# 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 = $3\times10^{-15}$ $s^{-1}$ 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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キーワード：Isotopic Anomaly、Solar Nebula
Keywords: Isotopic Anomaly, Solar Nebula

 

# Effect of carbon grain destruction on chemical structure in protoplanetary disks

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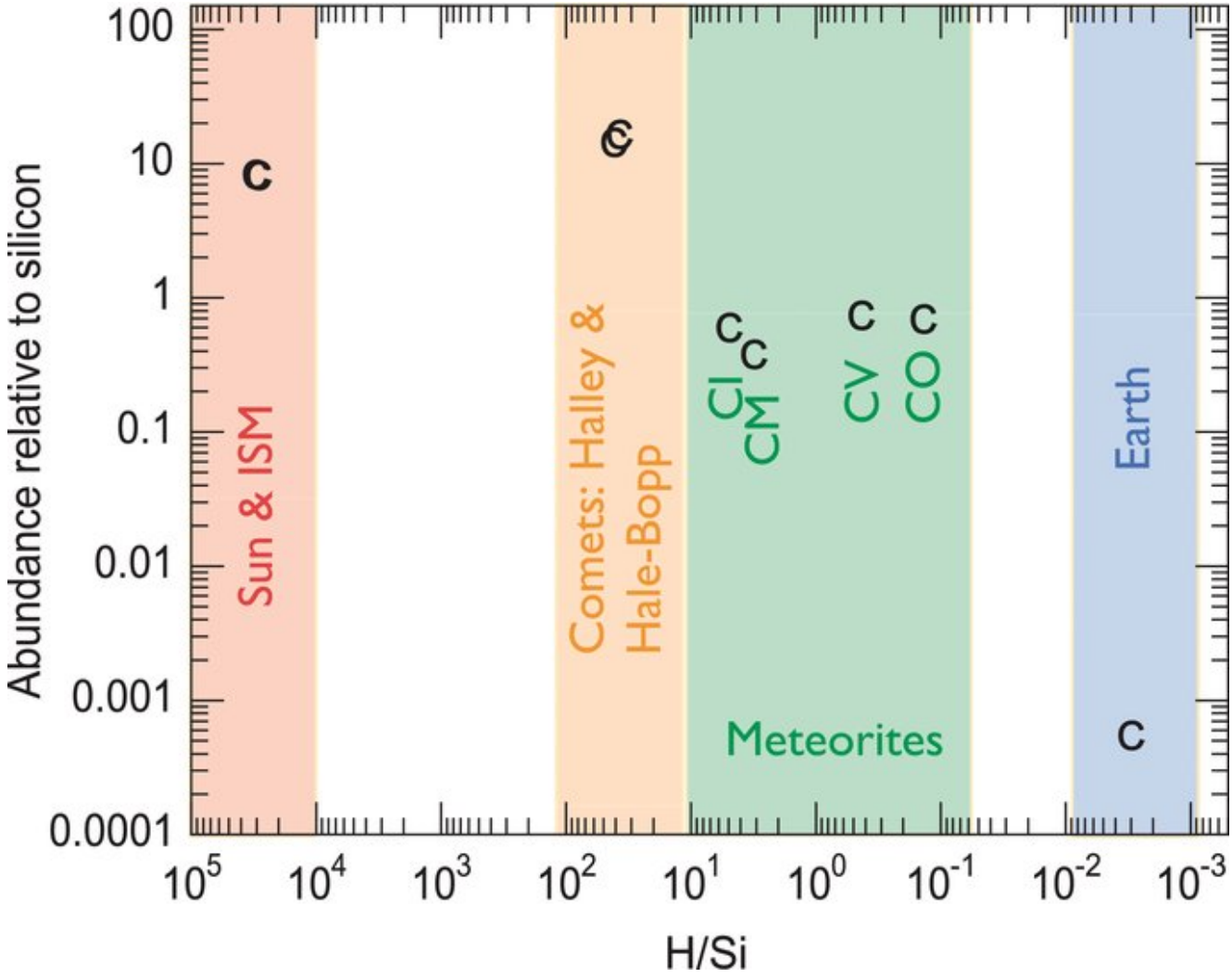
The bulk composition of Earth is dramatically carbon poor compared to that of the interstellar medium, and this tendency extends to the asteroid belt. There is a gradient in the amounts of condensed carbon relative to silicate.

