A Future Formation Flight Mission of Compact Satellites and Mission-Oriented Developments of Plasma/Neutral Particle Analyzers for Elucidating Space-Terrestrial Coupling Mechanisms

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In 21st century, we led the Reimei mission realizing the fine-scale auroral emission and particle observations by the high-time/spatial resolutions and also initiated the ERG mission based on the trinity research system consisting of in-situ observation using spacecraft, ground-based network observation, and data analysis/modeling approach. The main scientific targets of these missions are the space plasma dynamics occurring universally in the regional and energy couplings in the terrestrial ionosphere and magnetosphere. Through these space exploration missions, we have actually noticed and been proposing the importance of coherent cooperation in the different methodologies (in-situ/ground-based observations, data analyses, modeling/simulation) as well as the significance of appropriate international collaborations, especially in the instrumental developments. It should also be noted that some novel ideas and the cutting-edge technologies matching them have been stimulating new exploration missions. For example, the high-resolving simultaneous measurements of auroral emissions and particles were carried out in the Reimei mission by using both our original auroral camera and plasma instrument. Recently, we are also developing so-called software-type wave-particle interaction analyzer (S-WPIA) in ERG in order to elucidate the energy transport between the plasma waves and particles in the collisionless plasma regime. These research experiences and expertise in our community are now leading new research activities to propose a new exploration mission using polar formation-flight configuration of compact satellites for the space-terrestrial coupling mechanisms. In this future mission, we will directly investigate the interactions and couplings in the plasma and neutral particles and the electromagnetic fields and waves in addition to the plasma wave-particle interaction analyses for the ionospheric transverse ion acceleration (TIA) and the simultaneous auroral emission-particle observations for the magnetosphere-ionosphere coupling processes like Alfvenic electron acceleration and their related auroras, and the field-aligned current distribution and variation. In this presentation, We introduce the formation-flight exploration mission using compact satellites and also discuss the instrumental development plans for their realization.

Keywords: space plasma, atmospheric neutral particle, space electromagnetic fields and wave, integrated observation, compact satellite, formation flight

Digital Data Processing Module in the Low Frequency Analyzer System (LFAS) for the SS520-3 Rocket Experiment

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We introduce a digital data processing module for low frequency analyzer system (LFAS) on the “SS-520-3” rocket. The main objective of the SS520-3 rocket experiment is to identify ion acceleration and heating mechanism in the polar cusp region. The LFAS is equipped with two type of receivers; EFD (electric field) and WFC (waveform capture). The EFD measures electric wave field in the frequency range from DC to 400 Hz and the data will be sent by analogue telemetry, while WFC covers electric field measurements in the VLF range below 10 kHz and generate digital data which consist of one channel of spectrum and two channels of waveform. In order to achieve real-time data processing of the WFC receiver on the rocket, we plan to develop digital data processing modules on FPGA. The digital modules consist of three FFT modules with cascaded decimation filters for spectrum analyzers and a lossy data compression module for waveform data for the purpose of data reduction. We have already developed a general-purpose FPGA board for evaluation of various kinds of signal processing [1]. We can integrate our own signal processing module on it without any complicated wiring work for the peripheral circuits and evaluate the performance of our proposed module. In the presentation, we report the current design of these data processing modules.
[1] Y. Kasahara, H. Matsui, and Y. Goto, Abstract of JPGU Meeting 2015, PCG31-19.

Keywords: Plasma Wave Receiver, SS520-3 rocket, Digital signal processing

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Development of short-range LIDAR for future Mars landing mission

