

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

📅 Sat. Jun 5, 2021 3:30 PM - 5:00 PM JST | Sat. Jun 5, 2021 6:30 AM - 8:00 AM UTC | 🏠 Ch.04 Zoom Room 04

### [P-PS03] Regolith Science

convener:Koji Wada(Planetary Exploration Research Center, Chiba Institute of Technology), Akiko Nakamura(Graduate School of Science, Kobe University), Patrick Michel(Universite Cote D Azur Observatoire De La Cote D Azur CNRS Laboratoire Lagrange), John Kevin Walsh(Southwest Research Institute Boulder), Chairperson:Yuri Shimaki(Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency)



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.

3:30 PM - 3:45 PM JST | 6:30 AM - 6:45 AM UTC

[PPS03-07] Deciphering the regolith properties of small bodies from numerical modeling

★Invited Papers

\*Yun Zhang<sup>1</sup> (1.UCA, OCA, CNRS, Lagrange, Nice, France)

3:45 PM - 4:00 PM JST | 6:45 AM - 7:00 AM UTC

[PPS03-08] Charge Magnitude of Electrostatically Lofted Dust Grains over the Lunar Terminator

\*Necmi Cihan Orger<sup>1</sup>, Kazuhiro Toyoda<sup>1</sup>, Mengu Cho<sup>1</sup> (1.Laboratory of Lean Satellite Enterprises and In-Orbit Experiments - Kyushu Institute of Technology)

4:00 PM - 4:15 PM JST | 7:00 AM - 7:15 AM UTC

[PPS03-09] High-velocity impact experiments in reduced gravity: The effect of cohesive strength of particle layers

\*Masato Kiuchi<sup>1</sup>, Takaya Okamoto<sup>1</sup>, Yuuya Nagaashi<sup>2</sup>, Sunao Hasegawa<sup>1</sup>, Akiko Nakamura<sup>2</sup> (1.Japan aerospace exploration agency, Institute of space and astronautical science, 2.Graduate School of Science, Kobe UniversityKobe University)

4:15 PM - 4:30 PM JST | 7:15 AM - 7:30 AM UTC

[PPS03-10] Local variation in thermal inertia around the artificial impact crater on Ryugu

\*Naoya Sakatani<sup>1</sup>, Satoshi Tanaka<sup>2</sup>, Tatsuaki Okada<sup>2</sup>, Toru Kouyama<sup>3</sup>, Akira Miura<sup>2</sup>, Naru Hirata<sup>4</sup>, Hiroki Senshu<sup>5</sup>, Takehiko Arai<sup>6</sup>, Yuri Shimaki<sup>2</sup>, Hirohide Demura<sup>4</sup>, Tomohiko Sekiguchi<sup>7</sup>, Jun Takita<sup>8</sup>, Tetsuya Fukuhara<sup>1</sup>, Thomas Müller<sup>9</sup>, Axel Hagermann<sup>10</sup>, Jens Biele<sup>11</sup>, Matthias Grott<sup>11</sup>, Maximilian Hamm<sup>11,12</sup>, Marco Delbo<sup>13</sup>, Masahiko Arakawa<sup>14</sup>, Kazunori Ogawa<sup>15</sup>, Koji Wada<sup>5</sup>, Toshihiko Kadono<sup>16</sup>, Rie Honda<sup>17</sup>, Kei Shirai<sup>14</sup>, Takanao Saiki<sup>2</sup>, Hiroshi Imamura<sup>2</sup>, Yasuhiko Takagi<sup>18</sup>, Hajime Yano<sup>2</sup>, Masahiko Hayakawa<sup>2</sup>,

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4:30 PM - 4:45 PM JST | 7:30 AM - 7:45 AM UTC

[PPS03-11] Brightness change of Hayabusa2 SCI crater ejecta observed by ONC-T and its implication to the surface status of asteroid Ryugu

