Operation Status of Hayabuas2 in the Proximity of Asteroid Ryugu

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The Japan Aerospace Exploration Agency launched an asteroid sample return spacecraft "Hayabusa2" on December 3, 2014 by the Japanese H2A launch vehicle. Following the successful return back of Hayabusa from the asteroid 25143 Itokawa, Hayabusa2 aims at the round trip mission to the asteroid 162173 Ryugu. Ryugu is a near-Earth C-type asteroid, which is believed to contain organic and hydrated minerals. Thus it is expected that its successful sample return may provide fundamental information regarding the origin and evolution of terrestrial planets as well as the origin of water and organics delivered to the Earth.

On June 27, 2018, Hayabusa2 successfully arrived at Ryugu and began the asteroid-proximity operation, which is to last for 18 months. The spacecraft established “Home Position (HP)-hovering” at 20km disntace from the asteroid using optical navigation. In-situ instruments check-out and the initial chracteriszation of Ryugu were all performed as planned.

The first attempt to bring the spacecraft to low altitude is in “Box-C operation”, with which the lowest altitude of 6.5km was achieved, providing the first close-up view of Ryugu. From July 31 until August 2, the first fine-guided descent was attempted in the “Mid-aittude Descent Operation”. This operation applied the asteroid shape/landmark-based optical navigation called “GCP-NAV” and achieved 8 hour (i.e. >one rotation period of Ryugu) continuous hovering at 5km altitude. From August 5 until 7, the “Gravity Measurement Descent Operaton” was conducted. This operation includes the free-fall down to the altitude of 851m (above surface), and thus identified the gravity of the asteroid. Meanwhile number of Ryugu images taken by ONC-T and other important scientific observation data by LIDAR, TIR and NIRS3 are down-linked to the ground in timely manner using Hayabusa2’s X/Ka-band high-speed downlink capability. All these data were effectively used for the landing site selection (LSS) activity conducted from July to August, 2018. The LSS decision meeting was held on August 17 participated by the whole international project team, and concluded to select three landing site candidates (1 primary, 2 backups), 1 MINERVA-II-1 landing site and 1 MASCOT landing site.

From September through November 2018, Hayabusa2 is to attempt two rover release operations (MINERVA-II, MASCOT), and two touch-down rehearsal descents, and one touch-down based on the conclusion of the LSS decision meeting. Hence at the time of the Hayabusa simposium, we expect to be able to report some results of these critical milstones for the Hayabusa2 missions.

A reshaped rubble-pile asteroid Ryugu as observed by Hayabusa2

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After a 3.5 year outbound journey the Hayabusa2 spacecraft arrived at C-type near-Earth asteroid (162173) Ryugu on June 2018. This presentation reviews the scientific results from the first half year proximity operation around the asteroid. After a month approach phase in June, the spacecraft reached its home position (HP), about a 20 km altitude from the sub-Earth point of the asteroid's surface, and hovered. The onboard remote-sensing instruments for science are a multi-band visible camera ONC-T, a thermal infrared camera TIR, a NIR spectrometer NIRS3, and a LIDAR altimeter. The most of the sciece observations are performed from HP, but several observations from lower altitudes (5-7 km alititude) as well as a tour campaign to look into the pole resions of the asteroid was done. Shape models using Stereo-photoclinometry and Structure-from-Motion were constructed from ONC-T images.

The observations from HP revealed that the bulk mean density of Ryugu is as low as 1.2 g cm^{-3}, indicating a very porous and strenghless interior. The low bulk density and the abundant boulder appearance (largest one near the south pole is ~130 m across) suggest Ryugu is a rubble-pile body having accumulated impact fragments from the parent planetesimal. The prominent feature of Ryugu is its top-shape with a circular narrow equatorial ridge of ~500 m radius. There are several top-shaped asteroids have been identified from ground radar observations. Bennu, the target of OSIRIS-Rex mission is one of them. Contray to Ryugu having a rotation period of 7.632 hr, however, most of the top-shaped asteroids are rapid rotators with rotation periods less than 4.3 hr. Thus, it has been unexpected that Ryugu has a top shape. After the formation Ryugu should be reshaped by the past rapid rotations, the state of which may obtained by the initial accretion of fragments of the parent body or YORP-induced spin-up. The internal failure of the early Ryugu by ripid rotation made the circular equatorial ridge. Ryugu spins retrogradely around an axis almost perpendicular to the orbital plane (obliquity is ~172°), which is consistend with one of the final spin state of the YORP evolution.

The most of the surface has very low reflectance and flat featureless reflection spectra in visible and NIR wavelength ranges, and no clear 0.7-μm and 3-μm absorption bands indiacing the presence of hydrated minerals have been found so far. Such features may possibly correspond to meteorites like moderately dehydraed carbonecious chondrites by heat or shock. The equatorial ridge is bright and bluish compared with mid-latitudinal zones, suggesting its fleshness or less organic materials.

After the landing site selection Hayabusa2 will try to touch-and-go the surface and collect materials as a return sample. Landers MASCOT and MINERVA-II will descend and land on the surface performing in-situ various observations. The many boulders on the surafce of Ryugu would make the sampling difficult. Thus, in-situ information obtained from the landers as well as low-altitude observations of the surface during descents to deploy landers are very important to develope a strategy to get a sample safely from the "fort of boulders". The remote-sensing and in-situ observations of Hayabusa2 and laboratory analyses of the return sample will clarify the origin and history of this small body, early solar system environment around the snow-line, and material supply inventory from the Main Belt to Earth.

The first detailed visible multi-band imaging observations of asteroid Ryugu

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We have conducted multi-band visible imaging observations of asteroid Ryugu covering its entire disk from 20 km of distance and covering equatorial regions with higher spatial resolution at 5 – 7km of distance. These observations revealed a number of important properties of Ryugu: 1) a classic bi-cone top shape with upright spin axis, 2) equatorial ridge encircling the entire body, 3) the presence of large boulders particularly around the poles, 4) Gradual latitudinal decrease in number density of large boulders toward equator [1], 5) General uniformity in visible spectra on the entire globe [2], 6) The presence of bright spots and bright surfaces on a large boulder, which exhibit bluer spectra [2], 7) Circular depressions with bowl-shaped profiles and raised rimes, consistent with impact craters [3], 8) The number density of these depressions is on the same order of magnitude as that of crater candidates on Itokawa [4]. 9) Preferential deficiency in small circular depressions with a similar size frequency slope as Itokawa and Eros, suggesting the presence of granular medium subject to seismic shaking and crater erasure. 10) Boulder size measurements indicate that they are too large to be impact ejecta from observed craters, suggesting that they may be direct fragments from Ryugu's parent body.

The bowl-like shape of large (~200m in diameter) circular depressions, consistent with gravity-controlled craters, and the deficiency in small circular depressions suggest that Ryugu may be mantled with strengthless materials at least 10's meter of thickness. Such mobile interior in Ryugu may have played an important role in forming/modifying the circum-equatorial ridge belt [5] and clustered large boulders around the poles, underling the importance of high-resolution observations for granular flows by both Hayabusa2 and MASCOT lander [6]. Furthermore, variations in spectroscopic properties of large boulders may reflect heterogeneity in Ryugu's parent body, its detailed spectroscopic characterization is of great importance for uncovering the history of asteroid leading to the present state of Ryugu and will be also important for understanding the geologic context for the samples to be obtained from Ryugu.

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References: [1] Honda, C. et al. (2018), DPS mtg [2] Tatsumi, E. et al., (2018) DPS mtg, [3] Cho et al. (2018), DPS mtg, [4] Morota et al., DPS mtg, [5] Michel et al., DPS mtg, [6] Jaumann et al. (2018) DPS mtg.

First Global Thermal Images of Asteroid 162173 Ryugu and Implications to Its Surface Thermal Inertia, Grain Size and Roughness

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The Thermal Infrared Imager TIR [1] onboard the Japanese asteroid explorer Hayabusa2 [2], investigating the thermo-physical properties of the surface of asteroid 162173 Ryugu, a C-type near-Earth asteroid. The asteroid was observed by TIR almost daily during the approach in June 2018, finding the asteroid rotation period of about 7.6 hours to be consistent with the ground observations [3]. After arrival at the Home Position, 20 km earthward from the asteroid, Ryugu was imaged by the TIR on 30 June 2018, with about 50 pixels size, covering its rotation in steps of 6 degrees. This is the first set of high-resolved global thermal images of an asteroid. The temperatures on the sunlit area varied from 300 to 370K at 0.986 AU from the Sun. A north-south hemispheric difference in temperature was found, which is a seasonal variation due to the pole declination and consistent with the results of numerical simulations using a high-resolved thermo-physical model of Ryugu [4]. Global maps of thermal inertia and grain size were estimated [5] from the temperature profile at each site on the asteroid, especially prepared for the landing site selection. Diurnal temperature profile shows rather flat pattern, indicating the effect of surface small-scale roughness. Several models with surface roughness have been investigated to interpret the flat pattern, and we estimated the most suitable thermal inertia and consequently the grain size. For the safety assessment of touchdown for sampling, the highest temperatures at the time of touchdown have been predicted using the best fit thermal model, suggesting no critical temperature (below 370K) for the spacecraft. Higher-resolved thermal images were obtained during the descent to the lower altitude: 5km during the "Mid-Altitude" observation, 1 km during the "Gravity Measurement", 60 m during the MINERVA and MASCOT lander release operations, and 10 m for "Touchdown". The surface physical state and temperature at the landing site of MASCOT will be verified by MARA onboard the lander [6]. We also estimated the highest temperatures ever experienced in the past asteroid trajectory, to investigate the possible existence of organic materials in the surface layer of Ryugu. Large scale geologic features such as craters and boulders are also identified in the thermal images by the temperature difference, indicating the physical state of them. Temperature profiles of several large boulders are basically the same as those of the surrounding surface, which implies the materials with high porosity, which is consistent with the rubble-pile asteroid that formed by reacretion and sedimentation of impact fragments from a larger parrent body, and with the desiccated and vacuum-dried surface of originally volatile-rich materials.

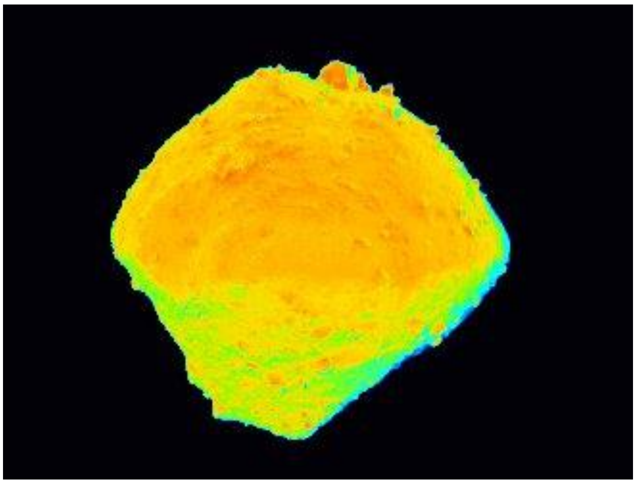

Figure 1 Thermal image of Ryugu observed at 5 km altitude on 1 Aug 2018 (modified from hyb2_tir_20180801_152656_l2a)

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References

[1] Okada, T. et al, 2017. Space Sci. Rev., 208, 255-286. [2] Tsuda, Y., et al. 2016. Acta Astronaut. 127, 702-709. [3] Mueller, T.G. et al., 2017. A&A, 599, A103. [4] Takita, J., et al. 2017. Space Sci. Rev., 208, 287-315. [5] Sakatani N. et al.2017. AIP Adv, 7, 015310. [6] Grott, M., et al., 2017. Space Sci. Rev., 208, 413-431.