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



# 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.

キーワード：太陽系外縁天体、カイパーベルト、望遠鏡による遠隔観測
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.

キーワード：彗星、67P/Churyumov-Gerasimenko、超小型深宇宙探査機プロキオン、ライカ望遠鏡
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 $\alpha$ = 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

 

# 流星群予報-彗星ダスト・トレイルの軌道計算
# 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.

キーワード：彗星、流星群、ダスト・トレイル
Keywords: comets, meteor shower, dust trails

 

# 1998年うしかい座流星群突発出現と1972年ジャコビニ流星群不発の謎の完全解明
# 4-D dust trail calculations of 1998 Bootid outburst and 1972 Giacobinid absence

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1998年6月に71年ぶりに突然大出現したうしかい座流星群は、日本からヨーロッパ、北米にかけて半日にも及ぶ長時間の出現をしたが、その出現メカニズムはよくわかっていない。今回、世界初の4次元ダストトレール計算により、1998年のうしかい座流星群の突発出現の原因が19世紀に生成された複数のダストトレールの接近によってもたらされたことが判明した。母彗星であるポンス・ビネケ彗星から放出された時の速度は、最も遅いもので10m/sであり、日本で観測された出現ピークの時刻や長時間にわたる活動をよく説明できることがわかった。これは、従来の1次元理論ではできなかった画期的な成果である。

また、この理論を1972年のジャコビニ流星群について適用したところ、ダストの最低放出速度が約60m/sと、$H_2O$の昇華速度を下回らないことがわかり、母彗星から放出されたダストが地球に衝突する軌道に乗れなかったために流星が出現しなかったことがわかった。

キーワード：うしかい座流星群、ジャコビニ流星群、ダストトレール理論
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.

キーワード：小天体、惑星探査、地震学
Keywords: Small bodies, Planetary Exploration, Seismology

 

# MUレーダーと高感度カメラによる微光流星の軌道とサイズ分布
# 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 $10^{15}$g 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 $\mu$m. 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 $m^2$ 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).

キーワード：流星、メテオロイド、ダスト、小惑星、彗星
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 $\mu$m in diameter) [5], the $\delta^{18}O$ values of ~40‰ from 4 CSs (~100 $\mu$m 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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キーワード：溶融宇宙塵、酸素同位体比、同位体分別
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.

キーワード：アルベド、凹凸表面、熱進化
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.

キーワード：小惑星、形状復元、Structure from Motion、はやぶさ2
Keywords: asteroid, shape reconstruction, Structure from Motion, Hayabusa2

 

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

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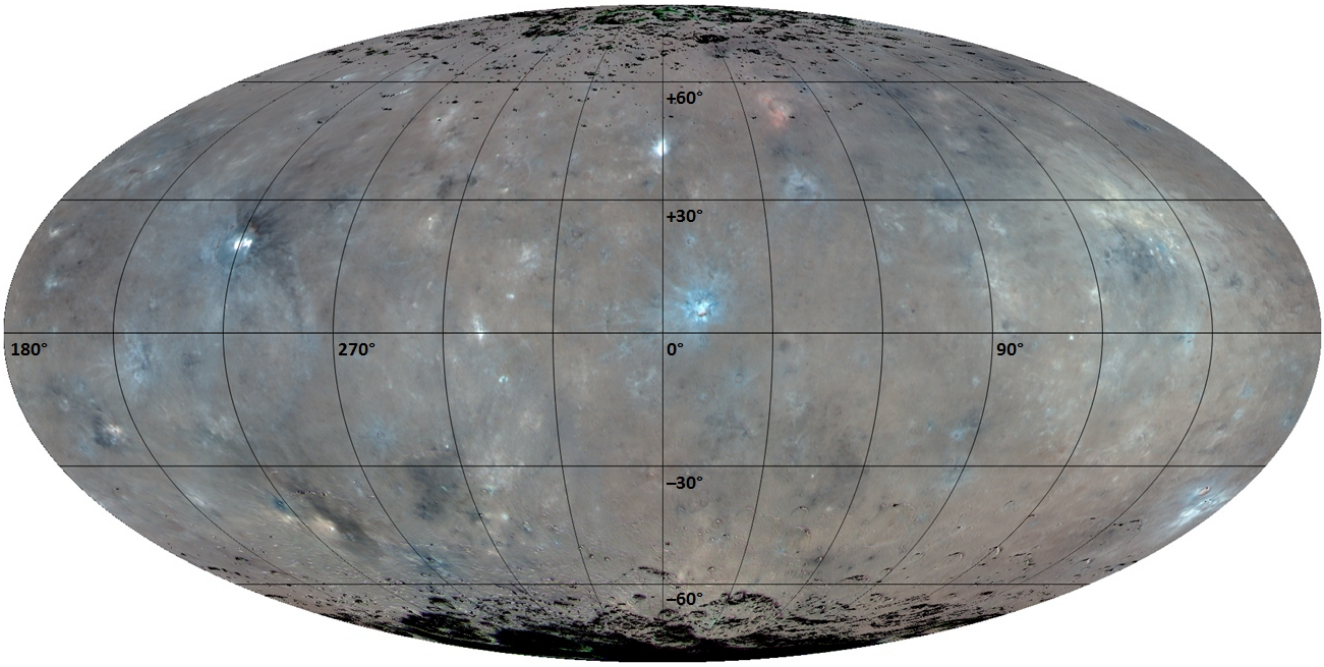
We present a global spectrophotometric characterization of the surface of dwarf planet Ceres using Dawn Framing Camera images. We employed a global photometric model to assemble photometrically corrected images acquired on approach to Ceres into global maps of albedo and color. An accumulating body of 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



