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

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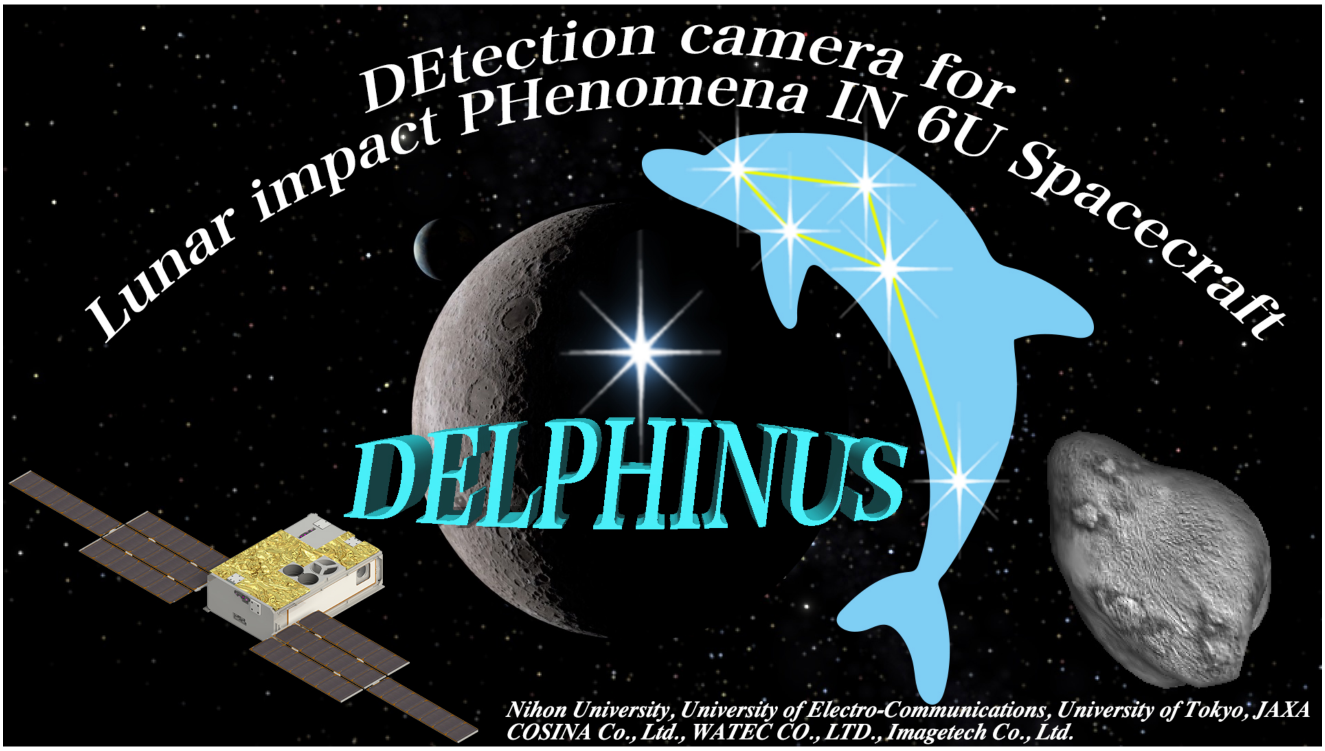
EQUULEUS (EQUilibriUm Lunar-Earth point 6U Spacecraft) will be the world's smallest spacecraft to explore the Earth-Moon Lagrange2 point (EML2). The spacecraft will be jointly developed by the University of Tokyo and JAXA which will be launched by NASA's SLS (Space Launch System) EM-1 (Exploration Mission-1) 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 km^2 of upper-atmosphere visible from their location. On the other, Lunar impact monitoring enables to monitor the more than 10^6 km^2 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.

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


DEtection camera for
Lunar impact PHenomena IN 6U Spacecraft
DELPHINUS
Nihon University, University of Electro-Communications, University of Tokyo, JAXA
COSINA Co., Ltd., WATEC CO., LTD., Imagetech Co., Ltd.

