National Aeronautics and Space Administration

FY23 Strategic University Research Partnership (SURP)

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

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Objectives: The goal of this seed project is to demonstrate reproducible, in situ tensile testing with simultaneous spectroscopic structure characterization of water ice under irradiation. This work will complement previous studies carried out by the JPL PI and Co-I by a) providing a wider range of mechanical property data through controlled in situ tensile testing, b) expanding the range of particle types, energies, and fluxes used during irradiation, developing robust methods to predict surface properties of Europa and other icy bodies under radiation, and c) providing spectral data, all critical for both remote-sensing and in situ lander missions.

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

Approach and Results:
Team developments: We have recruited and trained one PhD student and two senior undergraduate researchers, who have decided to continue on to graduate school, pursuing their PhD degrees working on this project. In January 2023, TAMU hosted a visit including tours of TAMU laboratories, a seminar, and meetings with TAMU faculty working in areas of interest to JPL.
Technical developments: Ice samples were vapor deposited in the ion beam target chamber, irradiated with protons, and characterized by Rutherford Backscattering Spectrometry (RBS, Fig. 1). We have carried out ex-situ tensile tests on ice using the tensile stage shown in Fig. 2.a), that will be used for in situ experiments. The engineering stress-strain curves obtained are shown in Fig. 2.b) We are adapting the DEEPER code, for characterization of radiation-induced damage (by both ions and electrons) in ice. In addition, we are developing procedures for additional, ex situ characterization of irradiated ice samples, allowing us to transport irradiated samples for additional characterization outside the ion beam and to transport ice grown under controlled conditions to the ion beam. Polarized optical microscopy and Raman spectroscopy has been conducted in the lab of TAMU Co-I Sarah Brooks. Our early measurements on ice samples solidified from the liquid phase are shown in Fig. 3. We are developing procedures to grow ice under controlled temperature and humidity. One of the TAMU students is now receiving training on cryo-scanning electron microscopy (cryo-SEM) using newly installed equipment at TAMU's Microscopy and Imaging Center (MIC).

Significance/Benefits to JPL and NASA: Our partnership with TAMU enables comprehensive investigations on irradiated water ice, including the effect of impurities and microstructure, and will lead to 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. While the proposed work is motivated primarily by mission needs for exploration of ice worlds, such as Europa, it also has the potential to impact a range of other mission goals, such as collection and analysis of ice particulates, mining of lunar ice, or construction of ice structures on Mars.

