SF2A 2019
P. Di Matteo, O. Creevey, A. Crida, G. Kordopatis, J. Malzac, J.-B. Marquette, M. N'Diaye, O. Venot (eds)

PREPARING SAMPLE RETURN FROM RYUGU AND BENNU ASTEROIDS WITH MICROMETEORITES FROM THE CONCORDIA COLLECTION

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Abstract. Hayabusa 2 and OSIRIS-REx space missions will give a unique access to the composition of carbonaceous asteroids. A key issue will be the comparison of the organic and mineral compounds from these near-Earth active carbonaceous asteroids with that of carbonaceous chondrites, carbon-rich interplanetary dust particles and cometary samples (81P/Wild2 or in-situ analyses from 67P/CG). The comparison of Ryugu and Bennu samples with chondritic micrometeorites and with extremely carbon-rich interplanetary dust particles such as the Ultra-Carbonaceous MicroMeteorites (UCAMMs) will provide a unique tool to assess their possible links with cometary organics. Analytical methods applied to study micrometeorites from Concordia collection (Antarctica) and the most recent results obtained are summarised. A particular emphasis is put on the dedicated experimental protocols that we developed to analyse micrometeorite fragments and study their mineral-organic association at scales relevant to their intimate association, ranging from tens of nanometers to a few microns.

Keywords: Solar System, space sample return mission, asteroid, micrometeorites, interplanetary organic matter

1 Introduction

Samples from dark asteroids Ryugu and Bennu will be collected and brought back to Earth by Hayabusa 2 and Osiris ReX missions in December 2020 and march 2023 respectively. It is the first-time material from the surface of known carbonaceous asteroids will be available for comparison with the different samples of primitive carbonaceous material. These primitive samples include carbonaceous chondrites, interplanetary dust particles and micrometeorites (MMs). Recent studies on cometary samples (Brownlee et al. 2006; Nakamura et al. 2008) showed that there is no marked difference between the solid phase of icy objects (i.e. comets) and primitive chondritic samples from carbonaceous asteroids. These samples originate from parent bodies that belong to an "Asteroid-Comet continuum". The fact that most of the dust belong to that reservoir strongly suggests that it is representative of most of the Asteroid Belt mass. Dark asteroids such as Bennu and Ryugu could be representative of this "Asteroid-Comet continuum" and, as such, samples from there surface will be of uttermost importance to challenge the relevance of this continuum concept.

The CONCORDIA micrometeorites collection contains one of the best sampling of the interplanetary carbonaceous dust complex encountered by Earth. The majority of the particles in the collection are related to CR and CM chondrites and exhibit both hydrous and anhydrous minerals (Engrand & Maurette 1998). The comparison of Ryugu and Bennu particles with the CONCORDIA collection will provide key constraints on similarities and differences between these samples and the asteroïdal and cometary end-members of interplanetary dust. The techniques developed recently on micrometeorites allow to combine the analysis of both minerals and organics phases at the sub-micron scale. They will be used in the rehearsal of Hayabusa 2 samples analysis.

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2 Micrometeorites from the CONCORDIA Collection

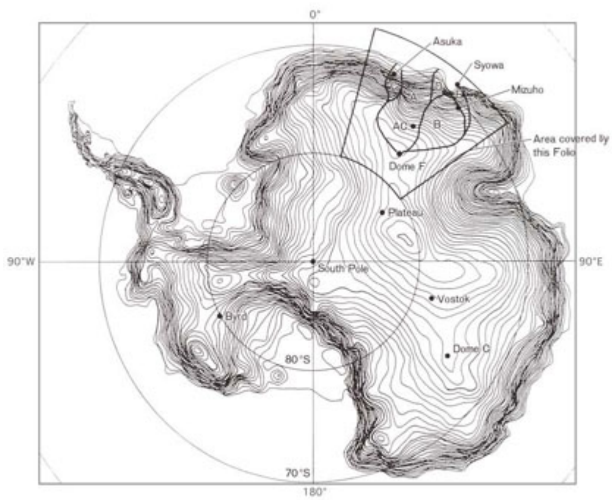

Fig. 1. Left: Dome C location in the central regions of the Antarctic continent. **Right:** CONCORDIA Station (IPEV).

