CHARACTERIZING SPECTRAL FEATURES OF WATER ICE, LUNAR REGOLITH ANALOGUES, AND THEIR MIXTURES AT THE VNIR REGION.

N. De Castro[1] and S. Li[1], University of Hawai'i at Mānoa, Honolulu HI 96822, ninacwdc@hawaii.edu.

Introduction: Surface exposed water ice in the lunar permanently shaded regions (PSRs) was confirmed by three near infrared (NIR) absorption features near 1.3, 1.5 and 2.0 µm in M^3 data [1]. However, the effect of particle size, viewing geometry, and abundance on the VNIR (visible to near-infrared) spectra of water ice is still poorly constrained, posing important limitations for detecting water ice on airless bodies. The purpose of our study is to characterize spectral features of water ice, lunar regolith analogues, and their mixtures at the VNIR region (350-2,500 nm). In this study, we investigated variations in visible (VIS) reflectance and NIR absorption with size of ice particles, viewing geometry, and ice content in mixtures with highland regolith simulants. These results are fundamental for interpreting VNIR data on the Moon and other airless bodies.

Methods: *Pure Water Ice.* We nebulized water in liquid nitrogen inside a freezer to create solid water ice particles that were sieved into particle size groups: 20-32 µm, 32-45 µm, 45-53 µm, 53-63 µm, 63-75 µm, 75-90 µm, 90-106 µm, and 106-125 µm, and 125-180 µm. We fixed an ASD FieldSpec 4 spectrometer onto a goniometer that acted as a principal plane to control the incidence angle (i) and emittance angle (e) relative to the normal. The spectrometer was calibrated using a Labsphere Spectralon, as outlined in [2].

We measured the VNIR reflectance spectra (350-2,500 nm) of pure water ice with varying particle size and viewing geometry. For the former, we set *i at* 30° and e at 0° that resulted in a phase angle (g) of 30°. We analyzed the VIS reflectance from 400-700 nm and calculated the band depth of the NIR absorptions by performing a continuum removal analysis on the corrected spectra for the Spectralon artifacts. For the viewing geometry experiments, we fixed the i at 45° and varied e from -60° to 60° (g = -15° to 105°) at 15° increments. We analyzed the reflectance at 700, 1,350, 1,850, and 2,250 nm and calculated the band depth of the NIR absorptions near 1.0, 1.3, 1.5, and 2.0 µm.

Water ice and regolith simulant mixtures. We used two regolith simulants to represent the anorthositic highlands and basaltic mare on the Moon. We dehydrated the simulants in an oven for 5 days at 350°C to remove any residual terrestrial water and intimately mixed them with water ice inside a freezer to simulate the intimate distribution of water ice in the lunar regolith. The ASD spectrometer had the same set up as in the pure water ice experiments.

We measured the VNIR spectra of water ice and lunar regolith simulant mixtures with varying water ice abundance and viewing geometry. For the former, we measured the water ice content for each particle size group at around 1, 2, 5, 10, 15, 20, 25, 30, 40, and 50 wt.%, with a phase angle of 30° (i = 30°, e= 0°). We analyzed the VIS reflectance at 700 nm and band depths near 1.3, 1.5, and 2.0 µm (the 1.0 µm feature is shallow and easily masked by the simulants). Our ongoing work involves the viewing geometry experiments, where we will use the same phase angles as those for pure water ice, at a low ice content scenario at ~2 wt.% and a high ice content scenario at ~15 wt.%. We will repeat these tests with the Mare simulants.

Results: *Pure Water Ice.* Our results for particle size exhibit a steep drop in average reflectance from 400-700 nm when particles are smaller than 100 µm (Fig.1). The correlation between particle size and band depth of the 1.5 and 2.0 µm absorptions is very weak (Fig. 2).The band depth of absorptions near 1.0, 1.2, 1.5, and 2.0 µm slightly increases in particle sizes smaller than ~50-60 µm, and remain almost constant when the particle size varies from ~70 to > 200 µm (Fig. 2).

Phase curves at the 700, 1350, 1850, and 2250 nm bands show forward scattering for all particle sizes (Fig.3). The phase curves are shaped by a surge in reflectance around zero phase, a gradual decrease at ~40-50° phase angles, followed by a gradual increase at higher phase angles between ~60-105°. Our results for the band depth at different viewing geometries show that the 1.0, 1.2, 1.5, and 2.0 µm features are strongest when measured at ~60°, regardless of particle size (Fig. 4).

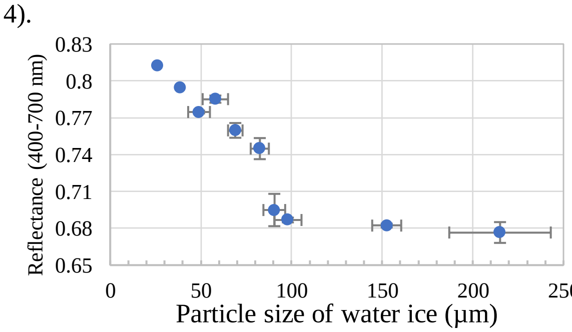

Figure 1. Variation in reflectance with particle size of water ice in the VIS range (400 – 700 nm).

Water ice and regolith analogue mixtures. Our preliminary results show that VIS reflectance at 700 nm increases with water ice content in mixtures of highland simulants (Fig.5), although this effect is inconspicuous when the ice content is less than ~30 wt.%. Similarly, the band depth of the 1.2, 1.5, and 2.0 µm absorption features is stronger at higher water ice contents (Fig. 6). The 1.0 µm is too shallow to be observed.

