Linking Remote Sensing, In-situ and Laboratory Spectroscopy for a Ryugu Returned Sample. A. Maturilli[1], S. Schwinger[1], E. Bonato[1], J. Helbert[1], M. Baqué[1], M. Hamm[2], G. Alemanno[1], M. D'Amore[1], [1]German Aerospace Center (DLR) - Institute of Planetary Research, Rutherfordstrasse 2, 12489 Berlin, Germany (alessandro.maturilli@dlr.de), [2]Freie Universität Berlin – FB Geowissenschaften – Institut für Geologische Wissenschaften Planetologie und Fernerkundung – Malteserstr. 74 – 100 – 12249 Berlin, Germany.

Introduction: In 2022 JAXA issued an Announcement of Opportunity (AO) for receiving Hayabusa2 samples returned to Earth. We responded to the AO submitting a proposal based on using a multi-prong approach to achieve two main goals. The first goal is to address the subdued contrast of remote-sensing observations compared to measurements performed under laboratory conditions on analog materials. For this we will link the hyperspectral and imaging data collected from the spacecraft and the in-situ observations from the MASCOT lander instruments (MARA and MASCam [1-3]) with laboratory-based measurements of Hayabusa2 samples using bi-directional reflectance spectroscopy under simulated asteroid surface conditions from UV to MIR/FIR achieved using three Bruker Vertex 80V spectrometers in the Planetary Spectroscopy Laboratory.

The second goal is the investigation of the mineralogy and organic matter of the samples collected by Hayabusa2, to better understanding the evolution of materials characterizing Ryugu and in general of protoplanetary disk and organic matter, investigating the aqueous alteration that took place in the parent body, and comparing the results with data collected from pristine carbonaceous chondrite analog meteorites. Spectral data will be complemented by Raman spectroscopy under simulated asteroid surface conditions, X-ray diffraction, would also allow us to define the bulk mineralogy of the samples as well as investigate the presence and nature of organic matter within the samples. In situ mineralogical and geochemical characterization will involve a pre-characterization of the sample fragments through scanning electron microscopy (SEM), low voltage electron dispersive X-ray (EDX) maps, and micro IR analyses of the fragments. If allowed, a thin section of one grain will be used for electron microprobe analyses (EMPA) to geochemically characterize its mineralogical composition.

To train our data collection and analysis methods on a realistic sample, we selected a piece of the meteorite Mukundpura, a CM2 carbonaceous chondrite,, as analogue to Ryugu's surface [4]. The Mukundpura chunk we selected for this study measures 4 mm in its maximum dimension, to have a test sample of similar size as the Hayabusa2 grain we requested in our proposal to JAXA's AO. The test gave us confidence that we can measure with good SNR measurements in bi-directional reflectance for samples around 3 mm in size.

To address our second goal the spectral data was complemented by Raman spectroscopy measured again under simulated asteroid surface conditions in our Raman Mineralogy and Biodetection Laboratory at DLR.

The Hayabusa2 sample A0112: Back in August 2022, the Institute of Planetary Research at DLR (Berlin) received a fragment retrieved by the Hayabusa2 mission from asteroid Ryugu [5]. The fragment assigned to us for analyses is sample A0112, a pristine sample with 5.1 mg weight, and 3046x1823 µm size collected from sampling chamber A (see Figure 1).

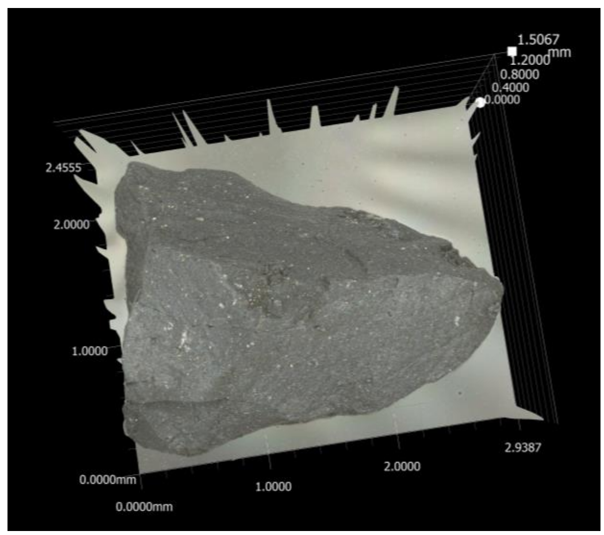

Figure 1. High resolution image and topographic map of Hayabusa2 sample A0112 in its container, acquired with a Keyence 3D VXX – 7000 microscope.

Research plan: The crucial point of our work is to use the very large collection of analytical instruments in our consortium to measure the requested Hayabusa2 grain using non-destructive techniques. With our FTIR spectrometers (3 identical Bruker Vertex80V) at the Planetary Spectroscopy Laboratory (PSL) of DLR we can measure bi-directional bulk sample spectroscopy of sample A0112 completely under vacuum in the whole spectral range from UV to FIR (0.25 µm to at least 25 µm spectral range). A Bruker Hyperion 2000 FT-IR microscope allows mapping the Hayabusa2 grain from

VIS to MIR (0.4 to at least 16 µm spectral range) with a spatial resolution down to 50 µm.

