CALIBRATION AND FIRST LIGHT OF OPTICAL NAVIGATION CAMERA (ONC) OF HAYABUSA 2.

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Introduction: The optical navigation camera (ONC) system of Hayabusa 2, which was launched on Dec. 3 of 2014 from Tanegashima, consists of three framing cameras (T, W1, and W2) with two-dimensional (1024×1024) charge-coupled devices (CCD's) (Fig. 1). By taking images of both the mission target asteroid 1999JU$_3$ and the star field, it navigates both the spacecraft and its scientific observations [1]. Because of its high spatial resolutions and global coverage, it is expected to provide geologic context to other science instruments on Hayabusa 2.

ONC-T is a nadir viewing camera with 6.35°×6.35° field of view (FOV) with eight filters. They are seven narrow band-pass filters centered at 390, 480, 550, 700, 860, 950, 589.5nm of wavelengths and a panchromatic filter "wide". It will cover the entire globe of 1999JU$_3$ with 2m/pixel of resolution at 20 km (home position; HP) of distance from the asteroid with these narrow-band filters. Much higher resolutions of multi-band images of regions of greater interests, such as touch-down candidate sites for sampling, will be taken at altitudes lower than HP for higher resolutions. These images will be used to examine these locations in terms of both safety for touchdown and scientific value for sampling.

ONC-W1 and W2 are panchromatic (485 – 655 nm) wide-angle cameras with 65.24°×65.24° of FOV. The W1 camera is a nadir viewing and the W2 camera is slant viewing. Their spatial resolution is modest at higher altitudes. However, because their focus distance is 1 m to infinity, they may be able to take extremely high-resolution images during the touchdown sequences of Hayabusa 2. If an image is taken at 1 m of altitude, it will have 1 mm/pixel resolution over 1×1 m of FOV. Such high-resolution images will be very useful for knowing the occurrence and geologic context of returned samples from 1999JU$_3$.

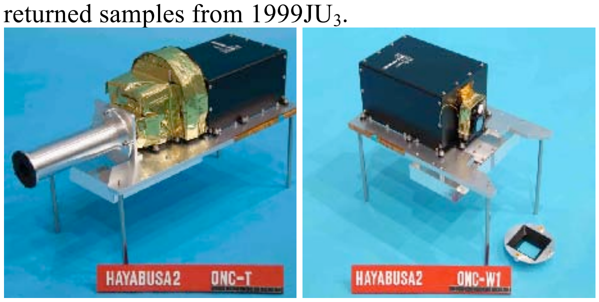

Fig. 1. The flight models of ONC-T and W1.

Calibration tests: We conducted optical calibration tests on standard camera properties, such as distortion, linearity, point spread function (PSF), spectral sensitivity, flatness, stray light level. These test results are, in theory, sufficient to assess the capabilities of cameras and to correct raw images of observation targets properly. In practice, however, there are often unexpected and/or overlooked problems. To such such problems, end-to-end tests to observe objects similar to the actual observation targets under conditions close to the actual flight situations are very effective. We conducted two types of such tests during our camera development.

ONC-T. Because the 0.7 μm absorption band, which may have only about 3 % of relative strength [2], is one of the most important observation targets of ONC-T multi-band imaging [1], we examined whether the actual ONC-T flight model can detect 0.7 μm absorption band of carbonaceous chondrites samples [3]. Because the minimum focus distance of ONC-T is as much as 100 m, a correction optics was inserted between the camera and meteorite samples.

We used two Murchison meteorite slabs, its powder pellet, a Nogoya slab, a Murray slab, and a Jbilet Winselwan slab for the measurements. The experimental results indicate that all the multi-band images of the former five CM samples clearly indicate the presence of 0.7 μm absorption and that that for Jbilet Winselwan, which is a CM chondrite with no 0.7 μm aborption, indicates the absence of the absorption. This result unambiguously shows that ONC-T can detect the 0.7 μm band if its strength is about 3%.

ONC-W1. Although the W1 camera does not have spectral resolution, their extremely-high-resolution images around asteroid touchdown may be able to resolve meteoritic textures, such as condrules and CAI's. It is noted that discerning such textures requires a camera to have high engougha dyanamic range for brightness as well as spatial resolution. We conducetd imaging tests of W1 using carbonecous chondreites, such as Murchison (CM), Nogoya (CM), Allende (CV), and NW64642 (CV). The CV chondrites were chosen because of their diagnostic large Ca-Al-rich inclusions (CAI's).

The experimental results indicate that large and bright CAI's in CV metorites are discernible. Although individual condrule fragments in CM meteorites are too small to resolve with W1 even at proximity, the gradual brightnesss unduration due to the inhomogenous distribution of condrule fragments are discernible in W1 images. Because spatial inhomogeneity in CM chondrites are may be due to impact brecciation on their parent body, observation of such brightness distribution might be useful for understanding the mechanical history of the asteoid surface.