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The thermal structure of the atmosphere is controled by the distribution of small particles (aerosol particles).
They absorb and scatter a part of the solar radiation and the thermal emission from the surface. The spatial and size distribution of small particles is therefore a key to understand the thermal structure of the atmosphere.
This is also the case for Mars. The red planet is known as having a dusty atmosphere whoes thermal structure drastically changes depending on the distribution of the dust grains. The total amount of the dust grains in martian atmosphere is to be decided by the balance between the supply of dust grains from the surface and the sink of dust grains onto the surface. But the mechanism of the dust supply is unclear yet. Although dust-devils are proposed to be the most plausible mechanism to make the dust grains detached from the surface, the efficiency of the dust detachment is still hard to estimate. This is because the efficiency depends on many factors, such as the shape of a dust grain, the humidity, the electrostatic state of the dust grain and the surface, the size distribution function of dust grains on the surface, and so on.
To unveil the distribution and the motion of dust grains in a dust devil, we are developping a LIDAR. This LIDAR observes the dust grains on the line of sight in the range of around 100m with the spacial and temporal resolution less than 1m and 1s, respectively. The verification test of the LIDAR is conducted at the large wind tunnel at Meteorological Research Institute, Japan Meteorological Agency.

Keywords: LIDAR, dust, dust devil

Development of an ultraviolet spectrometer for the Mars/Phobos exploration

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The UltraViolet Spectrometer (UVS) is a strong tool for observing the Martian atmosphere and the surface of its moon, Phobos. For example, UVS can observe the absorption of the ozone (~250 nm) in the Martian atmosphere. Ozone is a key species for understanding the stability and evolution of the Martian atmosphere. UVS can also observe the surface albedo of Phobos at the wavelength of 220 nm interpreted of polycyclic aromatic hydrocarbon (PAH) origin. The presence or absence of PAH is important to understand the origin and evolution of Phobos. In this presentation, we will show the optical design of UVS and the methods of measurements of the global distribution of total ozone on Mars and the surface composition of Phobos.

Keywords: Mars, Phobos, Deimos, Ultraviolet, Spectroscopy

SS520-3 Sounding Rocket Experiment Targeting the Ion Outflow over Dayside Cusp

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The SS520-3 sounding rocket is currently planned to be launched from Ny-Ålesund, Svalbard in Spitsbergen in December 2017. The objectives of this sounding rocket is to understand the particle acceleration processes that cause the ion outflow by making in-situ observation of the wave-particle interaction over the dayside cusp region. The wave-particle interaction is going to be resolved by WPIA (Wave Particle Interaction Analyzer) that is newly developed for satellite missions. Since these wave-particle interactions are predicted to be effective above ~800km altitude, a two-stage sounding rocket SS520 whose apex can be higher than 800km is necessary. The rocket range where SS520 can be launched over dayside cusp is only SvalRak at Ny-Ålesund in Svalbard. This sounding rocket experiment is a part of the comprehensive observation campaign including ground based radar (EISCAT Svalbard Radar) and optical observations. Following 10 science instruments are planning to be on board the SS520-3 sounding rocket. 1) Digital FluxGate magnetometer (DFG) 2) Coupled Dark State Magnetometer (CDSM) 3) Low Frequency Analyzer System (LFAS) 4) Thermal ion Spectrum Analyzer (TSA) 5) Low Energy Particle experiment (LEP) 6) Ion Mass Spectrometer (IMS) 7) Fast Langmuir Probe (FLP) 8) Needle Langmuir Probe (NLP) 9) Plasma and Wave Monitor (PWM) and 10) Sun Aspect Sensor (SAS). Part of the data simultaneously obtained by LFAS, TSA and IMS are stored in a memory on the sounding rocket with high data rate and the downloaded data are analyzed on the ground, which functions as WPIA. Two of the 10 science payloads CDSM and NLP are going to be provided by Austria and Norway, respectively.

