Analysis of the temperature distributions of boulders on C-type asteroid 162173 Ryugu observed in low altitude operation of the asteroid explorer Hayabusa2

*Ayumu Ohsugi[1,2], Naoya Sakatani[3], Yuri Shimaki[2], Hiroki Senshu[4], Takehiko Arai[5], Hirohide Demura[6], Toru Kouyama[7], Tomohiko Sekiguchi[8], Satoshi Tanaka[2], Tetsuya Fukuhara[3], Tatsuaki Okada[1,2]

1. Graduate School of Science, The University of Tokyo, 2. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, 3. Department of Physics, College of Science, Rikkyo University, 4. Planetary Exploration Research Center, Chiba Institute of Technology, 5. Faculty of Engineering, Department of Innovative Engineering, Division of Systems and Information Engineering,Ashikaga University, 6. Department of Computer Science and Engineering, University of Aizu, 7. National Institute of Advanced Industrial Science and Technology, 8. Hokkaido University of Education

The asteroid explorer Hayabusa2 [1] has the Thermal Infrared Imager (TIR) [2,3] which obtains the digital thermal images to indicate the thermal radiation from C-type asteroid 162173 Ryugu. In this study, to obtain detailed thermal properties of boulders at Ryugu, we analyzed TIR images taken below the altitude of 500 m and investigated temperature variations of boulders and their physical state in the specific regions.
TIR has a field of view (FOV) of 16.7˚×12.7˚ and the effective pixels of the detector of 328×248, resulting in the spatial resolution about of 0.051˚ per pixel [2]. The temperature range which TIR covers is 150 to 460 K and the well-calibrated temperature range is 230 to 420 K. We used TIR images taken during the release paths for the MINERVA rover (MNRV) and the MASCOT lander (MSCT). We identified boulders taken with more than 100 pixels and calculated the temperatures. The total numbers of detected boulders were 355 (MNRV) and 312 (MSCT), and the detection errors were obtained as ±5.2 % and ±5.5 % by Wald inequality [4]. In MNRV, the averages and the standard deviations of minimum, average, and maximum temperatures were 286 ±11.2 K, 314 ±5.65 K, and 332 ±5.74 K, respectively. In MSCT, the averages and the standard deviations of minimum, average, and maximum temperatures were 287 ±11.0 K, 313 ±5.53 K, and 332 ±5.99 K, respectively. From the normal Q-Q plots, where the x-axis is the observed value and the y-axis is the expected value which is assumed the detected value follows a normal distribution, the temperatures could follow the normal distribution. The YORP effect [1,5] might lead to the normality of the temperature distributions. Furthermore, the calculated slopes of the size-frequency distributions (SFD) divided by measured altitudes were in the range of 0.30 to 4.0 and these values were consistent with those investigated by Michikami T et al., (2019) [6], who suggested the existence of boulders formed when Ryugu's parent body was destroyed and those covered with regolith layers. Moreover, the range of thermal inertias [7] was calculated as low as 34.6-385 J m^{-2} $s^{-0.5}$ K^{-1} (hereafter, tiu) with the one-dimensional heat diffusion equation [8]. Our results are consistent with that of the global average estimated as 225 ±45 tiu by Shimaki et al. (2020) [9]. In this study, we assumed that the surfaces of boulders were confronted to the images so that further detailed study considering the surface local slopes is needed to estimate more accurately.
In summary, the total numbers of detected boulders were 355 (MNRV) and 312 (MSCT) and the normal Q-Q plots suggested that the average temperature distributions of boulders were close to the normal distribution. Moreover, the values of slopes of SFD and thermal inertias suggested the existence of boulders formed when Ryugu's parent body was destroyed, boulders covered with regolith layers, and porous and fluffy boulders. In the future, we will investigate other areas taken at low-altitudes.

Acknowledgments

The authors appreciate Dr. Koji Matsumoto and Kyoko Yamamoto at the National Astronomical Observatory of Japan for the use of the LIDAR corrected trajectory of the Hayabusa2 spacecraft. This study is partly supported by the JSPS Kakenhi No. JP17H06459 (Aqua Planetology) and the JSPS Core-to-Core Program “International Network of Planetary Sciences”.

References

[1] Watanabe S. et al., Science 364, 268-272 (2019), [2] Okada, T. et al., Space Sci. Rev., 208, 255-286 (2017), [3] Okada, T. et al., Nature 579, 518-522 (2020), [4] Kurihara, S., Introduction to statistics: from testing to multivariate analysis and experimental design, Ohmsha Ltd., pp.336 (2011), [5] Walsh et al., Nature 454, 188-191 (2008), [6] Michikami, T et al., Icarus 331, 179-191(2019), [7] Okada, T. et al, 13th Space Science Symposium, ISAS/JAXA, P2-117 (2013), [8] Takita, J. et al., Space Sci Rev, 208, 287-315 (2017), [9] Shimaki Y. et al., Icarus 348, 113835 (2020).

Keywords: Hayabusa2, Temperature, boulder, Ryugu

