VISIBLE AND IR HYPERSPECTRAL IMAGING OF RYUGU SAMPLES COMPARED TO METEORITES AND TO REMOTE SENSING OF BENNU AND OTHER PRIMITIVE ASTEROIDS

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Introduction: Since December 2020 the unique samples collected by Hayabusa2/JAXA from the C-type asteroid Ryugu are stored and pre-characterized in the JAXA Curation Facility [1]. A fraction of the collection is currently analyzed by six international Initial Analysis Teams [2] involving state-of-art techniques in laboratories all around the world.

As part of the Mineralogy / Petrology STONE team [3], we received ~20 microscopic particles [4] and a section of a larger (~ 700 μm) “stone" of Ryugu. We present here visible, NIR, MIR and FIR hyperspectral imaging results on the section of “stone” A0026 and on one isolated grain from “stone” C0002, that we compare to similar measurements on meteorites and to the remote sensing spectra of asteroid Bennu measured by OSIRIS-REx and of other primitive asteroids.

Samples: A section of the grain A0026 (from Chamber A, i.e. collected at the surface of Ryugu during the first touchdown) was prepared in Japan by a Xe plasma focused ion beam system (Xe FIB; AMBER X, TESCAN ORAY HOLDING) at TOYO corporation. The sample was cut using 30 kV and 2 µA Xe+ ions followed by cleaning at 30 kV and 300 nA. An isolated grain (FC018) sizing ~150 µm was extracted from C0002 (Chamber C, second touchdown after SCI impact) and deposited on a gold mirror [5] at Tohoku University in an air-tight condition.

Methods: We analyzed the Ryugu samples using three different FTIR microscopes at the SMIS beamline of SOLEIL synchrotron: (1) a synchrotron-radiation-fed microscope equipped with a large mid-IR range MCT/B-detector, (2) a far-IR bolometer-equipped microscope, (3) an imaging microscope equipped with a 128x128 pixels FPA detector. Hyperspectral maps in the mid-IR of the individual particles were acquired in order to assess the compositional heterogeneity at the diffraction limit. For (1) and (2), different apertures were used from 5 to 100 µm. For (3), we used different objectives and optics with variable fields of view in the 40 to 200 µm range, and pixel size from 0.67 to 11 µm. All instruments were used with a spectral resolutions of either 4 or 8 cm-1. Multiple detectors were used to access different wavelength ranges, covering from near-IR to far-IR (1 µm to 100 µm).

In the case of A0026-pFIB01, several FPA IR tiles were accumulated in a mosaic IR hyperspectral image to cover the whole surface while keeping a relatively small pixel size (~2.7 µm). Analysis of the hyperspectral maps was performed in Quasar (https://quasar.codes) using the Orange Spectroscopy toolbox [6].

Visible spectra were measured at IAS using an optical fibers setup coupled to a macroscope [7] to get a look at regions of interest defined thanks to the IR compositional map. With a collecting spot size of 20 μm we targeted matrix area, carbonates or opaques.

A few Raman spectra (laser wavelength 532 nm, power < 0.2 mW, spot ~1 µm) and maps were also acquired at SMIS, to get complementary information on the mineralogy and on the organics.

Results:

Average spectra: Putting all together these IR measurements, we obtained large-scale average spectra on the whole surface of A0026-pFIB01 (see Fig. 1) and of C0002-FC018. These are dominated by the Reststrahlen Si-O stretching and bending features, whose shapes and positions (10 and 22 μm) are typical of phyllosilicates [8], indicating that those are the main mineral component. Additional features produced by different carbonate modes (7 and 28 μm), by stretching and bending modes of phyllosilicate Mg-bonded hydroxyles (2.7 and 16 μm), and by CH and CO in organics are observed as well. The organics were also detected through D and G bands in Raman spectra. These compounds are also detected by [9].

Small scale variations: When looking at the scale of tens of µm, the different components of the stone A0026 clearly emerge in the IR hyperspectral maps. Thanks to a k-means clustering method, we separated the predominant phyllosilicate-rich matrix from other components like large sulfides and carbonate inclusions. The main carbonate IR features are compatible with dolomite, which is confirmed by independent Raman measurements performed on the same sample. Thanks to the IR mapping at smaller scale (few microns), we detected the presence of variable Si-O (10 μm) band position in the silicate-rich matrix, suggesting the presence of two components in the phyllosilicate population.

The visible spectra will be discussed at the time of the conference.

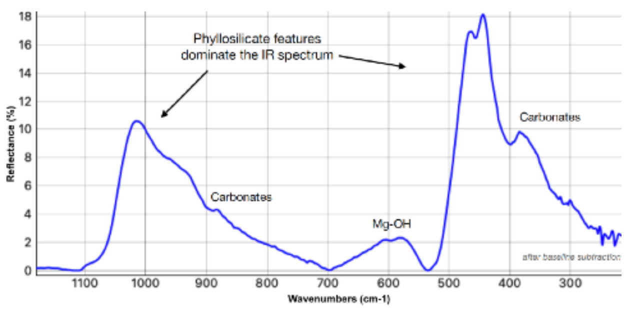

Figure 1: Average spectrum of the sample A0026-pFIB01. MIR and FIR measurements were combined after a baseline subtraction.

Discussion: We will compare the average spectra of the two Ryugu samples with carbonaceous chondrites we measured in the past few years with the same instruments and with the remote sensing spectrum of asteroid Bennu measured by the OTES instrument onboard OSIRIS-REx [10]. We will discuss similarities between these two small near-Earth asteroids (size, morphology, density, etc.) and to which extent they have distinct IR spectra also in the mid-IR and far-IR, in agreement to what was previously shown in the near-IR range from orbital data [10-11].

We will also investigate the composition effect in the visible range at the scale of 20 μm and compare the spectra with other primitive asteroid available data.

Conclusion: We probed two samples of Ryugu using reflectance spectroscopy on a wide wavelength range from visible to far-IR allowing us to compare with laboratory data on meteorites and remote sensing data on asteroids.

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