

THERMAL HISTORY OF RYUGU BASED ON RAMAN CHARACTERIZATION OF HAYABUSA2 SAMPLES. L. Bonal¹, E. Quirico¹, G. Montagnac², M. Komatsu³, H. Yabuta⁴, H. Yurimoto⁵, T. Nakamura⁶, T. Noguchi⁷, R. Okazaki⁸, H. Naraoka⁸, K. Sakamoto⁹, S. Tachibana^{9, 10}, S. Watanabe¹¹, Y. Tsuda⁹ and the Hayabusa2-initial-analysis IOM team, ¹Institut de Planétologie et d'Astrophysique de Grenoble, Université Grenoble Alpes, CNRS CNES, (Grenoble, France) (lydie.bonal@univ-grenoble-alpes.fr, ²Laboratoire de géologie de Lyon, CNRS/INSU - ENS de Lyon (Lyon, France), ³SOKENDAI, The Graduate Univ. for Advanced Studies (Japan), ⁴Hiroshima University (Japan), ⁵Hokkaido University (Japan), ⁶Tohoku University (Japan), ⁷Kyoto University (Japan), ⁸Kyushu University (Japan), ⁹JAXA, ¹⁰Univ. of Tokyo (Japan), ¹¹Nagoya University (Japan).

Introduction: JAXA's Hayabusa2 asteroid sample return mission targeted the carbonaceous (C-type) asteroid 162173 Ryugu. The Hayabusa2 spacecraft collected samples from two touchdown sites on Ryugu and returned them to Earth on December 6, 2020, six years after launch. Since then, the goal of the Insoluble Organic Macromolecule Initial Analysis Team is to elucidate the distributions and chemical characteristics of macromolecular organic materials in a C-type asteroid [1]. The degree of structural order of the polyaromatic carbonaceous matter present in extraterrestrial samples is a tracer of the thermal history they experienced (e.g., primitive chondrites: [2-5]; micrometeorites: [6-7]). To characterize Ryugu's thermal history (long vs. short thermal heating and its extent), we thus perform Raman characterization of several samples returned by the Hayabusa2 mission. In order to be fully confident in the obtained data and interpretation, Raman characterization was led independently by two groups in Japan and in France on distinct Ryugu particles. The results were subsequently compared.

Samples and methods: Raman point analyses were performed on several fragments of six intact grains from Chamber A aggregates (A0108) from the first touchdown site and six intact grains from Chamber C aggregates (C0109) from the second touchdown site. The insoluble carbonaceous residue isolated by acid treatment from intact Ryugu samples (A0106 and C0107 aggregates) is currently being characterized.

To be able to combine in situ IR and NanoSIMS measurements on the same samples, fragments of particles were manually selected under a binocular and pressed onto diamond windows. The Raman spectra were acquired with a 532 nm laser in both Japan and France. Because some Raman bands related to carbonaceous matter are dispersive, data for Ryugu particles and comparison samples have been acquired and analyzed consistently in both Japan and in France. In particular, in France, Raman measurements were performed at the Ecole Normale Supérieure de Lyon (Laboratoire de Géologie de Lyon—Terre, Planètes, Environnement) using a LabRam Raman spectrometer (Horiba Jobin-Yvon) equipped with a 600 g/mm grating. The laser was focused through a 100× objective

to obtain a <2 µm spot size. The power on the sample was 0.3 mW. Each acquisition comprised six integrations of 15 s that were averaged to make the final spectrum.

Results and Discussion: More than 200 spectra were acquired so far. The Raman data acquired in Japan and in France are fully consistent. Each acquired spectrum is characterized by a high fluorescence background and by the presence of the Raman D- (~1350 cm⁻¹) and G-bands (~1580 cm⁻¹), related to the presence of poorly ordered carbonaceous matter. The spectral parameters derived from the mathematical fitting of the individual spectra - band widths (FWHM_D, FWHM_G), band positions (ω_D, ω_G), and band intensity ratio (I_D/I_G) - are all clustering in the same area (Fig. 1).

In order to evaluate the thermal history of the Ryugu asteroid, the spectral parameters derived from Ryugu's samples were compared with those obtained on meteorites. In a plot FWHM_G vs. ω_G (Fig. 1B), the Ryugu samples are clearly distinct from petrologic type 3 chondrites. In the plots FWHM_D vs. I_D/I_G (Fig. 1C) and ω_G vs. ω_D (Fig. 1D), the parameters from Ryugu samples are comparable to those derived from the primitive Ivuna-type (CI) and Mighei-type (CM) carbonaceous chondrites of petrologic types 1 and 2, respectively. On the other hand, they are distinct from thermally metamorphosed CM chondrites, such as Wisconsin Range (WIS) 91600, Pecora Escarpment (PCA) 02012, and Jbilet Winselwan meteorites.

The characterization of IOM is currently under progress. So far, only the extract from C0107 aggregate was analyzed. The spectral parameters are consistent with those derived from intact particles originating from A0108 and C0109 aggregates.

These results indicate that Ryugu escaped significant long duration radiogenic thermal metamorphism as well as impact induced short-duration heating. This is consistent with tracers visible on IR spectra of the intact particles: presence of Mg-rich phyllosilicates and CH₂/CH₃ ratios comparable with primitive chondrites [8].

