FY25 Strategic University Research Partnership (SURP)

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

Principal Investigator: Bryana Henderson (322)**; Co-Investigators:** Murthy Gudipati (322), Michael Demkowicz (Texas A&M University), Lin Shao (Texas A&M University), Sarah Brooks (Texas A&M University)

Goal of initiative: to demonstrate in-situ testing of thermal and mechanical properties of water ice under irradiation, while also tracking structural changes via spectroscopy. This work complements previous mechanical strength studies carried out by the JPL PI and Co-I using indentation on electron irradiated specimens, by a) providing a wider range of mechanical property data, b) expanding the range of particle types, energies, and fluxes used during irradiation, developing methods to predict surface properties of icy bodies under radiation, and c) providing the corresponding spectroscopy data, critical for both remote-sensing and in-situ lander missions. The facilities at TAMU enabled a deeper exploration of ice properties under conditions characteristic of different locations on the Europan surface.

Background: Irradiation 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. Investigations of changes in ice and brines under irradiation could provide important data for the Europa Clipper mission and also help to constrain landing and sample collection conditions for future in-situ sampling by a Europa lander. Mechanical investigations of ice under irradiation are particularly scarce because few institutions possess the specialized cryogenic facilities and technical expertise required to conduct these types of experiments.

Texas A&M University (TAMU) has: 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 modeling and physics, radiation effects, and material properties. This seed effort contributed to a broader understanding of Europan physics and chemistry and helped to correlate surface properties with infrared spectroscopy and remote sensing data by providing experimental evidence of the response of water ice and related analogs under radiation.

Approach and Results: In FY25, we continued to investigate ices under irradiation. The TAMU accelerator laboratory is directed by TAMU Co-I Shao and provides:

- A wide range of ion types, energies, and fluxes. Accelerator voltages range from 10 kV to 3.0 MV.
- A temperature-controlled target stage.
- A microtensile stage integrated into the chamber.
- A wide range of in-situ characterization methods, including RBS (Rutherford Back Scattering) of protons and ERD (Elastic Recoil Detection), using a high-resolution mass spectrometer to measure the energies of scattered ions, enabling characterization of composition and depth profiles during irradiation.
- A large target chamber with multiple ports for in-situ spectroscopy of irradiated water ice. This project leverages microscopy and Raman spectroscopy capabilities at the lab of TAMU Co-I, Sarah Brooks.

FY25 achievements were as follows:

- Team and capability development: a PhD student (Wendy Storms) spent Summers of 2024 & 2025 working in residence with the JPL team. Wendy refined a spray-based ice deposition method for making complex ice brine analogs (e.g., salt+water solutions that cannot be deposited through vapor deposition), see Figs. 1&2.
- Modeling: Expanded and improved the open-source AMCSET (Aggie Monte Carlo Simulations of Electron and Ion Transport) code and released it this year (https://doi.org/10.1016/j.nimb.2025.165625; https://www.nature.com/articles/s41598-024-64024-5). It accelerates computational efficiency by more than two orders of magnitude for Monte Carlo simulations of electron-solid interactions.
- Modeling: A modeling study was conducted by TAMU PI Demkowicz showing that proton ordering in ice (ice XI) makes dislocations largely immobile, implying that irradiated or ordered ice is mechanically stronger but brittle and that ordering/disordering strongly influences mechanical behavior (see Publications). Ice XI has been demonstrated to form from UV irradiation of cryogenic materials and might be present on icy moons such as Europa (Kouchi et al. 2021).

SPECTROSCOPY AND MASS SPECTROMETRY OF ELECTRON-IRRADIATED BRINES

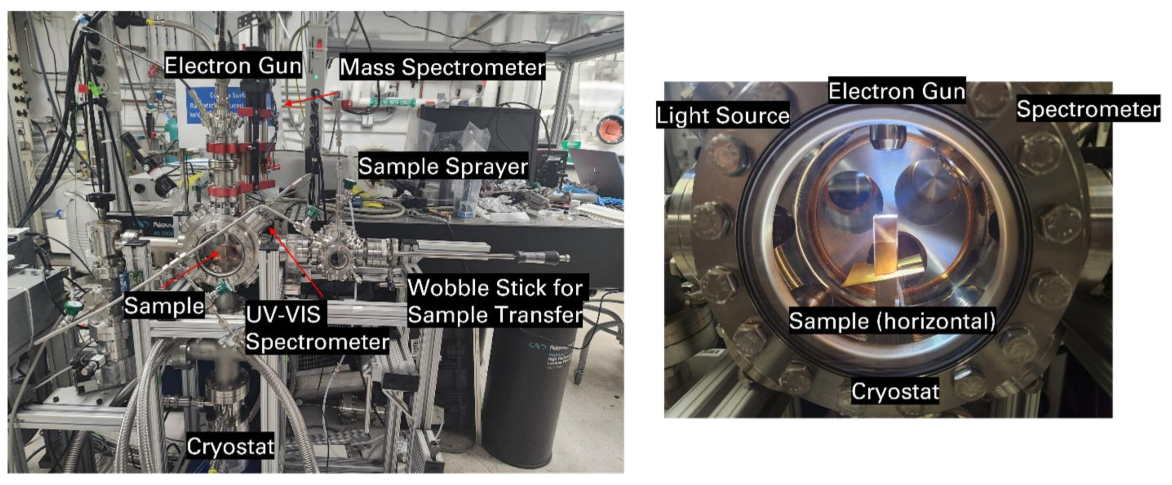

Figure 1. Experiments of ice and brine at Europa conditions. **Left:** the electron irradiation setup includes a UV-VIS spectrometer and a mass spectrometer. Ices are sprayed onto a cold substrate in a separate chamber and are introduced using a wobble stick into the main chamber. **Right:** a view from inside the cryogenic chamber where frozen brines are held at 100 K during irradiation.

