A NEW LOOK AT EUROPA'S PHOTOMETRY IN PREPARATION OF THE JUICE MISSION.

I. Belgacem[1], F. Schmidt[1] and Grégory Jonniaux[2]. [1]GEOPS, Univ. Paris-Sud, CNRS, University Paris-Saclay, rue du Belvédère, Bat. 504-509 Orsay, France., [2]Airbus Defence & Space, Toulouse, France.
Contact: ines.belgacem@u-psud.fr

Introduction: Europa is a prime candidate for habitability in our Solar System. The surface of the moon is the youngest of the Jovian icy satellites despite signs of erosion by space weathering and possible sublimation in the form of ice penitentes [1]. It seems to be continuously renewing by an expanding crust [2]. This activity appears to be driven by a global water ocean directly in contact with the rocky mantle [3]. This puts Europa and the other icy moons at the center of international space programs. The JUICE (JUpiter ICy moons Explorer) mission from the European Space Agency (ESA) is to be launched in 2022 and arrive at the Jovian system in 2030 to study Jupiter and its icy moons for three and a half years [4]. The spacecraft is being designed by Airbus Defence & Space in Toulouse, France, with a very innovative navigation system. The vision-based navigation algorithm implemented on JUICE will make the spacecraft more autonomous and more precise in its pointing by extracting navigation data from on-board image processing [5]. To offer the best of that algorithm, the spacecraft needs to have a proper knowledge of the photometric models of the moons targeted by the mission.

Significant work has been done using the Voyager and telescopic observations [6, 7, 8, 9]. But none of these models give satisfying results when simulating images and comparing them to reality.

This work revisits the study of Europa's photometry on restricted regions of interest using a new inversion approach to constrain Hapke's model parameters.

Method: A photometric study necessitates two pieces of information: reflectance and geometry. The first can be obtained after radiometric calibration. The second necessitates accurate projections of each pixel. Therefore, the first step of this work is image processing.

Dataset: This study uses images taken with the Imaging Science Subsystem (ISS) of the Voyager spacecrafts and includes more recent images taken of Europa with the LOng Range Reconnaissance Imager (LORRI) of the New Horizons probe. Both datasets were retrieved on NASA's PDS archive [10, 11].

Correction of meta-data: We simulated images with SurRender [12], an image renderer developed by Airbus DS allowing the input of custom reflectance models, and using meta-data obtained on NASA's PDS. We compared those simulations to the real images and computed the correction in pointing needed to make them match. The attitude of the moon was also refined by maximizing the correlation between simulations and real images. Additional corrections were needed on the Voyager images for which we also corrected for distortion and distance.

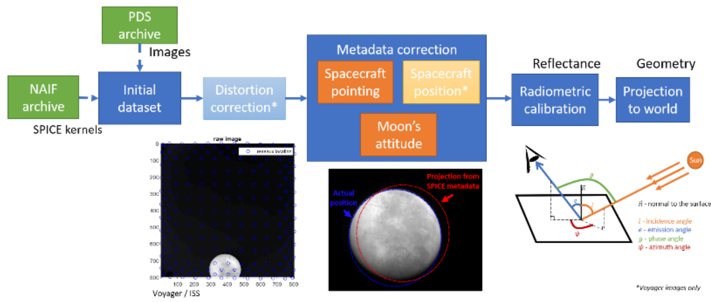

Figure 1: Entire pipeline to extract photometry from images

Photometry: With accurate meta-data and after full radiometric calibration of the images, we can successfully project every pixel onto the moon and compute the observation geometry – incidence, emission and phase angle – for each of them as well as their physical reflectance value. We arbitrarily selected thirty-six regions of interest across Europa's surface to study more closely.

Direct model: For this study we are considering Hapke's direct model [13]. Six parameters are to be estimated: b, c, ω, $\bar{\theta}$, h and B_0.

Bayesian inversion: We have developed an inversion tool using a Bayesian approach based on previous work done on Mars [14, 15, 16] and recent improvements [17]. No a priori knowledge of the parameters are inferred except for their physical domain of variation. A Monte Carlo Markov Chain algorithm is used to sample the Probability Density Function (PDF) of the a-posteriori solution of each parameter which gives us not only information about the most probable value but also tells us how well the parameters are constrained on the different ROIs.