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

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There are possibly information suggesting a liquid core or a partial melting zone in lunar rotational fluctuations, and we can get them if observe the lunar rotation with an accuracy of better than 1 milli-arc second. We developed a small telescope like Photographic Zenith Tube (PZT) for observations of lunar rotation and made some experiments in a laboratory and outside using a Bread Board Model (BBM) in order to check the total system of the telescope and the software.

In the laboratory experiments, which were made in August of 2014, 4 star images were recorded on a video camera at the rate of 30 frames/s. We found that the long periodic variations of centroid position of 4 stars in the field of view are similar, and the amplitude of the variations is reduced by subtracting the mean variation from each record, and only the random noises are remaining, which is regarded as the accuracy of centroid estimation. This suggests that the effects of vibrations are almost common to all the stars in the field of view. The variations have strong peaks in the frequency bands of 0 to 0.5 Hz and 5 to 6 Hz, which are confirmed to be stemming from vibration of the mercury surface. We can almost completely remove the effects of vibrations by subtracting the mean variation from each data.

The field observations, which were made in September of 2014 at Mizusawa VLBI Observatory of NAOJ, detected 6 stars of magnitude of 7 to 8, and they were recorded on a special CCD camera every 2s. The centroid position varies more largely than the case of the laboratory experiments. There were seen also common variations although it is not obvious. The scatter of the variation is reduced by subtracting the mean variation from each record, but it does not become as small as the case of the laboratory experiments

.

We calculated SNR in order to know the reason why the variation of centroid position in the field observations is larger than that of laboratory experiments. The SNR is here defined as the ratio of the maximum brightness of a star image to standard deviation (SD) of dispersion of brightness in the background around the star image. The SD of variation in measured centroid position is inversely proportional to SNR as shown in the Figure. The results of centroid experiments by JASMINE (Apr. 1, 2015) as well as those of the laboratory and field experiments are shown here. We can say that the less centroid accuracy in the field observations is due to lower SNR.

In summary,

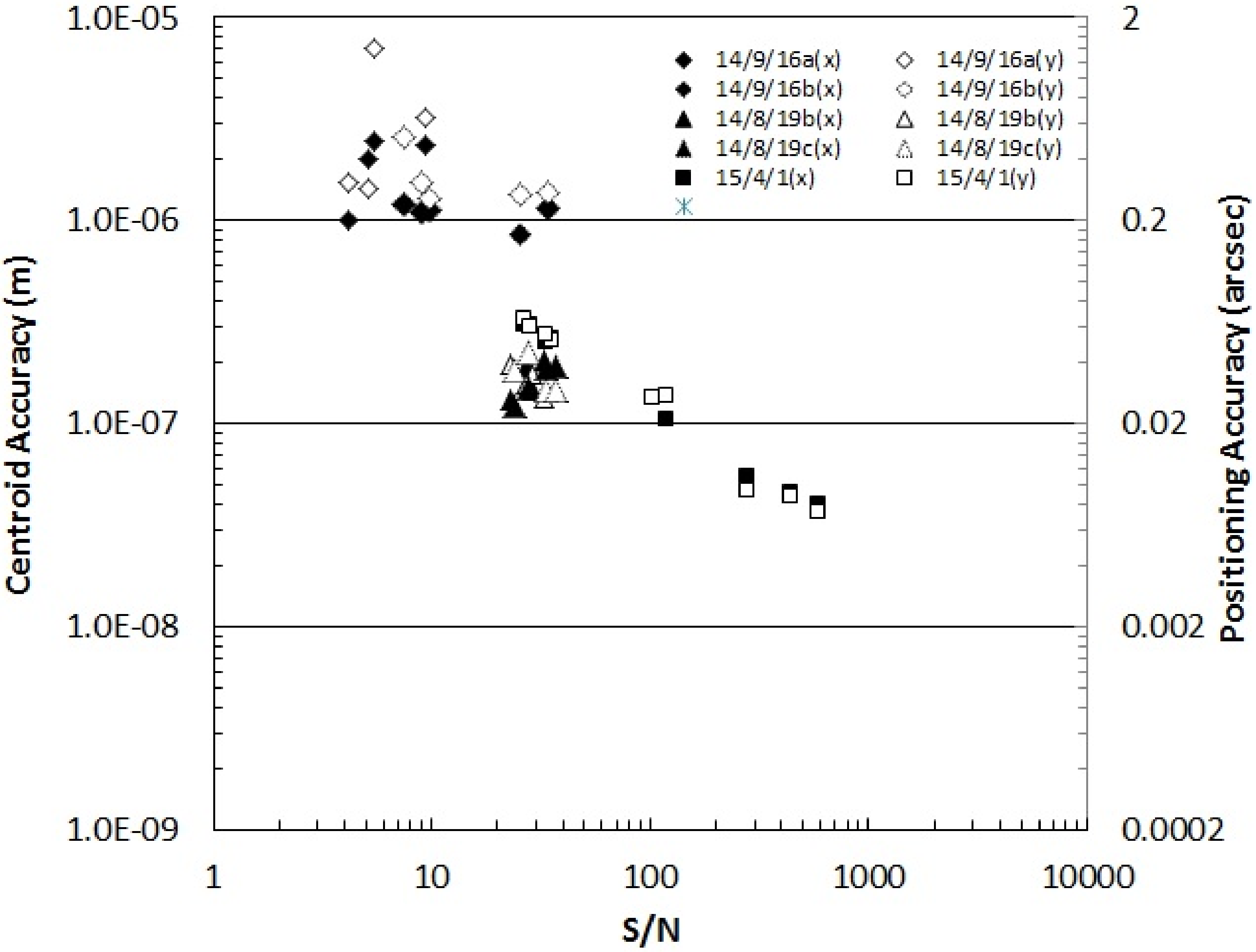
1) The experiments show that 1 mas accuracy is possible if SNR is high enough (~1000).

