Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

U06-01 Room:503 Time:April 28 09:00-09:15

On activities in the interdisciplinary science of Hayabusa-2

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Hayabusa-2 is an asteroid sample return mission of which target asteroid is 1999JU3, a near Earth asteroid of type C, and it is scheduled to be launched late in this year. As on-board scientific instruments, Hayabusa-2 has a near infrared spectrometer (NIRS3), thermal IR imager (TIR), optical navigation camera (ONC-T) used as a multi-band imager with seven band-pass filters, laser altimeter (LIDAR), sampler (SMP), small carry-on impactor (SCI), separation digital camera (DCAM-D), and small lander (MASCOT). Using these instruments, we try to characterize the surface properties and materials of 1999JU3 and select three sampling points from which material samples will be obtained to reveal physical and chemical processes on the asteroid and its history from the formation to the present. Thus scientific success of Hayabusa-2 strongly depends on a strategy for characterizing the surface and selecting sampling sites, which can be achieved making the best use of data from the above all sensors. We, for this purpose, organize a working team called as the Interdisciplinary Science Team (IDST) of Hayabusa-2. In this presentation, we introduce the activity of the IDST.

The IDST was established in the first meeting held on Dec. 2012. Its purposes are to obtain the general picture of a scientific scenario of Hayabusa-2, define interdisciplinary science themes and contribution of individual instruments to the themes, define scientific constraints and validations on the mission scenario, and promote planetary sciences and think out planetary sciences from a standpoint of the asteroid mission. The discussion in the IDST is open to the project members. So far, we have discussed deeply a strategy in return sample analyses, heterogeneity detection by the remote sensing sensors, surface temperature detection, crater chronology, morphology produced by meteoroid impacts, reflectance spectra of C-type asteroids, space weathering, and so on. As a result of these discussion, we produce a logical flow chart to characterize the surface material and property. In the chart, mutual relations between basic observation quantities, quantities inferred by multiple sensors, their indexes, identified characters and general inferences on primitiveness are described. Contributions from each sensor are clarified in the chart. In addition, we also depicted an operational picture of SCI which is a grand experiment for an impact process in the low gravity space and exposes material in a depth that can be less suffered by space weathering, but SCI is wasteful of the satellite resources. It is necessary to polish up the operation plan of SCI from the view point of the system resources.

The logical flow chart is a guiding principle in the science of the Hayabusa-2 mission. We continue to refine the chart and complete the logic. For this purpose, we make several working groups to reinforce the logic flows. As closing the development phase of on-board instruments, we now rush up to make the IDST of Hayabusa-2 more active. We think that the activity in the IDST is a key point to succeed in the science mission and promote planetary sciences and explorations in Japan.

Keywords: Hayabusa-2, asteroid, exploration, surface material, interdisciplinary science, sample return

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U06-02 Room:503 Time:April 28 09:15-09:30

Detectability of 0.7 um absorption band of hydrous minerals using the Hayabusa2 ONC-T Flight Model

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Hayabusa2 has three cameras for optical navigation to the asteroid 1999JU3. ONC-T is one of them and it can be used also for reflectance spectroscopy. The results of the ground-based observation suggested that hydrous materials might remain on the 1999JU3 but on the small part of the surface. To bring them to the Earth, we should perform reflectance spectroscopic observation near the asteroid using ONC-T to locate the point where hydrous mineral is rich.

In this presentation, we will report the result of final calibration test of ONC-T and discuss the detectability of hydrous minerals on 1999JU3.

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U06-03 Room:503 Time:April 28 09:30-09:45

Development and tests of Hayabusa-2 LIDAR

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The Japanese first asteroid mission, Hayabusa, visited at the small asteroid 25143 Itokawa in September, 2005. Images taken by Hayabusa are combined with other remote sensing observations and revealed that the asteroid as small as 500 m in the longest axis is the first rubble-pile body identified in our solar system. Despite of several serious failures of the spacecraft occurred during and after rendezvous, Hayabusa successfully retrieved samples from the surface of 25143 Itokawa to the Earth in 2010 to disclose unpredicted nature of a very small asteroid.

JAXA and collaborating scientists are now developing the second asteroid mission named ”Hayabusa-2”. Hayabusa-2 is based on a heritage of the first Hayabusa. At the same time, Hayabusa-2 is intended to improve engineering and scientific achievements of the first Hayabusa, and also to challenge new technologies. Furthermore, target asteroid is different from that of the first Hayabusa. The asteroid 25143 Itokawa is a silicate-rich S-type. On the other hand, Hayabusa-2 is visiting a C-type asteroid, (162173) 1999 JU3. Needless to say, C-type is more primitive than S-type, therefore is expected to be a key to understand chemical evolution of the early solar system.

LIDAR measures altitudes of the spacecraft from the surface of the asteroid by taking a time of flight of laser pulse. As a part of Attitude and Orbit Control System (AOCS), the LIDAR data are used for navigation of the spacecraft. The data are particularly important during touchdown operation. Besides, the LIDAR data are served for scientific analysis of the shape, mass, and surface properties of the asteroid in order to elucidate physical evolution of minor bodies such as impact fragmentation and coagulation. We also wish to expand outcomes of Itokawa exploration by examining uniformity and variation of porosity within rubble-pile body and detecting dusts levitating above the surface of asteroid. The remote sensing observations of Hayabusa-2 will be carried out from Home Position (HP), middle altitude, and low altitude whose distances from the asteroid surface are nominally 20 km, 5 km, and 1 km, respectively. We report recent progress of LIDAR development anticipating the launch in December 2014.

Keywords: Hayabusa, asteroid, exploration, LIDAR

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U06-04 Room:503 Time:April 28 09:45-10:00

A strategy to estimate thermal properties using Thermal Infrared Imager on board Hayabusa-2.

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Thermal InfraRed imager (TIR) on board Hayabusa-2, an upcoming japanese mission to C-type asteroid 1999JU3, is non-cooled bolometer which image mid-infrared thermal emission from the asteroidal surface. The field-of-view (FOV) of TIR is 16x12 degrees and ts effective pixels are 320x240. So the spacial resolution, which depends on distance from the suface, is about 18m from an altitude of 20km (Home position) and less than 1m from an altitude of 1km.

By comparing the temperature distribution obtained by TIR and thermal evolution model, we can get thermophysical properties such as thermal inertia and emissivity. These parameters are diagnostic for the characteristic size of surafce grain.

In this presentation we will present our strategy to estimate the thermophysical properties from TIR observation.

Keywords: hayabusa-2, thermal infrared imager, surface temperature, thermal properties, thernal inertia, emissivity

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U06-05 Room:503 Time:April 28 10:00-10:15

Relationship on Surface Morphology of Small Asteroids and Geopotential

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We compared the distribution of smooth terrains with the geopotential map of the asteroid Itokawa, and demonstrate that the distribution of smooth terrains on Itokawa is strongly controlled by the geopotential distribution. Because the geopotential distribution of an asteroid can be estimated from its shape, rotation state and density, we can predict the distribution of smooth terrains on the asteroid from these observations.

Keywords: Asteroid, geopotential, smooth terrain, Itokawa, 1999JU3

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U06-06 Room:503 Time:April 28 10:15-10:30

Spectral evolution of s-type asteroids suggested by principal component analysis of multi-band images of Itokawa

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Objective

Itokawa is covered with materials from the same initial material with different degree of space weathering[1,2]. However, it has not been verified sufficiently if there is other factors that change the spectra. Our analyses of principal component analysis (PCA) using multi-band images taken by Hayabsa's AMICA (Asteroid Multi-band Imaging CAmera) so far have provided the results that a component of spectral reddening, a typical trend of space weathering effect, is the first principal component (PC1) with comparison to laser-irradiated meteorites spectra. The comparison with main-belt asteroids suggests how the spectra of the asteroids develop in their PC space with weathering (by micrometeorites bombardment[3])[4]. However, further analysis had been impeded by electromagnetic noise. In this study, we remove the noise and examine spectral change trends caused by processes other than space weathering.

Methods

We used 2 sets of images of six visible bands (Central wavelengths of 381, 429, 553, 700, 861, 960 nm) taken by AMICA. Periodic electromagnetic noise is imposed on most of the images. We removed it by subtracting superposition of sine waves. The images were calibrated following [4] and coresistrated. Normalized ratio images were obtained by dividing the images by those of 553 nm.

We performed PCA on the normalized reflectance spectra. We used a set of images of a Itokawa semisphere and another set including a dark rock (Black Boulder). Shock darkening is indicated as a possible origin of it [5].

We also performed PCA on spectra of main-belt asteroids obtained in ECAS [6] and each Itokawa spectrum superimposed. Because AMICA and ECAS filter wavelengths are approximately same, we can compare the Itokawa surface in the PC space defined by ECAS data set.

Results

The PC1 of spectra of only Itokawa had a shape rising to the right with a steep rise in 430-700nm. The PC1 score spatial distribution was consistent with the distribution of space weathering degree obtained by [7]. PC2 had positive coefficients at the wavelengths except 553nm, and the spectrum shape was upward to both sides. The PC2 is different from sillicate spectra, therefore interpretation in a context of material science is difficult. We found a feature that PC1 score is low and PC2 score high in boulder-rich regions, but the muximum area of PC2 score lay around a boulder where PC1 score were minimum. Proportion of variance of PC1 and PC2 was 60-75% and 20-30%.

In the ECAS-defined PC space, the spectra of Black Boulder were distributed apart from the cluster of the other parts.

Discussion

The proportions of variance of PC1 and PC2 would suggest that the heterogeneity in Itokawa surface spectrum is dominated by two processes. The PC1 and PC2 score distribution might suggest that the process which changes PC2 score occurs where space weathering has moderately developed. We have observed only a part of the surface, and features observed in a global analysis will be reported in our presentation.

The fact Black Boulder spectral trend is different from that of the other parts suggests that another process than space weathering (shock darkening is a candidate) is the origin of its peculiar spectrum.

In this analysis, another trend than the general space weathering was captured. Consideration of an evolution caused by larger impacts together as well as the space weathering caused by micrometeorites bombardment may enable us to constrain the spectral evolution processes of asteroids and derive relationships among asteroids of different spectral classes.

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Small carry-on impactor of Hayabusa2

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Small Carry-on Impactor of Hayabusa2

A Japanese spacecraft, Hayabusa2, the successor of Hayabusa, which came back from the Asteroid Itokawa with sample materials after its 7-year-interplanetary journeys, is a current mission of Japan Aerospace Exploration Agency (JAXA) and scheduled to be launched in 2014. Hayabusa2 is a similar sample return mission to Hayabusa, however the type of the target asteroid is different from that of Hayabusa. Asteroid Itokawa, explored by Hayabusa is a rock-rich S-type one. Hayabusa2 will go to a C-type asteroid. Both C-type and S-type asteroids consist of rocks, but C-type asteroids are considered to have organic and water materials. Hayabusa2 has two objectives to discover: organic matters and water in the solar system and relationship between life and ocean water. C-type asteroids are the most common variety and many of them are in the outer part of the asteroid belt beyond 2.7 AU. An asteroid, called 1999 JU3, is chosen as the target of Hayabusa2 mission because it is considerably easy to reach. It has a similar orbit as that of Itokawa and it is in the orbit that occasionally comes close to the earth orbit.

The design of Hayabusa2 basically follows Hayabusa. Its configuration, size and weight are almost same as Hayabusa and the touch-down operation will be performed in much the same way. However, it is planned to be equipped with some new components. Small Carry-on Impactor (SCI) is one of the new challenges. The observations by Hayabusa discovered that Itokawa was rubble-pile body with the macro-porosity. No direct observational data as for their internal structures and sub-surface materials were available, however. One of the most important scientific objectives of Hayabusa2 is to investigate chemical and physical properties of the internal materials and structures in order to understand the history of formation of small bodies such as small, un-differentiated asteroids. In order to achieve this objective, the SCI is required to remove the surface regolith and create an artificial crater on the surface of the asteroid. Different from other impact missions, Hayabusa2 can make a detailed observation of the resultant crater after the impact. Observing the size of the crater is very important to investigate the physical properties of the asteroid. Additionally, Hayabusa2 will try to touchdown near the crater to get the fresh material of the asteroid.

