

**VNIR SLOPES AND MIR EMISSIVITY FEATURES OF PRIMITIVE SMALL BODIES: THE INFLUENCE OF HYPERFINE GRAINS AND POROSITY.** P. Beck<sup>1</sup>, R. Sultana<sup>1</sup>, O. Poch<sup>1</sup>, E. Quirico<sup>1</sup> and B. Schmitt<sup>1</sup>. <sup>1</sup>Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France ([pierre.beck@univ-grenoble-alpes.fr](mailto:pierre.beck@univ-grenoble-alpes.fr))

**Introduction:** Solar System small bodies are presumed relics from the eve of the Solar System, as they were the first objects to accrete inside the protoplanetary disk. A significant fraction of these objects did not accumulate enough mass, or not fast enough, to achieve temperature sufficient to induce partial or full differentiation. Hence, they hold key information about the materials and the conditions found inside the disk.

The P-/D-type asteroids are particularly interesting because of their similarity in the visible (Vis) and near infrared (NIR) spectral range with cometary nuclei, suggesting that they are the most primitive types of small bodies [1-3]. In the mid-infrared (MIR), emission spectra of both comets and P-D type objects display a signature around 10  $\mu\text{m}$  related to the fundamental mode of vibrations of *Si-O* in silicates [4-5]. Remarkably, while emissivity observations of comets are performed on an extended cloud of dust, usually optically thin, the spectra are very similar to observations of P-/D-type asteroids that are performed on a compact surface [2].

In a previous work [6] we explored the influence on reflectance spectra of the presence of *hyperfine grains* (as defined in [7]), which sizes are smaller than the wavelength at which we observed them ( $< 1 \mu\text{m}$ ). We showed that the presence of these hyperfine grains tends to uniformize the spectra of different material (*spectral degeneracy*), especially when they form hyperporous structures. In this previous study we focused on weakly-absorbing particles ( $k < 0.01$ ) and did not study the effects of mixing different powders of hyperfine grains together. In the present work, we investigate the influence of mixing powders of submicrometric grains of materials having strongly different optical indexes. We compare our laboratory results to NIR and MIR observations of small bodies, and discuss the implications in terms of composition and texture for a few classes of Solar System small bodies.

**Methods:** In order to produce analogues of primitive small bodies, we used natural samples of the expected constituents: olivine as the silicate, iron sulphide (pyrrhotite and troilite; labelled as “FeS”) as an inorganic opaque mineral, and last, anthracite as an organic opaque phase. The sulphide and anthracite display relatively flat spectra in the Vis-NIR and in the MIR. In the MIR, their reflectance spectra are brighter than the olivine, with no strong absorption feature (Fig. 1b). Grain sizes were determined using FEG-SEM, and the values are between 0.3 and 0.7  $\mu\text{m}$  for the average particle diameter depending on the material. Mixing was achieved by adding the two powders in a mortar

and mixing them manually with the pestle for about 10 min. Reflectance spectra in the Vis-NIR range (0.4-4.2  $\mu\text{m}$ ) were obtained at IPAG with the SHADOWS instrument [8]. Samples were observed under an angle of emergence  $e=30^\circ$  and the incident light was set to normal incidence ( $i=0^\circ$ ). MIR reflectance spectra were obtained using a Brucker Vertex 70V FT-IR spectrometer equipped with a reflectance kit A513/QA. Because small bodies MIR observations are emissivity spectra (Fig. 1d), we show on Figure 1b the experimental spectra as “1-reflectance” to approximate their emissivity spectra according to the Kirchhoff’s law.

**An example of results: mixture of hyperfine grains of olivine and FeS.** Figure 1a presents the evolution of normalized reflectance spectra of olivine-FeS mixtures with decreasing volume concentration of olivine. We observe a general decrease of reflectance, associated to a modification of the spectral slope, as the concentration of FeS (opaque in the Vis) increases, with a blueing followed by a reddening of the spectra (Fig. 1a). This effect is most pronounced in the low-wavelength range (below 1.5  $\mu\text{m}$ ). We also observe a disappearance of the olivine band at 1  $\mu\text{m}$  when the amount of opaque grains increases above 5 vol. %.

In the MIR, while the spectra of the endmembers are relatively flat, the spectra of mixtures show the presence of features in the 9 to 12  $\mu\text{m}$  spectral range (Fig. 1b). Of interest is the appearance of a triplet around 10, 11 and 12  $\mu\text{m}$ , corresponding to IR absorption bands of olivine.

These observations reveal that spectra of mixtures of olivine and FeS exhibit an emissivity feature in the MIR and various degree of blueing or reddening in the Vis, as observed on several small bodies.

**Discussion.** Replacing the FeS grains (0.30  $\mu\text{m}$  average major dimension) by anthracite grains (0.35  $\mu\text{m}$ ) results in very similar evolutions of the Vis spectral slope and emissivity feature of the reflectance spectra (not shown here). Therefore, these evolutions of the spectra are due to the hyperfine size of the grains and to similar differences in optical properties between olivine versus FeS or anthracite (but not necessarily due to their chemical composition).

Following [9], we propose that in our sample hyperfine opaque grains, well dispersed in a bright transparent silicate matrix, can scatter the light following a Rayleigh-like regime, leading to a blueing of the spectra; smaller wavelengths are more efficiently scattered than higher wavelengths. In order to test this interpretation, we have used the theoretical

approach of [10], which confirmed this hypothesis for the origin of the spectral bluing.