Infrared spectra of asteroid 162173 Ryugu obtained by Near-infrared Spectrometer (NIRS3)

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The asteroid explorer Hayabusa2 was launched in December 2014, and arrived at the target asteroid 162173 Ryugu in June 2018. Near-infrared Spectrometer (NIRS3) onboard Hayabusa2 successfully obtained infrared spectra of Ryugu globally at ~20 km and ~5–7 km above Ryugu surface. The spectroscopic observations of Ryugu are important for estimating the compositional and physical properties of surface material, selecting the landing sites for sampling, and understanding the link between primitive asteroids and carbonaceous chondrites.

NIRS3 is composed of two units: the spectrometric unit (NIRS3-S) and the analog electric unit (NIRS3-AE), which are connected with a harness cable (NIRS3-HNS). A 128-channel indium arsenide (InAs) photodiode sensor is installed in the spectrometric unit and cooled down to 188 K (-85 °C) using a passive radiator. The detectable wavelength range of the spectrometer is 1.8–3.2 μm, and the spectral resolution is ~18 nm. The field of view (FOV) is 0.11° [1, 2] corresponding to the spatial resolutions of 40 m at 20 km altitude and 2 m at 1 km.

We found that Ryugu spectra obtained by NIRS3 are almost homogeneous between places, showing very low albedo (~2% reflectance at phase angle 30°), flat but slightly red slope, and no large absorption features at ~2.7 and ~3.1 μm in wavelength. However, the spectra exhibit slight variety from brighter and bluer spectra on the equatorial ridge to darker and redder spectra in the other areas. No carbonaceous chondrite spectrum collected so far matches exactly with Ryugu spectra. However, some spectra of experimentally-heated hydrous carbonaceous chondrites are similar in terms of their flat shape and low albedo. Ryugu surface might not be totally hydrated because of (1) dehydration due to heating and/or space weathering, or (2) the lack of hydration process.

It is expected that further NIRS3 observations at a lower altitude, at a solar distance larger than 1.027 AU, ONC and NIRS3 observation of the SCI impact crater, MicrOmega observation of the surface regolith, and returned sample analysis will give us more detailed information on the spectral and mineralogical characteristics of Ryugu.

References

[1] Kitazato K. et al. 2015. Abstract #2158. 46th LPSC. [2] Iwata T. et al. 2017. Space Science Reviews 208: 317-337.

Scientific Evaluation on the Asteroid Ryugu in Hayabusa2 Landing Site Selection

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On June 27, 2018, the spacecraft of the Japanese C-type asteroid sample return mission, Hayabusa2, has arrived at the asteroid Ryugu. During its 18-month stay, remote-sensing observations will be carried out with the on-board instruments, Optical Navigation Camera (ONC), Near Infrared Spectrometer (NIRS3), Thermal Infrared Imager (TIR), and Laser Altimeter (LIDAR). Hayabusa2 plans to collect asteroid samples from up to three sites. Based on the remote-sensing data, we will carry out the landing site selection (LSS) in the end of August 2018, for the first touch down (TD1) and for releasing a hopping lander, MASCOT, in the beginning of October 2018. Based on the mission's scientific goals, the most scientifically valuable site for TD1 will be a less altered region where water and/or carbon are abundant.

Seven potential landing sites including equatorial regions (L5, L7, L8, L12) and mid-latitude regions (M1, M3, M4) were proposed based on spacecraft safety and boulder size-frequency by the system engineering team and ONC team. The data products will be obtained at 20 km, 5-7 km and at 5 km in altitude. Shape modeling team produced polygon shape models of Ryugu by two different methods; Shape-from-Motion (SfM) and Stereophotoclinometry (SPC). ONC produces the six types of spectral indices: (i) 0.7 μm absorption depth, (ii) spectral slope from 0.39 μm to 0.95 μm, (iii) spectral slope in ultraviolet, (iv) 0.95 μm absorption depth, (v) scores of PC1 to PC5. NIRS3 produces the spectral feature maps: (i) 3-μm band depth/center, (ii) spectral slope, and (iv) near-infrared albedo. TIR provides the maps of thermal inertia, grain size, and maximum temperature for TD1.

Based on the data products, evaluation and scoring was performed from the three perspectives; Science, Safety, and Sample recovery. Scientific evaluation included the seven topics; 1. Physical properties of surface, 2. Surface age and morphology, 3. Organic carbon compositions and contents, 4. Hydrous minerals distributions, 5. Degrees of heating dehydration, 6. Other minerals and 7. Surface secondary processes.

Distributions of temperature and grain sizes were mostly homogeneous for all the potential landing sites. L7, 8, 12 and M4 are more rough than others. L regions were evaluated as highlands and M regions were evaluated as low lands. The density of craters of Ryugu were comparable to those of Itokawa and Eros, and the surface age of 0.1 to 1 billion years was evaluated. Regarding boulder distributions, L8 and M4 contain less density of large boulders than others.

There was no large variation in the UV-Vis and NIR spectral patterns between all the potential landing sites. Based on the unusual excess of reflectance at 390 nm, the presence of extensively graphitized carbonaceous material is indicated. Assuming that the correlation between v-band albedo (550 nm) and carbon contents is directly applicable, it is estimated that carbon contents of Ryugu is higher than 3%. However there remains uncertainties on the effects of grain size, porosity, and space weathering. Small absorption at 2.7 μm was identified from the NIR spectra of Ryugu, indicating the presence of phyllisilicates. Comparison between the NIR spectra of Ryugu and those of meteorites indicated that the abundances of phyllosilicates are low for all the regions of Ryugu surface. Ryugu could be composed of similar materials to dehydrated C chondrites containing darkening materials, or dark anhydrous material.

The correlation was observed between v-band albedo and b-x slope (480-860 nm). L regions show bluer spectra, while M regions show redder spectra. M1 was particularly red. In the individual regions, L regions are more heterogeneous compared to M3 and M4 regions, showing that wider variety of materials are collected from L regions compared to M regions.

Safety evaluation was complimentarily conducted with engineering safety evaluation, based on the area occupied by boulders, median filter, SPC topograph, Hapke roughness parameter, sigma roughness parameter, and grain sizes. Evaluation of samplability was conducted based on the grain sizes and boulder distributions. Summarying each evaluation, we selected L8, L7 and M4, as the regions that meet both the safety and scientific value for TD1. A variety of topography and geology of Ryugu revealed by the remote sensng observations and LSS scientific evaluation indicates that the mixed samples with different origins would be collected from the selected sites. This would provide the initial sample analysis a great advantage that the origin and chemical evolution of the solar system as well as the formation process and structure of the asteroid Ryugu are comprehensively investigated.

MASCOT's first sight of Ryugu

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Japan Aerospace Exploration Agency's (JAXA) Hayabusa2 successfully arrived to the asteroid Ryugu on 27th of July. In October, a small lander, developed by German Aerospace Center (DLR) and Centre National d'Etudes Spatiales (CNES), called MASCOT is planned to be released from Hayabusa2 to land on Ryugu. MASCOT is equipped with four instruments: MARA - a radiometer (DLR Berlin), MASCAM - a camera (DLR Berlin), MASMAG - a magnetometer (TU Braunschweig), and MicrOmega - an IR imaging spectrometer (IAS Paris). Hereby we will present the first observations and results from the surface of Ryugu as seen by the MASCOT instruments.

Quick-look results for the surface/regolith mechanical properties of Ryugu based on MASCOT bouncing analyses

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We present quick-look results and constraints on the mechanical properties of the regolith on asteroid 162173 Ryugu, based on expected data regarding the mechanical interactions by the lander MASCOT as well as data from MINERVA nano-landers and possibly from the first sampling touchdown by Hayabusa2.
MASCOT is going to be deployed from an altitude of ~55 m and has a touch-down velocity of ~0.2 m/s. It is expected to bounce several times before coming to rest [3]. The descent trajectory and the larger bouncing arcs can be captured by optical imaging from the spacecraft (ONC [5]) giving constraints on MASCOT in-flight trajectories. Moreover, direct images of footprints as well as data from MASCOT's magnetometer MASMAG [4] on bounce times (and possibly rotation rates or changes thereof), images by MASCOT's camera MASCAM [2] during bouncing and their fusion with ONC images projected to the shape, and finally MASCAM images after rest offer a rich database that allows us to constrain Ryugu's surface mechanical properties, with implications on the asteroid's surface history. Variations of the radio-frequency signal all along MASCOT's trajectory and day/night detection by MASCOT's photoelectric cell sensors can also contribute to the analysis.
The measured total linear energetic coefficient of restitution (CoR), i.e. the fraction of energy dissipated at each bounce, can be compared to the CoR values measured for the MASCOT structure bouncing against a hard wall [6] and soft-sphere DEM simulations of MASCOT landing on a bed of granular material [7,8]. Footprint images of the bounce imprints in loose granular material also constrain the granular frictional properties and the regolith depth.

Preliminary conclusions on the mechanical properties of Ryugu's surface material will be drawn.

References

[1] Ho, Tra-Mi, et al. "MASCOT—the mobile asteroid surface scout onboard the HAYABUSA2 mission." Space Science Reviews 208.1-4 (2017): 339-374.MASCAM

[2] Jaumann, R., Schmitz, N., Koncz, A., Michaelis, H., Schroeder, S. E., Mottola, S., ... & Kachlicki, J. (2017). The camera of the MASCOT asteroid lander on board Hayabusa 2. Space Science Reviews, 208(1-4), 375-400.

[3] Garmier R. et al: "MASCOT landing on Asteroid Ryugu : flight dynamics team contribution to the landing site selection process", 2018 SpaceOps Conference, SpaceOps Conferences, (AIAA 2018-2645)

[4] Herčík, D., Auster, H. U., Blum, J., Fornaçon, K. H., Fujimoto, M., Gebauer, K., ... & Matsuoka, A. (2017). The MASCOT magnetometer. Space Science Reviews, 208(1-4), 433-449.

[5] Kameda, S., Suzuki, H., Takamatsu, T., Cho, Y., Yasuda, T., Yamada, M., ... & Sato, M. (2017). Preflight calibration test results for optical navigation camera telescope (ONC-T) onboard the Hayabusa2 spacecraft. Space Science Reviews, 208(1-4), 17-31.

[6] Biele, Jens, et al. "Experimental Determination of the Structural Coefficient of Restitution of a Bouncing Asteroid Lander." arXiv preprint arXiv:1705.00701 (2017).

[7] Maurel, C., Michel, P., Biele, J., Ballouz, R. L., & Thuillet, F. (2017). Numerical simulations of the contact between the lander MASCOT and a regolith-covered surface. Advances in Space Research.

[8] Thuillet, Florian, et al. "Numerical modeling of lander interaction with a low-gravity asteroid regolith surface-Application to MASCOT on board Hayabusa2." Astronomy & Astrophysics 615 (2018): A41.

Brightness and Color Variations on the Surface of 162173 Ryugu:
Space Weathering, Thermal Fatigue and Mass Movement

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162173 Ryugu is a dark body with overall visible albedo is 4.6% and photometry standard reflectance is lower than 2% (Tatsumi et al., 2018, DPS&AGU). Ryugu is the one of the darkest body in the solar system. However, there is striking brightness (and associated) color difference on the surface. Bright, large boulders are on polar regions and smaller ones with similar brightness are scattered globally. Regionally, the equatorial ridge and some of undulated crater rim zones are brighter. Some boulders shows brightness variation within their surface, suggesting brightness/color difference may not be due to compositional variation but to the differences of space weathering maturity. Two types of space weathering are advocated for carbonaceous asteroids: darkening (and reddening) or brightening (and bluing) with time. On Ryugu, probably thermal fatigue and/or local impacts should have brightened the boulder surface (i.e., large boulders on both poles). Ridge/crater brightness can be ascribed to movement of fine darker materials to potentially lower region. In high-resolution images (<1m), Ryugu's surface is covered with fine (and darker) regolith materials that would cover and bury boulders. Like the large boulders on both poles, bright boulders usually have smooth surface and brightness is affected by darker regolith and shadow (Fig.1). There observed also darker boulders with rough/undulated surface, which would have experienced longer exposure and thus more erosion and weathering. We can observe the relation between brightness and surface roughness also in close-up images (Figs.2). In the left figure, there is a large (40m) relatively darker boulders with rough and layered surface. This is partially covered with much darker regolith materials. In the right figure, we observe bright layered boulders with smooth surface. Some feature (e.g., Fig. 3) would be explained by conglomerate or breccia, rather than regolith coverage.