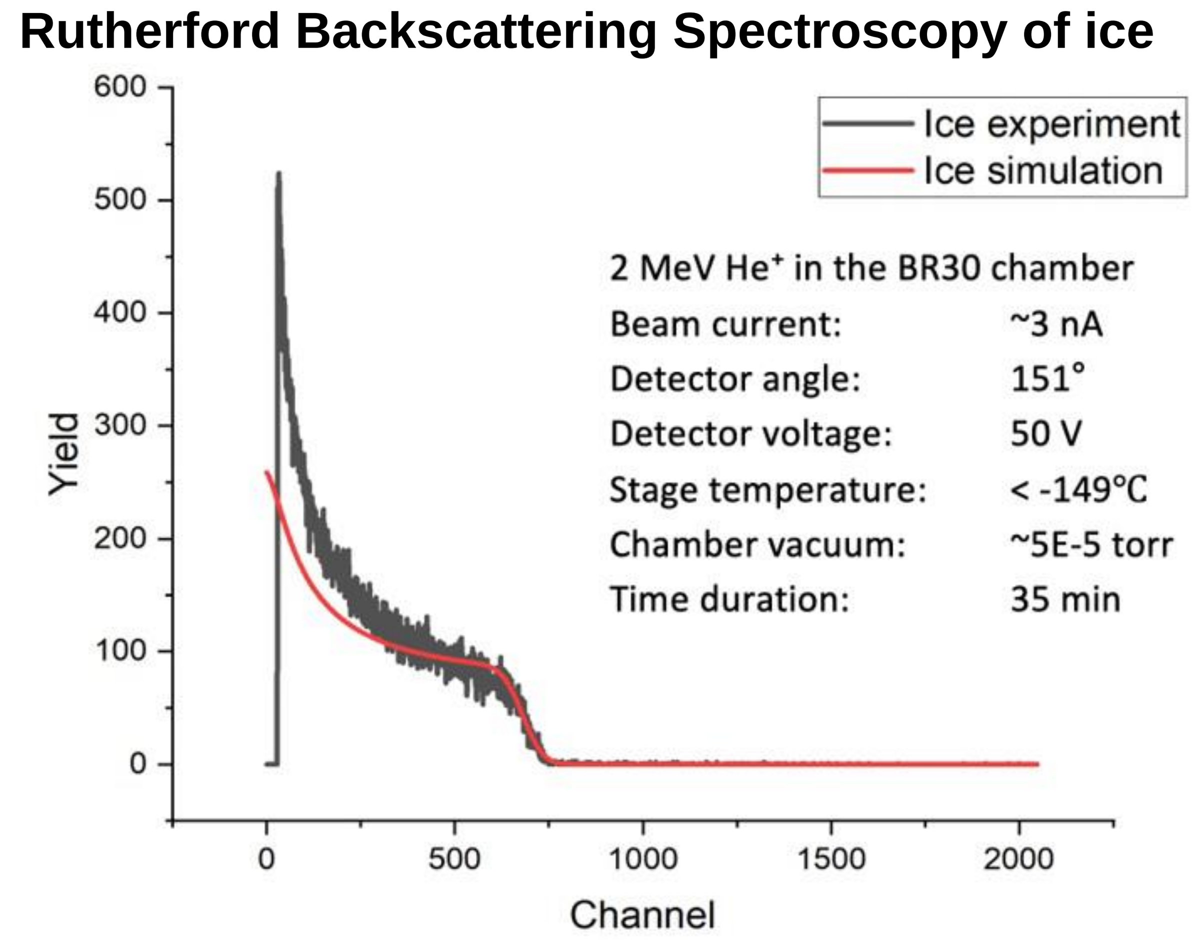

Figure 1. RBS spectrum of vapor-deposited ice taken at the TAMU accelerator lab. This measurement gives a high-fidelity characterization of sample composition as a function of depth beneath the surface (related to channel number here), and can provide information about crystallinity vs. amorphization in a sample and the location and amount of damage of the ice. RBS can also measure the depth of implantation of species in an ice.

