Discrepancies Between the Modeled and Observed Surface Water Ice Crystallinity of Europa’s Leading Hemisphere

Jodi R. Berdis¹, Nancy J. Chanover¹, Murthy S. Gudipati², Jim R. Murphy¹

1. Astronomy Department, New Mexico State University, Las Cruces, NM, USA  2. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

berdis@nmsu.edu

Thermal Relaxation
- Amorphous water ice relaxes into a crystalline structure (Figure 1) over timescales inversely proportional to the temperature of the ice.
- For inactive objects with surface temperatures > ~75 K over the age of the Solar System, water ice should be in the crystalline form (Figure 2).

Particle Bombardment
- However, charged particle bombardment from a gas giant’s magnetic field (Figure 3) can cause disruption of the crystalline structure.
- This produces an amorphous structure in the water ice at a rate dependent on the ion flux of bombardment.

Cryovolcanic Processes
- Additionally, active plumes could coat localized regions of the surface with vapor-deposited amorphous water ice.
- Dispersal and other forms of cryovolcanic activity (Figure 4) could help raise the temperature of the ice, aiding thermal relaxation into the crystalline structure.

Crystallinity of Europa
- Europa’s surface (~100 Myr).
- Subsurface liquid water ocean influences surface directly: diapirs, plumes, etc.
- Particle radiation from Jupiter’s magnetic field.
- The crystallinity percentage (or fraction of crystalline water ice compared to amorphous water ice) is a balance between:
  - Thermal relaxation of amorphous • crystalline
  - Conversion of crystalline • amorphous due to charged particle bombardment from Jupiter’s magnetic field
  - Vapor deposition of amorphous water ice as plume material (increase amorphous fraction)
- And any additional ongoing cryovolcanic activity such as diapirs that could convert amorphous • crystalline
- Goal: Identify whether the crystallinity we observe from ground-based spectra differs significantly from the crystallinity we expect to see based on temperature modeling and radiation flux, and why they may differ.

Ground-Based and Laboratory Spectra
- Step 1: Data acquisition (Figure 5)
  - Disk-averaged, NIR reflectance, ground-based observations of Europa’s leading hemisphere with TripleSpec on the Apache Point Observatory ARC 3.5m.
  - NIR transmission spectra from laboratory experiments of pure water ice at T = 18 - 140 K (Ice Spectroscopy Lab [ISL] at JPL and Mastrapa et al. [2008]).
- Step 2: Band area ratios (Figure 6)
  - Calibrate cryostat crystalline and amorphous water ice are spectrally distinct in the NIR.
  - Integrate band areas of 1.5 and 1.65 µm bands, where the relative strength of these two bands is an indicator for crystallinity percentage.
- Step 3: Calculate crystallinity
  - Perform linear unmixing of band area ratios by unmixing the ground-based spectra from both sets of the laboratory spectra.

Modeling with ICICLE
- ICICLE: the Incipient Code for Investigating the Crystallinity of the Leading-hemisphere of Europa
- Adaptation of a 1D thermophysical model
- Spatially variable thermal inertia, emissivity, and albedo values as derived in Trumbo et al. (2018).
- Results from four locations throughout Europa’s orbit around the Sun were averaged to simulate a full European year.
- Crystalline “ages” (time elapsed since surface ice thermally relaxed into 100% crystalline) Figure 8 of the surface at each gridpoint were used as the radiation exposure time.
- Hemisphere-averaged crystallinity computed by implementing cosine weights and gridpoint size weights.

Discussion and Future Work
- Thought experiments to be pursued as 0th-order calculations.
  - If we simulate depositing amorphous water ice plume material, what would happen to the full-disc crystallinity if the plume were:
    - At the equator, 30° lat, 60° lat?
    - 25 km, 50 km, 500 km across?
    - Deposited today, 1 year ago, 5 years ago?
    - Diffusely deposited, densely deposited?
- Would these change the crystallinity substantially to be detectable, i.e., larger than the uncertainty of the current crystallinity calculations?

<table>
<thead>
<tr>
<th>Method</th>
<th>Case</th>
<th>Crystallinity [%]</th>
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<tbody>
<tr>
<td>Ground-based</td>
<td>Telescope vs. ISL at JPL</td>
<td>48.7 ± 6.0</td>
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<tr>
<td></td>
<td>vs. Mastrapa et al. (2008)</td>
<td>47.5 ± 11.3</td>
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<tr>
<td>ICICLE modeling</td>
<td>Fill T1/em no-data regions with longitudinal average (Figure 9)</td>
<td>85.2 ± 11.0</td>
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<tr>
<td></td>
<td>Fill T1/em no-data regions with T1+10%, T1-10%, T1+10% of above values</td>
<td>86.0 ± 10.9</td>
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<tr>
<td></td>
<td>Fill T1/em no-data regions with T1+10%, T1-10%, T1+10% of above values</td>
<td>84.5 ± 10.8</td>
</tr>
</tbody>
</table>

Crystallinity we expect to see based on temperature modeling and radiation flux, and why they may differ.

References

Acknowledgments
The authors would like to thank Samantha Trumbo for providing thermal inertia, emissivity, and albedo maps for use in ICICLE and Eleanor Armstrong for conducting the water ice experiments at ISL JPL. This work is supported by NASA under Grant 80NSSC17K0408 issued through the NASA Education Minority University Research Education Project (MUREP) as a NASA Harriett G. Jenkins Graduate Fellowship through the Aeronautics Scholarship & Advanced STEM Training and Research (AS&ASTAR) Fellowship. A part of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA). Funds were provided through NASA Solar System Workings Program.