REAPPRAISAL AND NEW CONSTRAINTS ON EUROPA'S SURFACE COMPOSITION WITH THE NEAR-INFRARED IMAGING SPECTROMETER SINFONI OF THE VLT.

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Context: Europa possesses an important geological activity expressing itself through plate tectonics [**1**] and plumes [**2**]. This activity is allowed thanks to a tens or hundreds km-thick subglacial liquid ocean very likely in contact with a silicate mantle [**3**]. By interacting with that silicate mantle, the subglacial ocean should contain an important variety of chemical species, gathering most of the requirements needed for the apparition and development of exobiological activities [**4**]. Because of Europa's geological activity, it seems very plausible that some chemical traces of that enriched ocean should lay on its surface. In the near future, the missions JUICE (ESA) and Europa Clipper (NASA) will investigate the composition of the satellite in details, getting data with a spatial resolution down to a few hundred meters or less thanks to very close fly-bys. The NIR imaging spectrometer of JUICE, named MAJIS, aims to detect and characterize all the spectral signatures existing from the visible (0.5 µm) to the mid infrared (5.54 µm) [**5**]. To prepare MAJIS's radiometric budget, a large ground-based campaign using the H+K band (1.45 – 2.45 µm) of the NIR imaging spectrometer SINFONI was done in 2011 – 2012. A paper showing evidence of…. Mg-bearing chlorinated salts was published based on the data [**6**]. In light of the results, a second campaign was led in April 2017, this time investigating the J band of SINFONI (1.05 – 1.45 µm). In this abstract are presented the new results obtained through the analysis of the data in the J band and also the updated assessment of the data in H+K following a new photometric correction.

Datasets: At the time of acquisitions, the field of view of SINFONI (0.8×0.8 arcsec) was always smaller than the actual angular diameter of Europa, thus requiring a mosaic of observations (five in our case) to cover Europa's entire disk. After normalizing each pieces of a mosaic, the final reduced data consists in one 3D-cube (x, y, λ) for every night of acquisition. Five H+K observations were acquired from October 2011 to January 2012 and three J observations were all acquired in April 2017, everytime very close to the opposition with the Jovian system. While a full table in [**6**] describes all the observational parameters for the H+K data, some of these parameters for the J data are provided in table 1.

Acquisition date	Distance to Earth	Strehl ratio	SSP lat./long.
2017/04/21	4.47 A.U.	29.2 ± 3.5	[232ºW, -3ºN]
2017/04/22	4.48 A.U.	45.0 ± 0.4	[321ºW, -3ºN]
2017/04/26	4.50 A.U.	36.9 ± 0.6	[18ºW, -3ºN]

Table 1. *Main observational and geographical parameters of each observation in the J band. These observations mostly cover the trailing hemisphere, where the chlorinated salts were mostly found from the H+K data. [1] SSP: Sub-Solar Point.*

Photometric model: The photometric correction is a major step in the data processing. It corrects geometric biases in terms of measured flux specific to each pixel. In [**6**], the Lambertian model was used for that purpose and was considered good enough until inclination angles ~55º. However, unlike H+K data, a Lambertian approach of Europa's surface quickly seems irrelevant in the J-band as pixels at the periphery of the disk rapidly appear over-corrected. Hence, a better photometric model was looked for and was finally used: the Oren-Nayar model, generalizing the Lambertian one for rough surfaces [**7**]. In addition to properly recover the surface of Europa in the J-band for inclination angles reaching 50º, this model also produces better results for the H+K data, allowing to recover pixels with higher inclination angles, up to 65º, compared to the Lambertian model. Consequently, even for Europa, which possesses one of the smoothest surface known in the Solar System, the surface roughness plays an important role in terms of photometry. The roughness parameter, σ, is obtained empirically until getting corrected 3D-cubes showing no inclination residuals over the entire wavelength range. σ ranges from 8° to 12° for the three J-band observations, while it ranges between 13° and 15° for the five H+K data. The difference between the σ of the H+K data and the J data is within the error bars, $\pm$5°, and no hemispherical dichotomy is clearly observed in both datasets.

Results:

1. The H+K data

Using the Oren-Nayar model instead of the Lambertian model for the H+K dataset do not change the shape of the absorption features existing in this range, only the reflectance level is actually affected. The reflectance level variation is highlighted by comparing albedo maps (figure 1).

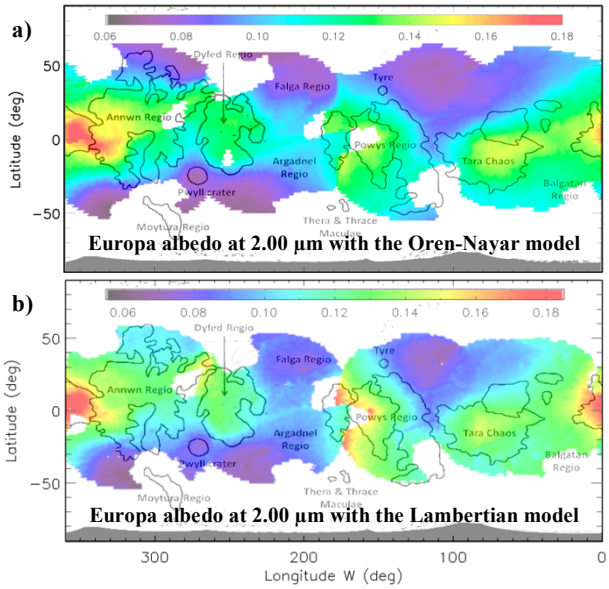

Figure 1. *Comparison of Europa's albedo maps at 2.0 µm using two different photomometric model: the Oren-Nayar model (a) and the Lambertian model (b).*

