A GLOBAL CHARACTERIZATION OF PRISTINE RYUGU SAMPLES WITH THE NIR HYPERSPECTRAL MICROSCOPE MICROMEGA WITHIN THE ISAS CURATION CENTER AND PERSPECTIVES FOR THE BENNU SAMPLES. C. Pilorget[1,2], T. Okada[3,4], J.-P. Bibring[1], R. Brunetto[1], V. Hamm[1], D. Loizeau[1], L. Riu[1,5], T. Usui[3,4], T. Yada[3] , M. Abe[3,6], A. Aléon-Toppani[1], D. Baklouti[1], J. Carter[1], K. Hatakeda[3,7], Y. Hitomi[3,7], T. Jiang[1], K. Kumagai[3,7], Y. Langevin[1], C. Lantz[1], T. Le Pivert-Jolivet[1], A. Miyazaki[3], A. Moussi-Soffys[8], A. Nakato[3], K. Nagashima[3], M. Nishimura[3], F. Poulet[1], Y. Sugiyama[3], K. Yogata[3], [1]Institut d'Astrophysique Spatiale, Université Paris-Saclay, CNRS, 91400 Orsay, France, [2]Institut Universitaire de France, [3]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara 252-5210, Japan, [4]University of Tokyo, Bunkyo, Tokyo 113-0033, Japan, [5]ESAC, ESA, Madrid, Spain, [6]The Graduate University for Advanced Studies (SOKENDAI), Hayama 240-0193, Japan, [7]Marine Works Japan, Ltd., Yokosuka 237-0063, Japan, [8]Centre National d'Etudes Spatiales, 18 Avenue E. Belin, 31401 Toulouse, France, (cedric.pilorget@ias.u-psud.fr)

Introduction: In December 2020, the Hayabusa2 mission successfully returned to Earth samples collected at the surface of the C-type asteroid Ryugu, a first in space exploration [1]. The collected samples are now kept at ISAS (Institute of Space and Astronautical Science) 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 [2] (https://darts.isas.jaxa.jp/curation/hayabusa2/). Importantly, the analyzed samples have always been kept, since their collection and even during their analysis, in a fully clean and controlled environment either under vacuum or ultra-clean GN2.

By the beginning of 2023, bulk samples from both collection sites, as well as >400 individual grains (a few mm in size each) and a few tens of "small-bulks" (a few tens of mg each) extracted from them have been analyzed by the NIR hyperspectral microscope MicrOmega (spectral range: 0.99-3.65 µm). Such extensive characterization in an environment preserved from any terrestrial contamination provides a unique opportunity to perform a global analysis of the samples in their pristine condition, assessing their diversity down to the scale of a few tens of microns and putting in their context further characterizations performed at smaller scale or on a small fraction of the samples.

Methods: MicrOmega illuminates the samples, present in the Curation chamber, with a monochromatic beam (incidence angle of ~35°), scanning over the NIR spectral range [3]. For each spectral channel, MicrOmega acquires 256x250 pixels images with a pixel scale of 22.5 µm in a "nadir" configuration. 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. Within the Curation Facility, MicrOmega is mounted in an ultraclean-N_2 purged chamber to prevent H_2O/CO_2 contamination.

Results: When looking at the scale of a few mm, the bulk material appears extremely dark (albedo of ~2-3 %) and exhibits absorption features at ~2.72 µm, due to Mg-rich phyllosilicates, and ~3.4 µm, due to organics and/or carbonates [2,4,5]. A faint ~3.1 µm, likely due to NH-rich compounds, can also be observed [2,4]. While such spectral behavior appears typical of Ryugu material, some variations can be observed in the position (up to ~10 nm) and depth of the ~2.72 µm feature between grains extracted from the bulks [5]. In particular, grains extracted from "bulk A" and "bulk C" (corresponding to the 2 collection sites, the 2nd one being close to an artificial crater) exhibit different trends in their distributions, while both bulks appear similar on average. Small variations in the depth of the ~3.1 and 3.4 µm features are also observed at the scale of a few mm, both on the bulks and on extracted grains, pointing towards local enrichments.

