Distribution of ^{54}Cr Isotope Anomalies in Asteroid Belt

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Isotope Anomalies of ^{54}Cr in Various Meteorites: The degree of ^{54}Cr anomalies in various meteorites was shown to have a good correlation with the evaluated formation ages of their parent bodies [1], except for CAIs [2]. A possibility that the correlation is caused by an input of ^{54}Cr-rich grains ejected from a nearby supernova was proposed [1]. In the model, the input material was assumed to land on a certain ring of the solar nebula at the certain time. Then, the model may reproduce the increase of the ^{54}Cr content, but a spike of ^{54}Cr anomaly contained in CAIs cannot be reproduced by the model. Here, we look for the other process. Inside a molecular cloud core that would form a star and a protoplanetary disk system could be inhomogeneous [3]. This suggests that the isotope anomalies seen in meteorites today may be caused by the isotopic heterogeneity in the molecular cloud core.
In this study, a model that may reproduce the observed anomalies of 54Cr starting from the inhomogeneous molecular cloud core is examined.

Model: It is assumed that isotopically heterogeneous dust grains are inhomogeneously distributed in the initial molecular cloud core; especially, ^{54}Cr-rich grains are concentrated in the central part of the cloud core. Then, the concentration of ^{54}Cr-rich grains is calculated numerically as a function of the time and the place in the solar nebula. Model parameters are the initial angular velocity of the molecular cloud core omega, which determines the size of growing solar nebula, and the strength of the gas turbulence in the solar nebula alpha, which controls the radial flow of the gas and the diffusive motion of dust grains. The mass infall from the molecular cloud core lasts 0.4 Myr.

Results: A typical result is as follows. When omega = 3×10^{-15} s^{-1} and alpha = 10^{-4}, in the early phase (< 0.4 Myr), the concentration decreases as time because the infall of new dust grains from the cloud core dilutes the concentration of ^{54}Cr rich dust grains. Later (> 0.4 Myr), the concentration increases because of the diffusive motion in the nebula. These features are consistent with observations [1, 2].

Summary: We examined the possibility that an inhomogeneous molecular cloud core could generate the inhomogeneous and time dependent distribution of ^{54}Cr-rich dust grains in the asteroid belt. We found that indeed the mechanism may work. The isotope anomalies may be caused by the inhomogeneous initial molecular cloud and by the incomplete mixing of dust grains in the solar nebula.

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Keywords: Isotopic Anomaly, Solar Nebula

Effect of carbon grain destruction on chemical structure in protoplanetary disks

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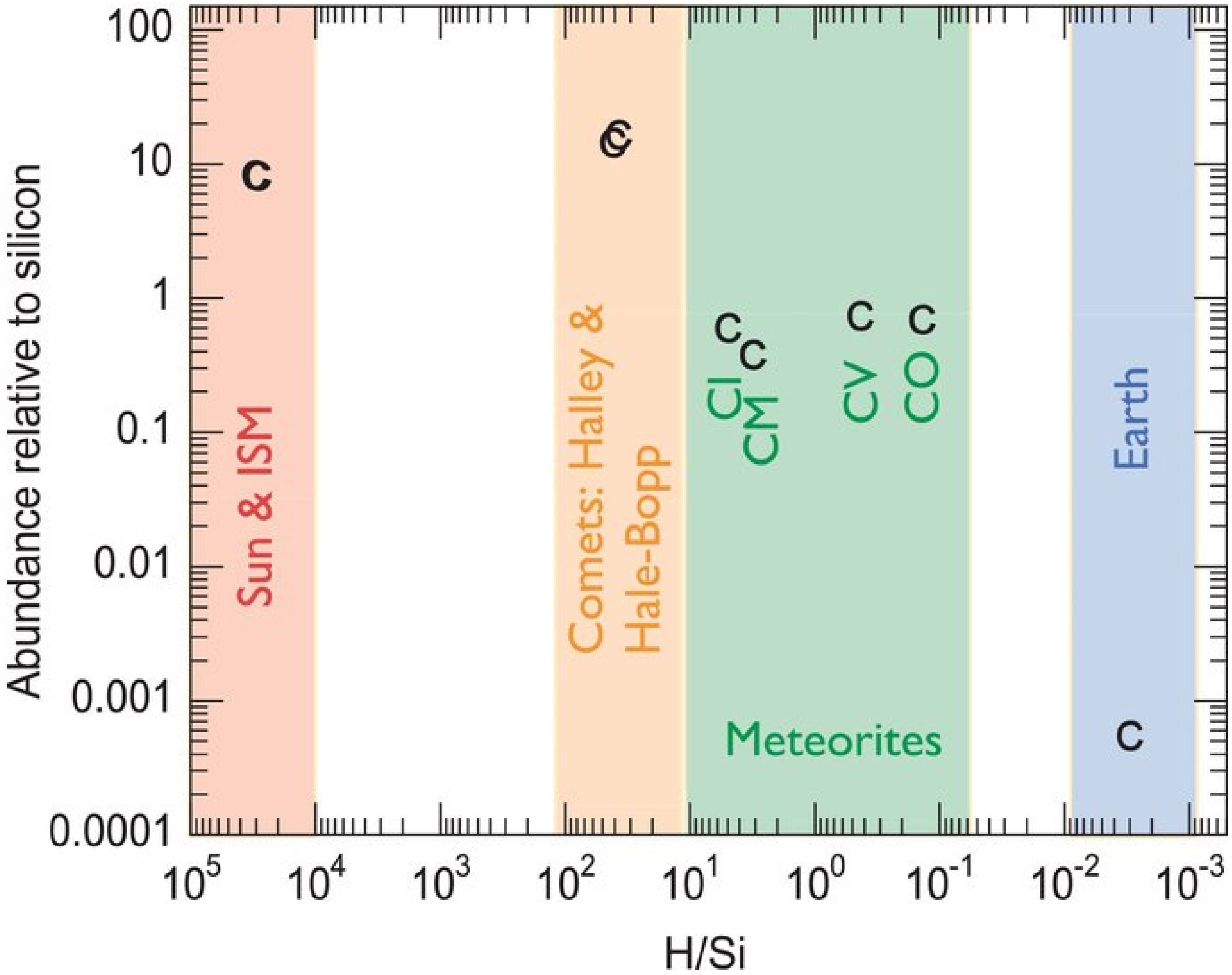
The bulk composition of Earth is dramatically carbon poor compared to that of the interstellar medium, and this tendency extends to the asteroid belt. There is a gradient in the amounts of condensed carbon relative to silicate.

Based on Lee et al. (2010), we calculate the molecular abundances in the protoplanetary disk using chemical reaction network, taking into account of carbon grain destruction in the inner disk. In this study, we consider two kinds of gas-phase abundances of carbon as initial condition. First, the normal abundance of Taurus molecular cloud, where oxygen abundance is larger than carbon abundance, is assumed. Second, we considered that all the carbon in the grain are sputtered into gas-phase, and thus the abundance of carbon is larger than that of oxygen. We compared the molecular abundances at different distance from the central star and find the differences between two initial conditions. Furthermore, we calculate the fraction of carbon in/on grains at different radii of the disk in order to understand the gradient of condensed carbon in our solar system.

Keywords: protoplanetary disk, chemical network, carbon depletion


Abundance relative to silicon
100
10
1
0.1
0.01
0.001
0.0001
Sun & ISM
Comets: Halley & Hale-Bopp
CI
CM
CV
CO
Meteorites
Earth
C
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
H/Si

Understanding Molecular Oxygen in Cometary Atmospheres

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The Rosetta spacecraft discovered molecular oxygen during its orbiting of comet 67P Churyumov-Gerasimenko [Bieler et al., Nature 526, 678-681 (2015)]. Based on previous ground-based cometary observations, this was an unexpected finding, as was the significant amount of O_2 detected. The average value of $[O_2]/[H_2O]$ reported by Rosetta was 0.038, with a range of 0.01-0.10. Previous cometary ground-based measurements have relied on optical measurements, whereas the Rosetta study utilized mass spectroscopy.

We have initiated a research program to investigate optical spectra from various comets for evidence of molecular oxygen. Such emission from comets has not been reported previously, but there are compelling reasons for its presence in light of the Rosetta results. In contrast to the situation with molecular oxygen, the presence of atomic oxygen in cometary atmospheres is well established, with both $O(^1D)$ and $O(^1S)$ known emitters that give rise to the green and red emission lines. Nevertheless, it it is generally assumed that their source is photodissociation of CO_2, H_2O, and other oxygen-bearing species. Based on the most recent results by the Rosetta mission, photodissociation of O_2 itself becomes a viable source of $O(^1D)$, which is produced over a large spectral region, 130 to 175 nm.

This type of information has profound consequences for the understanding of cometary formation and the evolution of our solar system. This research also impacts future studies of extrasolar planets. Optical techniques will be the only means for studying *in situ* exoplanet atmospheres, at least in the short term, and thus it is critical to resolve the present conundrum.

