DISCREPANCIES BETWEEN THE MODELED AND OBSERVED WATER ICE CRYSTALLINITY OF EUROPA'S LEADING HEMISPHERE. J. R. Berdis[1], N. J. Chanover[1], M. S. Gudipati[2], and J. R. Murphy[1]. [1]Astronomy Department, New Mexico State University, [2]Jet Propulsion Laboratory, California Institute of Technology.

Introduction: Europa's young, predominantly water ice surface is only ~10-100 million years old due to resurfacing by geophysical processes and effects of its sub-surface liquid water ocean [1,2]. 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 should be primarily in the crystalline form [3,4].

However, radiolytic processes, such as charged particles from a gas giant's magnetic field, and vapor deposition of water ice from plumes can produce partial amorphous ice surface deposits on shorter timescales. The type and magnitude of physical processes at play, such as charged particle bombardment, vapor-deposited plumes, and cryovolcanic activity, could likely be deduced by the fraction or percentage of water ice in crystalline form compared to that in the amorphous form, referred to subsequently as the crystallinity percentage.

The purpose of this investigation is to identify whether the crystallinity percentage that we observe from ground-based spectra differs significantly from the crystallinity percentage we expect to see based on laboratory data, temperature modeling, and radiation flux. Preliminary results suggest that discrepancies exist between the derived modeled and observed crystallinity percentages. We will discuss whether the discrepancy is a result of geophysical processes, such as by vapor-deposited plume material, or assumptions and uncertainties in the crystallinity calculations.

Using a 1D thermophysical model [5] of Europa's surface, we calculated an expected full-disk crystallinity of Europa's leading hemisphere by incorporating the thermal relaxation of amorphous to crystalline water ice and the formation of amorphous water ice by irradiation; it should be noted that no cryovolcanic activity is simulated in this study. We also derived the observed crystallinity of Europa's leading hemisphere using a comparison of near-infrared ground-based observations from Apache Point Observatory in Sunspot, NM, and experimental data from Mastrapa et al. [6] and the Ice Spectroscopy Lab (ISL) at the Jet Propulsion Laboratory (JPL).

Ground-Based and Laboratory Methods: We obtained full-disk near-infrared spectra of Europa's leading hemisphere with the Astrophysical Research Consortium (ARC) 3.5 m telescope at Apache Point Observatory (APO) using the TripleSpec instrument, which has a spectral resolution of R=3500 in the wavelength range λ = 0.96-2.47 μm for the 1.1" slit [7]. With an angular diameter of 0.97" at the time of observation, Europa fits within the slit on the sky to provide a full-disk spectra.

The Ice Spectroscopy Lab (ISL) at JPL attempts to reproduce environmental conditions (such as radiation, temperature, and composition) of various Solar System objects, such as comets and Europa [8,9,10]. The ISL utilizes infrared, visible, ultraviolet, and vacuum ultraviolet spectroscopy to characterize ice phases and composition. NIR spectra (1.25-4 μm) of pure water ice were acquired in 2010 by both depositing water ice (from vapor) at constant temperature, and ceasing deposition while varying the temperature. Amorphous and crystalline water ice spectra were obtained at temperatures ranging from 18 to 140 K. Spectra in the 1.5 and 1.65 μm window for the TripleSpec observations and crystalline and amorphous water ice from both Mastrapa et al. [6] optical constants and the ISL's absorbance measurements are provided in Figure 1.

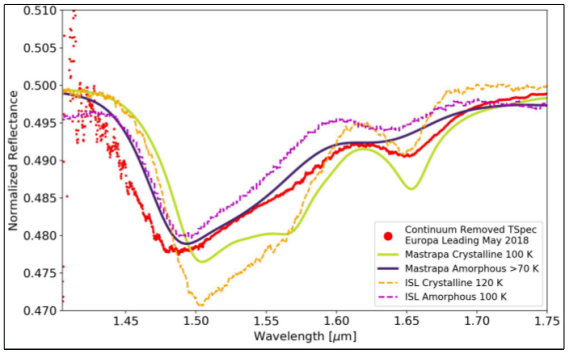

Figure 1: Continuum-removed Europa leading hemisphere ARC/APO TripleSpec data (red) compared to laboratory spectra from Mastrapa et al. [6] (crystalline: lime, amorphous: indigo) and the ISL at JPL (crystalline: orange, amorphous: magenta).

1D Thermophysical Model: We implemented an adaptation of a 1D numerical thermophysical model for airless bodies [5] which has been adjusted to reflect environmental conditions on Europa's leading hemisphere, where the spatial thermal inertia, emissivity, and albedo values employed are those derived in Trumbo et al. [11]. Equilibrated daily simulated surface temperature cycles at 3° lat/lon spatial resolution at four locations throughout Europa's orbit around the Sun were generated in order to average the results to simulate a full Europan year.