Besides being spectrally blue, B-type asteroids present a convex spectral shape; the magnitude of the spectral slope decreases from the visible to the infrared, reminiscent of the Rayleigh-like scattering observed in our experiments. In Figure 1c we plot the spectra of three B-type asteroids (top-most spectra). It appears that the spectra of (2) Pallas and (3200) Phaeton are most similar in shape to the spectra of the mixtures containing from 60 to 70 vol% olivine.

Now, how to explain the mid-infrared spectra of the mixtures? A surface made of pure hyperfine olivine grains has a very low MIR reflectance with weak spectral signatures. When hyperfine olivine grains are mixed with KBr grains, it was found that the resulting MIR reflectance spectra are much brighter and show pronounced signature of olivine [5]. This effect can be explained by the fact that the large KBr grains scatter light, unlike olivine grains, and enable photons to “escape” the sample. Because some of these escaping photons will have interacted with olivine grains, the olivine signature is imprinted on the measured spectra.

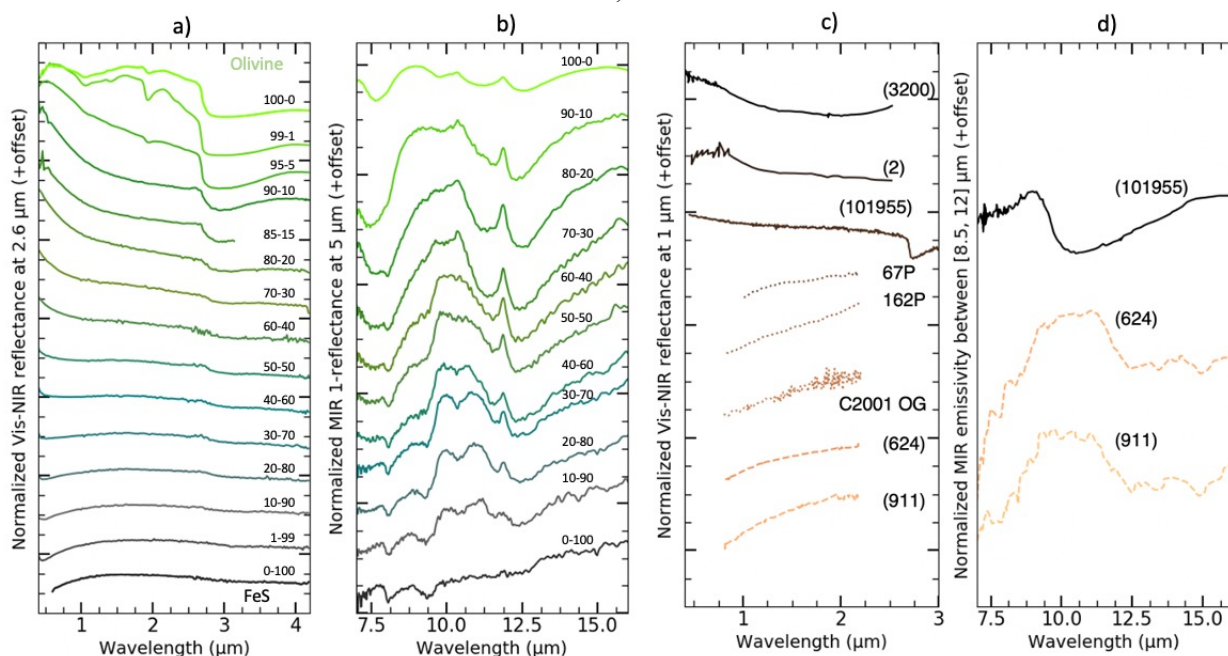
We propose that the effect of mixing olivine with sulphide and anthracite is somehow similar to that of mixing it with KBr powder, but to a lower extent. The FeS and anthracite grains enable photons to escape the sample and some of those will have interacted with olivine grains in the mixture. As a consequence, the obtained spectrum is reminiscent of an olivine absorption spectrum as seen in Figure 1b. Moreover, while mixtures with KBr are very reflective, mixtures with FeS or anthracite have a much lower reflectance,

compatible with the low reflectance and high emissivity values observed on small bodies.

The resemblance between mid-IR spectra of our hyperfine mixtures and P-/D-type asteroids emission feature (Fig. 1d), including Trojan asteroids such as (624) Hektor or (911) Agamemnon, implies that ***elevated porosity is not a requirement for the presence of a silicate signatures at 10  $\mu$ m***. We show here that relatively compact surface (porosity of the order of 50 %) may exhibit similar mid-IR feature as cometary dust tails. An interpretation that can be proposed is that in both cases an optical separation of olivine grains occurred, whether by vacuum in the case of cometary dust tails, or by optically featureless and relatively opaque grains in the case of P-/D-type asteroids.

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**References:** [1] Capaccioni et al. (2015) *Science* 347, 6620. [2] Vernazza and Beck (2017) in *Planetesimals*, Cambridge Univ. Press. [3] Poch et al. (2020) *Science* 367, 6483. [4] Emery et al. (2006) *Icarus* 182, 496-512. [5] Vernazza et al. (2010) *Icarus* 207, 800-809. [6] Sultana et al. (2021) *Icarus* 35, 11412. [7] Mustard and Hays (1997) *Icarus* 125, 145-163 [8] Potin et al. (2018) *App. Optics* 57, 28. [9] Clark et al. (2008) *Icarus* 193, 372-386. [10] Brown (2014) *Icarus* 239, 285-295. Full reference of the data in Fig. 1 will be provided at the meeting.



**Figure 1:** Olivine-FeS mixture in the a) NIR and b) MIR. Spectra of selected objects in the a) NIR and b) MIR.