In addition to the extension to higher latitudes, we observe a smoother transition at the antijovian longitude (180°W), proving the better efficiency of the Oren-Nayar photometric model. Furthermore, the modeling confirms the results published in [**6**]: (i) the H_2O-ice is mostly crystalline, (ii) the sulfuric acid hydrate strongly dominates the trailing orbital hemisphere with abundances above 65% around its apex, and (iii) the need of Mg-bearing chlorinated salts, especially on chaos regions, to better reproduce the global shape and the spectral signatures of spectra, including the shoulder at 2.07 µm initially wrongly attributed to epsomite [**8**], a magnesium sulfate.

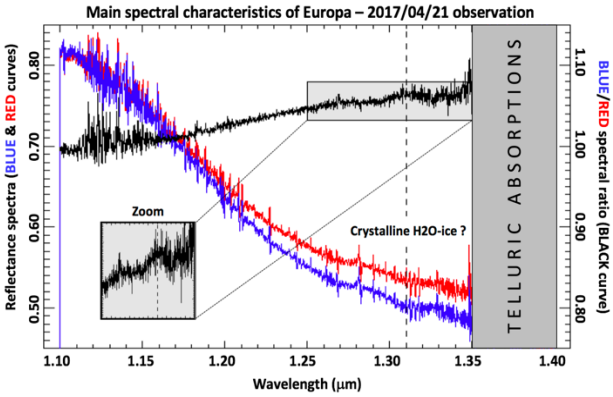

Figure 2. *Two spectra (blue and red lines) in the J-band of the 2017/04/21 observation with the spectral ratio (dark line). The spectral feature at 1.31 µm (dashed line) is very likely due to the crystalline H_2O-ice.*

2. The J data

Unlike the H+K data, Europa's spectra in the J-band do not exhibit strong spectral features. The spectral variability is rather weak and mostly relies on the curvature of the spectra (figure 2): in this wavelength range, spectra at the equator are less curved than at the pole. This result is in agreement with data acquired by the NIMS instrument of the NASA Galileo mission [**9**]. There is however one subtle absorption observed for the first time, at 1.31 µm precisely, which is probably related to the crystalline form of the ice. Last but not least, even if the presence of slight but significant non-H_2O spectral feature was expected, especially in the spectral range 1.15 – 1.25 µm [**10**,**11**], and would have helped to better characterize the composition of Europa's surface, the lack of absorptions also bring important additional constraints on the salty species present on the surface. Consequently, hydrated chlorinated salts not showing strong absorptions in this wavelength range, like brine $MgCl_2$ or NaCl [**11**], are good candidates.

Conclusions & future work: Through the processing and the analysis of two different datasets acquired by the ground-based imaging spectrometer SINFONI, we have demonstrated the efficiency of Oren-Nayar's photometric model and the need to take the roughness parameter into account even for smooth surfaces like the one of Europa. The reanalysis of H+K data using this model led us to the same results published few years earlier, thus confirming our hypothesis about the existence of chlorinated salts on Europa's surface. Their emplacement is very likely to be endogeneous, probably through the fractional crystallization of upwelling fluids issued from the subglacial ocean [**12**,**13**]. No characteristic absorptions of these salts have been detected in the J-band, suggesting that the salty species present on Europa's surface should not have spectral absorptions in that wavelength range, unless pretty weak. Some hydrated chlorines, like $MgCl_2$ or NaCl, share such characteristics [**11**]. By the time of the meeting, we will conduct spectral modeling specifically for the J-band, and also over the entire J-H-K wavelength range. The results will be confronted to those obtained in [**6**] and should help to lift the veil about the nature of the non-ice compounds relying on Europa's surface.

References: [**1**] Kattenhorn & Prockter 2014, Nature Geosciences 7, 762 – 767. [**2**] Roth et al. 2014, Science 343, 171 – 174. [**3**] Sotin & Tobie 2004, Comptes Rendus Physique 5, 769 – 780. [**4**] Chyba 2000, Nature 403, 381 – 382. [**5**] Langevin et al. 2018, IPM, p. E1. [**6**] Ligier et al. 2016, The Astronomical Journal 151, 163. [**7**] Oren & Nayar 1994, SIGGRAPH 94, ACM Press, 239 – 246. [**8**] Brown & Hand 2013, The Astronomical Journal 145, 110. [**9**] McCord et al. 1998, Science 280, 1242 – 1245. [**10**] Dalton 2007, Geophyical Research Let. 34, L21205. [**11**] Hanley et al. 2014, Journal of Geophyical Research: Planets 119, 2370 – 2377. [**12**] Zolotov & Shock 2001, Journal of Geophyical Research 106, 32815 – 32827. [**13**] Johnson et al. 2019, Icarus 321, 857 – 865.