NEAR-INFRARED SPECTRAL VARIABILITY ON ASTEROID RYUGU. K. Kitazato[1], R.E. Milliken[2], T. Iwata[3,4], M. Abe[3,4], M. Ohtake[3,4], S. Matsuura[5], T. Arai[6], Y. Nakauchi[3], T. Nakamura[7], M. Mastuoka[3], H. Senshu[8], N. Hirata[1], T. Hiroi[2], C. Pilorget[9], R. Brunetto[9], F. Poulet[9], L. Riu[3], J.-P. Bibring[9], D. Takir[10], D.L. Domingue[11], F. Vilas[11], M.A. Barucci[12], D. Perna[13,12], E. Palomba[14], A. Galiano[14], S. Watanabe[15,3], and the Hayabusa2 team, [1]The University of Aizu, Fukushima, Japan (kitazato@u-aizu.ac.jp), [2]Brown University, Providence, RI, USA, [3]Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), Sagamihara, Japan, [4]The Graduate University for Advanced Studies (SOKENDAI), Kanagawa, Japan, [5]Kwansei Gakuin University, Hyogo, Japan, [6]Ashikaga University, Tochigi, Japan, [7]Tohoku University, Sendai, Japan, [8]Chiba Institute of Technology, Chiba, Japan, [9]Institut d'Astrophysique Spatial (IAS), Université Paris-Sud, Orsay, France, [10]Astromaterials Research and Exploration Science, NASA Johnson Space Center, Houston, TX, USA, [11]Planetary Science Institute, Tucson, AZ, USA, [12]Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique (LESIA), Observatoire de Paris, Meudon, France, [13]Osservatorio Astronomico di Roma, Instituto Nazionale di Astrofisica (INAF), Mote Porzio Catone, Italy, [14]Istituto di Astrofisica e Planetologia Spaziali, INAF, Roma, Italy, [15]Nagoya University, Nagoya, Japan.

Introduction: In June 2018, the JAXA's Hayabusa2 spacecraft arrived at the target C-type asteroid 162173 Ryugu, and has since then continued its observations with the onboard remote sensing instruments. The Hayabusa2 NIRS3 instrument acquired near-infrared spectra of Ryugu in the wavelength range from 1.8 to 3.2 μm to provide direct measurements of the surface composition [1,2]. On June 21, 2018, NIRS3 made the first observations of Ryugu at a distance of 70 km and proceeded to acquire more than 400,000 spectra of Ryugu's surface through July 27, 2019. In order to acquire near-global coverage, NIRS3 operated in a scanning mode, in which slews of the spacecraft were combined with the rotational motion of the asteroid. During the descent operations, NIRS3 had acquired spectra down to 50 m altitude, corresponding to a spatial resolution of 9 cm. In addition, in April 2019, Hayabusa2 conducted an artificial cratering experiment using the small carry-on impactor. On May 30 and June 13, 2019, NIRS3 successfully observed the subsurface materials ejected from that experiment at a spatial resolution of 2 m. Together, these data provide an unprecedented view of a C-type asteroid at near-infrared wavelengths that can be used to constrain surface composition of the asteroid.

Spectral features: The thermally and photometrically corrected NIRS3 spectra of Ryugu exhibit several common features. The first is a very low reflectance value across nearly the entire body. The globally-averaged reflectance value at 2.0 μm is 0.017 ± 0.002, which is consistent with values at visible wavelengths observed by the Hayabusa2 ONC-T camera [3]. Reflectance values vary within 15% across the entire observed surface, excluding regions in shadow. Brighter surfaces are primarily observed along the equatorial ridge, crater rims and for individual boulders, again similar to visible wavelength images. NIRS3 spectra of Ryugu also commonly exhibit a weak positive spectral slope (0.2 to 0.6 %/μm) between 2.0 and 2.5 μm. Finally, all spectra of Ryugu exhibit a weak, narrow absorption feature centered at 2.72 μm, with intensities ranging from 7 to 10%. The intensity of the 2.72 μm feature exhibits a positive correlation with estimated surface temperatures, which indicates that uncertainties in the radiometric calibration and/or thermal emission component could be responsible for the observed variations in the band depth of this feature. When normalized by the observed temperature trend, no significant variations correlated with topographic features are observed in the intensity of the 2.72 μm feature.

The detection of an absorption feature at 2.72 μm indicates the presence of OH attached to a cation, and the position of the reflectance minimum indicates is most likely Mg. The band position is similar to Mg-OH features observed in Mg-rich phyllosilicates, such as serpentine and saponite, which are known to be present in aqueously altered CI and CM chondrites [4,5]. Ryugu spectra indicate that the OH band position does not vary across the surface of Ryugu within the ~18 nm spectral sampling of the instrument, suggesting a relatively homogeneous phyllosilicate cation composition.

Comparison with meteorites: There are currently no meteorite samples whose reflectance spectra perfectly match that of Ryugu at visible to near-infrared wavelengths. However, spectra of thermally-metamorphosed CI chondrites and shocked CM chondrites are most similar to Ryugu at near-infrared wavelengths in terms of brightness and shape. Laboratory spectra of an Ivuna (CI1) sample heated to 500˚C and a MET 01072 (shocked CM2) sample are relatively dark and flat yet retain a weak 2.72 μm feature. These meteorite data suggest that thermal alteration processes such as partial dehydration and decomposition of hydrated minerals induced by static or shock heating can act to darken hydrated carbonaceous chondrites. Such processes are consistent with current interpretations of Ryugu's formation history. The low bulk density (~1.2 g/cm3) of Ryugu suggests that it is a rubble-pile asteroid formed by a collisional event with the parent body [6], thus it is likely to have experienced shock and post-shock heating. However, it is also possible that the weak OH absorption is because the degree of aqueous alteration on Ryugu was never extensive to begin with, perhaps due to low water-to-rock ratios or slow/incomplete hydration reactions on the parent body.

Alternatively, it has been suggested that Ryugu's orbit might have had shorter perihelion distances in the past, a characteristic that would have increased radiative heating from the Sun [7] and altered the mineralogy of the uppermost surface. Similarly, the surface of Ryugu has experienced solar-wind irradiation and micrometeorite impacts (space weathering), which can alter surface composition and spectral properties. These processes represent near-surface phenomena that continue to operate at Ryugu today, whereas the other interpretations for the apparent low hydration state represent inherent chemical and mineralogical attributes of the asteroid as a result of its early geological history.

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