FY24 Strategic University Research Partnership (SURP)

Characterizing the structure and mechanical properties of water ice under ion irradiation

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Background: The icy crust of Europa undergoes continuous irradiation by the Jovian magnetosphere. These processes modify the surface's chemistry and physics and can hinder the ability to connect remote sensing data to composition, habitability and other key properties, for example, for the Europa Clipper mission or for a future Europa lander. Mechanical investigations of ice under irradiation are scarce because few institutions possess the specialized facilities and technical expertise required.

The partnership with Texas A&M University (TAMU) provides JPL long-term access to a) laboratory-based equipment capable of simulating irradiation by a wide range of particle types, energies, and fluxes, b) cryogenic facilities for precise sample preparation, characterization, and mechanical testing, and c) technical expertise on ice physics, radiation effects, and material properties.

The goal of this SURP seed project is to demonstrate reproducible, in-situ testing of thermal and mechanical properties of water ice under irradiation with applications to Europa. This work complements previous mechanical strength studies carried out by the JPL PI and Co-I using indentation on MeV-electron-irradiated ice cores.

Approach: In FY23-FY24, we investigated ice under irradiation by a single ion type, i.e., protons, at 50 K to 150 K, covering the range of surface temperatures on Europa. This project relies upon the unique facilities available at TAMU, which complement existing capabilities at JPL. The TAMU accelerator laboratory (https://engineering.tamu.edu/nuclear/research/facilities/accelerator-laboratory.html) is directed by TAMU Co-I Shao and provides a wide range of ion types, energies, and fluxes with accelerator voltages range from 10 kV to 3.0, a temperature-controlled target stage down to liquid helium levels (~4 K), and a microtensile stage integrated into the target chamber. To the best of our knowledge, this unique capability differentiates the TAMU accelerator laboratory from all other facilities capable of conducting ion irradiations on targets at cryogenic temperatures. The TAMU accelerator laboratory performs in-situ characterization by RBS and ERD using a high-resolution mass spectrometer to measure the energies of scattered ions. These techniques enable characterization of sample composition and impurity depth profiles during irradiation. The lab has a large target chamber with multiple ports for in-situ reflectance infrared spectrometry of irradiated water ice, and leverages microscopy and Raman spectroscopy capabilities at the lab of TAMU Co-I, Sarah Brooks, and at the TAMU Microscopy and Imaging Center (https://microscopy.tamu.edu), which contains cryogenic light and electron microscopy instruments for ex-situ microstructure characterization.