10% NACL BRINE COLOR CENTERS FORMED AT 100 K

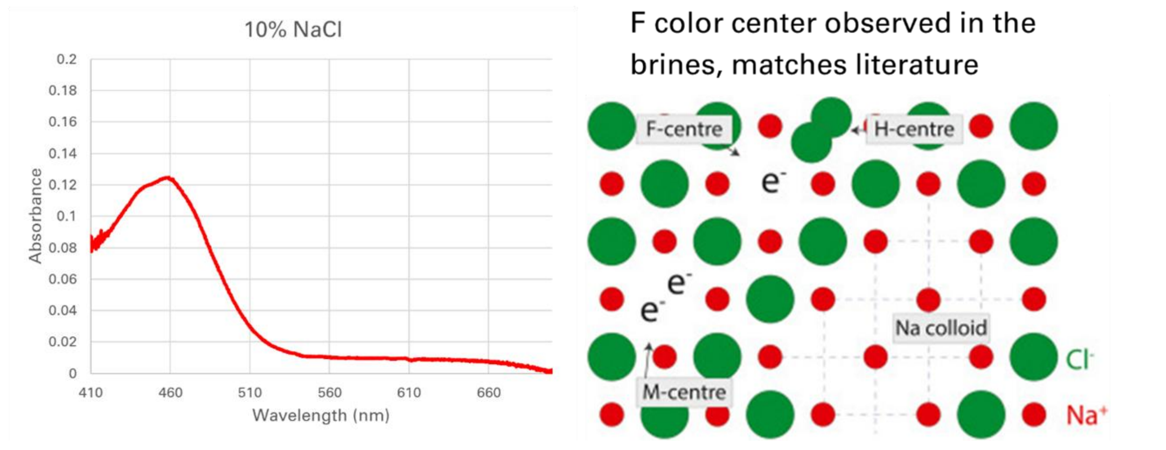

Figure 2. Electron irradiation of sprayed frozen NaCl brines yielded F-centers that match known values from the literature.

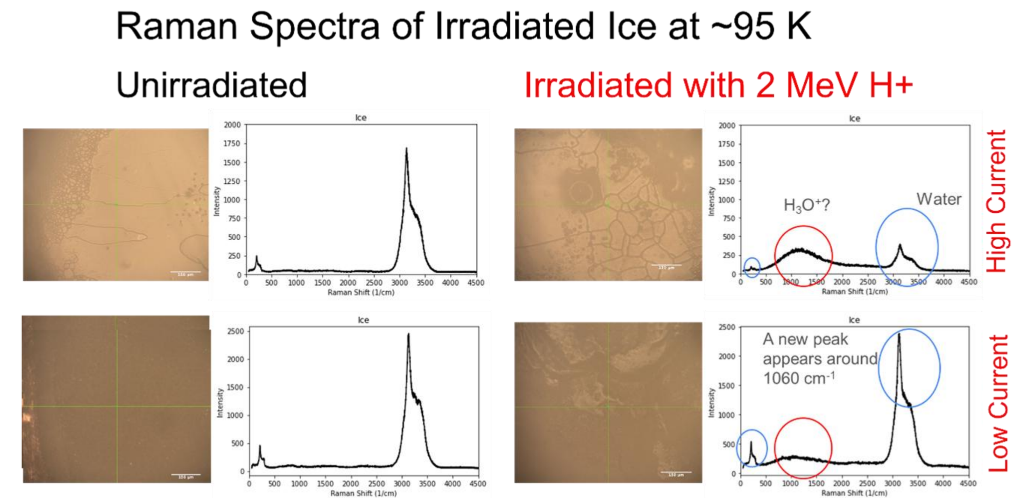

Figure 3. Irradiation tests at TAMU characterized by microscopy and Raman spectroscopy demonstrate that high proton flux generates a new signature near 1060 cm^{-1} (red circle) and decreases the ordered structure of the water ice (blue circles).

Significance to JPL and NASA: This partnership with TAMU has enabled comprehensive investigations on irradiated water ice, including the effect of impurities and microstructure, and lead to the formulation of constitutive models for mechanical behavior, thermal conductivity, and other properties of interest. While the proposed work was 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. The results obtained through the proposed work can support future joint proposals relevant for Europa or other Solar System bodies.

Publications:

Demkowicz, Michael J. "Basal dislocations in proton-ordered hexagonal ice." The Journal of Chemical Physics 163.4 (2025).

PI/Task Mgr. Contact Information:

818-354-2416; Bryana.L.Henderson@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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