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Keywords: comets, cometary atmospheres, oxygen airglow

Kilometer-sized trans-Neptunian objects revealed by OASES

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Organized Autotelescopes for Serendipitous Event Survey (OASES) is an optical observation project that aims to detect and investigate stellar occultation events by kilometer-sized trans-Neptunian objects (TNOs). The abundance and the size distribution of the kilometer-sized TNOs is thought to provide fundamental knowledge of the accretion processes from the early stages of the outer solar system. However, they are extremely faint and are impossible to detect directly even with 8-m˜10-m aperture telescopes. Instead of the direct detection, a monitoring observation of stellar occultation events is one of the possible ways to estimate the abundance and the size distributions of the kilometer-sized TNOs. Since stellar occultations by the TNOs are very rare (lower event rate than 10^{-2} events per year per star) and short duration (shorter than one second) events, a lot of stars must be monitored simultaneously with a sampling cadence much higher than general optical observation instruments. We thus developed multiple low-cost observation systems for wide-field and high-speed photometry. The observation system consists of commercial off-the-shelf 0.28 m aperture f/1.58 optics providing a 2.3 ×1.8 square-degree field of view and a commercial CMOS camera obtaining full-frame imaging with a frame rate greater than 10 Hz. This project currently exploits two observation systems, which are installed in Miyako island, Okinawa, Japan. Owing to the recent improving CMOS technology of high-speed imaging and low readout noise, the observation system is capable of monitoring ˜2000 stars at the Galactic plane simultaneously with V-band magnitudes down to ˜13.0, providing ˜20% photometric precisions in light curves with a sampling cadence of 15.4 Hz. The OASES two observation systems are therefore executing coordinated monitoring observations of a dense stellar field in order to detect the occultations by the kilometer-sized TNOs for the first time.

Keywords: trans-Neptunian objects, Kuiper Belt , remote sensing by telescopes

Lyman α imagings of comet 67P/Churyumov-Gerasimenko by the PROCYON/LAICA

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Water production rate of a comet is one of the fundamental parameters to understand not only the cometary activity when a comet approaches the Sun within 2.5 AU but also the formation processes of molecules that were incorporated into comets formed in the early Solar System.
Comet 67P/Churyumov-Gerasimenko (hereafter 67P/C-G) is a Jupiter-family comet with an orbital period of ~6.5 years. Because the comet during the apparition in 2015 was a target of ESA’s Rosetta mission, comet 67P/C-G was the most interesting comet. By the Rosetta spacecraft along with Philae lander, various kinds of observations of the comet were carried out from close to the surface of the nucleus for more than two years including its perihelion passage on 2015 August 13. However, observation of the entire coma was difficult by the Rosetta spacecraft because the spacecraft was located in the cometary coma. An estimated water production rate strongly depends on physical models of the coma, notably depend on the asymmetry of the coma and nucleus of the comet.
To derive an absolute water production rate of the comet, wide-field imaging observations of the hydrogen Lyman α emission in comet 67P/C-G were carried out by the Lyman Alpha Imaging CAmera (LAICA) on board the 50 kg-class micro spacecraft, the PROCYON on UT 2015 September 7.40, 12.37, and 13.17. Our observational dates correspond to 25, 30, 31 days after the perihelion passage of the comet. We derived the water production rates of the comet from Lyman α fluxes of the comet by using a two-dimensional axi-symmetric Direct Simulation Monte-Carlo (DSMC) model of atomic hydrogen coma. Derived water production rates, $(1.46 \pm 0.47)\times 10^{28}$, $(1.24 \pm 0.40)\times 10^{28}$, and $(1.30 \pm 0.42)\times 10^{28}$ moleules s-1 on September 7.40, 12.37, 13.17, respectively, are comparable to the water production rates estimated from *in situ* measurements by the Rosetta instruments based on the coma model of the comet.
We discuss about and secular change of water production rate, and also suggest an importance of observations with small satellites.

Keywords: Comet, 67P/Churyumov-Gerasimenko, PROCYON micro spacecraft for deep space exploration, LAICA telescope

THE ROLE OF ELECTRON DYNAMICS IN THE SOLAR WIND INTERACTION WITH COMET 67P/CHURYUMOV-GERASIMENKO AT 3 AU

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ESA’s Rosetta orbiter spacecraft escorted comet 67P/Churyumov-Gerasimenko for almost two years, carrying 21 scientific instruments. Five of those were dedicated to plasma measurements. The mission revealed for the first time, and in unprecedented detail, the fascinating evolution of the former Kuiper Belt object as it races along its 6.45yr elliptical orbit around the Sun [1]. Using a self-consistent 3-D fully kinetic electromagnetic particle-in-cell approach [2-3], we focus on the global cometary environment and, in particular, on the collisionless electron-kinetic interaction. We include cometary ions and electrons produced by the ionization of the outgassing cometary atmosphere in addition to the solar wind ion and electron plasma flow. We approximate mass-loading of the cold cometary ion and electron populations using a 1/r relation with distance to the comet with a total neutral production rate of $Q = 10^{26}\ s^{-1}$ [4-5]. Our simulation results disentangle for the first time the kinetic ion and electron dynamics of the solar wind interaction with a weakly outgassing comet. The simulated global structure of the solar wind - comet interaction confirms the results reported in hybrid simulations of the induced cometary magnetosphere [6-8]. We show that cometary and solar wind electrons neutralize the solar wind protons and cometary ions, respectively, in the region of influence around the comet, representing to first order a four-fluid behavior [9]. Analyzing ion and electron energy distribution functions, and comparing with plasma measurements from ESA's Rosetta mission to comet 67P/Churyumov-Gerasimenko, we conclude that a detailed kinetic treatment of the electron dynamics is critical to fully capture the complex physics of mass-loading plasmas [10].

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Keywords: Comets, Rosetta, 67P/Churyumov-Gerasimenko, particle-in-cell simulations, Electron dynamics

Polarimetric Study of (331471) 1984 QY1, a Potential Dormant Comet Candidate

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Identification between asteroids and comets are fundamental to know the spatial distribution of small bodies in the solar system, and yet, it is challenging to find dormant comets in the list of known asteroids because their appearances are indistinguishable from asteroids. Here we provide a unique research to discriminate asteroids and dormant comets via ‘polarimetry’. We thus conducted a polarimetric observation of (331471) 1984 QY1 (hereafter QY1) using the Multi-Spectral Imager (MSI) on the 1.6-m Pirka Telescope from UT 2016 May 25 to June 24. The object has been regarded as a dormant comet candidate in terms of the dynamical property (i.e. the Tisserand parameter with respect to Jupiter T_J = 2.68, the probability of Jupiter-comet origin P_{JFC} = 96 %; Bottke et al. 2002). We investigated the phase angle dependence of polarization degree of QY1, and found that it shows the polarization degree P_{max} = 7.4 +/- 0.2 % around the phase angle α = 100 degree. The polarimetric property is similar to those of S-type asteroids rather than cometary nuclei. In this presentation, we introduce our observation and discuss about the possible origin of QY1 based on our observation together with the dynamical properties.

Keywords: asteroid, polarimetry, potential dormant comet

Meteor shower Forecast - Orbital Calculation of Cometary Dust Trails

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Meteor is a plasma emission that occurs when interplanetary dust called meteoroid enters the Earth's atmosphere. Meteoroids are thought to originate from asteroids and comets.mm-sized meteoroids ejected by a comet generate a meteoroid stream called dust trails, and when they intersect with the Earth’s orbit they can create meteor showers. Every time a comet returns to the sun, a large amount of dust is released with gas and a new dust trails is formed. Furthermore the orbit of the dust trails changes complicatedly due to gravity perturbations by planets, dwarf planets, moon. We can predict the appearance of meteor shower by calculating the orbit of dust and considering the intersection condition with the earth orbit. Meteor shower forecast can provide the date and time when dust trails encounter with the Earth’s orbit. We performed orbital calculations of dust trails formed by comet 109P/Swift-Tuttle, the parent body of Perseid meteor shower. In this study, the maximum of the 2016 Perseids is successfully predicted by our 1D orbital calculation and 2D orbital calculation model which are comparable to optical observational result. 1D orbital calculation supposes that dusts are emitted when comet is in perihelion (2D orbital calculation: perihelion and surroundings). Our new 4D orbital calculation model is also discussed. This calculation supposes that dusts are emitted from the comet in three axial directions. Three axial directions are progress direction of comet, radial direction and perpendicular to the orbital plane (1D and 2D orbital calculation consider only progress direction of comet). And, ejection velocity of dust in 2D orbital calculation and 4D orbital calculation was compared. We found that there was a difference in ejection velocity.