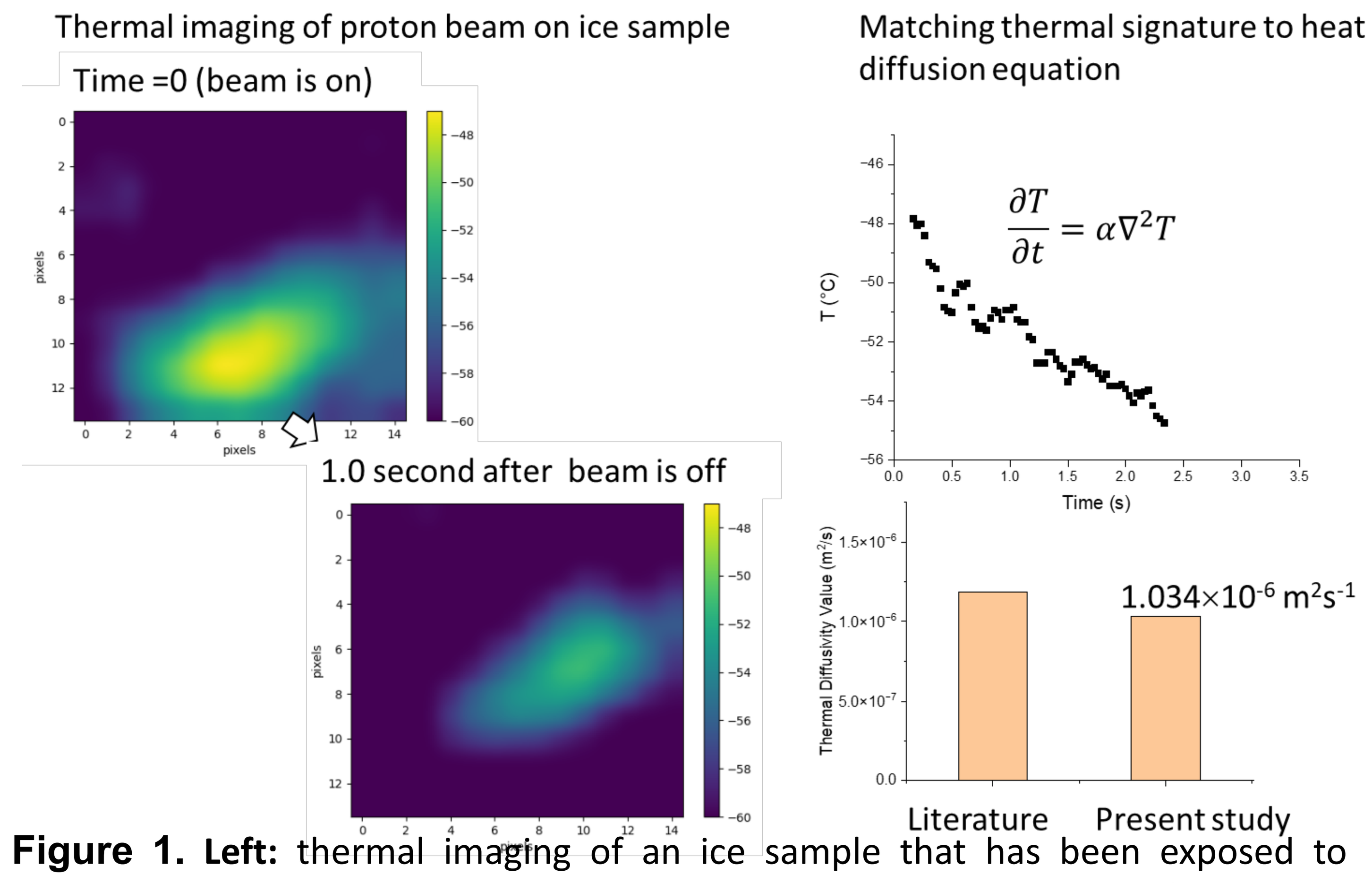

Figure 1. Left: thermal imaging of an ice sample that has been exposed to proton irradiation. The upper panel shows the temperature of the ice (in degrees Celsius) at time zero, and the **lower left** image shows the ice after it has been allowed to cool for 1.0 seconds. **Upper right:** the maximum temperature is plotted vs. time, and the heat diffusion equation is used to calculate the thermal diffusivity (**lower right**). We will use this technique to determine whether ices that very in terms of crystallinity (highly crystalline vs. amorphous) or ices that have been heavily radiation-processed give different thermal diffusivities.

