VSWIR MICROIMAGING SPECTROSCOPY FOR GEOLOGIC HISTORY AND IDENTIFYING AND QUANTIFYING MINERAL, ICE, AND ORGANIC ABUNDANCES ON PLANETARY SURFACES

B.L. Ehlmann[1,2], D.L. Blaney[2], R.O. Green[2], P. Mouroulis[2], [1]Division of Geological & Planetary Sciences, California Institute of Technology, 1200 E. California Blvd., Pasadena, California, 91125 (ehlmann@caltech.edu), [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, California, 91109.

Introduction: Visibile to shortwave infrared (VSWIR) microimaging spectroscopy provides simultaneous fine-scale composition (mineralogy, ices, and organics) and fine-scale imaging at a grain scale. A major advantage of assessing composition with texture preserved is the ability to infer a time-ordered history of geologic processes. An ultra-compact imaging spectrometer (UCIS) has been built and demonstrated [1], a flight configuration is being matured to TRL 6 under MatISSE [2], and UCIS and commercial instruments (e.g. at Ehlmann's lab at Caltech) are presently being used for science investigations of meteorite [e.g. 3, 4], terrestrial sedimentary, hydrothermal, igneous, impactite, and biological samples [5, 6, 7]. Here, we briefly describe the specifications and choices for flight implementation, characteristics of the instrument approach, and science use scenarios.

Instrument Characteristics Summary: The UCIS flight implementation, SPIM [8], and commercial VSWIR microimaging spectrometers are, like proven orbiting/airborne systems, pushbroom sensors and build up the complete image using a scanning approach to build an image line-by-line (vs. MicrOmega [9] which adopts a framing camera approach and has an order of magnitude longer data acquisition time). Desired target measurement area, desired spatial resolution, and choice of focal plane array size, lead to selection of microscopic foreoptics to set a desired pixel size (typically 20-150 µm). Full spectral information is obtained for each pixel by projecting light from a spatial slit, through a grating onto the focal plane array. Acquisition is typically optimized for a specific wavelength range between 400 nm and 5000 nm, a spectral range which includes most diagnostic spectral information of most minerals, ices, and organics. The target temperature, desired NR, and chosen spectral range and resolution dictate cooling requirements. A simple visible to shortwave infrared light source further shortens measurement time.

Example flight implementations are discussed in [10, 11]. Typically, a 12x12x12 cm arm-based sensor of 2-2.5 kg with a DPU of 1-2 kg acquires several hundred thousand simultaneous independent measurements (pixels) of composition over a few cm^2 area of sample in <10 min. Data can be downlinked as full images (~200-500Mb/each) or processed onboard to downlink compositional summary products and "best" spectra when downlink volume-constrained.

Datasets and Use Cases: We are presently using microscopic imaging spectroscopy to investigate clast heterogeneity in impact melts [5,6], serpentinization and biomatter entombment in travertine springs [7], mafic composition of HED meteorites from Vesta [3], the nature of aqueous alteration in carbonaceous chondrite and martian meteorites (Figs. 1, 2), stromatolite

Figure 1. VSWIR Microimaging spectroscopy of a fragment of Allende demonstrates the ability to map mineralogical variability in fine-grained dark materials characteristic of small bodies. We map the compositional variability of chondrule fragments and the matrix.

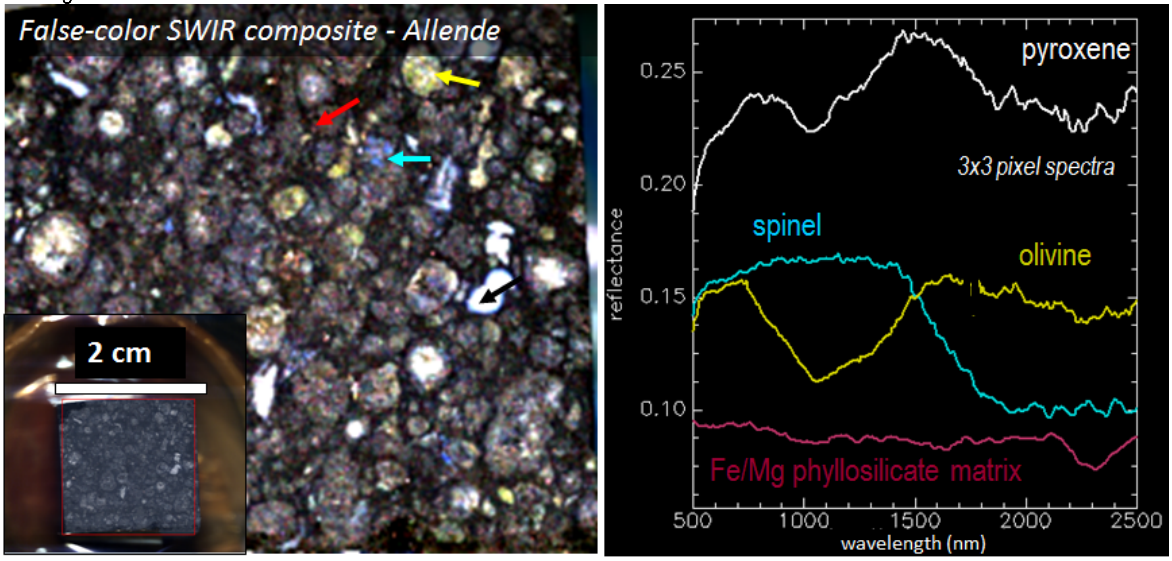


Figure 2. Laboratory microspectrometer test data demonstrate the ability of microVSWIR imaging spectroscopy to directly interrogate primitive materials to determine the products of aqueous alteration in the early solar system. Samples of Tagish Lake matrix minerals compared to single large crystal serpentine and chlorite from the Rossman lab collection show Mg-serpentine, identified by Blinova et al [2014] in their Tagish Lake study (thanks to G. Rossman for spectra).

