

Visible to Near-Infrared Spectrophotometry of C0002 Powder Samples of Asteroid 162173 Ryugu in Comparison with ONC-T and NIRS3 Instruments Onboard Hayabusa2 Spacecraft

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Samples and Spectrophotometric Measurements

Powder samples of the largest sampled stone C0002 of asteroid 162173 Ryugu returned by Hayabusa2 mission were loaned for visible and near-infrared (VNIR) spectrophotometric studies. The powder samples were produced by physical-strength measurements and were partially contaminated with a glue (glycol phthalate). Part of the powder was washed with acetone, which turned it into a fine powder (<125 μm estimate). Large glue fragments were handpicked from the remaining coarse powder (125-500 μm estimate) and a bulk powder sample was produced by combining the two powder samples.

Bidirectional VNIR reflectance spectra (0.3-2.6 μm) of the samples were measured at NASA Reflectance Experiment Laboratory (RELAB) using its bidirectional reflectance spectrometer at the standard viewing geometry of 30° incidence and 0° emergence angles, and their photometric properties were measured at a limited number of viewing geometries. The photometric property of a Labsphere Spectralon standard was measured relative to the standard viewing geometry at 550 nm in wavelength.

Biconical Fourier-transform infrared (FTIR) reflectance spectra (1-100 μm) of the samples were measured in a dry-air purged environment. The VNIR and FTIR spectra were combined at 2.5 μm in wavelength by scaling the FTIR reflectance to the VNIR reflectance.

Spectrophotometric Analyses

Phase-angle dependency of the powder samples at 550 nm in wavelength is plotted in Fig. 1, and VNIR-FTIR spectra up to 4 μm are plotted in Fig. 2 along with sample photos under a microscope. The phase curve in Fig. 1 shows much brighter albedo and lower inclination than those obtained by ONC-T measurements in proximity of asteroid Ryugu [1]. It may be due to the difference between the flatter surface of the powder sample compared with the rough asteroid surface that includes shadows. Further photometric modeling analysis is warranted.

The OH and H₂O absorption bands near 3 μm in spectra shown in Fig. 2 were analyzed in the same manner as [2]. Natural log reflectance spectra of the powder samples were fit with a linear-in-wavelength continuum background and Gaussians (in wavenumber) over the wavelength range of ~2.6-3.6 μm (variable depending on spectral shape). One of the results (fine powder) is shown in Fig. 3. Because the first two Gaussian bands (labeled as 1 and 2 in Fig. 3) are believed to be characteristic of carbonaceous chondrite classes [2], their

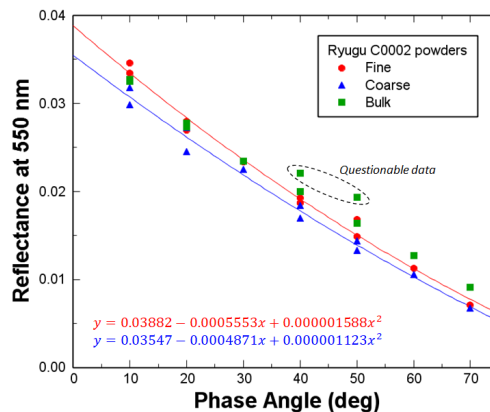


Fig. 1. Phase-angle dependency of reflectances of C0002 powder samples at 550 nm in wavelength.

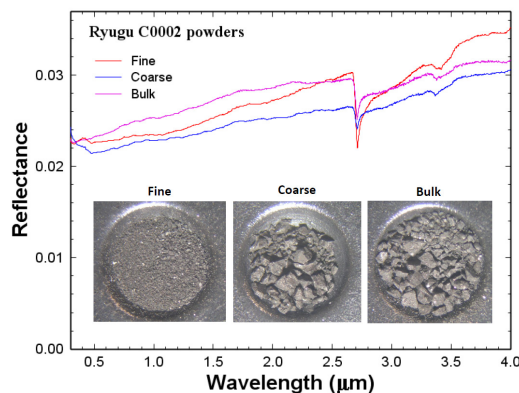


Fig. 2. VNIR-FTIR spectra (0.3-4 μm) and photos of C0002 powder samples. Cup diameter is 4 mm.

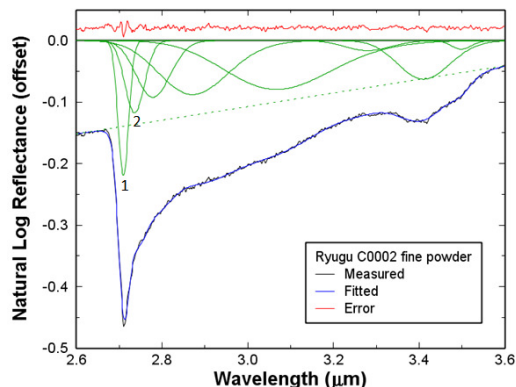


Fig. 3. Gaussian fitting of C0002 fine powder spectrum.

Band 1 centers and Band 1 / Band 2 strength ratios are plotted in Fig. 4. Ryugu C0002 powders all plot very close to unheated CI1 chondrites and Ivuna heated up to 400°C. This result is consistent with previous studies of Ryugu being mostly unheated CI1 chondrite [e.g., 3], and low-degree heating may not be detected by this method.

Comparison with ONC-T and NIRS3 Observations

Shown in Fig. 5 is a plot of linear combinations of the VNIR-FTIR spectra of the C0002 fine and coarse powder samples to match average spectra of representative (but different) areas of Ryugu acquired by ONC-T and NIRS3. Most of the ONC-T band reflectance values, overall spectral shape, and 2.7 μm absorption band strength could be matched.