Keywords: comets, meteor shower, dust trails

4-D dust trail calculations of 1998 Bootid outburst and 1972 Giacobinid absence

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June Bootid out bursted in 1998, but its mechanism has not been known well. We made the first 4-D dust trail calculation for the meteor shower and revealed that several duat trails yielded in the 19th century close encounterd to the earth to show the meteors. The minimum velocity ejected from 7P/Pons-Winnecke is 10 m/s, and the peak time and the arc of the activity can be explained clearly. Also, the 4-D duat trail calculation revealed the mechanism of 1972 Giacobinid. Giacobinid was expected to show the activity in 1972 but almost no activity. This is because that the minimum ejection velocity from the parent comet was 60m/s which is over the sublimation velocity of H_2O.

Keywords: Bootid, Giacobinid, dust trail theory

Conceptual Study of Small Active Seismic Exploration Package on Moons and Small Bodies

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Seismic exploration is a powerful tool to probe inner structure of planetary bodies. Developing a seismic observation package that is compatible with small to middle size spacecraft will open a new window to investigate deep interior of planetary bodies including asteroids and small satellites such as Phobos. We have been designing and developing a seismic observation package with 3 axes seismometers, active seismic source and anchoring system. This was originally designed for Japanese Martian Moons eXploration (MMX) Mission. We were not selected for the nominal payload but the selection process of optional instruments is still ongoing. Here we will present the basic concept of our seismic observation package and describe each subsystem. The seismic observation package consists of 3 components, a seismometer, an active seismic source, and an anchoring mechanism. The seismometer is based on a short period sensor that was designed for Japanese Lunar A mission. In addition to the previous design, we are developing a new feedback for higher sensitivity at lower frequencies. Current sensitivity of the SP seismometer decrease below 1 Hz but with new feedback, the sensitivity stays high down to 0.1 Hz. The active seismic source is designed so that we can control the generated waveform. This is a well-developed method in terrestrial seismology known as ACROSS (Accurately Controlled Routinely Operated Signal System). By controlling the waveform of the seismic source we can search for the reflected signal through cross correlation method. The anchoring mechanism will be necessary especially on low gravity condition. One of the major problems in planetary seismic observation is the coupling between the instruments and the ground. This will be an important issue especially for active seismic source. We will describe results of our conceptual study of the seismic observation package and discuss the possibilities of future space missions.

Keywords: Small bodies, Planetary Exploration, Seismology

Orbit and Size Distribution of Faint Meteors by MU Radar and Highsensitive Cameras

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Solar system small bodies ranging between 10-15 and 1015g are continuously colliding with the Earth. Majority of them are so called meteoroids or IDPs (Interplanetary Dust Particles) whose diameters are estimated between 10 and several 100 μm. It is indicated by ground-based optical and radar observations or in-situ measurements that a daily mass influx of meteoroids is ranging from 100 to 300 tones. However, it is still a matter of determining size distributions of influx meteoroids and finding parent bodies of them, while parent bodies of major meteor showers have been identified as comets or dormant comets. Their physical and chemical aspects such as orbits, composition and structure are also poorly known. The influx rate of interplanetary dusts onto the Earth’s surface is essential for the human space activities. Thus, it is also very important to investigate influx rate, orbits and mechanical strength of meteoroids.
High power large aperture (HPLA) radar observations have enabled to provide information on individual meteoroids’ orbits, their influx and ablation processes in the upper atmosphere. The meteor head echo observation has been carried out using the middle and upper atmosphere radar (MU radar) of Kyoto University at Shigaraki (34.9N, 136.1S), which is large atmospheric VHF radar with 46.5 MHz frequency, 1 MW output transmission power and 8330 m2 aperture array antenna. We have revolutionary achieved to determine the most precise orbits of approximately 180,000 meteoroids observed between 2009 and 2016. In order to investigate the size distribution of these meteoroids, simultaneous observations using MU radar and high-sensitive optical observations, about 9th limiting magnitude, were achieved to obtain the relationship between Radar Cross Section (RCS) and visual magnitude that can provide the size of meteoroids.
This paper describes size distributions and orbital parameters of faint meteors observed by MU radar and a high-sentive camera (limiting magnitude˜9th).

Keywords: Meteors, Meteoroids, Dusts, Asteroids, Comets

Oxidation processes of I-type spherules during atmospheric entry

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Oxygen isotope fractionation of atmospheric O_2 ($\delta^{18}O$ ~ 23.5‰) from ocean water (0‰) [1] is explained by photosynthesis and respiration of terrestrial biomes (Dole-Morita effect; [2-3]). One can expect that temporal variation of terrestrial biomass has been reflected in temporal $\delta^{18}O$ variation of atmospheric O_2, which may be recorded in iron-oxide rich cosmic spherules (I-type CSs) that were originally extraterrestrial FeNi metal and oxidized in the upper atmosphere upon entry. In this study, we analyzed oxygen isotope ratios of I-type CSs using ion microprobe in order to understand oxidation processes of I-type CSs.

Samples in this study are Antarctic I-type CSs and 3 iron-oxide spherules (MRs) artificially produced by melting of metallic iron powder. 9 CSs that show none or low Cr contents and contain coarse magnetite/wustite grains were selected and analyzed for oxygen isotopes using IMS-7f at Tohoku University. The analytical conditions were similar to those in [4].

The polished surface of the samples consists of wustite and magnetite. 4 out of 9 CSs are extraterrestrial in origin, given the low Cr_2O_3 contents (<0.2wt%). The $\delta^{18}O$ and $\delta^{17}O$ values of CSs and MRs plot on the terrestrial fractionation line with a slope of 1/2, indicating that oxygen isotope ratios of CSs reflect terrestrial ones. Similarly to deep-sea CSs (400-600 μm in diameter) [5], the $\delta^{18}O$ values of ~40‰ from 4 CSs (~100 μm in diameter) are higher than that of atmospheric O_2, suggesting oxygen isotope fractionation due to evaporation during atmospheric entry heating. But unlike the previous study [5], there is no correlation between radii of CSs and $\delta^{18}O$, suggesting that oxygen isotope fractionation requires factors besides particle radius. The $\delta^{18}O$ values of MRs are low at from 1‰ to 17‰ and similar to those of iron meteorite fusion crust [6], which are explained by kinetic isotope effect. It is suggested that MRs did not experience significant isotopic mass fractionation via evaporation and/or affected by adsorbed H_2O (~ 0‰) on metallic iron powder.

We performed numerical simulations of oxygen isotope fractionation during atmospheric entry heating of a FeO spherule with $\delta^{18}O$ of 15‰ by changing entry velocity, entry angle and initial radius based on the data in [7]. It is suggested from the comparison between results of simulation and measured CS data that entry velocity and angle besides particle radius may be the key factor for degree of oxygen isotope fractionation due to evaporation during atmospheric entry. The similar $\delta^{18}O$ values and different sizes between CSs in this study and those in [5] may be explained by difference in entry velocity (14-18km/s vs. 12km/s).

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Keywords: cosmic spherules, oxygen isotope ratios, isotope fractionation

Visualization of Near-Infrared Spectral Data of Eros Using the Small Body Mapping Tool

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One of the primary drivers for many missions visiting asteroids is to advance our understanding of their composition beyond what can be (and is) already measured by telescopes. Without sample return or lander missions, this task relies primarily on resolved near-infrared spectroscopic measurements. Scientific analysis using spectral data collected by point spectrometers is not as straightforward as for imaging spectrometers, where the local spatial context is immediately available. In the case of Eros and other highly non-spherical bodies, this problem becomes even more severe when trying to locate spectra that cross a mapped feature that bends over an irregularly shaped surface. Thus, it is often the case that outside of the mission teams, few from the community at large delve into these data sets, as they lack the tools necessary to incorporate the spectral information into geological analyses of the asteroids. Ultimately, we seek to make such spectral datasets, which NASA has invested significant amounts of money to obtain, more widely accessible and user-friendly. The Small Body Mapping Tool (SBMT) is a Java-based, interactive, three-dimensional visualization tool written and developed at APL to map and analyze features on irregularly shaped solar system bodies. The SBMT can be used to locate and then “drape” spacecraft images, spectra, and laser altimetry around the shape model of such bodies. It provides a means for rapid identification of available data in a region of interest and allows features to be mapped directly onto the shape model. The program allows the free rotation of a shape model (including any overlain data) in all directions, so that the correlation and distribution of mapped features can be easily and globally observed.

We will present the results of our work on the NEAR/Near-Infrared Spectrograph (NIS) data, including improvements to the calibration made by using the geometric information provided by the SBMT and improvements to the SBMT itself to allow spectral visualization, manipulation, and analysis of these data in a spatial context.

Keywords: IR Spectroscopy, Asteroid, Mapping, Eros

Numerical simulation on the albedo of rough surfaces

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The bond albedo, or energy reflectance, is one of the most important physical parameters because it decides the thermal evolution of the surface. However the bond albedo could change with the roughness of the surface. Although the Hapke's parameter is often introduced to represent the effect of roughness on the phase function, the parameter is not straightforward.

We developed a new numerical model to simulate the image of a rough surface and by using the model calculated the bond albedo of the rough surface.
According to our model, even for the case with Lambertian polygons the bulk bond albedo depends not only on the roughness of the surface but also on the solar incident angle, because of heterogeneous distribution of irradiated area. In this presentation we will propose a new equation to calculate the bond albedo of a rough surface.

