UV TO FIR REFLECTANCE SPECTROSCOPY OF FRESH CARBONACEOUS CHONDRITE, MUKUNDPURA METEORITE: A POTENTIAL ANALOGUE TO JAXA HAYABUSA 2's TARGET RYUGU. I. Varatharajan[1], A. Maturilli[1], B. Sivaraman[2], J. Helbert[1], J.K. Meka[2], S. Vijayan[2], A. Bhardwaj[2], and K. Otto[1], [1]Institute for Planetary Research, German Aerospace Center DLR, Rutherfordstrasse 2, 12489 Berlin, Germany (indhu.varatharajan@dlr.de), [2]Physical Research Laboratory, Navrangpura, Ahmedabad, Gujarat 380009, India

Introduction: Carbonaceous chondrites include most primitive known meteorites. Although carbonaceous chondrites occupy a major fraction (75%) among asteroids, they are rare [4.6%] in Earth's meteorite inventory [1,2]. This limits us in understanding the diversity in mineralogy and composition of this asteroid class. Two of the sample return missions to NEAs which include JAXA Hayabusa 2 mission to Ryugu and NASA OSIRIS-Rex mission to Bennu are both C-type asteroids. For remote sensing classification and mapping of C-type asteroids, it's important to perform detailed spectroscopic investigation of this meteorite class at wide spectral range [3] (from ultraviolet to far-infrared) and varying phase angle combinations. In this study, we investigated the mineralogy of the fresh carbonaceous chondrite fall, Mukundpura, through reflectance spectroscopy at wide spectral range (0.2-100 μm) of varying phase angle combinations with phase angles varies from 26° to 100°.

Sample: On June 6, 2017, a meteorite weighing ~2 kg fell in Mukundpura village (26° 52' 53"N, 75° 39' 54"E) at Rajasthan, India. This impact formed a nearly circular crater of ~40 cm diameter with a depth of ~15 cm and impactor shattered into several large pieces and numerous small pieces which weigh from gram to subgram-sized fragments. This meteorite is then classified as CM2 class of carbonaceous chondrites [4-6].

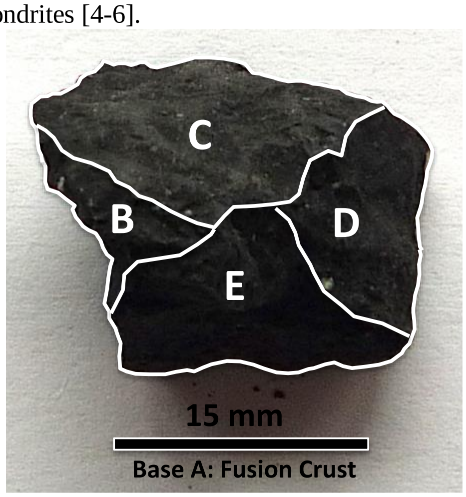

Figure 1. The Mukundpura sample analyzed. The boundaries show the faces of the samples for which the spectroscopy is analyzed. The base A of the sample is the fusion crust of the meteorite.

We collected multiple fragments from the Mukundpura impact site one amongst them shown in Fig. 1. The broken piece consists of 5 separate faces (Fig.1; A-E), and one among them is the fusion crust (Fig.1; A). Therefore, this study allows us to do understand the spectral nature of fusion crust and the sample itself.

Planetary Spectroscopy Laboratory (PSL): In this study, the reflectance spectroscopy of the Mukundpura sample in wide spectral range covering from ultraviolet (UV) to far-infrared (FIR) spectral regions (0.2μm – 100μm) is carried out at varying phase angle combinations at Planetary Spectroscopy Laboratory (PSL) facility located at the Institute of Planetary Research (PF) at the German Aerospace Center (DLR), Berlin [7].

Two Bruker Vertex 80V instruments hosted at PSL are used for the reflectance measurements. One of the spectrometers is optimised for spectral measurements in the ultraviolet (UV: 0.2-0.6 μm), visible-infrared (VIS-IR: 0.4-1 μm) range, mid infrared (MIR: 1-25 μm), and the second one for the Far infrared (FIR: 14-100 μm). Their corresponding specifications are tabulated in Table 1.

