**LABORATORY DERIVED MINERAL-ICE MIXTURES WITH APPLICATIONS TO CHAOS TERRAIN FORMATION ON EUROPA.** K.M. Robertson[1], S. Li[2]. [1]Dept. of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, 02912, [2] Hawai'i Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI 96822.

**Introduction:** Chaos terrains on Europa's icy surface consist of disrupted crustal units [1,2] that are composed of 'rafts' (broken pieces of the shell) and a 'matrix' (hummocky plains). Understanding the formation mechanism of these complex geological features is critical for constraining the surficial and interior processes of Europa.

Commonly accepted hypotheses propose that chaos terrains are either formed from the re-solidification of the ice shell that has been melted through by interior thermal activities [3] or that they are collapsed ice shells due to brine mobilization [1,4]. The melt through model predicts elevated water ice content in the matrix and chaos terrain boundaries [3] while the brine mobilization model predicts higher abundances of brine minerals in these regions [2,4]. Quantitative estimates of the compositional variability among the crustal units are pivotal to constraining these formation mechanisms.

The Hapke [5] and Shkuratov [6] radiative transfer models (RTMs) account for non-linear spectral un-mixing in intimate particulate mixtures. RTM's are well established in assessing the modal mineralogy of airless bodies [7] and icy bodies [8] and are sensitive to subtle differences in hydration band parameters [9] making them ideal for the spectral un-mixing of Galileo NIMS reflectance spectral data and modal mineralogy studies of Chaos terrains.

The proposed RTMs are well suited to quantify the distribution of brine minerals in the Chaos terrains, however they require laboratory validation to evaluate uncertainties. Validation involves 1) producing a suite of laboratory-derived ice-mineral mixtures over a wide range of particle sizes and wt%, 2) measuring the icy samples in a controlled environment over a wavelength range representative of the NIMS reflectance data and 3) modeling the spectra and quantifying the modal abundances. Here we discuss the methodology for the preparation and measurement of laboratory derived ice-mineral mixtures and present preliminary results of ice end-members and ice-$MgSO_4$ mixtures.

**Methods:** The RTMs rely on precise particle size and porosity values to establish optical path lengths' therefore controlling these parameters is crucial in the synthesis of polycrystalline ice. Fine-grained ice (10-100μm) requires nebulizing water into a $LN_2$ bath and sieving the resulting slurry to the appropriate particle size ranges [10]. Coarse-grained (100-500μm) ice powders are produced by freezing water filled molds, processing through an industrial blender, and combining with $LN_2$ to form an ice-slurry for sieving [11]. Reducing porosity/bubble formation is accomplished by heating deionized water at 50°C for 30 minutes and then using a vacuum to remove residual gas prior to freezing.

Sample preparations were performed in a large chest freezer to prevent melting and to reduce condensation. All laboratory paraphernalia (samples, vials, dishes, spatulas) were equilibrated in an $LN_2$ bath to reduce the potential for melting and recrystallization. The resultant ice-slurry mixtures for both fine and coarse ice powders were passed through sieves (25-53μm, 53-75μm, 75-125μm, 125-250μm, 250-500μm) to obtain the desired particle size ranges. The size-separated powders were then placed in cooled glass vials and stored in $LN_2$ filled dewars until mixed with salts and/or measured on the spectrometers.

Mineral end members were crushed and powdered in a mortar and pestle and dry sieved with the same sieve ranges as the ice powders. The samples were then stored in a chest freezer until mixed with the ice powders and/or measured on the spectrometers.

Ices and minerals ($MgSO_4$ in this case) of the same particle size ranges were mixed in 3 different abundances (25,50,75 wt% ice) to test their limits of detection and uncertainties in modal mineralogy estimation. The samples were weighed and transferred to a vial and then returned to the $LN_2$ until measured.

Spectral measurements of polycrystalline ice and ice-salt mixtures were taken in the VIS-NIR (300 - 2500 nm) wavelength range using an ASD Fieldspec3 field spectroradiometer. This unit is equipped with a QTH fiber optic light source and is housed on an optical bench with adjustable goniometers to control the viewing geometry ($i$=30°,$e$=0°).

Samples were loaded into a Linkam Low-T environmental stage from Linkam Scientific. The samples studied in this preliminary work were measured at -50°C. Laboratory controlled 'dry' air (-70°C dewpoint) was connected to the chamber to maintain relative humidity below saturation. The sample and reflectance standard (pressed halon) are both mounted in a single sample cup in direct contact with the heating/cooling block, which allows us to measure the standard under the same conditions as the sample. The icy samples were loaded into the sample cup in the chest freezer and transferred to the equilibrated linkam chamber for measurement.

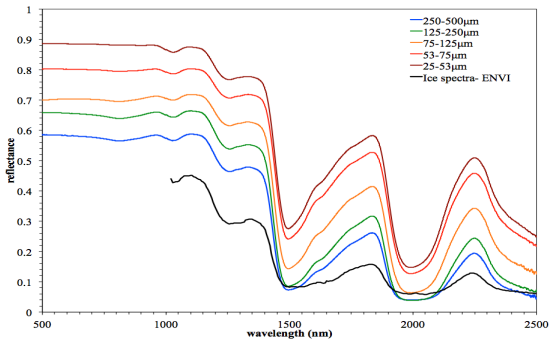


**Fig.1.** UV-VIS reflectance spectra of a suite of pure ice for various particle sizes measured on the ASD fieldspec3 spectrometer. An ice spectrum taken from ENVI is compared.

