APPARENT BRIGHTNESS CHANGE OF HAYABUSA2's ARTIFICIAL CRATER EJECTA OBSERVED BY THE ONC-T AT DIFFERENT PHASE ANGLES AND IMPLICATIONS FOR THE PHISICAL STATE OF NATUAL CRATER EJECTA.

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Introduction: JAXA's Hayabusa2's conducted the Small Carry-on Impactor (SCI) experiment, creating an artificial crater on the surface of asteroid Ryugu on April 5 [tph], 2019. A crater, hereafter referred as SCI crater, with a rim diameter of 17.6 meters was successfully formed at latitude 7.9°N and longitude 301.3°E. A darkened area was observed by the telescopic optical navigation camera (ONC-T) around the northern part of SCI crater in comparisons between pre-SCI impact and post-SCI impact images [1]. This darkened area is believed to be the result of material excavated from depth by the SCI impact and deposited on the surface. Hayabusa2 conducted its second touchdown to the northern of the SCI crater and successfully sampled this excavated surface material on July 11th, 2019.

Since the dark ejecta was observed at a phase angle of about 30°, the reflectance properties might be caused by the physical state of the surface, such as changes in surface roughness. For example, Schröder et al. (2013) showed that the photometric properties vary between fresh and older craters on Vesta [2].

In this study, we analyze the apparent brightness changes of the darkened area affected by the SCI ejecta at different phase angles taken from the home position (HP) with a spatial resolution of 20cm/pixel. We investigate whether this darkening is caused by changes in the physical state or compositional changes. We also create global phase ratio images similar to those used to investigate the change in the physical state of the lunar regolith around the Apollo landing sites [3]. Finally, we examine whether similarly darkened areas exist around natural craters on asteroid Ryugu by using this phase ratio technique.

Data: For analysis, we used v-band images obtained by the Hayabusa2's ONC-T. We selected images from the global mapping campaign acquired at 20 km altitude (HP) between March 29th and Nov. 7th in 2019 to cover both before and after the SCI artificial crater experiment. The spatial resolution of the images used is 20cm/pixel. The images are photometrically corrected using the shape model (SCI crater is not considered, thus the values inside SCI crater may be inaccurate) and global photometric model (Hapke's model) [4] to convert the images into reflectance values at the standard viewing and illumination condition of (i, e, α) = (30°, 0°, 30°), where i is the incidence angle, e is the emission angle and α is the phase angle. We hereafter denote the reflectance factor obtained from the observation with a phase angle α° as REFF(α°).

The spatial resolution of the images used in this study is lower compared with the previous study focused on the morphological change in the area around SCI crater [5]. That work was based on images taken at an altitude of ~1.6 km, resulting in a spatial resolution of 1.6cm/pixel. Local disturbances created by boulders excavated and landed as ejecta or displaced boulders and texture change by seismic shaking were observed. However, these changes occurred in a limited area compared to the entire darkened area. The darkening due to the SCI ejecta is thus interpreted to be created by the particles smaller than 1.6cm.

Change of apparent reflectance as a function of phase angle: Fig. 1 shows the temporal change in the normalized reflectance factor REFF(α°) before and after the SCI impact. REFF(α°) is normalized by the values from the southmost area of the extraction area (20° ×20° in lat. and lon.) to focus on the spatial difference in the

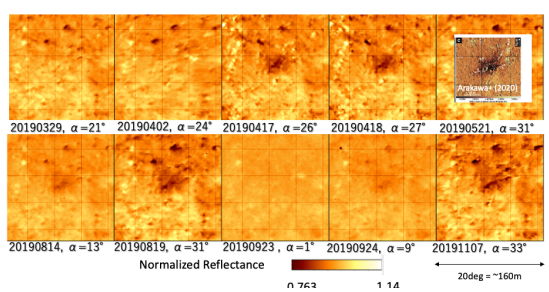

Fig. 1. Temporal change of normalized reflectance factor before and after SCI experiment for phase angle ranging from 1° to 33°. A small figure overlapped in the upper right is the reflectance change before and after SCI impact taken from [1] .

reflectance factor. The reflectance factor must be the same for material with the same composition, thus if the normalized reflectance differs between the observation at the difference phase angles, it implies the photometric properties are different from the nominal area.