\*Rie Honda<sup>1</sup>, Yasuhiro Yokota<sup>2</sup>, Masahiko Arakawa<sup>3</sup>, Seiji Sugita<sup>4</sup>, Yuri Shimaki<sup>2</sup>, Koji Wada<sup>5</sup>, Toshihiko Kadono<sup>6</sup>, Kei Shirai<sup>3</sup>, Kazunori Ogawa<sup>7</sup>, Naoya Sakatani<sup>8</sup>, Ko Ishibashi<sup>5</sup>, Takanao Saiki<sup>2</sup>, Hiroshi Imamura<sup>2</sup>, Satoru Nakazawa<sup>2</sup>, Masahiko Hayakawa<sup>2</sup>, Hajime Yano<sup>2</sup>, Yasuhiko Takagi<sup>9</sup>, Naru Hirata<sup>10</sup>, Hiroataka Sawada<sup>2</sup>, Tomokatsu Morota<sup>4</sup>, Shingo Kameda<sup>8</sup>, Eri Tatsumi<sup>11</sup>, Manabu Yamada<sup>5</sup>, Toru Kouyama<sup>12</sup>, Yuichiro Cho<sup>4</sup>, Moe Matsuoka<sup>2</sup>, Kazuo Yoshioka<sup>4</sup>, Hidehiko Suzuki<sup>13</sup>, Chikatoshi Honda<sup>10</sup> (1.Department of Science and Technology, System of Natural Science, Kochi University, 2.Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3.Kobe University, 4.The University of Tokyo, 5.Planetary Exploration Research Center, Chiba Institute of Technology, 6.University of Occupational and Environmental Health, 7.JAXA Space Exploration Center, Japan Aerospace Exploration Agency, 8.Rikkyo University, 9.Aichi Toho University, 10.The University of Aizu, 11.Instituto de Astrofísica de Canarias, University of La Laguna, 12.National Institute of Advanced Industrial Science and Technology, 13.Meiji University)

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4:45 PM - 5:00 PM JST | 7:45 AM - 8:00 AM UTC

[PPS03-12] Study of Hydrated Asteroids via Polarimetry: Correlation between Polarimetric Properties and Degree of Aqueous Alteration of Hydrated asteroids.

\*Jooyeon Geem<sup>1</sup>, Masateru Ishiguro<sup>1</sup>, Hiroyuki Naito<sup>2</sup>, Daisuke Kuroda<sup>6</sup>, Koki Takahashi<sup>3</sup>, Tomohiko Sekiguchi<sup>3</sup>, Seiko Takagi<sup>4</sup>, Tatsuharu Ono<sup>4</sup>, Kiyoshi Kuramoto<sup>4</sup>, Tomoki Nakamura<sup>5</sup> (1.Astronomy program, Dept of Physics and Astronomy, Seoul National University, 2.Nayoro Observatory, 3.Hokkaido University of Education, 4.Department of CosmoSciences, Graduate School of Science, Hokkaido University, 5.Department of Earth and Planetary Material Sciences, Faculty of Science, Tohoku University, 6.Okayama Observatory, Kyoto University)

# Deciphering the regolith properties of small bodies from numerical modeling

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Surfaces of small bodies experience a wide range of processes that alter their local and global characteristics. Numerical modeling allows us to investigate these processes and decipher the history and physical properties of small bodies from their surface characteristics. I will present an overview of our recent investigations based on numerical modeling and give some examples below.

For objects whose surfaces have been characterized in detail by spacecrafts, e.g., Ryugu by Hayabusa2 (JAXA) and Bennu by OSIRIS-REx (NASA), comparisons with numerical modeling can be used to shed some light on the formation of these surface features. For instance, some surface local mass movement features in the downslope direction were detected on asteroid Bennu [1]. This direction and color variation analyses suggest that these mass movements occurred at times close to the current spin-period regime, which may result from YORP rotational accelerations. We carried out a numerical study using the soft-sphere discrete element modeling (SSDEM) to test Bennu's structural evolution under the YORP spin-up effect. The current surface slope, the recent surface mass movement, and the old surface age of the equatorial bulge are used as constraints to shed some light on Bennu's surface properties and internal structure.

