SPECTRAL ANALYSIS OF DARK CRATER EJECTA ON EUROPA. T.C. Tomlinson and P.O. Hayne, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303. Tara.tomlinson@lasp.colorado.edu, paul.hayne@lasp.colorado.edu.

Introduction: The origins of low-albedo hydrate material on the surface of Europa have been a source of great curiosity since Voyager first returned close-up images of the icy moon. Sulfur originating from Io is known to contribute an exogenic flux of dark material to Europa's trailing hemisphere, and hydrated salt compounds are concentrated within chaos, ridges, and pits. Many of Europa's impact craters also exhibit dark ejecta, the origins of which are unknown. Our study examines the ejecta of several large impact craters to determine the origins and composition of the dark materials found in the ejecta.

Our previous work attempted to understand whether intrinsically dark impactors could be responsible for this low-albedo component in the crater's ejecta. Using crater scaling laws, we estimated the impactor size for each crater and, using a radiative transfer model, determined the potential contribution of dark material to the ejecta by the impactor. Our results show that, by comparing the ratio of dark vs light material in the ejecta to the ratio of impactor mass vs ejecta mass, the concentrations of dark material found in the ejecta of these craters cannot be solely attributed to the impactor itself. This result indicates that dark crater ejecta on Europa are dominated by endogenic material.

Approach: To identify and understand these endogenic sources, we examined several surface features on Europa of varying albedos using the Galileo Near-Infrared Mapping Spectrometer (NIMS) data. We began by comparing the dark material found in some of our sample craters, then extending our analysis to other dark materials on the suface and eventually other areas of Europa with varying albedos and geologic features. By comparing the spectral makeup at each of these steps, we should be able to constrain the chemical makeup of the dark ejecta and, ideally, relate it to other surface alteration processes to come up with a coherent narrative on the origins of the dark crater ejecta.

Methods: To begin our analysis, we identified all NIMS cube files that contained craters at a resolution suitable for analysis of their ejecta. We found three cubes in total for this criteria, covering one dark-ejecta crater (Cilix), one dark ringed feature (Tyre), and one light ejecta crater with a dark interior (Pwyll). We compared the spectra of the dark elements of each crater under various conditions of normalization and continuum-scaling to look for compositional similarities. The same procedure was then used to compare spectra from our dark crater materials to that of other dark geologic features, such as linea and pits, as well as areas with high concentrations of sulfitic materials on the trailing hemisphere. A final comparison of the spectra of high-albedo areas was also undertaken, including sampling Pwyll's light ejecta and elements of high-albedo and knobby chaos on Europa's leading hemisphere.

Results: Without scaling or normalization, all the NIMS spectra that were analyzed, regardless of reflectivity, showed the same basic shape indicative of an abundance of water ice, which is shown by the band shapes specifically at 1.25, 1.5, and 2.0 microns . (*Figure 1*) While the water ice bands are dominant for all spectra, they do vary in their band depths and overall reflectance. Continuum-scaling of the spectra at some of these water ice wavelengths allowed for a more accurate comparison of each spectra's band depths and features by removing the variable reflectance. (*Figure 2*) These scaled comparisons showed little deviation from the trend of all areas being composed mostly of water ice with small absorption differences in some non-ice wavelengths.

Closer examination of these non-ice absorptions, however, did not provide any additional insight into their chemical makeup than has already been established by previous work. (e.g. [1][2]) Most notably, we see traces of magnesium and iron II in the near IR wavelegths, a "hydrated salt" material at 1.83 microns, and clay-like compounds at 2.2 microns. [3][4] While our results do not add to these previous studies, they could be considered independent verification of their results.

Discussion: While the confirmation of high amounts of water ice on Europa is hardly surprising, the similarities between spectral features of vastly different terrains and albedos is more unexpected. In particular, the spectra of Pwyll's dark interior most closely matches that of high-albedo chaos on the leading hemisphere; this is especially surprising, as Pwyll is considered the youngest impact feature on Europa while the high-albedo chaos is thought to be some of the oldest terrain. [5]

Cilix's dark ejecta also shows a lack of the hydrated minerals at 1.83 microns, which are prominent in the spectra of lineae in the same area. This could imply that the ejecta may not share the same darkening agents as the lineae, however the low resolution of the NIMS data cube at this location could be a limiting factor in our analysis. Low resolutions and a lack of detailed coverage of craters in the NIMS observations has been a challenge throughout this work.

An unintended yet interesting result of our investigation concerns the distribution of crystalline and non-crystalline ice features on Europa. A global overview of the distribution of crystalline ice spectral features was mapped using band depths at 1.65 microns, and it was found that crystalline ice appears to be less abundant in low albedo regions, including those associated with darker geologic features like lineae. (*Figure 3*) One explanation for this observed distribution could be that these areas lacking in crystalline ice could have high amounts of amorphous ice, which could yield insight into the formation mechanisms behind these dark features and possibly our crater ejecta. Another explanation, however, could be that the dark surface materials are simply obscuring the crystalline ice spectral features, and without them the ice in these dark areas would be no different than that in other areas. Currently, no data is available to tell which option is the correct one.

