MODELING WATER ICE ON PLANETARY SURFACES OF SILICATE BODIES.

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Introduction: Multiple solar system bodies have water ice with silicate regoliths. For instance, there have been confirmed detections of water ice on the surfaces of the Moon [1], Ceres [2], Mercury [3], and Mars [4]. Studying the composition of surface ice deposits, their purity, and ice grain size sheds light on the delivery of volatiles as well as the formation and history of given planetary bodies and, hence, of the solar system, which is the motivation for this work.

The parameters of surface ice deposits can be inferred from SWIR (shortwave infrared) spectral data. In this spectral range, water ice has diagnostic absorption features [5]. To date, such datasets at high spatial and spectral resolution are available from the Moon Mineralogy Mapper (M^3) instrument [6], the Dawn Visible and Infrared spectrometer (VIR) for Ceres [7], and multiple Mars instruments (e.g., Compact Reconnaissance Imaging Spectrometer (CRISM) [8]). Potentially, similar datasets will become accessible for Mercury from the SIMBIO-SYS instrument aboard the ongoing BepiColombo mission [9]. Furthermore, the Moon will soon be visited by the Lunar Trailblazer mission [10], whose instruments have been designed specifically to look for water on the lunar surface.

Here, we report on a framework to model spectra of ice on planetary surfaces with no atmospheres. This framework aims to put constraints on water-ice scenarios and facilitate the interpretation of SWIR spectral data. The focus of our current research is Ceres and the Moon.

Methods: We first develop four conceptual scenarios for the occurrence of water ice – patchy ice (areal mixture), pore ice (intimate mixture), and frosts or slabs (layered systems). In our implementation, water ice is either mixed with or covers planetary regolith (Fig. 1).

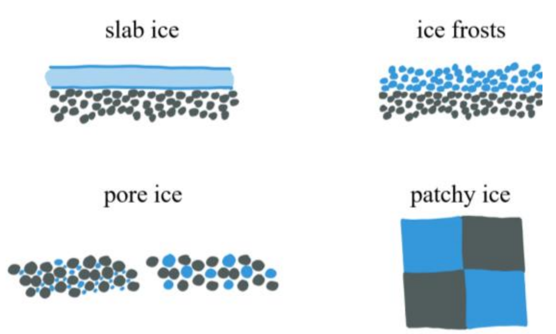

Fig. 2. The conceptualized scenarios for water ice on planetary surfaces: ice (blue) is either mixed with regolith (grey) or covers it.

To model the reflectance spectra of planetary bodies, we employ the Hapke mixture and two-layer models [11]. Input parameters to the models include optical constants of planetary surface materials. We treat planetary surfaces consisting of two endmembers – water ice and regolith.

An extensive literature review of the published water-ice optical data has shown that ice optical constants in the SWIR range are less well-studied at temperatures below 110 K, which are most relevant for the thermal stability of water ice on airless planetary bodies on geologic timescales [12]. For instance, the confirmed locations of water ice deposits on the Moon exhibit maximum temperatures of ~110 K [1]. Therefore, we decided on splicing high spectral resolution water-ice optical constants from works [13], acquired at 160 K, for our 0.6-1.4 µm and 2.53-3.6 µm spectral ranges, and [14], acquired at 110 K, for our 1.4-2.53 µm range. These datasets – if compiled together – provide the water-ice optical constants in the SWIR range under low temperatures with appropriate spectral resolution. For our modeling, we are initially utilizing optical constants for crystalline water ice; however, the low temperatures on the planetary bodies in question may also require amorphous ice phase consideration [14].

To obtain optical constants of regoliths, we performed an inverse Hapke modeling procedure [15] with the observed average reflectance spectra of planetary surfaces as inputs. To calculate reflectance (precisely, the radiance factor [11]) of regoliths, we

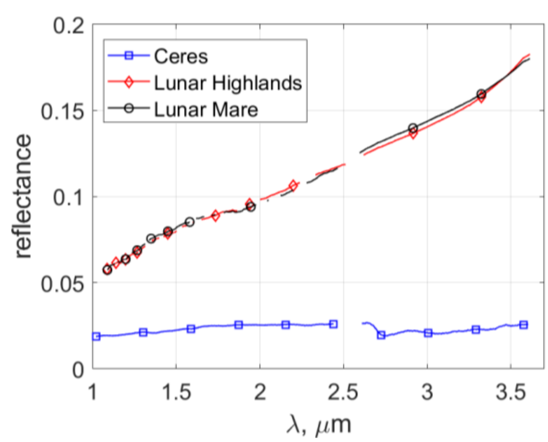

Fig. 1. The spectra of Ceres and Moon regoliths that are used to derive the regolith optical constants in this study.

used radiance spectra from past missions (Fig. 2).

