HAYABUSA2'S MULITBAND DISK-INTEGRATED PHOTOMETRY OF 162173 RYUGU.

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Introduction: Hayabusa2 arrived at its home position above the target asteroid 162173 Ryugu on 26 June 2018. During its approach the Optical Navigation Camera (ONC) observed Ryugu in all seven color bands, ranging in wavelength from 0.4 – 0.95 µm, over several rotations. These observations form the base of the approach disk-integrated data set that was compared with ground-based observations for calibration verification, color/spectral characterization, and photometric characterization of the asteroid's surface. Additional data extracted from images acquired from the home position were used to confirm the asteroid's disk-integrated photometric properties.

The combined ONC-T and ground-based telescopic observations were analyzed using Hapke's photometric model to provide an initial photometric standardization for the imaging data in all seven filters. This photometric standardization was used to create initial albedo and color maps of Ryugu's surface.

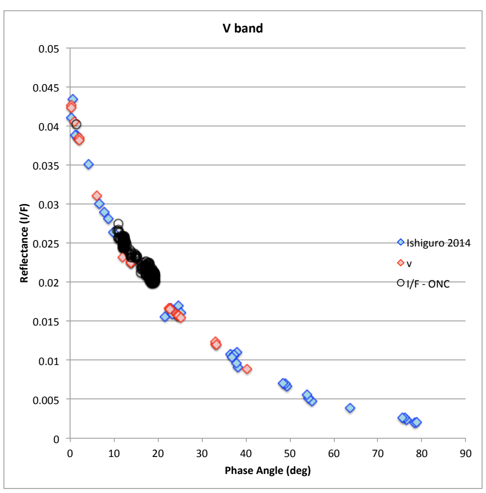

Fig. 1. This graph compares the 550-nm ground-based phase curve observations from Ishiguro et al. [4] in blue, the convolved spectral observations [5 – 7] in red, and the ONC-T derived measurements in black. The overlap among the data sets provides validation of the camera calibration.

Calibration Verification: We have conducted a series of photometric calibrations on the ground and during flight [1-3]. The disk-integrated phase curves from ground-based observations of Ryugu were compared with disk-integrated measurements extracted from the ONC-T images in order to verify the calibration. The ground-based data included the 550-nm phase curve data from Ishiguro et al. [4] and spectral observations [5-7] convolved with the ONC-T filter response functions to provide phase curve information for all the ONC-T wavelengths. Comparison of the ground-based and ONC-T data from the approach phase are shown in Fig. 1. The comparisons show that the ONC-T phase curves, at each filter wavelength, overlap well with the ground-based observations, validating the camera calibration.

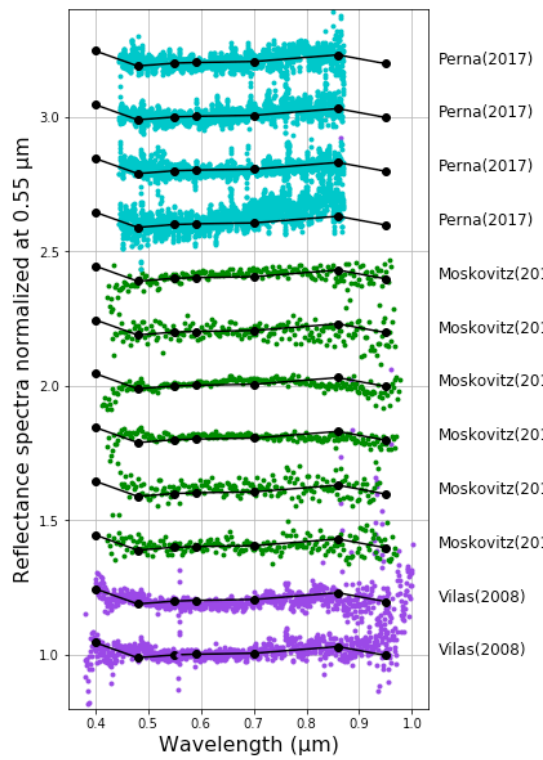

Figure 2. Comparisons of the broadband spectral properties of Ryugu derived from the ONC-T images (ul: 400 nm, b: 480 nm, v: 550 nm, Na: 590 nm, w: 700 nm, x: 860 nm, p: 950 nm) with ground-based spectral observations [5-7]. Spectra are normalized to unity at 500 nm and offset by 0.2 for visibility.

Color/Spectral Behavior: The disk-integrated measurements extracted from the ONC-T also provide a broadband spectrum of Ryugu's surface which is comparable to ground-based spectral observations. An example of the comparisons in shown in Fig. 2, also validating the calibration of the ONC-T camera over all filters.

