

[E] Oral | P (Space and Planetary Sciences) : P-PS Planetary Sciences

📅 Sun. Jun 6, 2021 9:00 AM - 10:30 AM JST | Sun. Jun 6, 2021 12:00 AM - 1:30 AM UTC | 🏠 Ch.04 Zoom Room 04

**[P-PS04] Small Solar System Bodies: A New Insight from Hayabusa2, OSIRIS-REx and Other Space Missions**

convener: Tatsuaki Okada (Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Taishi Nakamoto (Tokyo Institute of Technology), Daisuke Kuroda (Kyoto University),  
Chairperson: Tatsuaki Okada (Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Taishi Nakamoto (Tokyo Institute of Technology), YACHEN YANG (Center for Space and Remote Sensing Research)

Small Solar System bodies, including asteroids, comets, satellites, and interplanetary dust particles, are notably important for understanding the origin and evolution of our Solar System, as well as investigating the sources of building blocks of life. Many new discoveries on small bodies have been carried out by observations from ground-based and space-based observatories, and explorations by spacecraft rendezvous and flyby. New perspectives on solar system evolution have been paved by analyses of extraterrestrial materials such as meteorites, IDPs, and return samples by space missions. Numerical and laboratory simulation studies have helped interpretations for those results and proposed new insights on these topics. In this session, new results of scientific studies and new ideas of methodology for investigating small solar system bodies are highly welcome, especially the topics on the remote sensing, surface experiments, and analysis of return sample in the Hayabusa2 and OSIRIS-REx missions, as well as the expectations and preparations for future missions including MMX, Destiny+, Hera, Comet Interceptor, and Hayabusa2-Extended missions.

9:00 AM - 9:05 AM JST | 12:00 AM - 12:05 AM UTC

[PPS04-01] Introduction

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9:05 AM - 9:20 AM JST | 12:05 AM - 12:20 AM UTC

[PPS04-02] Interdisciplinary Science of Hayabusa2 Mission

\*Sei-ichiro WATANABE<sup>1</sup>, Hikaru Yabuta<sup>2</sup>, Koji Wada<sup>3</sup>, Naru Hirata<sup>4</sup>, Naoyuki Hirata<sup>5</sup>, Yuri Shimaki<sup>7</sup>, Rina Noguchi<sup>7</sup>, Seiji Sugita<sup>6</sup>, Kohei Kitazato<sup>4</sup>, Tatsuaki Okada<sup>7</sup>, Noriyuki Namiki<sup>8</sup>, Shogo Tachibana<sup>6,7</sup>, Masahiko Arakawa<sup>5</sup>, Satoshi Tanaka<sup>7</sup> (1. Nagoya University, 2. Hiroshima University, 3. Chiba Institute of Technology, 4. University of Aizu, 5. Kobe University, 6. University of Tokyo, 7. JAXA/ISAS, 8. National Astronomical Observatory)

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9:20 AM - 9:35 AM JST | 12:20 AM - 12:35 AM UTC

[PPS04-03] Progress report of initial description of the C-type asteroid Ryugu samples returned by Hayabusa2

