MICROIMAGING SPECTROSCOPY FOR THE EXPLORATION OF SMALL BODIES: FIRST LABORATORY MEASUREMENTS OF CARBONACEOUS CHONDRITE AND HED METEORITES AND A PROPOSED M6 INSTRUMENT FOR IN SITU MEASUREMENT.

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Introduction: Analysis of mineralogy in geological samples typically requires the preparation of thin sections or preparation of powders for determination of crystal structure of chemical composition. Here we describe a new technique for petrology, i.e., simultaneous analysis of small-scale mineralogy and texture, using visible/shortwave infrared (VSWIR) imaging spectroscopy, that requires no sample preparation and can be performed on a rough or cut surface. This approach is ideal for the survey of a collection of rare or precious samples to best target locations for followup destructive analyses or for *in situ* exploration of planetary surfaces, when multi-step sample preparation procedures may be prohibitively complex. Herein, we describe first results from analyses of meteorites (carbonaceous chondrites and HEDs) as well as an implementation of our microimaging spectroscopy instrument that is proposed for the Discovery-class mission MERLIN [1] to investigate the moons of Mars by landing and conducting in situ elemental and mineral abundance measurements on Phobos, a D-class small body.

Development History and Laboratory Instrument Specifications: Investments in imaging spectrometer miniaturization via a joint JPL-APL effort under the MatISSE program and JPL internal funding have led to the development of a hand-sized prototype instrument, the Ultra Compact Imaging Spectrometer (UCIS) (for details, see [2]). The UCIS prototype can be fitted with a variety of foreoptics for panoramic [3] or microscopic [4] imaging spectrsocpy investigations. Both were proposed for Mars2020 as MinMap [5] and CIMMBA [6], respectively, receiving Category 1 rankings. Presently, the UCIS prototype is operating at JPL, equipped with a spare focal plane array having a wavelength range of 500-2500 nm and breadboard foreoptics and an illumination system that achieves 81 µm/pixel spatial resolution on rock samples up to ~10 cm × ~10 cm in size with ~5 min required for data acquisition. Studies are being conducted for a variety of Earth and planetary science applications [e.g., 7, 8].

Utility for Meteorite Science in the Laboratory: VSWIR imaging spectroscopy provides a means of rapidly surveying the mineralogy and petrology of a meteorite, characterizing its compositional diversity and identifying key areas for followup investigation with very high resolution techniques that require sample preparation (e.g., SEM, TEM, FIBS, etc.). For our initial meteorite pilot study, we use a simple VSWIR

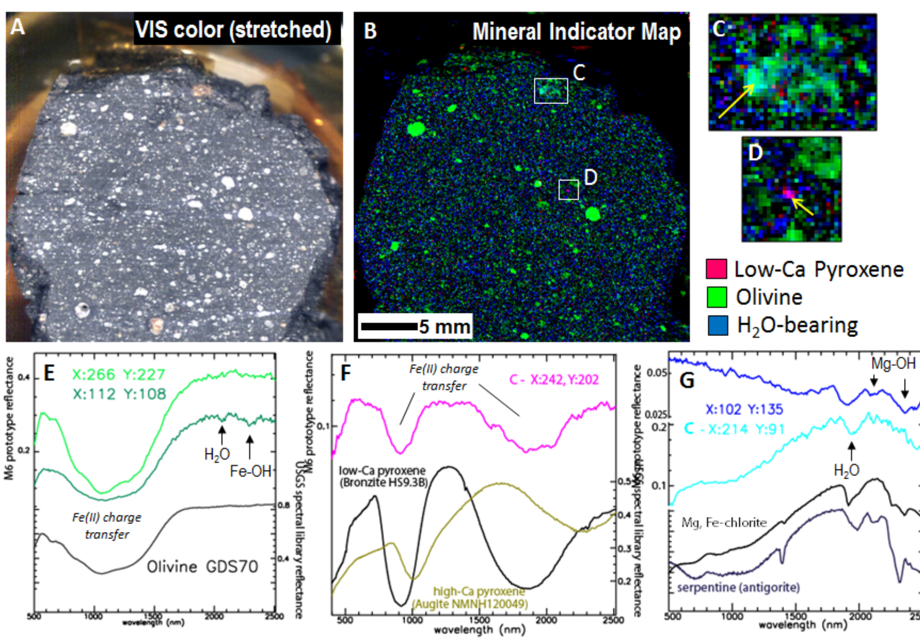

Figure 1: VSWIR imaging spectroscopy of the Murchison CM2 chondrite shows chondrules of diverse composition and fine-grained matrix with varying degrees of aqueous alteration. (a) approximate true color RGB combination (b) parameter map of mafic minerals and hydrated phases (R: LCPINDEX, G: OLINDEX, B: BD1900); (c) zoom of a region with aqueously altered or finely intermixed olivine and Fe/Mg phyllosilicates; (d) zoom of a rare location with pyroxene; (e, f, g) single pixel spectra specific locations (indicated by x,y coordinates) compared with library spectral data [14].

parameter-based approach for mapping absorption band depths, similar to that employed for analysis of VSWIR spectroscopic data acquired from Mars orbit [9], although more complex machine-learning algorithms for characterizing endmembers [10] or quantifying endmember abundance [11] and mineral chemistry [12] also are possible.

