# MOON IMAGING BY OPTICAL NAVIGATION CAMERA (ONC) DURING HAYABUSA2 EARTH RETURN.

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**Introduction:** Hayabusa2 completed in-situ observations on the asteroid Ryugu from June 2018 to November 2019, and then successfully completed an Earth swing-by as well as delivering samples from Ryugu to Earth on December 6, 2020. The Hayabusa2 team is planning an extended mission to the asteroid 1998KY26 in 2031.

The Optical Navigation Camera (ONC) onboard Hayabusa2 is a two-dimensional CCD camera system consisting of a multi-wavelength spectroscopic telephoto camera (ONC-T) and monochrome wide-angle cameras (ONC-W1 and W2) [1-4]. It has been reported that the optical performance of this camera was degraded during two touchdown operations due to fragments of asteroids flown up during sample acquisition at Ryugu [5].

Therefore, it is important to monitor the performance of the cameras for the extended mission, and we had an opportunity to compare the performance of the ONC cameras by taking images of sufficient pixel size objects such as the Earth and the Moon after the Earth swing-by in 2020 as well as the Earth swing-by in December 2015.

**Moon Observations:** After the Earth swing-by, we conducted observations of the Moon in seven bands of ONC-T. The date and time of the observation and the distance between the spacecraft and the Moon at the time of the observation are shown in Table 1. The moon was imaged three times on December 6, 2020, just after the swing-by, with the moon in the center and corner of the field of view, respectively, to confirm the uniformity of sensitivity. After that, we observed the moon in the center of the field of view only. Figure 1 shows the superimposition of the three v-band images taken on December 6, 2020.

**Comparison with the 2015 Swing-by Observation:**

Figure 2 and Figure 3 show observed lunar irradiance by ONC-T bands at 2020-12-06 08:05, and modeled irradiance estimated from a lunar reflectance model based on SELENE/SP observations (SP model, [6]). Similar to the Moon observations in 2015, the band ratios between observed and modeled are well consistent within 5 %.

**Table 1**: The list of the start time of the V-band imaging, which is the first of the 7-band imaging, and the moon distance and phase angle from the spacecraft at that time.

| Time [UT] | S/C - Moon Distance [km] | Moon Phase Angle [deg] |
|---|---|---|
| 2020-12-06 06:05 | 547276 | 50.1 |
| 2020-12-06 07:05 | 559732 | 49.8 |
| 2020-12-06 08:05 | 572191 | 49.5 |
| 2020-12-07 15:35 | 964171 | 43.9 |
| 2020-12-08 19:59 | 1312234 | 41.6 |
| 2020-12-09 15:35 | 1551067 | 40.3 |
| 2020-12-10 15:35 | 1846332 | 38.9 |
| 2020-12-11 15:35 | 2149945 | 37.5 |
| 2020-12-12 15:35 | 2467330 | 36.3 |
| 2020-12-13 15:35 | 2802961 | 35.1 |
| 2020-12-14 15:35 | 3159766 | 34.0 |

