

[E] 口頭発表 | セッション記号 P (宇宙惑星科学) : P-PS 惑星科学

■ 2019年5月29日(水) 15:30 ~ 17:00 | 会場 A01 東京ベイ幕張ホール

### [P-PS02] Regolith Science

コンビーナ: 和田 浩二(千葉工業大学惑星探査研究センター)、中村 昭子(神戸大学大学院理学研究科地球惑星科学専攻)、Patrick Michel(Observatoire De La Cote D'Azur)、Kevin John Walsh(Southwest Research Institute Boulder)、座長: 中村 昭子(Graduate School of Science, Kobe University)

Recent planetary explorations have revealed that almost all solid bodies in the solar system are covered with small particles, called regolith. The surface geology, especially regolith behavior on the surfaces of solid bodies, becomes increasingly more important as represented by Hayabusa mission and other on-going and planned sample-return missions such as Hayabusa2, OSIRIS-REx, and MMX. For fully understanding the regolith science, it is required to know and compare the regolith conditions on various celestial bodies, from asteroids to planets, with various methods. Therefore, this session welcomes broad topics related to regolith on various celestial bodies, such as asteroids, comets, the Moon, the martian moons, Mars, etc. Papers on the formation, evolution, and alteration processes of regolith particles and regolith systems on the surface of planetary bodies, remote and in-situ observational results and techniques, analyses and results of returned samples, and laboratory, numerical, and theoretical studies on the fundamental physical and chemical processes are all welcome. Note that what we call regolith is not just fine grains: all kinds of materials (more or less loose) that lie on the surface, from cobbles to finer grains, are our targets.

15:30 ~ 15:45

#### [PPS02-07] Impact Ejecta Environment of an Eccentric Asteroid: 3200 Phaethon

\*Jamey Szalay<sup>1</sup>、Peter Pokorny<sup>2</sup>、Mihaly Horanyi<sup>3</sup>、Diego Janches<sup>2</sup>、Menelaos Sarantos<sup>2</sup>、Ralf Srama<sup>4</sup>  
(1.Princeton University、2.NASA/GSFC、3.University of Colorado Boulder、4.University of Stuttgart)

15:45 ~ 16:00

#### [PPS02-08] On the Detection of an Ejecta Dust Cloud Around Asteroid (3200) Phaethon by the DESTINY<sup>+</sup> Dust Analyzer

\*Hiroshi Kimura<sup>1</sup>、Masanori Kobayashi<sup>1</sup>、Koji Wada<sup>1</sup>、Tomoko Arai<sup>1</sup>、Hiroki Senshu<sup>1</sup>、Masateru Ishiguro<sup>2</sup>、Hidekazu Hanayama<sup>3</sup>、Ko Ishibashi<sup>1</sup>、Takayuki Hirai<sup>1</sup>、Fumi Yoshida<sup>1</sup>、Peng Hong<sup>1</sup>  
(1.Planetary Exploration Research Center、2.Seoul National University、3.Ishigakijima Astronomical Observatory)

