DETERMINING THE WATER ICE CONTENT OF MARTIAN REGOLITH BY NONLINEAR SPECTRAL MIXTURE MODELING. S. Gyalay[1,2] and E. Z. Noe Dobrea[2], [1]University of California, Los Angeles, Los Angeles, CA 90024, szilard3@ucla.edu, [2]NASA Ames Research Center, Moffett Field, CA, 94035

Background: In the search for evidence of life, Icebreaker[1] will drill in to the Martian ice-rich regolith to collect samples, which will then be analyzed by an array of instruments designed to identify biomarkers. In addition, drilling into the subsurface will provide the opportunity to assess the vertical distribution of ice to a depth of 1 meter. The purpose of this particular project was to understand the uncertainties involved in the use of the imaging system to constrain the water ice content in regolith samples.

Mixture Modeling. The key to constraining the water ice content of a mixture is to model said mixture. Shkuratov et al. modeling[2] was used instead of Hapke Modeling[3][4] due to the eschewing of viewing geometry in calculating the albedo (which can be related to the bidirectional reflectance[5]), as well as the fact that the Shkuratov model is reversible in that the imaginary index of refraction of a material can be calculated from its albedo.

Subtractive Kramers-Kronig analysis. Knowing the imaginary index of refraction is of little use without the real index of refraction as well. By using Subtractive Kramers-Kronig analysis[6], one can use the real index of refraction at a specific wavelength to iterate through and derive the real and imaginary indices of refraction for the rest of the wavelengths in the range observed[7].

Coming together. The idea then becomes that one can determine the fraction of water ice in a sample by taking a spectrum of a regolith sample, wait for the sample to dessicate, and then taking another spectrum using the same lighting and viewing geometry. From the second spectrum, the optical constants for the iceless mixture as a whole can be determined using the Subtractive Kramers-Kronig analysis. These optical constants can then be used in conjunction with the optical constants for water[8] to model mixtures of icy regolith until it matches the spectrum of the observed icy regolith. Theoretically, this would determine the water ice abundance of the regolith, which in turn gives insight to the chemical and geological history of the region.

A Case Study: Early experiments wherein samples were observed before and after sublimation of water ice seemed to support the theory that the water ice content of these samples could be estimated using Shkuratov modeling and Subtractive Kramers-Kronig Analysis. An example of this is seen in Figure 1.

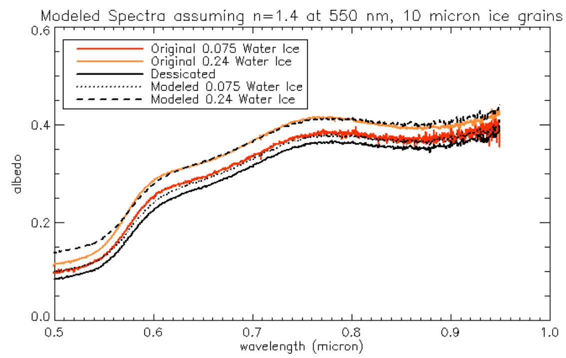

Figure 1: Silicate Sand was observed with two concentrations of ice mixed in. Spectra were taken of these icy samples as well as the dessicated sample. Above are the modeled mixtures overlaid on the spectra of the original samples. Grain size of the silicate sand was assumed to be 100 µm, with a volume fraction filled by particles of 0.85. It was also assumed the silicate sand had a real index of refraction of 1.4 at 550 nm.

For another test of the theory, Phoenix data was looked at, of samples before and after sublimation on the Martian surface—in particular of Snow White Trench between Sol 45 and 50 of Phoenix's mission[9].

Unlike with the silicate sand observed in Figure 1, the viewing geometry of the Snow White Trench was not quite of incidence angle 30°, emission angle 0°; however, the formula $\log(R_{30}) = 1.088 * \log(A)$ was used to approximate the hemispheric albedo used by Shkuratov et al. modeling from the bidirectional reflectance[5]. This approximation should remain accurate within a few percent reflectance.

Unlike previous models that attempted to determine the water ice content of the trench by assuming the composition of the regolith[10], we derived the optical constants from the observations of the sublimation lag using the Subtractive Kramers-Kronig analysis outlined earlier. Since the true real index of refraction of the regolith is not known, it is assumed to be between 1.4 and 1.8 at 550 nm. The optical constants of water ice come from [8]. Various concentrations of water ice and regolith are then modeled using [2].

The volume fraction filled by particles was assumed to be 0.85. Varying this fraction does not shift the modeled spectra to a great degree—perhaps by 0.1 albedo when varied from 0 to 99% porosity. The effective grain size of the sublimated regolith was assumed to be 60 µm[10]. However, it does not matter what grain size is used to derive the optical constants of the regolith so long as this same grain size is used in the modeling of this regolith.

Results: Various mixture models were generated, assuming different real indices of refraction for the regolith, as well as different ice grain sizes. Figures 2-5 show these models alongside the original spectra (both initial and sublimated).