Large collections of interplanetary dust within the 20 μm-1000 μm size range (i.e. micrometeorites) have been recovered from many type of sediments, deep sea floor and polar ice caps.Thanks to the support of the Institut Polaire Français, Paul Emile Victor (IPEV), we collect micrometeorites at the vicinity of the French-Italian polar station CONCORDIA located at Dome C (5° S, 123° E). The location of CONCORDIA station is in the central east regions of the Antarctic continent, at more than 1100 kms from Adélie Land (Figure 1). The surface snow at Dome C is exceptionally preserved from terrestrial dust contamination with the size range of micrometeorites (Duprat et al. 2007). For more than two decades, we recovered manually thousands of particles from ultra-clean snow samples extracted from 4-7 meters deep trenches. The resulting collection contains many unaltered interplanetary dust particles. The micrometeorites from the CONCORDIA collection are well preserved from terrestrial weathering as they were preserved at low temperature (< -40 ° C) within the Antarctic surface snow. The main part of the collection contains micrometeorites typical from the carbonaceous "Asteroid-Comet continuum". Aside from these chondritic micrometeorites, some particles stand apart and exhibit distinctive characteristics of asteroïdal of cometary origins. Some particles exhibit exceptionally high carbon content, with concentrations above 50% of the mass, in the form of organic matter with extreme deuterium enrichments; they are the so-called Ultra-Carbonaceous Antarctic MicroMeteorites (UCAMMs) (Duprat et al. 2010). The mineralogy, the elemental and isotopic composition of these particles clearly indicates that they belong to the cometary reservoir (Dartois et al. 2013). UCAMMs have been identified in both the CONCORDIA and the Japanese collection from Dome Fuji (Nakamura et al. 2005; Yabuta et al. 2017). By contrast, some micrometeorites exhibit clear asteroïdal signature in their mineralogy (Genge et al. 2008; Gounelle et al. 2005) and isotopic composition. As these samples represent somehow the cometary and asteroïdal end-members, the comparison of the Ryugu and Bennu particles to such samples will shed light on primitive carbonaceous material from the solar system protoplanetary disk.

3 Key questions on Ryugu and Bennu minerals and organics

The return of Hayabusa 2 samples will provide for the first-time particles from a known C-type asteroid, 162173 Ryugu (aka 1999 JU3). Together with Secondary Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) measurements, the infrared spectra will reveal both the mineral and organic content of Ryugu particles. To what extent the Ryugu particles will be similar to chondritic MMs, and will the distribution of their Olivine/Pyroxene ratio be similar to that of MMs? The average amorphous/crystalline ratio of minerals from Ryugu particles will also be of crucial importance, will it be in the classical range of chondritic dust particles (i.e. chondritic MMs)? These measurements will be important to distinguish the interstellar heritage from minerals reprocessed within the carbonaceous asteroïdal reservoir. How extensively will the samples of Ryugu or Bennu exhibit traces of ion irradiation by solar wind and energetic particles like those reported

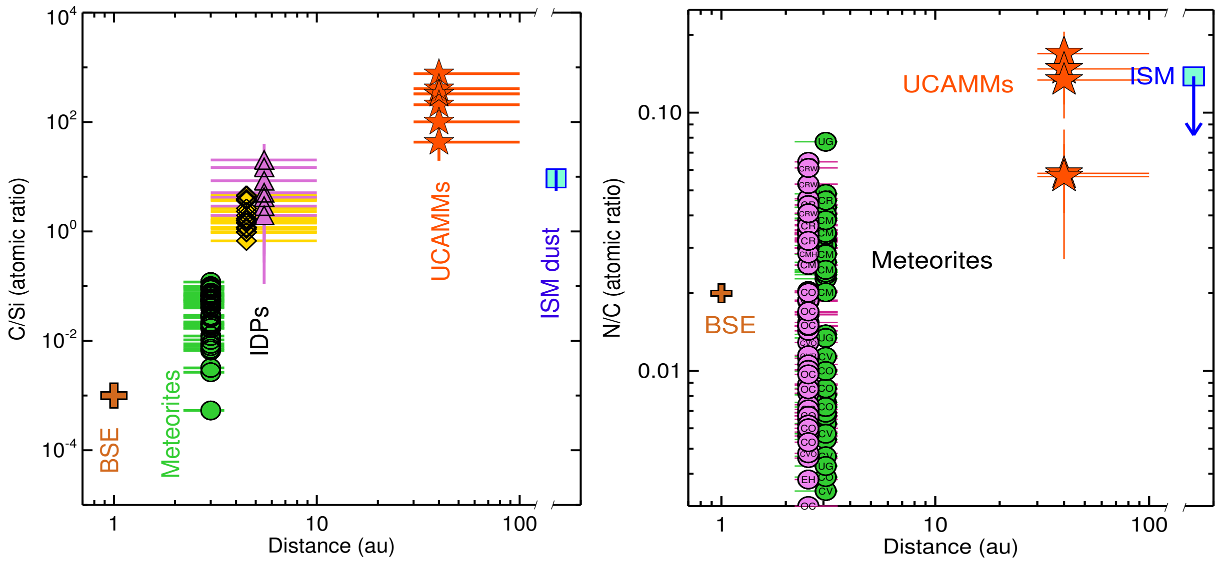

Fig. 2. C/Si **Left:** and N/C **Right:** ratio in different early solar system samples and reservoirs (figure from Dartois et al. 2018)