It is very difficult to create a meaningful crater on the asteroid. High kinetic energy (i.e. about 2km/s impact speed and 2kg impact mass) is required to make a crater, but the high speed is difficult to realize. The famous impact mission, Deep Impact was the direct impact mission, which used the interplanetary velocity for the impact speed. Consequently, the impact energy became very high. On the other hand, SCI of Hayabusa2 is a carry-on type impactor and it should accelerate itself after the separation from the mother spacecraft. Therefore, how to accelerate the impact body is a big challenge of SCI. The traditional acceleration devices such as rocket motors and thrusters are difficult to hit the asteroid without a guidance system because the acceleration distance is large. To overcome this difficulty, the powerful explosive is use in SCI. The special type of shaped charge makes it possible to accelerate the impact head in a very short amount of time (less than 1 millisecond) and it becomes possible to crash into the asteroid.

The development of SCI is now almost finished. A lot of tests were conducted during the development period. The overview of the small carry-on impactor system and the results of the development tests will be presented in the conference.

Keywords: Hayabusa2, Impactor, Artificial Crater

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U06-08 Room:503 Time:April 28 11:15-11:30

Small Carry-on Impactor Elucidates the Nature of Craters and the Evolution of our solar system

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Hayabusa-2, the Japanese next asteroid exploration mission, equips Small Carry-on Impactor (SCI) to launch a decimeter scale projectile on an asteroid surface. This is a novel apparatus to excavate the asteroid surface, and hopefully it will enable us to observe a fresh surface without space weathering and thermal alteration. Furthermore, we will be able to recover the asteroid sample excavated from several 10 cm depth at the deposit of the impact ejecta. The SCI impact on the asteroid is very good chance to examine the projectile scale on the crater scaling law in addition to the study on the gravity effect on the crater formation process. In this presentation, I will introduce the scientific goals of Hayabusa-2 mission using SCI and the scientific problems to be solved in the near future to maximize the scientific outputs of the SCI impact.

Keywords: Hayabusa-2, SCI, impact, asteroid

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U06-09 Room:503 Time:April 28 11:30-11:45

The final impact tests of Small Carry-on Impactor(SCI) equipped on HAYABUSA-2

HAYAKAWA, Masahiko[1*] ; SAIKI, Takanao[1] ; IMAMURA, Hiroshi[2] ; SHIRAI, Kei[2] ; WADA, Koji[3] ; ARAKAWA, Masahiko[4] ; OKAMOTO, Chisato[2] ; TSUDA, Yuichi[1] ; TAKAGI, Yasuhiko[5] ; KADONO, Toshihiko[6] ; NAKAZAWA, Satoru[2] ; IIJIMA, Yuichi[1] ; YANO, Hajime[2] ; KAMITOMAI, Hideo[7] ; MATSUZAKI, Shinichi[7]

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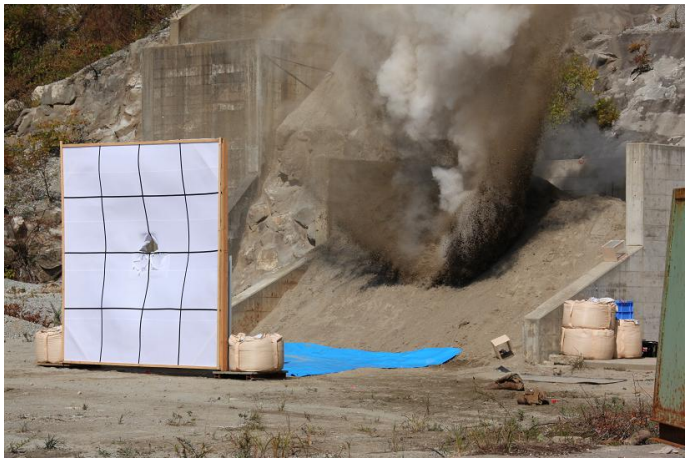
HAYABUSA-2(the next Japanese Aseroid Sumple Return Explorer) is now at the final integrated test. Before this test, all sub-systems experienced final test individually. The Small Carry-on Impactor:SCI has been adopted the new sub-system of HAYABUSA-2, it is one of the self forging fragment which will be able to eject the 2kg projectile by 2km/sec velocity by detonation.

In this paper we show the outline and results of the final performance test of the SCI explosive part on Oct. 2013. The test bodies have be made by the same rot of flight model, and experienced environmental stress tests. The projectiles formed explosion impacted on the sand target and made craters.

A point of view of understunding of impact phenomina, these tests are larger scale impact experiments than thats made in labolatory, between space scale and labolatory scale. Therefore we observed and measured the crater formation prosesses by two high-speed video cameras, a infrared video camera, accelerometers, geophons, and digital handy video cameras. We succeeded to obtaine five cratering prosesses.

Keywords: HAYABUSA-2, Small Carry-on Impactor, impact experiment, crater, explosion



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U06-10 Room:503 Time:April 28 11:45-12:00

Optical performance verification of DCAM3-D/Hayabusa 2

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Small Carry-on Impactor (SCI) is one of the instruments carried on Hayabusa-2 space craft. It will be used for an active exploration on the surface of asteroid 1999JU3. The SCI consists of a disk impactor made of copper. This disk will be accelerated to a velocity of ˜2km/s for the collision onto the asteroid surface, creating an artificial crater on 1999JU3. Then, samples in the crater and/or around the crater will be recovered by the Hayabusa-2 mother ship. Observation of the crater is expected to reveal the surface structure of 1999JU3. This SCI impact also has an aspect of an ”impact experiment” on an asteroid that elucidates the impact phenomena on small bodies.

A miniaturized optical camera unit (DCAM3) is being developed for observations of the SCI impact. DCAM3 will be detached from Hayabusa-2 mother ship and obtain a close-up image of the SCI impact. The detached part of DCAM3 has two cameras; one is an analog camera (DCAM3-A) and the other is a digital camera (DCAM-3D). The purposes of DCAM3-D are (1) the detection of SCI explosion and impact on the asteroid and (2) the observation of ejecta created by the SCI impact.

DCAM3-D optical system has to satisfy strict required specifications to fulfill these purposes: it requires a large view angle (74 deg) to detect both the SCI and the asteroid, high imaging capability for whole sensor area, a bright optical system (F $>$1.7) to detect dark SCI and ejecta, resistance to radiation, and limited size and weight . Moreover, these conditions have to be accomplished without active temperature control.

In this presentation we report the results of the optical performance verification of a flight model of DCAM3-D. The optical performance verification tests consist of electrical test, collimator test, and integration sphere test. The electrical test evaluated the performance of the CMOS sensor. In the collimator test, lens-sensor distance and lens-sensor angle were adjusted. Then, imaging capability (i.e., ensquared energy), spatial resolution, and distortion were evaluated under vacuum condition ($<$1 torr) with various temperatures, wavelength regions, and angles of view. In the integration sphere test, sensitivity, limb darkening, and stray light were evaluated. We confirmed that the results of these evaluations were favorable and that the strict required specifications of the optical system are almost satisfied.

Keywords: asteroid, planetary exploration, Hayabusa-2, scientific payload

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U06-11 Room:503 Time:April 28 12:00-12:15

The effect of substrate structure of rubble-pile bodies on cratering process

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Introduction: Hayabusa obtained many high-resolution images and revealed that this asteroid has many unique morphological features which are not seen on other small planetary bodies. One of the most symbolic configurations are quasi-circular depressions (QCD) on boulder-rich surfaces, which are inferred as impact craters (Hirata et al,. 2009). If the QCDs are impact craters, then the surface crater retention age of Itokawa can be estimated based on crater chronology approach. However, age estimates has great uncertainty: 75Myr-1Gyr (Michel et al., 2009). The uncertainty in age results mostly from the uncertainty in crater scaling formed on the boulder-rich surface observed on rubble-pile bodies. The impact energy required for forming a crater on a small body is much smaller than that on a large body because of the limitation of catastrophic disruption energy (Benz and Asphaug, 1999). Impact cratering with such small energy on rubble-pile bodies are expected to follow a scaling low between the strength-regime rates and the gravity-regime cratering. The impactor destroys a surface boulder and dissipates its energy, then leading to a smaller crater: an armoring effect.

Moreover, impact induced mass loss is a critical value for estimating the life time of small bodies. The escape velocity of small bodies is very small. For example, Itokawa has an escape velocity of 10-20cm/sec. Thus, small bodies can easily lose their mass upon impact cratering.

As mentioned above, crater size and ejecta mass are important parameters for calculating the life-time of small bodies. However, these values for the rubble-pile bodies are not constrained well. Cratering process may be influenced greatly by the substrate structure of small bodies. In this study, the effect of the substrate structure of the rubble-pile bodies on the impact process is examined experimentally.

Experiment: Sintered glass beads blocks crashed into 8-15 mm chips and 200 micro meter glass beads are used as boulder simulants and regolith simulant in our experiments, respectively. We employ two types of targets: one consists of all boulders simulants (target 1) and the other consists of a surface layer of boulders simulants and regolith substrate (target 2). Polycarbonate projectiles 10mm diameter were launched at 160-180 m/sec of velocities. The impact cratering process was observed by a high-speed camera. We also measured the size of final crater and the ejecta mass.

Result: Crater size of target 1 is smaller by $\sim$20% than target 2, and ejecta mass of target 1 is smaller than by a factor of five than target 2. High-speed camera observations revealed that the surface boulders are destroyed by the impactor more heavily in the target 1. This difference occurs because the shock impedance of boulder simulants are larger than that of regolith simulant by a factor of ten and much stronger reflected stress waves comes back to the surface boulders for target 1, but the stress wave transmits efficiently from surface boulders to legolith layer in target 2.

These results suggest that the substrate structure of small bodies changes the impact process greatly. Crater size varies by $\sim$20% depending on substrate layers: boulders or regolith. Crater forming on bodies consisting of only boulder is smaller than bodies with regolith substrate but still much larger than crater on monolith (i.e., the scaling in strength-regime scaling). Consequently, the surface age of Itokawa could be on the younger side of the previous estimates as 75Myr-1Gyr with the strength-regime crater scaling. Furthermore, the substrate structures of the rubble pile bodies change the ejecta mass by 5 times. Rubble-pile bodies consisted of boulders possibly live longer.

Keywords: rubble-pile bodies, impact cratering, mass loss, fragmentation

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Computer Vision in Space: Optical Navigation Technology Development for Hayabusa-2

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Computer vision (CV) is a research field aiming to establish technologies by which information of objects is extracted from their images. Using CV technologies, our research group are developing methods to construct shape model of an asteroid for Hayabusa-2 navigation. We report this activity in this article. In addition, applying CV technologies to space environment has a potential to drive CV itself to a new research direction. We also touch on this observation.

For Hayabusa-2 navigation, we need to know shape of the destination asteroid, but the long distance between the asteroid and the earth prevent us from measuring it from the earth. Therefore we have to measure it after the arrival to the asteroid. Because active measurement methods need too much power, we are developing methods using images taken from the spacecraft.

Our project is mainly run by Dr. Seiji Sugita at Univ. of Tokyo and Dr. Naru Hirata at Aizu Univ., who are researchers in planetary science. However, because shape reconstruction techniques using images have intensively been studied in CV and CG (computer graphics) areas, the project is contributed by Dr. Hiroshi Ishikawa at Waseda Univ. and the author from CV area, and Dr. Shigeo Takahashi at Univ. of Tokyo from CG area.

We have applied a structure from motion technique developed in CV without modifications to the shape reconstruction of asteroids. We have had a minimum result required for Hayabusa-2 navigation, but more precise model is needed to make the navigation more certain and flexible. Therefore, we are combining photometric stereo to it.

Photometric stereo is a shape reconstruction method utilizing reflectance information of objects. However, we cannot directly apply such techniques developed in CV to the asteroid, because the conditions assumed in CV are fairly different from our case. The CV techniques assume that a number of images are taken from the same position, but the spacecraft cannot be controlled in such a way because it requires too much fuel. In addition, the reflectance models are different; Lambertian and Phong, for example, are used in CV, but we need algorithms based upon models such as Hapke and Minnaert, which describe reflectance of planet materials. Therefore, we are developing new algorithms that match the space environment for Hayabusa-2 navigation.

Looking at the origin of CV, it was regraded as a part of artificial intelligence research and has been motivated by artificially realizing functions of visual systems of human beings, or creatures in general. It seems that, from this reason, methods developed in CV tend to be general-purpose, and also that environments on the earth are implicitly assumed. Therefore, algorithms in CV are sometimes not applicable to problems in space science. However, viewing the situation from a different point, it may inspire CV itself to a new research direction by giving clear purposes.