First Light of ONC: Soon after the launch, an image of the Moon was obtained with the W2 camera at ~50° of solar phase angle (Fig. 4). This became the first light of ONC system. A preliminary analysis based on the brightness recorded in the image and preflight calibrations indicates that the apparent reflectance of the Moon is about 7%. The data by the Multiband Imager (MI) onboard KAGUYA indicate that typical visible range (415 – 1000 nm) reflectances for lunar highlands are 4.5 – 10.7 % for 50° of solar phase angle [4]. This agreement between W2 and MI suggests that the W2 camera has been calibrated properly and are functioning properly.

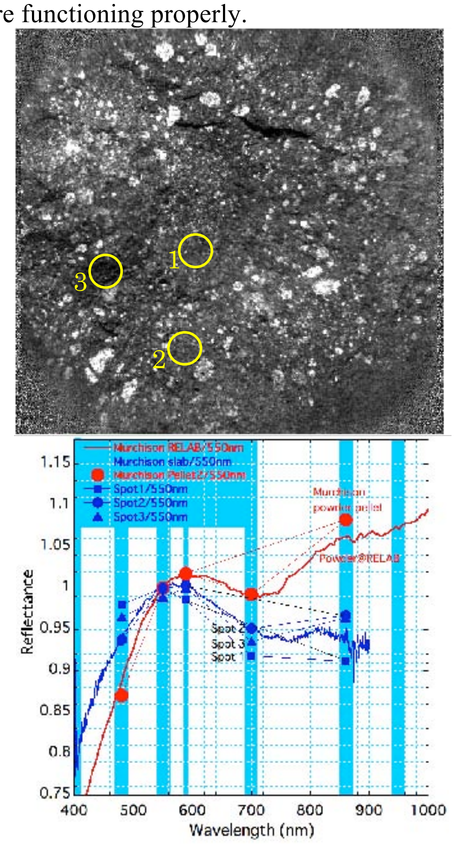

Fig. 2. A v-band image of Murchison meteorite slab taken by ONC-T and multi-band spectra of Murchison. The reflectance spectra of both slab sample (blue curve and circles) and powder sample (red curve and solid circles) are shown for comparison along with the filter wavelengths of ONC-T. Note that there is substantial difference between slab and powder saples and that ONC-T measurements reproduces these differences.

References: [1] Sugita, S. et al. (2013) *LPS XXXIV,* Abstract #3026. [2] Hiroi, T. et al., (1996) *MAPS*, *31*, 321-327. [3] Kameda, S. et al. (2014) *COSPAR,* #B0.4-33-14. [4] Yokota, Y. et al. (2011) *Icarus*, *215*, 639-660.

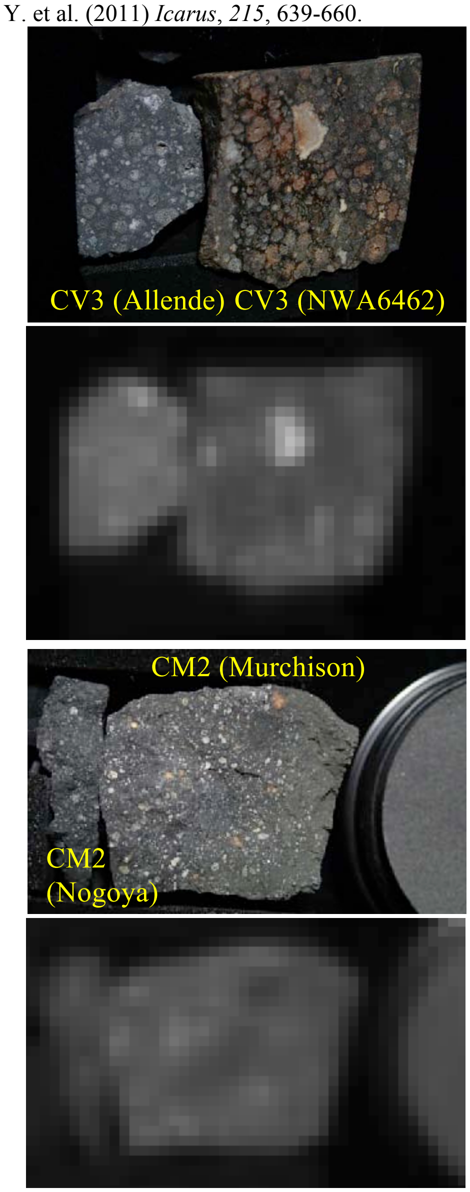

Fig. 3. Comparison of carbonaceous chondrites images between W1 and a commercial digital camera. All the images were taken at 0.8 m. Both NWA6462 and Murchison samples is 1” across. The circular object next to the Murchison sample is a 5% reflectance standard.

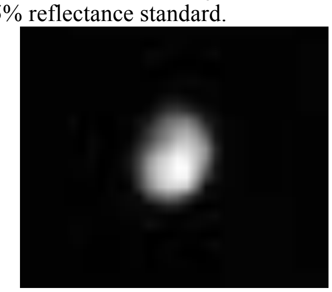

Fig. 4. The first image of the Moon taken by ONC-W2. Smear correction has been applied.