Keywords: Sounding Rocket, Ion Outflow, Cusp

Development of a light-weight X-ray imager for future explorer missions

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We would like to introduce a ultra light-weight X-ray optics and present recent results on X-ray performance test with these optics.
X-ray observatories are essential for X-ray astrophysics. Hence, revolution of observation technologies could lead to new discoveries. Detection of X-rays from the solar system objects including planets (Venus, Earth, Mars, Jupiter, Saturn), satellites (Moon, Galilean satellites), comets, and heliosphere is one of the discovery by recent X-ray observatories, i.g., Chandra, XMM-Newton and Suzaku. Representative mechanisms of their X-ray emission could be divided into three categories. First one is an elastic and a fluorescent scattering of solar X-rays by neutrals in the planetary atmosphere. Second one is a charge exchange with neutrals in the tenuous planetary exosphere and the cometary gas. Last one is collisions of energetic electrons in the planetary aurora with atmospheric neutrals producing bremsstrahlung emission and emission lines. Since these mechanisms are closely related to surrounding environments of the objects, we can obtain detailed information on planets such as density and spatial distribution of not-well known planetary tenuous atmosphere and magnetosphere. Overall pictures of them can be taken with remote sensing X-ray observatories. On the other hand, snapshots are obtained by the in-situ explorer missions. They are complementary to the in-situ explorer missions.
A key technique for the X-ray explorer or small satellite missions is a reduction in weight of optics. Conventional X-ray optics have a trend that optics with better angular resolution have larger ratio of the weight to effective area. Therefore, it is difficult to utilize them for the X-ray planetary missions which has a severe weight limit. Micro pore optics are being developed based on a concept of a miniature optics. To compensate decrease of reflection area, amount of mirrors are needed to increase. We have developed a novel type of micro pore optics with MEMS (MicroElectroMechanical System) technologies (Ezoe et al. 2006, 2010). We call them MEMS X-ray optics.
An instrument composing of the MEMS X-ray optics and a radio-hard semiconductor pixel detector is being developed. It aims at the first in-situ measurement of X-ray emission related to planetary atmosphere and magnetosphere. For example, JUXTA (Jupiter X-ray Telescope Array) is intended to observe Jovian X-rays (Ezoe et al., 2013). It covers 0.3-2 keV with the energy resolution of <100 eV at 0.6 keV. The major advantage of JUXTA compared to the Earth-orbiting X-ray observatories is proximity. Hence, if JUXTA has the effective area of 3 cm^2 at 0.6 keV and the angular resolution of 5 arcmin and orbits in ~30 Jovian radii at periapsis, these numbers scaled to the Earth orbit observation of Jupiter are 24 m^2 and 1 arcsec, respectively.
We fabricated the MEMS X-ray optics for JUXTA. The MEMS X-ray optics are made of 4-inch silicon wafer with 300 um thickness. A lot of micro-pores are formed in the thin silicon wafer by photolithography and deep reactive ion etching (DRIE). A typical pore width is 20 um and the sidewall of these pores play a role as X-ray reflective surfaces. After DRIE, sidewalls of the pore structures are smoothed by annealing in order to reflect X-rays with a micro roughness of less ~1 nm rms. Finally, the wafer is plastically deformed to a spherical shape. We constructed an approximately Wolter type-I telescope stacked two bending 4-inch optics with different curvature radii, and confirmed a clear X-ray focus for the first time (Ogawa et al., submitted in MST). We

also confirmed a need of improvement for a surface roughness and a vertical profile of sidewalls within pores.

Keywords: X-ray, light-weight optics

Development of a Thermal and Supra-thermal ion Analyzer for an experiment of Sounding Rocket

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In the terrestrial magnetosphere, plasma particles with a wide energy range from < 1eV to MeV exist simultaneously. These particles are generated and/or transported via interactions with plasma waves. For example, in-situ particle observations have revealed that the inner magnetosphere contains significant fraction of low-energy plasma particles originated from the ionosphere. Their typical energy is a few tens of eV in contrast to much lower energies in the ionosphere. However, acceleration and transport processes of these particles are still unknown. This is mainly due to lack of observations of thermal and supra-thermal ions. In general, a measurement of plasma particles with energies less than a few tens of eV is easily affected by spacecraft potential. One of the solutions to suppress this effect is to mount the instrument on top of an extendable boom. The effects of the spacecraft potential are suppressed by controlling the chassis potential of the instrument.

We are developing a thermal and supra-thermal ion mass spectrometer which is light enough to be mountable on top of the boom. This instrument consists of a top-hat type electrostatic energy analyzer and a time-of-flight type mass analyzer. In the current design, diameter of the instrument is less than 10 cm. We will show the instrument design and its development status.