When assuming usage in space, the following peculiarities are observed. The light source is usually only the sun, so it often suffice to consider only parallel light as the illumination. We can develop algorithms fully taking advantage of this simplicity. As mentioned above, reflectance models special to planet are used. If the process is executed in spacecrafts, the amount of computation is very limited, so the view point to develop a minimum algorithm to fulfill the objective becomes important. On the other hand, if images are transferred to the earth, the number of images is limited, but usually no limitation exists in amount of the computation. In such a case, CG-CV loop where a CG model is iteratively modified so that the generated images match to the observed images becomes to have reality. In addition to stated above, computing other information needed for space science than shape, estimating error information (variance), and so on, are important tasks for space science. We believe developing these techniques is an important direction of CV research.

Keywords: image measurement, shape reconstruction, optical navigation, Hayabusa-2

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(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

U06-13 Room:503 Time:April 28 14:35-14:55

Analytical chemistry of organic compounds in the Solar System: An attempt to link with planetary science

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Analytical chemistry of organic compounds in the Solar System small bodies is a microscopic approach for understanding of the origin and evolution of building blocks of the Solar System and life, which has a complementary relationship with macroscopic approaches such as observational and theoretical astronomy. This approach would provide a significance of considering organic compounds in the planetary formation theory, which has been constructed only by silicate and ice dusts. Indeed, significant roles of organic compounds in the early Solar System are explained by (1) high abundances of C, H, O, N in the Solar System, (2) major components of dusts in interstellar clouds, (3) high reactivity to heat, light, shock, water, and minerals (chemical indicator recording the processes in the Solar System), (4) possible contribution to accretion of dusts, due to their stickiness (Kouchi et al. 2002), and (5) possible contribution to redox imbalance in solar nebula (that determined the chemical compositions of chondrules) (Yurimoto and Kuramoto, 1998). Despite these significant roles, however, organic cosmochemistry was not a very popular field in planetary science until several years ago. One of the reasons may be because of difficulty in visualization of organic compounds, i.e., drawing of a big picture. In this point, I attempt to show a simple example. When starch-syrup is heated, how is it changed. One would tell that the color is changed from colorless to brown, the originally sticky syrup becomes less sticky candy, and water-soluble syrup becomes an insoluble solid. These descriptions are based on visuality and are easy to understand. On the other hand, if these phenomena are translated to organic analytical chemistry, the description becomes quite different from the former; hydroxyl groups of glucose changes to carbonyl groups via dehydration as well as aromaticity increases with heating. However, it should be noted that two ways of descriptions explain exactly the same phenomenon. That demonstrates that physical properties (color, stickiness, and solubility) are determined by molecular chemical structures. Likewise, analytical chemistry of organic compounds in the Solar System has a potential to reveal the molecular science that determines physics of macroscopic planetary formation, such as the color of asteroids (albedo). This will become possible by improvements of the in-situ organic analyses such as spectromicroscopy (e.g., STXM), electron microscopy (TEM), and ion probe mass spectrometry (e.g., nanoSIMS), through visualization of the distributions of organics and minerals in the Solar System materials which record the chemical evolution from dusts to planetesimals.

Keywords: Organic compounds, Solar System, Analytical chemistry, small bodies, planetary formation, visualization

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U06-14 Room:503 Time:April 28 14:55-15:15

Formation Process of Complex Organic Molecules in Protoplanetary Disks

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It is believed that chemical reactions in protoplanetary disks will lead the origin of materials in our Solar System. Recently, many complex organic molecules (COMs) have been found in molecular clouds by radio observations of molecular transition lines. Meanwhile, amino-acids are found in a comet and meteorites in our Solar System. In this work we investigate the synthesis of complex organic molecules in protoplanetary disks using a large gas-grain chemical network together with a 2D steady-state physical model of a disk irradiated by UV and X-rays from the central star. We find COMs are efficiently formed on cold and warm grains in the disk midplane via grain-surface reactions through efficient migration of icy species on grain surface. Radiation processing on ice forms reactive radicals and helps build further complexity. We find the grain-surface abundances predicted by our calculations are consistent with those derived from cometary comae observations. We also predict line spectra of COMs, which are partly photodesorbed into gas from grain surface, will be observable in nearby protoplanetary disks with ALMA. In this talk I would like to discuss further on formation process of COMs on grains in the asteroid belt region, too.

Keywords: protoplanetary disks, formation of organic molecules

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U06-15 Room:503 Time:April 28 15:15-15:30

Status report of curation of Hayabusa-returned samples

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Hayabusa spacecraft returned samples from S-type Near-Earth Asteroid (NEA) Itokawa in June 2010. After the return, Extraterrestrial Sample Curation Team (ESCuTe) of JAXA have recovered particles from a sample catcher of Hayabusa, and more than 400 particles initially described have been presented in public (Yada et al., 2014a). In this presentation, we review the recovery and initial description of Hayabusa-returned samples and mention their future schedule.

A sample container had been extracted from the reentry capsule of Hayabusa and cleaned in cleanrooms of the Extraterrestrial Sample Curation Center (ESCuC) of JAXA. It was introduced into a clean chamber No.1 and opened in vacuo, and then a sample catcher, which enclosed samples captured on the surface of asteroid Itokawa, was extracted to be transferred to a clean chamber No.2 which is designed to handle Hayabusa-returned samples in highly purified nitrogen condition. The sample catcher is mainly composed of a rotational cylinder through which captured samples had been transferred, a room A in which samples obtained by the second touchdown on Itokawa and a room B in which captured those of the first one. At first, we had prepared quartz glass disks of the same size with covers of the room A and B, on which particles inside each room were fallen by tapping. The particles on the quartz disks have been picked up one by one with a specially designed electrostatically-controlled micromanipulator to be placed onto a SEM holder which can seal the samples in nitrogen condition and initially described by SEM-EDS. Then they sent back to the clean chamber No.2 to be placed onto gridded quartz glass slides to be given their ID and preserved. In fiscal year of 2013, we started to describe particles on a cover of the room B with SEM-EDS directly, utilizing a SEM holder specially designed for the cover of the catcher (Yada T. et al., 2014b).

The initial description method using the quartz glass disks has disadvantages in inefficiency and risk of particles transportation one by one with the micromanipulator. In order to resolve these disadvantages, we have developed metal disks which particles can be fallen on by tapping and can be set to the SEM holder designed for the covered of the catcher in fiscal year of 2013. We are planning to start sample recovery by the metal disks in fiscal year of 2014, and going to confirm vast majority of particles inside the catcher for more than two years (Yada T. et al., 2014a).

The ESCuTe of JAXA started the international AO for Hayabusa-returned samples in the beginning of 2012. In the international AO, worldwide researchers can apply their proposals and the committee composed manly of top scientists outside JAXA reviews the proposals to determine which proposal the precious samples should be distributed. The AO have been published approximately annually, and the third AO will be published in the beginning of fiscal year 2014. The research results of the AOs are presented in the international symposium held by JAXA, named as ”Hayabusa 2013: Symposium of Solar System Materials”, and its proceedings will be published in the international journal.

Particles having rare features have not been provided to the international AOs, but to consortium studies led by ESCuTe of JAXA until 2013. So far, four consortia, including the maximum-sized particle, a NaCl-bearing one, an iron sulfide one, and ones containing phosphates Uesugi et al., 2013; Yada et al., 2013; Karouji et al., 2013). Particles having other rare features will be provided to consortium studies in future.

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Yada T. et al. (2014a) LPS XLV, Abstract #1759.
Yada T. et al. (2014b) MAPS, in press.

Keywords: Hayabusa, asteroid, curation, sample return

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Examination of the origin of carbonaceous particles in Hayabusa-returned samples

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Extraterrestrial Sample Curation Team (ESCuTe) recovered more than 50 carbonaceous particles from the sample catcher of the Hayabusa spacecraft. Those carbonaceous materials, named as category 3, were found in the form of particles with similar size range of the silicate particles those confirmed as Itokawa regolith particles. Initial description by the SEM-EDS analysis shows variable textures and chemical compositions of them, suggesting the multiple origins of the carbonaceous materials.

Preliminary examinations of category 3 particles were carefully processed in parallel with those of silicate materials. However, we could not obtain the information for the origin of category 3 particles before the opening of international announcement of opportunity (A/O). The ESCuTe and preliminary examination team of category 3 particles have continued the investigations. In this paper, we report the several recent results obtained from the sequential analyses.

Samples allocated for the preliminary examinations of category 3 are RA-QD02-0008, RA-QD02-0120, RA-QD02-0180, RB-QD04-0001, RB-QD04-0037-01 and RB-QD04-0047-02. RA-QD02-0008 was lost during the manipulation at first preliminary examination. Three samples, RA-QD02-0120, RB-QD04-0001, and RB-QD04-0047-02, were pressed on the Au plate and fixed without any adhesive materials. We analyzed H, C and N isotopic composition by nano-SIMS in the beginning of the sequential study, in order to investigate the isotopic anomaly which is a direct evidence of extraterrestrial origin of organic materials [8]. FT-IR and micro-Raman spectroscopy were also applied for the pressed samples [9]. After ToF-SIMS analysis of those particles, the samples were sliced by FIB in order to investigate the fine structure of the samples by XANES and TEM/STEM [10].

We performed those analyses with determining the effect on the subsequent analyses, such as sample damages and contaminations. The rest two particles, RA-QD02-0180 and RB-QD04-0037-01 were pressed on indium plates, because significant disturbance by Au on the ToF-SIMS analyses was found. We will also report the construction of the sequential analysis flow of tiny carbonaceous particles.

In parallel with the Hayabusa-returned particles, we processed observation and analysis of insoluble organic matter (IOM) of A881458 (CM2) and several possible materials of the origin of the category 3 particles, such as viton, silicon rubber, vectran and particles collected from the Hayabusa2 clean room.

We did not obtain any signature of extraterrestrial origin from category 3 particles so far. We are planning to continue the preliminary examination of category 3 by the end of March 2014. We are also planning to open the category 3 particles to the future International A/O, with the data of preliminary examinations before the end of 2014.

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(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

U06-17 Room:503 Time:April 28 15:45-16:00

H, C and N isotopic compositions of HAYABUSA Category 3 organic samples

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Hayabusa spacecraft had brought back asteroid Itokawa particles to the Earth on June 2010. More than 1,500 mineral particles were identified on the Qz glass after the compulsive free fall, and most of them were very small ranging from 10 to 300 μm but are mostly smaller than 50 μm (Nakamura et al., 2011). In addition several amount of carbonaceous materials were found that is called Category 3. Based on FE-SEM and EDS observations at JAXA Extraterrestrial Sample Curation Team, those samples mainly composed of C, N, O and some of them contain NaCl and KCl (JAXA Hayabusa sample catalogue).

H, C and N isotopic compositions of extraterrestrial organic materials in Stardust cometary samples (McKeegan et al., 2006), IDPs (Messenger, 2000), IOM (Busemann et al. 2006) and nanoglobules in primitive chondrite (Nakamura-Messenger et al., 2006) provide a clue for understanding of origin and nature of the Solar System. Large D and 15N isotopic enrichments were observed, and C isotope is slightly enriched in 13C in extraterrestrial organic materials (Pizzarello, 2005). Those data suggest that extraterrestrial organics are probably interstellar material that was survived through formation processes (planetesimals) of the Solar System (Sanford et al., 2001), and may also have material that formed in the cold molecular cloud region of the protoplanetary disk (Aikawa et al., 2002).

Here we report H, C and N isotopic measurement of organic materials from Hayabusa Category 3 samples, RB-QD04-0047-02, RA-QD02-0120 and RB-QD04-0001, by an ion imaging with the JAMSTEC NanoSIMS ion microprobe. The purposes of this study are to evaluate terrestrial contaminations in the Hayabusa spacecraft and in the JAXA curation facility, and to find extraterrestrial organic materials on the basis of H, C and N isotope measurements.

Each Hayabusa organic sample was pressed on Au plate together with terrestrial organic standards of 1-hydroxybenzotriazole hydrate and BBOT with known H, C and N isotopic compositions. Following the SEM study to check the sample condition, texture and morphology, the samples were analyzed for H, C and N isotopic compositions by an isotopic imaging with the JAMSTEC NanoSIMS 50L at Kochi Institute for Core Sample Research.

We studied three Hayabusa organic samples, RB-QD04-0047-02, RA-QD02-0120 and RB-QD04-0001. All of the samples have been initially investigated by a FE-SEM and EDX observation at JAXA Hayabusa curation facility, and the EDX spectra of the samples contain C, N and O; the dominant elements are C, and N (Hayabusa sample catalogue).