The intact samples from Chamber A and Chamber C characterized so far are all derived from A0108 and C0109 aggregate, respectively. We thus considered the parameters obtained on the individual samples, A0108-

6, 10, and 18, and C0109-5, 9, and 12, as representative of the A0108 and C0109 aggregates, respectively. A Student's T-test was used to test the null hypothesis that the means of a spectral parameter from A0108 and C0109 are equal: the mean value of FWHM_D and I_D/I_G from A0108 and C0109 cannot be considered as distinct, while the difference between the mean FWHM_G , ω_G and ω_D from the two chambers are statistically significant. The polyaromatic structure of organic materials in the intact samples from A0108 and C0109 thus appears to be slightly different. The specific features controlling each spectral parameter are not identified. A weak correlation has been observed among type 2 chondrites between FWHM_G and the O/C ratios of insoluble organic matter extracted from CM chondrites [5]. The structural difference between A0108

and C0109 could reflect some variability in the oxidation state between the two collecting sites, but further investigation and a higher statistic of measurements are necessary to draw some firm interpretation.

Acknowledgments: L.B. and E.Q. thank the French space agency CNES for its support.

References: [1] Yabuta et al. Submitted to Science [2] Bonal L. et al. (2006) *GCA*, 70, 1849-1863. [3] Bonal L. et al. (2016) *GCA*, 189, 312-337. [4] Busemann H. et al. (2007) *Meteoritics & Planet. Sci.* 42: 1387-1417. [5] Quirico E. et al. (2018) *GCA*, 241, 17-37. [6] Dobrica E. et al. (2011) *Meteoritics & Planet. Sci.* 46, 1363-1375. [7] Battandier M. et al. (2018) *Icarus*, 306, 74-93. [8] Kebukawa et al. (2022) LPSC abstract.

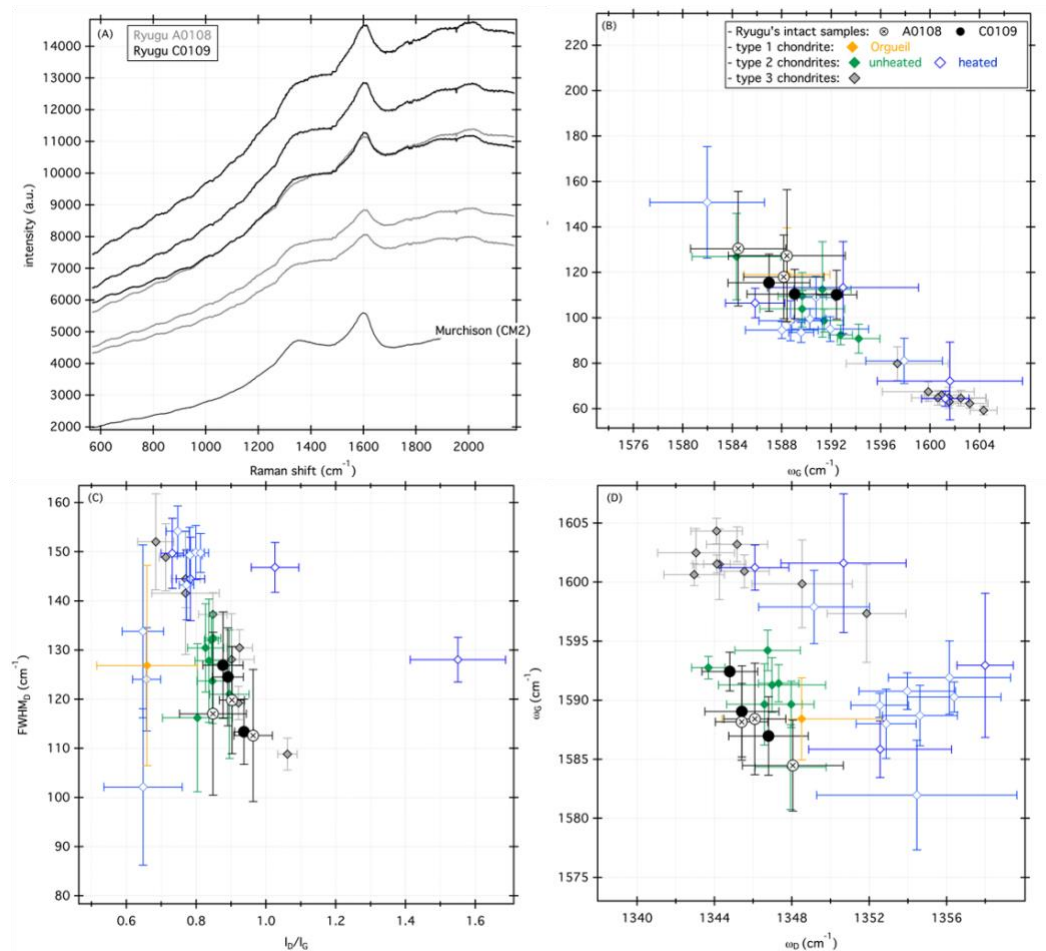


Fig. 1: Average Raman spectra and spectral parameters of Ryugu intact samples in comparison to primitive chondrites. (A): Average Raman spectra of 3 Chamber A (in grey) and 3 Chamber C (in black) samples, in comparison to Murchison (CM2 chondrite). (B), (C), (D): Spectral parameters (B: FWHM_G vs. ω_G ; C: FWHM_D vs. I_D/I_G ; D: ω_G vs. ω_D) of Chamber A (open circles) and Chamber C (black filled circles) samples in comparison to Orgueil (CI, orange diamond), primitive (green filled diamonds) and heated (open blue diamonds) type 2 chondrites and type 3 chondrites (filled grey diamonds). CMs are described as unheated (e.g., Murchison) or heated (e.g., Jbilet Winselwan) as defined by [5]. All spectra were acquired under the same analytical conditions.