INFRARED SPECTRA OF ASTEROID RYUGU: COMPARISON TO LABORATORY-MEASURED CARBONACEOUS CHONDRITES. M. Matsuoka[1], T. Nakamura[2], T. Hiroi[3], K. Kitazato[4], T. Iwata[1], M. Abe[1], K. Amano[2], S. Kobayashi[2], T. Osawa[5], M. Ohtake[1], S. Matsuura[6], T. Arai[7], H. Senshu[8], M. Komatsu[9], A. Nakato[1], Y. Nakauchi[1], C. Pilorget[10], R. Brunetto[10], F. Poulet[10], L. Riu[1], D. Domingue[11], F. Vilas[11], D. Takir[12], E. Palomba[13], A. Galiano[13], R. Milliken[3], D. Perna[14,15], A. Barucci[14], J-P Bibring[10], N. Imae[16,17], A. Yamaguchi[16,17], H. Kojima[16,17], S. Nakazawa[1], S. Tanaka[1], M. Yoshikawa[1], S. Watanabe[18], Y. Tsuda[1], [1]Institute of Space and Astronautical Sciences, Japan Aerospace Exploration Agency, Kanagawa, 252-5210, Japan (matsuoka.moe@jaxa.jp), [2]Tohoku University, Miyagi, Japan, [3]Brown University Providence, USA, [4]University of Aizu, Fukushima, Japan, [5]Japan Atomic Energy Agency, Ibaraki, Japan, [6]Kwansei Gakuin University, Hyogo, Japan, [7]Ashikaga University, Tochigi, Japan, [8]Chiba Institute of Technology, Chiba, Japan, [9]The Graduate University for Advanced Studies, Kanagawa, Japan, [10]Institut d'Astrophysique Spatiale, Orsay, France, [11]Planetary Science Institute, Tucson, AZ, USA, [12]Jacobs/NASA Johnson Space Center, Houston, TX, USA, [13]Istituto di Astrofisica e Planetologia Spaziali, Rome, Italy, [14]LESIA-Observatoire de Paris, Meudon, France, [15]INAF - Osservatorio Astronomico di Roma, Monte Porzio Catone, Italy, [16]National Institute of Polar Research, Tokyo, Japan, [17]Department of Polar Science, School of Multidisciplinary Science, SOKENDAI (The Graduate University for Advanced Studies), Tokyo, Japan, [18]Nagoya University, Nagoya, Japan.

Introduction: The Near-infrared Spectrometer (NIRS3) onboard the Hayabusa2 spacecraft obtained NIR reflectance spectra of C-type asteroid 162173 Ryugu at an altitude of <20 km from the asteroid's surface. After asteroid arrival, Ryugu was observed globally by NIRS3 on 11 and 19 July 2018 with spatial resolution of ~40 and ~20 m, respectively. During recent observations at a longer solar distance, we successfully obtained Ryugu's NIR spectra with less thermal effects. A 2.7-μm OH stretching absorption is consistently present in NIRS3 data. In this study we compared Ryugu spectra with those of carbonaceous chondrite meteorites, primarily from the NASA RELAB database, to further understand the origin of Ryugu's spectral properties and potential links to composition and geologic processes.

Instrument: NIRS3 is composed of two component units: the spectrometric unit (NIRS3-S) and the analog electric unit (NIRS3-AE) connected with a harness cable (NIRS3-HNS). A 128-channel indium arsenide (InAs) photodiode sensor is installed in the spectrometric unit and cooled to 193 K (−80 °C) using a passive radiator. The detectable wavelength range of NIRS3 is 1.8–3.2 μm and spectral sampling resolution is 18 nm.