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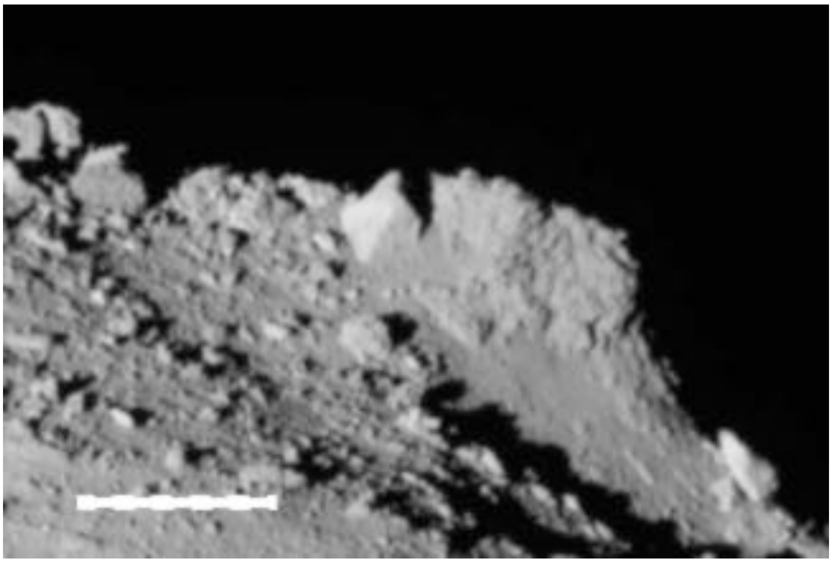
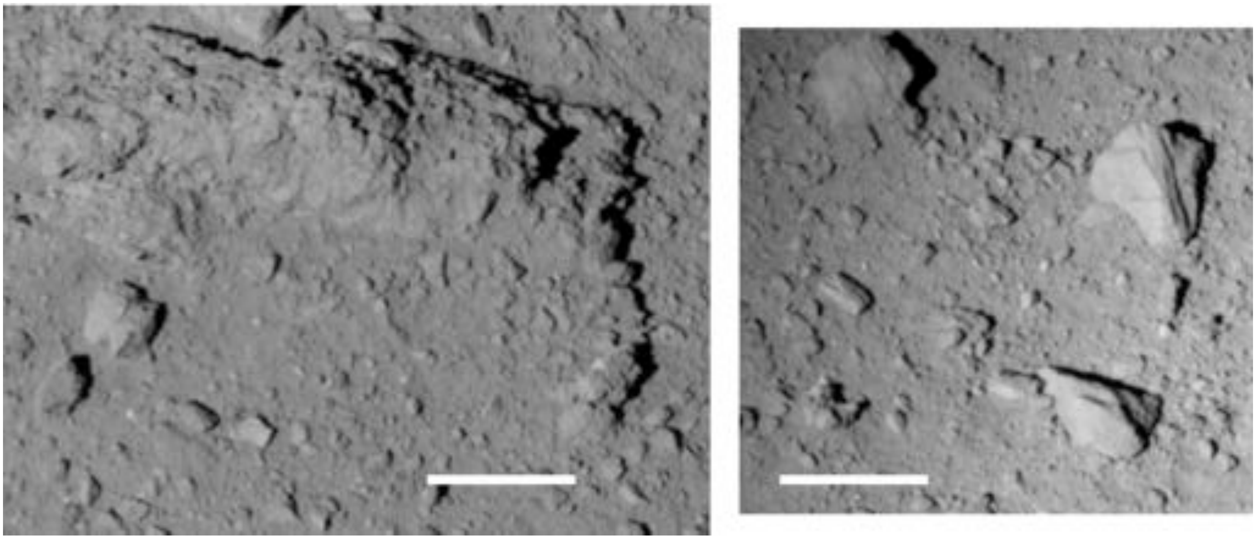


Figure1 Bright/smooth and dark/rough boulders on the polar region of Ryugu, Both are partly covered by darker regolith. The length of the white scale is 50m.



Figures 2 The surface of Ryugu where ONC-T camera captured from about 1km height.   Length of white scales is 10m.

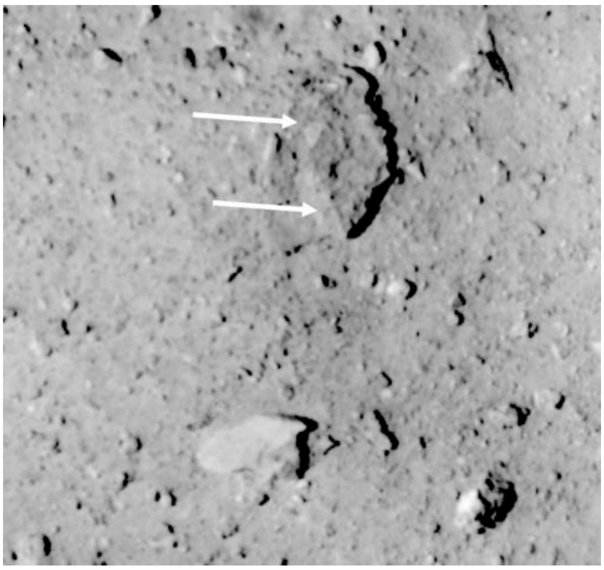


Figure 3   The surface of Ryugu (at relatively boulder poor region).   Arrows show possible breccia

Gaussian Deconvolution of the 2.7-µm Absorption Band of Type 1 and 2 Carbonaceous Chondrites for Interpreting Hayabusa2 Near-Infrared Spectrometer (NIRS3) Data

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Introduction: Continuing our previous work of deconvolving the composite 3-µm absorption band of type 1 and 2 carbonaceous chondrites (CCs) to derive the correlation between the 2.7-µm hydroxyl absorption band characteristics and CC types [1], in this study we have expanded the number of CC reflectance spectra, and also converted them into simulated Hayabusa2 Near-Infrared Spectrometer (NIRS3) [2] in an attempt to help interpreting data of the asteroid 162173 Ryugu.

Experimental: In addition to the previously studied reflectance spectra (2.5-4 µm) of powder or pressed pellet samples of CCs (CImix: Ivuna-Orgueil mixture, Murchison and Y-793595 (CM2), Renazzo (CR2), and Tagish Lake) [1], spectra of UV-irradiated Murchison and laser-irradiated Y-793595 pellet samples, powder samples of Kaidun and 15 CM2 chondrites including MET 00639 (probably shocked), and a chip sample of MIL 13005 (CM1/2) have been either newly measured or taken from the RELAB database [3].

Method: Following our previous study [1], natural log reflectance spectrum of each sample was deconvolved into a linear continuum background and Gaussians (both in wavenumber) over a wavelength range from 2.67 µm to around 3.8 µm. Gaussians centered beyond about 2.8 µm were regarded as due to adsorbed water or organics [4] and removed from the natural log reflectance spectrum, the remaining portion was restored to the reflectance space, and resampled to the NIRS3 bands.

Results: Examples of those Gaussian deconvolutions of simulated NIRS3 spectra of the CC samples are shown in Fig. 1. These deconvolution calculations used only two Gaussians for the hydroxyl bands, although the original laboratory spectra may have taken three to fit. The band centers and the relative strength of these two bands are plotted in Fig. 2. There seems to be a trend that aqueous alteration, shock, and space weathering all shift band centers toward shorter wavelength.

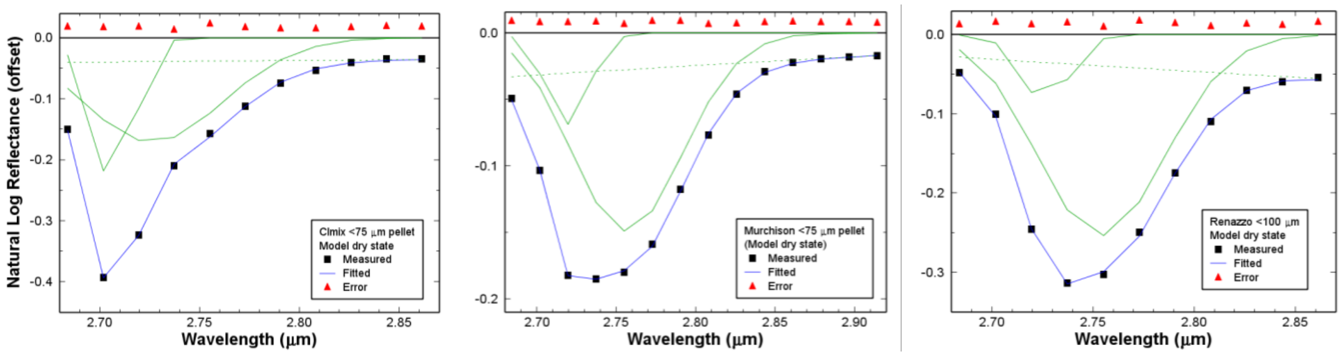

Figure 1. Examples of Gaussian deconvolutions of NIRS3-simulated spectra of type 1 and 2 carbonaceous chondrites.

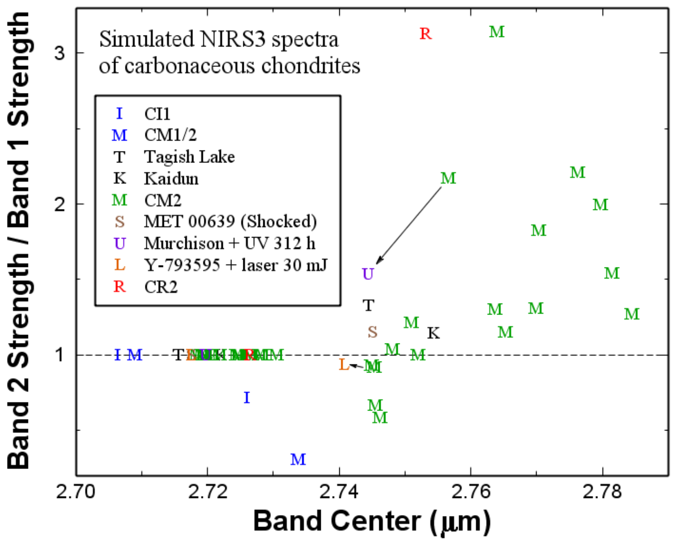

Figure 2. Band centers and relative strength of two hydroxyl bands of model spectra of CCs such as those shown in Fig. 1.

Acknowledgment: Antarctic meteorite samples were loaned from National Institute of Polar Research or NASA Johnson Space Center. RELAB is a multiuser laboratory supported by NASA SSERVI. T. H. was supported by NASA PDART grant.

References: [1] Hiroi T. et al. 2018. Abstract #1056. 49th LPSC. [2] Iwata T. et al. 2017. Space Sci. Rev. 208, 317. [3] RELAB database: http://www.planetary.brown.edu/relabdata/. [4] Takir D. et al. 2013. Meteoritics Planet. Sci. 48, 1618.

Abrasion experiments of mineral and meteorite grains: Application to grain abrasion of Itokawa, Ryugu and lunar regolith particles.