\*Toru Yada<sup>1</sup>, Masanao Abe<sup>1</sup>, Aiko Nakato<sup>1</sup>, Kasumi Yogata<sup>1</sup>, Akiko Miyazaki<sup>1</sup>, Kazuya Kumagai<sup>2</sup>, Kentaro Hatakeda<sup>2</sup>, Tatsuaki Okada<sup>1</sup>, Masahiro Nishimura<sup>1</sup>, Shizuho Furuya<sup>1</sup>, Yoshitake Miwa<sup>1</sup>, Ayako Iwamae<sup>2</sup>, Lucie Liu<sup>1</sup>, Lionel Lourit<sup>3</sup>, Cedric Pilorget<sup>3</sup>, Vincent Hamm<sup>3</sup>, Jean-Pierre Bibring<sup>3</sup>, Yuichiro Cho<sup>4</sup>, Koki Yumoto<sup>4</sup>, Yuna Yabe<sup>4</sup>, Seiji Sugita<sup>4</sup>, Shogo Tachibana<sup>4</sup>, Hirotaka Sawada<sup>1</sup>, Sakamoto Kanako<sup>1</sup>, Tasuku Hayashi<sup>1</sup>, Daiki Yamamoto<sup>1</sup>, Ryota Fukai<sup>1</sup>, Haruna Sugahara<sup>1</sup>, Hisayoshi Yurimoto<sup>5</sup>, Tomohiro Usui<sup>1</sup>, Sei-ichiro WATANABE<sup>6</sup>, Yuichi Tsuda<sup>1</sup> (1. Japan Aerospace Exploration Agency, 2. Marine Works Japan, 3. Institut D'Astrophysique Spatiale, 4. University of Tokyo, 5. Hokkaido University, 6. Nagoya University)

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9:35 AM - 9:50 AM JST | 12:35 AM - 12:50 AM UTC

[PPS04-04] EXPERIMENTAL STUDY ON IMPACT CRATERS FORMED ON MOUNTAIN-LIKE SURFACE TOPOGRAPHY OF ASTEROIDS

\*Yusaku Yokota<sup>1</sup>, Masahiko Arakawa<sup>1</sup>, Minami Yasui<sup>1</sup>, Yuya Yamamoto<sup>1</sup>, Sunao Hasegawa<sup>2</sup>, Hatsune Okawa<sup>1</sup> (1. Graduate School of Science, Kobe University, 2. Japan Aerospace Exploration Agency)

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9:50 AM - 10:10 AM JST | 12:50 AM - 1:10 AM UTC

[PPS04-05] The collisional history in the Main Belt

★Invited Papers

\*Hiroshi Kobayashi<sup>1</sup> (1.Department of Physics, Nagoya University)

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10:10 AM - 10:30 AM JST | 1:10 AM - 1:30 AM UTC

[PPS04-06] Internal structure of pebble-pile comets inferred from thermal and mechanical properties of dust aggregates

★Invited Papers

\*Sota ARAKAWA<sup>1</sup> (1.National Astronomical Observatory of Japan)

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[E] Oral | P (Space and Planetary Sciences ) | P-PS Planetary Sciences

## [P-PS04] Small Solar System Bodies: A New Insight from Hayabusa2, OSIRIS-REx and Other Space Missions

convener:Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Taishi Nakamoto(Tokyo Institute of Technology), Daisuke Kuroda(Kyoto University),

Chairperson:Tatsuaki Okada(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency), Taishi Nakamoto(Tokyo Institute of Technology), YACHEN YANG(Center for Space and Remote Sensing Research)

Sun. Jun 6, 2021 9:00 AM - 10:30 AM Ch.04 (Zoom Room 04)

Small Solar System bodies, including asteroids, comets, satellites, and interplanetary dust particles, are notably important for understanding the origin and evolution of our Solar System, as well as investigating the sources of building blocks of life. Many new discoveries on small bodies have been carried out by observations from ground-based and space-based observatories, and explorations by spacecraft rendezvous and flyby. New perspectives on solar system evolution have been paved by analyses of extraterrestrial materials such as meteorites, IDPs, and return samples by space missions. Numerical and laboratory simulation studies have helped interpretations for those results and proposed new insights on these topics. In this session, new results of scientific studies and new ideas of methodology for investigating small solar system bodies are highly welcome, especially the topics on the remote sensing, surface experiments, and analysis of return sample in the Hayabusa2 and OSIRIS-REx missions, as well as the expectations and preparations for future missions including MMX, Destiny+, Hera, Comet Interceptor, and Hayabusa2-Extended missions.