Keywords: albedo, rough surface, thermal evolution

Capability of Photoscan, a commercial implementation of the Structure from Motion technique, for Asteroid Shape Reconstruction

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Shape model reconstruction of asteroids from images take is important to control the spacecraft safely and scientific analysis of the asteroid exploration missions including Hayabusa2. Mori (2014) evaluated the capability of Bundler (Snavely, 2006), an implementation of structure from motion, in the asteroid shape reconstruction from images of explorer missions. However, Bundler has problems on robustness and stable processing. Agisoft Photoscan, a commercial implementation of structure from motion, is a possible alternate of Bundler. Photoscan is widely used in the geoscience research field. We evaluate the capability of Photoscan for asteroid shape reconstruction in Hayabusa2. We used image sets chosen from the asteroid Itokawa data set taken by Hayabusa as input images and the Itokawa's shape model reconstructed by Gaskell (2006) as the reference model. They are the same as those used by Mori (2014). We also follow his work on the evaluation scheme. Through our test, Photoscan successes to reconstruct the Itokawa’ s shape even from a dataset with a limited number of images, with which Bundler failed. Photoscan results also show stable accuracies in such cases. Robustness and stability of Photoscan are superior to those of Bundler. We conclude that Photoscan has enough capability for asteroid shape reconstruction.

Keywords: asteroid, shape reconstruction, Structure from Motion, Hayabusa2

Color and albedo on the Ceres surface from Dawn Framing Camera images

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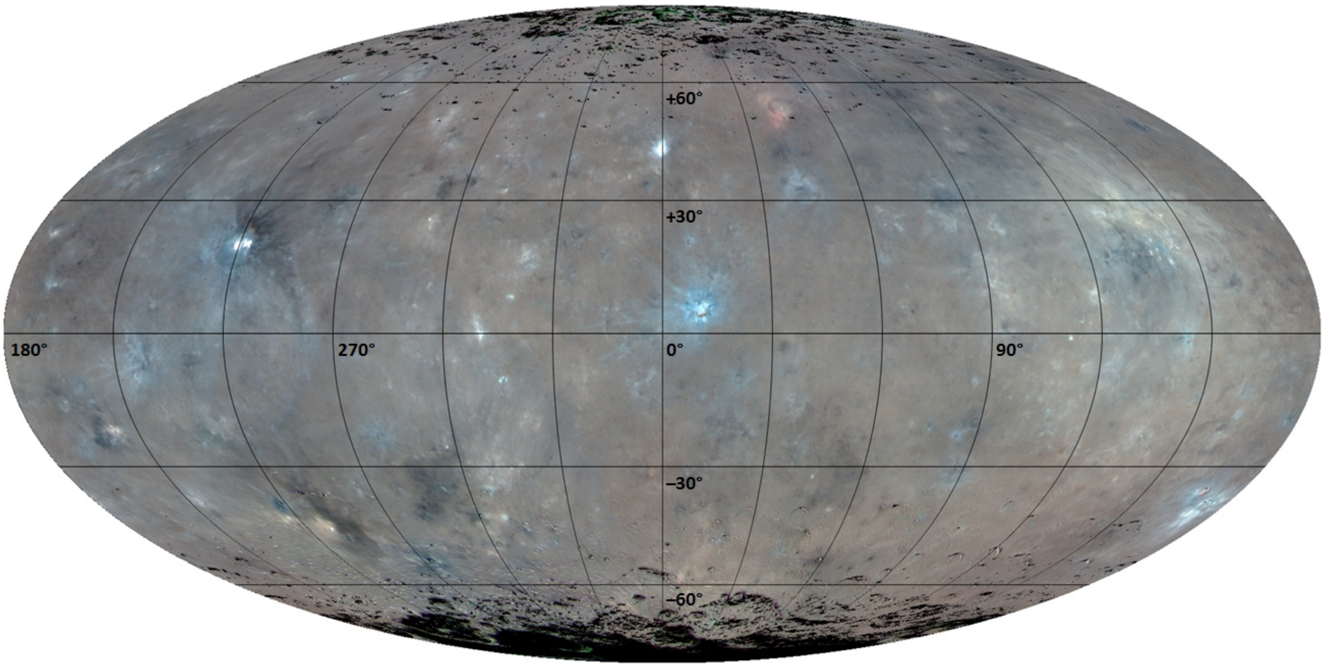
We present a global spectrophotometric characterization of the surface of dwarf planet Ceres using Dawn Framing Camera images. We employed a global photometric model to assemble photometrically corrected images acquired on approach to Ceres into global maps of albedo and color. An accumulating body of evidence suggests water ice is abundant below the Ceres surface. Water ice is not stable on the surface, yet has been directly detected in Oxo crater (Combe et al. 2016). Water may even exist in liquid form in the interior. Carbonates identified in the very bright and young Cerealia Facula in Occator crater suggest (past) hydrothermal activity (De Sanctis et al. 2016). We search for spectrophotometric evidence for water ice and hydrothermal activity in the visible wavelength range. Even though colors on Ceres are generally subdued, this small world is surprisingly colorful. The dominant color variation over the surface is represented by "blue" and "red" material, which have a negative and positive spectral visible slope, respectively. Blue terrain is widespread and often distributed in and around fresh craters. A clear correlation between blue color and youth exists (Schmedemann et al. 2016). One of the bluest, and possibly youngest, craters is Haulani, which may show evidence for cryovolcanic flows (Krohn et al. 2016). The blue color may be associated with dehydrated phyllosilicates (Schröder et al. 2017), although alternative explanations have been proposed (Stephan et al. 2017). On the other hand, red terrain is found in only a few locations, usually in small patches. The prime examples are found inside Occator crater and around Ernutet crater (Nathues et al. 2016, Schröder et al. 2017). The reddest terrain in Occator is found in the youngest parts of Cerealia Facula, and may be associated with hydrothermal activity. The origin of the red terrain near Ernutet has not yet been established. Our color and albedo maps allow us to identify sites of interest that we study in more detail using color images acquired at higher resolution.

Keywords: Ceres, surface, spectrophotometry


+60°
+30°
180°
270°
0°
90°
–30°
–60°

Surficial mineralogy of dwarf planet Ceres

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The Dawn spacecraft has been acquiring data on dwarf planet Ceres since January 2015 (1). The VIR spectrometer (0.25-5.0 μm) acquired data at different altitudes providing information on the composition of the surface of Ceres at resolutions ranging from few kilometers to about one hundred meters (2).
The average spectrum of Ceres acquired by VIR is well represented by a mixture of dark minerals, Mg-phyllosilicates, ammoniated clays, and Mg- carbonates (3). This result confirms and extends previous studies based on ground based spectra. Mg- phyllosilicates have been associated with the 2.72 μm absorption band precluded from telescopic measurements owing to the atmospheric absorptions. The ammoniated clays have been identified through the presence of an absorption feature centered at 3.06 μm as already suggested by (4) while the 3.9 μm absorption feature is indicative of the presence of carbonates as previously concluded by (5). Maps of the surface at about 1 km/px show that the components identified in the average spectrum are present all across the surface with variations in their relative abundance (6). Some localized areas however have peculiar spectral characteristics. One example is the spectrum of the bright faculae within Occator crater that is most consistent with a large amount of Na-carbonates and possibly ammonium salts (7). In addition, water ice has been detected on the surface (8) and organic rich regions have been identified in some localized areas across the surface (9). The retrieved composition indicates a pervasive aqueous alteration and at least localized hydrothermal activity of the surface of Ceres. In addition, the co-existence of ammonia-bearing hydrated minerals, water ice, carbonates, and organic material indicates a complex chemical environment that could allow the formation of prebiotic molecules making Ceres a primary target for exobiological studies.

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Keywords: Ceres, Dawn, VIS-IR spectroscopy, small bodies, asteroids, mineralogy

DETERMINING THE EFFECT OF INTERSTITIAL NEAR-SURFACE GROUND ICE ON THE MOBILITY OF LAYERED EJECTA DEPOSITS ON CERES

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During the Survey, High Altitude Mapping Orbit, and Low Altitude Mapping Orbit phases of the primary mission Dawn’s Framing Camera observed a multitude of globally distributed lobate deposits. These flows were broadly interpreted as either similar to ice-cored/ice-cemented flows (Type 1 flows) on Earth and Mars, long run-out terrestrial or martian landslides (Type 2 flows), or highly mobile fluidized ejecta-like deposits (Type 3 flows) (Schmidt et al., 2016; Buczckowski et al., 2016; Schmidt et al., *Accepted*). The Type 3 flows are morphologically similar to fluidized/layered ejecta found on Mars and Ganymede (Mouginis-Mark, 1979; Boyce et al., 2010). The main structural difference between these putative cerean fluidized ejecta flows and their martian/ganymedean counterparts is that the latter tend to form full aprons around the entire circumference of their parent crater, while the former generally only occur around a fraction of the circumference (usually < 180º) of their parent crater.

