FIRST NIR HYPERSPECTRAL IMAGING OF HAYABUSA2 RETURNED SAMPLES BY THE MICROMEGA MICROSCOPE WITHIN THE ISAS CURATION FACILITY. C. Pilorget[1], T. Okada[2], V. Hamm[1], R. Brunetto[1], T. Yada[2], D. Loizeau[1], L. Riu[1,3], T. Usui[2,4], A. Moussi-Soffys[5], K. Hatakeda[2,6], A. Nakato[2], K. Yogata[2], M. Abe[2,7], A. Aléon-Toppani[1], J. Carter[1], M. Chaigneau[1], B. Crane[1], B. Gondet[1], K. Kumagai[2,6], Y. Langevin[1], C. Lantz[1], T. Le Pivert-Jolivet[1], G. Lequertier[1], L. Lourit[1], A. Miyazaki[2], M. Nishimura[2], F. Poulet[1], M. Arakawa[8], N. Hirata[9], K. Kitazato[9], S. Nakazawa[2], N. Namiki[10], T. Saiki[2], S. Sugita[4], S. Tachibana[2,4], S. Tanaka[2,7,11], M. Yoshikawa[2,7], Y. Tsuda[2,7], S. Watanabe[12], J.-P. Bibring[1], [1]Institut d'Astrophysique Spatiale, Université Paris-Saclay, CNRS, 91400 Orsay, France, [2]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara 252-5210, Japan, [3]ESAC, ESA, Madrid, Spain, [4]University of Tokyo, Bunkyo, Tokyo 113-0033, Japan, [5]Centre National d'Etudes Spatiales, 18 Avenue E. Belin, 31401 Toulouse, France, [6]Marine Works Japan, Ltd., Yokosuka 237-0063, Japan, [7]The Graduate University for Advanced Studies (SOKENDAI), Hayama 240-0193, Japan, [8]Kobe University, Kobe 657-8501, Japan, [9]The University of Aizu, Aizu-Wakamatsu 965-8580, Japan, [10]National Astronomical Observatory of Japan, Mitaka 181-8588, Japan, [11]University of Tokyo, Kashiwa 277-8561, Japan, [12]Nagoya University, Nagoya 464-8601, Japan. (cedric.pilorget@ias.u-psud.fr)

Introduction: On December 6, 2020, the Hayabusa2 mission successfully returned to Earth ~ 5.4 g of samples collected at the surface of the C-type asteroid Ryugu [1,2]. Its surface was first sampled on February 22, 2019, then on July 11, 2019, close to a 15-meter large artificial crater, so as to possibly access sub-surface material [3]. The collected samples have been labelled "bulk A" and "bulk C", respectively and are now kept at ISAS for a first round of preliminary analyses, with the objective of characterizing in a non-destructive manner both the bulk samples and a few hundreds of grains extracted from them [4]. In particular, the goal is 1) to support their further detailed characterization by the international Initial Analysis Teams, and 2) to build a catalogue of the grains, accessible to the international community through AO selection, starting early 2022. Importantly, the analyzed samples have always been kept, since their collection, in a fully clean and controlled environment either under vacuum or ultra-clean GN2.

Methods: The preliminary characterization of these samples, divided into 6 sub-bulks (3 for bulk A and 3 for bulk C), is being conducted with a visible microscope with six color filters [4], a FTIR spectrometer operating in the 1-4 µm range [4], and MicrOmega, a hyperspectral NIR microscope developed at Institut d'Astrophysique Spatiale [5], operating in the near-infrared range (0.99-3.65 µm) where diagnostic signatures of most candidate minerals and molecules of relevance (e.g. mafic minerals, altered phases, ices, aliphatic/aromatic CH, NH-rich compounds) can be found.

MicrOmega works as follows: the instrument illuminates the samples with a monochromatic beam, scanning over the NIR spectral range. For each spectral channel, MicrOmega acquires 256x250 pixels images with a pixel scale of 22.5 µm. For each pixel the reflectance spectrum is retrieved in up to 400 contiguous spectral channels. Both the negligible amount of illuminating power at less than 10^{-8} W/px and the lack of contact with the samples allow entirely non-destructive and non-invasive characterization.

Results: When analyzed at the mm-scale (Fig.1) by averaging thousands of pixels, the spectra of both bulk A and bulk C exhibit a pattern similar to those acquired remotely down to the meter scale by the Near InfraRed Spectrometer (NIRS3) instrument on board Hayabusa2 [6]. The global reflectance is extremely low, 2 – 3 % over the entire NIR spectral range covered, in agreement with the remote sensing measurements of the Optical Navigation Cameras (ONCs) and NIRS3 at Ryugu [7,8], and in full consistency with the taxonomic spectral classification of Ryugu as a C-type asteroid [1,2].