However, when the 2.7 μm band region is closely examined, there are significant mismatches between the NIRS3 and C0002 spectra. The NIRS3 spectrum shows absorption bands at 2.65 and 2.81 μm which are absent in C0002 spectrum. If this is not due to NIRS3 data calibration errors, there may be some unstable phases lost during the sample recovery.

Another mismatch is the 2.7 μm band center position. Fig. 6 shows the NIRS3 spectrum and the modeled C0002 spectrum with its wavelength resolution matched with that of NIRS3 spectrum (18 nm). While the NIRS3 spectrum (open black squares) shows the band center at around 2.72 μm asymmetrically expanded toward the longer wavelength, the modeled C0002 powder spectrum (solid purple circles) shows the band center clearly at a shorter wavelength near 2.71 μm. When the C0002 powder spectra are artificially shifted toward the longer wavelength by 6 nm before resampling for the NIRS3 resolution, the resulting modeled spectrum (open purple circles) matches with the NIRS3 spectrum much better. A difference in band position is consistent with spectra of ejecta from an artificial crater showing shorter 2.7 μm band positions [4].

Summary and Discussion

If the C0002 powder samples represent the average surface material of asteroid Ryugu, this study indicates that the global space weathering may have occurred mainly by solar wind that caused the 2.7 μm absorption band center to be shifted toward a longer wavelength [e.g., 5]. If such space weathering occurred, the 2.7 μm band strength and the visible spectra measured with ONC-T might have been altered as well. This would influence the physical interpretation of the model fits shown in Fig. 5.

References

- [1] Tatsumi E. et al. 2020. A&A 639:A83. [2] Hiroi T. et al. 2021. Polar Science 29:100723. [3] Yokoyama T. et al. 2022. Science 10.1126:7850. [4] Kitazato K. et al. 2021. Nature Astronomy 5:246. [5] Lantz C. et al. 2015. A&A 577:A41.

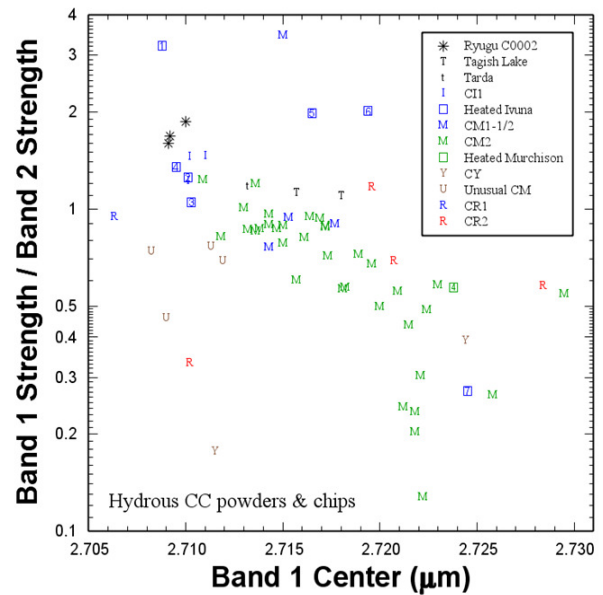


Fig. 4. Band 1 center vs. Band 1 / Band 2 strength ratio of C0002 powder samples plotted with hydrous carbonaceous chondrites (modified from [2]).

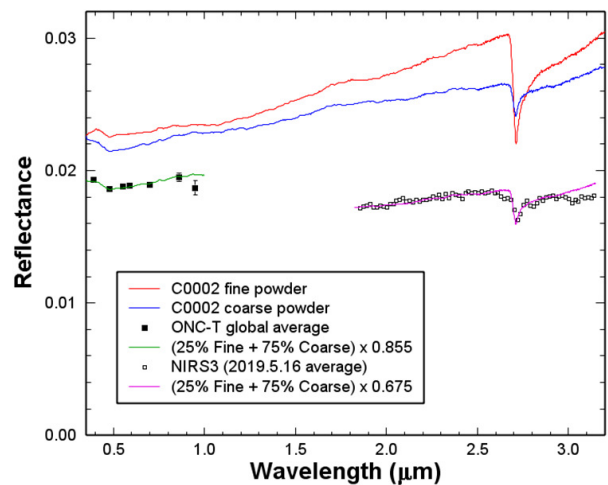


Fig. 5. Comparison of C0002 powder spectra with ONC-T and NIRS3 data.

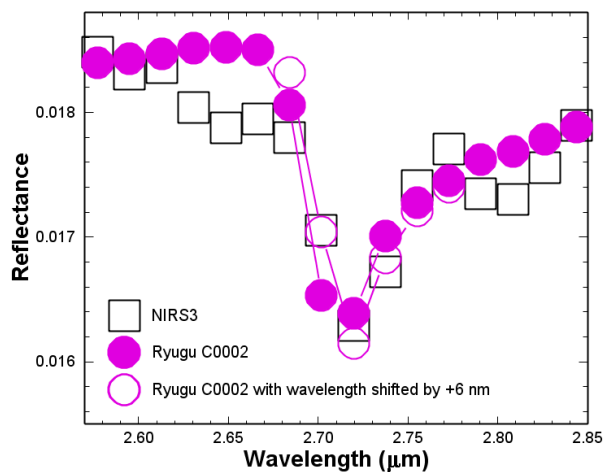


Fig. 6. Matching of the 2.7 μm absorption band feature between the modeled C0002 powder spectra and NIRS3 spectrum in Fig. 5.