SIMPLE CAMERA CONCEPTS FOR SURFACE VOLATILE CHARACTERIZATION AND MAPPING.

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Introduction: On the Moon, as on the Earth, water is essential for supporting life. On the Moon, it is also of great scientific interest, informing on the origin and evolution of the Moon and the inner solar system including factors that affected the early evolution of the Earth and possibly the appearance of life. We discuss two variants of a simple camera approach for rover-mounted or astronaut-operated detection and mapping of water on the surface of the Moon.

Background: Before Apollo 11 returned the first lunar sample, it was postulated that hydroxyl (OH, a simple form of water) could exist on a dry Moon, or other silicate body, via interaction of implanted solar-wind particles with the oxygen in the silicate regolith grains [1,2,3]. The discovery of water and hydroxyl on the illuminated portion of the Moon by three independent spacecraft [4,5,6], and additionally the excavation of water ice from within a permanently shadowed crater [7] suggest that reservoirs of accessible quantities of water (both H_2O and OH) exist at lunar high latitudes. On the portion of the Moon illuminated by the Sun, this water may be ephemeral, a product of solar-wind implantation into the surface and possible formation, transport, and re-adsorption of molecular water [e.g. 8]. The presence of water, whether molecular, dissociated, or a result of implanted solar-wind protons thus raises questions about the chemical state of the water and hydroxyl on the surface – including how to estimate abundances, understanding variations over time and surface, and accessibility for use as an in-situ resource. Answering these questions is of great scientific and exploration interest. Relatively simple instrumentation and measurements can be effective at addressing and possibly answering these key questions.

Measurement Approach: Detecting and charactering a single volatile, such as water in any of its various forms, can be accomplished with a relatively simple multi-spectral measurement. Feasibility has been repeatedly demonstrated using instruments designed for more complicated measurements (such as hyperspectral imagers), as well as with instruments only capable of single narrow-wavelength measurements, such as LIDAR [9]. Consequently, multispectral passive as well as active orbital instrument concepts designed specifically for water (or other single material detection such as organics) have been proposed for orbital flight and have in some cases been funded. [e.g. 10,11]. Here we discuss variants that would be better suited for operation from moving ground assets.

Three wavelengths enable mapping the continuum-removed band depth, whereas two wavelengths would only enable mapping spectral slope (Fig. 1). Spectral slopes, or color, are strongly affected by photometry whereas continuum removed band depths are not. Thus, although as few as two bands can be adequate for detecting and mapping water when photometry is constrained (such as for active illumination instruments), three bands offer robustness against naturally-occurring photometric changes that can be especially prevalent at the low Sun angles near the poles, as well as anytime an observer varies viewing geometry.

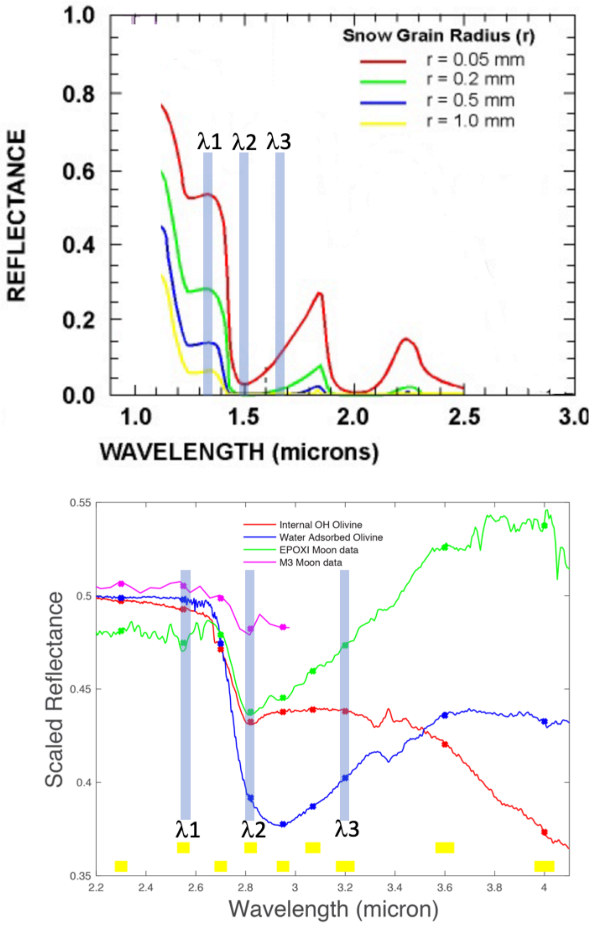

Fig. 1. TOP: The 1.5-µm band offers a simple detection scheme for water ice mapping in PSRs. BOTTOM: While the 3-µm spectral region can be sufficiently characterized to discriminate various forms of water with 9 spectral channels, only 3 wavelengths are needed for mapping water regardless of chemistry.

