

**OBSERVATIONS OF C-RICH PHASES IN RYUGU RETURNED SAMPLES BY THE MICROMEGA INSTRUMENT WITHIN THE JAXA HAYABUSA2 EXTRATERRESTRIAL CURATION CENTER.** <sup>1</sup>Carter J., <sup>1</sup>Bibring J.-P., <sup>1</sup>Brunetto R., <sup>1</sup>Baklouti D., <sup>1</sup>Gondet B., <sup>1</sup>Pilorget C., <sup>1</sup>Hamm V., <sup>2</sup>Hatakeda K., <sup>1</sup>Langevin Y., <sup>1</sup>Lantz C., <sup>1</sup>Le Pivert-Jolivet T., <sup>1</sup>Loizeau D., <sup>3</sup>Moussi A., <sup>2</sup>Nakato A., <sup>2</sup>Okada T., <sup>1,2</sup>Riu L., <sup>2</sup>Usui T., <sup>2</sup>Yada T., <sup>2</sup>Yogata K. <sup>1</sup>Institut d'Astrophysique Spatiale, Université Paris-Saclay, CNRS, 91400 Orsay, France (john.carter@ias.u-psud.fr), <sup>2</sup>Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagami-hara 252-5210, Japan, <sup>3</sup>University of Tokyo, Bunkyo, Tokyo 113-0033, Japan, <sup>4</sup>Centre National d'Etudes Spatiales, 18 Avenue E. Belin, 31401 Toulouse, France, <sup>5</sup>Marine Works Japan, Ltd., Yokosuka 237-0063, Japan, <sup>6</sup>The Graduate University for Advanced Studies (SOKENDAI), Hayama 240-0193, Japan, <sup>7</sup>Kobe University, Kobe 657-8501, Japan, <sup>8</sup>The University of Aizu, Aizu-Wakamatsu 965-8580, Japan, <sup>9</sup>National Astronomical Observatory of Japan, Mitaka 181-8588, Japan, <sup>10</sup>University of Tokyo, Kashiwa 277-8561, Japan, <sup>11</sup>Nagoya University, Nagoya 464-8601, Japan.

**Introduction:** The JAXA Hayabusa2 mission successfully returned ~5.4 g of samples collected at two locations at the surface of the C spectral-type asteroid Ryugu. They were delivered to the JAXA/ISAS Extraterrestrial Samples Curation Center, in Sagami-hara (Japan), in which they are maintained within an ultraclean facility, under pure N<sub>2</sub> flow. In this environment, samples are deposited on sapphire dishes, weighted and analyzed with color optical microscopy, point FT-IR spectroscopy, and with MicrOmega hyperspectral imaging [1]. For the first time it is possible to characterize pristine samples from a C-type asteroid, preserved from any terrestrial alteration/contamination which would originate from oxidation, aqueous alteration, heating, or contact with terrestrial gases and organics. Within this facility, samples are characterized non-destructively and non-invasively, with no treatment nor processing. The samples are either as “bulks” or as larger grains, the latter remotely extracted within a globe-box [2].

MicrOmega [3] has a 5x5 mm<sup>2</sup> field of view, made of 256x256 pixels ~22 μm large. From each pixel is extracted the diffuse-directional reflectance spectrum in the [0.99-3.6] μm range. It has the demonstrated capability to identify various minerals [4,5] and organic matter. Here we report on nearly one year of preliminary observations of the C-rich content of the bulk and ~100 extracted grains, including those then distributed to the international Initial Analytical Teams [2].

**Methods:** Within the curation Facility, MicrOmega is maintained at ~10°C within a GN<sub>2</sub>-flushed chamber, interfacing the sample chamber through a sapphire window. This allows conducting analyses in a purely non destructive/invasive fashion so as to preserve sample integrity. With the huge number of grains returned with a wide size range, the coupled imaging, spectroscopic and radiometric capabilities of MicrOmega have allowed both 1) a statistical approach to composition and morphology and 2) the study of individual grains and inclusions of specific composition down to a few 10's of μm. Each spectral image cube is processed to reflectance [6,7]. A number of different

approaches to data analysis have been concurrently implemented, ranging from blind unsupervised algorithms (e.g. clustering, PCA) to supervised diagnostic spectral band mapping and spectral extraction. Here we focus primarily on the spectral region diagnostic of C-rich compounds in the 3.25-3.55 μm range. We also investigate overtones in the lower spectral region, as well as non-organic diagnostic absorptions (mediated by CO<sub>3</sub>, OH, NH) which may co-occur with organic-bearing grains.

**Results:** At the mm scale and to the exception of the occasional carbonate-rich grains/inclusions [5], reflectance is extremely low (<3%) and consistently exhibits two dominant features centered around 2.7 μm and 3.4 μm [4,8]. The broad 3.4 μm band is attributed to undifferentiated organic matter and/or carbonates endogenous to Ryugu, while the other sharper band likely pertains to hydrous minerals (phyllosilicates or hydroxides). At that scale these spectral features appear poorly to non-correlated, with variable absolute and relative band depths. Most pixels with organics-related features do show a 2.7 μm OH<sup>-</sup> band. This is interpreted as likely indicating organics are predominantly present at sub-pixel scales mixed with OH-rich “matrix material”. Similar features are observed at the slightly larger spot-sized FT-IR instrument at the Facility.

