# ALBEDO AND SPECTRO-PHOTOMETRIC PROPERTIES OF RYUGU FROM NIRS3/HAYABUSA2, IMPLICATIONS FOR THE COMPOSITION OF RYUGU AND THE REPRESENTATIVITY OF THE RETURNED SAMPLES.

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**Introduction:** At the end of June 2018, the JAXA Hayabusa2 spacecraft reached Ryugu (1999JU3), a type C asteroid [e.g., 1,2], with the objective of characterizing the body and returning a sample to Earth, a first for a primitive object.

Observations performed by the Near-Infrared Spectrometer (NIRS3) [3] and the Optical Navigation Cameras (ONCs) [4] onboard the Hayabusa2 spacecraft revealed that the surface of Ryugu is to first order homogeneous and that its reflectance is very low (reflectance factor of ~2% for a geometry with the following properties: incidence=30°, emergence=0°, phase=30°) [5,6]. The NIRS3 spectra also display a weak, narrow absorption feature centered at 2.72 µm, present across the entire observed surface. These observations, combined with those of the ONCs, are consistent with Ryugu being a rubble-pile object generated from impact fragments of an undifferentiated aqueously altered parent body [5,6,7]. Though there are no published meteorite samples whose reflectance spectra perfectly match those of Ryugu at visible and NIR wavelengths, similarities in brightness and shape could be observed in thermally and/or shock-metamorphosed carbonaceous chondrites, meaning that Ryugu could be a thermally altered body.

Here, we report on the albedo and spectro-photometric properties of Ryugu as derived from the NIRS3 IR spectrometer and their implications for our understanding of Ryugu's composition.

**Global-scale NIR albedo map with a single/mean photometric parameters' set:** At first, we derived the photometric parameters of Ryugu using the Hapke model (Fig.1). The latter depends on the geometric conditions (incidence, emergence, and phase angles), as well as a set of photometric parameters: the single scattering albedo (SSA) $\omega$, the phase function of the particles, the macroscopic roughness $\theta$ and two parameters describing the opposition lobe (h and $B_0$). In this study, we used the Henyey-Greenstein phase function with only one lobe since there were no data available at a phase angles greater than ~50°. The 1-lobe phase function can be fully described using a single parameter *g*.

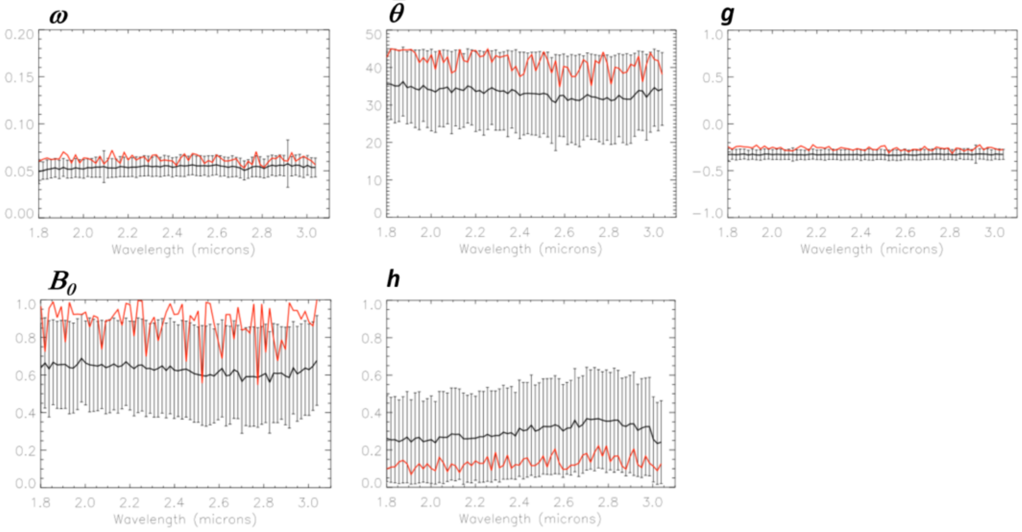

*Fig. 1 Spectral evolution of the posterior PDFs of each photometric parameter over area H (240-249°E, 4-13°N). The mean values and the standard deviations of the distributions are displayed in black while the likelihood maxima are displayed in red.*

To assess the potential spatial heterogeneity in these parameters, about two dozen of areas at the surface of Ryugu were selected. For each of them, the set of reflectances at different illumination and viewing geometries was inverted using a combined Bayesian/MCMC approach, similar to [8,9,10]. This inversion enables us to propagate the NIRS3 reflectance data uncertainties on the photometric parameters and assess to what extent the parameters are constrained or not. Results revealed an overall spatial homogeneity of the photometric parameters, though some small variations could be highlighted. A new photometric correction was derived and applied to NIRS3 data. A reflectance map at a reference geometry (i=30°, e=0°, φ=30°) was generated as can be seen in Fig.2.