Future Work: Moving forward, we intend to examine processes for chemical changes to crater ejecta due to impact physics. Preliminary calculations show that the extent of dark ejecta around Europa's craters matches the observed impact melt distribution for lunar and Martian craters, and the creation of impact melt and its relation to darkening ejecta on Europa is being investigated. Impurities in the ice can also affect the resulting viscosity of any impact melt created and should also be considered during this analysis. [2]

The surface of neighboring Ganymede has several similarities with that of Europa, including compositional similarities, and reviewing analysis done for Ganymede's dark ray craters (e.g. [6][7][8]) may prove useful in understanding surface darkening processes in the overall system of Galilean satellites. While radiolysis and photolysis are generally thought to be a major source of darkening for Ganymede, more care must be taken to consider Europa's increased radiation environment and complex interactions with Io.

Detailed examination of these processes will hopefully provide insight into this dark ejecta conundrum, and perhaps to Europan cratering physics as a whole.

References: [1] Dalton J.B. et.al. (2012) *JGR, 117,* E03003. [2] Carlson, R.W. et.al. (2002) *Icarus, 157,* 456-463. [3] McCord et.al. (1999) *JGR, 104,* 11827-11851. [4] McKinnon, W.B. and Zolensky, M.E. (2003) *Astrobiology, Vol.3, No.4,* 879-897. [5] Moore, J.M. et.al. (2001) *Icarus, 151,* 93-111. [6] McCord, T.B. et.al. (1998) *JGR, 103,* 8603-8626. [7] Hibbits, C.A. et.al. (2003) *JGR, 108, E5.* [8] Hibbits. C.A. et.al. (2003) *LPS XXXIV,* 1925.

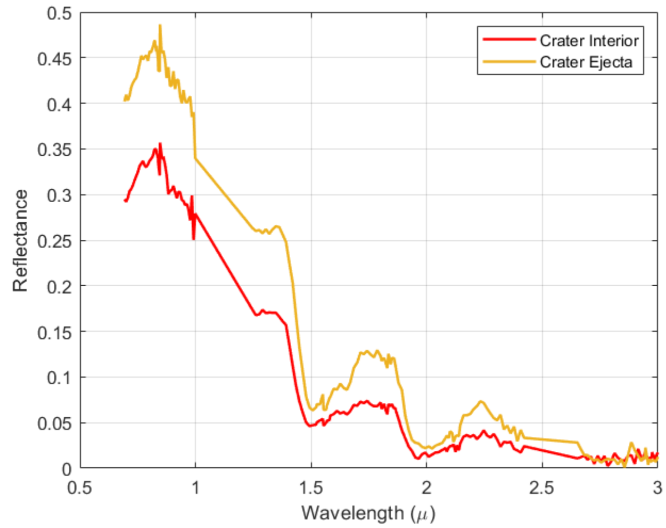

Figure 1: unscaled spectra of Pwyll's light ejecta and dark interior, showing similar shape despite albedo differences

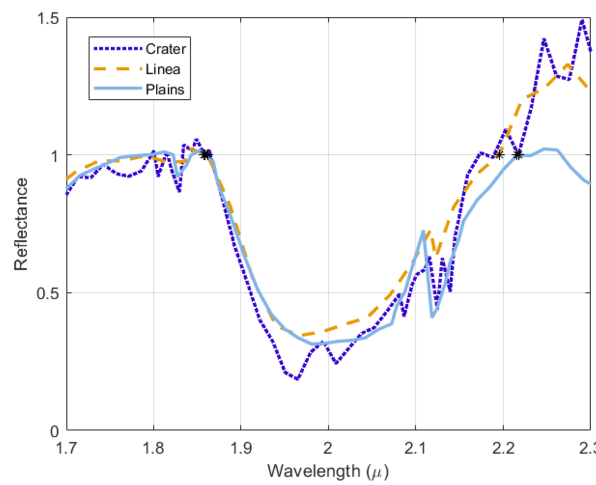

Figure 2: continuum-scaled spectra of three distinct regions of Europa, scaled to 2.0 microns. Ice band depths show similarities dispite individual non-ice absorption differences.

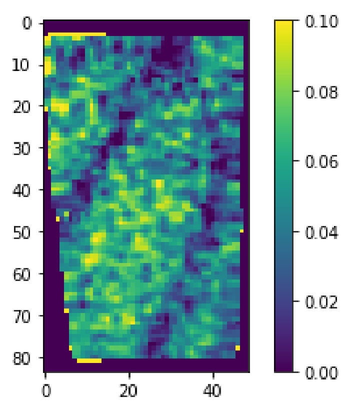

Figure 3: 1.65 micron band depth map, showing lack of the crystalline ice feature at lineae (high values indicate increased crystalline ice)