# 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

 

# はやぶさ２の着陸地点選定に向けた撮像模擬実験
# Simulated Imaging Experiment for Landing Site Selection by Hayabusa2

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2014年に打ち上げられたはやぶさ２は、C型小惑星リュウグウを目標天体とした小惑星探査機である。はやぶさ2におけるミッション目標の一つは、熱変成の進んでいない始原的な物質を地球へと持ち帰ることであり、リュウグウには、地上からの反射分光測定の結果[Vilas, 2008]から含水鉱物の存在を示す700nm吸収帯の存在が確認されている。はやぶさ２では、3つの可視カメラから成る光学航法カメラ（ONC）のうち、7枚のバンドパスフィルタの備わった望遠カメラ「ONC-T」を用いてマルチバンド分光観測を行う。そして、その撮像結果から700nm吸収帯の検出が可能であることを事前に確認しておく必要がある。我々はこれまでに、ONC-Tのフライトモデルを用いて、C型小惑星に対応する反射スペクトルを持つ炭素質コンドライトに対する反射分光実験を行い、700nm吸収帯の検出が可能であることを確認した[Kameda et al., 2015]。しかし、ONC-Tではフィルタホイールを回転させてマルチバンド分光観測を行うため、フィルタを回転させている間に、リュウグウの自転によりバンドごとの視野のずれが生じるが、700nm吸収帯が検出可能であることを示した先行研究ではバンドごとの視野のずれは模擬していない。

そこで本研究では、ONC-Tを模擬したカメラを用いて、リュウグウの自転によるバンドごとの視野のずれを模擬し、700nm吸収帯の深さへの影響を確認した。

本研究では、試料台の下にx軸ステージを設置し、バンドごとに隕石の位置を動かすことで自転によるバンドごとの視野のずれを模擬した。また、はやぶさ２の撮像を模擬するために、ONC-Tで使われているCCDチップと同じものを組み込んだカメラと、ONC-Tに搭載されているバンドパスフィルタと同等の透過中心波長を持つフィルタを用いた。

なお、自転によるバンドごとの視野のずれはリュウグウ表面からの高度によって変化するため、本研究では、高度20km（HP）と高度5kmにおける視野のずれを模擬した。また、含水鉱物の存在する領域を特定する際に予定されている空間分解能30mの場合で、炭素質コンドライトの反射スペクトル及び700nm吸収帯の深さを求めた。

キーワード：はやぶさ２、マルチバンド分光観測
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 $2 \times 10^7$ 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 $1.5 \times 10^8$ 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 $2 \times 10^3$ 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.

