**WHAT LIES ON EUROPA'S SURFACE? MICROPHYSICS AND SPECTROSCOPY OF ICE GRAINS UNDER RADIATION.** V. Singh[1, 2], M. S. Gudipati[2], A. R. Rhoden[3] and B. L. Henderson[2], [1]SESE, Arizona State University, 781 Terrace Road, Tempe, AZ 85287 (Vishaal.Singh@asu.edu), [2]Jet Propulsion Laboratory, Caltech, [3]Southwest Research Institute – Boulder.

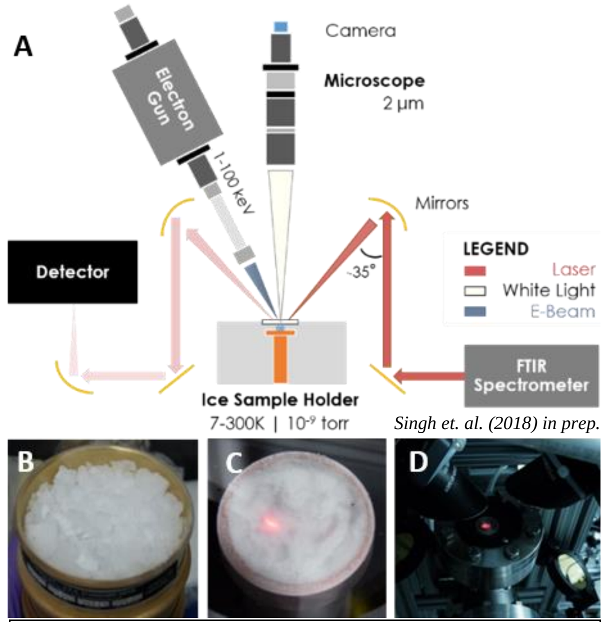


Fig 1. (A) The ISL experimental setup, shown schematically here, enables spectroscopic/microscopic measurements at Europa-like conditions. (B) We can deposit/sieve ice, (C) place in vacuum chamber, and (D) collect spectra.

**Introduction:** Measurements of the surface of Jupiter's moon, Europa – one of NASA's key targets for exploration of habitable worlds [1-2], 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 [3]. The Europa Clipper's Mapping Imaging Spectrometer for Europa (MISE) will further yield information about Europa's composition by collecting data that can reveal the distribution of organics, salts, water ice phases and other materials [4]. This data will be critical for answering key questions about Europa's surface geology, ocean chemistry, and habitability as it would allow us to identify surface materials, understand how they are processed, and how remote sensing data can help establish their origin and lifetime. However, our ability to interpret these measurements is limited by a lack of ground-truth/laboratory spectra of ices, and because the changes in optical/spectral/mechanical properties due to grain size, irradiation and/or mixing, is challenging to measure at relevant Europa conditions in the laboratory.

We present a laboratory-based pathway [5-6] designed to obtain these critical spectroscopic measurements of ices in the UV-VIS-NIR spectral range, at conditions relevant to Europa. We are particularly interested in how ices and their spectra evolve (specifically their grain size, coloration, and spectral albedo) under planetary conditions, and investigate their dependence on (1) grain size, (2) salt content, (3) extent of irradiation, and (4) thermal cycling. We also intend to present the thermal and radiation-induced sintering of ice grains, and correlate sintering with spectral changes.

Our goal is to link optical, spectral and surface properties, by using our laboratory data and spectral data from Galileo NIMS/Europa MISE instruments, to provide information critical for characterizing Europa's near-surface materials, and its harsh surface environment. For example, endogenic materials with low exposure ages are more likely to preserve biosignatures, so improving their detectability would be valuable for future mission planning.

**Methodology:** 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 trailing hemisphere conditions, using an ice deposition/sieving drybox, a high-vacuum chamber, a closed-cycle helium cryostat, UV-VIS-NIR reflection spectrometers, a remote microscope setup (2 μm), and tunable electron gun source (Fig 1a). We have developed protocols for ex-situ preparation of ice grains of controlled size (5 μm to >200 μm), with varying ice composition (ice + salts such as $MgSO_4$ and NaCl) at 77-150 K (Fig. 1b-c). We control grain size by misting ultrapure water into a dewar filled with liquid nitrogen (LN), followed by sieving in pristine $N_2$ environment [7]. Ice grains are transferred to a sample holder inside a high vacuum chamber [8], which is pumped down to $10^{-9}$ mbar and cryogenically cooled to 100 K to replicate Europa's surface conditions, specifically the dayside temperatures [9]. We collect the VIS-NIR reflectance-absorption spectra of these ice grains, using a NICOLET 6700 FTIR spectrometer and a MCT detector, quantify band depth, and study the variation of spectral properties with different parameters. For electron irradiation of our samples, we use a Kimball Physics tunable electron gun source (<100 keV), with a uniform electron beam focused on a ~20 mm diameter spot on the ice, prior to collecting the reflectance spectra. Electron flux is measured using a Faraday cup that is brought in and out of the path of the electron beam.