Direct interaction with a small body surface is the most effective way to understand the regolith mechanical properties and behavior in the actual gravitational environment. The outcome also provides precious opportunities to interpret the results using numerical modeling. For instance, the experiment performed by the Hayabusa2 Small Carry-on Impactor (SCI) on asteroid Ryugu in April 2019 offers the first opportunity for a direct confrontation of cratering on small bodies with numerical modeling [2]. We conducted SCI-like cratering tests using a hybrid Smooth Particle Hydrodynamics (SPH) and SSDEM framework. The preliminary results show that regolith near the SCI-cratering region should have little cohesion in order to match the crater morphology.

In an indirect way, the regolith properties can also be inferred for some small bodies that are at the limit of maintaining their structural stability. For instance, there are dozens of fast-rotating asteroids that require material cohesion to keep their integrity. With comprehensive numerical exploration, we can derive the minimum required amount of cohesion of their regolith and the corresponding grain size distribution. Connecting the regolith properties with other observational data can help to reveal the formation mechanism of small bodies. For instance, our numerical modeling showed that the lack of apparent cometary activity of the interstellar object 1I/ 'Oumuamua can be explained by the way its surface was built during its formation through a close encounter with its host star in another planetary system [3].

Reference: [1] Jawin et al. (2020) JGR: Planets, 125, e2020JE006475. [2] Arakawa M. et al. (2020) Science, 368: 67–71. [3] Zhang & Lin (2020) Nature Astronomy, 4, 852–860.

Acknowledgement: I acknowledge my collaborators (Ronald-L. Ballouz, Olivier S. Barnouin, Martin Jutzi, Douglas N. C. Lin, Patrick Michel, Derek C. Richardson, Stephen R. Schwartz, Kevin J. Walsh) for their contributions to these studies. I acknowledge funding from the Université Côte d'Azur "Individual grants for young researchers program of IDEX JEDI" and from the European Union's Horizon 2020 research and innovation program under grant agreement No. 870377 (NEO-MAPP project).

Keywords: Small body formation and evolution, Regolith properties, Granular material, Numerical modeling

# Charge Magnitude of Electrostatically Lofted Dust Grains over the Lunar Terminator

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The interaction with the solar wind has several consequences on the lunar surface, and one of them can be described as electrostatic transportation of the lunar dust grains. It has been proposed that the emitted electrons within micro-cavities between the neighboring dust grains can produce strong repulsion to detach the dust particles from the loose upper layer of the lunar regolith, and this mechanism has been demonstrated in several laboratory experiments. In order to launch a charged dust particle from the lunar surface, the electrostatic repulsion should overcome the forces of contact and gravity. In this study, the charge magnitude requirement of the lofted dust particles in the range of  $0.1 \mu\text{m}$  –  $10 \mu\text{m}$  in radius is investigated through a function of (1) specific gravity that is determined by the particle type such as agglutinates, basalt, or breccia, (2) inter-particle contact forces, (3) the surface electric field that is controlled by the solar wind, (4) the launch angle based on the experimental results, and (5) the characteristic size of micro-cavity that is related to the regolith configuration. It has been observed that the charge magnitude variation increases with the particle size, and the particles with  $5\text{-}6 \mu\text{m}$  radius can gain sufficient charges to loft and produce the near-surface lunar horizon glow.

Keywords: lunar regolith, lunar dust charging, electrostatic dust lofting, lunar horizon glow

# High-velocity impact experiments in reduced gravity: The effect of cohesive strength of particle layers

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The surfaces of small bodies are in a microgravity environment, and it is important to understand how gravity affects crater size to estimate the physical properties of the surface. Several studies have investigated the effect of gravity on crater size for low-velocity to high velocity ( $1 \text{ m s}^{-1}$  to  $6.6 \text{ km s}^{-1}$ ) impacts: the gravitational dependence of crater size was obtained in the low and high gravity range (Gault & Wedekind, 1977; Schmidt & Housen, 1987; Cintala et al., 1989; Takagi et al., 2007; Kiuchi et al., 2019). In most of the studies, the crater diameter was shown to be proportional to  $-0.165 \sim -0.19$  power of the gravitational acceleration. However, in a microgravity environment such as the surface of small bodies, the effect of the cohesive strength of the regolith layer on crater formation may be more dominant than the effect of the gravity. The transition condition between the gravity regime and the strength regime is not well understood because the available laboratory data is limited.

