Effects of porosity and space-weathering on the spectro-photometric properties of primitive dark asteroid surfaces

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Introduction:

The JAXA Martian Moon eXploration mission will be launched in 2026 toward the martian moon Phobos, which is spectroscopically and photometrically similar to dark asteroids. The mission will give the opportunity to give new insights into dark primitive asteroid surfaces, such as D-type asteroids. Laboratory experiments have already been performed to identify appropriate Phobos spectroscopic simulants based on D-type asteroid composition and to study the effects of observation geometry [1,2,3,4].

Surface porosity is a critical factor for these bodies, as it significantly influences their physical, spectroscopic, and photometric properties. However, the effects of porosity are not well understood, with studies giving conflicting results (e.g., [5,6,7]). High surface porosity has been suggested for some of these asteroids due to their low thermal inertia and the presence of potential features like a 10 µm plateau in the MIR spectra [8,9,10].

Airless bodies also experience significant space weathering from solar wind, galactic cosmic rays, and micrometeorites [11]. In this work, we investigate the spectroscopic and photometric modifications of Phobos/D-type regolith simulants, focusing on two key parameters: (i) porosity and (ii) space-weathering induced by solar wind.

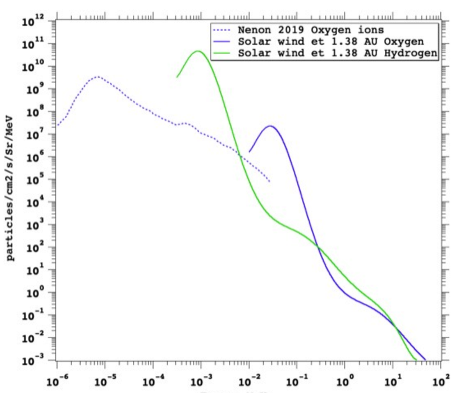

Figure 1: Flux density at Phobos' surface of oxygen ions produced in the upper layer of the Martian atmosphere, and of hydrogen and oxygen ions from the solar wind.

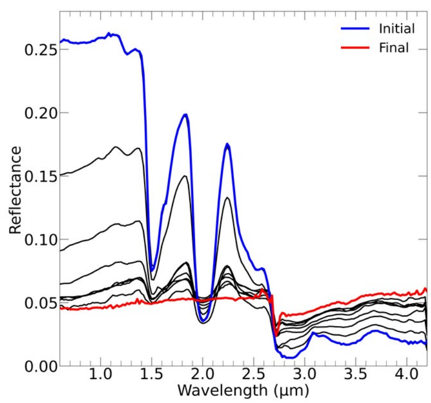

Figure 2: Evolution of a Phobos simulant during the sublimation experiment. The blue spectrum represents the initial spectrum and the red spectrum shows the final spectrum when the water ice is fully sublimated. Each spectrum is taken every hour.

Method:

To accurately represent the surface of Phobos and its spectroscopic properties close to those of D-type asteroids, several samples were selected, including two Phobos simulants [3,4], olivine, phyllosilicate (saponite), coal (anthracite, DECS-19 from the Penn State Coal Bank), and iron sulfide (troilite).

In order to study the porosity effect, porous simulants were created by sublimation of water ice mixed with grains (Fig. 2) of the simulants [12], resulting in a highly porous sublimation residue, as shown in Figs. 3 and 4. This study investigated the spectro-photometric variations induced by porosity using the SHADOWS spectro-goniometer [13] at IPAG (France) with spectroscopic measurements ranging from 0.4 to 3.6 µm. Additionally, mid-infrared (MIR) reflectance spectra (1.25 – 18 µm) were also obtained using the FTIR Bruker Vertex70v spectrometer. Our analysis in the MIR focuses on the modifications of shape and positional shifts of three key features for mineralogical interpretation: the Christiansen feature, the Restrahlen band, and the transparency feature.

For space weathering effect, we will present preliminary results on the irradiation of samples with 36 keV He^{2+}, 126 keV Ar^{7+}, and 72 MeV $^{129}Xe^{19+}$ ions. The irradiation experiment was performed using the ARIBE and IRSSUD beamlines at GANIL (France) with aim of reproducing the effects of solar wind and galactic cosmic rays that reach and altered Phobos' surface. The use of various ions allows to explore different regimes of deposited dose. By preparing individual grains pressed between a ZnS window and a diamond window, we also determined new estimation of sputtering yield for several materials of interest. Because the sputtering yield is linked to the erosion thickness, we proposed to measure the topography of the grains through atomic force microscopy before and after the irradiation.