from Hayabusa I samples? Recently, irradiation tracks and amorphised irradiated rims have been observed in minerals from a UCAMM (Engrand et al. 2019). Measurements will be performed to compare the irradiation history of Ryugu and Bennu surface with that of typical asteroïdal and cometary samples. The C-type asteroïds are expected to be carbon rich and thus their organic/mineral ratio (C/Si) will be of particular interest. Will it be in the range of typical chondritic MMs or higher? Samples from the cometary reservoir tend to exhibit higher concentration in carbonaceous material (see Figure 2), suggesting that an heliocentric (C/Si) gradient was present in the protoplanetary disk. The average value of this ratio will be of crucial importance to better understand the origin of the organic component of carbonaceous asteroïds.

The organic component of meteorites is rich and diverse, most probably reflecting the incorporation of different early solar system organic reservoirs and their subsequent evolution in their parent body. The origin of Ryugu and Bennu organic will provide constraints on the dynamic processes that affected the organics in the protoplanetary disk. A key feature to distinguish between organics produced at different temperatures is their N/C ratio (see Figure 2). The organics from particles of potential cometary origin (such as UCAMMs) exhibit a component with a N/C ratio higher than that usually reported in chondritic material (Dartois et al. 2018). This component was most probably formed by irradiation of ices at the surface of icy parent bodies beyond the nitrogen snow line (Dartois et al. 2013; Augé et al. 2016). Together with the general features of their infrared spectra, the comparison of the distribution of the N/C ratios of the organics in Ryugu and Bennu samples to that reported in MMs will shed light on the various solar system organic components and their different origins.

4 Micrometeorites for rehearsal

The analysis of Ryugu and Bennu samples will face technical issues related to careful handling and preparation of rare samples with sizes ranging from a few tens to a few hundred μm. The different groups working on IDPs and MMs have developed numerous techniques and skills to perform combined measurements on precious samples within this size range. The french micrometeorite collaboration developed expertise to perform mineralogical, elemental, structural and isotopic studies on the same sample. The samples are mounted on dedicated diamond cells allowing SEM, μ- Raman, μ-IR and NanoSIMs measurements on samples with sizes of few tens of microns (Dartois et al. 2013). More recently, thanks to the novel AFMIR technique, the infrared signature of different organic components have been imaged in a UCAMM (see Figure 3, Mathurin et al. 2019) at spatial resolutions lower than a micron (i.e. better than the diffraction limit). The AFMIR analysis of Ryugu and Bennu particles will provide a unique tool to reveal the relation between minerals and organics of carbonaceous asteroids at the sub-micron scale.

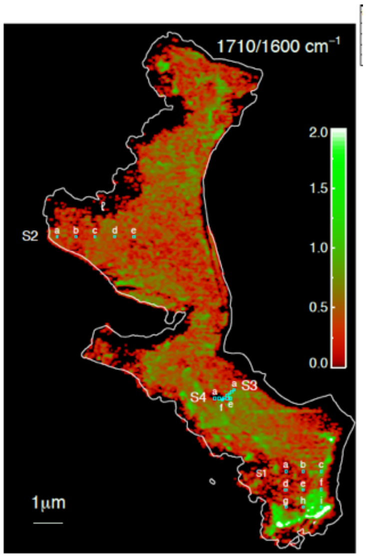

Fig. 3. AFMIR map of a micrometeorites reveals the diversity of organics at the sub- μm scale (figure from Mathurin et al. 2019)

5 Conclusions

The return of Ryugu and Bennu samples provide an opportunity to compare samples from two carbonaceous asteroïds with what we know from asteroïdal and cometary samples. The bulk of micrometeorites consists in chondritic carbonaceous particles that are most probably representative of the matter from the asteroïdal-cometary continuum. The comparison of both minerals and organics returned by Hayabusa 2 and OSIRIS-REx with micrometeorites will shed light on the dynamical evolution of these primitive components prior their incorporation in Ryugu and Bennu asteroïds.

The micrometeorite Concordia collection is supported by the French and Italian polar institutes IPEV and PNRA. This work was supported by the PNP and PCMI programs and by ANR project COMETOR (ANR-18-CE31-0011) and OGRESSE (11-BS56-026-01), DIM-ACAV+ (Région Ile de France), Université Paris-Sud, IN2P3 and the JWST project from the LABEX-P2IO. The NanoIR 2-s microscope was installed on the SMIS3 beam line at SOLEIL Synchrotron.

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