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Introduction: The external 3D shapes of Itokawa regolith particles by X-ray microtomography showed that some particles have rounded edges, which should be formed by mechanical abrasion [1]. Abraded surfaces were confirmed by detailed observation using SEM [2]. Mechanical abrasion of lunar regolith particles was also recognized by X-ray microtomography and SEM as well [3]. Seismic wave induced by micrometeoroid impacts [1], YORP effect and tidal motion [4] were proposed for the abrasion process on Itokawa.

In order to understand detailed process of the abrasion, abrasion experiments have been carried out [5]. In these abrasion experiments, quartz, olivine ($Fo_{\sim 90}$ from San Carlos), corundum and calcite (marble) as mineral samples and Sayh al Uhaymir 001 (L5) and Murchison (CM2) as meteorite samples were used. They were crushed into particles 1-2 mm in size except for corundum (~1mm). These particles (~6.5g) were put into a vessel (10 mL) (filling fraction of 50%) without any crushing tool, and the vessel was vibrated in a mill (Multi-beads-shocker: YASUIKIKAI Co.). Time changes of the amounts of powders produced by abrasion and their external shapes using X-ray microtomography were measured. In addition, the external shapes of marked particles were traced using X-ray nanotomography in a series of abrasion experiments. Based on the experiments, two modes of abrasion were recognized; gradual wearing and chipping of particle edges. The 3-axial ratios of particles almost unchanged by gradual wearing while they changed by chipping. It was proposed that the former process is responsible for Itokawa particle abrasion and later for lunar particle abrasion. However, the grain size used in the experiments (~1 mm) is larger than the regolith particle size (~0.1 mm).

In this study, additional experiments were made to understand the size effect and the abrasion rates were applied to abrasion on Itokawa and Moon by considering the size effect. Abrasion of Ryugu regolith particles, which will be returned by the Hayabusa2 spacecraft, was also discussed.

Experiments and analytical procedure: Quartz particles with three different sizes (0.5-1 mm, 1-2 mm and 2-4 mm) were used in the experiments on the size effect. The abrasion experiments were made at vibration rate of 2000 rpm only for 1 min. The other conditions are the same as those in the previous experiments. After the experiments, the mass of powder (<250 μm) produced by abrasion was measured.

Figure 1 shows the result in the previous experiments using olivine grains [5], where proportion of abraded powder in the total mass as the amount of abrasion, P, is plotted against the duration, t. We used the proportion at first 1 min., P_1, as the representative of the abrasion rate for comparison among different samples and sizes.

Results: In the present experiments, the P_1 value is almost proportional to the average of particles size, d; P_1 (%) = 0.849(12) × $d^{0.987(15)}$ (Fig. 2). By using this relation, we can correct P_1 values of a different size to that of 1-2 mm particle. Figure 3 shows the P_1 values for different samples with 1-2 mm as a function of the vibration rates, ω. P_1 increases with increasing ω in a power law with the power index of ~2 to 3. These relations may correspond to $E_{vib} \propto \omega^2$, where E is the vibration energy. The abrasion rate decreases from corundum, olivine ~

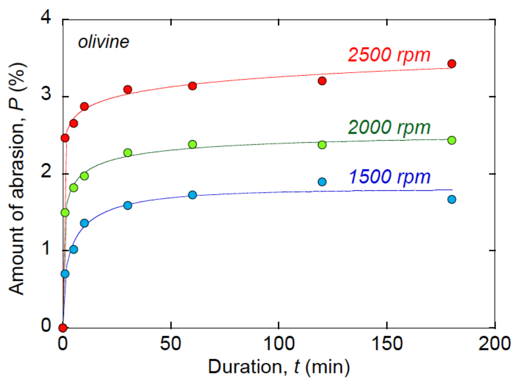

Figure 1. Amount of abrasion, P, plotted against duration, t, for different vibration rates, ω, using olivine samples.

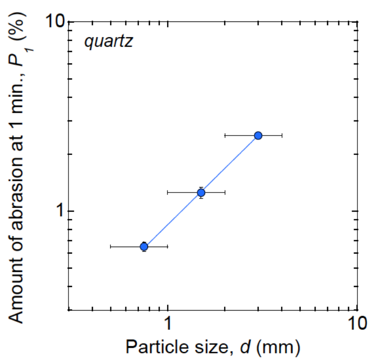

Figure 2. Amount of abrasion at 1 min., P_1, plotted against particle size, d, of quartz at ω =2000 rpm.

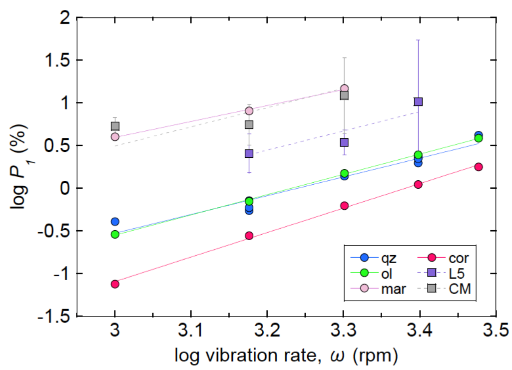

Figure 3. Amount of abrasion at 1 min., P_1, for 1-2 mm grains plotted against vibration rates, ω.

quartz to calcite (marble), and this order is consistent with their mechanical strengths. The data of L5 and CM chondrites were obtained from only six particles in each run and thus have large errors.

Discussion: The degrees of abrasion of regolith particles on Itokawa and Moon were roughly estimated from the present experiments. Figure 4 shows P_1 in a wide range of ω, where the values of P_1 of SaU 001 (L5) and Murchison (CM) grains obtained in the experiments are extrapolated with the log slop of 2 by considering $E_{vib} \propto \omega^2$. The following three types of estimation were made; (1) abrasion by impact-induced convection in a regolith layer, (2) abrasion in an ejecta during impact and (3) abrasion in a regolith layer during impact. In order to compare the grain velocity, v, and acceleration, a, in the models with those of the experiments, we used the means of absolute velocity and acceleration (<|v|> and <|a|>, respectively) by assuming simple harmonic motion of the sample vessel in the experiments (amplitude; 0.015 m). The corresponding values of <|v|> and <|a|> to ω are shown in Figure 4.

(1) *Abrasion by impact-induced convection*: Yamada and Katsuragi [6] estimated the convection velocity, v_{cov}, in a regolith layer of Itokawa due to impact-induced seismic shaking [1]. The typical value at the time of impact is ~6 mm/s. The corresponding P_1 for L5 is only 10^{-4}~10^{-5} %, and if the size effect ($P_1 \propto d^{-1}$) is taken into consideration P_1 with a few 100 µm grains should be 10^{-4}~10^{-5} %. These values indicate that abrasion cannot effectively occur by this process on Itokawa.

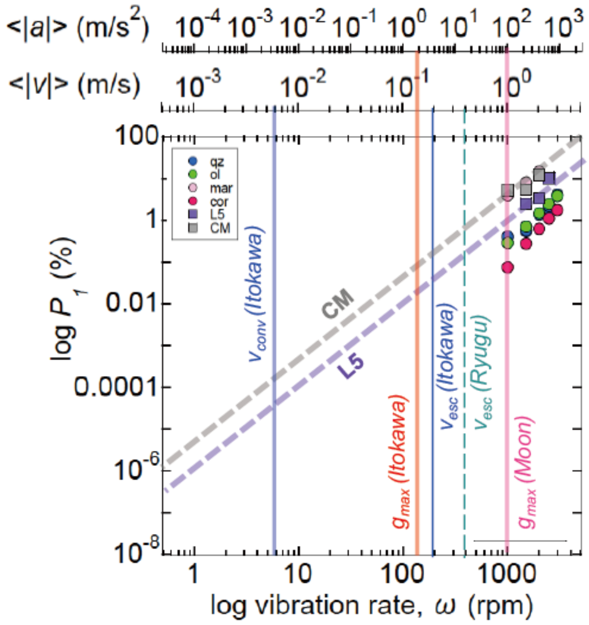

Figure 4. Estimation of the amount of abrasion at 1 min., P_1, with 1-2 mm grains for Itokawa, Ryugu and Moon.

(2) *Abrasion in an ejecta during impact*: In order to evaluate the possibility of abrasion by contact of grains during excavation and ejection by impact, the ejecta velocity, v_{eject}, was estimated as a function of the launch position of ejecta from the crater center, x, and the crater radius, R, using the model of [7]. On Itokawa, v_{eject} ~0.001–0.1 m/s (corresponding ω~1–100 rpm) for R=1 cm–100 m at x/R~1. The corresponding P_1 values for 1-2 mm L5 grains are ~0.01– ~10^{-6} % (Fig. 4) (~0.001– ~10^{-7} % for a few 100's µm grains). This indicates that effective abrasion is not expected. It should be also noted that only grains with v_{eject} less than the escape velocity of Itokawa, v_{esc}~0.2 m/s, can survive, suggesting P_1<~0.01 % for 1-2mm grains (Fig.4). In contrast, on Moon, v_{eject} > 1 m/s (ω>~1000 rpm) for R>1 m at x/R~1, indicating that abrasion is possible on Moon by this mechanism.

(3) *Abrasion in a regolith layer during impact*: In order to evaluate the possibility of abrasion by contact of grains in a regolith layer during impact, the maximum acceleration of the first peak on impact-induced seismic wave, g_{max}, was estimated as a function of distance from the impact point, x, for different impactor radius, r, using the model of [8] and the crater size model using the π-scaling theory [9]. The estimated g_{max} values on Itokawa and Moon are ~2 and ~100 m/s^2 irrespective of the impact conditions. The corresponding P_1 values for 1-2 mm L5 grains are ~0.01 and ~1 % (~0.001 and ~0.1 % for a few 100's µm grains) on Itokawa and Moon, respectively (Fig. 4). Therefore, abrasion on Itokawa is not possible while it is possible on Moon.

The above discussion suggests that abrasion by impact is almost impossible on Itokawa while it is possible on Moon. Mechanical abrasion is so high energetic process that this cannot occur on small asteroids, like Itokawa. Accordingly, Itokawa regolith particles with rounded surfaces by abrasion should originate from the parental body of Itokawa, where abrasion occurred by impact on the body. For the case of Ryugu, v_{conv} may be also small and thus abrasion is not expected even for materials with smaller strength, like CM, by the process (1). In the process (2), if v_{eject} is slightly less than v_{esc} (~0.4 m/s), the maximum values of P_1 for CM grains are estimated to be ~1 % (1-2 mm) and ~0.1 % (a few100's µm) (Fig.4). Similar values of P_1 are expected in the process of (3) although we cannot estimate g_{max} with good precision at this moment. These P_1 values may suggest that a small degree of abrasion of regolith particles on Ryugu is possible.

References: [1] Tsuchiyama A. et al. 2011. Science, 333: 1121. [2] Matsumoto T. et al. 2016. GCA 187: 195. [3] Tsuchiyama A. et al. 2016. 4th Symp. Solar System Materials. [4] Connolly H. et al. 2015. EPS 67: 12. [5] Tsuchiyama A. et al. 2018. Abstract #1844. 49nd LPSC. [6] Yamada T. M. and Katsuragi H. 2016. Planetary and Space Science 100: 79. [7] Housen & Holsapple, 2011. [8] Yasui, M. et al. 2015, Icarus 260: 320. [9] Holsapple, K. A. 1993. Annu. Rev. Earth Planet. Sci. 21: 333.

Comparison of solar wind He implantation profiles between Genesis collectors separately implanted fast-speed flow, low-speed flow, and coronal mass ejection flow components

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NASA's Genesis mission collected samples of solar wind that can be analyzed with high precision in laboratories. Sputtered neutral mass spectrometry (SNMS) with tunneling ionization has been applied to measure ^{4}He profiles in Genesis Bulk collector [1], of which apparatus was Laser Ionization Mass nAno Scope (LIMAS). The instrument can quantify ^{4}He presented at tens of ppma from an area of few-microns across of a solid surface. Depth profiling was carried out for isotope analysis of He and Ne of solar wind from a Genesis diamond-like carbon film on a silicon (DOS) substrate, which was irradiated by bulk solar wind for 2.3 years. The depth profile of ^{4}He in deep (>100 nm) was comparable with a background ^{4}He as residual gas a sample chamber of LIMAS [1]. The residual gas corresponded to ~3×10^{-4} He^{+} count per mass scan (cpms). Here we analyzed Genesis H, L, and E collectors of Genesis irradiated by high-speed or coronal hole flows, low-speed or interstream flows, and coronal mass ejection (CME), respectively.

