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Interpretation of VIRTIS/Rosetta surface spectra of comet 67P from laboratory reflectance measurements of cometary analogues, including iron sulphides

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Abstract

The Rosetta spacecraft has been orbiting the comet 67P from August 2014 to September 2016 with the aim to understand better the activity, the evolution and the surface processes of the nucleus. The VIRTIS spectrometer [1] has acquired reflectance spectra from two channels: VIRTIS-M, an imaging-spectrometer, ranging from 0.25 µm to 5.1 µm with ~2 nm and ~10 nm resolution (resp. in the VIS and IR) and VIRTIS-H, a point spectrometer ranging from 1.9 µm to 5.1 µm with a ~10 times higher spectral resolution than VIRTIS-M. The goal of this study is to reproduce the spectral behavior of the surface as observed by VIRTIS in the range 0.4 µm – 2.7 µm. For this purpose, we measured reflectance spectra of cometary analogs produced in the lab from iron sulphides, coal and silicates.

1. Introduction

Cometary nuclei are among the most pristine objects in the Solar System, having experienced no differentiation and moderate evolution during their lifetime. Their study helps to better understand the first stages of the formation of planetary bodies and the dynamics in the primitive nebula. Observations of cometary nuclei [2,3], dust sample returns [4] and collection of Interplanetary Dust Particles [5] give us important information about the composition of cometary surfaces while a number of experiment many experiments [6, 7] tried to reproduce the physical mechanisms of the activity in presence of ice and dust. Here we try to infer the global composition of the surface by comparing laboratory measurements to VIRTIS data.

2. Methods

Observations dedicated to study the dust in the coma made by the GIADA, COSIMA and MIDAS instruments on board Rosetta [8, 9, 10] have indicated particle size distribution extending to the sub-µm scale. The development of new grinding techniques at IPAG allows us to produce particles with sizes <0.4 µm for a series of tested materials: organic matter (coal), iron sulphides (pyrite, pyrrhotite) and silicates (olivine, pyroxene). Various compositions (coal+sulphide, coal+silicates, coal+sulphide+silicate…) and mixing modalities (intimate/linear) were tested in our mixtures as well as different grain sizes. Reflectance measurements at standard observation geometry (incidence = 0°, emergence = 30°) were made with a spectro-gonio-radiometer in order to understand the effect of these parameters and to reproduce as good as possible the VIRTIS spectra. A set of measurements at various observation geometries was also acquired.

3. Results

Pure phases (< µm): spectral effects of grain size variation were tested for pure sub-micrometric phases. While silicates and coal experience brightening with decreasing size (see Fig 1. for coal), Fe-sulphides get darker (Fig. 2). This influences the spectral shape of mixtures.

Mixtures - effect of composition: we use powders with sub-micrometric grains to realize different mixtures. Coal+silicate and pyrrhotite+silicate do not fit the VIRTIS spectra. A mixture of coal+33wt% of pyrrhotite provides a good fit (‘A’ – blue spectrum on Fig. 3). However, coarser grains are needed in this case.

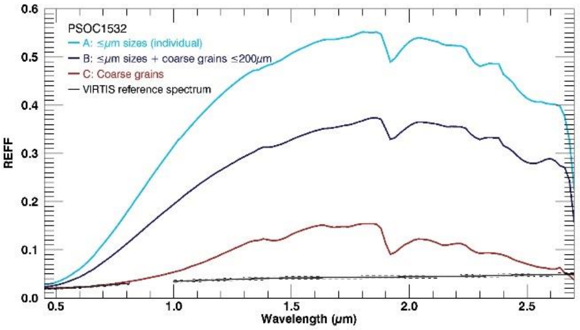

Figure 1: spectra of pure coal PSOC1532 powders with various grain sizes

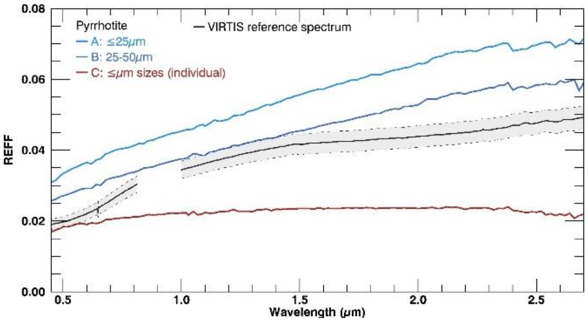

Figure 2: spectra of pure pyrrhotite ($Fe_{1-x}S$) powders with various grains sizes

Effect of mixing modalities (Fig. 3): spectral slopes and IR reflectance of intimate mixtures of coal and pyrrhotite are smaller with respect to the values inferred by VIRTIS ('B' – red spectrum, Fig. 3). In mixtures with coating of pyrrhotite over coal, the spectral slope is bluer and the reflectance value is higher but still does not fit the VIRTIS one ('C' – green spectrum, Fig. 3). Conversely, in the VIS, the fit is fairly good in both cases. The presence of silicate plays a minor role in these mixtures (intimate and coating, Fig. 4).

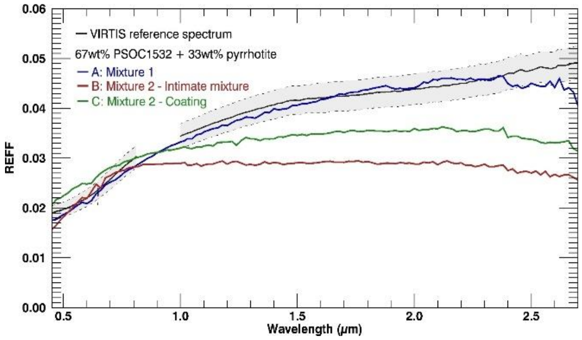

Figure 3: mixtures of coal and pyrrhotite against mean VIRTIS spectrum. See text for details

4. Summary and Conclusions

Our measurements indicate that sub-micron particles are needed to reproduce the spectral properties of the surface of 67P. This is particularly true concerning pyrrhotite which is able to darken spectra in the IR only with small grain sizes, unlike the used coal [11]. Our measurements highlight the importance of the effects of mixing modalities (intimate mixture, coating) and grain size. Some scattering properties could be better determined with multi-angular acquisition. Finally, this work may be relevant to the study of primitive asteroid types, in particular C and D-types which exhibit albedo properties similar to 67P in the VIS and NIR range.

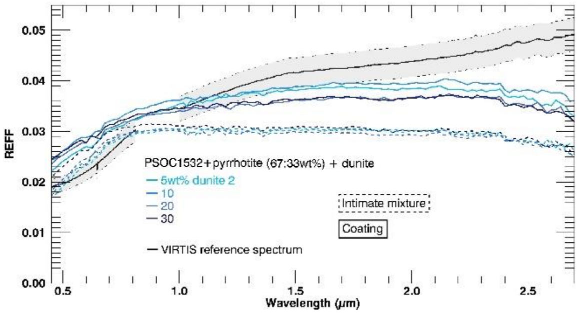

Figure 4: mixture of coal, pyrrhotite and various proportions of silicates. Intimate (solid) and coating (dotted)

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