In sharp contrast, MicrOmega analyses down to its sampling scale (~20 μm) reveal a rich variety of organics-related spectra, which 3.4 μm region features both single to multiple bands with variable band centers. Most distinguishable C-H signatures show a band center towards 3.42 μm interpreted as the asymmetric CH<sub>2</sub> stretching mode (figure 1). By contrast, there is little evidence for aromatic signatures in the 3.25-3.3 μm range nor strong asymmetric CH<sub>3</sub> below 3.4 μm. Occasional weak bands in the 3.4-3.5 μm region may indicate symmetric CH<sub>3</sub> but CH<sub>2</sub> bonds dominate over CH<sub>3</sub> in these organic compounds, suggesting the presence of molecules with high CH<sub>2</sub>/CH<sub>3</sub> ratios. As for the lack of aromatic signatures, it should be noted that these are intrinsically weaker and that even a majority fraction of aromatics may not be detectable in the presence of aliphatic matter [9].

The band shape of the 3.4  $\mu\text{m}$  aliphatic signature varies from sharp and symmetrical, to skewed or broad (figure 1). While some cases suggest potential sub-pixel mixing with carbonate minerals, many do not. In particular, the occasional presence of a  $\sim 3.55 \mu\text{m}$  band within the spectral shoulder of the former may indicate oxygen functions perhaps as C-OH or C=O. This interpretation may be further supported by an occasional additional absorption near 2.9  $\mu\text{m}$ .

In some instances, spectra with strong to no organic absorptions also exhibit a 3.05-3.1  $\mu\text{m}$  feature that bears resemblance with that of Ceres [10] and has been attributed to N-H bonds. Whether the N is part of a function in organic matter or not is an open question under investigation. Should this be confirmed, it would argue for the presence of amines and/or amides.

The tendency of the 3.4  $\mu\text{m}$  band to broaden and lose its finer structure when increasing the scale indicates that micrometric mixtures of organic/carbonates/OH are the norm, while high concentrations of specific organics is a rare feature, a fact which may also provide information on the primitive chemical evolution of Ryugu.

**Perspectives:** This preliminary analysis of MicrOmega data has confirmed the capability of NIR hyperspectral microscopes to provide efficient knowledge of large sample sizes, allowing science at several scales and over a range of compositions. While analyses are still underway as will be presented at this conference, preliminary results already indicate that organic matter, in its broad diversity, is present from the large to microscopic (sub-MicrOmega pixel) scale. Further work will focus on correlating CH<sub>2</sub> absorptions with other spectral bands to test the possibility for preferential co-occurrence with specific minerals. Investigations of the elusive aromatic matter will continue, as well as a focus on bands indicative of heteroatoms such as O and N.

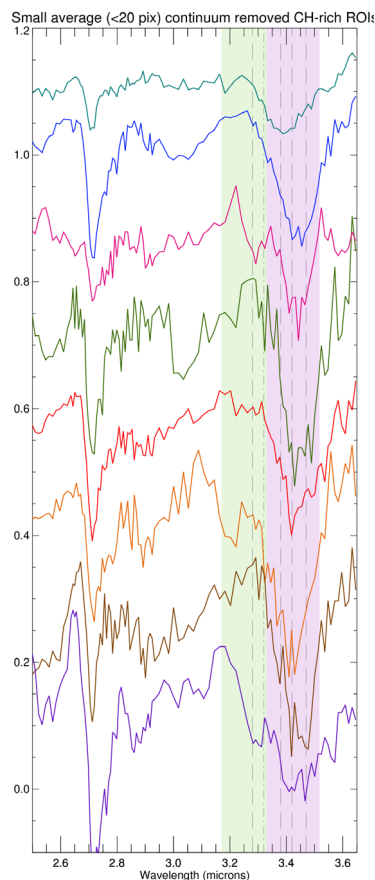


Figure 1. Example small-region averages (< 20 pixels) MicrOmega spectra of various C-bearing grains. The green shading denotes the aromatic spectral band range and the purple shading the aliphatic range. Spectra are continuum removed and offset for clarity.

**References:** [1] Morota et al. (2020) *Science* 368, Issue 6491, pp. 654-659. [2] Yada T. et al. (2021) *Nature Astronomy*, 10.1038/s41550-021-01550-6. [3] Bibring J.-P. et al. (2017) *Astrobiology* 17, 6-7, pp.621-626. [4] Pilorget C. et al. (2021) *Nature Astronomy*, 10.1038/s41550-021-01549-. [5] Damien L. et al. (2022) *this conference*. [6] Riu L. et al. (2018) *PSS*, 152, 31-44 (2018). [7] Riu L. et al. (2022) *submitted to RSI*. [8] Pilorget C. et al. (2022) *This conference*. [9] Vinogradoff V. et al. (2021) *Mineral*, 11(7), 719. [10] De Sanctis M.C. et al. (2019) *MNRAS*, 482, 2407-2421.