UV-VIS SPECTROSCOPY OF HAYABUSA 2 GRAINS: COMPARISON WITH CARBONACEOUS CHONDRITES AND ASTEROID (162173) RYUGU. M. M. Grady[1], F. A. J. Abernethy[1], M. Anand[1], I. A. Franchi[1], R. C. Greenwood[1], M. Suttle[1], A. B. Verchovsky[1], M. Ito[2], N. Tomioka[2], M. Uesugi[3], A. Yamaguchi[4], M. Kimura[4], N. Imae[4], N. Shirai[5], T. Ohigashi[6], J.-P. Bibring[7], D. Loizeau[7], C. Pilorget[7], M-C. Liu[8], T. Yada[9], M. Abe[9], T. Usui[9]. [1]School of Physical Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK monica.grady@open.ac.uk) [2]JAMSTEC-Kochi, [3]JASRI/SPring-8, [4]NIPR, [5]Kanagawa Univ., [6]PF/KEK, [7]IAS-Orsay, Fr [8]LLNL, [9]ISAS/JAXA, the Ph2K team.

Introduction: Material from asteroid (162173) Ryugu is the first material from a C-Class (carbonaceous) asteroid to be brought directly back to Earth, returned in December 2020 by the Japanese Hayabusa2 mission. September 2023 should see the return of samples from the B-Class asteroid (101955) Bennu, by NASA's OSIRIS-REx mission. Asteroids like Ryugu and Bennu are very rich in volatile elements and organic matter. This makes them particularly important for understanding the origin and distribution of such components in the formation of the Solar System – and, more specifically, for the composition and abundance of the building blocks of life on Earth. Spectral measurements, both from Earth [1] and when the spacecrafts were in orbit around their respective asteroids [2, 3] indicate a close relationship between the mineralogy of the asteroids to those of the most primitive carbonaceous chondrites. The significance of returning such material directly to Earth is that these meteorites are, for all elements heavier than lithium, close in composition to the solar photosphere. In other words, they record the composition of the primordial Solar System prior to aggregation into different parent bodies.

Unfortunately, the characteristics that make these asteroids extremely interesting also render them extremely friable – they are probably closer to dried clods of clay than indurated rocks [4]. Their fragility means that they are likely to be extremely susceptible to break-up during atmospheric entry and to terrestrial weathering, if not collected immediately after falling, implying that such material would be rare in the terrestrial meteorite collection [5]. Indeed, there are only 9 meteorites that have been classified as CI chondrites, 4 of which were preserved in Antarctic ice prior to collection [6], and some of which may be CY chondrites. Return of samples directly from primitive asteroids allows us to analyse volatile species that have not been subject to terrestrial alteration. They also enable predictions made from remote sensing to be confirmed or rejected – validating compositional estimates inferred from telescope observations and thus making models of planetary evolution drawn from asteroid spectra more robust. It is somewhat ironic that the first beneficiary of such an internally-consistent match between sample and asteroid is that of asteroid (162173) Ryugu itself. Prior to sample return, it was predicted from spacecraft spectral observations [7] to have a mineralogy similar to heated (CY-class) carbonaceous chondrites. However, analyses of the Hayabusa2 samples finds indicate that it is CI-like and has experienced minimal heating [8, 9].

As part of the preliminary curation activities in preparation for more detailed analysis of Hayabusa2 material, we have been developing a non-invasive and non-destructive technique to identify individual grains with specific compositional characteristics. The technique. UV-Vis-NIR reflectance microspectroscopy, has been trialled on powdered CI and CM chondrites.

Method: Diffuse reflectance spectra of a series of powdered minerals and carbonaceous chondrites were obtained using a newly-purchased JASCO MSV-5700 UV-Vis-NIR microspectrophotometer (MSP) fitted with a Cassegrain objective lens (magnification x 16). The MSP has two separate light sources (deuterium and tungsten; sources switched at ~ 330 nm) and diffraction gratings (200 – 900 nm and 700 – 2500 nm), giving a continuous useful spectral range of 200 – 2500 nm. The grating change is automatic and can be programmed to occur at any wavelength between 800 - 900 nm. There is almost aways a hiatus in signal at the grating change; in order to ensure that a complete spectrum is obtained over the grating change, each sample is analysed twice at the same position, with grating switches at 750 nm and 850 nm.

The output from the light sources are focusable through the microscope to spot sizes between 20 - 400 µm in diameter, depending on the combination of apertures selected. Viewing geometry is such that incidence and exit angles of the light are perpendicular to the sample. The system is calibrated with holmium-doped halon and spectra are reported relative to a Spectralon standard.