Keywords: Thermal and Supra-thermal ion, Ion analyzer, Sounding rocket

Plasma package for constellation of micro-satellite

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Multipoint observation of space plasma is essential to distinguish spatial and temporal variations and to increase the spatial coverage. However, making satellite needs too much cost and human power so that it has not been realistic to distribute tens of the plasma sensors at different points. Such situation is drastically and rapidly changing due to the appearance of micro or nano satellites with a weight less than 100 kg, which cost only 1/100 or even 1/1000 of conventional large satellite. Adding to Surrey Satellite Technology Ltd., a venture company of Surrey University in UK and one of the pioneers of microsatellite, not a few institutes, universities, space agencies and private companies started entering the international race of micro-satellite development. It is not unrealistic that 100s-1000 of satellites are launched every year in a several years from now. One of the fascinating ideas to realize super multipoint measurement for space weather monitoring might be installing a standardized scientific plasma sensor package at every micro-satellite to be launched in the world as a part of the BUS instruments. Here we would like to discuss how to promote and distribute this idea internationally.

Keywords: micro-satellite, nano-satellite, constellation, plasma instrument

The development of the one chip new spectrum plasma wave receiver

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The plasma wave receiver is essential instruments for plasma observation. However, the size of the receiver is the important problem, especially for small satellites. We have been attempting the miniaturization of the plasma wave receiver by designing the analog ASIC (Application Specific Integrated Circuit). In this presentation, we introduce the new spectrum receiver which is one kind of plasma wave receivers. Conventional spectrum receivers are categorized into three types: sweep frequency analyzer (SFA), multi channel analyzer (MCA), and fast Fourier transform (FFT) based receiver. The SFA and the MCA have the problem that its time resolution and frequency resolution are incompatible. Although the FFT based receiver can overcome this problem, it has a disadvantage that the receiver amplifies signals with a wide frequency band. To resolve above problems, we propose the new spectrum receiver.

The new spectrum receiver is composed of analog circuits and digital signal processor (DSP). Input signals are band limited and amplified by the analog circuits, and the band-limited signals are analog to digital converted and applied FFT by DSP. The receiver gets whole spectrum by repeating this process in three bands: from 10 Hz to 1 kHz, from 1kHz to 10 kHz, and from 10 kHz to 100 kHz. This method enables to realize the spectrum receiver which has high time and frequency resolution, and this method can avoid wide frequency band amplifying.

We succeeded in developing the analog circuits for the new spectrum receiver and the prototype model of the receiver. The analog circuits are realized in ASIC, and all components of the receiver except for analog to digital converter (ADC) and DSP is included in a 5 mm x 5 mm chip. The prototype model is composed of the ASIC, an ADC board, and a PC. The ADC is controlled by the program running on the PC, and converted data are applied FFT in the same program. The time resolution of the receiver is 0.4 second, and frequency resolution for frequencies from 10 Hz to 1 kHz, from 1 kHz to 10 kHz, and from 10 kHz to 100 kHz are 3.2 Hz, 32 Hz, and 320 Hz respectively. In this presentation, we introduce the design of the new spectrum receiver in detail, and we also introduce the measurement result of the receiver.

Keywords: Plasma wave, ASIC

The Miniaturization of Particle Detection Circuits Composing the Direct Observation System for Wave-Particle Interactions