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9:00 AM - 9:05 AM

### [PPS04-01]Introduction

## Interdisciplinary Science of Hayabusa2 Mission

\*Sei-ichiro WATANABE<sup>1</sup>, Hikaru Yabuta<sup>2</sup>, Koji Wada<sup>3</sup>, Naru Hirata<sup>4</sup>, Naoyuki Hirata<sup>5</sup>, Yuri Shimaki<sup>7</sup>, Rina Noguchi<sup>7</sup>, Seiji Sugita<sup>6</sup>, Kohei Kitazato<sup>4</sup>, Tatsuaki Okada<sup>7</sup>, Noriyuki Namiki<sup>8</sup>, Shogo Tachibana<sup>6,7</sup>, Masahiko Arakawa<sup>5</sup>, Satoshi Tanaka<sup>7</sup>

1. Nagoya University, 2. Hiroshima University, 3. Chiba Institute of Technology, 4. University of Aizu, 5. Kobe University, 6. University of Tokyo, 7. JAXA/ISAS, 8. National Astronomical Observatory

Asteroid explorer *Hayabusa2* completed its proximity operation around C-type asteroid Ryugu and returned to Earth with surface sample. More than 5 g of the particles in the sample catchers were successfully retrieved and wait for analyses. We will review the interdisciplinary science of *Hayabusa2* mission based on the proximity observations through visible and thermal IR imaging, NIR spectrometer, LIDAR, and the Small Carry-on Impactor (SCI) experiment, which will give a strategy of the return sample analyses. The SCI experiment reveals crater-to-impactor size ratio on Ryugu is more than 60 [1], contrast to the lower value of 10 derived from the size-frequency distributions of the main-belt asteroids and craters on the asteroids already explored [2]. This will change the chronology of the material transport process from the main asteroid belt to the Earth region. Based on the SCI scaling law, the surface age of Ryugu is estimated to be ~16 Ma, which is much shorter than the estimated ages (100 Ma to 1 Ga) of the candidate source collisional families in the inner asteroidal belt. This suggests that Ryugu is a product of a higher generation of the parent body disruption [3] or global resurfacing due to YORP induced past rapid rotation [4]. Visible color variations on Ryugu suggest the reddening of surface material by solar heating and/or space weathering under a temporal excursion near the Sun [5]. These hypotheses based on remote-sensing observations and the SCI experiment will be confirmed through return sample analyses.

Another important issue is the reconstruction of the properties of the parent body. Proximity observations using NIRS3 reveals the presence of global OH bearing minerals on Ryugu [6], whereas the amount is relatively small compared with hydrated carbonaceous chondrites and Bennu [7]. Both partial dehydration and incipient aqueous alteration will produce the weak OH absorption [3], which will be distinguished by return sample analyses. High porosity of Ryugu could be ascribed to loss of water ice during or after the formation of the rubble pile, if its parent body was an icy asteroid [4]. Water-rock ratio of the parent planetesimal with <sup>26</sup>Al heating will determine the set of coexisting minerals, which will also be determined by return sample analyses. Size-frequency distribution of surface particles as well as aggregate's constituent particles are important for identifying what kind of dust grains planetesimals are consist of. We will discuss the vision of exploration-based reconstruction of planetesimals.

[1] Arakawa et al. (2020), *Science* **368**, 268; [2] Bottke et al. (2020), *Astron. J.* **160**, 14; [3] Sugita et al. (2019), *Science* **364**, eaaw0422, [4] Watanabe et al. *Science* **364**, 268; [5] Morota et al. (2020), *Science* **368**, 654; [6] Kitazato et al. (2019) *Science* **364**, 272; [7] Hamilton et al. (2019), *Nature Astron.* **3**, 332.

