**ESTIMATION OF HAPKE'S PARAMETERS ON SELECTED AREAS OF EUROPA USING A BAYESIAN APPROACH.** 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. (Contact: ines.belgacem@u-psud.fr), [2]Airbus Defence & Space, Toulouse, France.

**Introduction:** Exploring the icy satellites of the outer planets is a major step in the search for habitability in our Solar System. This work focuses on Jupiter's icy moon Europa and the images captured by the Long-Range Reconnaissance Imager (LORRI) on-board the New Horizons spacecraft [1]. Images of the surface were combined to derive photometric and reflectance models.

*Context***:** Europa is a prime candidate for habitability in our Solar System. The surface of the moon is the youngest of the Jovian icy satellites. It appears to be continuously renewing by an expanding crust [2]. This activity may be driven by a global water ocean [3] for which more and more evidence seems to be advocating. 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. The spacecraft is being designed by Airbus Defence & Space in Toulouse, France, with a very innovative navigation system. Any mission to the outer Solar System is challenging considering local radiative and thermal conditions as well as the distance to the Earth. 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 [4]. To offer the best of that algorithm, the spacecraft needs to have a proper knowledge of the photometric models of the moons that will be observed.

*Previous work:* Significant work has been done using the Voyager and telescopic observations [5, 6, 7]. But none of these models give satisfying results when simulating images and comparing them to reality. This work aims at studying local photometric properties with the Hapke's model [8].

**Data set:** This study focuses on the images taken by the LORRI camera [1] on-board the New Horizons spacecraft during its flyby of Jupiter. With three-months worth of observation of Jupiter and its moons in 2007 and when combining all the images captured during this phase of the mission, the whole surface of Europa is accounted for.

**Method:** A crucial step before looking at the reflectance data is to make sure we have the correct position and attitude for both the spacecraft and the moon. The first step was then to correct the available meta-data. The second step is to estimate Hapke's model parameters for different areas of Europa using a Bayesian approach.

*Correction of meta-data:* We simulated images with SurRender [9], an image renderer developed by Airbus DS allowing the input of custom reflectance models, and using meta-data obtained on the NASA PDS. We compared those simulations to the real images and computed the correction in pointing needed to make them match. We developed an algorithm using cross-correlation and limb-matching. The attitude of the moon was also refined by maximizing the correlation between simulations and real images.

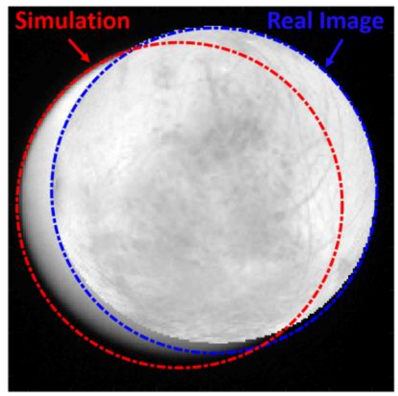


**Figure 1: Shift between real image and simulated image using available meta-data**

After that first step of improvement, images were compared two by two to ensure that the common part of the moon on each image would match.

*Photometry:* With accurate meta-data, we were able to successfully project every pixel onto the moon and compute observation geometries – incidence, emission and phase angle – for each of them.

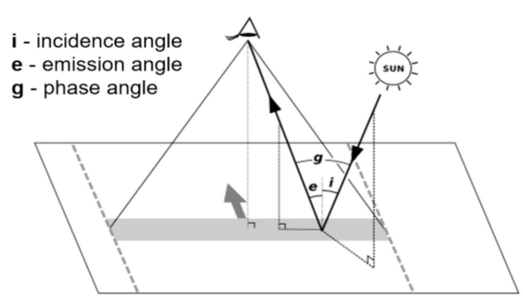


**Figure 2: Definition of viewing geometry**

Using [10] we adapted the LORRI's calibration process to Europa as target, extracted the measured radiance and converted it to reflectance in REFF units.

$$r = \frac{F_{rad}}{F_{Sun}} \qquad REFF = \pi \frac{r}{cos(inc)}$$

*Direct model:* For this study we are considering Hapke's direct model detailed in [8]. Six parameters are to be estimated: b, c, ω, θ, h and B0.

*Bayesian inversion:* A Bayesian approach has been used to constrain these parameters in selected areas of Europa. No a priori knowledge of the parameters were inferred except for their physical domain of variation. A Monte Carlo Markov Chain algorithm was used to sample the Probability Density Function (PDF) of the a-posteriori solution [11, 12, 13] with recently optimized implementation [14].

**Results:** Nine zones were considered, and results can be very different for parameters b, c and θ but are rather homogeneous for ω. As for h and B0, they cannot be constrained with no data under 20° in phase angle. As we could expect, parameters are better constrained on areas where the data points are numerous but in some cases, a restricted coverage of 20° in phase angle seems to be enough to constrain most of the parameters. Figure 3 and table 1 show results for the area between 7° and 40° longitude and 0° and 15° latitude.

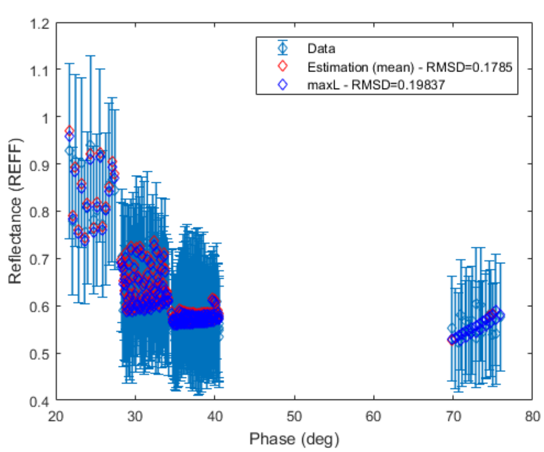


**Figure 3: Data and fits for estimated parameters and at maximum likelihood**

| | b | c | θ | ω | h | B0 |
|---|---|---|---|---|---|---|
| mean | 0.47 | 0.22 | 0.60 | 0.99 | 0.51 | 0.72 |
| std. dev. | 0.03 | 0.03 | 0.01 | 0.002 | 0.27 | 0.22 |
| maxL | 0.48 | 0.18 | 0.59 | 0.99 | 0.92 | 0.99 |

**Table 1: Estimation of Hapke's parameters with standard deviation and value at maximum likelihood**

In figure 3, data points are plotted with 2-sigma error bars. The computed data using the estimated Hapke's parameters summed up in table 1 are in red (estimated parameters) and navy blue (parameters at maximum likelihood).

**Conclusion:** This study is the start of a broader investigation on the photometric models of Jupiter's icy moons. It shows that Hapke's parameters can be constrained in restricted areas of Europa, opening the door for local photometric studies. However, more data is needed, for instance, at low phase angle to constrain the opposition effect.

*Perspectives*: In addition to New Horizons images, we are including data from other past missions such as Voyager and Cassini. We'll be merging these very heterogeneous datasets to constitute one coherent ensemble. This should help us constrain more efficiently the photometric model of Europa. We will also consider other models and compare their best fit. This entire method will then be applied to Jupiter's other two icy moons: Ganymede and Callisto.

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