Results:

Our results on porosity indicate that the spectrum samples tend to exhibit a bluing of its spectral slope in the visible and near-infrared, while increasing porosity (Fig. 3 and 5). In the mid-infrared range, the Christiansen feature is modified and the emissivity peak is larger for porous samples, leading to the formation of a 10 µm-plateau in the spectra of porous samples (Fig. 3) [9]. The study of the photometric properties reveals that porous samples exhibit a reduced single-scattering albedo and a slightly broader lobe that predominantly back-scattered, as for the compact samples, but with a higher contribution of forward scattering. The derivation of the Hapke parameters shows an increase in roughness for the porous sample, as expected by the macro-roughness visible on optical microscope images; but no modification of the opposition effect in contrast to what might have been expected with the modification of the surface texture [5]. Additionally, phase reddening varies between a compact and porous samples, suggesting it as an additional valuable observable for space missions.

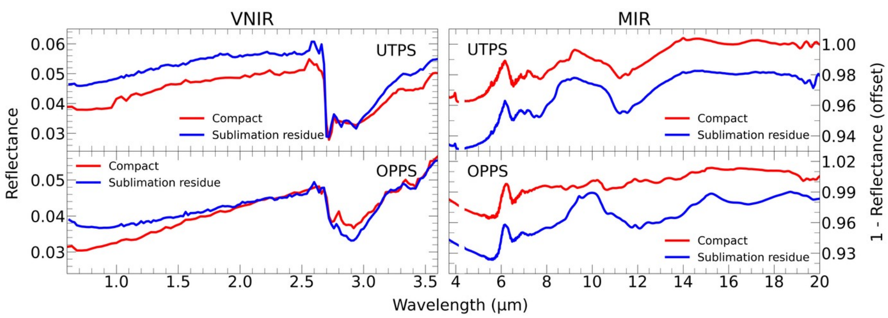

Figure 3: VNIR and MIR spectra of UTPS and OPPS simulant before and after the sublimation experiment.

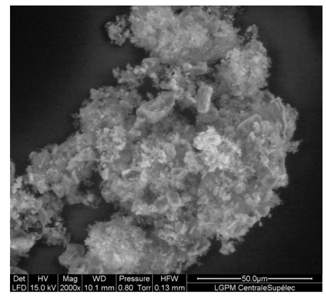

Figure 4: SEM image of a porous sublimation residue of the UTPS-TB Phobos simulant.

The preliminary ion irradiation results have already provided significant insights. In particular, the erosion thickness induced by ion irradiation has been estimated to be between 500 and 1000 nm for a saponite grain (Fig. 5), which is considerably greater than the estimation of erosion thickness provided by SRIM simulations (few nanometers). Further measurements using SEM and micro-IR will be performed to confirm this preliminary result, as well as measurements on the other endmembers. We will also show new results on the spectroscopic and photometric modifications induced by space-weathering, with a focus on the evolution of peculiar absorption bands such as the 2.7 µm O-H feature and the 3.4 µm C-H aliphatic and aromatic features.

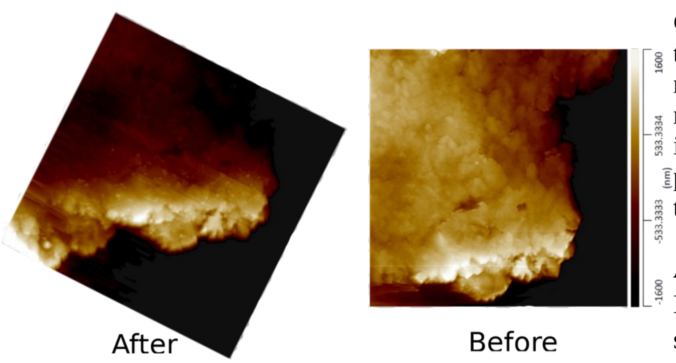

Figure 5: Evolution of the grains surface topography measured with AFM before and after ion irradiation. Note that the color scale is the same for both images.

Conclusion: This study gives novel and unique insights into the spectroscopic effects of porosity and solar wind on the regolith layer of dark primitive asteroids. Thanks to our measurements on regolith simulants before and after ion irradiation, we were able to show the impacts on their photometric properties, leading to a better understanding of the space weathering processes.

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References: [1] Wargnier et al (2023a), *A&A*, 669 [2] Wargnier et al. (2023b), *MNRAS*, 524, 3 [3] Wargnier et al., *Icarus*, 421 [4] Miyamoto et al. (2021), *EPS*, 73, 214 [5] Näränen et al. (2004), *A&A*, 426 [6] Hapke (2021), *Icarus*, 354 [7] Shepard and Helfenstein (2007), *JGR*, 112 [8] Emery et al. (2006) [9] Vernazza et al. (2012) [10] Martin et al. (2022) [11] Pieters and Noble (2016) [12] Poch et al. (2016), *Icarus*, 267 [13] Potin et al. (2018), *AO*, 57, 28