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New insights about Callisto's surface composition and properties from ground-based observations

N. Ligier[1], W.M. Calvin[2], J. Carter[3], C. Paranicas[4], F. Poulet[3], C. Snodgrass[1,5]

(*1*) School of Physical Sciences, The Open University, Milton Keynes MK7 6AA, UK. (*2*) Geological Sciences & Engineering, University of Nevada, Reno, NV 89557, USA. (*3*) Institut d'Astrophysique Spatiale, Université Paris-Saclay, 91405 Orsay, France. (*4*) Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 20723, USA. (*5*) School of Physics and Astronomy, University of Edinburgh, Edinburgh EH8 9YL, UK.

First author's contact: nicolas.ligier@open.ac.uk

1. Introduction

Callisto is the Galilean satellite farthest from Jupiter. Compared to Io with its numerous volcanoes, Europa with its geological diversity, and Ganymede with its intrinsic magnetic field, Callisto has not attracted as much attention as other Galilean satellites. Hence, its surface properties and composition are poorly known. However, like Europa and Ganymede, Callisto does possess a sub-glacial ocean [**1**] potentially inhabited. ESA's L-class mission JUICE will study the moon thanks a dozen of close fly-bys. The investigation of all the satellites' surface composition will be mostly performed by the near-infrared imaging spectrometer MAJIS [**2**]. In preparation of the JUICE mission and the MAJIS instrument, a ground-based observational campaign focused on Callisto was done from 2015 to 2016 with a near-infrared integral field spectrometer, SINFONI, mounted on one of the four unit telescopes (UT4) of the VLT. In this paper are described new data and results about Callisto's surface composition and properties stemming from this campaign.

2. Instrument and dataset

2.1. The instrument

SINFONI combines one adaptive optics module and an integral field spectrometer operating in the near-infrared with different gratings [**3**]. For this campaign, observations were carried out using the H+K grating, covering the spectral range 1.40 – 2.50 µm, and near opposition to optimize the angular resolution. The field of view of each observation is 0.8 × 0.8 arcsec, divided into 64 × 64 pixels. SINFONI's H+K grating has a spectral resolution R = 1500, but each spectrum is resampled at 2200 wavelengths. Consequently, each acquisition results in a 3-dimensional cube (x, y, λ) with dimensions 64 × 64 × 2200. The high spatial and spectral sampling of SINFONI, coupled with its performing adaptive optics and its excellent S/N ratio, allow to detect and map any spectral absorption that might exist in Callisto's spectra in this spectral range.

2.2. The dataset

The campaign took place in January/February 2015 and in March 2016. Four acquisitions were done, all with Callisto's angular diameter around 1.5 arcsec. This is almost twice as large as SINFONI's field of view, so, to cover the entire disk, each acquisition is composed of a mosaic of ten overlapping frames. In addition, to cover the satellite's surface as much as possible, each acquisition was scheduled to observe different phases of the moon. Table 1 provides some observational and geographical parameters useful for the data reduction and map projection.

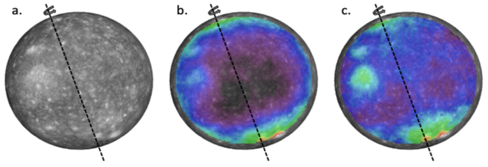
Acquisition date	Earth distance	Strehl ratio H+K	SSP lat./long.
2015/01/23	4.37 A.U.	18.8 ± 1.2	[158ºW, 0ºN]
2015/02/16	4.37 A.U.	27.1 ± 0.9	[312ºW, 0ºN]
2015/03/08	4.49 A.U.	26.1 ± 1.0	[20ºW, 0ºN]
2016/03/19	4.44 A.U.	28.8 ± 1.0	[206ºW, -2ºN]

Table 1. *Main observational and geographical parameters of each observation.* [1] *SSP: Sub-Solar Point.*