Analyses of the CM2 carbonaceous chondrite Murchison from the ASU meteorite collection demonstrate the ability to quickly map the distribution of mafic and altered phases, while highlighting key compositional variations (Fig. 1). Olivine-rich chondrules (green areas, Fig. 1b) of varying sizes are observed throughout the sample, and UCIS data permit the ready identification of an "anomalous" area, no more than a few pixels in size, with a low-calcium pyroxene-rich clast, most likely a chondrule fragment (magenta, Fig. 1d; 1f). Chondrules where olivine is affected by aqueous alteration (dark green spectrum) vs. those where they are not (light green) can be discriminated (Fig. 1e), and several Fe/Mg phyllosilicate alteration phases can be mapped in the matrix (blue areas in Fig. 1b; blue spectra in Fig. 1g).

Analyses of the howardite NWA1769 also demonstrate the ability of VSWIR imaging spectroscopy to map diversity among lithic fragments (Fig. 2). Understanding the abundance, distribution, and chemical composition of these minerals provides insight into processes on Vesta and linkages to interpretation to the Dawn dataset. Spectra from this sample show variations in Fe and Ca content among the abundant pyroxene clasts (red spectra Fig. 2c). Several large plagioclase grains are also readily apparent (black spectrum, Fig. 2c), as well as a small number of rare olivine-rich fragments (blue spectrum, Fig. 2c). Ongoing work includes SEM analyses to confirm and further characterize the identified phases [13].

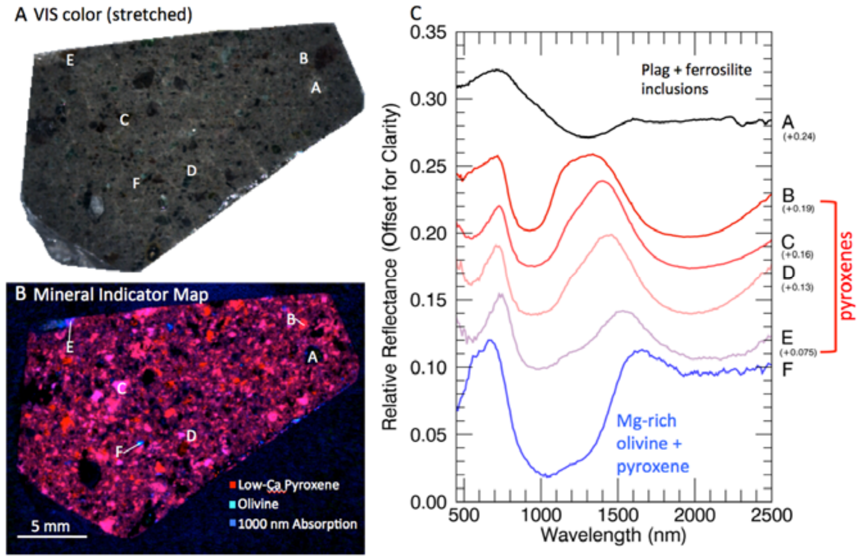

Figure 2: Howardite sample NWA1769 shows diversity in lithic fragments. (a) Approximate visible color image of sample (R: 750 nm, G: 650 nm, B: 550 nm), (b) Mineral indicator map (R: LCPINDEX, G: OLINDEX, B: BD1000) highlighting compositional diversity in pyroxenes within the sample (red to pink) and olivine (cyan). See [9] for parameter definitions. (c) Representative spectra from areas indicated by each letter.

Spacecraft Implementation for Small Body Exploration: Based on the heritage of the UCIS instrument, the MERLIN Mars Moon Microspectrometer/Microimager for Mineralogy (M6) was designed as an arm-mounted VSWIR infrared microimaging spectrometer system approximately 12 cm x 12 cm x 12 cm in size [1]. Operating over an expanded wavelength range from 500-3600nm using a Teledyne 6604a HgCdTe detector array with optimized cutoff wavelengths, M6 would be sensitive to all the phases in Figs. 1 and 2 and also possess improved sensitivity to volatile- and carbon-bearing phases via detection and spatial mapping of the fundamental absorptions of hydroxylated and hydrated phases (2600-3100 nm) as well as organics and carbonates, which have absorptions from 3300-3500 nm. After placement 5 ± 0.5 cm from the intended regolith or rock target, an illumination system, using heritage OCO-2 quartz-halogen lamps, lights the surface. Image cubes (~300 Mb compressed) are acquired at multiple focus positions of the actively illuminated target. The cubes are then are z-stacked using a MAHLI-like approach to produce best-focus, single images. Collectively, these data would enable identification of key silicate, hydrated, and organic phases in Phobos' regolith; point counting to quantify phase abundances; and testing hypotheses for the origin and evolution of this small body, working synergistically with other payload instruments.

Acknowledgements: This work has been conducted at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration. Thanks to J.A. Barrat (U Brest) for supplying this howardite.

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