16:00 ~ 16:15

#### [PPS02-09] Close-up thermal and optical observation of asteroid Ryugu

★Invited Papers

\*坂谷 尚哉<sup>1</sup>、岡田 達明<sup>1</sup>、田中 智<sup>1</sup>、千秋 博紀<sup>2</sup>、嵩生 有理<sup>1</sup>、荒井 武彦<sup>3</sup>、神山 徹<sup>5</sup>、出村 裕英<sup>6</sup>、須古 健太郎<sup>6</sup>、関口 朋彦<sup>4</sup>、滝田 隼<sup>15</sup>、福原 哲哉<sup>4</sup>、田口 真<sup>4</sup>、Thomas Müller<sup>7</sup>、Axel Hagermann<sup>8</sup>、Jens Biele<sup>9</sup>、Matthias Grott<sup>9</sup>、Marco Delbo<sup>10</sup>、杉田 精司<sup>13</sup>、本田 理恵<sup>12</sup>、諸田 智克<sup>11</sup>、山田 学<sup>2</sup>、亀田 真吾<sup>4</sup>、巽 瑛理<sup>13</sup>、横田 康弘<sup>1</sup>、鈴木 秀彦<sup>14</sup>、本田 親寿<sup>6</sup>、小川 和律<sup>16</sup>、早川 雅彦<sup>1</sup>、松岡 萌<sup>1</sup>、長 勇一郎<sup>13</sup>、澤田 弘崇<sup>1</sup> (1.宇宙航空研究開発機構 宇宙科学研究所、2.千葉工業大学、3.足利大学、4.立教大学、5.産業技術総合研究所、6.会津大学、7.Max-Planck Institute for Extraterrestrial Physics、8.University of Stirling、9.German Aerospace Center、10.Observatoire de la Côte d'Azur, CNRS、11.名古屋大学、12.高知大学、13.東京大学、14.明治大学、15.北海道教育大学、16.神戸大学)

16:15 ~ 16:30

#### [PPS02-10] In-Situ Investigation of Asteroid (162173) Ryugu by the Hayabusa2 MASCOT Lander

★招待講演

\*矢野 創<sup>1</sup>、Ho Tra-Mi<sup>2</sup>、Jaumann Ralf<sup>3</sup>、Bibring Jean-Pierre<sup>4</sup>、Glassmeier Karl-Heinz<sup>5</sup>、Grott Matthias<sup>3</sup>、Hercik David<sup>5</sup>、Biele Jens<sup>6</sup>、Hamm Maximilian<sup>3</sup>、Schmitz Nicole<sup>3</sup>、Schröder Stefanus<sup>3</sup>、Otto Katharina<sup>3</sup>、Krause Christian<sup>6</sup>、Lorda Laurence<sup>7</sup>、Moussi-Soffys Aurelie<sup>7</sup>、Pilorget Cedric<sup>4</sup>、Hamm Vincent<sup>4</sup>、Riu Lucie<sup>1</sup>、Okada Tatsuaki<sup>1</sup>、Sakatani Naoya<sup>1</sup>、Reill Josef<sup>8</sup>、Sasaki Kaname<sup>2</sup>、Schlotterer

Markus<sup>2</sup>、Tsuda Yuichi<sup>1</sup>、Ulamec Stephan<sup>6</sup>、Wolff Friederike<sup>8</sup>、Michel Patrick<sup>9</sup>、Delbo Marco<sup>9</sup>、Ogawa Kazunori<sup>10</sup>、Senshu Hiroki<sup>11</sup>、Yoshimitsu Tetsuo<sup>1</sup>、Preusker Frank<sup>3</sup>、Scholten Frank<sup>3</sup>、Elgner Stephan<sup>3</sup>、Mottola Stefano<sup>3</sup>、Kührt Ekkehard<sup>3</sup>、Saiki Takanao<sup>1</sup>、Mimasu Yuya<sup>1</sup> (1.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Japan, 、 2.German Aerospace Center DLR Bremen, Bremen, Germany、 3.German Aerospace Center, Berlin, Germany、 4.Univ. de Paris Sud-Orsay, IAS, Orsay, France、 5.TU Braunschweig, Braunschweig, Germany、 6.German Aerospace Center DLR Cologne, Cologne, Germany、 7.National Centre for Space Studies, CNES, Toulouse, France、 8.German Aerospace Center, DLR, Oberpfaffenhofen, Germany、 9.Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France、 10.Department of Planetology, Graduate School of Science, Kobe University, Kobe, Japan、 11.Planetary Exploration Research Center, Chiba Institute of Technology, Narashino, Japan)

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16:30 ~ 16:45

[PPS02-11] Evidence of Mass Movement and Boulder Transport on Bennu from NASA's OSIRIS-REx Space Mission

