

GLOBAL VIEW OF THE MINERALOGY AND SURFACE PROPERTIES OF THE ASTEROID RYUGU USING NIRS3 NEAR-INFRARED SPECTROMETER ON BOARD HAYABUSA2.

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Introduction: The Japanese Aerospace Agency's (JAXA's) Hayabusa2 spacecraft [1] has reached its target the asteroid (162173) Ryugu on June 27th and the mothership has been hovering since then, performing several mapping campaigns with various onboard remote sensing techniques. Such return sample missions, that carry significant payloads for both *in situ* (with MINERVA and MASCOT [2] rovers) and orbital characterization, are of key interest to help understanding early stages of Solar System and they provide unprecedented insights on the nature and origin of small bodies. An essential property to answer these problems is the mineralogy. By itself and by combining it to geological (such as the topography and morphology) and physical (such as the thermal inertia) properties of the surface, the mineral composition provides unique information on the past environment and possible processes that shape the surface of planetary bodies.

Remote sensing near-infrared (NIR) spectroscopy and hyperspectral imagery has proven very efficient to decipher the mineralogy of planetary surfaces. This technique enables the detection of both primary and altered phases and can highlight surface weathering processes. The NIRS3 instrument onboard Hayabusa2 is a point spectrometer that operates in the NIR, covering wavelengths from 1.8 to 3.2 μm with a field of view of 0.1° [3] enabling, thanks to the spacecraft slewing, quasi-global coverage of the asteroid.

Dataset & processing: We use NIRS3 complete dataset acquired between the 21st of June and today [4]. This dataset is constituted of more than 70000 spectra acquired at different locations and spatial resolutions, with some overlap between observations especially at the equatorial ridge.

Prior to perform investigations on the surface mineralogy and properties of Ryugu with this dataset, the NIRS3 raw data was converted onto reflectance data and the thermal emission component of the asteroid was subtracted for each spectrum. The thermal component is fitted with the Planck function assuming a constant emissivity of 0.986 based on on-ground observations [5] and then removed from the reflectance spectra. Additionally, the reflectance is corrected at each location from viewing geometry using Hapke model [6] to rescale all spectra to the same standard viewing geometry (incidence 30° , emergence 0° , phase 30°). Because some calibration residual were found in the processed spectra, for now prior to perform in-depth characterization of those potential biases, the spectral variations in the spectral range below 1.9 μm and above 3.0 μm (shown in gray on Figure 3) are taken with caution in the interpretation of the data.

Results:

1 - Albedo: Asteroid Ryugu is one of the darkest object ever observed in space.

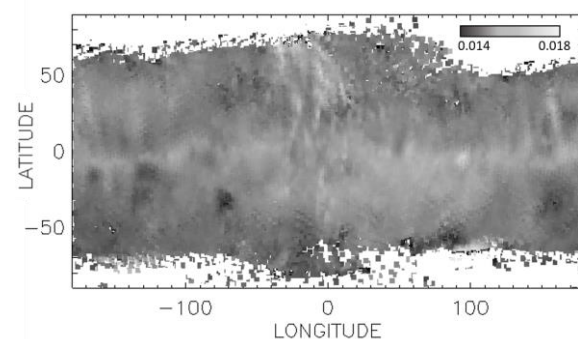


Figure 1 – Average albedo map of Ryugu derived from NIRS3 during the first global mapping campaign (June-August). The resolution used for the mapping is $2\text{px}/^\circ$.

Its albedo spatially varies from 0.014 to 0.018 on the overall surface, excluding the poles that were not observed with NIRS3 to this date (Figure 1). These low albedo values are consistent with what is observed in the visible with the ONC camera [7] and are close to the value expected for thermally and/or shocked carbonaceous meteorite chondrites.

2 - Temperature: For each of the observations the temperature is retrieved during the thermal component removal process (Figure 2). Several techniques were tested and compared, ultimately leading to very similar results ($< \sim 1\text{K}$ difference). The retrieved temperatures were also compared to the thermal infrared spectrometer TIR that observed similar variations on the overall surface. Except for special requested observations for the landing site selection of MASCOT, all observations were carried out at local noon. From the global mapping in July to the latest observations (October) the average surface temperature appears to have decreased by ~ 30 degrees which is consistent with Ryugu getting farther away from the sun.

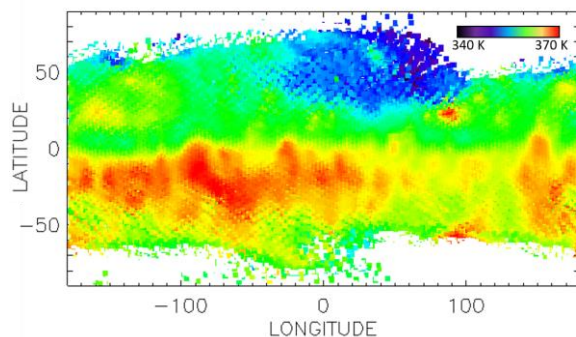


Figure 2 – Average temperature map of Ryugu derived from NIRS3 during the first global mapping campaign (June-August 2018). The resolution used for the mapping is 2px° .

3 – Spectral characteristics: At global scale from orbit, Ryugu's spectra appear to be quite flat, with a slight red slope (Figure 3). The spectra also appears to be almost featureless which may indicate a lack of strong alteration on the overall surface. However, all spectra display a shallow absorption feature centered on $2.72\ \mu\text{m}$ (Figure 3). The position of the band is homogeneous on the surface and the band depth only varies within a few percent.

This feature is characteristic of OH-bond and thus suggests the presence of phyllosilicates and/or organics. With the lack of other organics features in the NIRS3 spectra, the phyllosilicates appear to be more likely responsible for this absorption. Several hypothesis on the presence of this shallow absorption hydrated signature in addition with the very low albedo surface

of Ryugu are under investigations. This may be due to shock and post shock heating caused by the possible formation of Ryugu by a collisional event that could lead to dehydration and darkening of the surface. Also, it is possible that Ryugu was never hydrated in the first place. Other possible scenarios are under discussion, such as undergoing high radiative heating from the Sun and/or high rate of surface weathering that may have caused the top surface to alter.

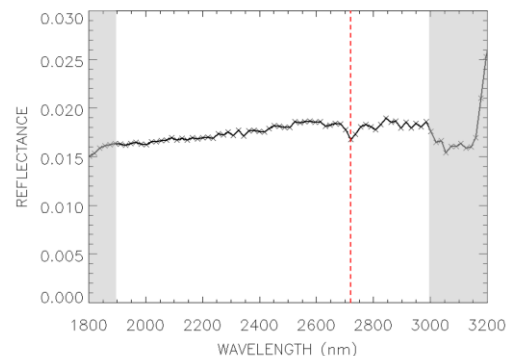


Figure 3 - Representative reflectance spectra of Ryugu[4].

Close comparison with heated and shock C-type meteorites are ongoing to try to decipher between those different hypothesis. In addition, the Hayabusa2 spacecraft will perform an impact with a small carry-on impactor (SCI) onboard the mothership in 2019. This may uncover fresher material, that after characterization with NIRS3 and the other remote sensing instrument and combining with lab experiments, shall provide additional answers.

Conclusion: The NIRS3 instrument has already provided a lot of information about the surface of asteroid (162173) Ryugu with the first six months of observations. The investigations are ongoing and more mapping campaign should be performed after the conjunction phase in December 2018. With the MINERVA's and MASCOT landers' *in situ* characterization and future samples return, we envision a thorough multi-scale characterization of the surface both in terms of composition and morphology. Those investigations will constitute an unprecedented milestone in planetary bodies exploration.

References: [1] Tsuda, Y. et al. (2013), *AA*, 91. [2] Ho et al. (2016), *SSR*, 208. [3] Iwata, T., et al. (2017), *SSR*, 208. [4] Kitazato et al. (2019), *Science*, under review. [5] Ishiguro, M. et al. (2014), *AJ*, 792. [6] Hapke, B. (2012), *Camb. Univ. Press, ed. 2*. [7] Sugita et al. (2019), *Science*, under review.