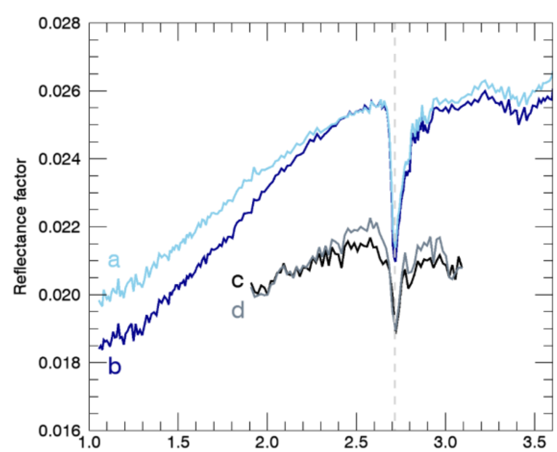

Figure 1. Typical MicrOmega Spectra within bulk A (a) and bulk C (b), compared to NIRS3 spectra at the surface (c) and close to the SCI impact crater (d). NIRS3 normalized spectra are from [9].

The main spectral feature is the diagnostic OH absorption centered at 2.715 +/- 0.005 µm, position compatible with that of NIRS3 spectra (Fig. 1) [8,9]. No significant differences can be observed between bulk A and bulk C for this specific feature. MicrOmega spectra also exhibit a broad feature in the 3.3 – 3.5 µm range, centered around 3.4 µm (Fig. 1), present throughout the sub-bulk samples, although with varying band depths of typically a few percent. This feature is considered indicative of the large-scale presence of a variety of CH-rich compounds. A fainter ~3.1 µm broad feature is also detected, although with varying and much fainter intensities.

Only at a sub-millimeter scale do heterogeneities clearly show up, either or both at grain level or as inclusions within grains. Detections include:

- carbonates, most of them being enriched in iron (Fig. 2). Carbonates are detected on a rather large number of occurrences with sizes ranging from a few tens to a few hundreds of micrometers [10] ;
- spots enriched in organics, in particular through a 3.4 µm feature indicative of the presence of aliphatic compounds [11] ;
- spots enriched in a nitrogen-rich phase, through a ~3.1 µm feature sometimes coupled to additional spectral features. Candidates include NH_4-phyllosilicates, NH_4-hydrated salts, and/or nitrogen-rich organics [11].

The various detections will be presented and candidates will be discussed.

Slight variations in the 2.7 µm feature were also identified at grain scale [12]. Noticeably, no chondrules nor refractory inclusions have been identified yet.

Conclusion: The initial spectral characterization of the returned samples by MicrOmega currently points towards Ryugu containing a fascinating variety of grains, including OH-, CH- and NH- rich compounds spread at a global scale, and alteration products, among which highly diagnostic carbonates. The occurrence of volatile-rich species, likely originating from the outer solar system, would support Ryugu having preserved some of its building blocks, together with their partially altered phases.

The Hayabusa2 returned samples, thus, appear among the most primordial material available in our laboratories. They constitute a uniquely precious collection, which may contribute revisiting the paradigms of Solar System origin and evolution

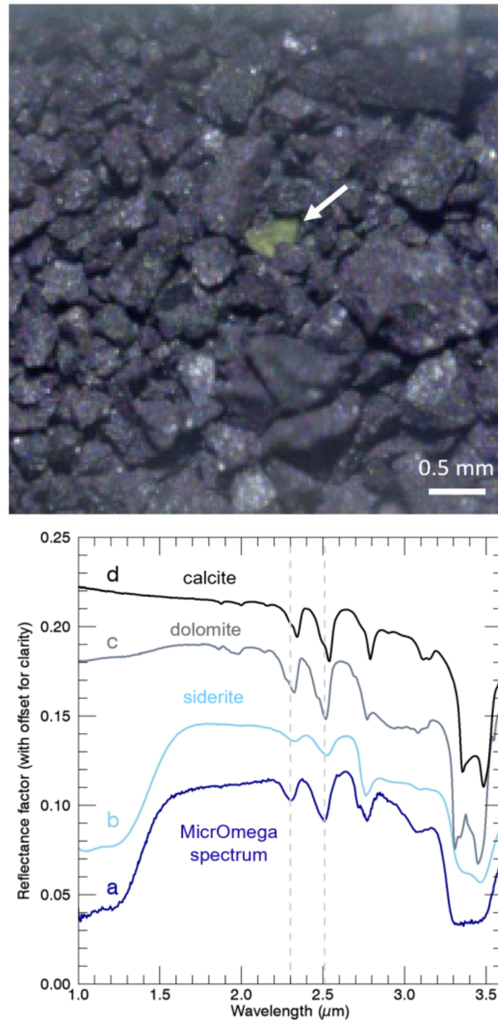

Figure 2. Average MicrOmega spectrum (a) of a large carbonate grain in sub-bulk A1 (dark blue) with three library reference spectra (b, c, d), together with an RGB image (top) showing the large carbonate grain (R: 2.5 µm, G: 2.7 µm, B: 3.4 µm).

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