We assembled a simple drop tower in the vacuum chamber of a two stage light gas gun at the Japan Aerospace Exploration Agency (JAXA) to conduct high velocity impact experiments in reduced gravity. We used quartz sand (particle size is  $\sim 425 \mu\text{m}$ ) as the target material, and used a glass sphere of diameter 1 mm as the projectile. The target material was loosely filled in a stainless steel container with a diameter of 30 cm and a height of 10 cm. A projectile was impacted at a velocity of  $1.2 \text{ km s}^{-1}$ . As a result, the diameters of craters formed at 0.05 G was about 1.8 times larger than the one formed at 1 G and gravitational dependence of the crater diameter was clearly observed(Kiuchi et al., 2020, JpGU-AGU). We compiled the results using pi-scaling (e.g., Holsapple, 1994) and showed that our results in reduced gravity agreed well with the crater size scaling law for non-cohesive sand targets (Housen and Holsapple, 2011).

In addition, we used targets of fine glass beads (particle size is  $\sim 40 \mu\text{m}$ ) and fused alumina particles (particle size is  $\sim 40 \mu\text{m}$ ). As a result, the crater diameter formed at 0.05 G was not much different from the one formed at 1 G for both targets. We infer that the gravitational dependence of the crater diameter was reduced due to the effect of the cohesive strength of these targets. We constrained the transition condition between the gravity regime and the strength regime by estimating the tensile strength of the particle layers based on the measured cohesive force of the particles (Nagaashi et al., in press). From our experimental results, it was found that the effect of the target strength becomes dominant when the tensile strength of the particle layer is larger than  $10 \rho gD$ , where  $\rho$  is the density of the particle layer,  $g$  is the gravitational acceleration, and  $D$  is the crater diameter. We will discuss the effect of the cohesive strength on the size frequency distribution of small craters on particle layers.

This research was supported by the Hypervelocity Impact Facility (former facility name: The Space Plasma Laboratory) of ISAS, JAXA, and JSPS KAKENHI Grant Number JP19K14824 and 18K03723.

Keywords: Impact crater formation experiments, Gravitational dependence of the crater diameter, Cohesive strength of particle layers



## Local variation in thermal inertia around the artificial impact crater on Ryugu

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The Hayabusa2 spacecraft has completed the rendezvous phase around Cb-type asteroid Ryugu in 2019. From thermal infrared imaging by TIR, global temperature distribution of Ryugu is consistent with the thermal calculation with thermal inertia of  $300 \pm 100 \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{-0.5}$  [1], and thermal inertia values of the floors of craters are in general roughly comparable with the global average [2]. On the other hand, few small and fresh craters show anomalously low thermal inertia less than  $100 \text{ J m}^{-2} \text{ K}^{-1} \text{ s}^{-0.5}$ , contributed from the highly porous nature of boulders exposed by the impact cratering [3]. On April 2019, Hayabusa2 performed an artificial impact (Small Carry-on Impactor or SCI) experiment [4], whereby a ~2 kg mass was fired at 2 km/s against the asteroid surface. As a result of the successful operation, an artificial crater (SCI crater) with diameter larger than 10 m was created on the asteroid.

In the preliminary analysis of TIR data of the SCI crater, we suggested no thermally-anomalous materials on the crater floor [3]. In other words, the SCI crater has similar thermal inertia with the global average, and physical properties of the subsurface materials are similar to that of the top surface, at least on the SCI impact site. However, regional difference in the thermal inertia inside and outside the SCI crater have not been discussed. We will present whether the regional variation of the thermophysical properties appears around the SCI craters.

