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Vis-NIR Spectroscopy of Highly Porous Surfaces

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1. Introduction

Small bodies of the Solar System are known to be coated by very fine dust, which may be smaller than the wavelength at which we usually observe them in the Vis-NIR. MIDAS and COSIMA [1] measurements on the comet 67P/Churyumov-Gerasimenko show that the particles are more likely micrometer sized fluffy aggregates, constituted of sub-microscopic grains. On the same comet, VIRTIS spectral observations display a lack of spectral features and a low reflectance in the Vis-NIR [3]. Due to their formation processes and their activity, cometary surfaces are more likely to be porous, their bulk porosity estimated larger than 65% [5].
Flat and featureless spectra might be explained by surfaces that scatter light into comet's interior. The present study is meant to determine how the grain size and the porosity of those surfaces can affect light propagation. To this aim, it is important to make samples which present close similarities with cometary surfaces in terms of structure, that we call cometary analogues. Hereby we will present methods to create fluffy aggregates constituted of hyperfine silicates.

2. Methods

Submicroscopic-sized grains are obtained by performing series of dry and wet grindings using a "planetary grinder" and balls of zirconium of decreasing size. Samples are originally millimeter sized crystals of olivine, quartz and rhyolite (igneous rock composed of phyllosilicates, quartz and feldspath). They are first dry-grinded for 20 minutes. The obtained powder is then sieved and the finest part is dry-grinded again. These grindings are repeated until most of the powder is smaller than $< 50\mu m$.
Colloidal grinding is then performed for 60 minutes or 150 minutes depending on the hardness of the starting material. The particle size distribution is determined from Scanning Electron Microscopy (SEM) images. In order to minimize biases of overlapping particles, powder is put into ethanol and agitated using ultrasounds. A drop of the mixture is placed on a SEM sample holder, so that particles are dispersed and easy to recognize. Particles are hand-counted and measured using the ImageJ software; their size is determined by fitting ellipses.

Powders are then used to create porous analogues [6]. They are mixed with water and dispersed using ultrasounds to separate aggregates that may have been formed. Then, the mixture is nebulized into liquid nitrogen. Water drops containing the powder freeze immediately, forming small spheres. Ice is then sieved to remove aggregates larger than $400\mu m$ and to assure a homogenous density in the whole sample, and put into a vacuum chamber to gently let the water sublimate. During the sublimation, grains organise themselves into filaments, sheets or aggregates, and thus form a porous "foam" of silicates.
Spectroscopy measurements are operated all along the sublimation with the spectro-gonio-radiometer SHINE [2] to measure spectra in the Vis-NIR with an incidence angle of 0º and an observation angle of 30º. Once the sublimation done, the sample is collected and now called "sublimation residue".

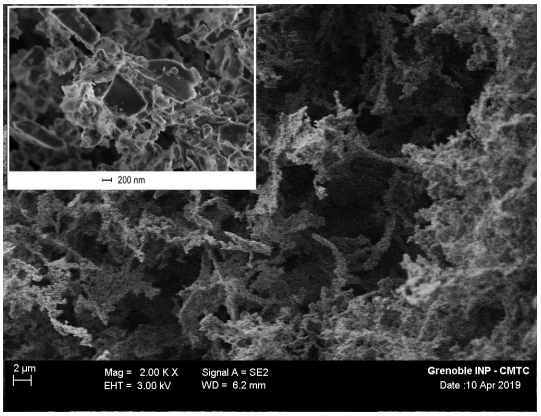

Figure 1: This SEM image of a sublimation residue of a (70wt% olivine and 30wt% rhyolite) mixture shows the organisation of the grains. Two kinds of porosity can be observed: a microporosity between individual grains inside the filaments/sheets and a macroporosity between these structures. The dendritic formation witnesses the fluffiness of the sample at this small scale.

3. Results

As shown on these SEM image (see Figure 1), we managed to create $95\% \pm 3\%$ porous analogues from hyperfine grains. Porosity is estimated by measuring the volume of the sublimation residue after the experiment. There are two kinds of organisation of the grains in the sample, depending on the

starting material. Some grains are arranged in filaments or sheets, where grains are interacting each other. For example, Figure 1 shows the case for mixtures containing rhyolite. On the other hand, grains can form relatively large aggregates sized from a few to tens of microns. In both cases we obtain two regimes of porosity: a microporosity inside aggregates or filaments/sheets from a few tens to hundreds nanometers and a macroporosity between these aggregates which is comparable in size to the aggregates themselves.
Spectra measured on these analogues (see Figure 2) all display low general reflectance level and a loss of band contrast. Notice that only the strongest absorption bands are still visible in these spectra (see Figure 2).

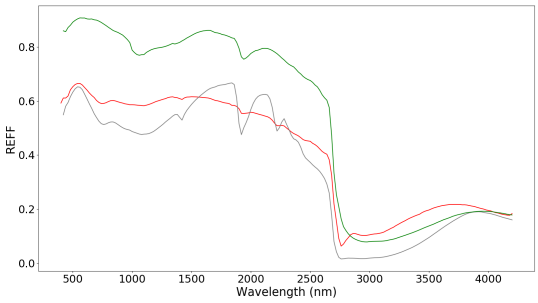

Figure 2: This figure displays spectra of a (70wt% olivine and 30wt% rhyolite) mixture (red) at the end of a sublimation experiment. Both loss of band contrast and lower reflectance are observed, with respect to olivine's (green) and rhyolite's (gray) spectra.

The origin of these effects may reside in the fact that when the sample becomes porous, light can interact with grains deeper into the sample but does not go out. Thus, photons will more probably continue their way into the sample and not reflected toward the observer, which would inevitably leads to a loss of reflectance [7]. Furthermore, since it is scattered by small grains, it is characterized by a typically short optical path length in the medium and then less absorption is observed. Moreover, the organisation of the grains inside this kind of sample in addition to forward scattering particles can act like an optical fiber and guide the light into the sample and not reflect it like a less porous powder (see Figure 3).

4. Summary and Conclusions

These first observations of spectral changes in highly porous cometary analogues constituted of hyperfine grains reveal a decrease of band contrast and a spectral darkening. Future work will include the making of more porous analogues with various grain size ranges, spectral Bidirectional Reflectance Distribution Function measurements on these samples to determine how the structural organisation is actually scattering light. Numerical models [4, 8] are currently trying to reproduce spectra of mediums composed of hyperfine grains, but they are not accurate for such porous surfaces. We are also considering the implementation of Monte-Carlo Ray Tracing methods in order to mimic the light propagation between aggregates using Mie theory to compute optical properties of these aggregates.

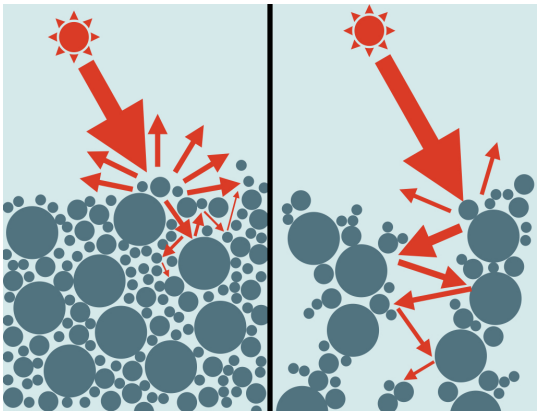

Figure 3: Representation of the light propagation into a powder and into a highly porous sublimation residue.

Acknowledgements

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