EUROPA’S OBSERVED SURFACE WATER ICE CRYSTALLINITY INCONSISTENT WITH THERMO-
PHYSICAL AND PARTICLE FLUX MODELING. Jodi. R. Berdis1, Murthy. S. Gudipati2, James R. Murphy3, and Nancy J. Chanover1. 1Astronomy Department, New Mexico State University, Las Cruces, NM, USA, 2Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

Introduction: Physical processing of Europan surface water ice by thermal relaxation, charged particle bombardment, and possible cryovolcanic activity can alter the percentage of the crystalline form of water ice compared to the combined content of amorphous and crystalline water ice (the “crystallinity”) on Europa’s surface. The timescales over which amorphous water ice is thermally transformed to crystalline water ice at Europan surface temperatures (80-130 K) suggests that the water ice there should be primarily in the crystalline form, however, surface bombardment by charged particles induced by Jupiter's magnetic field, and vapor deposition of water ice from Europan plumes, can produce amorphous water ice surface deposits on short timescales.

The purpose of this investigation is to determine whether the Europan surface water ice crystallinity derived from ground-based spectroscopic measurements is in agreement with the crystallinity expected based upon temperature and radiation modeling. Using a 1D thermophysical model of Europa’s surface, we calculate an integrated full-disk crystallinity of Europa's leading hemisphere by incorporating the thermal relaxation of amorphous to crystalline water ice and the degradation of crystalline to amorphous water ice by irradiation. Concurrently, we derive the full-disk crystallinity of Europa's leading hemisphere using a comparison of near-infrared ground-based spectral observations from Grundy et al. [1], Busarev et al. [2], and the Apache Point Observatory in Sunspot, NM, with laboratory spectra from Mastrapa et al. [3] and the Ice Spectroscopy Lab at the Jet Propulsion Laboratory. We calculate a modeled crystallinity significantly higher than crystallinities derived from ground-based observations and laboratory spectra. This discrepancy may be a result of geophysical processes, such as by vapor-deposited plume material, or it may arise from assumptions and uncertainties in the crystallinity calculations.

Observed Crystallinity: We employ both ground-based observations of Europa’s illuminated leading hemisphere and also laboratory data of crystalline and amorphous water ice (Figure 1).

Mastrapa et al. [3] find the 1.65/1.5 μm integrated band area ratio to be one of the best metrics for distinguishing between crystalline and amorphous water ice. The integrated band area ratio (B) is calculated as the integrated area of the 1.65 μm band divided by the integrated area of the 1.5 μm region, where a larger B corresponds to a higher crystallinity. The 1.65/1.5 μm integrated band area ratio of the ground-based observations is a linear combination (similar to that used by Hansen and McCord [4]) of the crystalline and amorphous laboratory integrated band area ratios. Our derived crystallinities are displayed in Table 1.

Modeled Crystallinity: Baragiola et al. [5] modified a methodology from Famá et al. [6] for determining the fraction of an assumed 100% crystalline water ice surface that has been converted into amorphized ice due to a radiation dose over a given timescale at a given temperature. In addition, the rate of thermal relaxation of amorphous to crystalline water ice can be inferred based on the present-day surface temperatures of an object [7,8]. The expected crystallinity percentage may then be calculated based on the fraction of radiation-induced amorphized ice, provided the temperature of the surface is known. We employ an adaptation of a 1D numerical thermophysical model for airless bodies [9] that has been adjusted to reflect orbital characteristics of Europa and environmental and surface
conditions of its leading hemisphere. Using the modeled average surface temperatures, we compute the fraction of water ice that was converted from the crystalline to the amorphous phase due to a particle radiation dose over a given timescale. This timescale, or radiation exposure time, represents the amount of time that initially pure crystalline water ice is exposed to radiation. This is also the age of the surface crystalline water ice, which is dependent on temperature, where the relaxation of amorphous into crystalline water ice is much faster at warmer temperatures [7,8,10]. Calculated crystallinity fractions for nine “cases” in which we conducted an exploration of the parameter space is displayed in Table 2.

### Table 2: Model-derived crystallinities for several cases of differing thermal inertias (TI) and emissivities (e) in the latitudinally-averaged, extended filled regions, and differing temperatures (T) and fluxes (F) to explore the full range of the parameter space.

<table>
<thead>
<tr>
<th>Case Method</th>
<th>Crystallinity</th>
</tr>
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<tbody>
<tr>
<td>1 Filled TI/e</td>
<td>89.8 ± 8.3 %</td>
</tr>
<tr>
<td>2 Filled TI/e with TI+10%, e−10%</td>
<td>90.6 ± 8.1 %</td>
</tr>
<tr>
<td>3 Filled TI/e with TI+10%, e+10%</td>
<td>89.5 ± 8.4 %</td>
</tr>
<tr>
<td>4 Filled TI/e with max TI, min e</td>
<td>90.8 ± 8.1 %</td>
</tr>
<tr>
<td>5 Filled TI/e with min TI, max e</td>
<td>87.2 ± 7.1 %</td>
</tr>
<tr>
<td>6 Filled TI/e with T=T+3 K</td>
<td>94.4 ± 4.8 %</td>
</tr>
<tr>
<td>7 Filled TI/e with T=T−3 K</td>
<td>83.0 ± 13.3 %</td>
</tr>
<tr>
<td>8 Filled TI/e with F=F+10</td>
<td>81.1 ± 14.6 %</td>
</tr>
<tr>
<td>9 Filled TI/e with F=F/10</td>
<td>95.0 ± 4.4 %</td>
</tr>
</tbody>
</table>

### Results & Discussion:
Using full-disk ground-based observations from Grundy et al. [1], Busarev et al. [2], and the APO TripleSpec instrument, concurrently with laboratory spectra from Mastrapa et al. [3] and the ISL, we calculate Europa’s leading hemisphere crystallinity percentage as ~27–36% (for the Grundy et al. [1], Busarev et al. [2] 5-point moving window, and APO TripleSpec data), and ~65–71% (for the original Busarev et al. [2] data). The full-disk crystallinity percentage as approximated by thermophysical and radiation flux modeling is ~80–95% (Figure 2). We explore a few possible sources for this discrepancy, including surface deposits of vapor-deposited plume material. When we emplaced various types of plume sources (see Figure 2), the modeled full-disk crystallinity decreased by at most a few percent. These changes to the full-disk crystallinity are well below the uncertainty of the modeled and observed crystallinities and would therefore be undetectable. We test the contribution of several other possible sources for the discrepancy between the modeled and observed crystallinities, including uncertainties in temperature, thermal inertia, emissivity, and particle flux.

### Figure 2:
Model-generated crystallinities of the leading hemisphere of Europa. Overlayed are symbols indicating the three plume deposition trials.

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### References: