HYDRATION STATE OF ASTEROID (162173) RYUGU'S SURFACE USING HAYABUSA2/NIRS3 SPECTRAL DATA. A. Praet[1], M. A. Barucci[1], P. H. Hasselmann[1], K. Kitazato[2], T. Iwata[3], M. Matsuoka[3], D. Domingue[4], and B. E. Clark[5].
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Introduction: The JAXA asteroid sample return mission Hayabusa2 was launched in December 2014 and conducted scientific survey of asteroid (162173) Ryugu from its arrival at the asteroid (June 2018) to departure (November 2019) [1]. The mission succeed to artificially impact the asteroid's surface as well as to collect surface regolith twice (on February 22nd 2019 and on July 11th 2019) [2]. The analyzed data revealed that Ryugu is a dark object with an average geometric albedo of 0.045±0.02 [3], a mean equatorial diameter of 1.004±0.004 km, and a rotational period of 7.63262±0.00002 [4]. Ryugu showed a top-shape form with a polar to equatorial axis ratio of 0.872±0.007 and a very low density which could imply a rubble-pile nature [4]. The Near-Infrared Spectrometer (NIRS3) collected reflectance data of the asteroid's surface from 1.8 to 3.2 microns, that show a narrow absorption band centered at 2.72 microns diagnostic of OH-bearing minerals [5]. The surface shows a spectral homogeneity with small variation in particular in the spectral slope and albedo [3, 6, 7]. Kitazato et al. [5] showed that Ryugu's closest meteorite analogs are the thermally-metamorphosed and shocked CM and CI chondrites, which is consistent with visible spectral results [3]. In this study, we go further and estimate the hydrogen content of H_2O and OH^- groups in hydrated phyllosilicates (H content) using two different spectral parameters and comparing NIRS3 spectral data of Ryugu's surface with laboratory-measured spectral data of a wide range of carbonaceous chondrites found in the literature [8, 9, 10, 11, 12, 13].

Analyzed Data:

Ryugu spectral data. In this study, we chose to focus on the spectral dataset acquired by NIRS3 on July, 19th 2018 with phase angles ranging from 17.5° to 17.8°, that present a high coverage of Ryugu's surface (from – 70° to +70 ° latitudes) with a spatial resolution of 20m/pixel. This dataset was calibrated and photometrically corrected using Hapke model [5] to the standard viewing geometry of (30°, 0°, 30°) for the incidence, emergence and phase angles respectively.

Meteorite spectral data. The meteorite reflectance data are from [8, 9, 10, 11, 12]. We selected 43 reflectance spectra of 30 meteorites in total including 15 CM, 8 heated CM, 2 CI [13], 2 CV, 2 CR, as well as Tagish Lake that all exhibit an absorption band in the 3-micron region diagnostic of H_2O and/or OH-bearing hydrated phyllosilicates.

Meteorite H content data. The H content of the selected meteorites are from laboratory-studied composition in [14, 15, 16]. We take into account all H content values for the meteorite for which H content data of different lithologies are available.

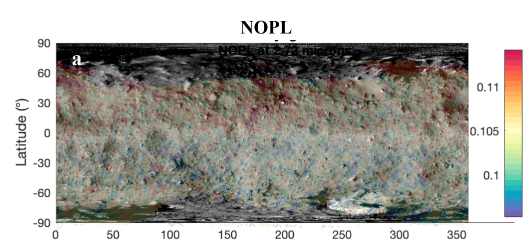
Methods: We applied two different methods to estimate Ryugu's surface H content.

Normalized Optical Path Length (NOPL). The NOPL parameter was calculated as described in [11, 16, 17] on each meteorite spectrum, and in each individual Ryugu reflectance spectrum. A linear continuum was fitted from 2.6 to 2.9 µm. The wavelength, at which the NOPL parameter is calculated, is the mean band minimum position for the data set at 2.72 µm [5].

Effective Single-Scattering Albedo (ESPAT). The ESPAT parameter was calculated following the method of [11, 16, 17] using the Hapke model. Absolute reflectance spectra of meteorites and Ryugu's I/F spectra surface were first converted into single-scattering albedo spectra [11, 16, 17, 18]. A linear continuum was then fitted from 2.6 to 2.9 µm and the ESPAT parameter is calculated at 2.72 µm as well. We compare NOPL and ESPAT results with the hydrogen content of H_2O-OH^- groups in hydrated phyllosilicates only, measured for the selected meteorites [13, 14].