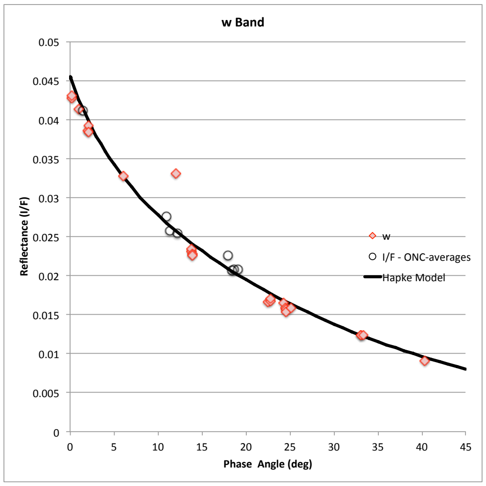

Fig. 3. Comparison of the w-band (700 nm) phase curve with the Hapke modeling results. The red diamonds are from ground-based spectral observations convolved with the ONC-T filter response function, the black circles are reflectance values extracted from the ONC-T w-band images, and the black line is the Hapke model.

Photometric Standardization: The resulting phase curves were modeled using Hapke's set of equations [8]. An example of the modeling fits are shown in Fig. 3 for the 700-nm (w-band) phase curve. The modeling results are commensurate with a surface that is much rougher than the lunar surface (as is seen in the images), with a regolith that is predominately backward scattering and dark.

The photometric model results were used to standardize the imaging data to common incidence, emission, and phase angle values of 30°, 0°, 30°. Using the photometrically-standardized images, an albedo map of the surface was created for each ONC-T wavelength. This standardization enables examination of the surface for albedo variations. Using albedo maps from the ul-band (398 nm), w-band (700 nm), and p-band (945 nm) for the blue-green-red channels, respectively, a color map of the surface of Ryugu was created (Fig. 4). Different color units are discernable across the surface, with bluer units along the equatorial ridge and poles.

References: [1] Kameda et al. (2017) *Space Science Reviews, 208, Issue 1-4, 17*, [2] Suzuki et al. (2018) *Icarus, 300, 341*, [3] Tatsumi et al. (2019) Icarus, submitted [4] Ishiguro et al. (2014) *Astrophysical Journal, 792,* 74, [5] Perna et al. (2017), *Astronomy & Astrophysics, 599, 4.* [6] Moskovitz et al. (2013), *Icarus, 224, 24.*[7] Vilas (2008) *Astronomical Journal, 135, 1101*, [8] Hapke (2012) Cambridge Univ. press.

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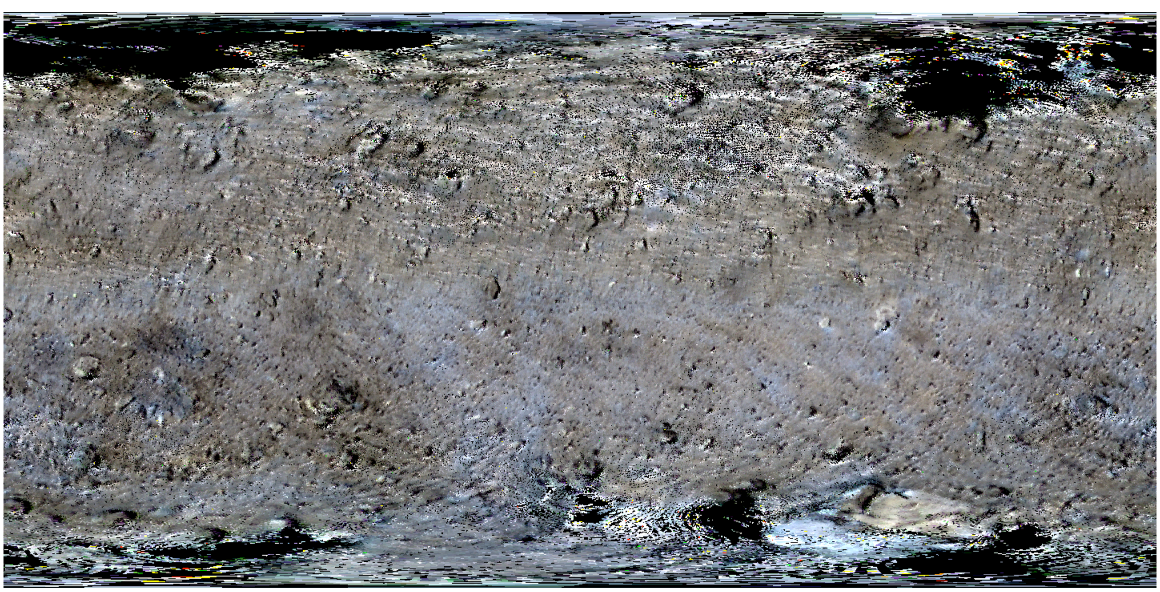

Fig. 4. This simple cylindrical projection of the color mosaic of Ryugu's surfacs (2m/pxl resolution) is centered at 0N, 180E. The blue, green, and red channels correspond to the ul-band (398 nm), w-band (700 nm), and p-band (945 nm), respectively.