★Invited Papers

\*Erica R Jawin<sup>1</sup>、Kevin J Walsh<sup>2</sup>、Tim McCoy<sup>1</sup>、Harold C Connolly<sup>3</sup>、Dante S Lauretta<sup>4</sup>、Ron L Ballouz<sup>4</sup>、Jamie L Molaro<sup>5</sup>、Olivier S Barnouin<sup>6</sup>、Mike Nolan<sup>4</sup> (1.Smithsonian National Institute, Washington, DC, USA、 2.Southwest Research Institute, Boulder, CO, USA、 3.Dept. of Geology, Rowan University, Glassboro, NJ, USA、 4.Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA、 5.Planetary Science Institute, Tucson, AZ, USA、 6.The Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA)

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16:45 ~ 17:00

[PPS02-12] Resurfacing processes on small asteroids constrained by crater size distributions on Ryugu, Itokawa, and Eros

\*高木直史<sup>1</sup>、長勇一郎<sup>1</sup>、諸田智克<sup>3</sup>、巽瑛理<sup>1</sup>、吉岡和夫<sup>1</sup>、澤田弘崇<sup>5</sup>、横田康弘<sup>2,5</sup>、坂谷尚哉<sup>5</sup>、早川雅彦<sup>5</sup>、松岡萌<sup>5</sup>、本田理恵<sup>2</sup>、亀田真吾<sup>4</sup>、山田学<sup>6</sup>、神山徹<sup>8</sup>、鈴木秀彦<sup>10</sup>、本田親寿<sup>7</sup>、小川和律<sup>9</sup>、宮本英昭<sup>1</sup>、Olivier Barnouin<sup>11</sup>、Patrick Michel<sup>12</sup>、Carolyn Ernst<sup>11</sup>、杉田精司<sup>1,6</sup> (1.東京大学、2.高知大学、3.名古屋大学、4.立教大学、5.宇宙航空研究開発機構 宇宙科学研究所、6.千葉工業大学 惑星探査センター、7.会津大学、8.産総研、9.神戸大学、10.明治大学、11.ジョンスホプキンス大学 応用物理学研究所、12.ニース天文台)

## Impact Ejecta Environment of an Eccentric Asteroid: 3200 Phaethon

\*Jamey Szalay<sup>1</sup>, Peter Pokorny<sup>2</sup>, Mihaly Horanyi<sup>3</sup>, Diego Janches<sup>2</sup>, Menelaos Sarantos<sup>2</sup>, Ralf Srama<sup>4</sup>