Instrument Approach: The type of multispectral imaging described above could be accomplished in several ways, with two methodologies lending themselves well to the CONOPS from an unstable platform such as a moving rover or astronaut on the surface of the Moon. The mapping of water ice in PSRs via the 1.5-μm band can be done with an uncooled, high-TRL, low-cost InGaAs detector camera. Mega-pixel focal planes are available and inexpensive. More difficult is the mapping of water, regardless of chemical state, which would be required for investigations on illuminated terrain. These measurements require the use of a cryogenically cooled detector such as HgCdTe, InSb, bBn, or T2SL arrays to access the 3-μm region. While providing substantially more measurement capability, these detectors are also significantly more expensive than InGaAs, and in addition require a cooler and use significantly more power.

Single Focal Plane Bayer Filter Camera: A Bayer pattern approach directs lends itself to both measurements. In this approach, filters are placed over each pixel and after image acquisition, camera processing combines the output to provide a color image but at somewhat reduced spatial resolution due to the spatial merging of individually filtered pixels. The advantages include instantaneous color imaging (strongly desired for operation from an unstable platform) and a relatively low size, weight and power (SWaP) because of being a single camera with an integrated detector and filter. The 1.5-μm camera would essentially be a COTS-like device similar to a vis-NIR version for rock and soil mapping proposed by [12], though the 1.5-μm Bayer filter would be custom. The 3-μm variant could also be COTS-like, though implanting a Bayer filter on a cryogenic focal plane array would be more complex.

Multi-sensor Camera: If maintaining a COTS form factor and minimizing technology development are required, a multi-camera approach like that taken by [13], represents a possibility for which the cost and SWaP of the individual cameras are low but in aggregate are larger (Table 1). Here, the concept is to fly 3 separate cameras (detector and lens) with a common power supply and processing unit and control electronics. While having the disadvantage of larger SWaP, this approach has the advantage of maintaining the intrinsic native spatial resolution of the detector while also enabling quantitative analyses through continuum-removed band-depth calculations. With modern processor and miniaturized camera-interface cards, it is possible to acquire video-rate imaging from multiple cameras, apply a spatial transformation matrix to align the images, and conduct spectral analyses for band depth mapping.

Potential Applications: These cameras are envisioned to provide instantaneous and accurate water abundance information in simple measurements with minimal effort. Real-time imaging of water, OH, and water-ice at video rate that can operate effectively from an unstable platform would mean rover-mounted cameras could map water abundance over the surface of the Moon anytime the rovers are utilized and hand held units could be feasible. Lunar surface hydration maps would thus be quickly obtained while requiring little effort. Also, given that adsorbed water and water ice may be more prevalent in the near surface, especially on the illuminated portion of the Moon, this instrument would enable easy and rapid hand held use by astronauts for characterizing the hydration state of exposed subsurface materials in trenches dug and in pilings of excavated regolith.

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References: [1] Hapke, B. (1965), Annals NY Acad. Sci., 123, 2, 711-721; [2] Zeller et al., (1966), J. Geophys. Res., 71, 20, 4855-4860; [3] Starukina et al., (2001), J. Geophys. Res., 106, E7, 14701-14710; [4] Pieters et al., (2009), Science, 10.1126/science.1178658; [5] Sunshine et al., (2009), Science, 10.1126/science.1179788; [6] Clark, (2009), Science, 0.1126/science.1178105; [7] Colaprete et al., (2010), Science, 330, 463-468; [8] Hibbitts et al., (2011), Icarus, 213, 64-72, 2011; [9] Lucey, P.G., et al., (2014), J. Geophys. Res., 119, 1665-1679; [10] Cohen, B. et al., (2017), 48th LPSC, ; [11] MIMSI, [12] Blewett, D. et al., (2020), this workshop, abstr. no. 5008; [13] Hibbitts, C. A. et al., (2019), SPIE, 1101211.

Table 1. Estimated parameters for the hydration-mapping imagers discussed here.

**Estimated* Values	1.5-μm Spectral Imager		3-μm Spectral Imager	
	Bayer Pattern	Multi-Camera	Bayer Pattern	Multi-Camera
Size (cm x cm x cm)	10 x 10 x 10	15 x 10 x 10	15 x 10 x 20	15 x 20 x 20
Weight	1 kg	2 kg	5 kg	13 kg
Power	5 W	20 W	20 W	65 W
Cost	TBD	TBD	TBD	TBD
Crew Interaction	Turn on, point, obtain map of surficial water at video rate			
Other	none		Waste heat rejection needed	

*power supply not included