PHOTOMETRIC PARAMETERS OF THE EJECTA DEPOSITS AROUND AN ARTIFICIAL CRATER ON ASTEROID RYUGU. Y. Yokota[1], R. Honda[2], M. Arakawa[3], S. Sugita[4], K. Shirai[3], K. Ogawa[5], K. Ishibashi[6], N. Sakatani[1], T. Kadono[7], K. Wada[6], Y. Shimaki[1], E. Tatsumi[8], D. Domingue[9], S. E. Schröder[10], M. Matsuoka[11], L. Riu[12], A. Longobardo[13], T. Saiki[1], H. Imamura[1], S. Nakazawa[1], M. Hayakawa[1], H. Yano[1], Y. Takagi[14], N. Hirata[15], H. Senshu[6], T. Sawada[1], T. Morota[4], S. Kameda[16], M. Yamada[6] , T. Kouyama[11] , Y. Cho[4] , K. Yoshioka[4] , H. Suzuki[17], and C. Honda[15], [1]ISAS/JAXA, (3-1-1 Yoshino-dai, Chuo-ku, Sagamihara, Kanagawa, Japan, yokota@planeta.sci.isas.jaxa.jp), [2]Ehime Univ., Japan, [3]Kobe Univ., Japan, [4]Univ. of Tokyo, Japan, [5]JAXA Space Exploration Center/JAXA, [6]PERC, Chiba Inst. Tech, Japan, [7]Univ. of Occupational and Environmental Health, Japan, [8]Instituto de Astrophysics de Canarias, Univ. of La Laguna, Spain, [9]Planetary Science Institute, USA, [10]Luleå Univ. of Technology, Sweden, [11]AIST, Japan, [12]Univ. Paris-Saclay, France, [13]INAF, Italy, [14]Aichi Toho Univ., Japan, [15]Univ. of Aizu, Japan, [16]Rikkyo Univ., Japan, [17]Meiji Univ., Japan.

Introduction: The asteroid explorer Hayabusa2 conducted the Small Carry-on Impactor (SCI) experiment on April 5, 2019, to generate an artificial crater on the surface of the asteroid Ryugu [1]. This experiment successfully formed a crater with a rim diameter of 17.6 meters ("SCI crater") at (7.9N, 301.3E) [1]. Comparing images of the Telescopic Optical Navigation Camera (ONC-T) [2] taken before and after the SCI impact, a darkened area was observed around the northern side of the SCI crater [1].

This darkened area is thought to be ejecta deposits from the SCI impact. From a comparison between ONC-T images at various solar phase angles, Honda et al. (2022) [3] showed that the darkening of this region is due to photometric effects from changes in the physical state of the surface, such as surface roughness, rather than albedo changes. The purpose of this study, a continuation of [3], is to advance the work of [3] by deriving the Hapke model parameters for the surface around the SCI crater.

Data and methods: We used ONC-T v-band (550 nm) images taken from 20 km distance. A unique feature of Hayabusa2 operations was that it usually rendezvoused at a distance of 20 km from Ryugu during the preparation period for close approach operations. Although the spatial resolution of these images is coarse (2 m/pixel), their homogeneous spatial resolution is an advantage for our analysis. Additionally, these images are suitable for photometric analysis because their solar phase angles ranging from a very low (~0º) to moderate values (~40º).

We divided the dataset into two analysis periods, 'before' and 'after' the SCI impact. Observations for 8 days were used, respectively (Table 1).

The source images are calibrated data which were converted to I/F (radiance factor) values by the ONC team. This data is available as a PDS4 bundle (Web site at JAXA: https://darts.isas.jaxa.jp/doi/hyb2/hyb2-00200.html ; Planetary Data System (PDS) Small Bodies Node web site: https://sbn.psi.edu/pds/resource/hayabusa2/onc.html). The I/F image dataset is called 'Level 2d' in the ONC team's own nomenclature. In the PDS4 directory, they are stored in 'data_iof'.

Table 1. Observation dates and solar phase angles of the analyzed data.

Before impact		After impact	
Date	Phase (deg)	Date	Phase (deg)
2018-07-03	18	2019-04-17	26
2018-07-12	19	2019-04-18	27
2018-08-24	29	2019-05-21	30
2018-08-31	40	2019-08-14	13
2019-01-08	0	2019-08-19	29
2019-01-24	27	2019-09-23	0
2019-01-31	10	2019-09-24	8
2019-03-29	21	2019-11-07	32

Observation geometry information (latitude and longitude, incidence angle, emission angle, and solar phase angle) for each image pixel is also included in 'geometry' directory in the published dataset. This geometry information was used to project the I/F data onto a simple cylindrical map image.

For a given point on the map, we collected I/F data with its associated observation angle information. The parameter fitting with the Hapke model [4,5] was performed for each point on the map.

The fitting method was similar to that of [6] and [7]. The Hapke model we used includes five parameters: the single scattering albedo (w), the scattering function parameter amplitude (b), the opposition surge width (h) and strength ($B0$), and the macroscopic roughness ($\bar{\theta}$). Since it is difficult to separate all five parameters from the limited phase angle range of this data set, we first performed the fitting varying only two parameters (w and h), using the Least Squares Fitting library (Levenberg-Marquardt method, MINPACK [8]). Other parameters were fixed by the values of [9]. We then re-modeled the data using two free parameters (w and $\bar{\theta}$).

Results and discussion: Fig. 1a shows a comparison of the images before (2019-03-29) and after (2019-04-17) impact. A red arrow indicates the areas darkened by the ejecta deposits after the SCI experiment.

