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<tr><td>ESRF</td><td>Experiment title:<br>Wavelength-dispersive X-ray fluorescence spectroscopy of rare-earth elements in extraterrestrial material enabled by a highly-curved HAPG crystal optic</td><td>Experiment number:<br>ES-1319</td></tr>
<tr><td>Beamline:</td><td>Date of experiment:<br>from: 05/04/2023 to: 11/04/2023</td><td rowspan="2">Date of report:<br>21/09/2023<br><br>Received at ESRF:</td></tr>
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**Report:**

The energy-dispersive confocal X-ray fluoresence spectroscopy setup (**Figure 1**) available at the ID13 nano-hutch was used succesfully for the non-destructive, in-situ analysis of samples returned from asteroid Ryugu by JAXA's hayabusa2 space probe. The HAPG crystal optic was not used as its mosaicity was too large.

A plethora of individual sub-µm sized grains rich in Ti, Cr, Cu, Zn and to a lesser extent Ni were found to be spread in a heterogeneous manner on the sub-µm scale in the phyllosilicate matrix of Ryugu sample C0070-10 (**Figure 2**).

Refractory inclusions, Ca, Al-rich inclusions (CAIs) and chondrules are very rare or absent in Ryugu material and their analogue (CI carbonaceous chondrites). It is still uncertain if they were ever present as matrix components, or if they, or their primary textures, were destroyed during aqueous alteration. A refractory metal nugget (RMN), with a euhedral shape and diameter of ~1.5 µm, is reported for the first time in an asteroid Ryugu sample (**Figure 3**), and contained the following elements: Os (very refractory), Sc (very refractory), Ir (refractory), Pt (refractory), As (moderately volatile) and Se (very volatile). These elements are not expected to all condense together in the Solar Nebula due to their large difference in condensation temperature and geochemical affinities and would suggest that such a phase is the result of an (aqueous) alteration process.

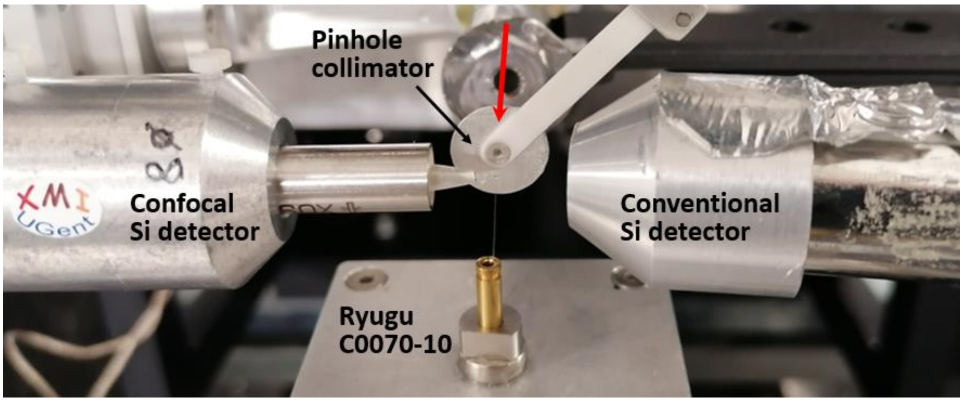


**Fig. 1** Low-energy (19.1 keV), sub-micrometer resolution (~ 80 nm x 80 nm) synchrotron radiation X-ray fluorescence spectroscopy setup used at beamline ID13 (ESRF, Grenoble). The experimental setup utilized a confocal and conventional Si drift detector which are placed on opposite sides of the sample. The incoming SR beam is indicated with a red arrow.

