics during space storms. The medium-energy electron measurement is one of the most important issues in this mission since these electrons generate whistler chorus waves, which are believed to play significant roles in the relativistic electron acceleration and loss during storms. On the other hand, such a measurement has been a challenging issue due to the harsh radiation environment, where penetrating particles and secondary particles result in significant background. Our strategy for enhancing signal-to-noise ratio is to combine an electrostatic analyzer and silicon detectors, which provide energy coincidence for true signals. In parallel with the electron instrument, we also have designed and tested a medium-energy ion mass spectrometer. This instrument is comprised of an electrostatic analyser, time-of-flight (TOF) mass spectrometer, and solid state detectors, hence it can measure energy, mass and charge state of medium-energy ions. It provides significant information of particle flux and pitch angle distribution of ring current core components, which contributes to the radiation belt dynamics via electromagnetic waves and global magnetic field deformation.

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超高エネルギー電子観測装置（XEP-e)
Extremely High-Energy Plasma/Particle Sensor for Electron (XEP-e)

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It is well known that satellites are always in danger in space and especially high-energy radiation damages them. One of the sources that cause them is the radiation belt (the Van Allen belt). It was thought to be static, but in the 1990s it rediscovered the radiation belt fluctuates greatly. There are some reasons to occur this phenomenon, but we have not understood a clear reason of this yet. On the other hand, it is well known that the energetic particle flux vary during geomagnetic disturbances and the relativistic electrons in the other radiation belt change with solar wind speed. Recently solar activity is getting larger, so now we are trying to develop the satellite (ERG) to reveal this mechanism in this solar maximum phase. ERG (Energization and Radiation in Geospace) satellite is the small space science platform for rapid investigation and test satellite of JAXA/ISAS, and our group is developing the instrument (XEP-e) to measure high-energy electrons (200keV˜20MeV), that is one of many ERG satellite instruments. XEP-e (eXtremely high Energy Plasma/ particle sensor for electron) is consists of three SSDs (Solid-State Silicon Detectors) and a GSO single crystal scintillator. It has one-way conic sight and an electric part is unified with a part of sensor that is covered with aluminum to protect from contamination. The front part of the SSDs discriminate a radiation enters into the sensor and the back part of the plastic scintillator get the value of its energy. We can get the data of high-energy electron by using this sensor and it will be useful to reveal the detail of the radiation belt’s fluctuation.

キーワード: ERG, 電子
Keywords: ERG

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ERG 搭載 HEP-e の ASIC による高速ディジタル処理システムの開発状況
Current status of development of the high-speed digital processing system by ASIC for HEP-e on board the ERG satellite

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ERG (Energization and Radiation in Geospace) satellite will be launched in 2015 to understand the acceleration process of relativistic electrons and dynamical variations of the space storm in the inner magnetosphere. In efforts to understand the cross-energy coupling process generating relativistic electrons, the satellite is equipped with instruments for comprehensively observing plasma/particles, fields and waves. The Plasma and Particle Experiment (PPE) utilizes four electron sensors and two ion sensors in order to cover the wide energy range. HEP-e is one of the four electron sensors and uses sets of SSSD (Single-sided Silicon Strip Detector) to detect energetic electrons. HEP on board MMO (Mercury Magnetospheric Orbiter) also employs an ASIC called VATA for read-out system from the detector, but HEP-e on board the ERG satellite aims at handling data with higher speed and has VATA which can process simultaneously signals from 32 channels with ADC function. We present the current status of development of the high-speed digital processing system for HEP-e on board the ERG satellite.

