

Micrometers Regolith Grain Size Properties Inferred by Laboratory Infrared Observation and their Implication for Planetary Protection.

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INTRODUCTION

Asteroids, characterized by their rocky compositions, represent a captivating topic for space exploration, offering glimpses into the primordial building blocks of our Solar System. Among these celestial bodies, asteroid (99942) Apophis has garnered particular attention due to its close approaches to Earth in 2029 [1,2]. In this study, we explore the pivotal role of laboratory measurements on planetary rocky analogs in unravelling the link between physical properties and remote sensing observations from ground and space telescope or spacecraft exploration. Indeed, it's well known that grain size plays a pivotal role in the study of regolith, dust, and fragmented rock covering solid planetary surfaces such as asteroids [3,4]. Indeed, grain size influences various physical properties of regolith, such as thermal conductivity [5], surface roughness [6], and spectral reflectance [7], which are essential for interpreting remote sensing data.

AIMS OF THE PROJECT

Nowadays, the understanding of complex sample characterized by several grain size is still uncompleted; therefore, we performed a series of laboratory studies to improve our knowledge on this fundamental topic. Mixture of different grain size in complex sample can also offer a hint on the effect of macro porosity on the infrared spectrum. The goal of this study was to investigate the modification of infrared spectroscopic features due to mixing of components with different grain size:

1. A first study investigated mix of anhydrous mineral with hydrated hyperfine minerals [8]
2. The second work focused on the mix of a dark component with minerals at different grain size [9]

The ambitious objective is to link micro-scale properties observed in laboratory analogs, meteorites and returned samples to remote observations taken directly on planetary surface both from spacecraft and ground-based observations.

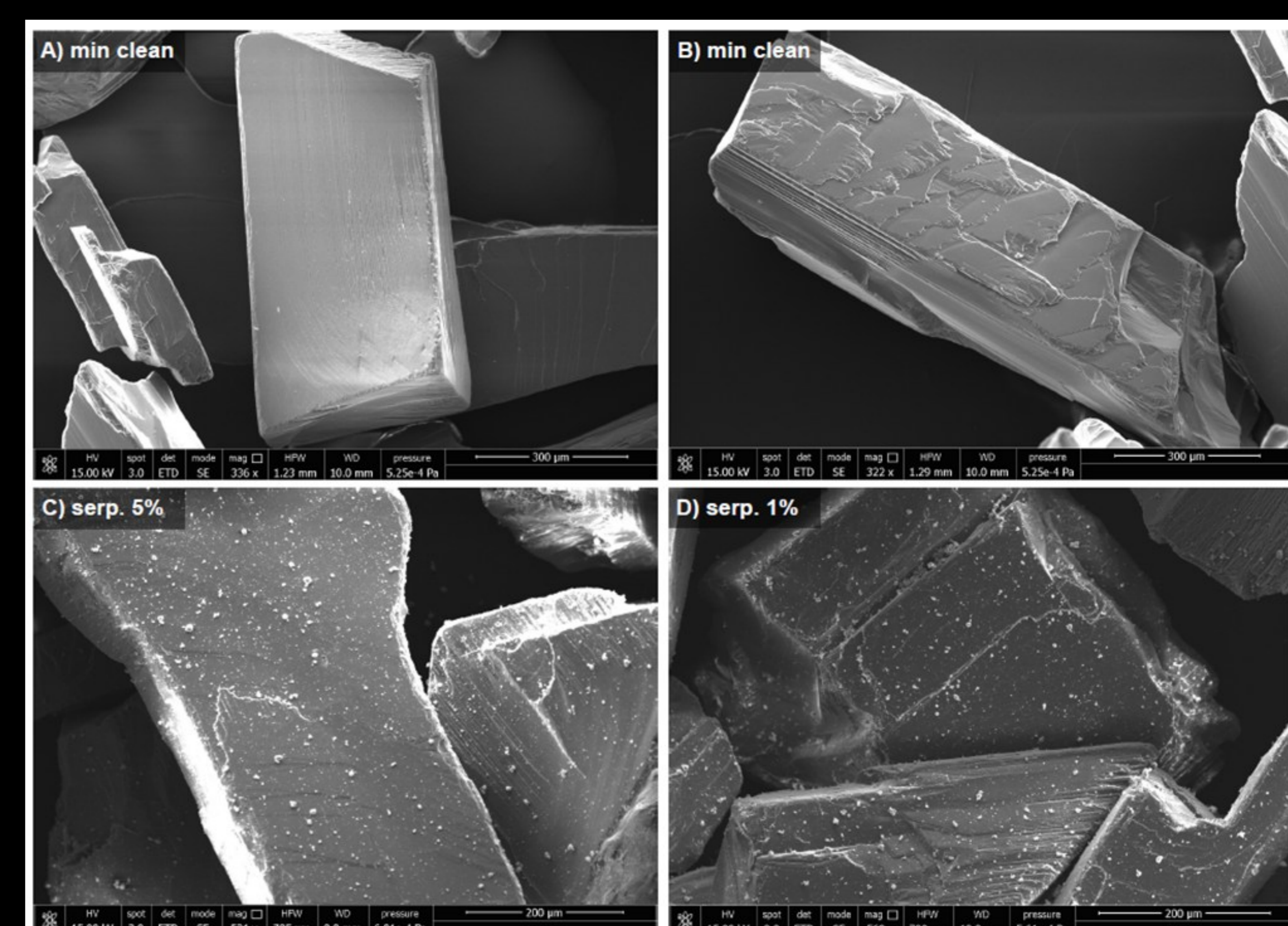
METHODS AND SAMPLE PREPARATION

Sample prepared for the laboratory measurements benefit of a new protocol we developed to effectively select grains to hyperfine size, cleaning bigger grain size by small grain size contamination and mix several components with different grain sizes assuring homogenization and, at the same time, preservation of the initial grain size distribution. The method passes through a series of steps