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キーワード：小惑星探査、はやぶさ２、熱物性、熱赤外カメラ、熱慣性
Keywords: asteroid exploration, Hayabusa2, Thermo-physical property, thermal infrared imager, thermal inertia

 

# はやぶさ２搭載中間赤外カメラの地球撮像による較正

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

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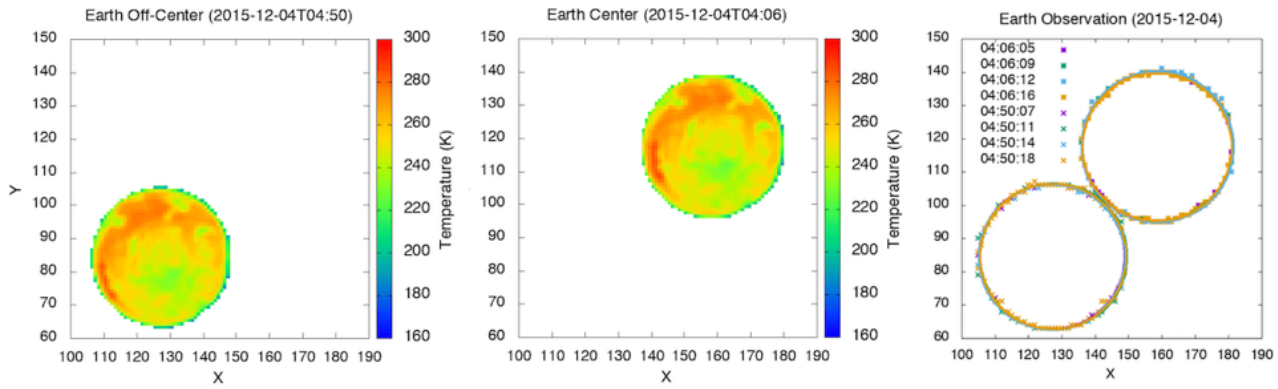
はやぶさ2搭載中間赤外カメラ（TIR）は、2018年にC型小惑星Ryuguに到着し、上空から中間赤外域(8~12μm)で熱撮像を行って、約10m@10kmの空間解像度で地域毎の表層温度を決定する予定である。特に小惑星の自転に伴って時々刻々と変化する表層温度のプロファイルから表層の熱物性値を推定して、小惑星の熱に関連する進化の歴史を紐解く。本発表では、2015年12月3日に行った地球スイングバイ前後のTIRによる地球観測での検出器の性能チェック結果、特に検出器のアライメントと観測される絶対温度の校正を地球観測データと比較して報告する。

キーワード：はやぶさ２、中間赤外カメラ、地球、較正
Keywords: Hayabusa2, Thermal Infrared Imager, Earth, Calibration



# はやぶさ２に搭載される中間赤外カメラのための画像及びデータベースブラウザ

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

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はやぶさ２は小惑星162173リュウグウへ向けたサンプルリターンミッションであり、到着は2018年を予定している。搭載されている中間赤外カメラ(TIR)は着陸ならびに試料採取地点の選定、小惑星表面の熱特性の知見を得る。そのTIRの画像データベースとブラウザが複合したHEAT：Hayabusa2 Exploration Assistant for TIRを開発したので報告する。HEATは可視化、較正、解析の3つのユースケースを持つ。較正において、回帰式に基づく温度変換と、地上試験データに基づいて直接温度変換する方法の２通りを実装した。TIRのデータ解析は以下の手順で行われ、それらのほぼ全てで活用できる。1 解析するTIR画像のメタデータを収集する。2形状モデルの指定された経度域についてローカルタイムを得る。3 表面温度の時系列変化と個々のTIR撮像画像及びローカルタイムを対応づける。4 そのプロファイルをもとに局所的な熱慣性を見積もる。5 小惑星形状モデルと対応付けられた熱モデルを得る。

キーワード：はやぶさ２、中間赤外カメラ、HEAT、キャリブレーション、ソフトウェア、データベース
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.