References: [1] Okada et al. (2020), *Nature* 579, 518-522. [2] Shimaki et al. (2020), *Icarus* 348, 113835. [3] Sakatani et al. (2021), *LPSC #1832, #2189*. [4] Arakawa et al. (2020), *Science* 368, 67-71.

# Brightness change of Hayabusa2 SCI crater ejecta observed by ONC-T and its implication to the surface status of asteroid Ryugu

\*Rie Honda<sup>1</sup>, Yasuhiro Yokota<sup>2</sup>, Masahiko Arakawa<sup>3</sup>, Seiji Sugita<sup>4</sup>, Yuri Shimaki<sup>2</sup>, Koji Wada<sup>5</sup>, Toshihiko Kadono<sup>6</sup>, Kei Shirai<sup>3</sup>, Kazunori Ogawa<sup>7</sup>, Naoya Sakatani<sup>8</sup>, Ko Ishibashi<sup>5</sup>, Takanao Saiki<sup>2</sup>, Hiroshi Imamura<sup>2</sup>, Satoru Nakazawa<sup>2</sup>, Masahiko Hayakawa<sup>2</sup>, Hajime Yano<sup>2</sup>, Yasuhiko Takagi<sup>9</sup>, Naru Hirata<sup>10</sup>, Hirotaka Sawada<sup>2</sup>, Tomokatsu Morota<sup>4</sup>, Shingo Kameda<sup>8</sup>, Eri Tatsumi<sup>11</sup>, Manabu Yamada<sup>5</sup>, Toru Kouyama<sup>12</sup>, Yuichiro Cho<sup>4</sup>, Moe Matsuoka<sup>2</sup>, Kazuo Yoshioka<sup>4</sup>, Hidehiko Suzuki<sup>13</sup>, Chikatoshi Honda<sup>10</sup>

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## Introduction:

On April 5, 2019, Hayabusa2 Small Carry-on Impactor (SCI) experiment was conducted to form an artificial crater on the asteroid Ryugu. As a result, a crater with a rim diameter of 17.6 meters was successfully formed on the surface of Ryugu [1]. Comparison of the Hayabusa2 Telescopic Onboard Navigation Camera (ONC-T) [2] image data before and after the impact revealed that the brightness around the crater was darkened by 20% at the maximum due to ejecta rays [1]. Investigating the cause of this darkening and its temporal change will provide important insights into the weathering and alteration process on the asteroid's surface. We conducted a detailed analysis on the brightness of the SCI crater and its surrounding area by using the images of ONC-T v-band (0.55  $\mu\text{m}$ ) just before SCI impact and after SCI impact until the end of the proximity phase, Oct. 2019.

The analysis is conducted by two methods: (1) comparison of reflectance at the standard viewing geometry derived from images at a different time and phase angles and (2) evaluation of global phase-ratio map created by dividing two global mosaics at phase angle  $31^\circ$  and  $1^\circ$ .

## Analysis1. Comparison of images over 7 months:

High spatial resolution ONC-T images around the SCI crater was obtained just during the operations of the Hayabusa2 sampling (touchdown) and rehearsals. Thus we used images taken at an altitude of 20 km distance. This dataset contains various solar phase angle ( $1-33^\circ$ ) observations. We used the photometrically corrected reflectance images (Level 2e product) for this analysis. In addition, we normalized each image by the average of a reference area defined far from the SCI crater.

From comparison around the SCI crater over 7 months, we found that the relative brightness of the ejecta and SCI crater varies with solar phase angle, rather than the elapsed time from SCI impact. Since the photometric correction for this Level 2e product did not concern the regional photometric difference, this residual dependency on the phase angle means that the photometric characteristic (surface roughness/texture) around the SCI crater is different from the reference area.

**Analysis 2. Phase ratio image:** To search the area of hidden ejecta around the natural crater similar to SCI crater ejecta, we made a global phase-ratio map by dividing two global mosaics (phase angle  $31^\circ / 1^\circ$ ).