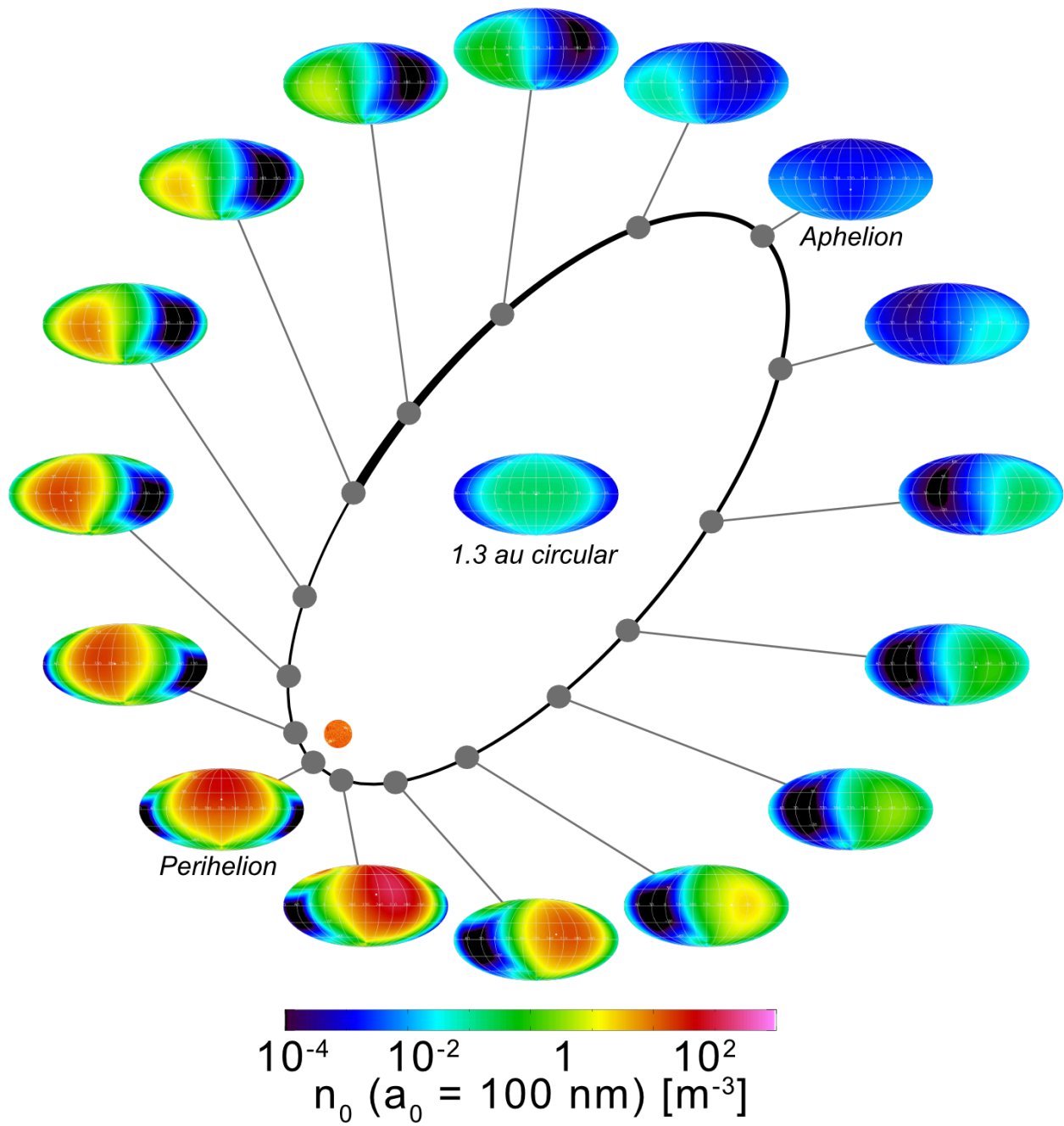
1. Princeton University, 2. NASA/GSFC, 3. University of Colorado Boulder, 4. University of Stuttgart

Airless regolith bodies in the solar system are continually bombarded by meteoroids, modifying their surfaces and sustaining impact ejecta clouds. While large bodies like the Moon retain a significant fraction of ejected regolith, small asteroids shed this material into the interplanetary dust complex. Measurements of the lunar impact ejecta cloud found it was sustained by the known sporadic meteoroid sources. Here, we extend lunar ejecta measurements using a model of the meteoroid environment at 1 au to investigate the structure of an ejecta cloud at an eccentric airless body, asteroid 3200 Phaethon: the target of JAXA's DESTINY+ mission.

Due to Phaethon's large eccentricity, Phaethon's peak ejecta density at 1 au is approximately 30 times higher compared to a body in a circular orbit at 1 au, largely due to enhanced ejecta production from meteoroids shed from Jupiter Family Comets. Such asymmetric ejecta production suggests Phaethon experiences significantly different meteoroid-specific space weathering processes than a body with a similar semi-major axis on a circular orbit. We estimate impact ejecta processes at Phaethon shed approximately 1 ton per year, which is not sufficient to appreciably contribute to the Geminids meteoroid complex, yet provides ample ejecta densities to measure with an in-situ dust detector aboard DESTINY+. These results suggest eccentric asteroids shed more material than those on near-circular orbits, and are suitable candidates for in-situ dust detection and chemical characterization due to their amplified asymmetric ejecta production.

In this presentation, we will summarize recent efforts to constrain the evolution and ejection of asteroid regolith for 3200 Phaethon. We will present predicted impact counts for a dust detector on close flybys of Phaethon in preparation for JAXA's DESTINY+ mission and discuss how such measurements would provide critical insight into Phaethon's origin and evolution in a manner unique to dust detection data.