Based on NanoSIMS isotopic images of H, C and N in RB-QD04-0047-02, RA-QD02-0120 and RB-QD04-0001, all three samples show homogeneous and terrestrial H, C and N isotopic compositions within an error (δD = 60 $\pm$ 13 permil, δ13C = 3 $\pm$ 3 permil and δ15N = -4 $\pm$ 2 permil for RB-QD04-0047-02; δD = 81 $\pm$ 54 permil, δ13C = -20 $\pm$ 8 permil and δ15N = 2 $\pm$ 2 permil for RA-QD02-0120; δD = 135 $\pm$ 32 permil, δ13C = -20 $\pm$ 9 permil and δ15N = 16 $\pm$ 12 permil for RB-QD04-0001).

The IOMs in CI and CM chondrites show heterogeneous distributions of delta-D at the molecular (Remusat et al. 2009) and micron scale level (Busemann et al., 2006). The IOMs of CR, CM and CI have D and 15N isotopic enrichments in micron-sized regions (hot spots). The IOMs in ordinary chondrites are heterogeneous, however, they do not show many micron-scale anomalies as IOMs in carbonaceous chondrite (Remusat et al., 2013). It is obvious that H, C and N isotope signatures of Hayabusa organic samples are different from those of IOMs in carbonaceous and ordinary chondrites: i.e., No hot spots, terrestrial values for H, C and N isotopes.

We have not found strong evidence of extraterrestrial origin because isotope compositions of H, C and N in Hayabusa organic samples show terrestrial values, and homogeneous distributions of H, C and N in the samples, which are unlike to IOM in various types of chondrites.

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U06-18 Room:503 Time:April 28 16:15-16:35

Albedo properties of main belt asteroids based on the infrared all-sky surveyors

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Presently, the number of asteroids is known to be more than 620,000, and more than 90% of asteroids are classified as the main-belt asteroids (MBAs). The spatial distribution of compositions among MBAs is of particular interest, because the main belt is the largest reservoir of asteroids in the solar system. Asteroids are thought to be the remnants of planetesimals formed in the early solar system, and have a clue to study the formation and evolution of asteroids, origin of meteoroids and the near-Earth asteroids, as well as the formation of the solar system. Size and albedo are one of the most basic physical quantities of asteroid. Knowledge of size and albedo is essential in many fields of asteroid research, such as chemical composition and mineralogy, the size-frequency distribution of dynamical families and populations of asteroids, and the relationship between asteroids in the outer solar system and comets.

Several techniques have been developed to determine the size of asteroids. One of the most effective methods for measuring asteroidal size and albedo indirectly is through the use of radiometry, where a combination of the thermal infrared flux and the absolute magnitude as the reflected sunlight. Using radiometric measurements, a large number of objects can be observed in a short period of time, providing coherent data for large populations of asteroids within the asteroid belt. Infrared observations can be made still better under ideal circumstances, from space. The first space-borne infrared telescope is the Infrared Astronomical Satellite (IRAS; Neugebauer et al. 1984), launched in 1983 and performed a survey of the entire sky. To date, there are two other infrared astronomical satellites dedicated to all-sky survey: the Japanese infrared satellite AKARI (Murakami et al. 2007), and the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010). Based on the all-sky survey data obtained by IRAS, AKARI, and WISE, the largest asteroid catalogs containing size and albedo data were constructed (e.g., Tedesco et al. 2002; Usui et al. 2011; Mainzer et al. 2011). The total number of asteroids detected with size and albedo information with these three surveyors is 138,285, which is 22% of currently known asteroids with orbits.

In addition, several outstanding works have provided the taxonomic classification of asteroids (e.g., Tholen 1989; Bus & Binzel 2002; Lazzaro et al. 2004; Carvano et al. 2010), based on ground-based spectroscopic observations within optical and near-infrared wavelengths. Along with these taxonomic classifications, size and albedo data also contribute to our understanding of asteroid compositions. In general, the albedo of C-types is considered as low and that of S-types is high (e.g., Zellner & Gradie 1976). The relationship between taxonomic types and albedo is, however, complex and type determinations cannot be made on the basis of albedo values alone. Recently albedos of C- and S-type asteroids are found to vary widely, especially for sizes smaller than several tens km (Usui et al. 2013). Furthermore, in spite of the albedo transition process like space weathering, the heliocentric distribution of the mean albedo of asteroids in each taxonomic type is found to be nearly flat. In the total distribution, on the other hand, the mean albedo value gradually decreases with increasing the semimajor axis, presumably due to the compositional mixing ratios of taxonomic types.

In this talk, we present the details of data compiling of size, albedo, and taxonomy of MBAs, and discuss the compositional distribution in the main belt regions.

Keywords: asteroids, main belt, infrared surveys, size and albedo, taxonomic classifications

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Lightcurve Survey of Vestoids in the Inner Asteroid Belt

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We have made the lightcurve observation of 13 vestoids ((1933) Tinchen, (2011) Veteraniya, (2508) Alupka, (3657) Ermolova, (3900) Knezevic, (4005) Dyagilev, (4383) Suruga, (4434) Nikulin, (4796) Lewis, (6331) 1992 FZ_1, (8645) 1998 TN, (10285) Renemichelsen, and (10320) Reiland).

Lightcurves in the R-band of rotation periods were found for (1933) Tinchen, (2011) Veteraniya, (2508) Alupka, (3657) Ermolova, (3900) Knezevic, (4005) Dyagilev, (4383) Suruga, (4796) Lewis, (6331) 1992 FZ_1, (8645) 1998 TN, and (10320) Reiland.

The distribution of rotational rates of 59 vestoids in the inner main belt, including 29 members of the Vesta family that are regarded as ejecta from the asteroid (4) Vesta, is inconsistent with the best-fit Maxwellian distribution.

This inconsistency may be due to the effect of thermal radiation Yarkovsky- O'Keefe-Radzievskii-Paddack (YORP) torques, and implies that the collision event that formed vestoids is sub-billion to several billion years in age.

Keywords: asteroid, vesta

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Near-infrared spectral measurements of zodiacal light by CIBER rocket experiments

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We have observed the cosmic near-infrared background light as the integrated light along the line of sight, which is the near-infrared diffuse radiation in wide range of the cosmic structure from the solar system to extragalactic universe, with the CIBER (Cosmic Infrared Background ExpeRiment) rocket experiments. One of scientific objectives of CIBER is to measure the zodiacal light in the near-infrared, which is the scattered sun light by interplanetary dusts. From the results of CIBER, we first observed the zodiacal light spectrum and its polarization in the near-infrared range from 0.8 to 2 mincrons. In this paper, we present the observation results.

CIBER is an international collaboration study among Japan, US and Korea, and a sounding rocket program by NASA. In a term from 2009 to 2013, we have carried out four times of launch and obtained high quality data at the altitudes above 200 km with no contamination by the earth atmosphere. In order to measure the extragalactic background light, we selected the observation field to have solar elongation over 90 degrees with relatively low brightness. We extracted the zodiacal light component from the total sky brightness by using the ecliptic latitude dependence. As the result, we could obtain information of spectrum, polarization and seasonal variation of the zodiacal light.

The observed infrared spectrum shows neither ecliptic latitude dependence nor time variation, and reddened color compared with the solar spectrum at wavelengths below 1.5 microns. From this result, size of interplanetary dust is larger than the order of micron, and there may be absorption of dust minerals at shorter wavelengths. We found the polarization of 20-25% at the maximum at the north ecliptic pole, which is higher than that previously observed in the visible wavelength range. The polarization result also suggest that the majority of the dust size is much larger than the observation wavelength.

In this paper, we report the observation result, and we discuss the optical properties of interplanetary dust by comparing our result with the spectral reflectance of meteorites and cometary dust.

Keywords: zodiacal light, interplanetary dust, infrared, observation

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Reflectance Spectra of Jovian Small Satellites and Implication of their Origin

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Abstract

Jupiter has many small satellites other than the four giant Galilean satellites. Four of them revolve inside Io's orbit and others revolve outside Calisto's orbit. Based on the similarities of their photometric and orbital properties, these small satellites are thought to be captured asteroids. However, it is still unknown where and when these satellites were captured by Jupiter. We can reveal the dynamic history of our solar system evolution by investigating these questions.

Here, we have made optical spectroscopies of 11 small satellites which were not yet taxonomically classified by spectroscopy so far. We compared the number ratio of C- and X-type to D-type of the 11 satellites, and the Hilda and Trojan groups observed recently by Grav et al. (2012) as a function of diameter. We found that the diameter-(C,X)/D relation of the Jovian irregular satellites is similar to that of Hilda's, not Trojan's. This result suggests that the Jovian irregulars and the Hilda members originate from the same source of asteroids.

We also observed the 3.05 μm narrow-band photometry of the inner small satellite Thebe and found that there is absorption. This can be attributed to hydrated minerals.

Keywords: satellites, Jupiter, spectrum, Hilda group, Trojan

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U06-22 Room:503 Time:April 28 17:20-17:35

Weathering effect of solar wind proton on hydrated silicate minerals

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NIRS3 is an on-board near infrared spectrometer of Hayabusa-2 project which is aimed at returning samples from C-type asteroid 1999 JU3. In this project, it is important to characterize mineralogical and heterogeneities on the asteroid surface for the sampling site selection. Observing wavelength of NIRS3 is including the 3 μm band which is charactering C-type asteroid (*Rivkin et al. LPSC 2002, Milliken et al. 2007*). The NIRS3 will measure reflectance spectra of asteroid surface in the wavelength range of 1.8 - 3.2 μm. This wavelength region includes features mainly related to OH and H_2O.

The spectral properties of the surface, however, would have different trend to the subsurface, because the surface of asteroids would be exposed to solar wind and micrometeorite. As for the reflectance spectrum of the moon, the absorption feature from 2.8 μm to 3.0 μm was reported in M^3 data (*Pieters et al. 2009*). It is thought that the implantation of solar wind proton is one of the causes (*McCord et al. 2011*). The solar wind protons will affect the spectral shape of 3μm region of air less bodies. Thus we study effect of irradiation of solar wind protons on near-infrared reflectance spectra by laboratory experiment.

We executed the simulation of irradiation of solar wind protons using ion implantation device at the Wakasa Wan Energy Research Center (WERC), Fukui. This device can irradiate $H_2{}^+$ beam with 10 keV in a vacuum (under 1×10^{-5} Pa). The total amount of $H_2{}^+$ was about 10^{18} ion/cm^2. Three samples were prepared; olivine (San Carlos, Arizona), antigorite (Sangenchaya, Kyoto), saponite (synthetic: Kunimine Industries Co., Ltd.). Antigorite and saponite were sieved between 50 μm and 75 μm and olivine served between 75 μm and 105 μm, and then they were heated for 24 hours at 423 K. They were packed into Cu cups and formed pellets. After irradiated the spectra were measured using FTIR, which resolution was 2.0 cm^{-1} in wavenumber. We adopted the analysis method of *Ichimura et al. (2012)*, which is to compare the reflectance spectra of altered sample, R, with unaltered sample, R_0, to determine the alteration ratio of spectra, R/R_0, without absorption water.

The alteration ratios of irradiated samples were different between minerals. The alteration ratio of olivine showed increasing of broad absorption feature from 2.8 μm to 3.8 μm due to OH/H_2O production. In antigorite and saponite, the alteration ratio, additionally, showed characteristic change related to coupling state of -OH. In the alteration ratio of antigorite, stretching of -OH bonded water molecule (-OH $\cdots$ ^{H}OH) at 2.77 μm and stretching of -OH $\cdots$ ^{H}OSi at 2.85 μm was increased conspicuously. On the other hands, the alteration ratio of saponite was changed conspicuously at 2.77 μm.

We think that the difference of the bands which showed conspicuously change is related with structure of minerals. Antigorite have -OH into the crystal. Therefore the irradiated protons broke bonds of Si-O and produced newer hydrogen bonds which are -OH $\cdots$ ^{H}OH or -OH $\cdots$ ^{H}OSi. Saponite has H_2O as interlayer water. It would be similarly broken bands of Si-O and produced newer hydrogen bonds which are -OH $\cdots$ ^{H}OH. These spectral changes can explain same process. These features support that the irradiated protons react with bonds of Si-O in the crystal.

In this study, we showed that the alteration of feature related with OH/H_2O is different from each mineral. Next step, we will examine the other minerals against determination minerals and the amount of water from reflectance spectra.