Keywords: planetary exploration, material transport in the Solar System, planetary accretion process, planetesimals

## Progress report of initial description of the C-type asteroid Ryugu samples returned by Hayabusa2

\*Toru Yada<sup>1</sup>, Masanao Abe<sup>1</sup>, Aiko Nakato<sup>1</sup>, Kasumi Yogata<sup>1</sup>, Akiko Miyazaki<sup>1</sup>, Kazuya Kumagai<sup>2</sup>, Kentaro Hatakeda<sup>2</sup>, Tatsuaki Okada<sup>1</sup>, Masahiro Nishimura<sup>1</sup>, Shizuho Furuya<sup>1</sup>, Yoshitake Miwa<sup>1</sup>, Ayako Iwamae<sup>2</sup>, Lucie Liu<sup>1</sup>, Lionel Lourit<sup>3</sup>, Cedric Pilorget<sup>3</sup>, Vincent Hamm<sup>3</sup>, Jean-Pierre Bibring<sup>3</sup>, Yuichiro Cho<sup>4</sup>, Koki Yumoto<sup>4</sup>, Yuna Yabe<sup>4</sup>, Seiji Sugita<sup>4</sup>, Shogo Tachibana<sup>4</sup>, Hiroataka Sawada<sup>1</sup>, Sakamoto Kanako<sup>1</sup>, Tasuku Hayashi<sup>1</sup>, Daiki Yamamoto<sup>1</sup>, Ryota Fukai<sup>1</sup>, Haruna Sugahara<sup>1</sup>, Hisayoshi Yurimoto<sup>5</sup>, Tomohiro Usui<sup>1</sup>, Sei-ichiro WATANABE<sup>6</sup>, Yuichi Tsuda<sup>1</sup>

1. Japan Aerospace Exploration Agency, 2. Marine Works Japan, 3. Institut D' Astrophysique Spatiale, 4. University of Tokyo, 5. Hokkaido University, 6. Nagoya University

The Hayabusa2 spacecraft reached the C-type near-Earth asteroid 162173 Ryugu in June 2018 and observed the asteroid with onboard instruments and from the landers [1-8], and accomplished two touchdown samplings on 22 Feb. and 12 Jul. 2019 [9]. After the 2<sup>nd</sup> touchdown, the sample catcher which contains samples was transferred into its reentry capsule. The spacecraft left the asteroid in Nov. 2019 and returned the capsule to the Woomera Prohibited Area in South Australia on 6 Dec. 2020. The handling processes for the capsule and the sample container in it after its landing have been detailed in a previous report [10].

The clean chambers in the Extraterrestrial Sample Curation Center of JAXA Sagami-hara campus are composed of five chambers; CC3-1~3 and CC4-1~2 [12]. The container was installed into CC3-1 on 11 Dec. 2020 and opened after evacuated to high vacuum. The sample catcher was extracted from the container, and transported to CC3-2. The catcher is composed of three small chambers A, B and C. The chambers A and C contain sample obtained by the 1<sup>st</sup> and 2<sup>nd</sup> touchdowns, respectively. As the cover of the chamber A was opened in vacuum in CC3-2, a large number of black particles were observed inside the chamber A, as shown in the Fig. 1. Two particles inside the chamber A were picked up and placed on a quartz glass dish for future science. The catcher with the greater part of samples was transferred to CC3-3, and the gate valve between CC3-2 and CC3-3 was closed. Then, CC3-3 was slowly purged with purified nitrogen gas to the atmospheric pressure, in which the catcher was handled with Viton-coated butyl gloves.

The catcher containing samples was transferred to CC4-2 and its bulk weight was measured with an electronic balance. The total weight of the samples inside the catcher is 5.4g, subtracting the designed weight of the catcher and a tare weight of an attached jig. The catcher was then dismantled to extract samples from the chambers A, B and C to sapphire glass dishes in CC4-1. The bulk samples held in the dishes were photographed with an optical microscope installed above CC4-2. The same microscope was used to take images of the samples with illumination through five filters (0.40  $\mu\text{m}$  (ul), 0.48  $\mu\text{m}$  (b), 0.55  $\mu\text{m}$  (v), 0.59  $\mu\text{m}$  (Na), and 0.70  $\mu\text{m}$  (w)) matched to the ONC-T camera of Hayabusa2 [2]. The weight of each dish was measured with the balance in CC4-2. The bulk samples in the dishes were measured with the FT-IR (JASCO VIR-300) installed to CC4-2 for their average spectra from 1 to 5  $\mu\text{m}$  and were also measured with MicrOmega installed to CC3-3, a noncontact version of the hyperspectral microscope onboard the MASCOT lander [11], to investigate spectral features from 0.99 to 3.65  $\mu\text{m}$  of the samples. After the bulk initial description, individual particles >1mm in size are handpicked one by one with a vacuum tweezer to be enclosed into individual particle containers. They are to be characterized in the