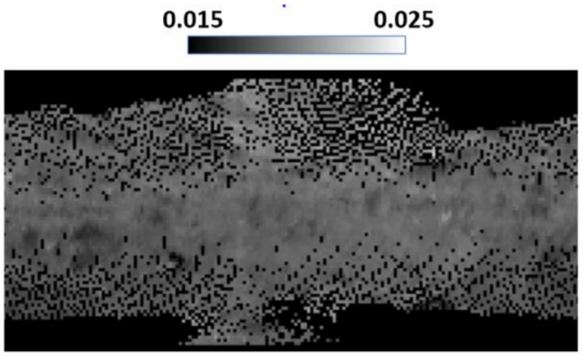

*Fig. 2 Reflectance map of Ryugu (i=30°, e=0°, φ=30°).*

**Global multi-scale single scattering albedo map of Ryugu:** Reflectance spatial heterogeneity was quantitatively investigated, in particular by deriving and mapping the single scattering albedo (SSA) at various spatial scales (10x10° and 5x5° bins). This parameter could be derived with confidence on about one fourth of Ryugu's surface, especially around the equatorial region and the southern middle latitudes (Fig.3).

Although Ryugu is to first order homogenous with a typical SSA of 0.045-0.050, we could demonstrate with a local-scale photometric correction 1) the presence of a large "bright" area between ~190°E and ~290°E longitude around the equator and the southern middle latitudes, and 2) the presence of darker areas with a clear connection to geomorphological features.

**Connection to the 2.72 µm feature:** These darker regions tend to have a slightly deeper 2.72 µm feature, at least compared to the surrounding areas, similar to what was observed by [11]. This could possibly be explained by an enrichment of the top-surface in dark fines coupled to hydrated phases. Some spatial variability observed in the coupling between the SSA at 1.89 µm and the 2.72 µm feature also suggests that Ryugu exhibits some (slight) heterogeneity in its building blocks [12].

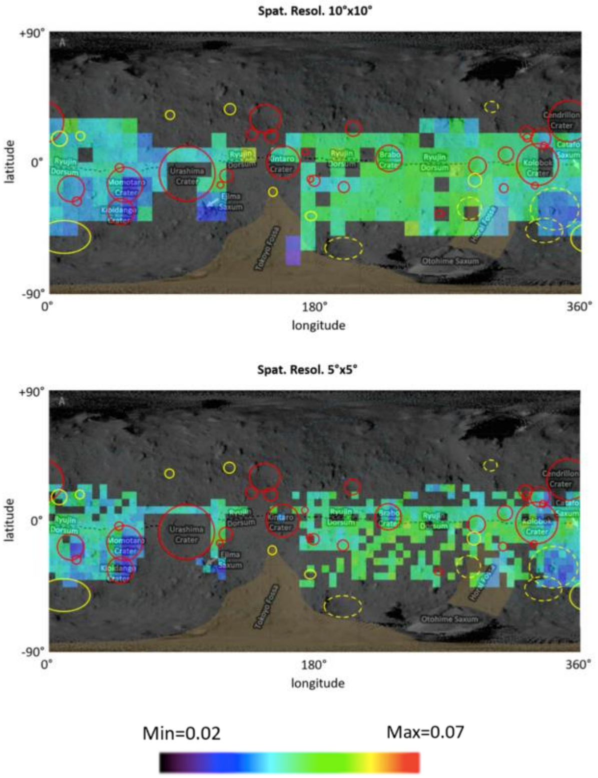

*Fig. 3 Single scattering albedo maps derived at 1.89 µm for different bin sizes. The mean values of the solutions' distribution are displayed here. The SSA maps are fused with the geomorphological map adapted from [6] to highlight the connections between the two. In particular, red circles correspond to impact craters, yellow circles to candidate craters (higher confidence) and yellow dashed circles to candidate craters (lower confidence).*

**References:** [1] Binzel R. P. et al. (2002), Physical Properties of Near-Earth Objects. pp. 255-271, [2] Vilas F. (2008) *The Astronomical Journal* 135 (4), 1101-1105, [3] Iwata T. et al. (2017) *Space Science Reviews* 208 (1-4), 317-337, [4] Kameda S. et al. (2017) *Space Science Reviews* 208 (1-4), 17-31, [5] Kitazato K. et al. (2019) *Science* 364 (6437), 272-275, [6] Sugita S. et al. (2019) *Science* 364 (6437), 252-252, [7] Watanabe S. et al. (2019) *Science* 364 (6437), 268-272, [8] Fernando J. et al. (2013) *JGR (Planets)* 118, 534-559, [9] Fernando J. et al. (2015) *Icarus* 253, 271-295, [10] Schmidt F. and Fernando J. (2015) *Icarus* 260, 73-93, [11] Riu L. et al. (2021) *Icarus* 357 114253, [12] Pilorget C. et al. (2021) *Icarus* 355 114126.