The dark spot appearing in the center of those images in Fig. 1 acquired after the SCI impact corresponds to the darkened area including the SCI crater. This dark spot disappears at the phase angle of 0°, which suggests that this darkening is caused by the shadow created by fine particles that settled on the surface after the SCI impact.

The graph in Fig. 2 displays the average in the normalized reflectance factor, REFF(α°), for the darkened area that is shown as a blue semi-circle in the image in the right of Fig. 2. The designated area is defined by $r < R_{sc}$, where r is the distance from the center of SCI crater and R_{sc} is the rim radius of SCI crater. This figure indicates that the reflectance linearly decreases with the phase angle, α, after the SCI impact. The relative reflectance factor at α=1° is almost the same as the pre-impact values, however, the reflectance decreases by 10-15% compared with the pre-impact condition at a phase angle α=30°, which indicates the photometric properties changed after the SCI impact.

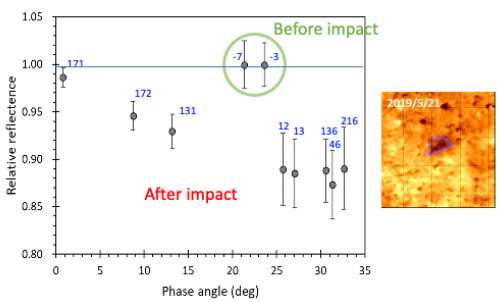

Fig. 2. Relative reflectance factor averaged in the area inside and around SCI crater. Numbers in blue attached to each data are the number of days of the date after SCI experiment. The blue semi-circle in the right image is a target area used for averaging.

Global Phase Ratio Map and the Search for Fresh Craters: Considering the photometric characterization results of the SCI crater ejecta area at phase angles ranging from 1° to 33°, it is likely that fine dust particles from the crater created the darkened area inside and around the fresh crater. In terms of natural craters on Ryugu, craters with dark floors are often observed in the visible images, however, no eminent darkened ejecta deposit-like area outside crater has been recognized. This indicates the lifetime of the disturbed darkened ejecta deposit is short compared with the geological time, such as the surface age of 8 to 17 Myr obtained from the crater chronology [5].

The phase ratio map created by calculating the ratio between the reflectance map obtained at different phase angles is an effective tool to check the diversity of photometric properties including the physical state of the surface of planetary bodies.

Fig. 3 shows the phase ratio map of Ryugu created by dividing REFF (31°) created from the observations of May 21st, 2019, by REFF (1°) created from the observations of Sept. 23rd, 2019. In this map, the colorless area has the nominal photometric properties similar to Ryugu's average [4], and the reddish and bluish area indicate different photometric properties from Ryugu's average. The reddish areas are darker at α=31° compared with the near opposition condition. The SCI crater area, marked by a green circle, is recognizable as a reddish area in this figure. For comparison, natural craters are shown as black circles. Circles with black solid lines are bluish (in real color) and circles with black broken lines are reddish in color [5]. The bottom of these craters tends to exhibit unusual photometric properties that are similar to the SCI crater ejecta deposit area. On the other hand, we do not recognize ejecta deposit areas showing the unusual photometric properties at this spatial scale. This suggests there exists a mechanism for smoothing the rough ejecta structure, such as seismic shaking or micrometeorite bombardment.

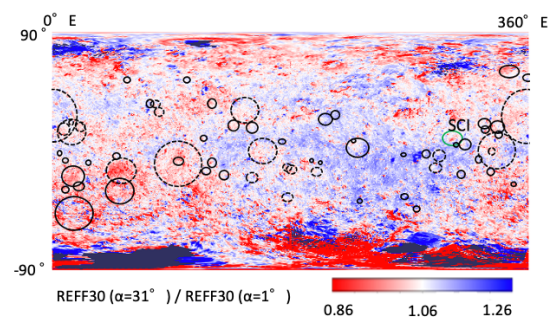

Fig 3. The phase ratio map REFF (31°) / REFF (1°) . Circles in green is SCI crater area and circles in black solid lines and broken lines are blueish and reddish crater, respectively [5].

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