The technique is complementary with methods that analyse finely-ground homogenized powders, as we are able to obtain spectra from either powdered materials or thin sections, as long as the grains at least fill the minimum field of view.

Results: Figure 1 shows a representative selection of spectra from minerals characteristic of carbonaceous chondrites. Figure 2 gives spectra from a series of CI and CM chondrites. Each spectrum was a single scan across the grains, at a speed of 400 nm per minute and data collection intervals of 0.2 nm. All materials are finely powdered but are unsieved; microscope images (Figure 3) show that the grains are generally < 100 µm across.

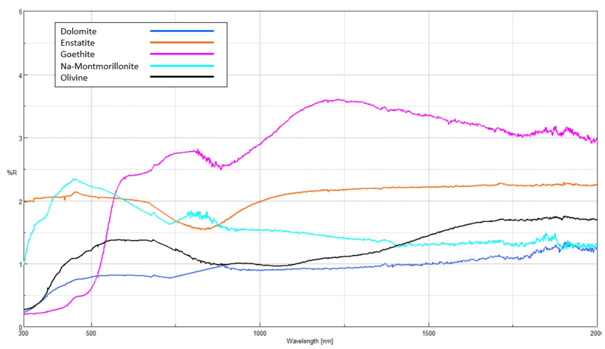

Figure 1: UV-Vis-NIR spectra of single mineral grains typical of CI and CM chondrites. Aperture was 50 µm. y-axis: Reflectance (arbitrary units); x-axis: Wavelength 200 – 2000 nm. Apologies for small print, still getting to grips with instrument software. Each spectrum was a single scan across the grains, at a speed of 400 nm per minute and data collection intervals of 0.2 nm.

The single grain mineral spectra show most of the characteristics exhibited by spectra taken from homogeneous powders from larger reservoirs [10,11], demonstrating that the microspectrophotometer system is capable of producing spectra from very small samples: we have not yet pushed the system to its limits, by reducing the aperture to its minimum value of 10 µm or using the higher magnification objective lens (x 32).

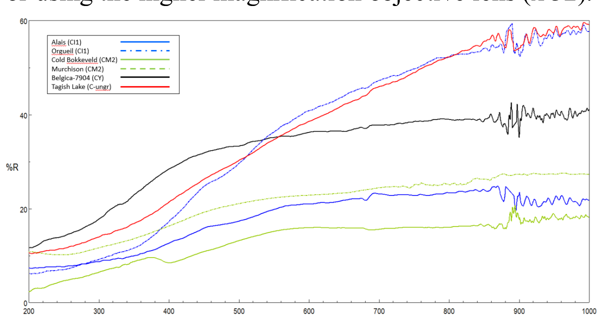

Figure 2: UV-Vis-NIR spectra of clumped mineral grains from six carbonaceous chondrites. Aperture was 50 µm. y-axis: Reflectance (arbitrary units); x-axis: Wavelength 200 – 1000 nm. Apologies for small print as above.

Spectra from the meteorite samples are noisier than those from the mineral grains, presumably because the surface of the samples are less well-defined (Figure 3). Even so, there are sufficient differences between the different meteorite groups that interpretation of spectral features from minerals can be seen – for example, the absorption feature from phyllosilicates around 680 nm is readily visible in the spectra from the CI1 chondrites Orgueil and Alais, but less obvious in the CM2 meteorites Cold Bokkeveld and Murchison (Figure 2).

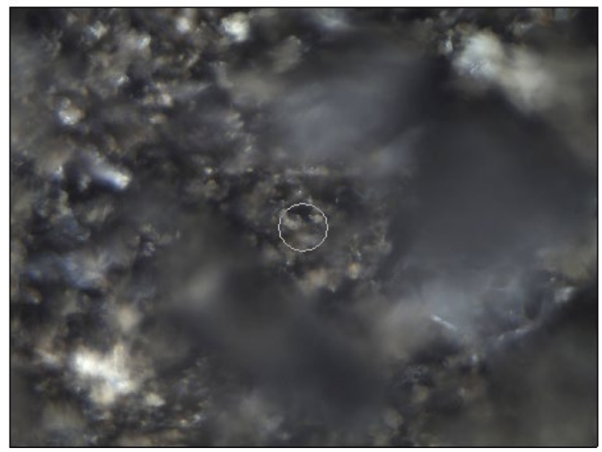

Figure 3: Image of a clump of particles from Orgueil in reflected light from the microspectrophotometer. The circle represents the aperture and is 50 µm across.

We have now established the main analysis protocols for handling and spectral analysis of 20 – 50 µm-sized grains of primitive carbonaceous meteorites. By the time of the conference, we anticipate having analysed material from asteroid Ryugu and are looking forward to the arrival of material from asteroid Bennu in autumn.

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