Though there exists no consensus on the mode of fluidization for these ejecta deposits on Mars or Ganymede a large number of authors have interpreted the martian variety to be related to the presence of volatiles (particularly water ice) within the regolith target materials (such as Mouginis-Mark, 1979; Carr et al., 1977; Woronow, 1981, Weiss & Head, 2014). We address the hypothesis that the occurrence, morphology, and mobility of Type 3 cerean flows are a result of impact into, and emplacement on, a ground ice rich near-surface layer and that variations in the upper structure of Ceres and/or quantity of ground ice alters the mobility of fluidized ejecta in otherwise similar craters. We do this by cataloguing the global distribution of these flows and making comparisons to elemental abundance and mineralogical data, gathered by Dawn’s Gamma Ray and Neutron Detector and Visible and Infrared Spectrometer respectively. We also quantify the ejecta mobility as a function of crater diameter and latitude. We define ejecta mobility (EM) as the ratio of the radius of the ejecta blanket versus the radius of the parent crater, and compare measured EM values of Cerean flows with various well studied martian analogs. We also measure drop-height-to-runout-length ratios (H/L) and compare them to planetary and experimental analogs of known composition.

We further asses the effect of ground ice as a lubricating agent in the production of these features by comparing the EM values for all Type 3 Cerean flows to a kinematic sliding model similar to the one developed by Weiss et al. (2014) to model the ejecta mobility for impacts into a variety of ground ice rich substrates of differing volatile content on Mars. This model should provide constraints on the relative importance of the effective coefficient of friction of the substrate beneath these flows, as well an independent estimate of the water ice content in the near surface.

Initial results from the global classification campaign suggests that Type 3 cerean flows preferentially occur at low- to mid-latitudes, which could be indicative of preferential creation or preservation at these locations. Measured H/L for these flows plot systematically lower than comparable length landslides on other terrestrial bodies. This reinforces their interpretation as propelled phenomena rather than gravitationally induced mass wasting. Since Ceres lacks any meaningful atmosphere, the morphological differences between Type 3 cerean flows and layered ejecta on Mars should be able to help quantify the role of interstitial gases and fluid drag in the creation of these features.

Keywords: Dawn, Ceres, Ground Ice, Fluidized Ejecta

Simulated Imaging Experiment for Landing Site Selection by Hayabusa2

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The Hayabusa2 spacecraft was launched in 2014 and is expected to arrive at the asteroid Ryugu, which belongs to the C-type asteroids in 2018. One of the objectives of the Hayabusa2 mission is to return with primordial samples from Ryugu. By using reflectance spectroscopy from the ground, Vilas (2008) detected the 700 nm-band absorption of Ryugu, indicating the presence of hydrated minerals. The *Hayabusa2* spacecraft performs multi-band spectrum observation using a telescopic optical navigation camera (ONC-T) with seven bandpass filters, and specifies the point at which the 700 nm absorption feature exists for the landing site selection. Thus, it is important to confirm the detectability of the absorption of 700 nm from multi-band spectral observation. Multi-band spectral imaging was performed using the ONC-T flight model on the carbonaceous chondrites having the similar reflectance spectrum as that of the C-type asteroid (Kameda et al., 2015). The ONC-T is equipped with a wheel containing seven bandpass filters that is rotated to perform multi-band spectrum observation. When the filter wheel is rotated to change the bandpass filters, the field of view of the ONC-T at the Ryugu surface drifts owing to asteroid spin; however, previous research that showed the detectability of the absorption of 700 nm did not simulate the drift of the field of view of each band.
In this study, this effect is confirmed by using a camera that simulates ONC-T.
An experimental system is used in which the x-axis stage is placed beneath the sample holder to simulate the drift of the field of view whereby the camera has the similar CCD and bandpass filters as that of the ONC-T. Multi-band spectral imaging was performed on these carbonaceous chondrites in which the x-axis stage moves with each change the bandpass filter.
Moreover, the amount of drift in the field of view varies depending on the altitudes from the Ryugu surface, which in this study are assumed as 20 km (HP) and 5 km, respectively. Therefore, we measure the reflectance spectra and depth of 700 nm absorption feature in the case of 30 m spatial resolution, which is specified as the region at which hydrated minerals are present.

Keywords: Hayabusa2, Multi-band spectral imaging

Detectability Performance of Thermal Infrared Imager TIR on Hayabusa2

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The thermal infrared imager TIR [1] onboard the JAXA’ s second asteroid explorer Hayabusa2 is a thermal camera based on two-dimensional uncooled micro-bolometer array, inherited from the Longwave Infrared Camera (LIR) on Akatsuki (formerly PLANET-C) Venus climate orbiter [2]. TIR is to observe the thermal emission from the target body, C-type near-Earth asteroid 162173 Ryugu (formerly 1999JU$_3$) to investigate its surface thermo-physical properties that are strongly related to representative grain size and porosity. Such information enables us to understand its formation process and surface evolution processes. The data from TIR will be used to select the landing sites for sample collection and for the surface lander and rovers both from scientific and technical viewpoints. Typical grain size derived from the thermal inertia map determined by TIR data is scientifically essential to select the suitable sites for collection by the sampling device and for the analysis of returned samples. Typical boulder abundance and predicted thermal environments are technically essential for safety and hazard-free landing operations.

TIR has been checked in flight by observations of the deep sky as backgrounds, and of the Earth and the Moon as known targets during the Earth swing-by operation campaign. The first and longest distance observation of the Earth and the Moon was carried out on 14 October 2015, at about 2 x 10^7 km from the Earth. There were opportunities that TIR observed the Earth and the moon 7 times before and 18 times after the Earth Swing-by on 3 December 2015. During that period, the distance changed by two orders of magnitude, and the distance dependency of TIR response is now derived for the thermal brightness of the Earth and the Moon. The dependency is inversely proportional to the square of distance, for the diameter of the Moon corresponding to 0.2 to 6 pixels of TIR images. From this trend, the detection limit (> 10 DN for the target body) is at about 1.5 x 10^8 km for the Moon [3].

This result indicates the possible detection of unknown asteroids closely passing by the Hayabusa2 spacecraft. For the 100 m sized asteroid of C-type (its geometric albedo ~ 0.05), the detection limit (> 10 DN) is estimated about 2 x 10^3 km from the spacecraft. During April to June in 2017, Hayabusa2 will be around the L5 point of the sun-earth Lagrange point, gravitationally meta-stable point, so that unknown small bodies may be detected if they pass within such a distance. Before arrival at asteroid Ryugu which is of rounded shape and with diameter of 0.88 km, it will be detected at 1.5 x 10^4 km distance. Ryugu will be investigated during the approach phase and its light-curve of brightness temperature will be investigated before arrival. Around Ryugu, TIR is estimated to detect small moons encircling Ryugu at Home Position (20 km from the target asteroid) if they have diameter larger than 1 m, and their orbits are traced by continual imags taken with TIR.

Acknowledgments

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Keywords: asteroid exploration, Hayabusa2, Thermo-physical property, thermal infrared imager, thermal inertia

Geometric and Radiometric Calibration of the Thermal Infrared Imager onboard the Hayabusa2 Spacecraft by the Earth Observation

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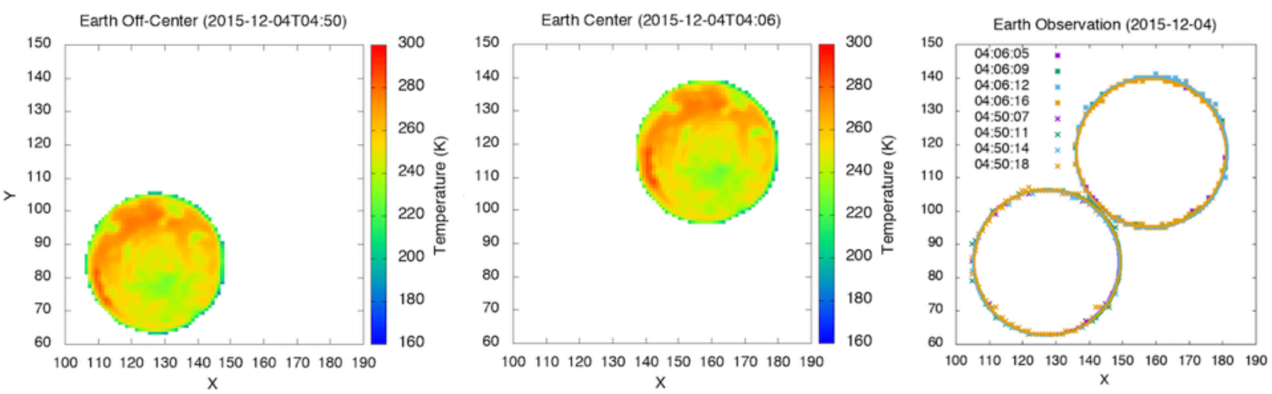
The TIR is an infrared thermal imager onboard the Hayabusa2 spacecraft, which will perform thermography of C-type asteroid 162173 Ryugu through in situ observations during the rendezvous phase in 2018 and 2019. The Hayabusa2 spacecraft carried out an Earth swing-by on December 3, 2015, and the TIR observed the Earth and the Moon for its performance checks. The detector of the TIR is an uncooled microbolometer array (320A, NEC Inc.), and the optical system has a germanium triplet lens. The observation wavelength is an integrated wavelength range of 8 to 12 micrometers. The field of view is 16 x 12 degrees, and the number of image pixels is 328 x 248 (Okada et al., 2016). The performance of the TIR was evaluated in the pre-launch test, and the conversion table from the detected radiation intensity to a brightness temperature was constructed for every pixel. The focal length was evaluated by using a large aperture collimator, as well as the image distortion and the ratio of pixel aperture. Otherwise, the performance check is necessary after launch because the observed temperature depends on surrounding changes, such as radiation and heat flow from the spacecraft and the TIR itself in space. The detector alignment correction and the observed temperature evaluation were performed by the Earth and the Moon observations in the Earth swing-by phase. The alignment was corrected to determine the Earth center position within a sub-pixel accuracy for the observed image pixel by fitting to the observed limb positions using the ellipse function for the flatness shape (6356.75 km / 6378.14 km) calculated by SPICE kernels (NAIF/NASA). The observed temperature evaluation was performed to compare the Earth sea data regarded as a blackbody with observed data with the Earth observation satellites, such as MODIS onboard Aqua and Terra. In this study, the results of the calibrations by the Earth and the Moon observations for the performance checks of the TIR are introduced.