2) Accuracy of several arc-seconds was attained in the field observations.

3) The difference can be explained mainly by the difference in SNR of stellar images.
4) The variations of centroid position of stellar images are mainly stemming from the vibration of mercury surface, and they are almost common to stars in the same view.

And for the future,
5) To develop a small sized instrument is also important in order to increase opportunities of boarding.
6) We started to investigate a new method to keep a tube in vertical direction.

Keywords: Lunar rotation, Small telescope, PZT, centroid



Laser-Induced Fluorescence Spectroscopy of Martian mineral analogues

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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.

Keywords: Laser-Induced Fluorescence, mineral

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

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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 be launched in the early to mid 2020s, will orbit Phobos and Deimos, and returns 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 um, hydrated minerals at 3.0 −3.2 um, and organics at 3.4 −3.4 um) and dynamics and climatology in the Martian atmosphere (e.g. H2O at 2.5 −2.65 um, and pressure with CO2 absorption at 1.2 −2.2 um). 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 um with a wavenumber resolution of 20 cm^-1. field-of-view. The detector is a Sofradir Neptune SMW HgCdTe 512 x 256 array with a pixel size of 30 x 30 um 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.

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

The Venera-D Mission Concept for Exploring Venus

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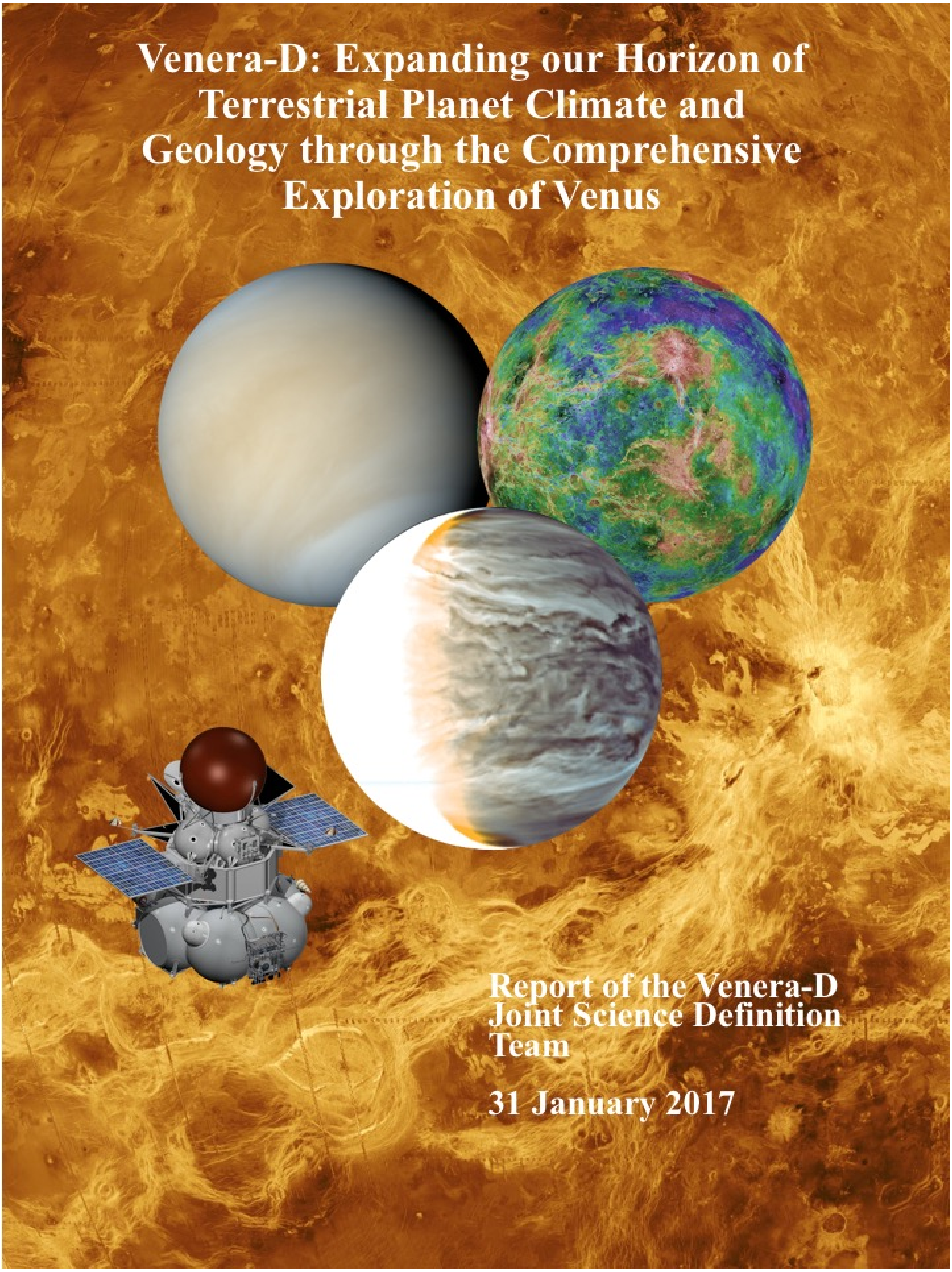
Many questions remain unanswered regarding the current state of Venus. Its global cloud cover and superrotating winds in the deep atmosphere, as well as the surface morphology and mineralogy remain poorly sampled. A better understanding of the interior structure is also needed in addition to understanding 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

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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.

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

