MICROIMAGING VSWIR SPECTROSCOPY INSTRUMENTS FOR PLANETARY EXPLORATION: MEASURING IN-SITU MINERALOGY, ICES, ORGANICS AND LINKING TO REMOTE OBSERVATION.

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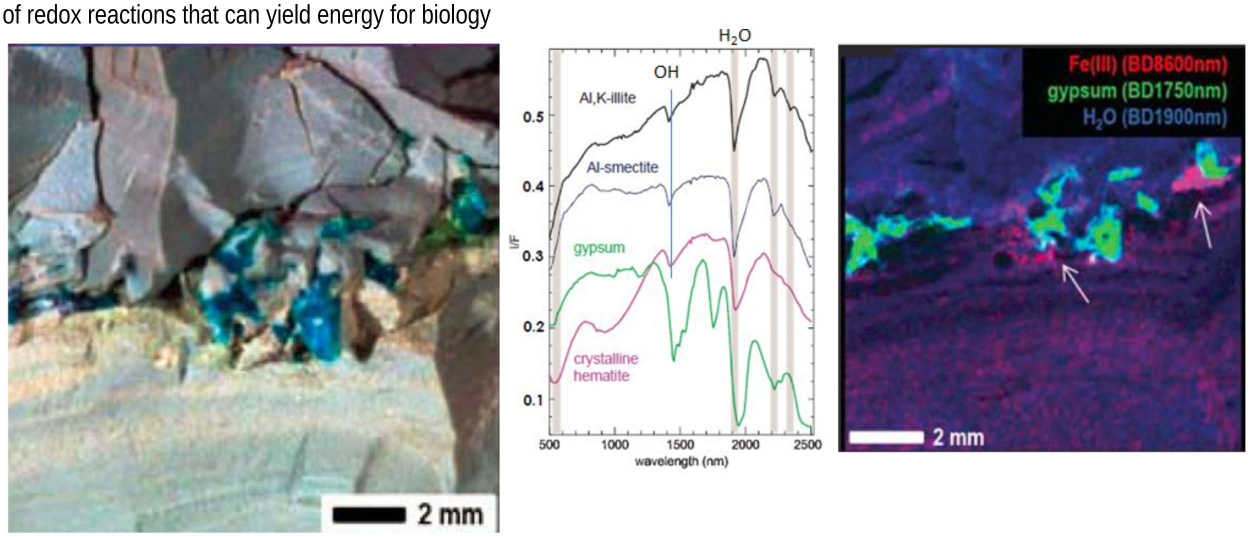
Motivation: As solar system exploration moves toward landed, rover, and sample return missions, key needs are the ability to assess surface composition as well as link findings on the ground to remotely measured spectroscopic characteristics. Non-destructive triaging of materials for sample return is also desireable in many contexts.Microimaging spectroscopy provides simultaneous fine-scale composition (mineralogy, ices, and organics) and fine-scale imaging at a grain scale. JPL has developed a microscopic implementation of an ultracompact imaging spectrometer (µUCIS) operating at visibile to shortwave infrared wavelengths (VSWIR) that demonstrates the importance of fine-scale compositional microimaging for a variety of geologic applications [1]. Furthermore, custom commericial systems are being developed for academic and industrial use [2]. Spatially coupled continuous fine-scale imaging spectroscopy is a significant information-rich step beyond grayscale or color microimaging, which provide a classification scheme and a means to assess texture but do not identify constituent phases. Similarly, the continuity of µUCIS's images vs. point-based techniques enables a refined understanding of surface texture and the spatial relationships between phases, providing insight into the geologic processes that have affected the sample.

Key advantages of VSWIR microimaging spectroscopy include:

Mineral, ice, and organics detection and discrimination: The VSWIR spectral region is sensitive to a wide range of secondary and igneous minerals. Vibrations from 800–2550 nm identify minerals with OH, H_2O, and CO_3 as well as several classes of organics and ices [3]. Strong absorptions from 2700-3500 nm provide more enhanced sensitivity to hydrous minerals/ices and organics. Importantly, even subtleties important for determining geochemical conditions during formation can be identified, e.g., class of phyllosilicate (smectite, serpentine, chlorite) its major cation, or impurities in ices [4,5]. The 500–1100nm region is critical to identifying minerals with Fe, Mn, and other transition metals as well as assessing redox state. The Fe content of olivines and pyroxenes can be estimated [6]. Detection sensitivity to all of these phases is <5 vol% per pixel and 10s ppm bulk volume if grains are at least a few microns in size. Spectral libraries are well-established from decades of study [e.g. 3,7].

Rapid Acquisition: The imaging spectrometer format means tens to hundreds of thousands of independent spectra of surface composition (pixels) are acquired in a few minutes. Highly sensitive detectors and optimized illumination mean rapid (msec) integration

Figure 1. VSWIR microimaging spectroscopy identifies key minerals on the basis of absorption features and enables mapping the spatial relationships between grains. In this rough sample from the China Ranch beds, Califonia, aluminum clay-bearing lake bed sediments (montmorillonite) alternate with layers of tuff (illite), indicating nearby explosive volcanism, and precipitated gypsum, indicating lake evaporation. Co-precipitation of ferric oxides with gypsum records oxidative weathering processes - a suite of redox reactions that can yield energy for biology



times.

<u>*Tolerance of natural surfaces*</u>: Rough or fine-grained textures that can confound some other techniques are easily accommodated by VSWIR imaging spectroscopy, which requires no sample preparation. µUCIS has been demonstrated with fine sands, rough rocks, and cut surfaces.