Helium depth profiles for the three collectors should be different each other on the basis of ACE/SWICS data [2]. A measurement condition for the depth profiling was improved to distinguish each depth profile of the target isotopes. An ion pump of 410 l/s (Agilent Vaclon plus 500) and a non evaporation getter (NEG) pump were replaced to reduce residual noble gases in the sample chamber. To increase ion intensity, we installed high power Ti-sapphire fs laser (Astrella, Coherent, Inc.) of 6 mJ per 30 fs pulse to increase ionization efficiency for He [3]. As a result, the background He abundance, which was the same measurement for sample without the primary beam pulse for sputtering, decreased from ~3×10^{-4} He^{+} cpms to ~2×10^{-5} cpms. The ion intensity of 2×10^{-5} cpms corresponds atom concentration of ~10^{17} cm^{-3} (~1 ppma) under the same measurement condition. A useful yield of He are increased from 9×10^{-5} [1] to 5×10^{-4}. Control timing for the mass spectrometer [3] were also refined to measure multi-isotopes at the same time. Mass resolving power for He depth profiling was ~13,000 in 99% valley after 95 multi-turn of m/z = 4 in MULTUM II to separate $^{4}He^{+}$ from $^{12}C^{3+}$ of the main element of the DOS.

Depth profiles for ^{4}He and $^{20,22}Ne$ of the DOS samples from the three Genesis collectors were measured at the same time. A ^{4}He depth profile of the H collector showed relatively symmetric with a peak of 35 nm. A profile of the L array showed that ^{4}He was concentrated less than 40 nm and the peak was 10−20 nm, which was close to the limit of the depth resolution of 30 keV Ga^{+} beam. The E array demonstrated broad ^{4}He profile and observed ^{4}He in deep (>100 nm) as well as the bulk collector. On the other hand, He in deeper than 150 nm of the Genesis H and L arrays were equivalent to the background level. This He in deep indicates that the ^{4}He in deep should be derived from the questionable very high-speed flows (Halloween event of 2003) during October 23−November 3 2003 [2]. The depth of the 35 nm for the H collector corresponds to the speed of 600 km s^{-1}. The L collector profile should be corresponded to 400 km s^{-1} of the solar wind. The ^{4}He deeper than 100 nm of the E collector represents faster than 1000 km s^{-1} derived from the Halloween event of 2003.

References

[1] K. Bajo et al. (2015) Geochem. J., 49, 559-566. [2] D. B. Reisenfeld et al. (2013) Space Sci. Rev. 175, 125-164. [3] A. Tonotani et al. (2016) Surf. Interface Anal., 48, 1122-1126. [4] K. Bajo er al. (2018) Surf. Interface Anal., accepted.

Hayabusa2 sample recovery and phase-1 curation

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Hayabusa2 spacecrat will bring back the C-type asteroid Ryugu sample to the Earth in the end of 2020. Astromaterials Science Research Group (ASRG) of ISAS/JAXA will excute re-entry capsule recovery at landing site, sample extraction from sample container, initial description of the sample, distribution the samples to succeeding detail analysis, and storage the sample for future generation.　In this presentation, we report the current plan of sample recovery and phase-1 curation of our group.

10 % amount of Hayabusa2 returned sample will be delivered to NASA according to MOU between NASA and JAXA. The rest of the sample will be used for detail analysis operated by initial analysis team directed by Hayabusa2 project and phase-2 curation teams collaborated with ASRG, and after that, will be open for internation AO. Shcedule of curatorial work and sample distribution plan for Hayabusa2 will be shown in Fig.1 as below.

Initial analysis will be done by the Hayabusa2 mission to maximize the scientific achievement of the project for 12 months after the phase-1 curation (sample description at the ISAS curation facility).　　The initial analysis should be a good showcase to prove the potential of the rest of samples.　Along with the initial analysis, the phase-2 curation of returned samples will be done for integrated thorough analysis and description of samples to build a sample database and to obtain new scientific perspective from thorough analysis of samples.　The phase-2 curation will be done both in ISAS and also in several research institutes outside JAXA led by the ISAS curation facility.

After the recovery of the re-entry capsule, the sample container will be extracted from the re-entry capsle at the landing site like hayabusa mission.　In hayabusa2 mission, residual gas sampling from the sample contener will be done at the landing site moreover.　After that the sample contener will be transported to ISAS curation facility, and outer lid extraction and cleanig of the outer surface of the sample container will be done in the clean room.　Opening operation of the inner lid of the saple container and picking up operation of a few sample from sample container will be done in the clean chamber in vacuume environment.

The rest sample will be handled in the another clean chamber in ultra pure nitrogen environment.　Returned sample will be stored in the sample catcher connected with inner lid of the sample container.　Sample catcher is consisted in 3 rooms. The samples obtained from 3 tatch down sites of the spacecraft at the asteroid ryugu is stored in each rooms.　In the clean chamber, we will observe inside of each rooms using optical scope, and remove the samples of each rooms to the each quartz dishes.　After extraction of the sample from sample cather, we will initial description of bulk sample at first.　These procedure will be used by optical microscope, infrared spectroscope, and weighing device.　After bulk observation, we will pick up each particles of larger than 1 mm (TBD) size and storage into each quartz dishes separately.

In the pahse-1 curation will be done within 6 monthe after the re-entry capsule recovery.　After phase-1 curation, we will delivered some portion of the returned sample to detail analysis, which is operated by initial analysis team and phase-2 curation team.　The amount of the sample for the initial analysis will be 15%(TBD) of the recovered samples. Representative and unprocessed sample will be desired by the initial analysis.　Initial analysys also desires coarse and fine particle.　ISAS curation will be delivered the fine particle in one bundle.　The samples delivered to phase-2 curation will be selected by ISAS curation considerling the result of the initial description.　The amount of the samples will be 15%(TBD) including detail analysys at phase-1 curation and outreach sample.　The purpose of phase-1 detaile analysys is confirmation of the sample origin (the return sample is origined from Ryugu or not), ascertainment of the sample heterogeneity, and discrimination of the contamination by composition analysis of some portion of the returned sample using SEM (TBD) at ISAS curation.

In principle, during phase-1 curation, it is based on nondescrupted and uncontaminated description, however, for conduting compostion analysis, we will allow the contamination for some potion of the sample by SEM observation..

New clean room and clean chamber for receving Hayabusa2 returend sample will be established by the end of this year. We are currently preparing the observation instrument and handling tool of returned sample. From this year we started the operational test of the clean chamber, and we will start to the rehearsal operation including handling test of the analog sample from next year. We will finish rehearsal and reharbish of the clean chamber by earth return of the spacecraft in the end of 2020.

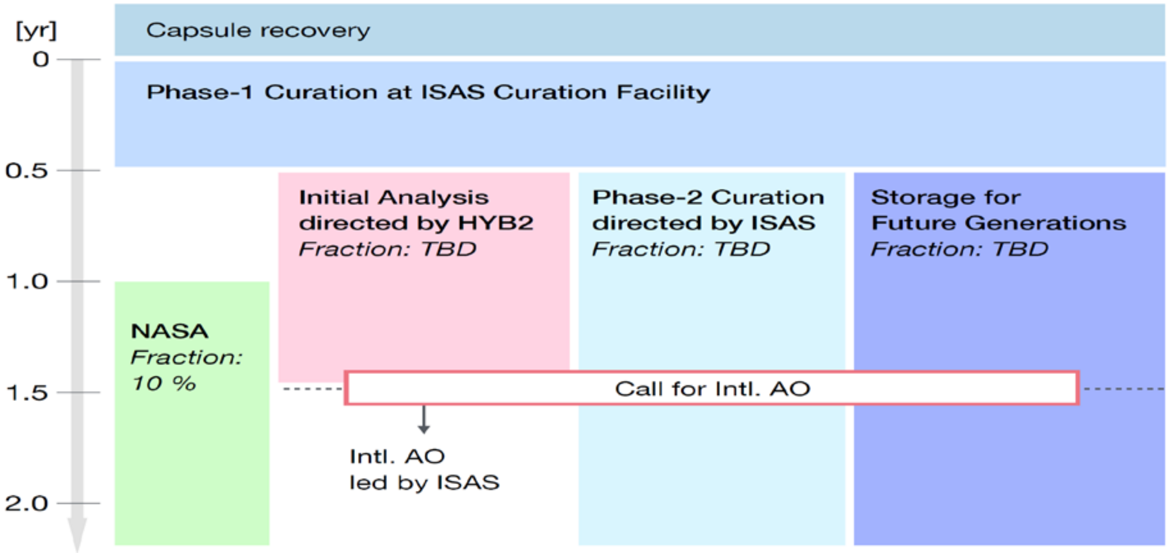

Fig.1 Shcedule of curatorial work and sample distribution plan for Hayabusa2

A perspective of Phase 2 Curation “Team Kochi” for Hayabusa2 returned sample: *in-depth* analysis of a single grain utilizing linkage microanalytical instruments

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Analyses of returned samples from asteroid [1] and comet [2] were essential to understand their origin and nature as well as increasing our knowledge about the Solar System. The most recent returned sample was from the S-type asteroid Itokawa by Hayabusa mission in 2010. The results by series of researches provided new insights for the connection to meteorites, space weathering processes, small asteroidal body formation in the Solar System [e.g., 1, 3, 4]. JAXA Hayabusa2 and NASA Osiris-REx are both current sample return missions from the organic-rich asteroids, Ryugu (C-type) and Bennu (B-type), respectively [5, 6]. Both missions have complementary scientific goals that are to understand the Solar System evolution in the point of view of organics, water, and associated minerals.

Phase 2 curation teams will be acting under the scientific direction and strong ethic of the Astromaterial Science Research Group (ASRG) of JAXA and was authorized 2 institutes by the steering committee of the ASRG in 2017: (1) Kochi Inst. for Core Sample Research, JAMSTEC in collaboration with JASRI/SPring-8, UVSOR/Inst. Molecular Science, National Inst. Polar Research and Tokyo Metropolitan University, and (2) the Inst. for Planetary Materials, Okayama University at Misasa. The JAXA Curation requested us to make an *in-depth* analysis of few grains by our *state-of-the-art* instruments/techniques and nationwide corroborative research abilities. We will conduct on analyses in parallel with the initial analysis team led by the Hayabusa2 project.

Here are our policies as Phase 2 curation team:

1) We will analyze Hayabusa2 samples utilizing the *state-of-the-art*, original analytical and research in collaboration with several institutes and universities to acquire petrological and chemical characteristics to the utmost. Our results and developed techniques are fed back to the initial analysis teams, and will be a benchmark that contributes to the international announcement of opportunity and curation works.
2) We will acquire a 2D / 3D high resolution texture of a single grain, molecular structures, chemical species identifications, light element isotopic ratios, major and trace elemental abundances, microtextural features, and crystal structures. To make this successfully we will apply the sequential analysis protocol from non-destructive analyses at synchrotron radiation facility such as 3D-CT and XRD, STXM-XANES to destructive analyses such as FIB sample preparations, TEM observations and mass spectrometry with SIMS, LA-ICP MS.
3) We will explore *in-depth* of Hayabusa2 samples from the viewpoint of similarities or different characteristics with the current knowledge of extraterrestrial materials (meteorites, micrometeorites, Hayabusa samples) in Antarctic Meteorite Center of National Inst. Polar Research and JAXA curation facility. Primary objective will focus on studying of extraterrestrial water and primordial organic components in Hayabusa2 samples.