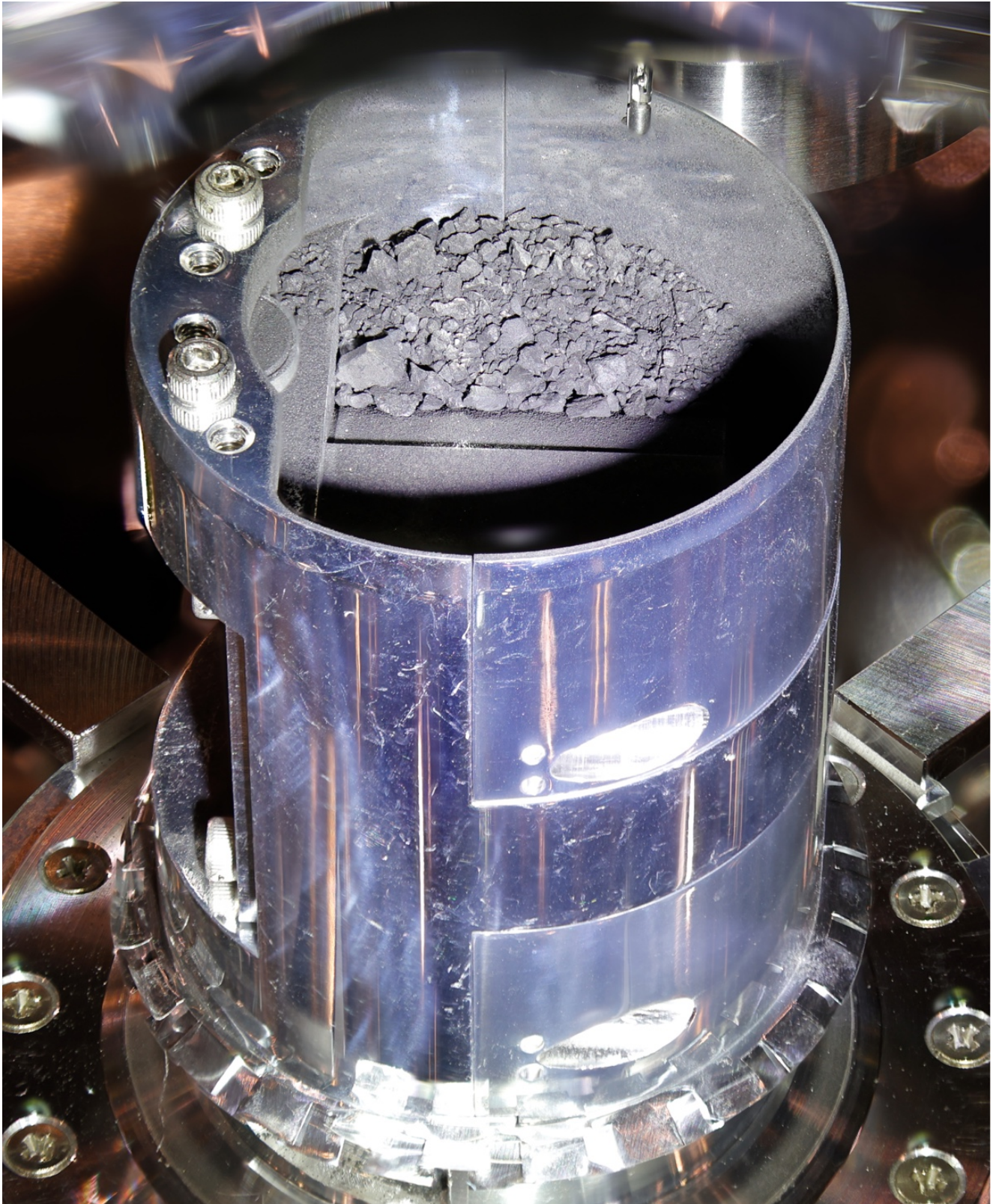
same manner as the bulk samples.