キーワード：HARMONICS、ソフトウェア、可視化、はやぶさ２、探査、SPICE
Keywords: HARMONICS, Software, Visualization, Hayabusa2, Exploration, SPICE

 

# イトカワ分光画像解析と「はやぶさ２」可視カメラの光学特性解析
# Multi-band image analysis of Itokawa and optical properties analysis of Hayabusa2/ONC-T

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はやぶさ２が探査するC型小惑星は、 含水鉱物や有機物を多く含んでいると推定されている。そのため、小惑星の詳細物質分析からは生命誕生に重要な水や有機物の起源に関する情報が得られる可能性がある。さらに、太陽系の起源に関する情報も得られるかもしれない。小惑星の試料を精密分析することで小惑星の進化や移動の過程を知ることができる可能性がある。このような情報は太陽系形成の過程に関する重要な制約条件となる。

はやぶさ２は、このリュウグウの試料を採取して地球に持ち帰る予定である。この際、どのような場所から試料を採取するべきかは非常に重要な課題である。 上記のような情報を得るためには、ごく最近の変成作用である宇宙風化の影響を受けていない試料を採取する必要がある。この実現のため、はやぶさ初号機により取られたイトカワのデータを解析し、宇宙風化の少ない場所がどのような物理的特徴を持った場所に存在するのかを検討した。 加えて、はやぶさ２でも同様の宇宙風化度のスペクトル解析を行うため、光学特性評価を分光カメラONC―Tに対して行った。

具体的に行ったことは以下の2つである。

1. はやぶさ初号機のデータを用いて宇宙風化度を評価し、それと相関の強いパラメータを見つけ出すことで、宇宙風化の少ない地点の特徴を見つけ出すこと。
2. １の手法をはやぶさ２でも行えるように、正確な PSF補正係数を求めること。

1.に関しては、まず、はやぶさ初号機により撮られたイトカワの画像補正を行った。さらに、宇宙風化の赤化作用を利用して、p-band (960nm)とb-band (429nm)の画像の強度比 (P/B)を取り、これをイトカワ表面の宇宙風化度を表す指標とした。さらに、このP/Bと、物理的なパラメータである表面の傾斜や重力との相関を調べることで、宇宙風化の少ない地点の物理的特徴を見つけ出した。

以上の解析を、試料採取可能な、レゴリスで覆われた滑らかな地形であるSagamiharaとMUSES-Cについて行った。表面の傾斜に関してはどちらも同様に小さく平坦な地形であったが、P/B比を取るとSagamiharaの方がMUSES-Cよりも大きな値を示しており、宇宙風化が進んでいることが示された。一方で、表面の重力の大きさを比べてみると、Sagamiharaの方がMUSES-Cよりも大きいことが分かった。そこで、Sagamiharaと

 

MUSES-Cそれぞれについて、斜面に沿って4本ずつ測線を引き、P/B比と傾斜、P/B比と重力との相関係数を求めた。その結果、P/B比と傾斜の相関係数は約-0.40, P/B比と重力の相関係数は約0.85の値を示していることが分かった。このことから、イトカワ表面の宇宙風化度の分布は傾斜よりも、重力の絶対値に対する正の相関が強いことが分かった。これは表面重力の強い場所ほど表面物質が長時間その場にとどまり続けているということを示唆している。この解釈の一つとして、例えば、小惑星表面の物質が斜面を転がったり、崩れたりすることで起きるのではなく、表面から宇宙空間に飛散していく形で起きていると説明することができる。以上のことから、今後の小天体探査で宇宙風化の少ない試料を採取するには、レゴリスに覆われた場所の中でも重力の弱い地点が適しているとの示唆を得た。

2.に関しては、Ishiguro (2014)と同様にPSFの式をガウス関数の和で近似し、それぞれのガウス関数の係数を決定することでPSFの式を導出した。係数の決定方法は、まず、較正用の画像データに対して、エッジを取ることで、ぼけのない画像を作り出す。この画像に対して、PSFを畳み込み積分することで、元のぼけを再現する。これを係数を1変数ずつ変化させて繰り返し、元の画像データとの残渣が最小となるように係数を決定した。

テスト計算としてまず、はやぶさ初号機のデータで行いPSF補正係数を求め、先行研究 (Ishiguro 2014)で求められているPSFを再現できるか試した。その結果得られたPSF と先行研究のPSF との差異は、9.8%となった。さらに、本研究で得たPSFを用いて、はやぶさ初号機の撮影した複数の画像に対して実際にPSF補正を行った。その結果、残渣は光源強度の0.2~0.8%ほどになった。これは、先行研究での補正係数を用いた場合と同程度の残渣であり、先行研究で目標基準としていた光源強度の1%以下も達成している。そこで、これと全く同様の方法で、はやぶさ2のPSF補正係数も算出した。さらに、その値を用いてはやぶさ2の撮影した画像に対してPSF補正を行った所、どの波長域においても、残渣は光源強度の1%以下となった。これにより、はやぶさ２においても、はやぶさと同程度の画像補正を行えるようになった。