Avoiding terrestrial contaminations (i.e., atmospheric water/air, organics) during sample curation, transportation and analysis are important to obtain original chemical characteristics of Hayabusa2 samples. We, then, have developed novel and universal sample holders for a linkage analysis utilizing micro-analytical instruments of FIB, TEM, STXM and NanoSIMS minimizing terrestrial contaminations and sample damages of lost or broken. We also made an additional sample holder (namely Okazaki cell) for STXM analysis (Ohigashi T. et al. i*n preparation*), and a sample transport vessel (FFTC: facility to facility transfer container) under vacuum or inert gas (Uesugi K and Uesugi M. et al. *in preparation*) in parallel.

We will report current status of “Team Kochi” of Phase2 Curation and our developed universal sample holders for FIB, TEM, NanoSIMS, STXM, and a sample transport vessel under vacuum or inert gas among nationwide/international universities and institutes.

References

[1] Nakamura T. et al. (2011) Science 333, 1113–1116. [2] Brownlee D.E. et al. (2006) Science 314, 1711–1716. [3] Yurimoto H. et al. (2011) Science 333, 1116–1119. [4] Noguchi T. et al. (2018) Science 333, 1121–1125. [5] Tachibana S. et al. (2014) Geochemical J. 48, 571–587. [6] Lauretta D.S. et al. (2014) Meteorit. Planet. Sci. 50, 834–849.

DESTINY+: Flyby to Asteroid (3200) Phaethon and in-situ dust analyses

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Introduction: More than 40,000 metric tons per year of extraterrestrial dust accrete onto the Earth [1]. While carbonaceous meteorites are rare (less than 5%) among meteorite collection, interplanetary dust particles (IDPs) generally include carbon and organic materials and their carbon contents are 5-10 times richer than those for carbonaceous meteorites. Dust particles are likely major carriers of carbon and organic matters to the Earth and potentially be precursors to the terrestrial life. Extraterrestrial dust particles are derived either from cosmic dust background or from meteor showers. The former consists mostly of IDPs which originate from miscellaneous comets and asteroids, with minor interstellar dusts. The latter are meteoroids transported via dust trails or streams, where dust ejected from specific comets and asteroids, whose orbits cross that of the Earth.

Asteroid (3200) Phaethon is a parent body of Geminid meteor shower [e.g. 2], which is amongst the most active meteor showers. While parent bodies of meteor showers are mostly comets, Phaethon is an Apollo type asteroid with carbonaceous, B-type reflectance spectra [e.g. 3]. Recurrent dust ejection at its perihelion (0.14 au) are reported [4-6], while no coma was observed around 1.5 au [7]. The dust ejection mechanism of the active asteroid remains unknown. Na depletion is reported for Geminid meteor shower [8] and higher dust density (2.9g/cm^3) is estimated [9], both of which hints volatile depletion possibly by solar heating. Phaethon is of great interest and significance because it is a carbonaceous asteroid providing dust to the Earth via dust stream, has a break-up body, 2005 UD [10], is possibly a breakup from main-belt asteroid 2 Pallas [11], experiences extensive solar heating at a small perihelion distance, and among the largest potentially hazardous body. Due to its scientific importance, Phaethon was a potential target for previous missions, such as Deep Impact and OSIRIS-REx. However, sample return, impact experiment, as well as rendezvous are difficult for Phaethon with a large relative velocity due to its large eccentricity and inclination. Only viable approach for Phaethon is flyby.

Mission overview: DESTINY+ (Demonstration and Experiment of Space Technology for INterplanetary voYage, Phaethon fLyby and dUst Science) is a mission proposed for JAXA/ISAS Epsilon class small program, currently in the pre-project phase (Phase-A) with a launch targeted for 2022. DESTINY+ is a joint mission of technology demonstration and scientific observation. It will demonstrate high performance electric propelled vehicle technology and high-speed flyby exploration of asteroid (3200) Phaethon. DESTINY+ aims to realize high-resolution imaging during close proximity flyby, high-accuracy navigation and wide-range observation, and these implemented for multiple small bodies (multi-flyby). Engineering challenges include proximity fly-by navigation with adequate risk of collision, radio-optical hybrid navigation guidance and control, and autonomous imaging based on optical information for target tracking. System design of DESTINY+ is summarized in Table 1.

Science goal of DESTINY+ is to understand the nature and origin of cosmic dust brought to the Earth, in the context of exogenous contribution of carbon and or-ganics to the origin of terrestrial life. The science mission objectives are to measure physical properties (velocity, orbit, mass) and chemical composition of interplanetary and interstellar dust particles around 1 au during deep space cruising phase, and to conduct geological observation of Phaethon to understand dust ejection mechanism of active asteroid, surface compositional variation, and analyze dust particles from Phaethon during high-speed flyby (33 km/sec).

Mission profile: DESTINY+ spacecraft is injected into an elliptical orbit around the Earth by an Epsilon launch vehicle and then the electric propulsion is used to raise the orbit to reach the moon. Subsequently, it escapes from the Earth's gravity sphere through multiple lunar gravity assists, and heads for Phaethon after cruising by electric propulsion in deep space, and finally conducts flyby observation. A flyby point is around descending node of Phaethon with a geocentric distance of 1.72 au and a heliocentric distance of 0.87 au. After Phaethon fly-by, DESTINY+ may head for another target asteroid such as 2005 UD, a breakup body of Phaethon, as an extended mission. The summary of mission profile is shown in Table 2.

Science payloads: DESTINY+ has three science payloads, panchromatic telescopic camera (TCAP), VIS-NIR multiband camera (MCAP) and dust analyser (DDA) for science observation. The three payloads in relation to science requirements are shown in Fig. 1. Dust analyzer is developed with a heritage of Cosmic Dust Analyzer (CDA) onboard Cassini and provided by a team led by Stuttgart University [12]. TCAP and MCAP are developed by a team led by Planetary Exploration Research Center, Chiba Institute of Technology. TCAP is equipped with a tracking mirror. The observation profile during flyby and the current design of the cameras are presented by Ishibashi et al. [13].

Observation campaign for Phaethon and 2005UD: Phaethon approached the Earth as close as 10,000,000 km in December 2017. Variable observation of Phaethon, such as photometric, spectroscopic, polarimetric and radar observation were successfully conducted over the world [e.g.14, 15]. Asteroid 2005UD, which is a likely breakup body and a target candidate for multi-flyby of DESTINY$^+$ will approach to the Earth as close as 0.2 au in October 2018. Another observation campaign for 2005UD is currently organized. These observation data are crucial to better characterize Phaethon for further mission plan and detailed payload design for DESTINY$^+$.

References:

[1] Love S. G. and Brownlee D. E. (1993) Science 262, 550. [2] Williams I. P. and Wu Z. (1993) Mon. Not. R. Astron. Soc. 262, 231-248. [3] Licandro J. et al. (2007) A&A 461, 751-757. [4] Jewitt D. and Li J. (2010) AJ, 140, 1519. [5] Jewitt D. et al. (2013) Astrophys. J. Lett. 771, L36. [6] Li J. and Jewitt D. (2013) AJ. 145: 154. [7] Jewitt D. and Hsieh H. (2006) AJ, 132, 1624. [8] Kasuga T. et al. (2006) A&A 453, L17. [9] Borovicka J. et al. (2009) Icy Bodies of the Solar System, Proc. IAU symp. No 263. 218. [10] Ohtsuka K. et al. (2006) A&A 450, L25. [11] De Leon J. et al. (2010) A&A 513, A26. [12] Kobayashi M. et al. (2018) LPS 49th, abstract#2050. [13] Ishibashi K. et al. (2018) LPS 49th, abstract#2126. [14] Takir D. et al. (2018) LPS 49th, abstract#2624. [15] Taylor P. A. et al. (2018) LPS 49th, abstract#2509.

Table 1. System design of DESTINY$^+$ spacecraft.

Mission Period	> 4 years
Mass	480 kg (including 60 kg Xenon and 15.4 kg Hydrazine)
Launcher	Epsilon rocket + kick motor
Trajectory	230 km x 49913 km, 30 deg. → Lunar swing-by → Phaethon transfer
Attitude control	3-axis (Error < 1 arc-min.)
Communication	X band (GaN SSPA, HGA 4 kbps, MGA 1 kbps, LGA 8 bps at 1.9 AU)
Solar Array	High-specific power light-weight paddle (138 W/kg, 4.7 kW (BOL), 2.6 kW (EOL))
Battery	Li-ion (42 Ah, 11s1p)
Propulsion	RCS (Hydrazine) + Ion thrusters (μ10 x 4)
Thermal control	Loop heat pipes, Reversible Thermal Panels
Radiation dose	Approx. 30 krad (with aluminum shield of 3-mm thick)

Table 2. Mission profile of DESTINY$^+$.

	Period	Operation
1	1 month	Launched into a highly elliptic orbit (230 x 49913 km) by Epsilon rocket
2	0.5-2 years	Spiraled orbit raising by electric propulsion
3	0.5 years	Lunar swing-by
4	2 years	Phaethon transfer orbit (Aphelion 1.16 au)
5	Several days	Phaethon flyby
6	0.5-1 years	Earth swing-by transfer orbit (Perihelion 0.83 au)
7	Several days	Earth swing–by
8	T.B.D.	Transfer orbit to next target

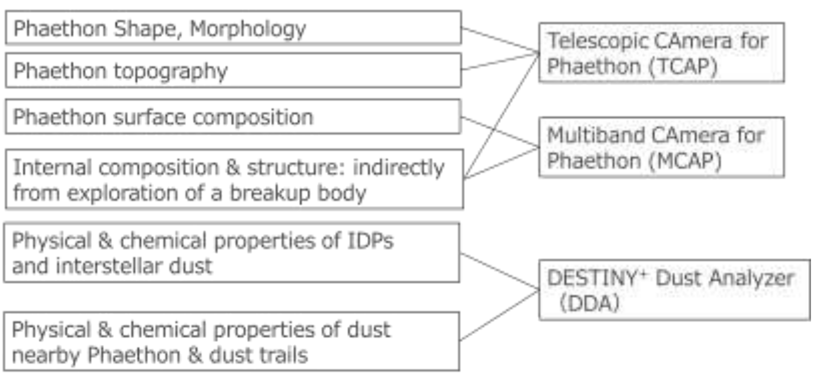

Fig. 1. Science goals and related instruments for DESTINY$^+$.

Martian Moons eXploration (MMX)

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Martian Moon eXploration (MMX) is the 3rd Japanese sample return mission followed by Hayabusa [1] and Hayabusa-2 [2]. The MMX spacecraft is scheduled to be launched in 2024, orbit both Phobos and Deimos (multi-flyby), and retrieve and return >10 g of Phobos regolith back to Earth in 2029 [3]. The origins of Phobos and Deimos are still a matter of significant debate: capture of asteroids versus in-situ formation by a giant impact on Mars. In either case, MMX will definitely provide clues about their origins and offer an opportunity to directly explore the satellite building blocks or juvenile crust/mantle components of Mars. MMX will also aim to understand physical processes in the circumplanetary environment of Mars. The new knowledge of Phobos/Deimos and Mars will be further leveraged to constrain the initial condition of the Mars-moon system and to gain vital insights regarding the sources and delivery process of water (and organics) into the inner rocky planets.

We select seven nominal science payloads for the remote sensing observations: 1) wide-angle multi-band camera (OROCHI), 2) telescope camera (TENGOO), 3) near-infrared spectrometer (MacrOmega), 4) gamma-ray and neutron spectrometer (MEGANE), 5) light detection and ranging (LIDAR), 6) circum-Martian dust monitor (CMDM), and 7) mass spectrum analyzer (MSA) (Table 1). The spacecraft also carries a sampler system equipped with a robotic manipulator and corers, which enables the acquisition of Phobos regolith >2 cm beneath the surface.