We derived crystallinity fractions at each 3° lat/lon location using the amorphous fraction equation originating from Baragiola et al. [12] and implemented by Dalle Ore et al. [13]:

$$\Phi_A = \Phi_{A_{max}}\left(1 - \exp\left[\frac{-kFt}{N}\right]\right) \quad (1)$$

where Table 1 presents the preliminary values used for each of the variables in Eqn. (1). Finally, we computed a hemispheric cosine-weighted average to derive a full-disk crystallinity percentage.

Parameter	Description	Value	Unit
Φ_A	amorphous fraction	Seeking	
$\Phi_{A_{max}}$	maximum amorphous fraction	$0.9 - 1.0$	
F	irradiation flux	$0.6 - 1.2$	ions cm^{-2} s^{-1}
t	exposure time;		
	for t > Europa's surface age	$10^7 - 10^8$	yrs
	for t < Europa's surface age	$t_{100\%\,cryst}$ for latitude band of T	yrs
N	number of H_2O molecules in volume V;		
	for $V = 7\mu$m × 1cm × 1cm	2.2×10^{19}	# molecules
	for $V = 8\mu$m × 1cm × 1cm	2.5×10^{19}	# molecules
	for $V = 9\mu$m × 1cm × 1cm	2.8×10^{19}	# molecules
k	fitting parameter dependent on temperature for T = 53 – 100 K (Baragiola+ 2013, Fig. 16.3)	$0.12 - 0.17$	

Table 1: Descriptions and preliminary values for each parameter in Eqn. (1) to determine the rate of crystalline to amorphous transformation due to irradiation.

Results and Discussion: As the crystalline fraction of water ice increases, the spectral areas (relative to the continuum) of both the 1.65 μm band and the extended 1.5 μm region increase [4,6]. We make use of the optical constants from Mastrapa et al. [6] and calculate absorbance spectra from the *k* extinction coefficients; the boundaries for the integration of band depths are the same used by Mastrapa et al. [6] for consistency. We will present the calculated crystallinity of the TripleSpec observations band areas as compared to those from both Mastrapa et al. [6] and the ISL by implementing a linear unmixing method; preliminary results are provided in Figure 2. The crystallinities derived from TripleSpec observations are then compared with the crystallinity derived from the thermophysical model, and we will discuss any discrepancies that may exist between them. Possible causes of crystallinity percentage discrepancies include assumptions or uncertainties in either analysis techniques, and/or the presence of geophysical processing on the surface, such as by vapor-deposited plume material.

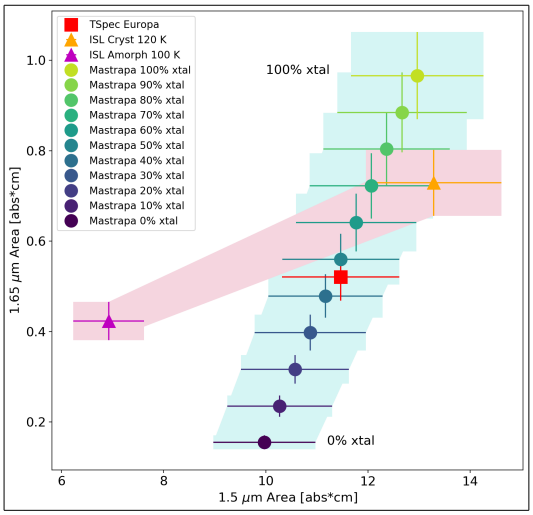

Figure 2: Integrated band areas of the 1.5 and 1.65 μm bands for the observed (TripleSpec) Europa leading hemisphere and varying fractions of water ice crystallinity ("xtal") from Mastrapa et al. (2008) and the ISL at JPL. The color scheme matches that in Figure 1.

References: [1] Zahnle, K. et al. (1998), *Icarus*, 136, 202. [2] Pappalardo, R. et al. (1999), *JGR*, 104, 24015. [3] Kouchi, A. et al. (1994), *A&A*, 290, 1009. [4] Mastrapa, R. et al. (2013), *The Science of Solar System Ices*, 371. [5] Spencer, J. et al. (1989), *Icarus*, 78, 337. [6] Mastrapa, R. et al. (2008), *Icarus*, 197, 307. [7] Wilson, J. et al. (2004), *SPIE*, 5492, 1295. [8] Barnett, I. et al. (2012), *ApJ*, 747, 13. [9] Lignell, A. & Gudipati, M. (2015), *Phys Chem A*, 119, 2607. [10] Gudipati, M. et al. (2017), *AAS DPS #49*, Abstract 203.10. [11] Trumbo, S. et al. (2018), *AJ*, 156, 16. [12] Baragiola, R. et al. (2013), *The Science of Solar System Ices*, 527. [13] Dalle Ore, C. et al. (2015), *Icarus*, 261, 80.

Acknowledgments: The authors would like to thank Samantha Trumbo for providing thermal inertia, emissivity, and albedo maps for use in our thermophysical model, and Eleonora Ammannito for conducting the water ice experiments at ISL JPL. This study was funded by NASA under Grant 80NSSC17K0408 issued through the NASA Education Minority University Research Education Project (MUREP) as a NASA Harriett G. Jenkins Graduate Fellowship. A part of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. Funds were provided through NASA Solar System Workings Program.