For the derived single scattering albedo shown in Fig. 1b, there is no significant decrease in the albedo in the ejecta deposit areas. This result supports the work of [3]. The small area corresponding to the SCI crater is rather brightened by the impact. However, this may be an artifact because the asteroid shape model used for geometry calculation does not reflect the shape of the SCI crater. Preparation of a shape model that include the SCI crater shape is a subject for future work.

The parameter h (Fig.1c) at the ejecta deposit areas became smaller after the impact. On the other hand, the parameter $\bar{\theta}$ became larger in Fig.1 (d). The parameters h and $\bar{\theta}$ show a roughly inverse correlation. This tendency was also observed in the global analysis of [7]. From this point of view, we can say that this change trend is typical for Ryugu's surface.

Based on the derivation of the Hapke model, the smaller h implies a narrower gap in the surface structure that produces the shadow hiding opposition effect. The increase in $\bar{\theta}$ implies an increase in surface roughness at scales that light does not penetrate (scales larger than the opposition effect). These two changes are consistent with the interpretation that the top surface layer of the area has become a more porous structure as a result of the deposition of the ejecta material.

References: [1] Arakawa et al. (2020) Science 368.6486, 67-71. [2] Sugita S. et al. (2019) Science 364, 252. [3] Honda R. et al. (2022) LPS 53rd, Abstract 2549. [4] Hapke B. (1981) JGR 86(B4), 3039–3054. [5] Hapke B. (2012) Theory of Reflectance and Emittance Spectroscopy (2nd ed.). Cambridge Univ. Press. [6] Yokota Y. et al. (2021) LPS 52nd, Abstract 2105. [7] Yokota Y. et al. (2022) LPS 53rd, Abstract 2385. [8] https://pages.physics.wisc.edu/~craigm/idl/cmpfit.html [9] Tatsumi E. et al. (2020) A&A 639, A83.

Acknowledgments: This study was supported by JSPS Core-to-Core program International Network of Planetary Sciences. D.D. was supported by NASA's Hayabusa2 Participating Scientist (NNX16AL34G) and SSERVI/TREX (NNH16ZDA001N) programs.

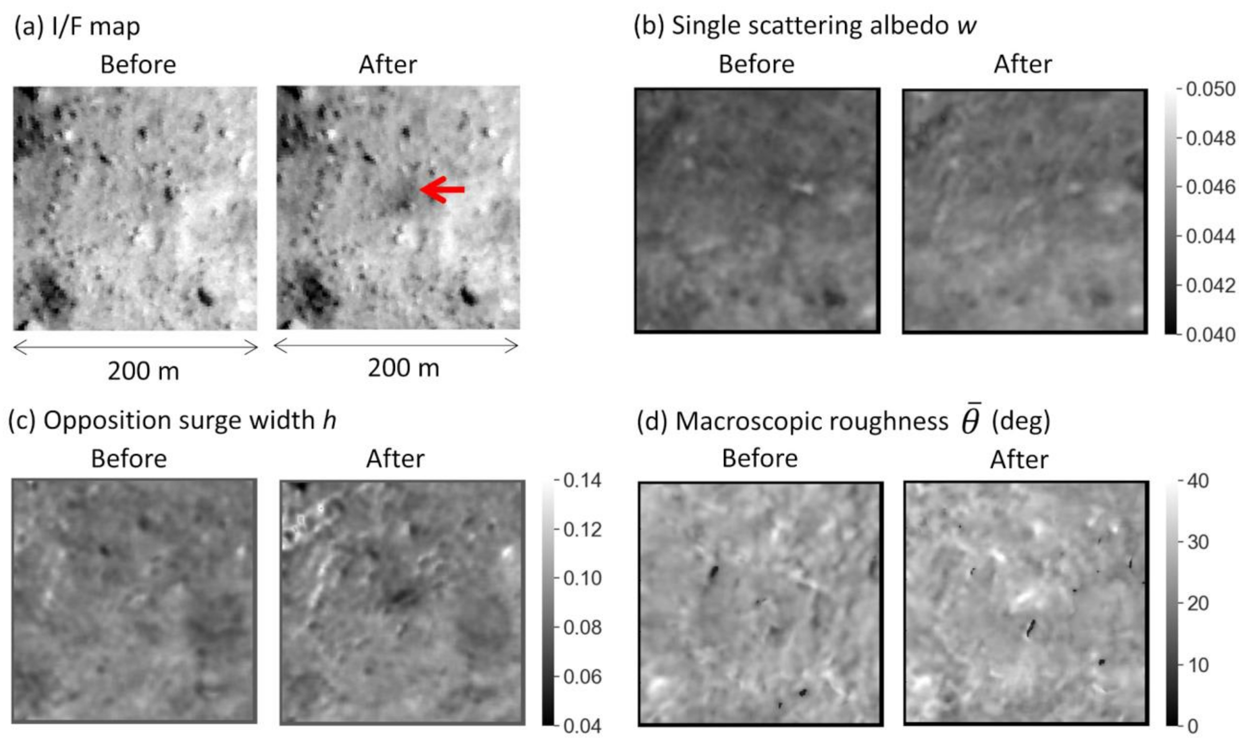

Fig. 1. Example images and derived Hapke parameters. (a) I/F map. Red arrow indicates the darkened area appeared after the SCI impact. Image IDs: [left] hyb2_onc_20190329_102047_tvf, [right] hyb2_onc_20190417_120409_tvf. (b) Single scattering albedo w. (c) Opposition surge width h. (d) Macroscopic roughness $\bar{\theta}$ (deg).