 

# レゴリス層に形成されるエジェクタカーテン解析法の提案：はやぶさ2小型搭載型衝突装置による衝突実験への応用

# 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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衝突クレーター形成は、天体の表層進化において重要な現象である。天体スケールの衝突現象を推測するため、衝突スケール則の構築を目指した室内衝突実験が行われている。しかしながら、微惑星等の小天体で重要となる微小重力下では、衝突スケール則に対する微小重力の影響は良くわかっていない。そこで、クレーター形成に対する微小重力の影響を調べるため、小惑星探査機「はやぶさ２」において宇宙衝突実験が計画されている。「はやぶさ2」のミッションは、小型搭載型衝突装置（SCI）を用いて、2kgの銅板を2km/sで小惑星表面に衝突させる(Saiki et al., 2016)。銅板は、衝突前には直径約15cmの球殻弾丸に成型されている。衝突の様子を、小型分離カメラ(DCAM3-D)で観測し、SCIの点火からクレーター形成までを撮影する(Ishibashi et al., 2016, Ogawa et al., 2016)。このように、「はやぶさ２」では小惑星上でのクレーター形成過程を詳細に観測することが予定されている(Arakawa et al., 2016)。

クレーター形成時に放出される物質(エジェクタ)の速度分布を求めることは、天体表層進化過程を研究する上で非常に重要である。そのため我々はこれまで、粒径500μmの石英砂に対するクレーター形成実験を行い、エジェクタ速度分布を系統的に調べてきた(Tsujido et al., 2015, 松榮 他、連合大会2017)。室内実験において、高解像度のハイスピードビデオカメラを用いて、エジェクタ粒子1粒の放出軌跡を計測することでエジェクタ速度分布を調べてきた。しかしながら、エジェクタ粒子が細かい場合、個別に粒子を識別することは難しい。実際、「はやぶさ2」のDCAM3-Dでは、エジェクタカーテンの外形は観測できるが、個々のエジェクタ粒子を識別することはできないと考えられている。そこで、我々は個別粒子を追跡しない方法でエジェクタ速度分布を求める手法（ECG analysis method、以下ECG）を提案している(Arakawa et al., 2016)。ECGは、ある高さでの水平面におけるエジェクタカーテン外縁の成長速度とその場所でのエジェクタカーテン角度を計測することによって速度分布を算出する方法である。本研究では、様々な衝突条件で行われた室内衝突実験のエジェクタカーテン画像を用いて、ECGによるエジェクタ速度分布の決定精度やその適応範囲を調べた。また、ECGで求めた速度分布と、個別粒子追跡法で求めた結果との整合性を調べた。室内衝突実験は、石英砂を標的とし、8種類の弾丸を1.5~6.9km/sで衝突させた (松榮 他、連合大会2017)。

また、2013年に実施された実スケールのSCIを用いた地上実験の結果(Wada et al., 2014)を解析した。斜面下方向から観測したクレーター形成過程の動画を用いて、個別粒子追跡法とECGを用いてエジェクタ速度分布を計測し、ECGが実スケールのクレーター形成過程に応用可能かどうかを検証した。さらに、全5ショットについて、形成したクレーターサイズをπ-スケール則でまとめ、乾燥石英砂で得たスケール則(Matsue et al., in prep)と比較した。

キーワード：イジェクタカーテン、はやぶさ２ SCI、イジェクタ速度分布
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)

 

