ICES IN THE OUTER SOLAR SYSTEM – LAB REFLECTION SPECTROSCOPY OF IRRADIATED EUROPAN ICES AT DIFFERENT GRAIN SIZES & TEMPERATURES WITH COMPARISON TO HAPKE MODELING.

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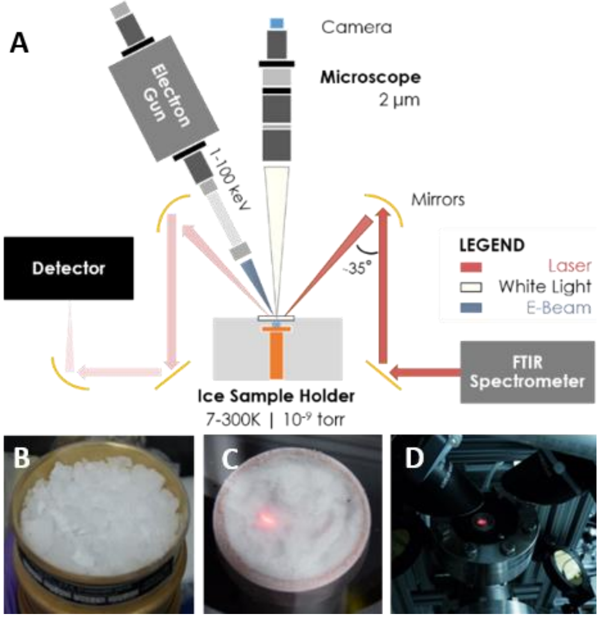
Introduction: The ocean-bearing world, Europa, is one of NASA's key targets for exploration of habitable worlds [1-3], owing to the presence of a subsurface ocean with potential to host life, the detection of plumes offering a pathway for transport of oceanic material to the surface, and its unique radiation environment which can modify this emplaced material over geologically short timescales. Our near-term understanding of Europa's habitability and future exploration will rely on our ability to assess ocean chemistry without direct ocean access and evaluate candidate sites of fresh extruded material using remote sensing [4,5].

Measurements of Europa's surface indicate the presence of several distinct, absorption bands of water ice (and salts) in the near-infrared spectrum; their presence, shape, and positions are functions of grain size, radiation, temperature, and lattice order of ices [6]. Among the suite of instruments on board the Europa Clipper, the Mapping Imaging Spectrometer for Europa (MISE) [7] could further help reveal this surface distribution of organics, salts, water ice phases and other materials [6]. However, there is a pressing need for cryogenic laboratory reflection spectra of multiple icy satellite candidate materials of appropriate quantity and sample thickness, under relevant temperatures and irradiation (with realistic electron energies) [8] to interpret these measurements.

We have built on previous work [9-14] to develop a lab-based pathway [15-17], with which ***we have obtained these critical spectroscopic measurements of Europa-like materials under Europan conditions.*** We present these new data, along with comparisons to Hapke model predictions, to enable better interpretation of Europa's surface composition and microphysical properties through planetary remote sensing.

Lab Instrumentation: The Ice Spectroscopy Laboratory (ISL) at JPL is equipped with state-of-the-art infrastructure for studying the spectral, optical, and compositional properties of ices, under Europa's radiation conditions. This facility includes an ice deposition and sieving drybox with continuous N_2 purge, a high-vacuum chamber ($<10^{-9}$ mbar), a closed-cycle helium cryostat (maintain Cu substrate at 10K – 300K), UV-VIS-NIR reflection spectrometers, a remote microscope setup (resolution of 2 µm at 10 cm distance), and tunable electron gun sources (Fig 1A) [15-16,18]. Optimized protocols were developed for preparation of ice grains of controlled size (5 µm to >200 µm), with varying ice composition (ice+salts such as $MgSO_4$, NaCl) at 77-150 K, as described in detail in [16]. VIS-NIR reflectance-absorption spectra of these ice grains are collected using a NICOLET 6700 FTIR spectrometer and a MCT detector, band depth quantified, and the variation of spectral properties with different parameters is investigated. Samples (at 100 K) are exposed to electron radiation using a Kimball Physics tunable electron gun source (<100 keV), mounted onto the vacuum chamber (Fig 1A), with a uniform electron beam focused on a ~2 cm diameter spot on the ice.

Fig 1. (A) The ISL experimental setup, shown schematically here, enables spectroscopic/microscopic measurements at Europa-like conditions. (B) We can deposit/sieve ice, (C) place in vacuum chamber, and (D) collect spectra.



