Inferring the presence of near surface ice through infrared reflectance measurements.

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Water ice exists on the Moon's southern pole, sequestered in PSRs [1] and possibly buried in partially lit terrain where the low subsurface temperature is maintained by an insulated overburden of regolith [2]. Water ice, inferred to be frost, has been found to cover portions of the surfaces of PSRs as well [3,4,5] even though its distribution does not conform to current temperature distribution. It is hypothesized the current surficial and subsurface water ice distributions reflect both a prehistoric accumulation of ice subsequently modified due to a shift in the Moon's spin axis billions of years ago [6] followed by the accumulation of more recent ice. Neutron spectroscopy has provided insight into the average polar abundance of the near surface water, with a ~ 150 ppm overall abundance that could range from a few hundred ppm to several 10s of percent in very localized spots [7]. Radar has suggested possible discrete locations of more massive ice [e.g. 8]. However, neither neutron spectroscopy nor radar offers robust high spatial resolution measurements of near surface water while ultraviolet, visible and infrared reflectance measurements can provide robust high spatial resolution measurements of ice, but only sense the upper few microns. Unfortunately, linkage between the surface signature of ice and subsurface ice is proving difficult to untangle. Thus, near surface ice abundance cannot yet be reliably inferred from surficial reflectance measurements.

However, the nature and specifically the grain size of the surficial ice may potentially be informative on whether or not the ice is a frost or is indicative of an excavated or exposed more substantial subsurface deposit. Surficial frost will likely be relatively fine-grained regardless of its origin. As an example, vapor deposited frosts on similarly cold surfaces of icy satellites are less than 20 um [9]. In contrast, subsurface ice, possibly initially deposited by large cometary impacts, are expected to be initially much more massive deposits. There are several processes that will modify any deposits over time, dominated by impact gardening, resulting in most of the ice being retained many 10s of centimeters under the surface [e.g. 10]). However, even after being comminuted through impact gardening, several forms of water ice that is larger-grained than frost is likely to exist [11] possibly similar in form to the grain size distribution of the dry lunar regolith of between ~ 40 to > 200 microns [12]. Relatively larger grained ice may thus be indicative of an exposure of a relatively high concentration deposit of near surface water ice.

Upcoming orbital infrared spectroscopy missions will provide that can be mined for spectral evidence of water ice grain size variations potentially indicative of significant near-surface ice. Water ice grain size in the presence of abundant regolith can be inferred from its near infrared spectral properties where the spectrally benign matrix of highland soils results in the spectra of the water ice dominating even at very low single percentages abundance [e.g. 5]. Straight-forward ratios of the depths of water ice absorption bands at 1.25, 1.5, and 2 microns have been leveraged to characterize the grain sizes of water ice on Ganymede and other icy satellites [e.g. 8,12,13]. A variant of those approaches, using the ratio of the

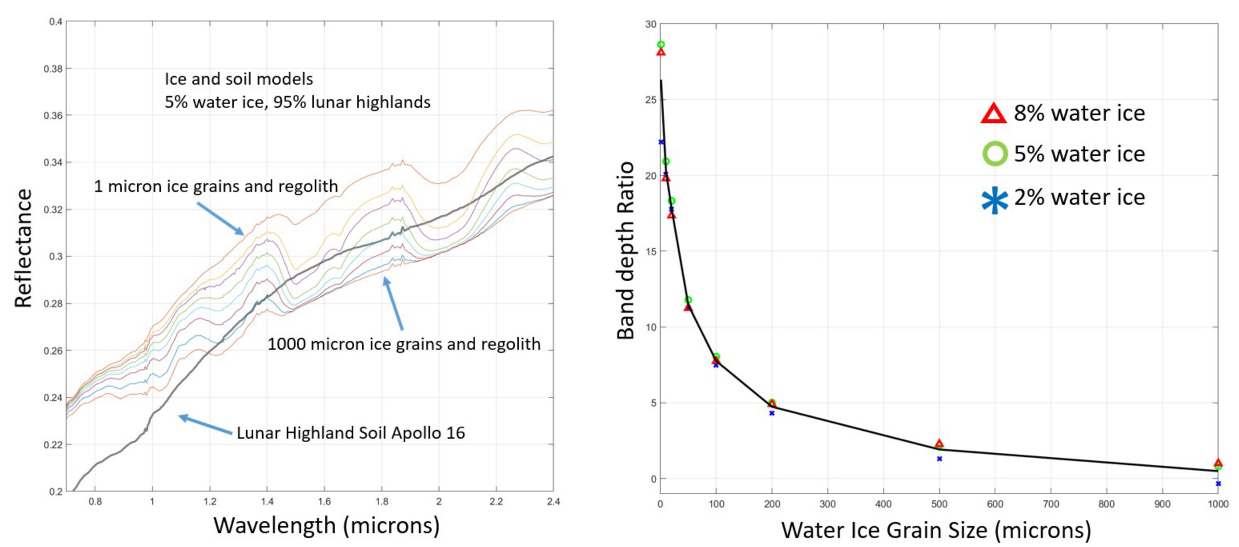

Figure 1. Grain size can be inferred independently of abundance using a normalized ratio of water ice band depths at 1.25 and 1.5 microns, if areal mixing is present. (right) Normalized band depth ratios for 2%, 5%, and 8% water ice and highland regolith fractional models, and piecewise linear fit.

1.25 and 1.5-micron bands, normalized to overall reflectance in the visible, holds some promise in providing a robust, yet simple, approach for mapping relative and possibly absolute band depths (Figure 1). This initial effort assumes linear mixing of the ice and regolith, whereas intimate mixing will be far more likely, result in reduced contrast of the water ice absorption features likely requiring a modification of this approach.

Conclusions: A potential leverage arm to linking the presence of surface ice to significant near surface ice reservoirs will be provided by using upcoming high signal to noise, high spectral resolution near infrared spectral measurements of the surface from the Lunar IceCube mission [14] and the Trailblazer mission [15]. A relatively straight-forward analysis approach of normalized water-ice band depth ratios may enable the data from those missions to precisely locate exposures of ancient ice and potential near-surface water ice reserves, for follow up by more rigorous non-linear spectral unmixing analyses for selection of in-situ sites to characterize in more detail.

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