キーワード: ERG, HEP-e, ASIC
Keywords: ERG, HEP-e, ASIC

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米国磁気圏探査衛星 MMS 搭載高時間分解能低エネルギーイオン観測器 FPI-DIS の開発
Development of high time resolution ion sensors (FPI-DIS) on MMS

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現在米国では、磁気リコネクションの物理機構解明を主目的とした磁気圏探査ミッション MMS(Magnetospheric MultiScale) が 2014 年 10 月打ち上げを目指し進行中である。近年のジオテイルをはじめとする衛星観測により、磁気リコネクションの駆動には粒子個々の微視的な運動スケールにおける現象が重要であることが分かってきた。MMS は磁気圏リコネクション領域において 4 衛星による同時多点観測を行う。さらに、高時間分解能を持った粒子観測器による 4 π str の視野をカバーした観測（電子:30msec、イオン:150msec）により粒子スケールでの現象解明を可能とする。

上記の観測に必要不可欠な超高時間分解能粒子観測器のうち、我々はイオン観測器 FPI-DIS（Fast Plasma Instrument Dual Ion Sensors）を新規開発し、現在その FM フェイズが進行中である。FPI-DIS は、150msec の時間分解能及び Az90 °x Pol180 °の観測視野を持ったセンサーを 1 衛星につき 4 台（4 衛星計 16 台）搭載することにより衛星スピンに依存せず 4 π str の視野をカバーした高時間分解観測を実現する。

2012 年から 2013 年にかけて 16 台全ての特性取得試験を完了した。特性取得試験の結果、全観測器において設計通りの性能を満たしていることを確認した。本発表では、FPI-DIS の特性取得試験の結果と、そこから予想される FPI-DIS の観測性能について報告する。
Keywords: MMS, FPI-DIS, reconnection, high time resolution ion sensor

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ノルウェーの観測ロケット ICI-4 搭載高時間分解能低エネルギー電子計測装置 LEP-ESA
High time resolution low energy electron spectrometer LEP-ESA on Norwegian sounding rocket ICI-4

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極域電離圏の対流パターン推定に有効な HF レーダ観測において、予期しないような強い後方散乱波を受信する事がある。ノルウェーの観測ロケット ICI(Investigation of Cusp Irregularities) は、これらの後方散乱を引き起こす散乱源（プラズマ擾乱）の生成メカニズムを解明することを主な目的としている。ICI プロジェクトではこれまでに ICI-2 観測キャンペーンを平成 20 年 12 月に実施したほか、ICI-3 観測キャンペーンを平成 23 年 12 月に実施した。我々は、プラズマ不安定現象のエネルギー供給源としての低エネルギー電子の寄与を明らかにするため、ICI-2, ICI-3 観測ロケットに高時間分解能低エネルギー電子計測装置 LEP-ESA を搭載して観測を行った。ICI-2 観測ロケットは 12 月 5 日にノルウェー・スピッツベルゲン島のニーオレスンロケット実験場から打ち上げられ、カスプ領域から極側に向けて移動するオーロラ発光領域で電子密度擾乱を直接観測することに成功した。一方、12 月 3 日に打ち上げられた ICI-3 観測ロケットは Reversed Flow Channel 上空のデータ取得に成功した。ICI-2、ICI-3 の成功を受けて、平成 25 年 11 月に ICI-4 観測ロケットが今度は、Flow Channel Event を横切るように打ち上げられる予定である。

ICI-2, 3, 4 搭載の LEP-ESA は、センサー及び伸展機構と電子回路部で構成される。ESA は 10eV から 10keV の範囲の電子の分布関数を測定するトップハット型の静電分析器であり、２重に重なったトロイダル型の電極の内側に正極性の電位を与えて 0V から約 3kV まで掃引することによって電子の分布関数の計測を行う。この観測装置の電子の検出器部分には、高時間分解能計測を実現するために開発した、ASIC 搭載型ディスクリート MCP アノードを使用している。ディスクリートアノード自体は従来から広く用いられていたが、位置検出の分解能（荷電粒子計測の入射角度分解能に相当する）を上げようとすればするほど多数のアンプを必要としてその結果回路規模や消費電力が観測ロケットや人工衛星に搭載困難なほど大きくなるという問題があった。そこで、この問題を解決するために開発を行ったのが、多数のアンプとカウンタを含んだ数ミリ角の ASIC (Application Specific Integration Circuit) を搭載したディスクリートアノードである。このアノードは、ディスクリートアノードを 1mm 厚のセラミック上の金属パターンで構成し、背面に ASIC を BARE CHIP のままで搭載する構造を採用している。