Results: We computed the two spectral parameter, NOPL and ESPAT, on the reflectance spectra and on the single-scattering albedo spectra respectively, of Ryugu's surface to investigate their spatial variations on Ryugu's surface. Both spectral parameter (NOPL in **Fig. 1a** and ESPAT in **Fig.1b**) are mapped and overlaid on Ryugu global basemap [3].

The NOPL and ESPAT parameters are not correlated with the geomorphology of Ryugu's surface, as shown on both global maps (**Fig. 1**).



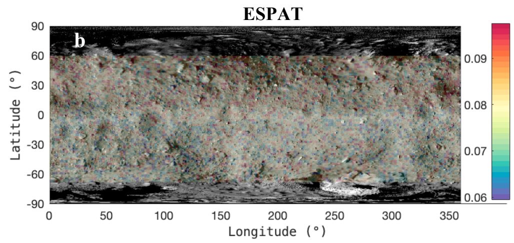


Figure 1*: Global map of the NOPL (a) and ESPAT (b) parameters computed on NIRS3 spectra of the surface of Ryugu, acquired on July 19th, 2018. Both spectral parameters are computed at 2.72 µm with a linear continuum from 2.6 to 2.9 µm, and finally overlaid on Ryugu's global basemap.*

The selected meteorite NOPL and ESPAT values versus their H content are shown in **Fig. 2a** and **2b**, respectively. In both cases, we fund an exponential correlation.

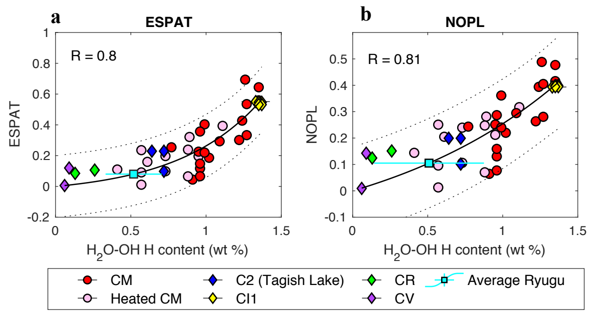


Figure 2: *Exponential correlation fund between the selected meteorite H content and their ESPAT parameter (left), their NOPL parameter (right), as well as average Ryugu H content data point deduced from the correlations. The thick black line is the exponential regression of the meteorite data ; the two dashed black lines define the prediction bounds, which indicate the area in which a new data point would fall with 95% probability. The vertical error bar on the values for Ryugu is 1-sigma error value of each spectral parameter. The H content (horizontal) error bars are computed for each method by propagating the error in the determination of the exponential regression coefficients.*

Using the mean value ± 1σ of NOPL and ESPAT of Ryugu as well as the respective exponential correlations, we estimate the mean H content of Ryugu's surface to be 0.51 ± 0.37 wt.% from the NOPL method, and 0.52 ± 0.19 wt.% from the ESPAT method. The two estimated Ryugu mean H content values are consistent and similar to heated CM H content (**Fig. 2**). From the two methods, the average H content value of Ryugu's surface is 0.51 ± 0.17 wt.%.

Conclusions: Both methods are based on estimating global H content (in H_2O and OH^- groups of hydrated phyllosilicates) by analogy with meteorite data. The average value of H content of Ryugu's average surface we obtained is 0.51 ± 0.17 wt.% combining the NOPL and the ESPAT methods. From our results (**Fig. 2**), Ryugu's average surface is most similar to heated CMs (0.41–1.11 wt.%) [12], which is consistent with Kitazato et al. [5] that showed the best Ryugu meteorite analog to be the thermally-metamorphosed and shocked CM and CI chondrites. Both estimated H content ranges of Ryugu's surface are more consistent with those of CM chondrites (0.46–1.36 wt%), Tagish Lake (0.50–0.69 wt.%), CR chondrites (0.30–1.20 wt.%), and CO chondrites (0.49–0.52 wt.%) [13]. The obtained results will be compared with the laboratory ground-based analysis of Ryugu's samples returned on December 6th, 2020 to the Earth. If the ground-based analysis confirm our results, we will be able to apply this methods to the population of other primitive asteroids exhibiting a 3-micron region absorption band.

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