The spacecraft consists of propulsion, exploration, and return modules (total launch mass = ~3,500 kg). The chemical propulsion system is utilized for Mars orbit injection and escape maneuver. The outward interplanetary flights take ~1 year by the most efficient Hohmann-like transfer. The spacecraft stays at circum-Mars orbits ~3 years for exploration followed by the ~1 year homeward interplanetary flight to Earth. The Phobos exploration includes multiple landing/sampling operations; each takes ~2.5 hours. The spacecraft employs ballistic descent to reach the space right above a landing site before the final free-fall descent without a thruster jet to prevent whirling wind from blowing regolith particles.

Table 1. Nominal science payload

Payload	**Measurements**
Wide-angle multiband camera (OROCHI)	• Global mapping of hydrated minerals, organics, and the spectral heterogeneity of the Martian moons
Telescopic camera (TENGOO)	• Determine the global topography and surface structure of the Martian moons • Characterize the topography around the sampling sites
Gamma-ray, neutron spectrometer (MEGANE)	• Determine the bulk elemental abundance and compositional variability of Phobos
Near-infrared spectrometer (MacrOmega)	• Global mapping of minerals, molecular H_2O and organics of the Martian moons • Characterize the material distribution around the sampling sites • Monitor the transport of H_2O vapor, H_2O/CO_2clouds, and dust in the Mars atmosphere
Light detection and ranging (LIDAR)	• Determine the Phobos shape and topography
Circum-martian dust monitor (CMDM)	• Detect and monitor: 1) the circum-martian dust ring; 2) interplanetary dust; 3) Interstellar dust
Mass spectrum analyser (MSA)	• Determine the mass and energy of ions from Phobos, Mars and Sun

References

[1] Fujiwara, A. et al.2006, Science 312: 1330-1334. [2] Tsuda, Y. et al. 2013. Acta Astronautica 9: 356-362. [3] Usui, T. et al. 2018, Abstract# B4.2-0007-18, 42nd COSPAR.

HERACLES – The exploration of the Moon including sample return mission

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Inspired by the Global Exploration Roadmap (GER), the HERACLES (Human-Enhanced Robotic Architecture and Capability for Lunar Exploration and Science) is designed to demonstrate key elements and capabilities for sustainable human exploration of the Moon while maximizing opportunities for unprecedented scientific knowledge gain. To enable human lunar exploration, which is one of the four cornerstones of the European Exploration Envelope Program, it is planned to launch a sub-scale demonstration mission in the mid-2020's timeframe to test key components of lunar vehicles, including a lander, rover and ascent vehicle. European Space Agency (ESA) will coordinate and undertake the study of the ascent module, Japan Aerospace Exploration Agency (JAXA) will study the lander, and the Canadian Space Agency (CSA) will investigate the rover element. In parallel, we are developing surface operational scenarios that reflect the input from the international lunar science community. This will include the selection and characterization of a potential landing site with a large scientific potential and return of lunar samples of high scientific value before conducting a long distance traverse that will provide further opportunities for in-situ science and exploration. The coordination of the planning of science opportunities is performed by the multi-agency HERACLES Science Working Group (SWG). This working group is also responsible for developing a mission science management plan to describe science team and science payload selection processes, and data and sample policies. In the next steps, we will engage the science communities of the study agencies and install an international HERACLES Science Definition Team (iSDT). The iSDT will generate a prioritized list of investigations and will provide input for the landing site selection. In the initial phase of mission planning, the HERACLES study team has developed a nominal scenario with Schrödinger basin as the reference landing site with the purpose of driving engineering requirements. On the basis of studies by the Lunar Planetary Science Institute in 2015 and preliminary studies by the HERACLES team, Schrödinger basin might be a potential landing site that could satisfy may science objectives although other sites may also be considered. The iSDT will provide the report on candidate landing sites in mid-December 2018.

The current mission planning foresees a 70-day surface sample return mission, followed by a 1-year traverse encompassing one or more additional potential human exploration landing sites. We plan to return maximum of 15 kg of samples. A possible mission scenario to accomplish these objectives is shown in Fig. 1. The first HERACLES mission starts with the launch of a mid-sized launch vehicle (baseline Ariane 64) to lunar transfer orbit (LTO). The lunar descent element (LDE) will performs the landing to the lunar surface carrying the Lunar Ascent Element (LAE) and the rover. It is assumed that the landing is to occur during daylight conditions. On the surface, the rover egresses the LDE and starts the surface campaign. Initial exploration of the surface by the rover is supported by ground control and time-tagged commanding until the crew arrives on the Lunar Orbital Platform-Gateway (LOP-G). Once the crew is present, the crew-supported surface mobility operations will start. The rover then is commanded to drive, to perform sample collection and to transfer the sample container to the LAE. The sample collection phase can take multiple lunar day-night cycles and ends with the deposition of the samples into the LAE. The LAE will ascends from the surface, and initiates the transfer to the LOP-G. The sample container will be removed from the LAE by the LOP-G robotic arm. HERACLES's rover remains functional on the surface and is driven by ground-control along the planned traverse to demonstrate long-life, long-range surface mobility and exploration activities (in-situ investigations and sampling).

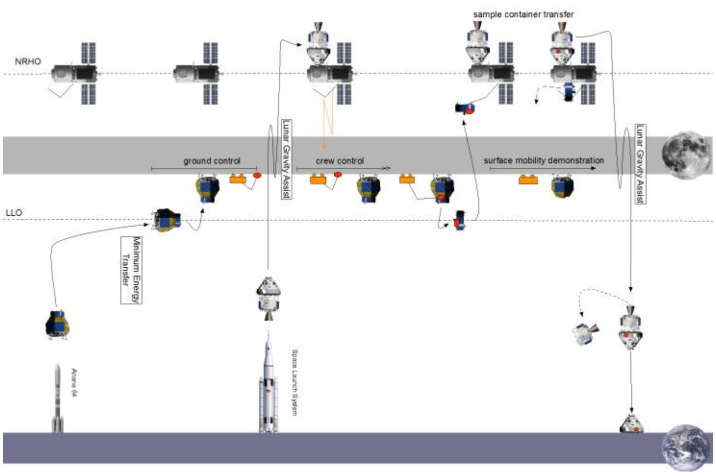

Figure 1. Baseline Mission Operations Scenario (left to right).

The OKEANOS: Small Body Exploration to a Jupitar Trojan Asteroid

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Introduction: The OKEANOS (Oversize Kite-craft for Exploration and AstroNautics in the Outer Solar system), which is also known as the Solar Power Sail (or SPS), mission is one of the candidates of the strategic middle-class space exploration to the outer Solar System lead by JAXA [1]. The mission will be launched in late 2020s, and rendezvous for spectral observations and landing for *in-situ* isotope/elemental measurements to a D or P type Jupitar Trojan asteroid of ~20-30 km in diameter on or about 2040. Unique scientific instruments of a high-resolution mass spectrometry (HRMS) together with suits of remote-sensing instruments will be on board. Currently we consider three mission plans for the OKEANOS, plan A is a rendezvous and landing for single asteroid, plan A' is multi-rendezvous and landing for single asteroid, and plan B is a rendezvous, landing for single asteroid and sample return. Note that the sample return is not yet fully developed. More detailed developments of the sample return canister, a plan to prevent sample heating and degradation during capsule reentry will be required.

Scientific Goals: Through in-depth scientific observations with HRMS and spectroscopy, the OKEANOS will provide critical input to the key questions of (1) constraining planet formation/migration theories, (2) inventory and distribution of volatiles (water and organics) in the Solar System.

In-situ HRMS analysis: The HRMS is one of the flagship instruments on the OKEANOS, conducting critical measurements towards the scientific goals of the mission. D/P-type asteroids likely consist of dominant of organics (carbonaceous materials) and anhydrous silicates (hydrated silicates cannot be excluded), possibly with water (ice) in its interiors [2]. We, therefore, plan to analyze volatile materials on the Jupitar Trojan, for their isotopic and elemental compositions using a HRMS (MULTUM: multi-turn ToF mass spectrometer [3]) with a combination of pyrolysis ovens and gas chromatography [4]. This HRMS system allows to measure H, N, C, O isotopic compositions and elemental compositions of molecules. Analyses of light isotopes and molecules of materials on a Trojan asteroid may permit deciphering if the Trojan bodies originate from the cometary reservoir or share similarities with asteroids (or meteorites) from the inner Solar System. Especially isotopic analysis may provide insight into the migration model of giant planets (Jupiter, Saturn) at the early Solar System.

The sample return from the Trojan asteroid: Beside *in-situ* HRMS analysis of isotopic ratios, elements and molecules in surface and subsurface samples on the Trojan asteroid, analysis of returned samples from Trojan asteroidal objects containing non-volatile materials (organics and minerals) as well as water (ice) will open a new insight of the detailed scientific objectives for the Solar System evolution. Since *in-situ* analysis is limited in terms of sample preparations, lack of relationship among components, and mineralogical/petrological contexts, the *state-of-the-art* microanalysis techniques on the Earth will provide these additional information such as isotopic ratios of individual component (organics and associated minerals), trace amount of gaseous species (e.g., Noble gases, CO, CO_2, NH_3, CH_4 gasses in ice), and organic compounds that are hard to be detected under the current *in-situ* HRMS system (e.g., amino acids).

Relationship to other missions: Collaboration with LUCY (multi-rendezvous) of NASA Discovery mission [5] will be enhanced an understanding of origin and nature of a Jupitar Trojan asteroid. Indeed, detailed chemical analysis of single Trojan asteroid by the OKEANOS will support to understand the diversity among other Trojan asteroids by LUCY. The sample return missions of C-type asteroid by Hayabusa2 [6], B-type asteroid by OSIRIS-REx [7] and comet by CAESAR [8] will provide chemical and physical properties of comets and asteroids. These may contribute better understanding of Trojan asteroids in combination with the OKEANOS's *in-situ* analysis and sample return from D/P-type asteroid.

References: [1] Okada T. et al. (2018) Planetary and Space Science, 161, 99, 2018. [2] Guilbert-Lepoutre A. (2014) Icarus, 231, 232–238. [3] Shimma S. et al. (2010) Anal. Chem., 82, 8456. [4] Goesmann F. et al. (2017) Astrobiology, 17, 655. [5] Levison H. et al. (2016) LPSC 47, abst#2061. [6] Tachibana S. et al. (2014) Geochemical J., 48, 571-587. [7] Lauretta D. S. et al. (2014) Meteorit. Planet. Sci., 50, 834-849. [8] Nakamura et al. (2018) in this meeting.

Project overview of CAESAR comet sample return mission

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The Comet Astrobiology Exploration Sample Return (CAESAR) mission will acquire both rocks and ice with a minimum amount of 80 g from the surface of short-period comet 67P/Churyumov-Gerasimenko and recover the samples to the Earth for laboratory analysis [1]. Since comets preserve the records of the early evolution of solar-system material, analysis of returned samples by CAESAR is expected to uncover the origin of the Solar System starting materials and how these components came together to form planets and give rise to life. ESA's Rosetta mission visited comet 67P and carried out detailed remote sensing observations, which provides us geomorphological information and composition of surface material. Infrared spectra of comet 67P show a large 3 μm absorption band from water ice, while no apparent 2.7 μm absorption band from phyllosilicates [2], which suggests minimum aqueous alteration and thus preservation of intact solid material. CAESAR can take the advantage from the Rosetta results to maximize science return and to reduce the risk for landing. CAESAR preserves much of the science of a cryogenic sample return by retaining volatiles in a dedicated reservoir securely separated from the solid sample.