ICI-2, ICI-3 に搭載した LEP-ESA は正常に動作しプラズマ擾乱領域における高時間分解能での電子のエネルギースペクトル計測に成功した。しかしながら、これらの観測装置は 100%完璧な性能を示したかというとそうではない。ICI-2, ICI-3 における電子のサンプリングはこれ迄に我々が用いて来た中でも最高速に当たる約 600 マイクロ秒であり、高圧電源の掃引レスポンスが問題になって来る時間領域である。事実、ICI-2, ICI-3 ではエネルギースペクトルの取得のための電圧掃引波形として三角波を用いたが、恐らく電圧の増加部分と減少部分のレスポンスが異なるため両方のデータを同等に扱うことができない結果となっている。もともと、三角波の電圧の増加部分 16 ステップと減少部分 16 ステップの測定電圧を少しずつずらすことで、32 ステップを用いるエネルギーカバレッジの稠密な約 22 ミリ秒/1 エネルギースペクトルの時間分解能観測と、エネルギーカバレッジは粗いが 16 ステップを用いる約 11 ミリ秒/1 エネルギースペクトルの高時間分解能観測の両方を実現する予定であったが、上記の理由で、16 ステップを用いた約 11 ミリ秒/1 エネルギースペクトルの観測は、限られた期間しか使用できていない。そこで、ICI-4 に搭載する LEP-ESA では、新たに高圧電源を設計し直し、特性の最適化を図ることで、当初の予定であった 16 ステップを用いた約 11 ミリ秒/1 エネルギースペクトルの高時間分解能観測の実現を目指している。

なお、ICI-4 は今後 10 年間に実現を目指している「極域電離圏におけるグローバルからメソスケール現象発生の鍵となるマイクロフィジックスの統一的理解とその役割（スケール間結合）の解明」を目的とする日本ノルウェー共同ロケット実験１０年計画の中の最初のミッションである。

キーワード: 観測ロケット, 荷電粒子, 検出器, ASIC, MCP アノード, カスプ
Keywords: sounding rocket, charged particle, detector, ASIC, MCP anode, cusp

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

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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り、昨年 3 月からの米国 MESSENGER による観測が初めてのものである。過去の探査から、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、その究明は未だこれからの課題となっている。「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。また、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。

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、日本側の詳細設計審査は平成 23 年 11 月に終了した。JAXA の開発する MMO は本年 1 月に電気・機械インターフェース試験が終了し、昨年 9 月末から総合試験が開始された。MMO 構造モデルは一昨年 11 月に ESA/ESTEC へ輸送され、昨年夏に行われた全体構造モデル試験に参加した。また MMO 電気モデルはドイツへ輸送され昨年 10 月から電気モデル試験に参加している。

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及び、日本側が製作を担当する MMO について最新状況を報告する。

キーワード: 水星, 惑星探査, 国際協力
Keywords: Mercury, Planetary Exploration, International Collaboration

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MMO 搭載 MIA センサー特性の最終較正試験結果
Final calibration results of MIA/MMO sensor characteristics

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The Mercury Ion Analyzer (MIA) on board Mercury Magnetospheric Orbiter (MMO) measures the velocity distribution of low-energy ions (5 eV to 30 keV) by using a top-hat electrostatic analyzer for half a spin period (2 s). By combining both the mechanical and electrical sensitivity controls, MIA has a wide dynamic range of count rates expected in the solar wind around 0.3 AU from the sun, and in the Mercury's magnetosphere. The entrance grid for the sensitivity control of ions is also expected to reduce significantly the contamination of solar UV radiation, whose intensity is about 10 times larger than that around Earth's orbit. In this presentation, we will summarize final results of the MIA sensor calibration experiment.

キーワード: MMO, センサー特性
Keywords: MMO, sensor characteristics