Keywords: Hayabusa-2, space weathering, solar wind, OH/H_2O, C-type Asteroid, proton implantation

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The effect of coexisting iron sulfide on space weathering by nanosecond pulse laser irradiation

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High-velocity impacts of micrometeorites and solar-wind particles change the surface optical properties of airless silicate bodies such as asteroids and the Moon. This process is called ”space weathering”. Experiments using nanosecond pulse laser confirmed the prediction that the formation of nanometer-size metallic iron particles should cause darkening, reddening and attenuation of absorption bands in visible and near infrared reflectance. The space weathering may explain the spectral mismatch between S-type asteroids and ordinary chondrites.

Previously sulfur depletion from asteroid surface was advocated on the basis of low sulfur abundance on Eros.

Recently on the surface of dust particles from Itokawa’s surface returned by Hayabusa, a thin layer containing nano particles of FeS over amorphous zone containing nano iron particles. A 10 micron size FeS crystal is also found in one Itokawa-derived grain.

To examine the effect of FeS on the space weathering, we conducted simulation experiments of the space weathering of silicate-FeS mixture using nanosecond pulse laser irradiation.

Then S is rich in volatility, so we guessed if sulfur has a certain influence on space weathering at the astronomical surface, and the experiments on chondrites with S by using nanosecond pulse laser.

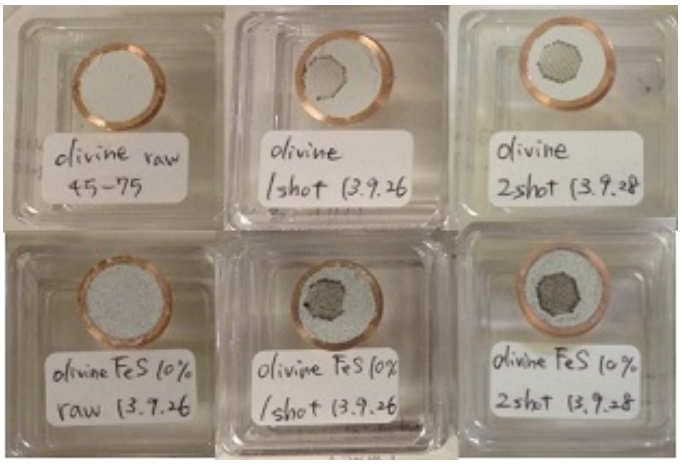
We prepared pellet samples of powdered olivine and pyroxene (45-75 micrometer) mixed with iron sulfide particles (of 10, 20wt%) with same (and smaller) size range. We also prepared olivine pellet samples containing metallic iron particles of 10 to 20 wt%.

We found that the addition of Fe should enhance reddening and also darken near infrared reflectance (about 20% in the case of 10-20wt % FeS)., as compared with the case of the addition of Fe.

Although it was space weathering which has so far attracted attention from reddening, such as reddening by weathering in case Fe is contained, in the case where FeS is added, darkening was also seen and it has checked that space weathering became strong. Although existence of nano iron particulates can be considered about reddening, about overall darkening, it is under examination.

The samples were irradiated by nano-second pulse laser.

Keywords: space weathering, iron sulfide, experiments using pulse laser, asteroids, Itokawa



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U06-P01 Room:Poster Time:April 28 18:15-19:30

Photometric Properties of (162173) 1999 JU3 in Preparation for JAXA Hayabusa 2 Sample Return Mission

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A near-Earth asteroid, (162173) 1999 JU3 (hereafter 1999 JU3), is a primary target asteroid for Hayabusa 2 sample return mission. We conducted a worldwide campaign to make photometric observations of the asteroid to determine the physical properties. 1999 JU3 is classified into C-type asteroid having a nearly spherical shape and the synodic rotational period of 7.6312±0.0010 hr.

In this presentation, we will report further information about 1999 JU3 determined since last JpGU meeting in 2013. We investigated the magnitude-phase angle relation. We obtained the parameters for IAU H-G formalism, H =19.20±0.12 and G=0.077±0.011 (V-band, 550nm), respectively. In combination of our result with infrared photometry, the geometric albedo is updated to be 0.05 (Mueller et al. in preparation), which is typical to but slightly smaller than the average of C-type asteroids in main-belt. We found that the magnitude-phase angle relation has a linear behavior in a wide range of the phase angles (5-80 degree) and show a possible non-linear opposition brightening within the phase angle of ‹ 5 degree. The phase slope is consistent to those of tens-km C-type asteroids, that is, 0.04 mag degree^{-1}. The opposition effect amplitude, ≈10% or less, is slightly weaker than that of a precursor C-type mission target body, (253) Mathilde, but the difference seems to reflect the diversity of C-type asteroids. Recently, Shevchenko & Belskaya (2010) reported that ˜20% of all studied low albedo asteroids did not show detectable opposition effect. We explore the significance of 1999 JU3 data with remote-sensing devices in terms of the opposition effect.

Keywords: Hayabusa 2, 1999 JU3, Ground-based observations

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U06-P02 Room:Poster Time:April 28 18:15-19:30

Observation of geometric albedo of the C-type asteroid by the laser altimeter on Hayabusa-2 spacecraft

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The Japanese asteroid explorer 'Hayabusa2' will be launched at end of 2014, and it will probe the near-Earth C-type asteroid '1999JU3'. In this mission, we have a plan to utilize the laser altimeter (LIDAR) to investigate the distribution of geometric albedo of 1999JU3 at laser wavelength (1064 nm). The LIDAR on-board Hayabusa2 has functions to measure the intensities of sending laser pulse and receiving laser pulse reflected from the asteroid surface in addition to measurement of distance between the spacecraft and the asteroid. We can evaluate the geometric albedo of the 1999JU3 using the measured intensities of sending and receiving pulses.

In this presentation, we will indicate results of the performance tests of the LIDAR and expected accuracy of the albedo evaluated from the results of the tests. We will also describe not only effect of characteristic of the LIDAR but also effects of inclination and roughness of the asteroid surface on estimation of the albedo.

In our study, three types of scientific topics using information of the albedo on asteroid surface estimated from the LIDAR data with other equipment data are considered; they are (1) rock and mineral category of 1999JU3, (2) degree of water content on asteroid surface and (3) variation of asteroid surface caused from space weathering and/or exterior material. We will report prospects to obtain information about these science topics applying the LIDAR which has our evaluated performance.

Keywords: Albedo of Asteroid, C-type asteroid, 1999JU3, Hayabusa-2, Laser Altimeter

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U06-P03 Room:Poster Time:April 28 18:15-19:30

Performances of Flight Model of NIRS3: the Near Infrared Spectrometer on Hayabusa-2

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NIRS3: the Near Infrared Spectrometer is one of the candidate scientific instruments which will be equipped on Hayabusa-2 mission. It aims to observe near infrared spectroscopy at the wave length band of 1.8-3.2 micrometer to detect specific molecular absorption lines, including the absorption by hydrated minerals at 3 micrometer, on the target C-type asteroid. The major purpose of NIRS3 is to observe the absorption bands of hydrated minerals in the 3 micrometer band on the candidate target C-type asteroid 1999JU3. C-type asteroids are thought to be mother celestial bodies of carbonaceous chondrites (C-chondrites). C-chondrites have been classified into sub-groups by their composition, organization, and isotope ratio of oxygen. The spectra of C-type asteroids have also been classified into sub-types by their inclination and the existence of absorption bands detected in ground observations. However, the relationship between the sub-groups of C-chondrites and the sub-types of C-type asteroids has not been clarified due to the effects of solar radiation and space weathering. Therefore, we will directly observe the surface of a C-type asteroid without the terrestrial atmospheric absorption in the 3 micrometer band using NIRS3. Detecting younger terrain by global mapping of the asteroid and the ejecta of new crater by the Small Carry-on Impactor (SCI) will also provide the spectra of surface less affected by space weathering. To estimate the quantities of the hydrated minerals with accuracies of 1 to 2 wt%, we designed the NIRS3 system to have a signal-to-noise ratio (SNR) exceeding 50 at 2.6 micrometer for global mapping.

The ground tests for NIRS3 flight model started in 2013. Results of the flight model tests implied that the dark current at the InAs sensor is much lower than that of the engineering model which improves SNR. The projected on-board SNR was confirmed to be sufficient during the one-year observation period of 1999JU3 assuming the asteroid surface temperature estimated from the heliocentric range and solar phase angle. The SNR exceeds 300 after 2.5 ms integration and 1024-stacking at the home position observations. The data obtained after the vibration tests and thermal-vacuum tests indicate that NIRS3 is sufficiently durable for the launching and on-orbit environments. The observed spectra for samples of serpentine, olivine, and C-chondrites (Murchison, Murray, and Jbilet Winselwan) demonstrated that the derived reflectances are almost the same as those obtained by Fourier-transform infra-red (FTIR) spectroscopy. These design results show that NIRS3 has sufficient performance for scientific objectives.

Keywords: Hayabusa-2, asteroid, 1999JU3, NIRS3, near infrared, spectrometer

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Thermal Infrared Imager TIR on Hayabusa2: Instrumentation and Ground Calibration

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Thermal Infrared Imager TIR onboard Hayabusa2 is to map thermo-physical properties of Near-Earth C-class asteroid (162173) 1999JU3 through thermal imaging. Scientific significance must be placed on physical properties of asteroids as well that imply the planetesimal formation in solar nebula and its mechanical evolution to current small bodies, although planetary material science is often more focused in small body missions.

In the typical solar system evolution scenario, very fluffy porous bodies are formed in solar nebula and then become denser due to high-speed collision and thermal metamorphism. Some C-class asteroids are less dense, implying a highly porous assembly of densely compacted rocks or a loosely bound rubble-pile of porous rocks and soils. Those features will be identified by thermo-physical properties derived with TIR. Some C-class asteroids must have experienced dehydrated process whose clues might be found as veins or grooves on the asteroid. Those features are expected to be investigated by TIR. Granular flows which were found on asteroid Itokawa and ejecta sediments around impact craters will be measured by TIR as different thermal inertia zones because they have smaller particle size or higher porosity. Floating boulders (or moons), surrounding dust or vapor clouds ejected from asteroid surface could be detected by TIR if they exist sufficiently. Furthermore, on-site TIR observation will contribute to more confident and accurate determination of asteroid thermo-physical properties by ground observation.

TIR is a thermal infrared imager using two-dimensional micro-bolometer array, which has 328 x 248 effective pixels, 16 x 12 degrees field of view, and 0.05 degree per pixel, so that pixel resolution is 20m when observed from 20km altitude Home Position (HP), and less than 1m from 1km altitude covering 280m x 210m. The imaging feature is suitable for obtaining asteroid global feature from HP and investigating local geological context before and after sample collection. Hayabusa2 will observe asteroid 1999JU3 at the heliocentric distance from 0.96 to 1.42 AU and the dayside surface temperature is estimated -40 to 150 ℃ assuming the albedo is 0.05 and emissivity is 0.90 to 0.95. Detection range of TIR is 8 to 12 μm, which is best for observing thermal radiation from asteroid.

We have calibrated TIR performance for the target temperature ranging from -40 to 150 ℃. Goal is to construct the calibration curves for each pixel by 3 ℃ absolute temperature as well as 0.3 ℃ NETD. The apparatus for TIR calibration are the vacuum chamber for cold target and the clean-booth for hot target, with adjusting the optics and mounted panel temperatures. It is ideal that a single OFPN (Onboard Flat Pattern Noise) data is applicable for all the temperature range. Now efforts have been taken to improve its performance by interrelation between cold and hot calibration cases, adjusting bias levels due to different thermal energy input to detector, as well as geometric calibration. Instrumentation and results of calibration for TIR will be reported in detail.

Keywords: asteroid, Hayabusa2, thermo-physical property, Thermal Infrared, bolometer, planetary exploration

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U06-P05 Room:Poster Time:April 28 18:15-19:30

Relationship between Regolith Particle Size and Porosity on Small Bodies

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Planetary small bodies are covered by a particulate layer called regolith. The particle size and porosity of the regolith surface of small bodies are important physical properties. The responses of the surface to solar irradiation are dependent on the particle size and porosity. The particle size and porosity have influences on the dynamic responses of the surface, such as cratering efficiency. By Apollo missions, the particle size was directly measured and estimated the mean porosity of the regolith 51% (Mitchell et al., 1974). The near-surface bulk porosity of asteroid was estimated using ground-based radar data to have a mean of 51∓14% (Magri et al., 2001). The angular width of opposition surge in optical reflectance was interpreted in terms of porosity and particle size distribution : surface porosities of S-class asteroidswere ranging from 40 to 80 % (Hapke, 1986; Domingue et al., 2002).