Keywords: Ejecta, Meteoroids, Regolith



## On the Detection of an Ejecta Dust Cloud Around Asteroid (3200) Phaethon by the DESTINY<sup>+</sup> Dust Analyzer

\*Hiroshi Kimura<sup>1</sup>, Masanori Kobayashi<sup>1</sup>, Koji Wada<sup>1</sup>, Tomoko Arai<sup>1</sup>, Hiroki Senshu<sup>1</sup>, Masateru Ishiguro<sup>2</sup>, Hidekazu Hanayama<sup>3</sup>, Ko Ishibashi<sup>1</sup>, Takayuki Hirai<sup>1</sup>, Fumi Yoshida<sup>1</sup>, Peng Hong<sup>1</sup>

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We will provide the most recent report on the detectability of an ejecta cloud around Asteroid (3200) Phaethon by the DESTINY<sup>+</sup> Dust Analyzer (DDA), based on a model of dust dynamics in the cloud. We demonstrate that solar radiation pressure plays a vital role in shaping the spatial distribution of dust particles in Phaethon's ejecta cloud, because small particles, albeit the majority, are expelled from the sunward direction. We find that the DDA will have an opportunity of detecting dust particles in the ejecta cloud of Phaethon during a flyby, depending on the closest approach to the asteroid, heliocentric distance, and the initial velocity of ejecta. There are no hazard from impacts of 100  $\mu\text{m}$ -sized ejecta particles that potentially could make tiny holes on the surface of the spacecraft during a flyby.

Keywords: Asteroid (3200) Phaethon, ejecta dust cloud, DESTINY+

## Close-up thermal and optical observation of asteroid Ryugu

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In 2018, the Hayabusa2 spacecraft successfully carried out four descend operations toward Ryugu's surface. During these operations, we acquired highly resolved optical and thermal images from altitudes below several hundred meters, using Hayabusa2's Optical Navigation Camera (ONC-T) and Thermal Infrared Imager (TIR), respectively. Close-up thermal images by TIR indicate thermophysical properties of the surface materials and its regional difference, which cannot be resolved by higher altitude observations (e.g., home-position observations from 20 km altitude). The temperature depends mainly on the thermal inertia of the observed medium; higher thermal inertia materials have lower daytime temperatures. Optical images by ONC-T show detailed physical conditions of the surface materials, such as particle size distribution of pebbles, surface morphology of small boulders and craters. At the spacecraft altitude of 100 m, for example, TIR and ONC-T have pixel resolutions of 8.9 cm/pix and 1.1 cm/pix, respectively. In this study, we report on a comparison of TIR and ONC images, especially for boulders and craters.

**BOULDERS:** TIR close-up observations showed various boulders with different daytime temperatures, or different thermal inertia. Typical thermal inertia of boulders is about  $300 \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{-0.5}$ , but there are a few boulders with thermal inertia up to  $1000 \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{-0.5}$ . The thermal inertia of rocks is mainly controlled by porosity, and porous rock has lower thermal inertia. Therefore, TIR observations show that the porosity of boulders is variable. Furthermore, boulders with high thermal inertia (low porosity) observed by ONC-T were found to be relatively brighter and had a smooth surface. Such variation in porosity, optical brightness, and surface morphology of boulders on Ryugu's surface might reflect the degree of thermal metamorphism (depth of the source) in the parent body. If the constituents of Ryugu originate from variable depths inside the parent body, this supports the idea of a rubble pile formation of Ryugu after the catastrophic disruption of the parent body. This will place important constraints on the thermal evolution of the parent body.