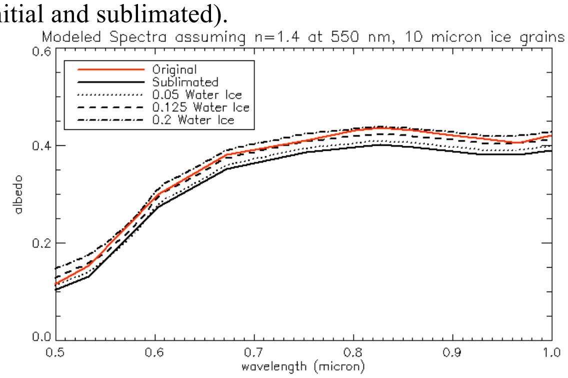

Figure 2: Modeled mixtures overlaid on actual spectra of the Snow White Trench before and after sublimation. Assumed n=1.4 at 550 nm, regolith grain size of 60 µm, porosity of 0.15, and ice grain size of 10 µm. Suggests water ice content lies between 5-20% ice.

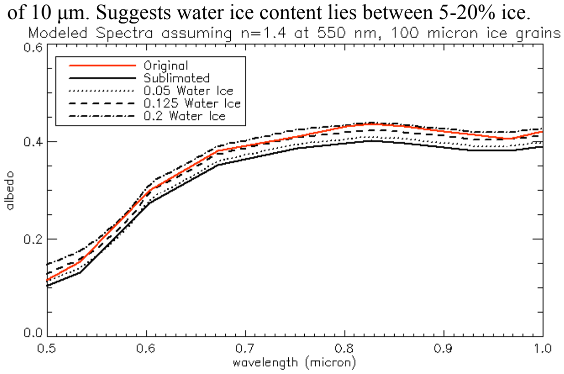

Figure 3: Modeled mixtures overlaid on actual spectra of the Snow White Trench before and after sublimation. Assumed n=1.4 at 550 nm, regolith grain size of 60 µm, porosity of 0.15, and ice grain size of 100 µm. Suggests water ice content lies between 5-20% ice.

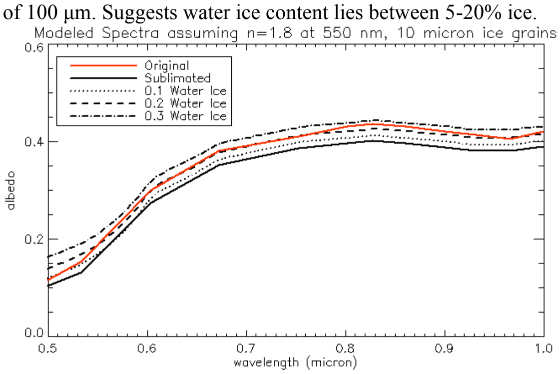

Figure 4: Modeled mixtures overlaid on actual spectra of the Snow White Trench before and after sublimation. Assumed n=1.8 at 550 nm, regolith grain size of 60 µm, porosity of 0.15, and ice grain size of 10 µm. Suggests water ice content lies between 10-30% ice.

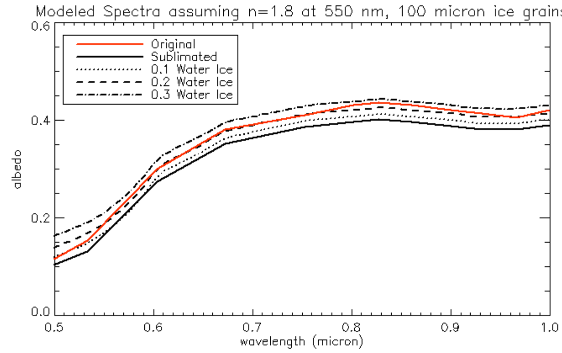

Figure 5: Modeled mixtures overlaid on actual spectra of the Snow White Trench before and after sublimation. Assumed n=1.8 at 550 nm, regolith grain size of 60 µm, porosity of 0.15, and ice grain size of 100 µm. Suggests water ice content lies between 10-30% ice.

The main effect of increasing the assumed real index of refraction of the regolith is to decrease the albedo of the modeled mixtures. Increasing the grain size of the ice grain meanwhile appears to have little effect for reasonable size ranges (however far larger increases would begin to lower the albedo in the near infrared wavelengths).

The plots show that this water-ice content is likely between 5 and 30%, but the models are not perfect. Not knowing the real index of refraction (as well as the approximation of the hemispheric albedo from the bidirectional reflectance) creates much uncertainty in the water-ice content of the sample. This can be mitigated by a closer approximation of the hemispheric albedo (or more constraining the viewing geometry), and knowledge of the real index of refraction (which can be approximated if one knows the constituents of the regolith).

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References: [1] McKay C. et al. (2013) *Astrobio., 13.4*, 334-353. [2] Shkuratov Y. et al. (1999) *Icarus, 137.2*, 235-246. [3] Hapke B. (1981) *JGR, 86,* B4 3039-3054. [4] Hapke B. (1993) *Theory of Reflectance and Emittance Spectroscopy*. [5] Shkuratov Y. G. and Grynko Y. S. (2005) *Icarus, 173*, 16-28. [6] Ahrenkiel R. K. (1971) *Journal of the Opt. Soc. Of America, 61.12*, 1651-1655. [7] Dalton J. B. and Pitman K. M. (2012) *JGR, 117,* E9. [8] Warren S. G. and Brandt R. E. (2008) *JGR, 113,* D14. [9] Smith P. et al. (2009) *Science, 325*, 58-61. [10] Cull S. et al. (2010) *Geophysical Research Letters, 37,* L24203.