An empirical relationship between porosity and the ratio of the magnitudes of the interparticle force that was estimated as the capillary force and gravity which act on a particle was presented by Yu et al. (2003). The porosity was measured for the particles in the loose packing state and different porosities were interpreted as due to the difference of particle size. In this study we assume that the van der Waals force is predominant in the interparticle forces. A model formula of the van der Waals force in which the effect of adsorbate molecules is taken into account by a parameter is defined as

$Fv=AS^2r/48\Omega^2$ (1)

where A is Hamaker constant, r is particle radius, Ω is diameter of an O^{-2} ion, S is cleanliness ratio which shows the smallness of a number of the adsorbate molecules (Perko et al., 2001). It was shown that cleanliness ratio, S, is approximately 0.1 on the Earth, and is almost unity in the interplanetary space. In addition to the data of the several past studies, our own measurement result of micron-size fly ash particles in atmospheric condition.

We calculate Fv of all data using Eq.2, and obtain a revised relationship between porosity and the ratio RF of the magnitudes of the van der Waals force and gravity Fg , $R_F = F_V/F_g$. An empirical formula used in the previous study (Yu et al., 2003) ,

$p=p_0+(1-p_0)\exp(-mR_F^{-2})$ (2)

is applied to fit the data, where p_0, m and n are constants. Substituting Eq.1 to Eq.2 yields,

$p=p_0+(1-p_0)\exp\{-m(AS^2/64\pi\Omega^2\rho gr^2)^{-n}\}$ (3)

where $\rho$is particle density and g is gravitational acceleration.

We apply Eq. 3 to the conditions of small bodies ' surfaces to derive the relationship between particle radius and porosity. For example, we obtained the relationship for asteroid 25143 Itokawa surface. The particle size of Itokawa is ranging from millimeter to centimeter in the area of fine particles, smooth terrain of the Muses Sea (Yano et al., 2006). The result shows the range of porosity would be 0.55-0.8. Similarly, we can calculate the above relationships for other small bodies.

Gundlach and Blum (2013) estimated the particle size of small bodies by using the thermal inertia data and a heat conductivity model for regolith. By combining the relationship described for Eq.3 with those of Gundlach and Blum (2013), we can estimate the particle size and the porosity of regolith for the small bodies simultaneously.

Keywords: asteroid, regolith, porosity

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How to detect a small crater produced by Small Carry-on Impactor (SCI) using Thermal InfraRed Camera (TIR)

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In Hayabusa-2 mission, a crater will be formed on the surface of a C-type asteroid 1999JU3 using Small Carry-on Impactor (SCI) and the crater should be quickly detected from the mother ship. The detection, however, will become difficult when the crater is very small with a diameter of only 30 cm, near to the resolution limit of on-board cameras. On the other hand, Thermal InfraRed Camera (TIR) mounted on Hayabusa-2 has a possibility to detect such a small crater even if the crater size is sub-pixel of TIR resolution, because the temperature on the surface of a small crater is expected to be different from that around the crater. We, therefore, have started examination about the possibility and method to detect a SCI-formed small crater using TIR. In this presentation, we introduce the basic idea and the preliminary results of our modeling.

Keywords: Hayabusa-2, Impact, SCI, TIR, cater thermal model, asteroid

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U06-P07 Room:Poster Time:April 28 18:15-19:30

Hayabusa 2/SCI: calibration impact experiments

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SCI (Small Carryon Impactor" boarded on "Hayabusa 2" is a hollow Cu sphere with a mass of 15 kg, a diameter of 15 cm, which will impact a surface of asteroid 1999JU3. To estimate the conditions of the surface of the asteroid, such as composition and structure, we should investigate the results of the impact experiments with similar projectiles and various targets. We carried out impact experiments with gypsum and basalt targets and small hollow projectiles accelerated by a two-state light-gas gun at ISAS/JAXA, and sand targets and real scale projectiles at Kamioka. We report a summary of the results of these experiments.

Keywords: Hayabusa 2, Small Carryon Impactor, Impact experiments

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Impact crater formation on quartz sand: the effect of projectile density on ejecta velocity distributions

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Introduction : Regolith formation and surface evolution on asteroid are caused by high velocity impacts of small bodies. The ejecta velocity distribution is one of the most important physical properties related to the crater formation and it is necessary to reconstruct the planetary accretion process among planetesimals. The surface of small bodies in the solar system has a various property on the porosity, strength and density. Therefore, the impact experiment on the target with the various properties is necessary to clarify the crater formation process applicable to the small bodies in the solar system. However, there have not enough studies on the effect of projectile density on the ejecta velocity distribution. Therefore, we would try to determine the effect of projectile density on the ejecta velocity distribution using 8 projectiles with different density by means of the observation of the each ejecta grain.

Experimental method: The cratering experiment was made by using a vertical type one-stage light gas gun (V-LGG) set at Kobe Univ. We used 3 types of targets: that is, they are the 100micron-glass beads target (porosity 37.6%), the 500 micron-glass beads target (porosity 37.6%), and 500-micron quartz sand (porosity 44.7%). These granular materials were put into the stainless steel container with the diameter of 30cm and the depth of 11cm. The target container was set in a large chamber with the air pressure less than 10^3 Pa or 10^5Pa. The material of the projectile that we used was a lead, a copper, an iron, a titanium, a zirconia, an alumina, a glass, and a nylon (1.1-11.3g/cm^3), and it had a diameter of 3mm and was launched at the impact velocity (v_i) of 24 to 217m/s.

We made an impact experiment using 8 types of projectiles on the 500-micron quartz sand target and observed each ejecta grain by using a high speed digital video camera taken at 2000-10000 FPS. Then, we measured the ejection velocity and the initial position of each grain. We successfully obtained the relationship between the initial position and the initial ejection velocity or ejection angle for the quartz sand grains.

Result: In (Eq.1), mu is proportional to density of projectile in the range less than 6g/cmˆ3. (Eq.2)

$v_e/v_i=a(x/R)^{(-1/mu)}$?(1)

, where ve is an ejection velocity of grain, x is the initial position of ejecting quartz sand grains and R is the crater radius.

mu=0.05ρ+038 -(2)

Moreover, we obtain the relation between crater size and projectile density.(Eq.3)

[R$*$(ρt/m)ˆ(1/3)]=11$*$[ρt/ρp]ˆ0.096 ?Eq(3)

The ejection angle of quartz sand grains is also obtained. For all projectiles, the grain that ejects from near impact point have high ejection angle and the more distant that grain ejects from, the lower the eject angle is. There are no effect of projectile density.

The obtained empirical equation between the ejection velocity and the initial position is as follows Eq(4),

$ve/vi=1.5*10^{-3}(x/R)^{-1.8}$ (0.3<x/R <0.9) -(4)

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Impact cratering experiments on granular slopes

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Impact cratering is an important process for the evolution of planetary surfaces. Many experiments of impact cratering into granular media have been conducted to understand its basic physics (e.g., Walsh et al., 2003, de Vet and Bruyn, 2007). These studies have shown that as impact energy becomes larger, simple craters transform into complex craters. In addition when gravity is more important than the target strength, the crater diameter increases in proportion to the 1/4 power of the impact energy. Peculiar craters on asteroids have been discovered in recent planetary missions. Some craters on asteroids are likely to be in the transitional regime between the gravity and strength dominated regimes. In order to better understand how such craters may have formed, we have recently conducted experiments around the transitional regime (Takita and Sumita, 2013). In addition, because asteroids have large topography relative to its size, some craters seem to have formed by impact on slopes (Jaumann et al., 2012). However, since most previous experiments were performed on horizontal targets, impact cratering on slopes is still poorly understood. In this study, we report the results of experiments to understand the effects of slope angle on crater formation.

The experiments in this study were performed by dropping spherical projectiles into an inclined granular target. Projectiles are made of stainless steel (density: 7.70g/cm^3) and their diameters are 11.0mm and 22.2mm. We use sand (mean diameter of 0.204mm, density of 2.66g/cm^3, angle of repose of 37.2○, volumetric packing fraction of 0.56) for the granular target. The slope angle ϑ was 0○,11○,16○,22○,34○. Impact energy E was 0.055 , 0.073 and 0.58 J. Crater formation process was recorded by a high speed camera. The 3-D topographies of the granular target before and after the impact were measured by a laser displacement meter which we move by a stepping motor. Resolution of the laser displacement meter is about 0.024mm for vertical direction, and about 0.1mm for horizontal direction. The stepping motor moves at 0.2mm intervals. We obtained the vertical displacement of the granular target caused by the impact by subtracting the topography of the target before and after the impact. We defined the maximum vertical displacement as the crater depth, the length of the crater in the dip direction projected to the horizontal plane as the crater length, and the width in the strike direction as crater width.

We find that the part of the crater rim disappears when ϑ is larger than about 20○. From studying the images recorded by high speed camera, we find that when ϑ becomes large, the slope above the impact point collapses and this causes the partial disappearance of the rim.

Comparing with the Vestan craters (Jaumann et al., 2012), we find that both laboratory and Vestan craters have common asymmetric shape with ejecta spreading down slope and the location of the maximum depth also shifted towards downslope. We find that the crater depth decreases with ϑ . On the other hand, crater length and crater width remains unchanged from 0○to 22○and increased when ϑ was larger than 22○. As a result, the depth / length ratio decreased from 0.25 to 0.05 with the increase of ϑ.

We also analyzed the impact energy dependence of the crater scales and fit them by a power law relation AE $\wedge$ α. We find that with the increase of ϑ, both the prefactor A, and the exponent α changes. This shows that the scaling law obtained for the horizontal granular target cannot be directly applied to impacts on slopes.

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Keywords: impact cratering, granular matter

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Size Dependence of Impact Disruption Threshold of Iron Meteorites

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Iron meteorites and some M-class asteroids are generally understood to be fragments that were originally part of cores of differentiated planetesimals or part of local melt pools of primitive bodies. On these primitive bodies and planetesimals, a wide range of collisional events at different mass scales, temperatures, and impact velocities would have occurred between the time when the iron was segregated and the impact that eventually exposed the iron meteorites to interplanetary space.

In this study, we performed impact disruption experiments of iron meteorite specimens as projectiles or targets at room temperature to increase our understanding of the disruption process of iron bodies. Our iron specimens (as projectiles or targets) were almost all smaller in size than their counterparts (as targets or projectiles, respectively), with one exceptional shot. Experiments of impacts of steel specimens were also conducted for comparison.

The fragment size distribution of iron material is different from that of rocks because in iron fragmentation, a higher percentage of the mass is concentrated in larger fragments, probably due to its ductility. The largest fragment mass fraction is dependent not only on the energy density but also on the size of the specimen. We show the largest fragment mass fraction has a power-law dependence to initial peak pressure normalized by a dynamic strength, which is defined to be dependent on the size of the iron material.

This work was supported by the Space Plasma Laboratory, ISAS, JAXA, Japan and by the Global Center of Excellence Program of Pulsed Power Science, Kumamoto University.

Keywords: Small Bodies, Iron Meteorite, Impact Process

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Cratering chronology models for the near-Earth asteroid 1999 JU3

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The Japanese asteroid explorer Hayabusa-2, that is scheduled for launch in 2014, will be observe a near Earth C-type asteroid 1999 JU3 and will return to Earth with its samples. In this study, we model cratering and crater erasure processes on 1999 JU3 to provide an age estimate for 1999 JU3 based on high-resolution images that will be obtained by Hayabusa-2. The impact rate on 1999 JU3 is calculated from population models of main-belt asteroids (MBAs) and near-Earth asteroids (NEAs) and the average collision probabilities for the main belt and for NEAs. By converting the impactor size to the size of consequent crater based on crater scaling law and the average collision velosities for the main belt and for NEAs, the cratering rate on 1999 JU3 is calculated. For comparison, we use two population models of asteroids, two crater scaling laws and five conditions of surface of 1999JU3. In addition, two crater erasure processes, seismic shaking and saturation of craters, are considered in our model. As a result, our models indicate that age estimate of 1999 JU3 primary depends on crater scaling laws used and assumptions of surface conditions of 1999 JU3 rather than population models of asteroids.

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Scaling analysis of cavity morphology and disruption threshold for highly porous targets

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The morphology of the cavity formed by an impact can be dependent on parameters such as porosity, bulk density and strength of target bodies and size, bulk density, strength and impact velocity of impactors. Laboratory impact experiments have been conducted and cavity diameter and depth have been studied in previous studies in which highly porous targets up to 60% in porosity were used (e.g. gypsum, sintered glass and snow). Based on recent spacecraft missions and ground-based observation, it is shown that small bodies have even higher bulk porosities up to 86% (Consolmagno et al., 2008). Experiments using further highly porous targets are necessary for understanding collisional evolution of such bodies in the formation period. We study cavity morphology of highly porous targets and compile the result with previous studies. We also study disruption threshold of targets and compile the results.