**CRATERS:** During the MINERVA descend operations at 21<sup>st</sup> Sep., we acquired highly resolved images of two craters with diameter of less than 35 m by TIR, but both craters exhibit different thermal characteristics. One crater has a hot spot close to the center of crater, where the thermal inertia is estimated to be less than  $150 \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{-0.5}$ . On the other hand, there seems to be no hot spot in the other crater. The difference in thermophysical properties between these craters might be attributed to formation age or original surface conditions. Our finding of a hot spot with low thermal inertia indicates the presence of a fine-particle deposit in the crater and regolith generation related to the cratering process on this low-gravity asteroid.

## In-Situ Investigation of Asteroid (162173) Ryugu by the Hayabusa2 MASCOT Lander

## In-Situ Investigation of Asteroid (162173) Ryugu by the Hayabusa2 MASCOT Lander

\*矢野 創<sup>1</sup>、Ho Tra-Mi<sup>2</sup>、Jaumann Ralf<sup>3</sup>、Bibring Jean-Pierre<sup>4</sup>、Glassmeier Karl-Heinz<sup>5</sup>、Grott Matthias<sup>3</sup>、Hercik David<sup>5</sup>、Biele Jens<sup>6</sup>、Hamm Maximilian<sup>3</sup>、Schmitz Nicole<sup>3</sup>、Schröder Stefanus<sup>3</sup>、Otto Katharina<sup>3</sup>、Krause Christian<sup>6</sup>、Lorda Laurence<sup>7</sup>、Moussi-Soffys Aurelie<sup>7</sup>、Pilorget Cedric<sup>4</sup>、Hamm Vincent<sup>4</sup>、Riu Lucie<sup>1</sup>、Okada Tatsuaki<sup>1</sup>、Sakatani Naoya<sup>1</sup>、Reill Josef<sup>8</sup>、Sasaki Kaname<sup>2</sup>、Schlotterer Markus<sup>2</sup>、Tsuda Yuichi<sup>1</sup>、Ulamec Stephan<sup>6</sup>、Wolff Friederike<sup>8</sup>、Michel Patrick<sup>9</sup>、Delbo Marco<sup>9</sup>、Ogawa Kazunori<sup>10</sup>、Senshu Hiroki<sup>11</sup>、Yoshimitsu Tetsuo<sup>1</sup>、Preusker Frank<sup>3</sup>、Scholten Frank<sup>3</sup>、Elgner Stephan<sup>3</sup>、Mottola Stefano<sup>3</sup>、Kührt Ekkehard<sup>3</sup>、Saiki Takanao<sup>1</sup>、Mimasu Yuya<sup>1</sup>

\*Hajime Yano<sup>1</sup>、Tra-Mi Ho<sup>2</sup>、Ralf Jaumann<sup>3</sup>、Jean-Pierre Bibring<sup>4</sup>、Karl-Heinz Glassmeier<sup>5</sup>、Matthias Grott<sup>3</sup>、David Hercik<sup>5</sup>、Jens Biele<sup>6</sup>、Maximilian Hamm<sup>3</sup>、Nicole Schmitz<sup>3</sup>、Stefanus Schröder<sup>3</sup>、Katharina Otto<sup>3</sup>、Christian Krause<sup>6</sup>、Laurence Lorda<sup>7</sup>、Aurelie Moussi-Soffys<sup>7</sup>、Cedric Pilorget<sup>4</sup>、Vincent Hamm<sup>4</sup>、Lucie Riu<sup>1</sup>、Tatsuaki Okada<sup>1</sup>、Naoya Sakatani<sup>1</sup>、Josef Reill<sup>8</sup>、Kaname Sasaki<sup>2</sup>、Markus Schlotterer<sup>2</sup>、Yuichi Tsuda<sup>1</sup>、Stephan Ulamec<sup>6</sup>、Friederike Wolff<sup>8</sup>、Patrick Michel<sup>9</sup>、Marco Delbo<sup>9</sup>、Kazunori Ogawa<sup>10</sup>、Hiroki Senshu<sup>11</sup>、Tetsuo Yoshimitsu<sup>1</sup>、Frank Preusker<sup>3</sup>、Frank Scholten<sup>3</sup>、Stephan Elgner<sup>3</sup>、Stefano Mottola<sup>3</sup>、Ekkehard Kührt<sup>3</sup>、Takanao Saiki<sup>1</sup>、Yuya Mimasu<sup>1</sup>