# はやぶさ帰還試料キュレーション及びはやぶさ2帰還試料受入設備開発の現状

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

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はやぶさ帰還試料は2010年に小惑星イトカワから帰還した、唯一の小惑星レゴリス試料である(Abe et al., 2011)。初期分析で鉱物学･岩石学･化学･酸素同位体組成的に見てそれらは平衡LLコンドライトと同等であることが分かっている(Nakamura et al., 2011; Ebihara et al., 2011; Yurimoto et al., 2011)。JAXA地球外物質研究グループでは、大気遮断環境でのFE-SEM/EDSによる、それら試料の初期記載、それらの高純度窒素環境での保管、国際公募研究による世界中の研究者への試料配付を進めている(Yada et al., 2014)。これまでに700個以上の粒子初期記載を行い、80%以上がイトカワ起源粒子だった。160個以上の粒子を4回の国際公募研究において配布している。最新の国際公募研究は2016年に行われ、6個の研究テーマが配布対象として選ばれている。

一方、はやぶさ２は現在、目標天体である近地球型C型小惑星リュウグウ(前名称1999JU3)に向かっており、2018年には到着し、表面にタッチダウンして試料採集を行う予定である(Yoshikawa et al., 2015)。その捕獲試料は2020年に地球に帰還する予定である。はやぶさ2プロジェクト、仕様検討委員会、専門委員会の指導の下、地球外物質研究グループではその帰還試料の受入設備の準備を進めている。はやぶさ帰還試料をとりあつかっているクリーンチェンバーが設置されているクリーンルームの隣に、新たにクリーンルームを建設する予定である。そのクリーンルームにはやぶさ２試料受入用のクリーンチェンバーを設置する予定である。炭素質コンドライトと関係があると考えられるC型小惑星リュウグウの帰還試料に含まれるかも知れない揮発性物質・有機物質に対する地球起源窒素の汚染を避ける為に、そのクリーンチェンバーにおいて、試料の一部を真空中で回収される予定である。残りの試料は、はやぶさ帰還試料と同様に高純度窒素環境で取り扱う。mmサイズの資料を取り扱う為に、μmサイズ試料を扱うチェンガートは異なった形状のチェンバーを準備する予定である。新しいクリーンルームの建設は今年中に始まり、最終的にクリーンチェンバーは2018年半ばに完成する。施設設備の完成後、機能･性能確認後、2020年の試料帰還に向けて試料受入のリハーサルが行われる予定である。

キーワード：小惑星、サンプルリターン、キュレーション、はやぶさ、はやぶさ２
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.

キーワード：Jupitar Trojan Asteroid、Sample Return

 

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

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.

キーワード：木星トロヤ群小惑星、ソーラー電力セイル、質量分析
Keywords: Jupiter Trojan Asteroid, Solar Power Sail , Mass spectrometry

 

# ソーラー電力セイル搭載の大面積薄膜ダスト計測器による惑星間塵および木星トロヤ群微粒子環境計測

# 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.

キーワード：Jupiter Trojans、Solar Power Sail、Slow Velocity Impacts
Keywords: Micrometeoroids, Hypervelocity Impacts, Circumsolar Dust Ring

 

# 火星衛星探査計画に搭載される望遠カメラと多波長広角カメラの設計
# Design of a telescopic camera and a multi-band wide-angle camera onboard the Mars Moons Exploration mission

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火星衛星探査計画に搭載される望遠カメラと多波長広角カメラの設計
Design of a telephoto camera and a multi-band wide-angle camera onboard the Mars Moons Exploration mission

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JAXAは火星衛星であるフォボスとダイモスの起源を明らかにするため火星衛星探査計画を検討している。この計画ではフォボス・ダイモス・火星の観測とフォボスからのサンプルリターンを計画している。この計画に搭載予定の望遠カメラ(TL)と多波長広角カメラ(WAM)の設計を行った。

TLの目的はフォボスの地形を明らかにすることである。平坦な着陸地点や、宇宙風化の影響が少ないとされる岩塊やクレーターを見つけなければならない。そこで本研究では高度20kmから10cm/pixの空間分解能を持った望遠カメラを設計した。この空間分解能ははやぶさ2に搭載された望遠カメラONC-Tの20倍である。焦点位置の選定や温度変化による性能変化についても述べる。

WAMの目的はフォボス表面の物質分布情報を得ることである。はやぶさ2に搭載された広角カメラでは多波長の画像を得ることができない。フィルターホイールを搭載したONC-Tには、探査機が降下中ではホイールを回している間に撮像範囲が変わってしまうという欠点がある。そこで新たに7つの異なる単色広角カメラを設計し、全波長同時撮像を行うことを提案する。被写界深度が1m~無限遠なので、探査機が着陸している時とフォボスを周回している時で使用可能である。

本発表では、以上のカメラの設計を紹介する。

キーワード：MMX、フォボス、カメラ
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.