The sample distribution plan was detailed in [12]. JAXA plans to release the announcement of opportunity for the Hayabusa2 samples to the international science community with the sample catalog after 18 months from their return to the Earth.

References: [1] Watanabe S. et al. (2019) *Science* 364, 268. [2] Sugita S. et al. (2019) *Science* 364, 252. [3] Kitazato K. et al. (2019) *Science* 364, 272. [4] Jaumann R. et al. (2019) *Science* 365, 817. [5] Grott M. et al. (2019) *Nat. Astron.* [6] Okada T. et al. (2020) *Nature* 579, 518. [7] Morota T. et al. (2020) *Science* 368, 654. [8] Arakawa M. (2020) *Science* 368, 67. [9] Tachibana S. et al. (2020) 51<sup>st</sup> LPSC, #2027. [10] Tachibana S. et al. (2021) 52<sup>nd</sup> LPSC, #1289. [11] Bibring J.-P. et al. (2017) *Space Sci. Rev.* 208, 401. [12] Yada T. et al. (2021) 52<sup>nd</sup> LPSC, #2008.

Figure 1. A photograph of the sample catcher of Hayabusa2 after opening its chamber A in CC3-2. A large number of black particles are observed inside the chamber. An outer diameter of the catcher is 48mm.

Keywords: Hayabusa2, Ryugu, asteroid, return samples, carbonaceous chondrite, C-type asteroid



# EXPERIMENTAL STUDY ON IMPACT CRATERS FORMED ON MOUNTAIN-LIKE SURFACE TOPOGRAPHY OF ASTEROIDS

\*Yusaku Yokota<sup>1</sup>, Masahiko Arakawa<sup>1</sup>, Minami Yasui<sup>1</sup>, Yuya Yamamoto<sup>1</sup>, Sunao Hasegawa<sup>2</sup>, Hatsune Okawa<sup>1</sup>

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Impact craters are one of the major geological features on solid bodies such as asteroids and satellites. A crater formed on a flat surface is observed to be a circle but a crater formed on a slope is ellipse. In particular, various topographic features such as slope, bulge, and canyon have been observed on asteroids and small satellites. Recently, Hayabusa2 and OSIRIS-REx revealed that Ryugu and Bennu have a large bulge on their equatorial regions. Furthermore, some craters with asymmetric profiles were found on the bulge of Ryugu. However, the conventional crater scaling laws based on the results of laboratory experiments conducted on the targets having the flat surface. In order to apply the scaling laws to the cratering process on the mountain-like surface topography of asteroids, it is necessary to improve the crater scaling laws including the effect of the surface topography. In this study, we conducted the impact cratering experiments on granular targets simulating the mountain-like surface topography of asteroids, and we investigated the effects of the surface topography on the crater size scaling law and the ejecta growth process.

We prepared two types of targets to simulate the surface topography of asteroids: they are granular targets having the shape of a mountain range and a cone. The inclination ( $\theta$ ) of the mountain range target was set to be  $20^\circ$  and  $30^\circ$ , and that of the cone target was  $\sim 30^\circ$ . We also prepared the target having the flat surface (that is,  $\theta = 0^\circ$ ). We changed the impact point  $d$  for the mountain range target; the  $d$  was defined as the horizontal distance between the impact point and the summit. In the case of the cone target, we changed the foot width of the target  $w$ .

We conducted impact experiments by using a one-stage vertical gas gun at Kobe University and a two-stage vertical gas gun at ISAS. The impact velocities ranged from 69 to 202 m/s for the mountain range target, and from 41 m/s to 4.21 km/s for the cone target. In order to analyze the crater morphology, we constructed the 3D shape model by using the software of PhotoScan Pro.