Experimental Protocols & Results:

Grain Size: Reflectance spectra of both amorphous and crystalline water-ice grains with grain-size from 25-153 µm (divided into 25 µm sets) were collected (Figure 2A,C). Samples displayed spectral signatures of crystalline water ice, with an observed non-linear increase in band depth of NIR absorption signatures with grain size: this trend is consistent with theoretical models and can be used to estimate Europa's surface particle size.

Temperature: Samples (ice and salts) undergo thermal cycling under high vacuum, in the range of 10-150 K, with spectra and optical images collected periodically. This investigation covered the range of expected diurnal temperature variations in the outer solar system. Thermal cycling of water ice prepared at 77K led to an increase in the 1.65 µm band depth (Fig. 2D), potentially due to a transition to crystalline ice upon heating.

Irradiation: Samples in 25 µm size sets are currently being targeted to determine how radiation affects periodically collected spectra, and to note the evolution of grain size. We are in an ongoing process of irradiating water-ice grains with electrons of different energies (up to 100 keV), times of irradiation, and total flux.

Composition: Pure water ice and two component ice-salt mixtures (NaCl, $MgCl_2$, Na_2SO_4, $MgSO_4$) were targeted in our study. Ice-salt mixtures were crystallized by (1) droplet condensation in liquid nitrogen of salts (10-30% by weight) mixed with ultrapure water, or (2) bulk solidification by cooling a homogenous liquid solution of premixed ultrapure liquid water-salt at constant temperature [19,20]. Solid ice grains were ground with a mortar & pestle in liquid nitrogen, sieved & loaded on sample holder for spectra collection, where their sizes were verified through microscopy.

Hapke Modeling: Lab reflection spectra for water ice samples were compared to Hapke-modeled water ice spectra (Fig. 2B) (both crystalline & amorphous) for the same grain size ranges. Model spectra were produced with Mastrapa 2008 [11] optical constants, with an asymmetry factor of -0.15 [21] and grain porosity of 0.1 (used to compute compaction factor [Eq.7 in [21]]). Illumination conditions (i=35, e=35, g=70) were identical between the model and the lab. While lab spectra broadly replicate band absorptions observed in modeled spectra, we were unable to replicate the band depths and spectral slopes, as observed in Fig. 2E.

Conclusions & Implications: Our study, for the first time, allows us to determine how the combination of high-energy electron radiation, salt content, grain size, and temperature together influence the spectral and sintering properties of Europa ice-analogs, which is critical for the Europa Clipper Mission. We find that laboratory spectral albedos and absorption band depths of water ice depend on grain-size, composition, and temperature, and that they are systematically lower than those obtained from modeling.

This work will help estimate how Europa's surface has evolved over the last 60-100 Ma, and will better constrain composition & grain size distribution, and how they are affected by radiation, which will enable better estimates of how subsurface ocean composition may be preserved or modified at the surface. This ISL dataset will improve the ability to interpret spectra of icy surfaces, and enhance the science value of potential sites for future in-situ exploration of Europa, other Jovian/Saturnian icy bodies, and Ice Giants.

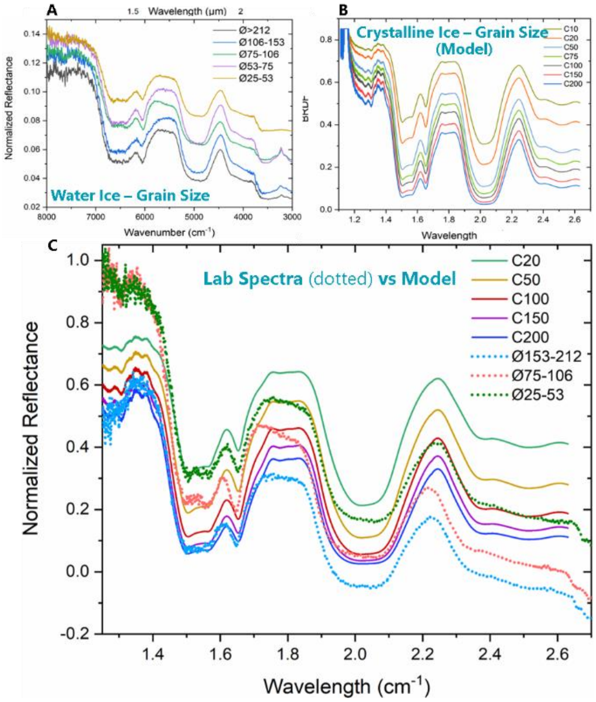


Fig 2. (A) Collected ISL lab spectra of water ice & (B) modeled crystalline spectra at different sizes are compared in (C).

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