PRELIMINARY STEPS TOWARD DERIVING OPTICAL CONSTANTS OF EUROPA-RELEVANT MATERIALS: A NUMERICAL OPTIMIZATION METHOD AND DEMONSTRATION OF WET GRINDING AND SIEVING. Y. Itoh1, J. R. Berdis1, F. P. Seelos1, and C. A. Hibbitts1, 1Johns Hopkins University Applied Physics Laboratory (Laurel, MD; Yuki.Itoh@jhuapl.edu).

Introduction: The evaluation of Europa’s surface composition through the analysis, interpretation, and modeling of optical remote sensing data requires accurate optical properties of candidate surface materials over the applicable wavelength range. Europa’s surface is altered due to the continuous bombardment of high-energy particles moving along Jupiter’s magnetic field [1]. The optical properties of cryogenic hydrated materials affected by such alteration are not well understood due to the lack of laboratory data available. In preparation for the Europa Clipper mission [2] it is necessary to experimentally determine optical properties of such altered materials under relevant environmental conditions. Here we report on two disparate but critical aspects of the requisite experimental and analytical procedures: 1) The preparation and handling of cryogenic samples (wet grinding and sieving), and 2) a robust approach to the retrieval of bidirectional reflectance model parameters from spectrophotometric goniometer data.

Our ultimate goal is to support the identification and abundance determination of materials present on the surface of Europa via spectral mixture modeling that uses optical constants (the real and imaginary parts of refractive index) derived from laboratory measurements along with parameters that describe the physical surface (particle size distribution, porosity) and scattering geometric dependencies (anisotropic single scattering phase function, internal scattering parameters). The derivation of such parameters from measurements has been challenging due to the complex nature of both the scattering process and the model formulation.

IMSA Model: The isotropic multiple scattering approximation (IMSA) model [3] is an anisotropic reflectance model of a surface composed of a particulate medium and is widely used in modeling planetary and astronomical body surfaces [3,4]. It models single scattering on the surface using an anisotropic single-particle scattering function and approximates multiply scattered light by that of isotropic scattering. It has also been used for modeling laboratory measurements to derive optical constants [3, 5-11] by using the volume averaged single scattering albedo (SSA) inferred from the IMSA model. The IMSA model is a non-linear function of several optical parameters including the SSA, a porosity coefficient, and the parameters of the single-particle scattering function. It can be challenging to accurately estimate them from measurements due to the complex nature of the function.

IMSA Model Inversion: The retrieval of the IMSA model parameters for a given sample requires multiple measurements acquired at varying geometries (incidence, emission, phase angles). The parameter space can then be searched for the configuration that best models the observed reflectance measurements. We have implemented an optimization approach similar to the Levenberg-Marquardt algorithm [12] with bounded parameters that iteratively solves a nonlinear least squares problem using a locally linear approximation of the IMSA model with its analytical derivatives. At the end of each iteration boundary constraints are enforced by repeatedly halving the iteration step size until the constraints are met.

IMSA Inversion on Randomly Generated Computationally Simulated Data: We first tested the IMSA model inversion method on computationally simulated data. Simulated reflectance data are created for a fixed set of multiple combinations of incident, emission, and phase angles using the two-parameter Henyey-Greenstein (HG2) function as the single scattering phase function. The parameters of the model are randomly sampled from uniform distributions over their realistic bounds: the porosity coefficient is fixed to one, SSA is sampled from [0.5, 1.0], and the parameters $b$ and $c$ of the HG2 function is sampled from [0, 0.8] and [-1, 1], respectively. The parameters are initialized as follows: 0.5 for SSA, 0.5 for $b$, and 0 for $c$ of the HG2 function. For the first simulation noise is not added so estimated optimizers are either almost identical to the true values or significantly deviated, corresponding to local minima. Therefore, we evaluate the performance of the algorithm by success rate, which counts success if the error is sufficiently small. For 100 trials, we found that the success rate is greater than 95%. Figure 1 shows two examples of the fit of our estimated model to simulated data: the left shows the perfect fit when the algorithm succeeded, the right shows a case of falling into local minima. We found that the algorithm seems to fail when both of $b$ and $c$ are close to extreme values (e.g., $b > 0.7$, $|c| > 0.8$). We will further investigate the

Figure 1: Fit of our algorithm on the simulated reflectance; Examples of (left) success and (right) failure.
behavior of the algorithm to efficiently perform the optimization and to reliably obtain accurate optimizers.

**IMSA Inversion on Laboratory Data:** IMSA Inversion on Laboratory Data: We also tested our algorithm on lab-measured bidirectional reflectance of bassanite previously used for deriving optical constants [8, 10]. Sklute and the authors published their code along with their data [13, 14], which we use as a basis of comparison for our approach. In our preliminary test, we use the version of spectra in the sample data folder included in the code package [14], containing measurements of samples with three different grain sizes, small (90-125µm), medium (125-180µm), and large (180-250µm), from seven different geometries. Figure 2 shows the comparison of the estimated SSA spectra and the estimated models by our method with those by Sklute et al. It shows that our estimated model is comparable to that obtained by their method, albeit with a slight difference in the estimated SSA.

**Motivation for Wet Grinding and Sieving:** Spectra and optical constants of relevant materials obtained after irradiation, at relevant temperature, and over the relevant near-infrared spectral range do not currently exist for any of the materials that are thought to be present on Europa’s surface. Therefore, the materials must be irradiated while being held at relevant cryogenic temperatures while under vacuum. In order to derive optical constants, the materials must be separated into grain size bins, which can be challenging under cryogenic conditions. We sought to create simulated Europa and icy moon hydrated non-ice material and demonstrate the ability to manipulate it (grind and wet sieve) under a cold, nitrogen atmosphere to provide a proof-of-concept to better prepare an extended experiment suite. We demonstrated this capability, and present a few results from that experiment here.

**Grinding and Sieving Results:** Using liquid nitrogen as the non-polar solvent, we wet ground and wet sieved epsomite (magnesium sulfate heptahydrate, MgSO₄·7H₂O) in a nitrogen atmosphere glove box, and compared the results to epsomite that underwent dry grinding with dry sieving, wet grinding with dry sieving, and dry grinding with wet sieving. We visually identified how “clean” they appeared, i.e., the extent to which the grains lacked attached particulates. The wet grind/wet sieve experiments produced the most “clean” results, with dry grind/wet sieve and wet grind/dry sieve producing more clean results than the dry grind/dry sieve results (e.g., Figure 3). We found that grinding and wet sieving using liquid nitrogen in a cold, nitrogen atmosphere glove box is an effective (and attainable) method for separating cryogenic materials into grain size bins.

**Future Work:** The current algorithm is only implemented the inversion of bidirectional reflectance up to the SSA. We will further extend our approach to derive optical constants. We have begun preparations for a proof-of-concept experimental suite at APL, which currently includes use of a large goniometer, and will be performed at ambient conditions to prove out this technique to prepare for experiments under irradiation and in a Europa-relevant environment.

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**References:**