We prepared porous targets with three different porosities, which have porosity of 94%, 87% and 80% (Okamoto et al.,2013). Various projectiles with different density and strength were used; titanium, aluminum, stainless steel and nylon spheres of 1 and 3.2 mm in diameter, and basalt cylinder of 3.2 mm in diameter and 2.0 mm in height. The impact velocity was ranged from 1.7 to 7.2 km/s.

The track was long and thin, in carrot-shape, when the projectile was intact, while it was short and thick, in bulb-shape, when the projectile was fragmented. We report the results of bulb-shape cavity in this presentation.

We apply crater scaling law in strength regime for maximum diameter and entrance hole diameter of the cavity. We compile data of previous studies and ours to obtain empirical relationships. A correlation is shown between the distance from entrance hole to maximum diameter and characteristic depth where initial kinetic energy of projectile becomes 1/e. Characteristic length is a function of drag coefficient. Since the drag coefficient depends on the fragmentation degree of projectile, it is shown that disruption of projectile affects the distance from the entrance hole to the maximum diameter.

Volume, maximum diameter and depth of cavity during its growth were measured on flash X-ray images. Normalized cavity volume and time (Schmidt and Housen., 1987) are applied for the analyses of the results. They have a power law relationship. The power law index for shots with larger density ratio (target density / projectile density) is slightly larger than those with smaller density ratio. Similarly power law relationships between normalized depth of cavity, maximum diameter and normalized time were obtained, respectively. The power indices are consistent of the power index determined for the normalized volume and time. Thus the growth of cavity volume can be explained by growth of maximum diameter and depth.

The threshold energy density for disruption $Q^*$is defined by energy density leading to a largest remnant having half the mass of the target. Q^*increases slightly with porosity of the targets. $Q^*$for the targets with equal diameter-height ratio is slightly larger than those with longer shape (diameter /height=0.5). In this presentation, we will discuss scaling of $Q^*$with various previous study.

Keywords: impact experiment, small body, crater, catastrophic disruption

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A consortium study of the largest particle of Hayabusa-returned samples

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Hayabusa-returned samples retrieved by the Hayabusa spacecraft were already distributed and investigated in the preliminary examinations and international A/Os. Through the investigations, several insights have been obtained on the formation process of 25143 Itokawa and surface processes occurred on the asteroid, as well as the confirmation that the particles were certainly regolith particles from there [1-6].

There are several particles, however, which have not been distributed for those examinations because of their rare features appeared in the initial description done by extraterrestrial sample curation team (ESCuTe) of JAXA. Though those particles will provide us further information for Itokawa and evolution of the asteroid, the samples should be investigated as carefully as possible to reduce consumption and damage of the samples. RA-QD02-0136-01 is currently the largest sample of Hayabusa-returned samples recovered from the sample catcher. The major axis of the particle ra is around 310 μm, and weight of the particles is estimated around 20 μg, assuming the volume V= $4/3\pi r_a r_b r_c \sim 4/3\pi/(2\sqrt{2})r_a{}^3$ and density of the particle as 3.4 g/cm^3, where r_a, r_b and r_c are major axis, semi-major axis and minor axis, respectively. The RA-QD02-0136-01 is mainly composed of Ca-rich pyroxene, and also contains minor amount of low-Ca pyroxene, olivine, plagioclase and troilite. In order to maximize scientific gain from the Hayabusa-returned samples, we decided to investigate this particle by constructing a specific consortium for the analysis.

6 teams were joined the consortium, and following analyses were proposed.
M. Uesugi and A. Tsuchiyama : CT observation of 3D texture and surface observation
J. Park and Rutger team : Ar age analysis to determine the shock ages
K. Nishiizumi and K. Nagao : Analysis of cosmogenic nuclides to estimate the erosion rate of Itokawa
N. Kita and D. Nakashima : O-isotope analysis of high-Ca pyroxenes and plagioclases by SIMS
F. Langenhorst : TEM observation of the dislocations for estimating shock effect by small impacts
L. Keller : TEM observation of the space weathering rims

Currently, we prepare the sample cutting method, and evaluate effect of the cutting and sample transfer on the subsequent analysis. We will report the sequential flow of the analyses and results of the rehearsals.

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Present status of a consortium study of a NaCl bearing Itokawa particle

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Hayabusa spacecraft returned samples from S-type Near-Earth Asteroid (NEA) Itokawa in June 2010. After the return, Extraterrestrial Sample Curation Team (ESCuTe) of JAXA have recovered particles from a sample catcher of Hayabusa, and more than 400 particles initially described have been presented in public (Yada et al., 2014). Among them, some types of particles having rare features are assigned to consortium studies, because they are supposed to be applied by multiple proposals so that they could not be distributed. Members of the ESCuTe would lead consortium studies to ask for research plans from worldwide researchers, discuss a research flow for the particles with the researchers to maximize their scientific gain, and push the plan forward.

One of the consortium studies is for a silicate particle bearing NaCl. The sample ID RA-QD02-0129 is 40 micron in size, mainly composed of silicate similar to plagioclase in chemical composition, and have euhedral NaCl particles of 3-5 micron in size on its surface. This is the only silicate particle bearing NaCl among those initially described so far.

In planetary material samples, NaCl is very rare and unique component. It has been discovered only in Monahan and Zag H chondrites among all ordinary chondrites so far. Trace of extinct 129I was discovered in the NaCl in the meteorites, which means that it should have formed in their parent body(ies), H chondrite or other, in the early solar system and involved in the meteorites in some processes afterward (Zolensky et al., 1999; Whitby et al., 2000). The formation of NaCl should be linked with water in their parent bodies, so it could provide important information about the origin of its parent body. Additionally, water and salt should be closely linked with organic material revolution and might provide interesting suggestion for the origin of life.

One of the most important purposes of this consortium is to prove extraterrestrial origin of the particle (silicate) and NaCl. And next step is to clarify whether its parent body would be Itokawa and/or LL chondrite parent body or other ones. What can prove the extraterrestrial origin of the NaCl is (1) discovery of solar flare tracks in the NaCl, (2) detection of solar wind He on its surface, (3) presence of space weathering layer on its surface. Transmitted electron microscope (TEM) observation for ultrathin section of the NaCl made by focused ion beam (FIB) system will be necessary for (1) and (3), and a laser ionization mass spectrometer is necessary for (2). In the research plan so far, terrestrial NaCl with instrumentally implanted He and NaCl in Monahan meteorite will be prepared for the rehearsal analyses to establish analytical techniques and then we will try the real particle.

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Keywords: Itokawa, asteroid, NaCl, consortium

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Three-dimensional structures of aggregate-type Itokawa particles

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Regolith particles, which should have been formed by fragmentation and abrasion due to impact and impact-induced vibration, exist on surfaces of minor bodies. Their formation processes and causes will tell us physical and chemical condition of the surfaces of the minor bodies and their parent bodies.

Hayabusa spacecraft returned samples from S-type Near-Earth Asteroid (NEA) Itokawa in June 2010 (Abe et al., 2011). Among the returned regolith particles, we focus on aggregate-type particles composed of tiny component grains to analyze their three-dimensional (3D) structure in order to clarify their formation processes and environments.

In this study, we chose five aggregate-type Itokawa particles, which are 55-128 micron in size, assigned for JAXA's research among more than 400 particles initially described. They were firstly analyzed by synchrotron X-ray computed tomography (CT). Because they might be fragile, they were placed inside tiny, upside-down pyramid-shaped sample holder made of SiN. They were irradiated in beam line (BL) 47XU of SPring-8 by photon light source of both 7keV and 8keV in energy and obtained their transmitted X-ray images. The obtained images were calibrated by computers, and their 3D structure could be reconstructed. Mineral species in the particles could be estimated by the different X-ray adsorption factors of different energy X-ray in each of the minerals.

The obtained data are under calibration so far. We will clarify their 3D structure and discuss about their formation processes. Additionally, we are planning to make their ultrathin sections by focused ion beam fabrication system (FIB) and confirm detailed structures between the tiny component grains with transmitted electron microscope (TEM).

References:

Abe M. et al. (2011) LPS XLII, Abstract #1638.
Tsuchiyama et al. (2013) GCA 116, 5.

Keywords: Itokawa, asteroid, aggregate, three-dimensional structure, synchrotron CT

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Consortium Study of Troilite and Phosphate-bearing HAYABUSA Returned Samples

KAROUJI, Yuzuru[1*] ; UESUGI, Masayuki[1] ; YADA, Toru[1] ; ISHIBASHI, Yukihiro[1] ; SATAKE, Wataru[2] ; OKADA, Tatsuaki[1] ; ABE, Masanao[1]

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HAYABUSA returned samples have been shown as Itokawa origin by the preliminary examinations (e.g. Nakamura et al., 2011). Furthermore, international AO study has begun last year, and a formation process of asteroid Itokawa is becoming revealed.

HAYABUSA returned samples are described initially by JAXA Extraterrestrial Sample Curation Team (ESCuTe), and a sample catalogue is prepared based on the data of initial description (e.g. Yada et al., 2014). More than 400 returned samples were described so far. These described samples are classified into four categories. A number of samples of each category to be distributed for international AO are decided based on the sample catalogue. But it is difficult to distribute such samples with rare characteristics in composition, mineralogy, structure, or size, although those samples should maintain scientifically important information.

Therefore, in JAXA, ESCuTe started to organize the consortium studies in order to obtain the scientific information as many as possible from these samples (e.g. Yada et al., 2014; Uesugi et al., 2014). In this paper, we report the research plan for the particles mainly composed of FeS and which contain phosphate minerals.

RA-QD02-0245 composed mainly of FeS (40 micron) with smaller attached olivine and pyroxene grains. This particle was analyzed by X-ray CT at SPring-8 for 3D texture without atmosphere. Two ultra-thin section will be made from the edge of this particle by FIB. The ultra-thin sections will be examined by TEM in detail for space-weathering effect on FeS surface. The main mass of this particle will be analyzed for chemical composition. Especially, the siderophile element composition gives us information on the formation process of Itokawa parent body.

Some particles including phosphate mineral were found by the initial description. Because Ca-phosphate tends to be enriched in incompatible elements such as REEs, Th and U, we propose the investigation of U-Pb systematics using Nano-SIMS in order to study the history recorded in the phosphates. We will perform the U-Pb dating of the phosphates as many as possible and aim to understand the thermal history of Itokawa parent body such as crystallization age and the catastrophic collition if recorded.

Keywords: HAYABUSA, Itokawa, troilite, phosphate, siderophile element, U-Pb dating

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Asteroid Shape Reconstruction by Structure-from-Motion Method with Bundler and PMVS2

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[1]ARC-Space/CAIST, The University of Aizu, [2]Hayabusa-2 project

Here we report results on application of open source shape reconstruction tools to an asteroid image data set. We test two tools that cooperatively work to reconstruct an object shape from images. Bundler is an open source implementation of a stereo shape reconstruction method called Structure from Motion (SfM). PMVS2 gives a more dense shape model, since Bundler only estimates 3D locations of a limited number of feature points. A global image data set of the asteroid Itokawa taken by AMICA on board the Hayabusa spacecraft is employed to our test data set. An obtained model satisfies that most requirements from the Hayabusa-2 mission on the shape model that used during the mission phase. An important advantage of these new tools compared to previous ones is its short processing time. This advantage will be effective in quick evaluation of observation data and decision making during the mission operations. More precise and high definition models will be reconstructed by other method such as shape-from-shading or photometric stereo.

Keywords: Asteroid, shape reconstruction, bundler, PMVS2, Structure-from-Motion, Hayabusa-2

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Feature matching in planetary images with multiple spatial resolutions by using SIFT algorithm

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This study uses feature matching in planetary images with multiple spatial resolution. To know where lower altitude images are taken in high altitude images is performed based on images without the position and attitude of spacecraft in this study. The lower altitude images of AMICA on-board the Hayabusa spacecraft, asteroid probe are found as a correspondence of image features (keypoint) in higher altitude images. We adopted the Scale Invariant Features Transform (SIFT) to represent a kind of key-point of image for image feature matching. In generally, the SIFT keypoint is robust to scale transition, change of lighting condition, parallel displacement, and rotation of image, so this keypoint is suitable to feature matching of planetary image which contains of scale and rotation between different images. As a result, for the improvement of accuracy of feature matching, it is important to have a preprocessing of image (e.g., equalizing).