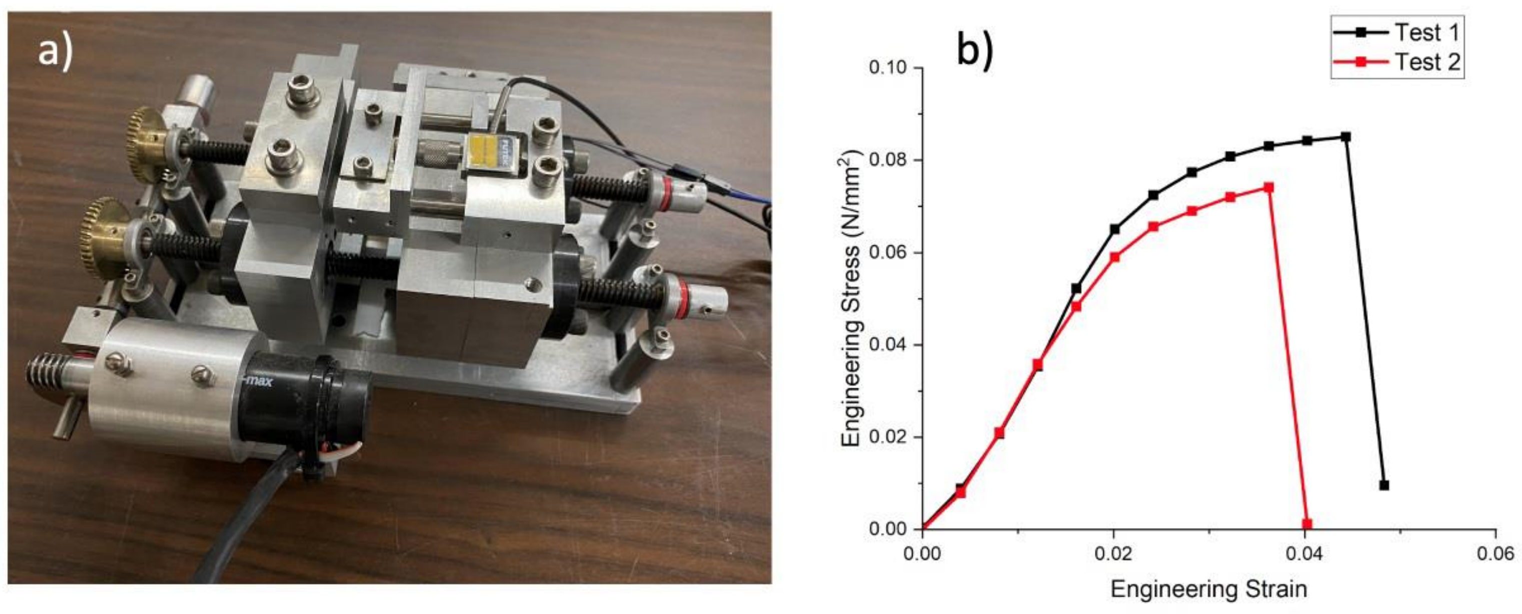

Figure 2. a) Micro-tensile stage for *in situ* mechanical testing at the TAMU accelerator laboratory. b) Engineering stress vs. strain curves taken from two polycrystalline ice cubes of dimensions 1 cm x 1 cm x 2 cm.

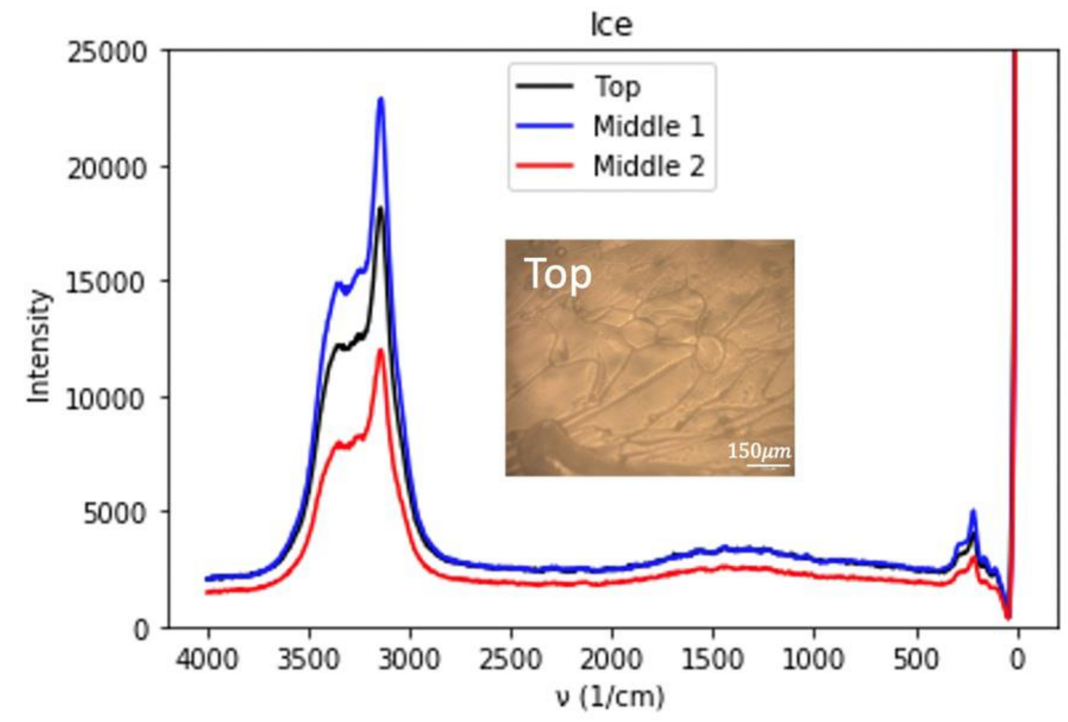

Figure 3. Raman spectra taken at different depths of focus on ice samples solidified from the liquid at -40 °C. The inset shows a polarized optical micrograph with the focal point on the sample surface.

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Clearance Number: CL#23-5117
Poster Number: RPC-164

Publications:
n/a

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