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2D and 3D FTIR hyperspectral imaging of the Paris meteorite

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Abstract

Significant compositional and structural heterogeneity at nm to mm scales is an important characteristic of primitive extraterrestrial materials. This heterogeneity has been observed by different techniques such as infrared (IR) micro spectroscopy mapping which is a powerful tool as it is (a) non-destructive, (b) allows comparison with astronomical observations of primitive Solar System small bodies (asteroids, comets) [1] and (c) access both to the mineral and carbonaceous phases. It also allows hyperspectral imaging studies, useful to visualize the spatial distribution of different components, their assembly and thus to deduce constraints about their formation and their evolution in the young Solar System.

Here, we report the analysis of high-resolution Fourier Transform IR hyperspectral imaging analytical measurements at the micron scale on a fragment of the Paris meteorite (one of the most primitive carbonaceous chondrites [2]), supported by Raman and SEM-EDS measurements. The fragment is crushed in a diamond compression cell. The micro-FTIR analyses are performed in transmission with two setups, an imaging microscope with a matrix detector using a thermal source and a system using a single point detector coupled with the synchrotron source at the SOLEIL synchrotron facility (SMIS beamline).

We obtain the spatial distribution of chemical/mineralogical components. We confirm at a larger scale (10 µm) the presence of hydrated amorphous silicates observed at a smaller scale (1 µm). Based on the relative abundance of different minerals (hydrated amorphous silicate, olivine, diopside and serpentine) we propose a sequence of aqueous alteration. Considering the spatial correlation of minerals with organic matter, we discuss the effects of aqueous alteration on the organic matter in bulk. In particular, we detect an increase of the CH2/CH3 ratio in the altered zone and present the possible scenarios that lead to the observed chain length shortening/cracking of hydrocarbons [3].

Thanks to the Focal Plane Array detector, 3D hyperspectral micro-tomography can be performed to access structural information on intact samples [4]. Here, we also present the first 3D infrared reconstruction of three fragments of the Paris meteorites combined to X-ray micro-tomography. Using a Focused Ion Beam (FIB), we fix the samples at the extremity of a needle (Fig. 1). This preparation minimizes the organic contamination. Then we perform IR 3D hyperspectral micro-tomography at SMIS to reconstruct the sample at different wavelengths and to reconstruct the spatial distribution of the different components. This allows to study the 3D spatial correlation between the meteoritic organic and mineral phases at scales down to ~3 µm.

Moreover, X-rays tomography is also performed on the same Paris particles (see Figure 1(c)), at the PSICHE beamline of the synchrotron SOLEIL, to obtain complementary information about the physical properties of the grains (shape, fractures, porosity). X-ray analysis are performed at low energy to preserve the organic matter inside our sample. By combining X-ray and FTIR data we obtain a physico-chemical description of precious grains in a non-destructive way.

Performing FTIR micro-tomography on extraterrestrial samples rich in organic matter, is an important step in view of the sample return of dust particles from carbonaceous asteroids Ryugu by the

Hayabusa2 mission and Bennu by OSIRIS-REx mission. In the sequence of analyses, micro-FTIR 3D spectral imaging coupled with X-rays tomography can provide a first, powerful non-destructive characterization of whole grains, in order to identify areas of interest and provide useful information before subsequent destructive analyses.

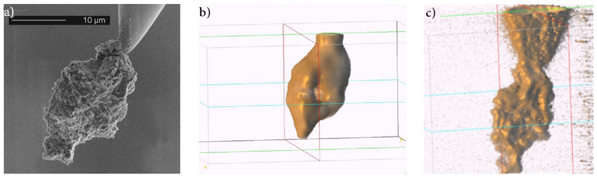

Figure 1: Paris meteorite sample welded at the extremity of the tungsten needle thanks to FIB preparation (a) TEM image, (b) IR reconstruction of the continuum at 2.6 µm and (c) X-ray reconstruction at 20 keV.

Acknowledgements

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