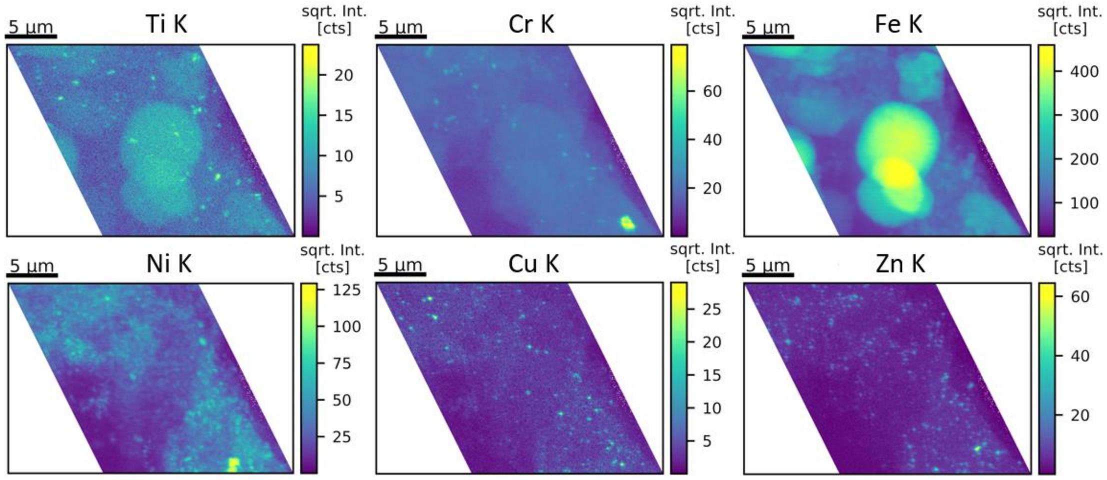


**Fig. 2** Confocal SR-XRF maps inside Ryugu sample C0070-10. Sub-micrometer mineral phases rich in metals Ti, Cr, Ni, Cu and Zn are present throughout the Ryugu matrix. The SR-XRF maps are slanted due to a horizontal motor drift which occurred when using a smaller stepsize of 50 nm (=slight oversampling). An acquisition time of 0.3 s per pixel was used.

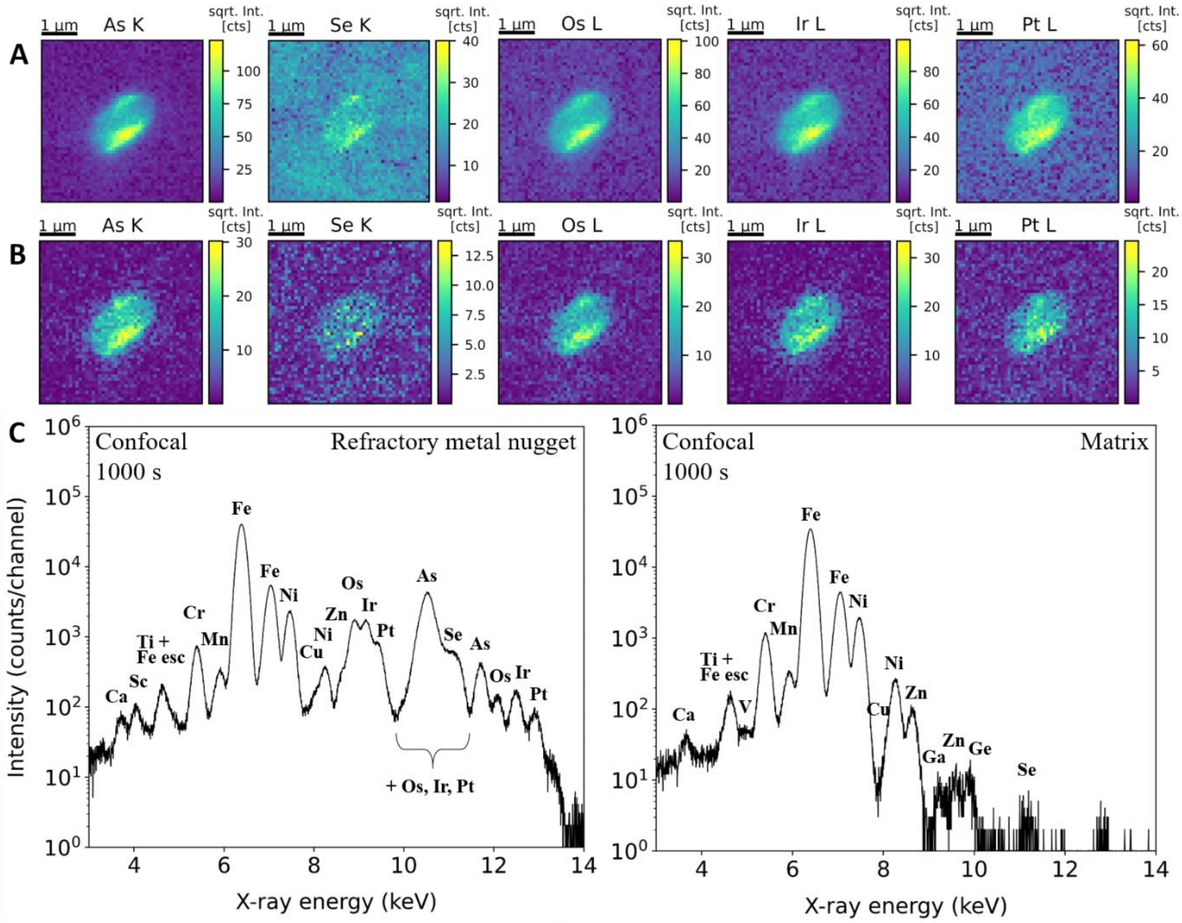


**Fig. 3** SR-XRF maps of a RMN inside Ryugu sample C0070-10 obtained with the conventional **(A)** and confocal **(B)** detector. The euhedral RMN contains the refractory Pt-group elements Os, Ir, Pt, together with As (moderately volatile) and Se (very volatile). **(C)** Confocal point spectra (1000 s acquisition time) on the RMN (left) and Ryugu matrix (right) ~ 10 µm below the RMN. Many matrix elements are detected in the RMN point measurement as the confocal volume is much larger than the RMN. The latter is also enriched in Sc, which was not visible in the SR-XRF maps due to a much shorter acquisition time, i.e. 0.25 s, per pixel.