キーワード：MMX、フォボス、デイモス、近赤外線、含水鉱物
Keywords: MMX, Phobos, Deimos, near infrared, hydrated mineral

 

# 火星衛星探査計画(MMX)のためのLIBSを用いた元素分析
# Elemental analysis using LIBS for Martian Moons Exploration (MMX)

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火星にはフォボスとダイモスという2つの衛星がある。両衛星の起源は、小惑星が火星の重力によって捕獲されたという小惑星捕獲説[Hunten, 1979]と、初期火星に天体が衝突して、その時に飛散した火星初期物質が集積したという巨大衝突説[Rosenblatt et al. 2016]の2つの説が存在している。

JAXAの火星衛星探査計画(MMX)は、フォボスからサンプルリターンを行い、両衛星の起源を判別することを大目標の1つとしている。起源を判別するためには、回収された試料が衛星形成時の情報を保持している必要があるため、試料回収地点の物質の均質性を、衛星表面その場で調べることが重要となる。搭載が決まっている、ガンマ線・中性子分光計で平均された元素組成を得ることができるが、試料回収範囲の約10 mmの分解能で元素組成を得ることはできない。そこで搭載機器の追加が可能な場合に、我々は1 m以上離れた場所でも1 mm以下の空間分解能で元素分析が可能な、レーザー誘起絶縁破壊分光装置(LIBS)を追加することを提案している。MMXでその場分析を行える時間は約1時間とされているため、数十秒という短時間で計測が可能なLIBSは、MMXに適した機器であるといえる。

試料回収地点付近の物質の不均質性を理解することは、回収試料の地質学的背景を決定づけるために重要である。そこで、我々はMMXに搭載予定の装置を用いて短時間で、フォボス表面と、火星隕石・炭素質コンドライトの類似性を判断するための実験を行った。レーザーは出力が約12 mJで波長が1535nmの小型のレーザーを使用した。分光器で取得したデータは波長が約380 nm～800 nmの範囲を解析で使用した。レーザー光を集光するレンズと試料との間の距離と、分光器用の集光レンズと試料との間の距離は共に約1.5 m、集光光学系の有効径は約20 mmとした。試料は真空容器内に設置し$10^{-3}$ Pa台になるまで排気した。このような探査の現実的な条件の下で、S/Nの成立性なども含めて検証した。計測した試料は、Allende(炭素質コンドライト)、NWA1068(火星隕石)、Zagami(火星隕石)である。レーザーの繰り返し周波数を10 Hz、分光器の露光時間を1 sに設定し、1試料に対して16箇所で測定を行い、1箇所に対してレーザーを150回照射した。隕石の平均組成を求めるために16箇所の発光スペクトルを平均した。平均スペクトルからは主要元素(Fe, Ca, Al, Mg, Si, Ti)の輝線が検出された。さらにAllendeから火星隕石の発光スペクトルを差し引くと、Allendeに多く含まれるFe, Mgの輝線波長のところは正の値になり、NWA1068とZagamiに多く含まれるAl, Caの輝線波長のところは負の値になった。これよりLIBS計測で得られた発光スペクトルの差は、測定試料の元素組成の差を定性的に表していることがわかり、LIBS計測で火星隕石と炭素質コンドライトが判別できる可能性が高いことが示せた。

次に、その場分析が行える1時間の間での本実験結果の実現可能性を検討した。1測定点あたりの焦点調整や撮像に30秒、測定点の移動に20秒かかると仮定した。また、レーザーの繰り返し周波数は電力の制約上2Hzとし、本実験の条件であった1測定点あたりのレーザー照射回数を150回、測定点を16点で計算すると、測定に必要な時間は約35分となった。これより実際の探査でLIBSを運用できる時間内で測定が行える可能性があることが示せた。

これらの結果は、フォボス上でLIBSを用いることで、フォボスの表面と、小惑星に似た物質、火星に似た物質の類似性を識別できる可能性が高いことを示している。

なお本発表では、エンジニアリングモデルの製作や、それを用いた実験結果も報告する。

キーワード：LIBS、火星衛星探査計画、その場分析

 

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

 