Only at a sub-millimeter scale do stronger compositional heterogeneities show up, either or both at grain level or as inclusions within grains [4]. The most prominent example concerns carbonates. A few hundreds of carbonate-rich areas larger than ~45 µm (2x2 MicrOmega pixels) have been detected among the grains and bulks/sub-bulks observed with MicrOmega (which does not preclude the presence of carbonates at finer scale) [6]. Their size ranges from a few tens up to a few hundreds of microns, displaying various kinds of morphologies that may be indicative of their formation process (e.g. Fig.1). The analysis of their spectral properties led to the identification of various types of carbonates, with most of the detections being similar to (Mg,Ca) and (Mg,Fe) carbonates, found with different occurrences and size distributions, thus constraining the early processes that shaped Ryugu's material.

Other examples of compositional heterogeneities include spots enriched in NH (through a ~3.1 µm feature sometimes coupled to additional spectral features) and CH (through a ~3.4 µm feature indicative of the presence of aliphatic compounds, also sometimes coupled to additional spectral features [7]).

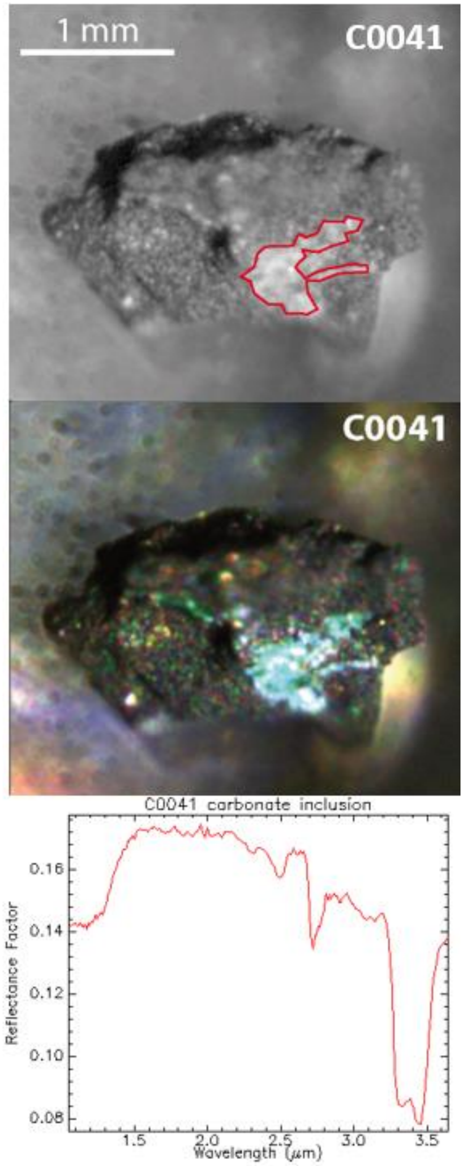

Fig. 1. Example of carbonate inclusion detected by MicrOmega on grain C0041. MicrOmega IR image at 2.5 µm (top), and RGB composite (R: 3.34 µm, G: 2.5 µm, B: 1.2 µm) highlighting carbonates in blue/green (center). At the bottom is the reflectance spectrum extracted from the ROI indicated in red color on the top image. The spectral features indicate a (Mg,Fe) carbonate. Adapted from [6].

Perspectives for the OSIRIS-REx samples: In parallel to the continuation of the analysis of the Ryugu material, MicrOmega will also be used to characterize the OSIRIS-REx samples from Bennu that will be delivered to JAXA by NASA end of 2023 [8]. These samples will be kept at ISAS in a dedicated Curation room and analyzed with a suite of instruments including the MicrOmega unit used on Ryugu samples, thus enabling a thorough comparison of NIR hyperspectral datasets between both C-type asteroids.

References: [1] Morota et al. (2020) *Science* 368, Issue 6491, pp. 654-659, [2] Yada T. et al., *Nature Astronomy*, https://doi.org/10.1038/s41550-021-01550-6, [3] Bibring J.-P. et al. (2017) *Astrobiology* 17, Issue 6-7, pp.621-626, [4] Pilorget C. et al. (2021) *Nature Astronomy*, https://doi.org/10.1038/s41550-021-01549-z, [5] Le Pivert-Jolivet T. et al., MetSoc 2022, [6] Loizeau D. et al., *Nature Astronomy, in press*, [7] Bibring J.-P.et al., LPSC 2022. [8] Yada et al., this conference.