EARTH-MOON IMAGING WITH HAYABUSA2 OPTICAL NAVIGATION CAMERA (ONC) DURING THE EARTH SWING-BY. [1]S. Sugita, [2]M. Yamada, [3]H. Sawada, [4]S. Kameda, [5]T. Kouyama, [4]H. Suzuki, [7]R. Honda, [8]T. Morota, [9]C. Honda, [10]K. Ogawa, [3]K. Shirai, [1]E. Tatsumi, [3]N. Ogawa, [3]Y. Iijima, and ONC Team, [1]Univ. of Tokyo (sugita@eps.s.u-tokyo.ac.jp), [2]Chiba Inst. Tech., [3]JAXA/ISAS, [4]Rikkyo Univ., [5]AIST, [6]Meiji Univ., [7]Kochi Univ., [8]Nagoya Univ. [9]Aizu Univ., [10]Kobe Univ.,

Introduction: The optical navigation camera (ONC) system of HAYABUSA2 consists of three framing cameras (T, W1, and W2) with 2-dimensional (1024×1024) charge-coupled devices (CCD's) [1-3]. In order to gain ΔV and to change the orbital elements, it conducted an Earth swing-by on Dec. 3, 2015.

This was a unique opportunity for obtaining images of extended light sources after the launch and before the arrival at the target asteroid Ryugu (1999 JU_3). Because strong vibration during a launch poses the greatest threat to the health of onboard instruments, inflight calibration tests are extremely important for ensuring the quality of the science data.

Lessons from HAYABUSA: First, inflight spectral irradiance calibration for Asteroid Multi-band Imaging Camera (AMICA) of the original HAYABUSA was conducted based on the average reflectance spectra of the target asteroid Itokawa because multiple telescopic observations for Itokawa consistently yielded spectra in mutual agreement within their errors. However, spectroscopic observations of Ryugu have not been converged yet. A multi-rotation phase observation shows that a large portion of its surface is covered with material with similar flat reflectance spectra, but other observation suggests possible variation in reflectance spectra [4-6]. It may be difficult to define the average spectra of Ryugu. Consequently, another well-defined light source, such as Moon, for spectral calibration is highly valuable.

Second, analyses using image data obtained by Asteroid Multi-band Imaging Camera (AMICA) of the original HAYABUSA underscored the value of such images of Earth and Moon during its swing-by. In particular, these images were very useful for obtaining detailed profiles of the point-spreading function (PSF) particularly in the far wing region (e.g., $>10^2$ pix away from the light source) [7,8]. The far wing region of PSF turned out to have a significant contribution to the apparent brightness distribution in asteroid images. Although the PSF value is as low as $10^{-7} - 10^{-6}$ at $\sim 10^2$ pix from a point source, the accumulated contribution from extended light source, such as 300×300 pix, may be on the order of 10^{-2} to 10^{-1}. This effect makes the apparent brightness in the peripheral region of an extended light source lower and the central region higher. Because the PSF's at different wavelength bands are different, the band ratio of an extended light source would be different.

Figure 1. Time-series images of Earth obtained by the W2 camera immediately before the Earth swing-by on Dec. 3, 2015. Low-latitude regions of the Earth, such as Arabia peninsula and Indian sub-continent, are seen.

Furthermore, because the wide-angles cameras on HAYABUSA were not used for science observations, the image quality of these cameras has not been quantified as much as AMICA. Thus, a careful calibration is needed for W1 and W2 on HAYABUSA2.

Observations and Analyses: In order to satisfy these needs, we conducted a series of imaging of Earth and Moon using all the three cameras. First, a time series of images of Earth was captured with W2 before the swing-by (Fig. 1).