Uncertainties: We modified the algorithm to accommodate a more complex covariance matrix considering both the noise in the image and the uncertainty on the absolute calibration of each image.

Results: We analyzed the results over twenty ROIs. Figures 2 and 3 show the values for the macroscopic roughness $\bar{\theta}$ and for the parameters of the particle scattering phase function - b, the asymmetry parameter and c, the back-scattering fraction.

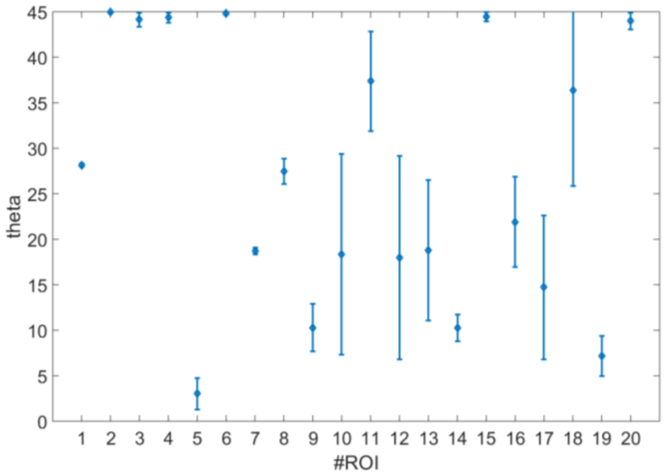

Figure 2: Values of the macroscopic roughness $\bar{\theta}$ over the different ROIs

$\bar{\theta}$ is well constrained for the majority of the ROIs and takes very different values from 2° to 45° although it mostly varies between 10° and 30°. It is the parameter that varies the most which makes sense since it is directly linked to the terrain. It is also worth noting that half of the ROIs do not have a phase coverage extending beyond 40° where the photometric effects of $\bar{\theta}$ are most significant [6, 18].

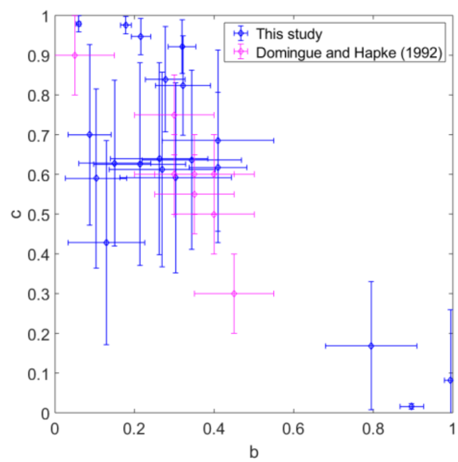

Figure 3: Values of the asymmetry parameter, b and the backscattering fraction, c over the different ROIs (in blue) compared to the work of Domingue and Hapke, 1992 [7] (in magenta)

The parameters b and c describe the shape of the diffusion lobe and correspond to the 2 parameters Heynyey-Greenstein's phase function.
Their values can shed light on the microtexture of the particles at the surface [19]. The results of most ROIs are situated in the top-left corner of the diagram indicating that we are rather dealing with rough, complex particles with high internal scattering. We note, however, that contrary to the results from Domingue and Hapke, 1992 [7] that we compare to ours in fig. 3, three ROIs are in the bottom-right corner of the diagram. These ROIs seem to be constituted of particles exhibiting a strong narrow forward scattering which would indicate smooth and clear particles in these areas.

Conclusion: This work is a new approach to the photometric study of Europa using a Bayesian framework. The addition of Voyager images gives us a far broader phase coverage and makes it possible to look at more regions than our work focusing on LORRI images alone. We can infer surface properties on the different areas and compare that to studies of surface processes to help better understand the geological history of this satellite. In the interest of finding the best model to fit our data, we want to test more photometric models in the same framework. It is also crucial to find a model that works in more extreme observing geometries with emission and incidence angles up to 90°. Finally, the microtexture of Europa's surface will be discussed with the recently proposed ice penitentes [1].

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