3. Results

3.1. Surface roughness

Then, photometric corrections are applied in order to get geometrically corrected reflectance spectra. Like Ganymede [**4**], the common Lambertian model does not return satisfactory corrections near the terminator (figure 1). Consequently, we used another photometric model, namely the model of Oren-Nayar generalizing the Lambertian model for rough surfaces by taking into account the surface roughness [**5**]. The roughness parameter σ is expressed in degree and is obtained empirically until getting reflectance cubes showing visually no inclination residuals any more at high inclination angles (~60º). Similarly to Ganymede, σ ranges between 17º and 19º whatever Callisto's phase. Weak variations of σ suggest an overall homogenous geology surface at 10s km scale, which is globally confirmed by the geological properties [**6**].



Callisto (in the visible) at the time of acquisition

Callisto (at 1.75 μm) after Lambertian correction

Callisto (at 1.75 μm) after Oren-Nayar correction

Figure 1. *(a.) Callisto's phase (2015/03/08) in the visible at acquisition time (Galileo data), (b.) phase's reflectance at 1.75 µm after applying the Lambertian model (SINFONI data), and (c.) phase's reflectance after application of the Oren-Nayar model. Major albedo variations are observed.*

3.2. Spectral modeling and composition

Based on previous studies of Ganymede and Europa [**4**, **7**], we have started the modeling of some Callisto's spectra with a spatial mixture including water-ice of different grain sizes (from 10 µm to 1 mm) and forms (crystalline and amorphous), sulfuric acid hydrated, salts and a darkening agent spectrally flat. At this stage, linear un-mixing shows that Callisto's "icy" spectra, located at the poles and on large bright (fresh) craters, are very well reproduced only using the crystalline ice and the dark compound (figure 2). This is in agreement with previous studies [**8**, **9**]. However, the modeling shows that the darkening agent is by far the most abundant species over Callisto's entire surface, with abundances exceeding 80% even for the iciest spectra.

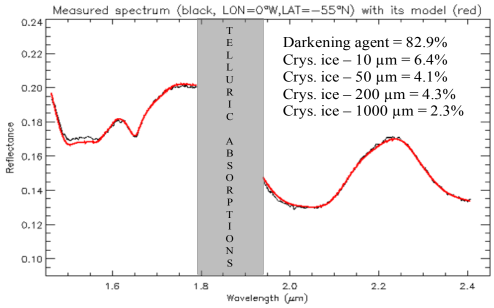


Figure 2. *SINFONI (black) and modeled (red) spectrum of the bright crater named Heimdall, with the abundances of the different species obtained thanks to the modeling.*

Apart from large bright craters and latitudes higher than 60º, Callisto's spectra look particularly flat, with only very weak remaining water-ice spectral features (figure 3). For this type of spectra, the abundance of the darkening agent always exceeds 95%.

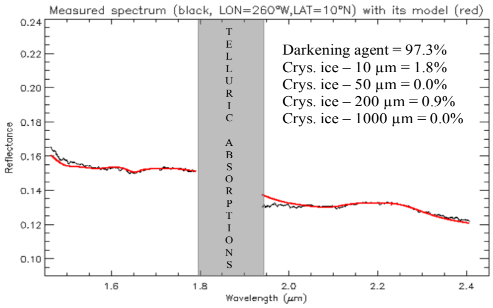


Figure 3. *SINFONI (black) and modeled (red) spectrum of a dark region without bright crater, with the abundances of the different species obtained thanks to the modeling.*

Additional modeling seem to highlight the variability of the darkening agent in terms of reflectance level; so far, depending on the spectrum, we have found that it ranges from 0.13 to 0.22 in the H+K range. It suggests that the darkening agent may be a mixture of different species or a unique one with different grain sizes. By the time of the conference, we will further investigate Callisto's surface composition by modeling the entire data set and producing abundance maps that will be compared to spectral parameter-based maps. We will also look for weak spectral features that would help to constrain Callisto's surface composition, especially in the 2.10 – 2.40 µm range where some specific spectral features of hydrated silicates are commonly present.

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