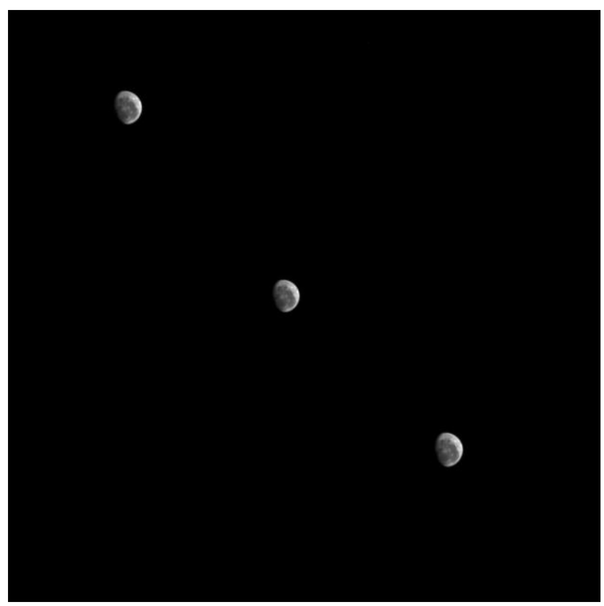

**Figure 1**: Superimposed image of three v-band lunar images taken on December 6, 2020.

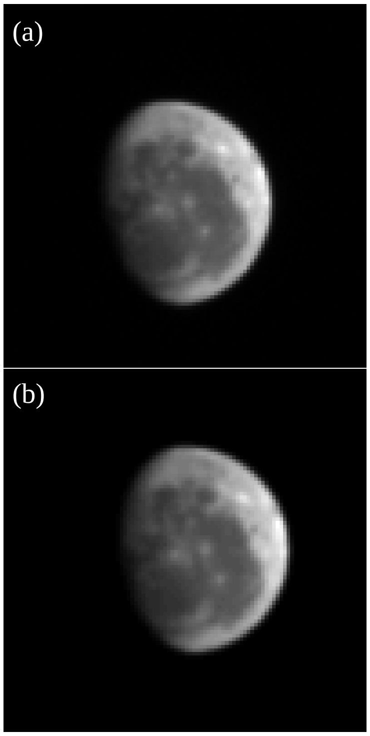


**Figure 2**. (a) Observed lunar image obtained by ONC-T (v-band) on December 6, 2020 and (b) simulated image calculated by the SP model [6].

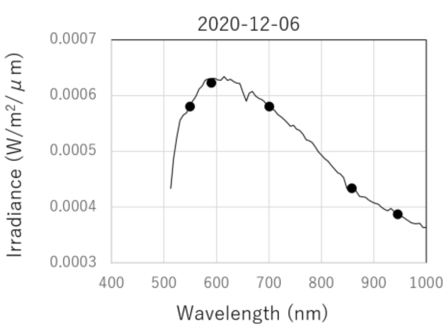


**Figure 3**. Observed lunar irradiance taken at 2020-12-06 08:05 (dots) and modeled spectrum (solid line).

Since the brightness of Moon has been well studied and modeled (cf. [7],[6]), sensitivity of a sensor can be evaluated from comparison between observed and modeled Moon brightness, which is called as lunar calibration. While the uncertainty in absolute accuracy from the lunar calibration has been still under discussion (larger than 5 %), the uncertainty for evaluating relative variation in the sensor sensitivity is sufficient small (less than 1 %).

In Figure 4a, ratios of observed and modeled lunar brightness in 2015 and 2020 are plotted for v, Na, w, x, and p-bands. Comparing to results in 2015, results in 2020 indicate clear sensitivity degradation in all bands.

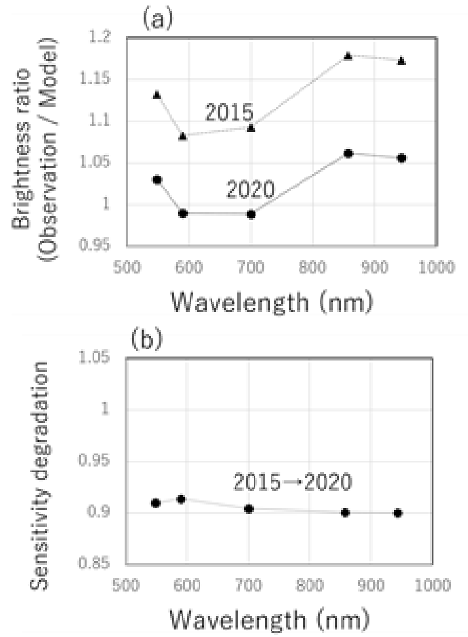


**Figure 4.** (a) Ratios between observed and modeled lunar brightness. The model brightness was estimated based on the SP model. (b) Sensitivity degradation between 2015 and 2020 Moon observations evaluated from (a).

Figure 4b shows quantitative evaluations of the sensitivity degradation between 2015 and 2020. For all bands, 10 % degradation was indicated from the results. The 10 % degradation from the lunar calibration is somewhat smaller than degradation estimations from star observations and Ryugu observations (~15 %, Kouyama et al., revised). The result from the lunar calibration is a preliminary one, and the inconsistency among different calibration sources will be studied in a future work.

**Conclusions:** The Moon was imaged in multiple bands of ONC-T during the Earth swing-by in December 2020. By comparing the December 2015 and December 2020 lunar images, we confirmed the sensitivity degradation of sensitivity in all bands. Although the results of the lunar calibration are preliminary, it is useful to confirm the areal sensitivity of the CCDs by performing lunar calibration for future swing-by in the extended mission.

**References:** [1] Kameda, S. et al. (2015) *Adv. Sp. Res., 56, 1519.* [2] Kameda, S. et al. (2017) *Space Sci. Rev., 208, 17.* [3] Suzuki, H. et al. (2018) *Icarus, 300, 341.* [4] Tatsumi, E. et al. (2019) *Icarus, 325, 153.* [5] Kouyama, T. et al. (2021) *Icarus, in revision*. [6] Yokota, Y et al., (2011) *Icarus, 215, 639.* [7] Kieffer, H. H. and Stone, T.C.,(2005) *Astron. J., 129, 2887.*