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1. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagami-hara, Japan, 2. German Aerospace Center DLR Bremen, Bremen, Germany, 3. German Aerospace Center, Berlin, Germany, 4. Univ. de Paris Sud-Orsay, IAS, Orsay, France, 5. TU Braunschweig, Braunschweig, Germany, 6. German Aerospace Center DLR Cologne, Cologne, Germany, 7. National Centre for Space Studies, CNES, Toulouse, France, 8. German Aerospace Center, DLR, Oberpfaffenhofen, Germany, 9. Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France, 10. Department of Planetology, Graduate School of Science, Kobe University, Kobe, Japan, 11. Planetary Exploration Research Center, Chiba Institute of Technology, Narashino, Japan

After a journey of almost four years to the C-type asteroid (162173) Ryugu, the MASCOT lander of the Hayabusa2 mission was delivered to the asteroid's surface on October 3<sup>rd</sup> in 2018 and successfully performed in situ investigations. MASCOT was released from the mother spacecraft at an altitude of 41 m and came to rest on the surface at a site located at  $22.31 \pm 0.05^\circ\text{S}$ ,  $317.16 \pm 0.05^\circ\text{E}$ . MASCOT observed the surface for a full day-night cycle using its four science instruments until batteries ran out after 17h and 7min. The payload consisting of a wide angle camera (MASCAM), an imaging IR spectrometer (MicrOmega), a multi-channel radiometer (MARA), and a magnetometer (MasMAG) provided a wealth of data which helped to characterize the asteroid's surface down to millimeter scale. MasCAM images revealed a surface dominated by rocks and boulders without showing fine-grained material. Boulders appeared either bright with smooth faces and sharp edges or dark with cauliflower-like crumbly surfaces.

Inclusions observed in high-resolution images showed that rocks had strong similarities with carbonaceous chondrites. Temperatures of a ~60 cm diameter rock that have been measured in situ, were found to be consistent with a thermal inertia of  $282(+93, -35) \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{-1/2}$ , much lower than anticipated when compared to samples in our meteorite collections. This indicated that rocks on Ryugu were highly porous and likely very friable. The remnant magnetization of Ryugu's surface material on scales larger than 1 m was estimated to be lower than  $3 \cdot 10^{-6} \text{ Am}^2/\text{kg}$  (the measurement limit of MasMAG). A preliminary analysis of the induction effect in Ryugu caused by the variation in the solar wind magnetic field revealed significantly high electrical conductivity (of the order 1 S/m).

キーワード : Ryugu、 Hayabusa2、 Asteroid Surface、 Lander、 Carbonaceous Chondrites、 High Porosity  
Keywords: Ryugu, Hayabusa2, Asteroid Surface, Lander, Carbonaceous Chondrites, High Porosity

## Evidence of Mass Movement and Boulder Transport on Bennu from NASA's OSIRIS-REx Space Mission

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The near-Earth Asteroid (101955) Bennu is currently being studied by the NASA OSIRIS-REx mission. This small, top-shaped asteroid has evidence of a diverse suite of geologic units, including impact craters, linear features, and abundant boulders at a range of sizes, geometric albedos, and morphologies. The surface of the asteroid appears to be old; however localized evidence of mass movement has been detected in various locations that suggests the surface is dynamic. The abundance of boulders on the surface varies widely with location, with concentrations of boulders located in local topographic lows (e.g. the interior of candidate impact craters, between linear ridges), suggesting that boulders travelled across the surface to result in these concentrations. Several locations that are abundant in boulders show evidence of imbrication in the local downslope direction, but evidence of imbrication is more localized than on other asteroids such as Itokawa. Evidence of mass movement at smaller particles sizes is also evident by burial of boulders: evidence of largescale W-E movement of material and burial of rocks has been identified, as well as pileup of boulders at locations downslope of scarps. In addition, the largest boulder on Bennu (~95 m diameter) appears to be partly buried, with a portion of the boulder of unknown size remaining in the subsurface. This boulder has an exposed face that extends vertically off the surface by ~20 m, suggesting that several tens of meters of finer-grained material could have accumulated to bury part of the boulder. The direction that material would have traveled to bury this boulder follows the regional slopes. As a comparison, the second largest boulder on Bennu (~50 m diameter) that is nearby albeit at a slightly higher latitude (45 S latitude, versus the buried boulder at 25 S latitude) is not buried –rather, this boulder appears to be perched on the surface. The variation in very large boulder burial suggests the surface of Bennu has potentially experienced large-scale material transport.