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"Wave-Particle Interaction Analyzer (WPIA)'' is proposed for a direct and quantitative analysis of wave-particle interactions. We aim to integrate the WPIA on one-chip by using the ASIC (Application Specific Integrated Circuits). In order to realize the one-chip WPIA, small-size particle detection circuits are required which continuously output a detection signal derived from each plasma particle.
The operation of the particle detection circuit consists of two stages. Since the plasma particle cannot be detected directly, the pre-stage converts and amplifies electric charge detected by a sensor to voltage first, enabling the post-stage to detect the voltage signal. The input waveform to the pre-stage circuit appears as a current pulse with its pulse width of a few tens of nano-seconds. In order to keep an enough response to the short time pulse in converting the electric charge to the voltage, we chose a current conveyor and a latch comparator for the pre-stage and post-stage circuits, respectively. First, we designed a current conveyor. The response of the current conveyor depends on mutual conductance (g_m) of MOSFETs and the output impedance (Z_{out}). With a large value of g_m and Z_{out}, we designed a high response current conveyor circuit. Simulation results show that when the amplitude of the input current pulse was 103 uA, the output was raised from -12.7 mV to 316 mV at about 1.8 ns and converged at about 16.2 ns. The operational performance of the current conveyor circuit was also verified by the measurement and simulation results. Next, we designed a latch comparator. Adjusting the current and the aspect ratio of MOSFETs on the latch circuit, we designed a high response latch comparator with the delay time of less than 2 ns. The measurement results, however, showed the delay time of about 200 ns, due to the time constant increased by parasitic capacitance at the output port, which was improved by decreasing Z_{out} in simulation.
In this presentation, we introduce the design and evaluation of the small particle detection circuit on a chip and propose a direct observation system for wave-particle interactions including the designed particle detection circuits.

Keywords: Wave-Particle Interaction, Wave-Particle Interaction Analyzer(WPIA), Particle Detection, Application Specific Integrated Circuits(ASIC)

Development of wideband impedance probe system for observation of the ionosphric ion composition

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The performance of new wideband impedance probe system for observation of the ionospheric ion composition have been evaluated in the plasma chamber. Measurement system of Number density of Electron with Impedance probe (NEI) were developed by Oya [1966], and successfully utilized for numerous sounding rockets and spacecrafts such as Denpa, Taiyo, Jikiken, Hinotori, Ohzora, and Akebono [e.g. Wakabayashi et al., 2013]. NEI measures the equivalent capacitance of the probe immersed in the magnetized plasma. By applying RF signal to the probe, we can identify the minimum of equivalent capacitance due to upper hybrid resonance (UHR). The frequency of RF signal is swept from 100 kHz to 25 MHz, in order to cover the UHR frequency range in the Earth’s ionosphere. We can obtain accurate electron number density from the measured UHR frequency.

The effective capacitance of the probe in the magnetized plasma shows minimum not only at UHR frequency but also at another resonance frequency: Lower hybrid resonance (LHR). If we can measure LHR frequency with UHR frequency and electron cyclotron frequency, we can derive effective mass of ionospheric plasma and determine the ionospheric ion compositions. Because LHR frequency is about several kHz in the ionosphere, we have to extend the lower limit frequency of the current impedance probe system to 100 Hz.

Through the plasma chamber experiment in 2014 with bread-board model (BBM) of the new impedance probe system, we confirmed that it could measure (1) UHR in high frequency range as well as the current NEI could, and (2) equivalent capacitance profile from 100 Hz to 100 kHz, which indicates sheath capacitance of 120 pF and sheath resistance of 30 kohm. But it could not detect LHR as predicted due to high electron collision frequency in the chamber using backscatter-type plasma source. We are planning to perform another chamber test in 2015. In this test, we used large UV light source with propylene gas (C_3H_6) as plasma source in expectation of reduction of the electron collision frequency. However, although we found slight decrease of effective capacitance around 2 kHz, we could not confirm clear LHR depending on changes of background plasma density. The constant sheath resistance in low frequency range shows the existence of large sheath current due to potential difference between the probe and background plasma. Therefore, we are planning another chamber experiment in which we perform DC-potential control of the probe.

Keywords: Impedance probe, Lower hybrid resonance (LHR), Ionosphric ion composition

The UV photon detector on board spacecraft with high-efficiency and stability

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The remote observation with ultraviolet (30-330nm) lights is essential for planetary science because there are many effective lines emitted from the ion and atoms which compose the planetary magnetosphere or atmosphere (exosphere too). The straightest way to improve the quality of the data is to increase the efficiency of the instrument. In this presentation, we will show the way to improve the detection efficiency of the photon detector. Furthermore, the way to keep the efficiency during the ground operation (before the launch) is also shown from the experimental aspect.

Keywords: ultraviolet, spacecraft, efficiency