The ratio of two different phase angle images is often used as a method to identify the distribution of a characteristic surface roughness/texture area. In this map image, the SCI crater ejecta deposit is recognized as an area with a lower ratio than the surroundings. However, the results showed that there were no areas similar to the SCI crater ejecta deposit. This may suggest that the natural crater ejecta deposits have been smoothed out over a long time.

**Summary:**

It was found that the surface roughness/texture may play a major role in the darkening of the SCI crater ejecta deposit. The contribution of the intrinsic albedo is still unknown and needs to be studied in detail. It is also a future issue whether there was any change in roughness/texture or albedo during the 7-month period. However, observation of the natural craters on Ryugu suggests that the darkening area may fade over a long period of time.

**References:**

[1] Arakawa M. et al. (2020) Science 368, 67. [2] Sugita S., et al. (2019) Science 364, 252.

Keywords: Asteroid, Ryugu, Impact, Ejecta

## Study of Hydrated Asteroids via Polarimetry: Correlation between Polarimetric Properties and Degree of Aqueous Alteration of Hydrated asteroids.

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Hydrated asteroids have been attracting widespread interest due to the Hayabusa2 and OSIRIS-REx mission. These asteroids are considered as fragments that have experienced varying degrees of aqueous alteration in their parent bodies. Such aqueously altered asteroids have been extensively investigated by spectroscopic observations and laboratory experiments of carbonaceous chondrites. From spectroscopy, it is known that the spectral features in 0.7  $\mu\text{m}$  or the 3  $\mu\text{m}$  bands depend on the degree of aqueous alteration [2, 3]. On the other hand, mineralogical studies of chondrites found that the transition of composed minerals such as the cronstedtite converting to Mg-rich serpentine occurs as the alteration progressed [4]. While approaches via spectroscopy and meteoritics are widely employed, “polarimetry” has rarely been used to study hydrated asteroids.

Polarimetry has the advantage of being able to know the physical properties like albedo, particle size, and porosity of the target's surface even without conducting space explorations [1]. The polarization degree ( $P$ ) of reflected light from atmosphereless bodies exhibits the phase angle ( $\alpha$ ) dependence, where the  $\alpha$  is the angle between Sun-Target-Observer. The  $\alpha$ - $P$  profile consists of several key parameters such as the minimum polarization degree ( $P_{\min}$ ) appearing at  $\alpha \sim 10^\circ$ . The polarimetric parameters are useful diagnostic tools to estimate the surface properties. In this study, we examine “how the physical properties change depending on the degree of aqueous alteration” by utilizing polarimetry.

In 2020, we made the polarimetric observation for 35 nights with the visible Multi-Spectral Imager (MSI) attached on the 1.6m Pirka Telescope at the Nayoro Observatory. We observed 18 C-complex main-belt asteroids in the visible band, including Ch type asteroids (i.e., hydrated asteroids). These asteroids were observed at  $\alpha \leq 20^\circ$ , which allows us to obtain the  $P_{\min}$  values of our targets. We also gathered archival data and derived the polarimetric parameters and spectral information of asteroids from the previous research.

As a result, we found that polarimetric parameters (e.g., the  $P_{\min}$ ) show a strong correlation with spectral features (e.g., the 0.7  $\mu\text{m}$  and 3  $\mu\text{m}$  range absorption). Because  $P_{\min}$  is attributed to the physical properties (albedo, particle size, or porosity) of the surface materials, our observation suggests these physical properties changed as the aqueous alteration progressed. In this presentation, we will introduce our polarimetric observation, and discuss possible interpretations of these results.

[1] Cellino et al., 2015, MNRAS, 451,4.; [2] Fornasier et al., 2014, Icarus, 233, 163-178.; [3] Takir et al., 2013, Meteoritics and Planetary Science, 48, 9.; [4] Tomeoka et al., 1985, GCA, 49, 10.

Keywords: Asteroids, Polarimetry, Aqueous alteration process, Hydrated asteroids