Keywords: Hayabusa2, Thermal Infrared Imager, Earth, Calibration



HEAT: Image and database browser for the thermal imager on Hayabusa2

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Hayabusa2 is a sample return mission to asteroid 162173 Ryugu, which will arrive at the asteroid in 2018. The Thermal Infrared Imager (TIR) on Hayabusa2 performs thermal observations of the asteroid to select sites for a safe touchdown and sample return, and to know the origin and thermal history of the asteroid. Procedures of nominal TIR data analysis are as follows; (1) Metadata of TIR image is collected. (2) Local time of a center of the raw image is solved as a specified longitudinal zone on the shape model. (3) the temporal profile of surface temperature is tagged with individual TIR images and the local time. (4) Thermal inertia of the local site is estimated from the profile. (5) Thermal model based on the thermal inertia is established on the shape model. This report introduces an efficient tool for the TIR to resolve the issues as mentioned above. The developed software includes functions of the calibration database and the visualizing browser, called HEAT: Hayabusa2 Exploration Assistant for the TIR. The HEAT has three specific use: visualization, calibration, and analysis.

Keywords: Hayabusa2, TIR, HEAT, Calibration, Software, Database

Database of observed areas and its visualizer in HARMONICS, Hayabusa/Hayabusa2

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We report a visualization tool HARMONICS (HAyabusa Remote MONItoring and Commanding System) for planning observations and scientific analysis in both Hayabusa and Hayabusa2 missions. This software visualizes positions and attitudes of spacecraft, and FOVs (Field Of View) of scientific instruments. The database of observation history and coverages is established for HARMONICS. Newly additional functions are projection of footprints of scientific instruments and observed images to irregular shape model and the conversion of file format from fits file to jpg, png.

Keywords: HARMONICS, Software, Visualization, Hayabusa2, Exploration, SPICE

Multi-band image analysis of Itokawa and optical properties analysis of Hayabusa2/ONC-T

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Hayabusa2 is planned to bring samples from Ryugu back to the earth. Choosing sampling sites on Ryugu is very important. Sampling fresh materials not affected by space weathering very much is important for obtaining information on early evolution of the Solar System, because space weathering may overwrite record from the long past. In order to understand where on small asteroid we can find fresh materials, we analyzed the data taken by AMICA/Hayabusa. In addition, we analyzed optical characteristic, especially the point spread function (PSF), of the multi-band visible camera (ONC-T) of Hayabusa2 in order to carry out the same spectral analysis of space weathering.

Specifically, we analyzed the following two things.

1. Based on the data taken by Hayabusa, we estimated space weathering on the surface of Itokawa and searched for geometric parameters (HAY-A-AMICA-3-AMICAGEOM-V1.0) that exhibit good correlation with space weathering.

2. In preparation of such data analysis using Hayabusa2 data, we investigated PSF characteristics of Hayabusa2/ONC-T.

First, we conducted image correction for Hayabusa images. We calculated the ratio of light intensity of p-band (860nm) image to b-band (430nm) image (P/B). The ratio represents the degree of space weathering because space weathering caused reddening. We investigated the correlation between the ratio and slope and between the ratio and gravity in order to find out physical characteristics of places unaffected by space weathering.

This analysis was carried out on Sagamihara and MUSES-C. Sagamihara and MUSES-C are smooth areas covered by regolith where safe sampling is possible. We found that the P/B of Sagamihara is larger than that of MUSES -C. That is, MUSES -C is fresher than Sagamihara, although the topographic slope of both areas is small. Furthermore, the surface gravity on Sagamihara is larger than that on MUSES-C. Then, we measured P/B ratio along four lines in both Sagamihara and MUSES-C. For each line, correlation coefficient between ratio P/B and slope and between ratio P/B and gravity was calculated. We found the calculation results indicate that correlation coefficient between P/B and topographic slope is low (~ -0.40) and that between ratio P/B and gravity is high (~0.85). This means that the distribution of space weathering correlates more strongly with gravity than topographic slope. This result suggests that areas with weaker surface gravity would retain regolith particles for longer period of time on Itokawa. Thus, in exploration of small bodies, we should carry out sampling where gravity is weak in order to sample fresh substance relatively unaffected by space weathering.

Second, we analyzed the PSF of Hayabusa2/ONC-T. In our analysis, we approximated PSF as summation of Gaussian functions following Ishiguro (2014). We derived PSF by calculating coefficients of Gaussian function. We made unblurred images by applying edge detection to images for calibration. We reproduced the blurred images by convolving estimated unblurred images with PSF. This procedure was repeated with changing coefficients one by one. We obtained optimum coefficients to make residuals smallest.

First, we calculated PSF correction coefficients of Hayabusa and tried to reproduce the PSF calculated by previous work (Ishiguro 2014). Results indicate that the error between our PSF and the PSF by Ishiguro 2014 was 9.8%. Although this difference in coefficients is not very small, both coefficient sets can remove PSF-derived halos around the asteroid disk very well. The intensity of halo residuals turned out to be only 0.2 - 0.8% of the intensity of the light sources. Then we calculated the PSF correction coefficients of ONC-T/Hayabusa2 by the same procedure. Finally, we correct images taken by Hayabusa2 by using the PSF we calculated. The residuals were less than 1% in all bands, indicating that the same-quality of image analysis as Hayabusa will be possible for Hayabusa2.

Novel method for analyzing ejecta curtain growth of impact crater formed on regolith layer: Implication for impact phenomena made by Hayabusa-2 Small carry-on impactor

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Impact cratering is recognized as an universal phenomenon in the formation and evolution process of the Solar System. The scaling laws for impact cratering are necessary in order to study the evolution of planetary surfaces caused by the impacts of small bodies. By using the scaling laws, we can apply experimental results of cm-sized craters formed in the laboratory to km-sized craters formed on the planetary bodies (e.g., Housen et al., 1983). However, it is necessary to study the gravity effect on the crater formation process. Then, Hayabusa-2 equips a Small Carry-on Impactor (SCI) to launch a copper projectile on the asteroid Ryugu (Saiki et al., 2016). We will observe the crater formation process and the ejecta curtain with a Deployable Camera 3 Digital (DCAM3-D) (Ishibashi et al., 2016, Ogawa et al., 2016). One of the scientific purposes of the ejecta curtain observation by DCAM3-D is to determine the scaling law for the ejecta velocity distribution on Ryugu (Arakawa et al., 2016,. However, it is difficult to deduce the relationships between the ejection velocity and the ejection distance from the successive images of the ejecta curtain. Thus, we are studying to construct the scaling law of the ejecta velocity distribution (Tsujido et al., 2015, Matsue, JPGU 2017), and more, we advocated a new simple theory predicting the ejecta curtain geometry called “Ejecta Curtain Growth (ECG) analysis method” (Arakawa et al., 2016). We can estimate the ejection velocity of the ejecta particle at each initial position using simple equations of ballistic motion, then we obtain an ejecta velocity distribution. Then, we compared the result of the ejecta particle tracking velocimetry (PTV) method with that of ECG analysis method on the quartz sand target (Matsue, JPGU 2017). Finally, we applied the ECG analysis method to the real scale SCI experiments conducted on the ground (Wada et al., 2014) and succeeded to obtain the ejecta velocity scaling law.

