SXRF ANALYSIS OF AN ORGUEIL FRAGMENT AS ANALOG MATERIAL FOR RYUGU SAMPLES RETURNED IN THE HAYABUSA2 MISSION. B. J. Tkalcec[1]*, P. Tack[2], E. De Pauw[2], B. Vekemans[2], T. Nakamura[3], M. Matsumoto[3], K. Amano[3], M. Takahashi[3], Y. Fujioka[3], E. Kagawa[3], G. Falkenberg[4], L. Vincze[2], F. E. Brenker[1]. [1]Goethe University, Altenhöferallee 1, 60438 Frankfurt am Main, Germany. [2]Ghent University, Belgium. [3]Tohoku University, Japan. [4]DESY, Hamburg, Germany. *tkalcec@em.uni-frankfurt.de.

Introduction: The recently harvested sample material from the surface and subsurface of C-class asteroid Ryugu by the Hayabusa 2 mission includes many coarse-grained fragments [1] and investigation of this material will inevitably include various analytical techniques, many of which will be invasive applications and require invasive sample preparation procedures. The ability to chemically identify and localize internal features by non-invasive techniques that also require no prior sample preparation is one of the essential first steps of the sequence of investigation. Synchrotron X-ray fluorescent computed tomography (SXRF-CT) [2] is an ideal non-invasive analytical technique to achieve this and was applied to a fragment of the CI chondrite Orgueil to identify and localize any internal features. Previous reports from Earth-based observations and orbital remote sensing results have concluded that the Ryugu surface material is likely most akin to CI or CM2 chondrites [3], such as Orgueil or Murchison, respectively. We present here some of our SXRF analysis results of a ~250 µm sized Orgueil fragment .

Method: The Orgueil fragment was mounted directly on a C-fiber pad on an Al-rod and encased inside a polyimide cap to simulate the air-free mounting construction planned for the investigation of the returned Ryugu material. For the chemical identification and spatial localization of internal features of Ryugu samples, a combination of confocal-SXRF [4] and SXRF-CT [2] was selected as the ideal time-efficient, non-invasive, non-destructive analytical technique. Both techniques were applied at 19 keV at the P06 beamline of the Deutsches Elektronen-Synchrotron DESY in Hamburg, Germany for 2D and 3D measurements. XRF data was processed using PyMca5 fitting routines. Elemental distribution images were corrected for probed sample volume and density per pixel, using the respective Compton signal.

Results: An initial rough overview scan was performed with a spatial resolution of 2 µm and acquisition time of 0.75 s/pixel, non-depth-resolved projections with the signal detected from the maximal information depth for a given element at that specific sample position. The results (Fig. 1) reveal various Sr-rich hotspots and an inhomogeneous Fe-distribution that includes several circular or oval features ~20-50 µm in diameter with thick iron-enriched rims and relatively Fe-poor interiors (Fig. 1, arrows).

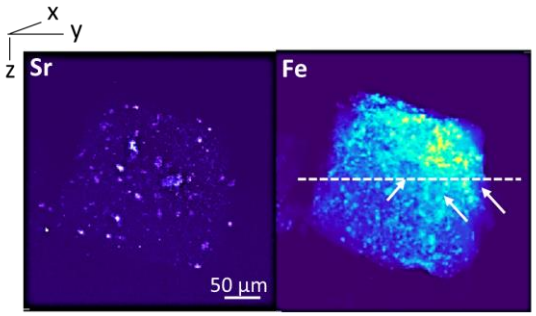

Fig. 1: Rough non-depth-resolved SXRF overview scan showing inhomogeneous Sr and Fe distributions. Arrows show Fe-rimmed features. White-dashed line is the z-position of the cross-section slice (Fig. 2 top).

A high resolution (HR) cross-section SXRF-CT scan slice through the entire sample depth (at the height indicated by a dotted line in Fig. 1) at 0.75 s acquisition time, 1.5 µm spatial resolution, and rotation steps of 2° over the full 360° sample rotation, reveals similar Fe-rich features (Fig. 2, top). A subsequent HR 3D confocal slab (Fig. 2 red box and bottom image) 20 µm x 187 µm x 99 µm reveals that the positions of the main Sr hotspots often coincide with the rims of the oval features (Fig. 2 bottom).

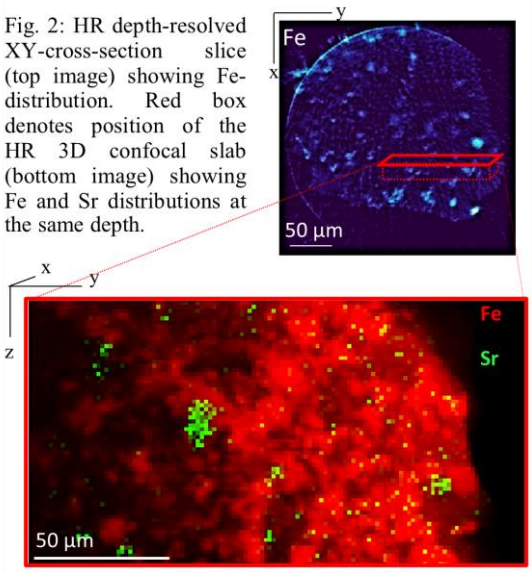

Fig. 2: HR depth-resolved XY-cross-section slice (top image) showing Fe-distribution. Red box denotes position of the HR 3D confocal slab (bottom image) showing Fe and Sr distributions at the same depth.

Discussion: The Sr-hotspots are likely attributable to either carbonates or CAIs. Further non-invasive analysis by, for example, inelastic X-ray Raman Scattering (XRS) [5] using a relatively low energy beam (9-13 keV) to excite light elements ($z \leq$ Fe) will determine the distinguishing presence or absence of, for example, carbon or aluminum. An interpretation of the Fe-enriched rim features will be possible after further quantification of the acquired SXRF data, and/or comparison with acquired CT data, to determine whether or how the observed Fe-enriched rim features are chemically and/or mineralogically distinct from the Orgueil matrix.

Conclusion: With a beam energy of 19 keV chemical compositions and elemental distributions can, for elements between Ca $\leq z \leq$ Zr depending upon the size of the sample, be determined and quantified for both matrix and internal features. Though similar results could also be achieved by a fully depth-resolved 3D SXRF CT scan, the latter would take considerably longer for a sample of this size, at similar spatial resolution and acquisition time per voxel, since the full sample volume would need to be scanned, in contrast to confocal XRF where one can selectively and directly investigate a smaller sub-volume, though the latter may entail a lower depth resolution. In view of the multi-phase investigation and invaluable nature of the returned Ryugu samples, this combination of confocal SXRF [4] and SXRF-CT [2] is an ideal, time-efficient, non-invasive, non-destructive analytical technique for the chemical identification and spatial localization of internal features of Ryugu fragments prior to sequential invasive sample preparation and further analysis.

References: [1] Hayabusa2 Project update, JAXA, www.hayabusa2.jaxa.jp/en/topics/20201225_samples (2020.12.28). [2] Vanhoof C. et al. (2019) *J. Anal. At. Spectrom.*, 2019, 34, 1750-1767. [3] Perna D. et al. (2017) *A&A*, L1, 599-602. [4] Bauters et al. (2018) *Anal. Chem.*, 90, 3, 2389–2394. [5] Huotari S. et. al. (2011) *Nat. Mater*. 10, 489–493.