For the Moon, the regolith endmembers are simplified to mare and highland regoliths with a gain size of 60 µm as the average from Apollo sample studies [16]. We utilize Deep Impact (EPOXI) spectral datasets that span the near-infrared range of 1.05-4.5 µm and encompass diagnostic water-ice absorption features [17, 18].

For Ceres, we are currently focusing on surface ice deposits linked to Oxo crater [19, 20] and are using regolith in the crater area for the Ceres regolith endmember, assuming an average grain size of 100 µm [21]. We utilize spectral datasets from the Dawn mission [7, 22] to calculate Ceres' average terrain spectrum as a median of 60 spectra.

Regolith properties and water-ice optical properties are treated as constant input parameters, whereas the abundance and characteristic size of ice vary. This allows us to place constraints on water-ice scenarios by comparing the modeled spectra to observational data.

Initial Results and Future Work: The described modeling procedures have been used to obtain optical constants of the Moon's and Ceres' regoliths and to generate predicted reflectance spectra of ice-deposits with various ice grain sizes and purities. Fig. 3 shows an example of generated Moon highlands spectra with a 100-µm ice grain size and a 50% ice content under the pore (intimate mixture) and patchy (areal mixture) assumptions. Fig. 4 shows how the reflectance spectra of the lunar surface with a 50% ice content would appear at various ice grain sizes (10-1000 µm) under the pore assumption.

Our ongoing work will focus on refining the methodology and defining spectral metrics that would help to identify the ice composition, grain size, and mixture scenarios that are consistent with the given lunar and Ceres SWIR data. In the case of Moon, we will also investigate how our predictions of ice parameters would change with a 15-µm regolith grain size, given the finest regolith fraction dominates the optical properties of the bulk lunar soil [23, 24].

Acknowledgements: Thanks to Jessica Sunshine, Kris Laferriere, and the EPOXI mission team, for providing calibrated radiance spectra of lunar highlands and lunar basalt for the lunar regolith endmembers.

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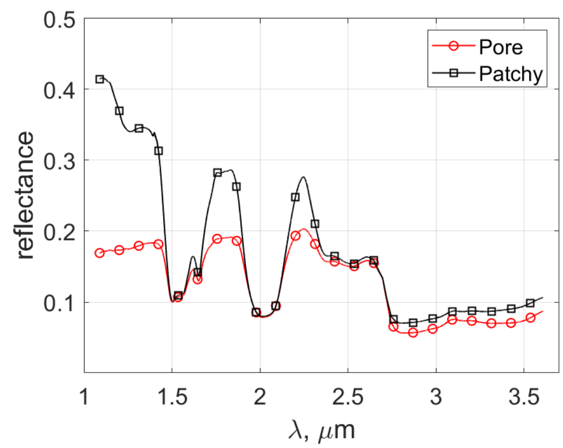

Fig. 3. An example of modeled reflectance spectra of Moon ice deposits with a 100-µm ice grain size and a 50% ice content under the pore and patchy assumptions.

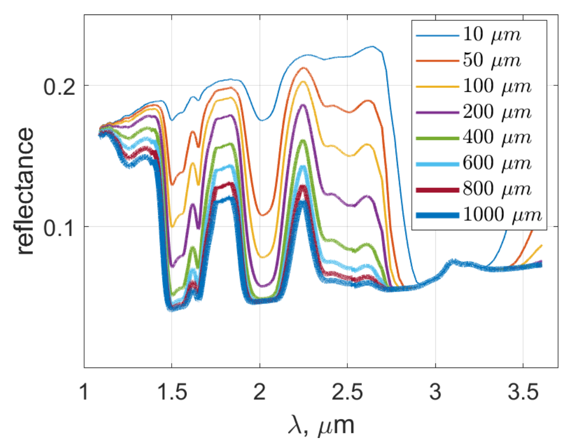

Fig. 4. An example of how modeled reflectance spectra of Moon ice deposits with a 50% ice content change with ice grain size (10-1000 µm) under the pore assumption.