Keywords: Ejecta curtain, Hayabusa-2 SCI, Ejecta velocity distribution

MASCOT –a Mobile Lander on-board Hayabusa2 Spacecraft - Operations and Status after Launch

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MASCOT (‘Mobile Asteroid Surface Scout’) is a 10 kg mobile surface science package on board JAXA’ s Hayabusa2 spacecraft, currently on its way to the near-Earth asteroid (162173) Ryugu. MASCOT has been developed by the German Aerospace Center (DLR) in cooperation with the Centre National d’ Etudes Spatiales (CNES). The concept of MASCOT is to perform in-situ measurements on the asteroid’ s surface and to support the Hayabusa2 mission in the sampling site selection. MASCOT is equipped with 4 scientific instruments, a wide angle camera, a hyperspectral IR microscope, a radiometer and a magnetometer. MASCOT is powered by a primary battery which shall enable MASCOT to investigate the asteroid surface for up to 2 asteroid days. An internal mobility mechanism shall relocate MASCOT on the asteroid surface to investigate different landing sites in detail.

MASCOT will be separated at a low altitude above the asteroid surface and its science activities will already start during the descent phase. After touching the asteroid surface MASCOT will bounce across the asteroid surface till it comes to rest. After autonomous self-rightening the scientific surface operations will start. Hayabusa2 will hover above the asteroid surface near the sub-solar point. MASCOT will also operate autonomously without visibility to its mother spacecraft during the asteroid night-time. The MASCOT system and its operational concept are designed to enable an optimum science return within its lifetime, which is driven by the capacity of the battery.

After an intensive development, integration and test campaign MASCOT is now on its way to its target Ryugu. Hayabusa2 launch took place on December 3rd, 2014 from Tanegashima Space Center, Japan. The target asteroid will be reached in summer 2018. Several In-Flight activities like health check and calibration of the scientific instruments have been performed on MASCOT during the past 2.5 years of the 4 years cruise phase. In cooperation with the Hayabusa2 team the MASCOT team is presently planning and testing the on-asteroid phase. First tests of an on-asteroid baseline scenario were performed with a functional-representative MASCOT Ground Reference Model. For environmental tests a MASCOT flight spare model is available.

The presentation will provide an overview of the MASCOT system and its planned operation concept on the asteroid as well an update of MASCOT status and its first operations in cruise.

Keywords: Hayabusa2, MASCOT, (162173 Ryugu)

Present status of curation of the Hayabusa-returned samples and development of the Hayabusa2 curation facility

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The Hayabusa-returned samples are only the regolith samples returned from surface of an asteroid at present on the Earth since its return in 2010 [1]. Their preliminary examination revealed that they were comparable to equilibrated LL chondrites in mineralogy, petrology and chemical and oxygen isotopic compositions [2-4]. The Astromaterial Science Research Group (ASRG) of JAXA has continued their initial descriptions using FE-SEM/EDS without exposing to air, stored them in highly purified N_2 environment and distributed them to the world-wide researchers, as the international announcement of opportunity (AO) for their researches [5]. So far more than 700 of particles have been described by FE-SEM/EDS, and more than 80% of them are Itokawa origin. And more than 160 of them have been distributed during the four times of the international AO. The latest international AO was performed in 2016 and six proposals have been selected for sample allocation. The fifth international AO will start soon in this year.

The Hayabusa2 is heading toward near-Earth C-type asteroid Ryugu, previously named 1999JU3, to reach there in 2018 and try to touchdown onto its surface for sample recovery [6]. It will return the captured samples to the Earth in 2020. The ASRG is now preparing for the curation facility to receive the recovered samples under the supervision of the Hayabusa2 project, the steering committee of the ASRG, and the advisory committee for specifications of the Hayabusa2 curation facility. One cleanroom will be newly constructed next to the one where clean chambers for the Hayabusa returned samples is situated. In the cleanroom, new clean chambers for the curation of Hayabusa2-returned samples have been developed. Because the target body Ryugu is C-type asteroid, which is thought to be related to carbonaceous chondrites, some fraction of samples will be obtained in vacuum condition to avoid terrestrial N_2 contamination to volatile and organic materials in them. After taking some fractions in vacuo, rest of the samples will be processed in highly purified N_2 condition as well as the Hayabusa-returned samples. One of the chamber is for handling mm-size samples, which has different shape from that of μm-size samples. The construction of the new cleanroom will start in this year and all the clean chambers will be set in the middle of 2018. After the establishment of them, their functional checks and then rehearsal for receiving returned samples will be performed until the Hayabusa2 sample return in 2020.

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Keywords: asteroid, sample return, curation, Hayabusa, Hayabusa2

The sample return from the Jupitar Trojan D/P type asteroid.

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Analyses of returned samples from Moon (e.g., New views of the MOON, 2006), asteroid (e.g., Nakamura et al., 2011) and comet (e.g., Brownlee et al., 2006) were essential to understand their origin and nature as well as increasing our knowledge about the Solar System. The most recent returned sample was from the S-type asteroid Itokawa by Hayabusa mission in 2010. The results by series of analyses provided new insights for the connection to meteorite researches, space weathering processes, small asteroidal body formation in the Solar System (e.g., Nakamura et al., 2011; Yurimoto et al., 2011). JAXA Hayabusa 2 and NASA Osiris-REx are both current sample return missions from the organic-rich asteroids, Ryugu (C-type) and Bennu (B-type), respectively (Tachibana et al., 2014; Lauretta et al., 2014). Both missions have complementary scientific goals that are to understand the Solar System evolution in the point of view of organics, water and associated minerals. We, therefore, are working on the possibility of the sample return from Trojan asteroid that is expected to contain primordial chemical information at the very beginning of Solar System formation.
D/P-type Jupiter Trojan asteroids likely consist of dominant of organics (carbonaceous materials) and anhydrous silicates (hydrated silicates cannot be excluded), possibly with water (ice) in its interiors (Guilbert- Lepoutre, 2014). Beside in-situ HRMS analysis of isotopic ratios, elements and molecules in surface and subsurface samples on the Trojan asteroid, analysis of returned samples containing non-volatile materials (organics and minerals) as well as water (ice) will open a new insight of the detailed scientific objectives for the Solar System evolution. Since, in-situ analysis is limited in terms of sample preparations, lack of relationship among components, and mineralogical/petrological contexts, the state-of-the-art microanalysis techniques on the Earth will provide these additional information such as isotopic ratios of individual component (organics and associated minerals), trace amount of gaseous spiecies (e.g., Noble gases, CO, CO2, NH3, CH4 gasses in the ice), and organic compounds that are hard to be detected under the current in-situ HRMS system (e.g., amino acids).
The details of the sample return capsule are not yet fixed but a cryo-system is highly encouraged. Thus, we will receive “extraterrestrial ice (water)” that has a pristine water at the Solar System which contains the information of nebular gas, formation of ice, reservoir of volatiles (water and organics), and the origin of the Earth’s water.
In this talk, we will present the possibility of sample return from the Trojan asteroid by the Solar Power Sail mission.

Keywords: Jupitar Trojan Asteroid, Sample Return

In-Situ Landing Analysis of a Jupiter Trojan Asteroid Using a High Resolution Mass Spectrometer in the Solar Power Sail Mission

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The Solar Power Sail (SPS) mission is one of candidates of the upcoming strategic middle-class space exploration to demonstrate the first outer Solar System journey of Japan. The mission concept includes in-situ analysis of the surface and subsurface (up to 1 m) materials of a Jupiter Trojan asteroid using high resolution mass spectrometry (HRMS). The current mission sequence proposes the launch in late 2020s, and rendezvous to a D or P type Trojan asteroid of ~20-30 km in diameter in 2030s.
The key questions for the Jupiter Trojan asteroid exploration are: (1) constraining planet formation/migration theories, (2) evolution and distribution of volatiles (water and organics) in the Solar System, (3) origin of Earth's water, and (4) surface processes of Jupiter Trojan asteroids.
We plan to analyze volatile materials on the Jupitar Trojan, for their isotopic and elemental compositions using a HRMS with a combination of pyrolysis ovens and gas chromatography (GC) columns. This HRMS system allows to measure H, N, C, O isotopic compositions and elemental compositions of molecules prepared by various pre-MS procedures including stepwise heating up to 600ºC, pyrolysis-GC, and high-temperature pyrolysis with catalyst in order to decompose the samples into simple gaseous molecules (e.g., H_2, CO, and N_2). The required mass resolution should be at least 30,000 for analyzing isotopic ratios (e.g., $H_2{}^{16}O$, $HD^{16}O$ and $H_2{}^{18}O$ for H and O isotopic measurements) for simple gaseous molecules. For elemental compositions of molecules/ions, mass accuracy of ~10 ppm is required to determine elemental compositions for molecules with *m/z* up to 300 (as well as compound specific isotopic compositions for smaller molecules). Our planned analytical sequences consist of three runs for both surface and subsurface samples. In addition, 'sniff mode' which simply introduces environmental gaseous molecules into a HRMS will be done by the system. The details of the analytical methods and apparatus are under developments.