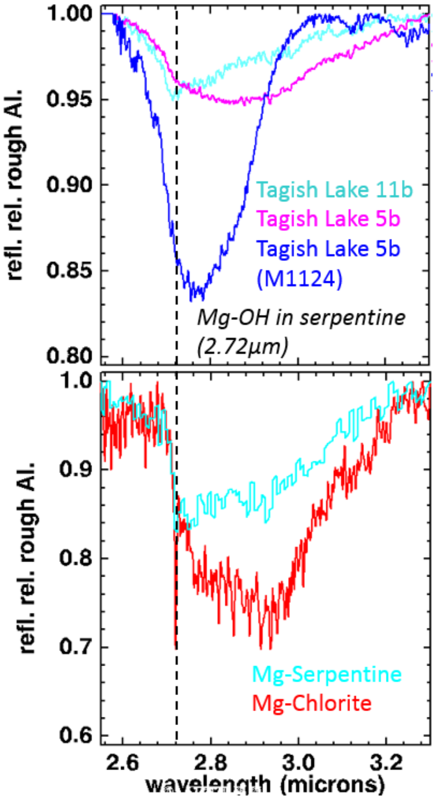
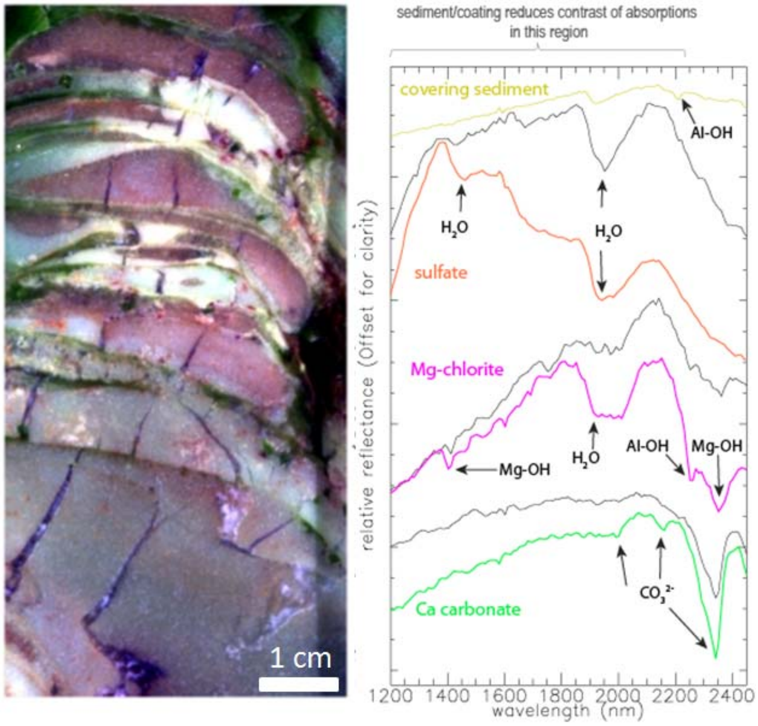


Figure 3. VSIWR microimaging spectroscopy of a stromatolite showing laminae with discrete sediments and zone of later metamorphic overprinting (sample courtesy W. Fischer).



sedimentation, and the structure of microbialites (Fig. 3).

Advantages and Disadvantages for Science: VSWIR microimaging spectroscopy has been developed to maturity for flight [1,2] and demonstrated in the laboratory and in the field to be useful in unraveling geologic histories. Disadvantages are few but include (i) relative insensitivity to anhydrous silicates with no iron (e.g. quartz); (ii) relative insensitivity to some metal oxides and some kerogens; (iii) semi-quantitative information only when the grain size of the sample is significantly below the spatial resolution (e.g. mudstones). These are relatively less important for many planetary targets and can be circumvented by use of VSWIR microimaging spectroscopy in concert with a synergistic payload (e.g. with chemistry, other spectroscopies). There are at least 7 key advantages: (1) demonstrated effectiveness in telescopic, spacecraft, aircraft, field, and lab modes for science objectives [5] with highly mature spectral libraries [12]; (2) provision of simultaneous composition and texture measurements (petrology); (3) non-destructiveness, ideal for reconnaissance for sample collection; (4) little to no sample preparation requirements as the technique works equally well on regolith and natural, rough rock surfaces (the Mars-2020 proposed implementation choice allowed 1cm of roughness over a 9 cm^2 area [10]); (5) rapid data acquisition with >100,000 independent samples of composition per each 5-10 minute measurement; (6) VSWIR spectra acquired provide direct linkages to remotely acquired datasets; and (7) the technique is robust under multiple planetary environments with significant measurement margin and well-understood cooling and radiation shielding requirements [1,2].

References: [1] Van Gorp, B., et al. (2014) *J.App. Rem. Sensing 8(1)*, 084988. [2] Blaney et al., this conf. [3] Fraeman et al., LPSC 2016, #2237 [4] Ehlmann, et al. 2016,. Asteroid Met. Connection, UCLA [5] Greenberger et al., 2015, *GSA Today* [6] Greenberger et al., this conf. [7] Leask & Ehlmann, this conf. [8] Manzari, P., et al., 2016, *Earth and Space Science*, doi:10.1002/2015EA000153. [9] Pilorget & Bibring et al., 2013, *Plan. Space Sci.*, doi:10.1016/j.pss.2012.11.004 [10] Ehlmann et al., Inst. Plan. Missions, 2014 [11] Green et al., LPSC 2015, #2154 [12] Clark et al., 2007, USGS spectral library