Our laboratory experiments are also designed to collect optical data of ices under relevant Europa conditions with continuous light microscopic studies, using a remote INFINITY K-2 DistaMax Microscope with a C2 objective. The images of samples are taken using a Zeiss Axiocam digital camera with a C-Mount adapter (resolution: 10 µm). This allows us to obtain a secondary assessment of average grain size, to image the evolving morphology of ice grains, and to study the effects of diurnal thermal cycling in samples.

**Preliminary Results:** The first two tasks of our laboratory investigation, which we report on here, are to characterize the effects of grain size and irradiation on the spectra and physical properties of ices, and identify any feedbacks such as how the grain size changes with radiation exposure and thermal cycling.

*Effects of Grain Size:* We have successfully produced water-ice samples, and collected reflectance spectra of pristine, water-ice grains with grain sizes ranging from 25-212 µm. Our samples display spectral signatures of crystalline water ice, with an observed increase in band depth of NIR absorption signatures with sample grain size, which is consistent with theoretical models (Fig. 2C) – we can use this trend to determine Europa's surface particle size, and relative surface age. Thermal cycling of samples (100 K to 170 K) leads to an increase in 1.65 µm band depth (see Fig 2B-D), which is potentially due to sample preparation in LN (at 77K) resulting in amorphous ice formation, which turns crystalline upon heating. There is also an observed change in grain size and morphology through ice sintering (see Fig 2E), which follows expected results from recent modeling work [10-11].

*Effects of Ice Irradiation:* A recent study at ISL determined the expected penetration depths of low-energy electrons (100 nm for 1 keV; 200 nm for 2 keV; ~200 µm for 100 keV), and found that it is sufficient to fully process the grain sizes selected for this study [12]. We are using this information to interpret the spectroscopic data of our samples at a given radiation dose. In our preliminary tests, we are exploring the effects of electron energy, time of irradiation, and total flux by performing multiple experiments: (1) varying electron energy and time of irradiation, with constant electron flux, and (2) constant electron energy, but varying flux and time of irradiation (50 to 200 Europa equivalent years).

We will present the findings of the grain size and initial irradiation experiments, discuss plans for delivering our measurements to the community through an ice spectral database (ICELIB), and describe upcoming experiments investigating salt content.

**Conclusions:** Our study will for the first time allow us to determine how the combination of high-energy electron radiation, salt content, and grain size together influence the spectral and sintering properties of Europa ice-analogs under relevant conditions. In future years, the collected spectra will allow us to accurately model Europa NIMS/MISE datasets, which can enhance our

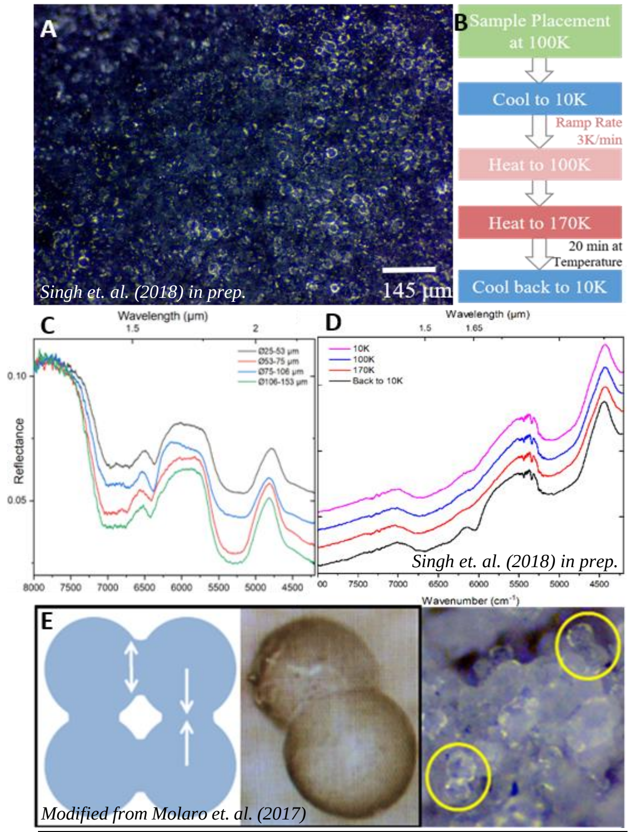


Fig. 2. We have successfully collected optical & spectroscopic data of ice grains: (A) 53-75 µm, using (B) methodology. (C) & (D) illustrate the effect of thermal cycling and grain size on spectra, while (E) illustrates the two stages of ice sintering observed (yellow circles) in our lab samples.

interpretation of icy surface spectra, and inform site selection for in-situ sample collection. More broadly, these methods should also be applicable to other icy surfaces, which is particularly relevant for future missions to Jovian and Saturnian satellites, and Ice Giants.

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