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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 bistatisc radar system was installed on the orbiter and lander of the 67P/Churyumov-Gerasimenko. The bistatisc 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.

Keywords: Subsurface radar, Bistatic radar, Asteroid exploration

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

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In order to find the wavenumber by deploying four magnetometers at edges of the large thin film solar cell (~50m each) of the Solar Sail (Trojan asteroid exploration mission), we are developing an ultra-slim and light magnetometer integrated with signal processing circuits of low power and noises. One of the problems for installing our magnetometers is that the signal process circuits are too large and heavy to deploying into the solar cell. Therefore we developed the 5mm-chip (ASIC; Application Specific Integrated Circuit) for the analog parts of our signal process circuits to achieve both weight saving and downsizing. This magnetometer is planed to perform a flight proof by SS-520-3 sounding rocket experiment. In our presentation, we will show the result of experiment tests, the sensitivity, offset and noise derived by the calibration test at Kakioka geomagnetic observatory, and the time delay of this magnetometer derived by the timing test.

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

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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.

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

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

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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 ~50ohm 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 $1X10^7$/sec/360deg., which is much higher than the widely used resistive anode, whose maximum count rate is around $1X10^6$/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 ($1.6X10^9$/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.

Keywords: charged particle measurements, MCP anode, detector

Bayesian Evaluation Technique for Direction Finding Method using Spectral Matrix

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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.

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