Keywords: Jupiter Trojan Asteroid, Solar Power Sail , Mass spectrometry

Meteoroid Environment Measurement during the Interplanetary Cruising and in the Jupiter Trojan Region by the ALADDIN-2 Dust Detector onboard the Solar Power Sail

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The IKAROS-ALADDIN was the world’ s largest PVDF-based micrometeoroid detector and successfully observed the distribution of >10 micron-sized dust particles between the Earth and Venus orbits in 2010-11. For the Solar Power Sail to Jupiter Trojan asteroids, we have improved the sensor design and signal processing of the dust detector as ” ALADDIN-2” , based on lessons learned from the development and operation of its first generation.
We hereby report current status of these advancements and applications of the ALADDIN-2. At the IKAROS-ALADDIN sensors, stapler-type terminal connectors were employed in combination with stitching by Kevlar threads. For increasing the robustness of terminal connection over a decade of the Solar Power Sail (SPS) mission duration, grommet-type terminal with washer will be used at ALADDIN-2. For better mass estimation of impacting meteoroids, signal integration circuit is added to the ALADDIN-based electronics so that it sums up values of multiple peaks of an impact signal that are related to meteoroid mass and impact velocity. As for the SPS, the ALADDIN-2 sensors of about 4-5 m^2 will be mounted on the sail membrane, i.e., an order of magnitude larger than that of the IKAROS-ALADDIN, for effective detection rate of decreasing meteoroid flux against heliocentric distance. Also slow velocity impacts on the same detectors will be processed their impact signals by a newly dedicated electronics unit for better understanding the meteoroid environment nearby Jupiter TTrojan astetoids after the spacecraft rendezvous. Both hypervelocity and slow velocity impact calibration tests are currently in progress.

Keywords: Micrometeoroids, Hypervelocity Impacts, Circumsolar Dust Ring

Design of a telescopic camera and a multi-band wide-angle camera onboard the Mars Moons Exploration mission

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Design of a telescopic camera and a multi-band wide-angle camera onboard the Mars Moons Exploration mission

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The Japan Aerospace Exploration Agency (JAXA) is planning the Martian Moons Exploration (MMX) mission to reveal the origin of Phobos and Deimos which are satellites of Mars. This mission will observe the two satellites as well as Mars and return samples from Phobos. We designed a telescopic camera (TL) and a multi-band wide-angle camera (WAM), which are installed onboard the MMX spacecraft.
The objective of TL is to reveal the geographical features of Phobos. We must find a flat area for landing point and identify rocks and craters. We designed the telescopic camera with a spatial pixel resolution of 10 cm/pix at the surface of Phobos when the spacecraft is at an altitude of 20 km. This resolution is twenty times higher than that of the telephoto camera (ONC-T) onboard *Hayabusa2*. We also discuss the selection of the focus position and the effect of temperature on the performance of the camera.
The objective of WAM is to determine the distribution of the materials on the surface of Phobos. We cannot get multiband images with the wide-angle camera onboard *Hayabusa2* because it has only a monochrome sensor. Moreover, the ONC-T with seven band-pass filters placed on a wheel results in a fault that its field of view is shifted during wheel rotation when the spacecraft is descending. Therefore, we designed seven wide-angle cameras with narrow band filters to simultaneously take images at all wavelengths. The depth of field of WAM is 1m to infinity such that we can determine the distribution of materials during landing and orbiting around Phobos.
In this presentation, we illustrate the design of these cameras.

Keywords: MMX, Phobos, camera

Observation Plans for Hydrated Minerals and Carbonaceous Materials on Phobos and Deimos by Near-Infrared Hyperspectral Imager MacrOmega

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The Martian Moons Exploration (MMX) is a probe which will be launched by the Japanese launch vehicle H-III and will navigate the quasi satellite orbit of Phobos, and will make a fly-by of Deimos.
NIRS4/MacrOmega is an imaging spectrometer in the wavelength range of 0.9 to 3.6 micrometers which is one of the candidate instruments to be installed on the MMX spacecraft.
It is based on MicrOmega on the ExoMars Rover and Hayabusa2 MASCOT and modified as a hyper-spectral imager with spectroscopic function provided by an Acousto-Optic Tunable Filter (AOTF).
MMX aims to elucidate the evolution of our solar system by investigating the migration process of primitive materials in the early stage. NIRS4/MacrOmega will observe hydroxide or hydrated mineral absorptions on Phobos and Deimos in the wavelength of 2.7-3.2 micrometers. By analyzing the shape of the spectra, we will distinguish between water in hydrous silicate minerals, water molecules, and water ice particles. NIRS4/MacrOmega will also try to detect the absorption by organic matter in the wavelength range of 3.3-3.5 micrometers. These results will support efforts to answer the question of the origin of the Martian satellites, and identify whether they are satellites formed by a giant impact or asteroids captured by Mars.
NIRS4/MacrOmega will observe Phobos to survey the sampling site before sampling, to investigate the sampling site precisely at the touch-down mode, and to make global mapping. Global mapping of Phobos to select prior areas and landing sites will be performed on the quasi satellite orbit at 100 to 200 km in altitude. Precise mapping for candidate landing sites will be followed at about 20 km in altitude. We will also examine the high-resolution observation for selected areas at the orbit lower than 10 km, and precise observations toward blue and red region at the Mars-Phobos Lagrangian points 1 and 2. In the touch down phase, we will observe toward sampling site at full wavelength in the altitude of 20 km to 1 m. Observations for Deimos will be basically executed from the fly-by orbit, and they are examined to be made at the near circular orbit.

Keywords: MMX, Phobos, Deimos, near infrared, hydrated mineral

Elemental analysis using LIBS for Martian Moons Exploration (MMX)

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Phobos and Deimos are the two satellites of Mars. There are two major hypotheses for their origin: asteroid capture [Hunten, 1979] and a giant impact [Rosenblatt et al. 2016]. JAXA's Martian Moons Exploration (MMX) is planned to be a sample return mission from Phobos. One of the main goals of MMX is to determine the origin of the two Martian moons. To determine the origin of the moons, it is necessary for the returned sample to contain information on satellite formation. Therefore, we should identify the uniformity or nonuniformity of the distribution of surface material on Phobos. We can obtain the averaged elemental composition using a gamma-ray and neutron spectrometer (GNS) as the nominal instruments, but the distribution of the elemental composition cannot be obtained with a resolution of about 10 mm. We propose using laser-induced breakdown spectroscopy (LIBS) that can perform an elemental analysis with a spatial resolution of 1 mm at a distance of 1 m or more. Because the MMX operating time is limited to be about 1 hour, a LIBS instrument that can perform measurements in tens of seconds could be suitable onboard MMX.

Understanding the heterogeneity of the materials around the sampling site is important for providing the geological context of the returned sample. Thus, we conducted an experiment to demonstrate that we can determine whether the Phobos surface composition resembles that of Martian meteorites or that of a carbonaceous chondrite in a short time by LIBS. We used a small laser with an output of about 12 mJ/pulse and a wavelength of 1534 nm. For the data acquired with the spectrometer, the range of wavelengths from about 380 nm to 800 nm was used for analysis. The distances between the lens to converge the laser beam and the sample and between the condensing lens of the spectrometer and the sample were both 1.5 m. The effective diameter of the light collection optical system was 20 mm. The samples were placed in a vacuum chamber, which was evacuated to 10^{-3} Pa. We verified the feasibility of the LIBS measurement, including signal-to-noise ratio, under realistic conditions. The samples were Allende (a carbonaceous chondrite), NWA1068 (a Martian meteorite), and Zagami (a Martian meteorite). The samples were irradiated 150 times at each measurement point at a frequency of 10 Hz. The exposure time of the spectrometer was 1 s. We measured 16 points per a sample to obtain the bulk composition of the meteorites. The emission spectra of the major elements, Fe, Ca, Al, Mg, Si, and Ti, were detected in the average spectra of the 16 measurement points. By subtracting the spectra of the Martian meteorites from that of the carbonaceous chondrite, we found that the intensity of the emission lines of Fe and Mg, which are abundant in the Allende meteorite, exhibited positive values. In contrast, the intensity of the emission lines of Al and Ca, which are abundant in the NWA1068 and the Zagami meteorites, exhibited negative values. These results showed that LIBS is able to distinguish between asteroid-like and Martian-like materials.

Next, we evaluated whether LIBS was able to conduct this measurement within the MMX operating time on the surface. It was assumed that the focus adjustment and image acquisition takes 30 s and moving from one measurement point to another takes 20 s. The laser irradiation frequency was assumed to be 2 Hz to reduce electric power consumption. With these times, it required about 35 minutes to conduct the data acquisition as in our experiment (i.e., measuring 16 points with 150 laser irradiations per point). This indicates that LIBS is able to obtain sufficient data within the operating time of the lander. Thus, our results suggest that LIBS can reveal whether Phobos is similar to the asteroids or to Mars.

In this presentation, we will also report on the production of an engineering model and the results of experiments using it.

Keywords: LIBS, Martian Moons Exploration (MMX), in situ analysis