We trained our analysis technique on a Mukundpura piece with diameter 4 mm, typically of the larger grains available in the Hayabusa2 sample collection. We manufactured a special sample holder for reflectance measurements in the FTIR spectrometer. We adapted our standard measurement approach at PSL reducing the aperture to fit the size of the samples. With this measurement configuration we obtained measurements of our test sample to show the feasibility of our spectral method on Hayabusa2 samples. As an example of this, in Figure 2 we show the MIR spectrum of the 4mm Mukundpura particle, obtained reducing the aperture of our light source beam to the minimum, 0.25 mm compared with a measurement of the same meteorite acquired with a much larger aperture (4mm, as standard). This figure shows that even after drastically reducing our beam aperture, we are able to obtain high quality FTIR spectra of an Hayabusa2 sample by just using our traditional spectroscopic set-up.

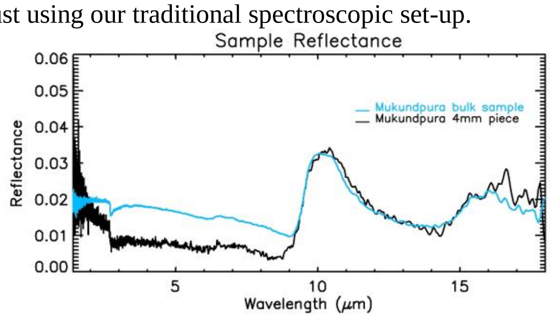

Figure 2. Mukundpura bulk sample measured with traditional beam aperture of 4 mm (light-blue) and with reduced aperture (0.25 mm) on the small 4 mm piece of the same meteorite.

Once the Hayabusa2 grain is spectrally characterized, we compare its spectra to our spectral database to confirm remote sensing and preliminary analysis identifications, and to compare with measurements of meteorites acquired in our PSL lab under exactly the same conditions as the Hayabusa2 samples. The sample will be characterized in parallel with a Keyence VHX-7000 3D digital microscope with the VHX-7100 observation system that allows very high-resolution 3D mapping of samples and grain size analysis.
To investigate the nature of Ryugu (and at the same time prepare for future data analysis from the JAXA MMX mission) the samples will be analyzed using Raman spectroscopy. Building on the experience gathered from the analysis of Hayabusa1 particles by Raman microspectroscopy, we can measure micro particles under neutral atmosphere with our WiTec Alpha 300 confocal Raman microscope [6]. Raman spectroscopy complements IR spectroscopy in the determination of the mineralogical composition of the sample, is performed in a contactless manner, and under neutral (e.g. nitrogen) atmosphere thanks to the long working distance objective. Figure 3 shows tests on the Mukundpura particle; different measurement modes were used (single spectra, line scans, and area scans) to reveal the presence of olivine, carbon, and magnesium silicates.

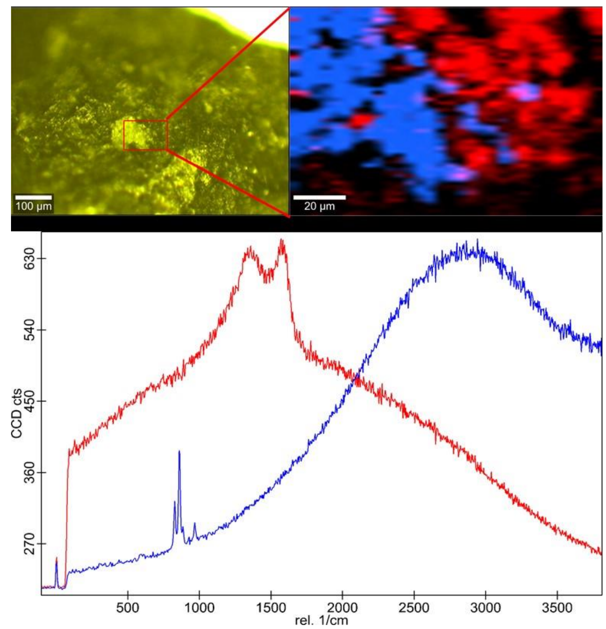

Figure 3. Raman spectra of the Mukundpura particle. The blue color denotes the presence of the olivine doublet (827 and 859 cm-1) and red the presence of carbon D and G bands (1340 and 1568 cm-1). The latter is in accordance with the abundance of organic matter in the chondrite.

Following the FTIR and Raman analyses, the particle will be characterized regarding their mineralogy and mineral chemistry using non-destructive scanning electron microscopy (SEM) and energy-dispersive X-ray spectrometry (EDS), whereas the bulk chemical compositions of the samples will be determined non-destructively by micro X-ray fluorescence (µXRF) analysis. In addition, electron microprobe techniques will be performed on a representative sample from which a section will be produced if permitted by the Hayabusa2 sample allocation committee.

References: 1] Jaumann, R., et al. (2019) *Science*, *365*, 817-820. [2] Grott, M., et al. (2019) *Nat Astron. 3*, 971–976, [3] Hamm, M., et al. (2022) *Nat. Comm.*, *13*, 364 [4] Ray D. and Shukla A. D. (2018) *PSS 151*, 149-154. [5] Nakamura, T. et al. (2022) *Science*. [6] Böttger, U. et al. (2013) *LPS XVIV*, Abstract #2092.