µUCIS Test Instrument: As described in greater detail in [1] the µUCIS system employs a miniaturized, all-reflective spectrometer of the Offner type in which front end optics direct light from the target onto a spectrometer input slit for the focal plane array.

In planetary applications, an integrated focus and scan mechanism enables collecting the scene line by line and then stepping through a z-stack of multiple images on a soil or rock sample for best focus and 3-d modeling of surface structure. Illumination is provided by two tungsten halogen lamps. Calibration is provided by measuring lamp input power (directly related to lamp radiance), dark current, and periodic flat fields, updated using a white paint calibration target on the system cover.

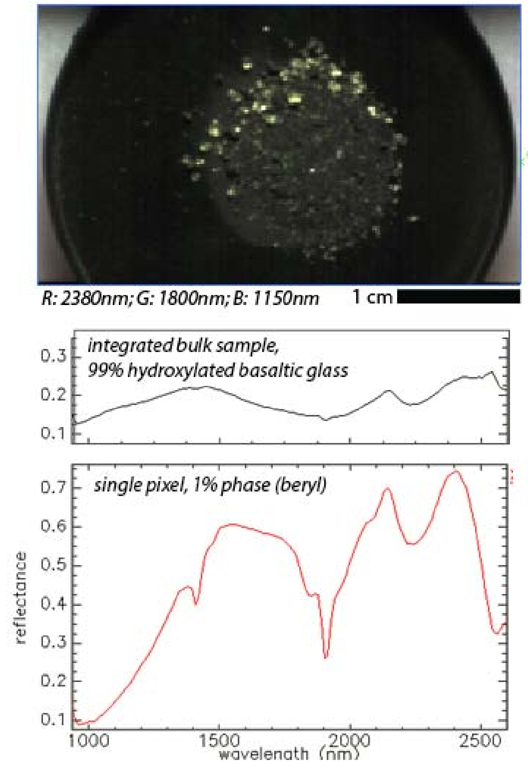
Applications for Planetary Missions:

Venus lander: Hosted in the interior of a lander so as to be protected from environmental conditions, µUCIS would measure VSWIR in order to perform igneous petrology (e.g. determine the composition of mineral grains and groundmass to classify the rocks and textural relationships between minerals), establish the oxidation state of iron, and search for the presence of hydroxylated materials.

Small or icy bodies explorer: µUCIS is ideally suited to identifying trace phases present in small abundances amid a matrix (Figure 2). It is also well-suited to assessing the composition ofparticulates in suited to identifying water ice, CO_2 ice, and impurities from acids, organics and silicate grains within. If the explorer can move from place to place on the body or excavate beneath the surface

Mars geology/astrobiology rover: Simultaneous mineralogy + fine-scale imaging enables petrology and the time-ordering of geologic processes. The µUCIS wavelength region can detect and discriminate all major phases related to aqueous alteration discovered on Mars and has the potential to detect those not yet reported (e.g. phosphates, nitrates). An implementation is detailed in Table 1 [8]. Key features designed to enable rapid operations with constrained tactical downlinks and limited instrument accommodation space relevant to a rover include: (1) reflection of light from the spectrometer slit to a microscopic imager for simultaneous microimaging at >3x greater spatial resolution for contextualization of VSWIR mineralogy; (2) onboard data storage of up to 64Gb; (3) onboard data processing to produce best-focus merged products and

Figure 2. High sensitivity to trace phases via high spatial resolution VSIWR spectroscopy.Here, beryl mixed with a hydroxylated basaltic glass is easily identified by analysis of the ~100-µm sized grains which occupy 1-2 pixels. From the commercial HySpex instrument.



mineral indicator maps (similar to CRISM parameter maps [9]) to enable tactical downlink of <10Mb and onboard processing to calibrate cubes and enable downlinking only specific regions. The last would use an APL-developed DPU system with heritage from MESSENGER.

Conclusions: Simultaneous measurement of minerals, ices, and organics and their spatial context is a rapid, cost effective way to determine the composition and history of the surfaces of solar system bodies. This non-destructive measurement is also an effective means of triaging materials of highest interest for sample return. Investment will continue in terrestrial laboratory studies employing uUCIS for petrology and inventories of volatiles, preparation for use in planetary exploration.

References: [1] Van Gorp et al., 2014, J. Appl. Rem. Sens.8, 084988. [2] www.hyspex.no/publications/publicationlist.php [3] Clark et al., 1990, J Geophys Res, 95(B8) 12653 [4] Ehlmann et al., 2009, J. Geophys. Res., 114, E00D08 [5] McCord et al., 1998, J. Geophys. Res., 103, E4, 8603 [6]

Sunshine & Pieters, 1998, JGR, 103, E6, 13675 [7] Clark et al., 2007, JGR, USGS Digital Spectral Library splib06a, U.S. Geol. Surv. Data, 231. [8] Ehlmann et al., 2014, Lun. Plan. Sci. Conf. abs 2824. [9] Pelkey et al., 2007, J. Geophys. Res., E08S14.

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Table 1. Example as proposed for Mars2020 rover [2]

Number of simultaneous independent mineralogy measurements	140,000
Spatial resoltolution	75 µm/pixel
Field of View	3 cm x 3 cm
Spectral range	450-2600nm (can be extended)
Spectral sampling	10nm
Co-aligned hi-res gray-scale microimager spatial res. (same FOV)	20 µm//pixel
Mass	2.5 kg (arm); 1.2 kg (DPU)
Volume	Sensor: 120x 114x 124mm DPU: 152x102x61mm
Power (peak)	46W data acquisition; 13W processing
Time per measurement	10 min. data acquisition on target; <30 min DPU-processing for low DL
Downlinked data	10Mb for first cut mineral summary; 450Mb for whole cube+microimage