Analyses of returned samples will determine the nature and abundances of interstellar materials that are present in the solar-system starting material. They will trace the evolution of volatile reservoirs, delineate chemical pathways that led from simple interstellar species to complex and prebiotic molecules, and constrain the geological and dynamic evolution of 67P. And they will evaluate the potential role of comets in delivering water and organics to the early Earth. These goals will be achieved by sample analyses that link macroscopic properties of the comet with microscale mineralogy, chemistry, and isotopic studies of volatiles and solids. These analyses can be performed in terrestrial laboratories with orders of magnitude greater sensitivity and precision than possible with spacecraft instrumentation.

CAESAR is one of the two finalists selected by NASA for Phase A study in the New Frontiers 4 program and the result of the final selection will be in public in late 2019.

References: [1] Squyres S. W. et al. (2018) 49th LPSC, Abstract #1332. [2] Barucci M. A. et al. (2016) A&A 595, A102.

Mars Sample Return – How Should it be Organised Into Science Objectives?

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The analysis in Earth laboratories of samples that could be returned from Mars is of extremely high interest to the international Mars exploration community. IMEWG (the International Mars Exploration Working Group) is currently exploring options to involve the international community in the planning for returned sample science, including the analysis of the returned samples. The Mars 2020 sample-caching rover mission is an essential component of a potential Mars Sample Return campaign, so its existence constitutes a critical opportunity - the prospects for MSR are more real now than they have ever been. The Mars 2020 samples, if returned, would provide the basis for performing a variety of Earth-based experiments including ones related to the search for the signs of life.

PROPOSED MARS SCIENCE OBJECTIVES

Seven objectives have been defined for MSR, traceable to published priorities established over more than two decades by Planetary Science Decadal Surveys in the USA and other international studies [e.g. 1, 2]. For each, their importance to science or engineering is described, critical measurements that would address the objectives are specified, and the kinds of samples that would be most likely to carry key information are identified.

1. Interpret in detail the primary geologic processes that formed and modified the ancient (pre-Amazonian) geologic record.

The objective seeks to investigate the geologic environment represented at a high-priority landing site (whichever site might be selected). All the sites are of ancient (Noachian or Hesperian) age. The intent is to provide definitive geologic context for samples and details that relate to past biologic processes. This objective is divided into sub-objectives that would apply at different landing sites.

1.1 Understand the essential attributes of a martian sedimentary system. The intent is to understand the preserved martian sedimentary record. Most important samples: A suite of sedimentary rocks that span the range of variation. Scientific importance: Basic inputs into the history of water, climate change, and the possibility of life.

1.2 Understand an ancient martian hydrothermal system through study of its mineralization products. The intent is to evaluate at least one potentially life-bearing ‘habitable’ environment via samples. Most important samples: A suite of rocks formed and/or altered by hydrothermal fluids. Scientific importance: A possibly habitable geochemical environment with high preservation potential.

1.3 Understand the rocks and minerals representative of a deep subsurface groundwater environment. The intent is to definitively evaluate the role of water in the subsurface. Most important samples: Suites of rocks/veins representing water/rock interaction in the subsurface. Scientific importance: May be the longest-lived habitable environments and key to the hydrologic cycle.

1.4 Understand ancient water/rock interactions at the martian surface, or more broadly, atmosphere/rock interactions, and how they have changed with time. The intent is to constrain the time-variable factors necessary to preserve records of microbial life. Most important samples: Regolith, paleosols, and evaporites. Scientific importance: Subaerial near-surface processes could support and preserve microbial life.

1.5 Understand the essential attributes of a martian igneous system. The intent is to provide definitive characterization of igneous rocks on Mars. Most important samples: Diverse suites of ancient igneous rocks. Scientific importance: Thermochemical record of the planet and nature of the interior.

2. Assess and interpret the biological potential of Mars.

The objective seeks to inform our efforts to understand the nature and extent of martian habitability, the conditions and processes that supported or challenged life, the timescales, and how different environments might have influenced the preservation of biosignatures and created non-biological ‘mimics’. This objective also has three sub-objectives.

2.1 Assess and characterize carbon, including possible organic and pre-biotic chemistry. Most important samples: All samples collected as part of Objective 1. Scientific importance: Any biologic molecular scaffolding on Mars would likely be carbon-based.

2.2 Assay for the presence of biosignatures of past life at sites that hosted habitable environments and could have preserved any biosignatures. Most important samples: All samples collected as part of Objective 1. Scientific importance: Provides the means of discovering ancient life.

2.3 Assess the possibility that any life forms detected are still alive, or were recently alive. Most important samples: All samples collected as part of Objective 1. Scientific importance: Planetary protection, and arguably the most important scientific discovery possible.

3. Determine the evolutionary timeline of Mars, including calibrating the crater chronology time scale.

This objective seeks to provide a radioisotope-based time scale for major events, including magmatic, tectonic, fluvial, and impact events, and the formation of major sedimentary deposits and geomorphological features.

Most important samples: Ancient igneous rocks that bound critical stratigraphic intervals or correlate with crater-dated surfaces. Scientific importance: Quantification of martian geologic history.

4. Constrain the inventory of martian volatiles as a function of geologic time, and determine the ways in which these volatiles have interacted with Mars as a geologic system.

Comprising the atmosphere and hydrosphere, volatiles play major roles in martian geologic and possibly biologic evolution. The objective seeks to recognize and quantify these roles.

Most important samples: Current atmospheric gas, ancient atmospheric gas trapped in older rocks, and minerals that equilibrated with the ancient atmosphere. Scientific importance: Key to understanding climate and environmental evolution.

5. Reconstruct the history of Mars as a planet, elucidating those processes that have affected the origin and modification of the crust, mantle and core.

The objective seeks to quantify processes that have shaped the planet's crust and underlying structure, including planetary differentiation, core segregation and state of the magnetic dynamo, and cratering.

Most important samples: Igneous, potentially magnetized rocks (both igneous and sedimentary) and impact-generated samples. Scientific importance: Elucidates fundamental processes for comparative planetology.

6. Understand and quantify the potential martian environmental hazards to future human exploration.

The objective seeks to define and mitigate an array of health risks related to the martian environment associated with the potential future human exploration of Mars.

Most important samples: Fine-grained dust and regolith samples. Scientific/engineering importance: Key input to planetary protection planning.

7. Evaluate the type and distribution of in-situ resources to support potential future Mars exploration.

The objective seeks to quantify the potential for obtaining martian resources, including use of martian materials as a source of water for human consumption, fuel production, building fabrication, and agriculture.

Most important samples: Regolith. Scientific/engineering importance: Facilitating long-term human presence on Mars.

References

[1] National Research Council (2003) New Frontiers in the Solar System: An Integrated Exploration Strategy. [2] MEPAG E2E-iSAG (2011) Planning for Mars Returned Sample Science.

ASPECT hyperspectral imager for small interplanetary spacecrafts

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The ASPECT Hyperspectral Imager is developed as a payload for APEX CubeSat to be deployed by Hera (ESA) spacecraft at asteroid Didymos. Hera (ESA) together with DART (NASA) will perform the first-ever kinetic impactor deflection test of an asteroid within the joint AIDA (Asteroid Impact & Deflection Assessment) project.

ASPECT is a miniaturized, CubeSat-sized, hyperspectral imager with primary scientific task of high resolution compositional mapping of Didymos surface and detailed characterization of impact crater created by impacting DART (NASA) spacecraft. Thanks to its modular design, ASPECT hyperspectral imager range and resolution can be easily modified to match specific objectives of different missions.

The ASPECT Hyperspectral Imager allows for global compositional mapping and imaging of the target asteroid with sub-meter resolution. The spectral range of 500-2500 nm covers most common silicate mineral (olivine, pyroxene, and plagioclase) absorption bands related to Fe^{2+} ions in their structure. Additionally, hydrated minerals as serpentine can be detected using ~700 nm Fe^{3+} absorption features. Direct presence of -OH an H_2O can be detected at 1400 and 1900 nm respectively. Observations at various phase angle allows for estimation of surface roughness. An extension of the spectral range into MIR (mid-infrared) region is being currently investigated. This spectral range allows for direct detection of hydrated materials and water/ice in 2700-3000 nm region as well as organic materials at 3200-3600 nm (Fig. 1).

In contrast to more traditional spatial scanning imaging spectrometers, ASPECT takes 2D snapshots at a given wavelength. When multiple snapshots are combined, a spectral datacube is formed, where the wavelength bands are separated in the time domain. The spectral separation is done by a tunable Fabry-Perot Interferometer (FPI).

The ASPECT asteroid hyperspectral imager is split into three measurement channels, one in the visible (VIS), and two in the infrared (NIR1 and NIR2). The parameters of each channel as well as possible extensions are summarized in Table 1. Sub-meter imager resolution can be achieved at orbital distances of 3 km or lower. All three channels have dedicated FPIs optimized for the desired wavelength range and are independent on each other. The imaged wavelengths are freely selectable within these ranges, and the targeted spectral resolution is 10-50 nm. Recently, a feasibility study of additional MIR channel with spectral range of 2500-4000 nm was launched. An extension in other direction towards UV (ultraviolet) is also currently under development for ESA ALTIUS mission and can be potentially integrated into the ASPECT Hyperspectral Imager.

The number of ASPECT imager channels, spectral range and resolution can be customized to meet specific mission objectives. Spectral resolution can be increased using FPI's higher orders of interference. However, this will result in smaller spectral range of the single channel and subsequent need to increase number of the imager channels. For example, improving the spectral resolution from 20 to 10 nm in NIR1 channel, the range will decrease from 900-1400 nm to approx. 900-1100 nm. Cascading the FPI will also result in better spectral resolution, however, the throughput and sensitivity will be decreased. Thus, there is a possibility for customization of ASPECT hyperspectral imager configuration satisfy mission requirements.

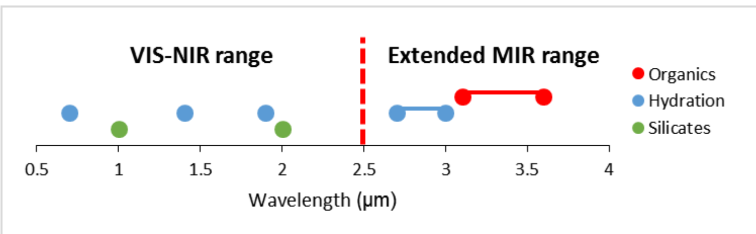

Figure 1. Spectral features detectable with ASPECT hyperspectral imager.

Table 1. ASPECT Hyperspectral Imager configuration with optional extensions.

Range	**VIS**	**NIR1**	**NIR2**	**UV (optional)**	**VIS (optional)**	**MIR (optional)**	**VNIR mini**
Size	0.5U	0.5U	0.25-0.5U	0.5-1U	0.5U	0.25U	1 cubic inch
FoV [deg]	10 × 10	5.3 × 5.3 10 × 10	5.3 × 5.3	TBD	2.5 × 2.5	TBD	10 × 10
Spectral range [nm]	500-900	900-1600	1600-2500	250 - 400	430-800	2500-4000	500-800 or 700-1000
Image size [px]	1024 × 1024	512 × 512	256 × 256	Single point	2048 × 2048	Single point	512 x 512
Spectral resolution [nm]	10-15 nm	20-40 nm	20-30 nm	< 2.5 nm	< 2.5 nm	30-50	20 nm
TRL	9	7	5	5	8	3	3-4
Flight heritage	Aalto 1 (in orbit, 2017)	Reaktor Hello World (FM delivered, launch 2018)	Under development, prototype in 2018	ESA ALTIUS (under development)	VISION (FM delivered, launch 2019)	Concept	Under development with ESA
Note			2 FPI cascade. With a single FPI the range is 1600 - 2100	4 FPI cascade. Can also be used with imaging detector		2 FPI cascade. With a single FPI the range is 2500 - 3500	Based on MEMS technology