Keywords: planetary image, SIFT, feature matching, AMICA

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Grooves on Phobos: Spatial distributions and their implications to the formational mechanism

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Grooves are roughly-defined as trough-like depressions commonly found on asteroids and small satellites. Among the various features categorized as grooves, the most typical are considered as those found on the surface of Phobos. Grooves on Phobos are the most extensively-existing geological features on the satellite, and thus are documented and discussed for years. However, their formational processes remain controversial. Previously-proposed hypotheses are (1) grooves are some kind of intentional fractures and (2) they are results of impacts caused likely by linearly-aligned impactors ejected from Mars.

Former hypothesis has difficulty in explaining the geographical distribution of grooves (Murray 2011). In fact, because of this difficulty, Murray (2011) concluded that the latter (i.e., secondary impactors derived from Mars) could only be the reasonable explanation for the observed characteristics of grooves on Phobos, including their morphological features, distributions, and hemispheric coverage. Nevertheless, Ramsley and Head (2013) recently showed that, in order to form grooves well organized as those found on Phobos, each of fragments ejected from Mars should have no relative velocity, which is difficult to be achieved for ejecta from Mars. They also showed that most grooves on the northern hemisphere cannot be formed as secondary impacts from Mars because the impactors ejected from Mars do not impact in the directions normal to the equatorial plane of Phobos. Therefore, neither hypothesis remains satisfactory to explain the observational facts.

We carefully reevaluate previous hypothesis based on recently-acquired data, which are partly not available at the time of previous studies. We scrutinize all of the high-resolution images obtained so far to map them out on a numerical shape model. As a result, we identify 488 grooves, whose spatial distributions are precisely mapped three dimensionally. We newly find that each of grooves is always aligned on a certain plain even though it sometimes appears to be an undulating curved depression. We consider this strongly indicates that a groove is a result of a series of impacts of aligned fragments.

We statistically study the angle between the equatorial plane of Phobos and the plane, which contain each groove and find that the distributions of the angles have three peaks at 25, 90 and 155 degrees (hereafter we call A, B, and C type, respectively). Most of the B type grooves exist on the northern hemisphere.

To explain our mapping results, we propose a new hypothesis for the formation of Phobos as follows: (1) An asteroid of a collection of smaller fragments held together by self-gravity in the form of a rubble-pile is pulled apart and stretched straightly by tides during a close approach to Mars; (2) The asteroid (now separates into a train of fragments) is caught by the Mars gravity and revolves around Mars; (3) Every time it revolves around Mars, a part of the fragments hit Phobos and form a lineated depression, which is observed as a type A or C groove; (4) When the eccentricity of the impartor becomes low until the overlapping the trajectory of Phobos, type B grooves are formed.

Our hypothesis is along the idea that grooves are formed by aligned impactors as proposed by Murray (2011) but essentially different in the origin of the fragments, which can resolve the difficulty pointed out by Ramsley and Head (2013). Not only that, our hypothesis has advantage of completely satisfying both the morphological and geographical characteristics of grooves on Phobos. Furthermore, our hypothesis can also explain the deficiency of grooves on Deimos.

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Keywords: Phobos, groove, Mars, tidal-disruption, impact

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Visible wavelength spectroscopy of sub-km-sized Near-Earth Asteroids with low delta-v

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We present a unique data set of the taxonomic type of near-Earth asteroids (NEAs) accessible with available spacecraft.

The research on NEAs has entered a new phase thanks to sample-return space explorations together with state-of-the-art large ground-based telescopes. We made observations of twelve asteroids with Subaru, GEMINI-North, GEMINI-South and Okayama 188cm telescopes. They have low delta-v orbits with potential to be investigated by manned/unmanned spacecraft. Also, ten sub-km-sized bodies are included in them, and are one of remarkable characteristics in terms of an evolutionary scenario.

We find that eleven asteroids are classified as S-complex and one asteroid as V-type. Most S-complex asteroids (eight out of eleven, $\sim$70%) have spectra similar to subgroups of Q or Sq-type, suggesting that these objects are less matured against space weathering.

In this presentation, we show their spectra and discuss dominance of S-complex asteroids based on the previous research.

Keywords: asteroid, visible spectroscopy, taxonomic classification

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U06-P21 Room:Poster Time:April 28 18:15-19:30

Development of a wide-band optical filter optimized for deep imaging of small solar-system bodies

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We developed a newly designed wide-band optical filter and evaluated its performance. It is optimized for deep imaging of small solar-system bodies. The new filter, which we denote as *Wi*, is designed to reduce contamination by light pollution from street lamps, especially strong mercury and sodium emission lines. For the reasons that (1) much of artificial light pollution concentrates in the *V* band, (2) the photon numbers peak at a wavelength of 6350 $\AA$ in the spectrum of sunlight, and (3) many asteroids have their peak/plateau reflectance at around 7000 $\AA$ in the optical range, the new filter's cut-on wavelength is set to 5880 $\AA$ by using an OG590 Schott color glass filter. On the other hand, the cut-off wavelength, which is achieved by a short-pass interference coating, is set to 9380 $\AA$ in consideration of worst of the OH night sky emission and the atmospheric water vapor absorption band at 9400 $\AA$.

Compared with the use of a commercially available long-wave cut wide-band filter (*W* filter, 4900-9100 $\AA$), the sky brightness is 10-20 % reduced by the *Wi* filter under bright-sky conditions by not only artificial light pollution but scattered moonlight. In the detection of asteroids, the detected total flux of an asteroid through the *Wi* filter has been 3% larger than that through the *W* filter, though the width of the *Wi* filter response function is 16% narrower than that of the *W* filter. By using the *Wi* filter, the S/N ratios in the detection of asteroids were improved by about 6%, on average, compared with the use of the *W* filter, and the improvements were slightly larger in a brighter sky. The use of the CCD with high sensitivity at longer wavelength, such as the back-illuminated, fully-depleted CCD, will show a larger improvement in the S/N ratio by using the *Wi* filter.

Reference:
Wide-Band Optical Filter Optimized for Deep Imaging of Small Solar-System Bodies,
Okumura *et al*. Publications of the Astronomical Society of Japan, **64**, 47 (2012)

Keywords: optical, small solar system body, light pollution, wide-band filter

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Prediction of Phoeincid in 2014

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Phoenicid appeared in 1956 is a meteors yielded by the comet 289P/Blanpain founded in 1819. We calcurated a prediction of Phoenicid in 2014.

Comet Blanpain has a mean motion resonance of 9:4 with Jupiter. Therefore Phoenicid has 95 year cycle. The next big apparition will be in 2051.

Keywords: Meteors

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Solidified and mixed materials on Asteroid body

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The results of the present study are summarized as follows:

1) Study of the Asteroids provides characteristic formation processes of primordial terrestrial and extraterrestrial celestial bodies.

2) Identification of crystalline solids are almost similar between the Asteroids and Earth, though the Asteroid rocks might be formed by similar formation processes of terrestrial rocks based on the crystalline parts. However, extraterrestrial Asteroids show irregular mixtures of multiple states solidified amorphous solids.

3) Formation of non-spherical Asteroid body formed mainly by impact-related melting process is observed as heterogeneous and irregular distribution of impacted grains.

4) Local fluid-bearing depositions irregularly distributed on the surface and interior of the Asteroids might be based on storages on the interior formed by solidified mixtures of multiple states triggered by impact process on the Asteroids.

5) Different processes of solids between the Asteroids and Earth can be observed silica Si-O frameworks which can be obtained by the ion bombardment experiments. Crystalline rocks with hard silicate structures on Earth show higher ion-peaks of alkali ions (Na, K and Ca etc.), whereas solid-aggregates of the Asteroids show higher ion-peaks of Si and Al ions which are relatively destroyed by ion bombardments.

6) Ion-peaks by the sputtering of terrestrial impact-breccias are clearly higher than those of the Asteroid meteorites, which the main differences are not rock textures of breccias but atomic bonding of slow or rapid cooling process.

7) The air- and water-less Asteroids with solidified materials with multi-states are formed from nano-grains to macroscopic rocks by impact-related evolution process,

8) The primordial planet Earth with remained heterogeneous surface by impact-related process is considered to be cyclic system of three material states (air, liquid and solid) with macro-life activity which is formed by huge production from the interior triggered by huge collision process of the giant impact. On the other hand, the Asteroids without global cyclic changes of three materials states, microscopic quasi life-like materials might be locally found (mainly by high-resolution electron microscopy on in-situ or returned samples finally).

9) It should be avoided to collect artificial impacted samples, because irregular mixtures of solidified amorphous solids from vapor and liquid states are easily destroyed to be escaped to be exaggerated solids with less volatiles.

Keywords: Asteroids, solid aggregates, amorphous materials, fluid, ion bombardment run, micro quasi life-like materials

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The Origin of The Moon and The Earth in Multi-Impact Hypothesis

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Origin of the moon and the earth in the multi-impact hypothesis

This new hypothesis to the origin of the Moon and Earth,This is the proposal of solutions that satisfy unified manner new hypothesis
to the origin of the Earth and the Moon, all of the following questions.

(1).Why, large biological extinction of five times or more were happened on the earth?
(2).The meteorite falling on Earth, why stony-meteorites, stony-iron meteorite, iron-meteorite, such as differentiated and undifferentiated chondrites, what mixed in there?
(3).The old theory, why cosmic dust or did not become a planet in the asteroid belt?I think Itokawa's aggregate piece of crust differentiated?
(4).We have proposed a theory of the origin of the original description to solve the problems of the giant planet collision theory, all of the earth and the moon and deep sea bottom.
(5).Why, protoplanetary Serra did they destruction? = The tragedy caused by tidal forces and deformation due to Jupiter orbit perturbation.
(6).Increase in the aspect ratio of Serra orbital perturbation by Jupiter, destruction by tidal force of the approaching Jupiter.
(7).Plate boundary formation of plate tectonics,I suggest the formation origin of the deep sea bottom crust by peeling.
(8).The origin of deep-sea bottom update and continental drift and Mystery of the driving force was solved.
(9).Why diamond pipe did formed in South Africa?
(10).Why core eccentric (about ten percent) of what is happening? Radiation anomaly of Brazil over the Van Allen belt.
(11).New hypothesis at the origin of Jupiter's Great Red Spot, I think about How and Why to that Mystery !
(12).Why is whether the silicate star (asteroid now) Pluto of the outer planets?

Until now, Giant impact hypothesis is a theory only for making the moon.Protoplanet is the result of accidental collision with the Earth there Mars core size to the Earth,
It only has to calculate the conditions formed by the mantle further moon.

It is the original collision hypothesis.

Protoplanetary Serra was born in Ceres position of Bode's law.The planet Serra that differentiated, elliptical orbit was flattened by the Jupiter perturbations.
Major axis is constant because of energy conservation law.Eccentricity of Serra increases, the orbit that focus of the solar get closer so as to extend to the point of near-side Jupiter.
Just before the collision with Jupiter, Serra was rupture in tidal forces of Jupiter.By the mantle debris collides with the Earth, the moon was formed.
Position Serra collides to the Earth becomes the Pacific Ocean, it becomes the origin of the plate boundary crack.In addition, deep-sea of multiple formed with Impact of Multi-attack which is the time difference.
Eccentricity of the moment of inertia is estimated to be the driving force of the seabed update theory and theory of continental drift.
Mantle debris energy is large becomes Pluto, heavy and high density Koaritchi debris became Mercury with scattered to the inner planet side.
I estimated that the debris of Serra collide to Jupiter, it became the origin of the Jupiter's Great Red Spot.
The fact that iron meteorites, stony-iron meteorites, stony meteorites are differentiated, and chondrite undifferentiated are mixed, Ceres is present in the asteroid belt, the origin of the meteorite is convinced straightforwardly with this hypothesis.
Multi-impact theory be the basis of large organism extermination repeated, it is also the reason sea accounts for 70%, it was possible to understand the origin of the plate boundary crack.
Multi-impact hypothesis can be explained in a unified manner present condition of the earth as well as make the moon in this manner.

It is believed that asteroid Itokawa could check a set? Like Serra crust, then it becomes even proof of this hypothesis.

Keywords: Serra tidal disruption, Perturbation of Jupiter, Orbit transition of Serra, Match of the planets revolving surface, Feedengue zone (integrated range), Origin of Deep Sea Bottom