Subsequently, we conducted multi-band imaging of the Earth on the day after the swing-by. The exposure times for each band were reconfirmed by the Earth-Moon images obtained a week before the swing-by (Fig. 2). Because the FOV of ONC-T is a tenth of W2, a sizable Earth image was obtained after one day of high-speed travel. The image clearly shows a number of prominent features on Earth, including the Transantarctic Mountains as a ridge striking horizontally across Antarctica near the terminator of Earth, swirling clouds in the Antarctic ocean, Australia, South Africa, and Madagascar (Fig. 3). The fact that these varieties of features on Earth are captured suggests that ONC-T images may be able to depict asteroid morphologies as well.

In the process of the analysis of this Earth image, we co-registered multi-band images and obtained band ratio images. In particular, vegetation distribution can be assessed with so-called "red edge" of its spectra. The 860/700nm band ratio is chosen to capture the red edge. The obtained image clearly shows lands not clearly seen in a usual RGB images, such as New Zealand, and, southern tip of India, and Indonesian islands despite the fact that the some vegetation is consealed by clouds. The ability to extract the land distribution from the ratio map strongly suggests that the quality of ONC multi-band images are high enough to conduct spectroscopic analyses.

Finally, we obtained multi-band images of the Moon. Because Moon is a large light source near the Earth with a very stable reflectance spectra, it is an ideal light source for irradiance calibration for a variety of cameras/spectrometers on spacecrafts. Thus, the obtained lunar images are analyzed with a global lunar spectral model [9].

Conclusions: During the Earth swing-by, we obtained many images of Earth and Moon using ONC. Our preliminary results suggest that the obtained images are useful for a variety calibration and quantification efforts for our cameras before our arrival at Ryugu.

References: [1] Sugita, S. (2015) *LPSC* #2169. [2] Kameda, S. et al. (2015) *Adv. Sp. Res.*, *56*, 1519. [3] Kameda, S. et al. *Sp. Sci. Rev.*, in press. [4] Moskovitz, N. et al. (2013) *Icarus*, 224, 24. [5] Lazzaro, D., *et al.*, 2013, *A&A* 549, L2. [6] Sugita, S. (2013) *LPSC* #3026. [7] Ishiguro, M. et al. (2010), *Icarus*, *207*, 714. [8] Ishiguro, M. *Pub. Astron. Soc. Jpn*, *66* (3) 55. [9] Kouyama, T. et al. (2016), *LPSC* this issue.

Figure 2. Earth-Moon images obtained by the ONC-T Nov. 26, 2015 one week before the swingby.

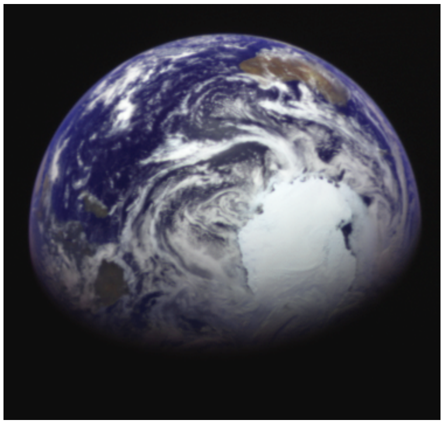

Figure 3. An Earth image obtained by ONC-T on Dec. 4, 2015, a day after the Earth swing-by. The RGB are from 700nm band, 860/700nm band ratio, and 480nm band.

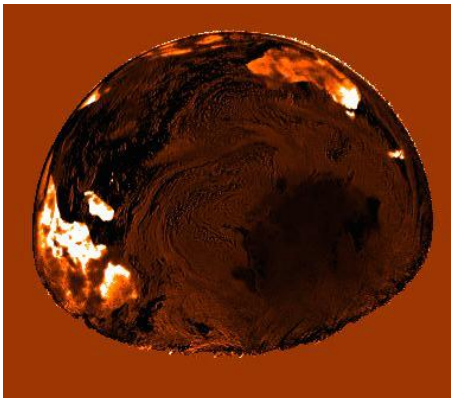

Figure 4. The 860/700nm band ratio of the Earth.

Figure 5. ONC-T 550nm band image of the Moon ON Dec. 5, 2015, two days after the swing-by.