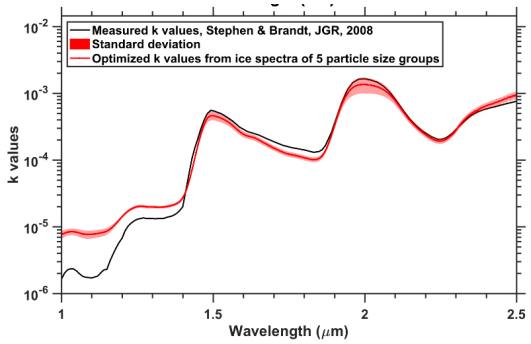


**Fig.2.** Derived *k* values from five groups of ice spectra at different particle sizes using Hapke's model compared with measured values in [12].

**Results:** A suite of pure ice samples with varying particle sizes are shown in Fig. 1. The diagnostic spectral parameters (albedo, band depth, band width, band position) are consistent with a typical ice spectrum from ENVI. As expected, particle size plays a significant role in controlling the spectral parameters, where the finer grain sizes show a much higher albedo and band depth. Differences in the observed slopes associated with the primary hydration bands at 1500nm and 2000nm are also observed. These differences in spectral parameters will be used by the RTMs to assess the modal abundances of ice-salt mixtures.

The optical constant (*k*-value) was derived for this suite of ice end-members (Fig. 2). Using an optimization routine [9] from 5 particle size groups yields an optical constant that is consistent with previous values. These results suggest that the particle size estimates for the pure ices are accurate and that the methodology results in consistent particle sizes.

A measurement of an ice-$MgSO_4$ mixture (Fig.3) includes the pure ice end-member, pure $MgSO_4$ end-member and the resultant binary mixture at a 50:50 wt% ratio for the fine (25-53 µm) and coarse (125-250 µm) particle sizes. While the overall shape of the hydration features in the pure ice and epsomite end members are similar, there are subtle differences that can be exploited by the RTMs to derive the modal abundances. In both cases, the 50:50 mixtures show an intermediate albedo and band shape between the two end-members.

**Conclusion:** In this work we provide the framework for the preparation of laboratory derived ice-mixtures. The methodology shown here is reproducible and produces ice powders of consistent particle size and porosity making them ideal for validating the RTM's ability to quantify ice-salt mixtures. These spectra highlight the important variability in the diagnostic hydration bands, which will be pivotal to assessing the mineralogy and modal abundance on the surface of Europa. Future work will incorporate a wide range of salts to properly represent all potential minerals on the surface of Europa with the ultimate goal of quantifying the brine minerals in Chaos terrains to constrain their formation mechanism.

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**References:** [1] Carr, M.H., et al. Nature, 1998. [2] Schmidt, B.E., et al. Nature, 2011. [3] Greenberg, R., et al. Icarus, 1999. [4] Head, J.W. and R.T. Pappalardo. JGR, 1999. [5] Hapke, B. JGR, 1981. [6] Shkuratov, Y., et al. Icarus, 1999. [7] De Sanctis et al., Science, 2012. [8] Protopapa et al., Icarus, 2017 [9] Robertson et al., Icarus, 2016. [10] Goldsby and Kohstedt, JGR, 1997. [11] Stern et al., JGR, 1997. [12] Stephen and Brandt, JGR, 2008.

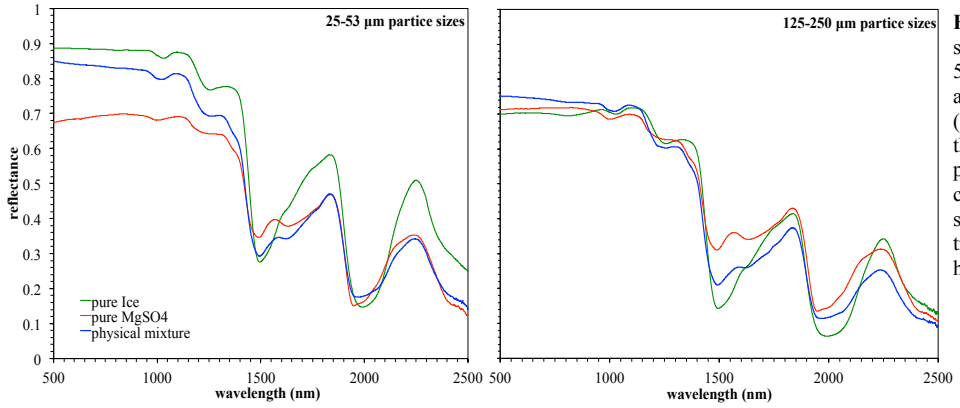


**Fig.3.** UV-VIS reflectance spectra of laboratory derived 50:50 mixtures of polycrystalline ice and epsomite ($MgSO_4 \bullet 7H_2O$) compared with their pure end-member components for fine (25-53µm) and coarse (125-250µm) grained samples. Subtle shifts in spectral parameters for diagnostic hydration bands are observed.