Results and discussion: Nearly all NIR reflectance spectra of Ryugu's surface exhibit very low reflectance values (less than 2% at 2.0 μm), a slightly red slope, and a narrow absorption feature centered at 2.72 μm with a band depth value of ~10%. A comparison between spectra of C chondrites and those of Ryugu shows that no chondritic reflectance spectrum is an ideal match to Ryugu at all wavelengths. However, spectra of several types of C chondrites exhibit important similarities: (1) moderately heated and dehydrated C chondrites [1–3], and (2) C chondrites having experienced impact and compression, such as the shocked carbonaceous chondrite Meteorite Hills (MET) 00639 CM2 [4].

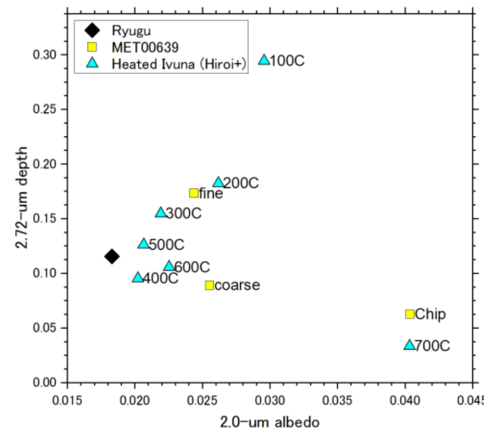

Fig. 1. Reflectance values at 2.0 μm compared with absorption band strength at 2.72 μm for the average Ryugu spectrum (at 5–7 km altitude) and various meteorite spectra from the NASA RELAB database.

The Ivuna CI meteorite has the closest albedo value to that of Ryugu (Fig. 1). Previously acquired spectra of an Ivuna sample heated to >500 °C [1] exhibit an increase in albedo that no longer matches the values observed for Ryugu. However, band depth values of the OH feature for moderately heated Ivuna samples are similar to that of Ryugu, Spectra of the shocked chondrite MET 00639, especially powdered versions, also exhibit Ryugu-like spectral properties including low-reflectance (~2.5%) and a weak, narrow OH absorption centered at 2.72 μm.

Several processes can contribute to the low albedo of Ryugu's surface, including (a) carbon-rich components [e.g., 5,6] (e.g., the organic-rich C chondrite Tagish Lake is spectrally dark), (b) physical properties such as grain size and porosity [e.g., 7] (larger grain size and/or increased porosity make spectra darker and bluer,

(c) space weathering effects: laboratory experiments simulating space weathering processes on C-type asteroids, such as solar-wind implantation [8,9], UV irradiation [10], and micrometeoroid bombardments [11,12], can reproduce the darker yet hydrous spectrum of Ryugu. Spectra of chondrites that have been moderately heated on their parent bodies are also relatively dark and similar to Ryugu's albedo, but their 3-μm band is broader and deeper than that of Ryugu [13].

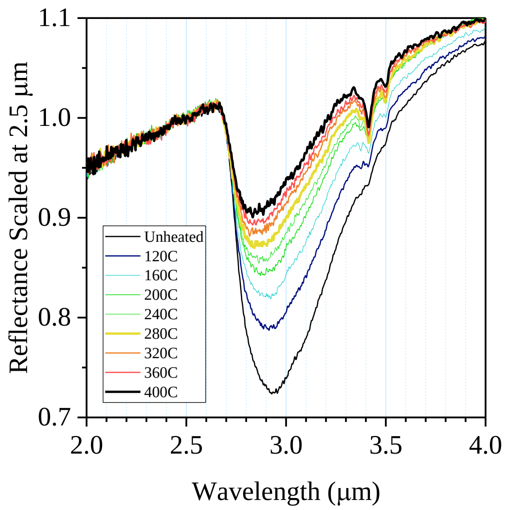

Fig. 2. Y-86720 spectra measured at different temperatures up to 400 °C under vacuum condition.