Table 1: Detector and Beamsplitters used for Reflectance measurements

Spectra	Detector	Beam-splitter
UV	GaP	CaF_2
VIS/IR	Si diode	CaF_2
MIR	MCT	KBr Broadband
FIR	DTGS201	Mylar

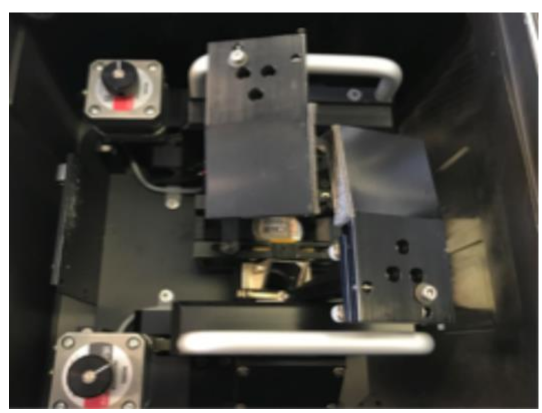

Figure 2. Bi-directional reflectance set-up at PSL

The Bruker A513 variable-angle reflection accessory facilitates the bi-conical reflectance measurements under vacuum conditions for phase angles between 26° and 170° (Fig. 2).

Methodology: In this study, we collectively measured the spectral reflectance at vacuum of all the faces of the sample (A-E) at wide spectral range (0.2-100 µm) at nine different phase angle combinations such as where the incidence (I°) and reflectance angles (R°) of each measurements (I°-R°) are 13°-13°, 13°-20°, 13°-30°, 13°-40°, 13°-50°, 20°-20°, 30°-30°, 40°-40°, 50°-50°.

Results: The visible-mid infrared (0.5-16 µm) spectra of the fusion crust (Fig. 3 a,b) and the sample face E (Fig. 3 c,d) measured at all phase angles is shown in Fig. 3.

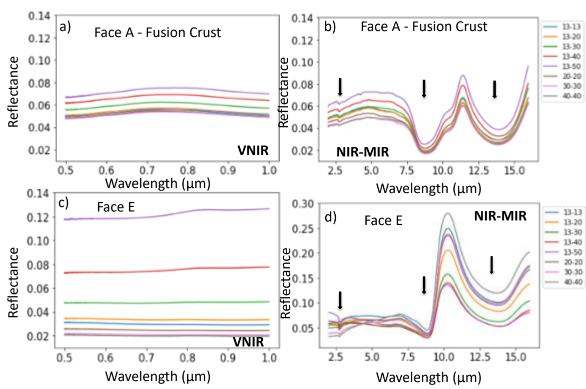

Figure 3. Visible – Mid IR spectra (0.5 – 16 µm) of Mukundupura meteorite at varying phase angle combinations.

In the visible-NIR region in Fig. 3a,c, the fresh meteorite spectra is nearly flat or not having any significant distinguishable absorption, however, the spectra of the fusion crust (Fig. 3a) shows a broad convex shape from end to end. The presence of OH bond in the meteorite is represented by the 2.8 µm absorption feature as shown in Fig. 3d. In the spectra of the fusion crust (Fig. 3b), the 2.8 µm absorption feature is highly subdued which could be explained by the loss of water within the mineral matrix during the atmospheric descent of the impactor. The shape and positions of absorption features near 9 and 13 µm for the fusion crust (Fig. 3b) and the sample (Fig.3d) is different suggesting the thermal weathering of the sample during the atmospheric descent.

Mukundpura vs Ryugu: Usually, spectroscopy of all the CM or C-class meteorites studied are powdered samples. Until Hayabusa 2, most of the solar system bodies possess a fine dusty surface and therefore studying the spectral properties of fine grained analogue materials were well-suited. However, Ryugu surprised us with a very rocky surface with no "smooth" surface to land [8]. This compels us to understand the spectral nature of the rocky undulated analogues such as our Mukundpura meteorite sample itself.

With Mukundpura meteorite we possess, which is not only a fresh CM2 type carbonaceous chondrite but is also solid rock which enables us to access the phase angle dependence on spectroscopy of such rough surfaces at wide spectral range. This will allow a direct comparison with the observations by Hayabusa 2 as well as the MASCOT lander.

On-going work and Conclusions: This study therefore directly enables us to understand the phase angle dependent spectral behavior of rocky carbonaceous class asteroids such as Ryugu. Part of the meteorite sample will also be powdered and the reflectance measurements will be repeated for the same to understand the spectral variations between rough-rocky surface and ash-like-regolith surface of C-type asteroids. The results of which will be presented at the meeting.

References: [1] Michel P. et al. (2015), *Asteroids IV*, Univ of Arizona Press. [2] Bischoff A. and Geiger T. (1995) *Meteoritics.* 30 (1): 113–122. [3] Trigo-Rodriguez J.M. et al. (2014) *MNRAS*, 437, 227–240 [4] Ray D. and Shukla A.D. (2018) *PSS*, 151, 149-154. [5] Tripathi R. et al. (2018), *Current Science*, 114,1. [6] Meteorite Bulletin Database, Code 66795. [7] Maturilli A. et al. (2019) at this LPSC meeting. [8] https://www.space.com/42131-asteroid-ryugu-mascot-landing-new-images.html