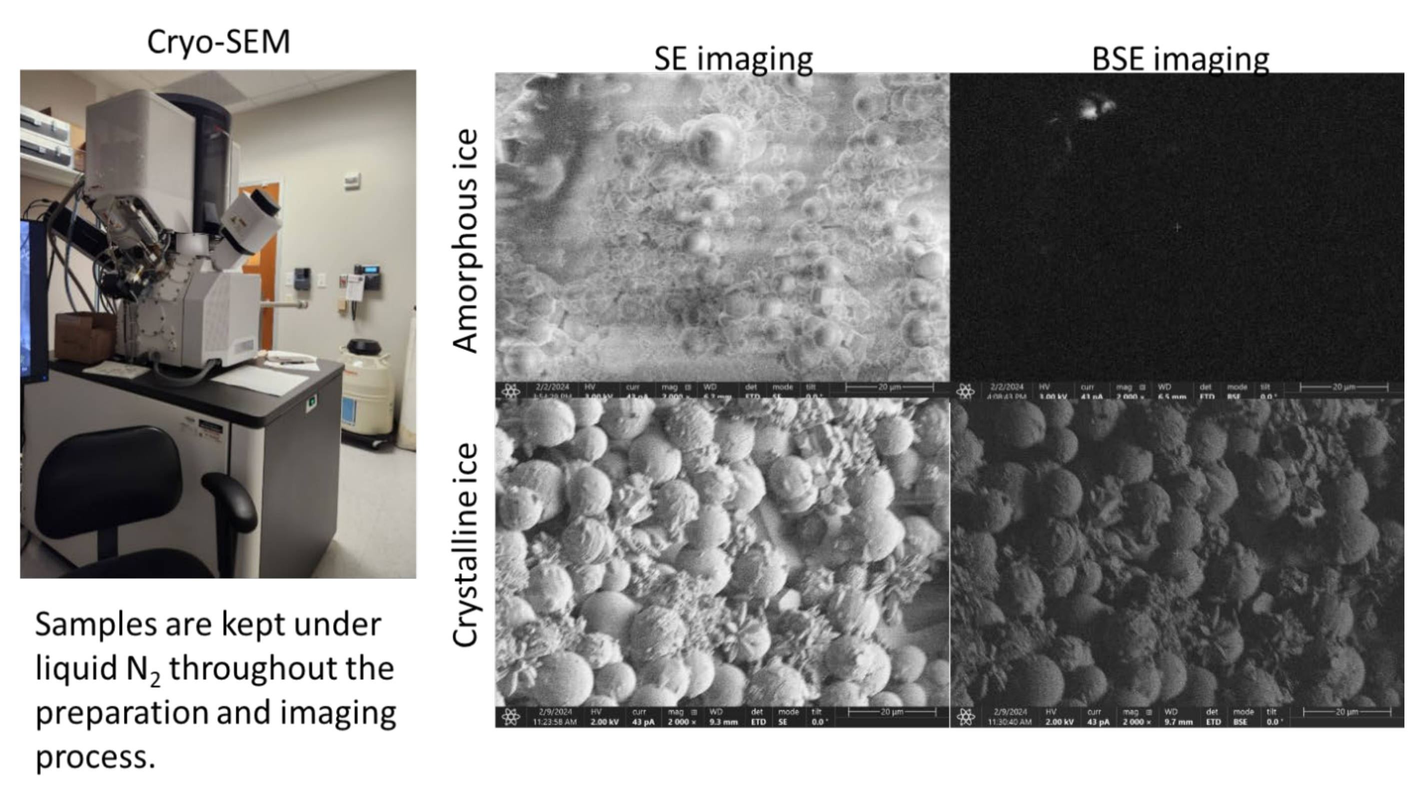

Figure 2. Preliminary results suggest that crystalline ice gives clear contrast under Back-Scattered Electron (BSE) imaging in a cryo-Scanning Electron Microscope (cryo-SEM), while amorphous has no contrast. This may indicate a novel way of distinguishing between crystalline and amorphous ice in cryo-SEM.

FY24 Activities and Results: In FY24, TAMU Co-I L. Shao and PhD student B. Mejia visited JPL to meet with JPL PIs and participate in the annual SURP poster session; TAMU funding enabled a PhD student (Wendy Storms) to spend Summer 2024 working at JPL with PI Henderson and Co-I Gudipati. Wendy developed new pneumatic spray-based ice deposition methods for making complex ice analogs (e.g., salt+water solutions that cannot be deposited through vapor deposition). She deposited ices onto a 100 K substrate, and followed their evolution through reflection-absorption and absorption FTIR spectroscopy. This work will enable new types of analogs to be studied in future JPL-based and TAMU-based experiments and will broaden the range of potential experiments that can be proposed. We also developed a process for transferring ice samples in liquid N_2 between the ion beam lab and the electron microscopy center at TAMU. In FY24, TAMU also expanded and improved the AMCSET (Aggie Monte Carlo Simulations of Electron and Ion Transport) code, performed electron microscopy imaging and in-situ heating of crystalline and amorphous ice in a cryo-SEM and demonstrated in-situ thermal diffusivity measurements on ice in the ion beam; validated against literature data (see **Figs. 1 and 2**). A contributed talk on this project was delivered at the TMS 2024 annual meeting in Orlando.

Significance/Benefits to JPL and NASA: This long-term partnership with TAMU enables comprehensive investigations on irradiated water ice, including the effect of impurities and microstructure, and enables the formulation of constitutive models for mechanical behavior, thermal conductivity, and other properties of interest. Such parameters can be fed into geological models to better characterize the surfaces and subsurfaces of icy bodies such as Europa. The results obtained through the proposed work will be used to support future joint proposals for ROSES programs (PSIE, SSW, HW, EW, etc.) involving compositions, temperatures, and radiation conditions relevant for Europa or other Solar System bodies.

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Publications:

Y Hong; B Mejia; W Storms; MS Gudipati; BL Henderson; L Shao; Michael Demkowicz. (2024, March 3–7). Investigating Water Ice Under Ion Irradiation for Future Exploration of Europa [Conference presentation]. TMS2024, Orlando, FL, United States.

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