For the mountain range target, we observed that the crater had an elliptical shape: the width of the crater on the ridge direction (major axis) was always larger than that on the slope direction (minor axis). Furthermore, the elevated crater rim was observed on the ridge direction but it was not observed on the slope direction. The asymmetry of the crater shape strongly depends on the  $d$ . Now, the crater asymmetry is shown by the aspect ratio defined as the ratio of major axis length to minor axis length. We found that the aspect ratio increases with the increase of the major axis length at the constant  $d$  value, and furthermore, it increases more rapidly with the decrease of  $d$ . These characteristics were also found on the target with the slope of  $\theta = 20^\circ$  but the aspect ratio for the target with the slope of  $\theta = 30^\circ$  was larger than that of  $\theta = 20^\circ$  at the same  $d$  and the major axis length. Also, we constructed the crater size scaling law described by  $\pi$ -scaling for the mountain range target. The normalized crater radius,  $\pi_{Rv}$ , clearly depends on the slope  $\theta$ , that is, they are  $\sim 1.3$  times larger than that of the flat surface,  $\theta = 0^\circ$ .

For the cone target, we observed the ratio of the initial target height to the impacted target height. We investigated the relationship between the height ratio and the  $v^*$  at different impact velocities. The  $v^*$  is defined as the velocity derived from the projectile momentum divided by the cone mass. At  $v^* < 0.5$  m/s, the height ratio decreases exponentially with the increase of the  $v^*$ , irrespective of the impact velocity. This means that the height ratio could be controlled by the projectile momentum. At  $v^* > 0.5$  m/s, most of the cone was excavated so the height ratio was almost zero. We also measured the crater diameter formed

on the cone target and it was almost the same as that formed on the flat surface at the same projectile kinetic energy.

Keywords: crater

## The collisional history in the Main Belt

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Asteroids in the Main Belt Mean collisional velocity between them is estimated to be about 5 km/s so that collisions lead to fragmentation. The collisional timescale for 100 km-sized or larger asteroids is estimated to be much longer than the age of the Solar System, while smaller asteroids are expected to have experience of catastrophic disruption. This estimate is consistent with the fraction of asteroids in collisional families. Therefore, such large asteroids may have formed in the planet formation era. The mass distribution of 100km-sized or larger main belt asteroids is explained by the onset of runaway growth of planetesimals. On the other hand, smaller bodies are fragmented into still smaller bodies. The mass distribution of 10km-sized or smaller asteroids is in the quasi steady state of the collisional cascade. However, the collisional lifetimes of such small asteroids highly depend on collisional outcome models. According to the collisional theory, we may discuss the possible histories of kilometer sized asteroids.

Keywords: Asteroids, planetesimals, Collisions

# Internal structure of pebble-pile comets inferred from thermal and mechanical properties of dust aggregates

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The *Rosetta* mission has provided new data to better understand what comets are made of. The weak tensile strength of the cometary surface materials suggests that comet 67P/Churyumov–Gerasimenko is a hierarchical dust aggregate formed through gravitational collapse of a bound clump of small dust aggregates so-called 'pebbles' in the gaseous solar nebula. Recently, we calculated the thermal inertias and thermal skin depths as functions of the size of pebbles (Arakawa & Ohno 2020). We found that the thermal properties of the comet are consistent with the hierarchical aggregate of cm- to dm-sized pebbles. This estimate is also consistent with the mechanical strength of the nucleus. In addition, we reanalyzed the stickiness of icy dust particles using a viscoelastic contact model. Our results indicate that not only H<sub>2</sub>O ice but also CO<sub>2</sub> ice particles could easily grow into cm-sized large pebbles in the solar nebula (Arakawa & Krijt 2021), and this size estimate may be consistent with that from thermal and mechanical analyses on comet 67P.

Keywords: Comet, Thermal inertia, Dust growth