For lab spectra of C chondrites, the influences of terrestrial water and hydrous alteration phases formed on Earth must be considered when interpreting the significance of features in the ~3 μm wavelength region. Figure 2 shows the spectral change of meteorite Yamato (Y) 86720 during in-situ heating at 120–400 °C. Y-86720 is classified as heating stage (HS) IV, which was strongly heated (estimated over 750 °C) and completely dehydrated on its parent body [14,15]. The strong 3-μm band observed in this meteorite is presumably due to terrestrial water, and this feature becomes weaker but is still present up to 400 °C. Gaussian fitting of the spectra reveal that Y-86720 may contain H_2O absorption bands in additional to a structural O-H band at 2.75 μm (Fig. 3). Gaussian fits to the Y-86720 spectrum have similar wavelength positions to those of moderately heated Y 982086 and unheated Murchison. It indicates that rehydrated water, which possibly has relatively strong bonds with tetrahedral-octahedral (T-O) layer of sheet silicates, would be bonded strongly and difficult to remove completely. Future work will focus on acquiring meteorite spectra with minimal terrestrial water, either experimentally or via numerical modeling. In addition, we plan to compare other NIR reflectance spectra of asteroids,

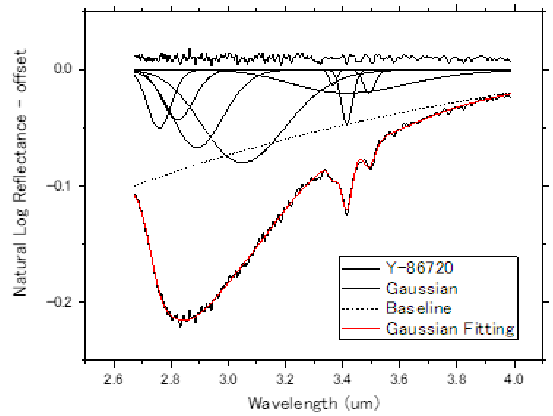

Fig. 3. Gaussian fitting of the 3-μm band of Y-86720 spectrum measured during 400 °C heating.

such as those acquired by AKARI [16], to better interpret remotely sensed data of Ryugu and Bennu (NASA's OSIRIS-REx mission target).

Summary: Near-IR spectra of Ryugu exhibit a weak 2.72-μm absorption band that is present across the surface of the asteroid. The albedo values of Ryugu's surface are nearly always darker than values typical for C chondrite meteorites. The meteorites whose spectral features are most similar to Ryugu are shocked or heated carbonaceous chondrites. Future NIRS3 observations before/after the Small Carry-on Impactor (SCI) crater experiment and lab analyses of returned samples will reveal additional compositional properties of Ryugu.

References: [1] Hiroi T. et al. (1996) *LPSC XXVII*, Abstract #551. [2] Yamashita S. et al. (2015) *78th Annu Meet. Met. Soc.*, Abstract # 5154. [3] Mogi K. et al. (2017) 80th Annu Meet Met. Soc., Abstract #6225. [4] McBride K. et al. (2003) Antarct. Meteorite Newsl. 26 (1). [5] Cloutis E.A. et al. (2011) *Icarus*, 216, 309-346. [6] Kiddell C.B. et al. (2018) *J. of Geophys. Res.: Planets 123.10*, 2803-2840. [7] Cloutis E.A. et al. (2018) *Icarus*, 305, 203-224. [8] Brunetto R. et al. (2018) *PSS*, 158, 38-45. [9] Lantz C. et al. (2017) *Icarus*, 302, 10-17. [10] Kaiden H. et al. (2018) *Symp. Polar Sci. 9th*, Abstract #106. [11] Matsuoka M. et al. (2015) *Icarus*, 254, 135-143. [12] Gillis-Davis J.J. et al. (2017) *Icarus*, 286, 1-14. [13] Matsuoka M. et al. (2017) *Earth Planets Space 69*, 120. [14] Nakamura, T. (2005) *J. Miner. Petrol. Sci.*, 100, 260-272. [15] Ikeda Y. (1992) *Antarctic Meteorite Research*, 5, 49. [16] Usui F. et al. (2018) arXiv:1810.03828.

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