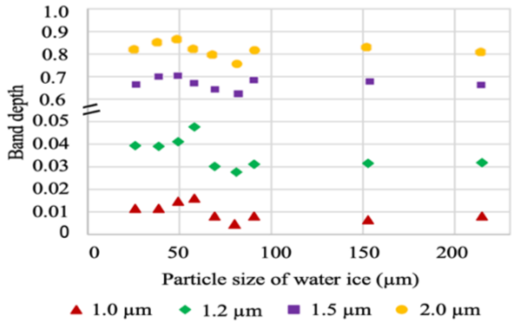

Figure 2. Band depth as a function of particle size for the characteristic NIR absorptions of pure water ice.

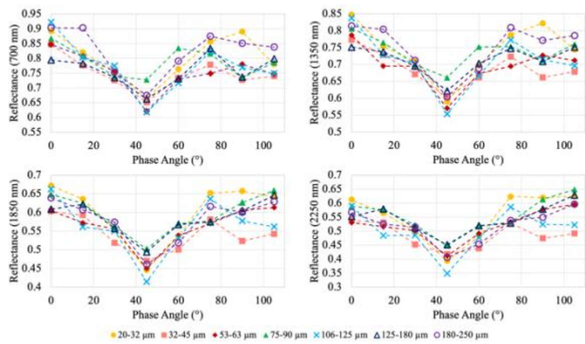

Figure 3. Phase curves of pure water ice with varying particle sizes.

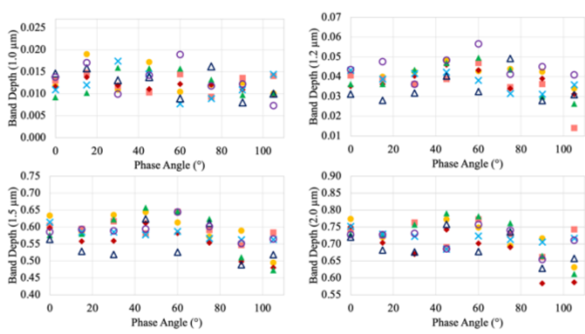

Figure 4. Band depth as a function of phase angle for four particle size groups of pure water ice.

Discussion and conclusion: Our results show that VNIR reflectance (350-2,500) is higher when the particle size of water ice is smaller than ~100 µm and are observed at high phase angles (<105°), regardless of particle size (Figs. 1, 3). When particles are smaller than ~100 µm, photons can overcome smaller optical path lengths and are more easily scattered into neighboring grains, leading to the increased VIS reflectance observed in Fig. 1 [3]. Similarly, VIS reflectance increases with ice abundance in mixtures with lunar regolith analogues; however, this effect can only be observed when the water ice content is >~30 wt.% (Fig. 5).

The strength of the diagnostic VNIR absorption features of water ice at 1.0, 1.2, 1.5, and 2.0 µm does not change significantly with particle size of water ice (Fig. 2). When mixed with highland simulants, the band depth at 1.2, 1.5, 2.0 µm increases in mixtures with higher water ice content (Fig. 6). However, this increase was not evident in the shallow 1.0 µm feature, suggesting that the stronger 1.2, 1.5, and 2.0 µm features are best suited for detecting water ice. We also found that a phase angle of ~60° yields the strongest signals for these absorption features. Our ongoing work includes continuing to prepare intimate mixtures of water-ice and lunar simulants, performing spectral measurements of these mixtures, and analyzing their spectral features.

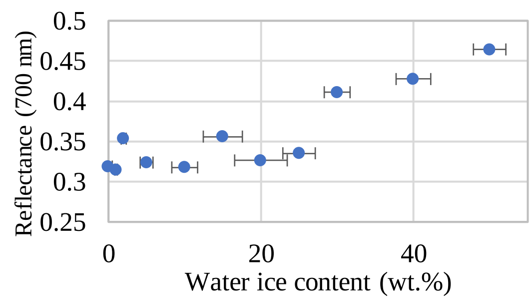

Figure 5. Variation in reflectance at 700 nm with water ice content in highland simulant mixtures. Water ice particle size is between 53-63 µm.

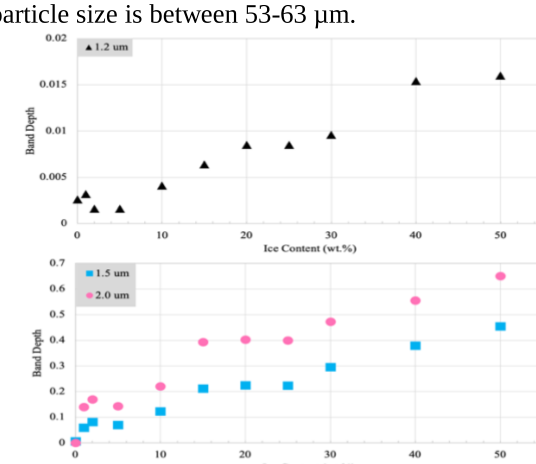

Figure 6. Band depth of water ice and highland simulant mixtures with varying ice abundance at the 1.2 µm (black triangles), 1.5 µm (blue squares), and 2.0 µm (pink circles).

References: [1] Li S. *et al.*, 2018. [2] Yang Y. et al. (2019) *Journal of Geophysical Research: Planets, 124,* 31-60. [3] Lucey P. G. and Clark R. N. (1985) *Ices in the Solar System*, 155-168. [4] Hapke B. (1981) *Journal of Geophysical Research: Solid Earth 86*, 3039-3054.