Keywords: OSIRIS-REx, Bennu, Mass-movement, Asteroid, Regolith

## Resurfacing processes on small asteroids constrained by crater size distributions on Ryugu, Itokawa, and Eros

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Recent ion irradiation experiments in laboratories suggest that space weathering may take place very rapidly [1], but telescopic observations of asteroids support much slower space weathering [2]. The spectral rejuvenation process on asteroid surfaces may hold a key for bridging the gap between the two opposite conclusions [3]. However, the nature of the spectral rejuvenation process has not been understood well yet. One approach for understanding the spectral rejuvenation process is to constrain the depth-age relation of surface layers on asteroids. In fact, imaging observations by Hayabusa2 revealed that smaller craters are highly depleted on the surface of the asteroid Ryugu [4], strongly suggesting that resurfacing is acting efficiently on near-surface layers. This depletion was already observed on Eros and Itokawa [5]. In this study, we analyze this depletion in small craters to constrain the resurfacing mechanism on small asteroids, such as Ryugu, Itokawa, and Eros. More specifically, we estimate the resurfacing age of Ryugu, Itokawa and Eros based on crater counting and crater production functions. Then we compare the analysis results with theoretical models for resurfacing mechanisms on such small asteroids.

Crater retention age can be estimated by using both the crater size frequency distribution (CSFD) and the crater production function (CPF). The CSFD on Ryugu shows that the large craters distribution ( $\geq 100$ m in diameter) is close to saturation level, but the number density of small craters ( $\sim 10$  m) is reduced by a factor of 100 [4]. Similar depletion in small craters is also observed on Itokawa [5]. We calculated crater retention ages for different size craters and derived the relation between crater retention ages and excavation depth of craters.

The CPFs on Ryugu, Itokawa, and Eros are estimated based on a classical main belt collisional evolution model and a scaling relation for crater formation. We used a scaling relation including armoring effect [6] for Ryugu and Itokawa to account for the high abundance of boulders on them. In this analysis, we used

larger craters than  $\sim 10$ m in diameter. Finally, we derived the relation between crater retention age,  $t$ , and depth,  $d$ , of crater,  $t \sim d^a$ , where  $a$  is found to be  $1.8 \pm 0.4$  on Ryugu,  $1.1 \pm 0.3$  on Itokawa, and  $1.9 \pm 0.3$  on Eros, respectively. If crater degradation is controlled by a diffusion process, the relation between crater retention age  $t$  is proportional to the square of crater depth  $d$ , i.e.,  $t \sim d^2$ . Ryugu's and Eros's power-law indices ( $a \sim 1.8-1.9$ ) are consistent with diffusion ( $a = 2$ ), which is not the case of Itokawa's power-law index. However, Itokawa's power-law index  $a$  increase to 1.9 if we include smaller craters than  $\sim 10$ m in diameter in this analysis. This value is consistent with diffusion ( $a = 2$ ). Actually, Michel et al. 2009 suggests that the depletion of small craters on Itokawa is reproduced by a seismic shaking model without taking an armoring effect into account [7]. The efficiency of an armoring effect for small craters on asteroids is uncertain, but an armoring effect may change the interpretation of CSFDs. In order to understand crater scaling for smaller craters, Small Carry-on Impactor (SCI) experiment on Hayabusa2 is important.

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