This protocol allow to produce unique samples with different grain size perfectly homogenized together reproducing realistic surfaces.

We measured the IR reflectance spectrum of these mixtures in the range 1.25–25 μm (8000–400 cm^{-1}) using a Bruker VERTEX 70v FTIR interferometer in biconical reflectance at INAF-Astrophysical Observatory of Arcetri in Florence, Italy. We analysed several features on the spectrum of each mineral mixture: (i) the near infrared slope; (ii) the 2.7 μm OH-stretching band; (iii) the Christiansen features; and (iv) the Reststrahlen band and Transparency feature.

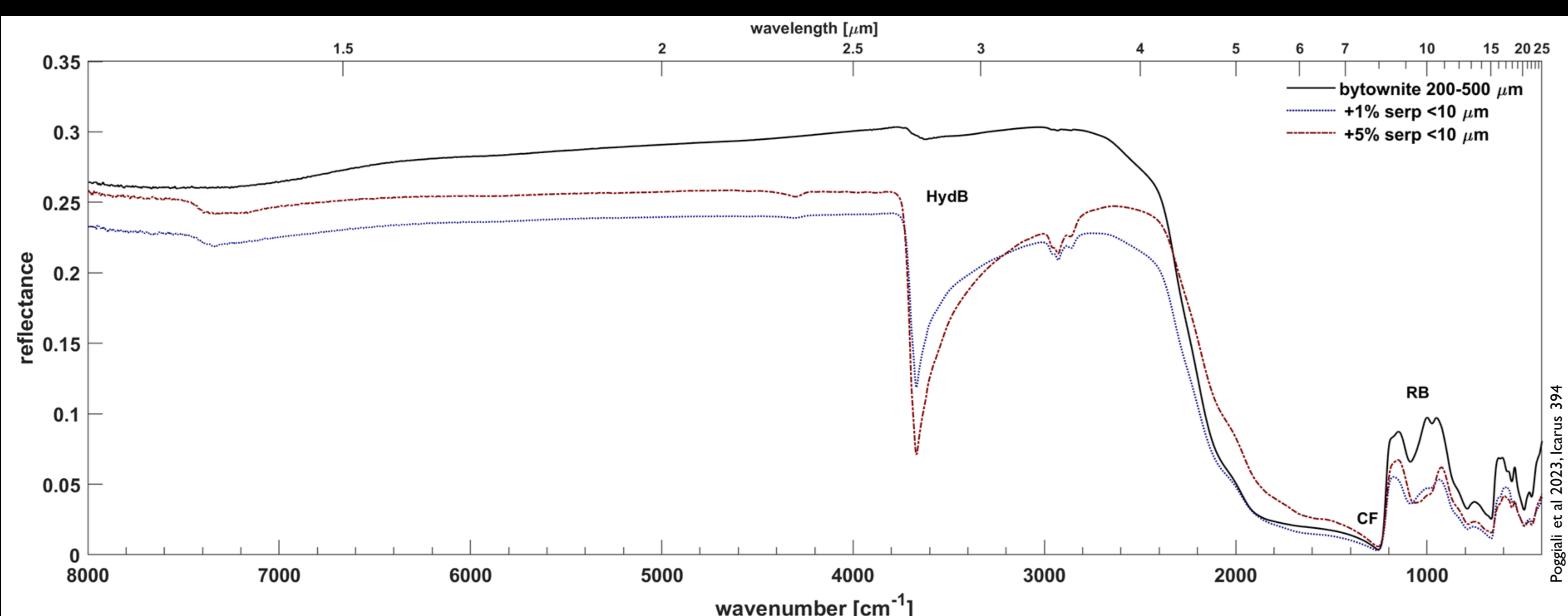
- 1 **Mechanical crushing**
Using a planetary mill and agate jar
 - A *Mechanical sieving*
Effective in selecting < 50 μm , 50–200 μm , 200–500 μm , 500–1000 μm
 - B *Time of fall sieving*
Used for hyperfine grain size selection < 5 μm and < 10 μm
- 3 **Ultrasonic washing**
To remove small grains stacked on grains with bigger grain size
- 4 **Ultrasonic mixing**
No intimate mixing using a mortar was used to avoid reducing grain size



HYPERFINE HYDRATED MIXING

In the first study [8] we mixed hyperfine (< 10 μm) hydrated minerals serpentine and montmorillonite with different anhydrous minerals (diopside, enstatite, bytownite and pyrite) with bigger grain size (200–500 μm).

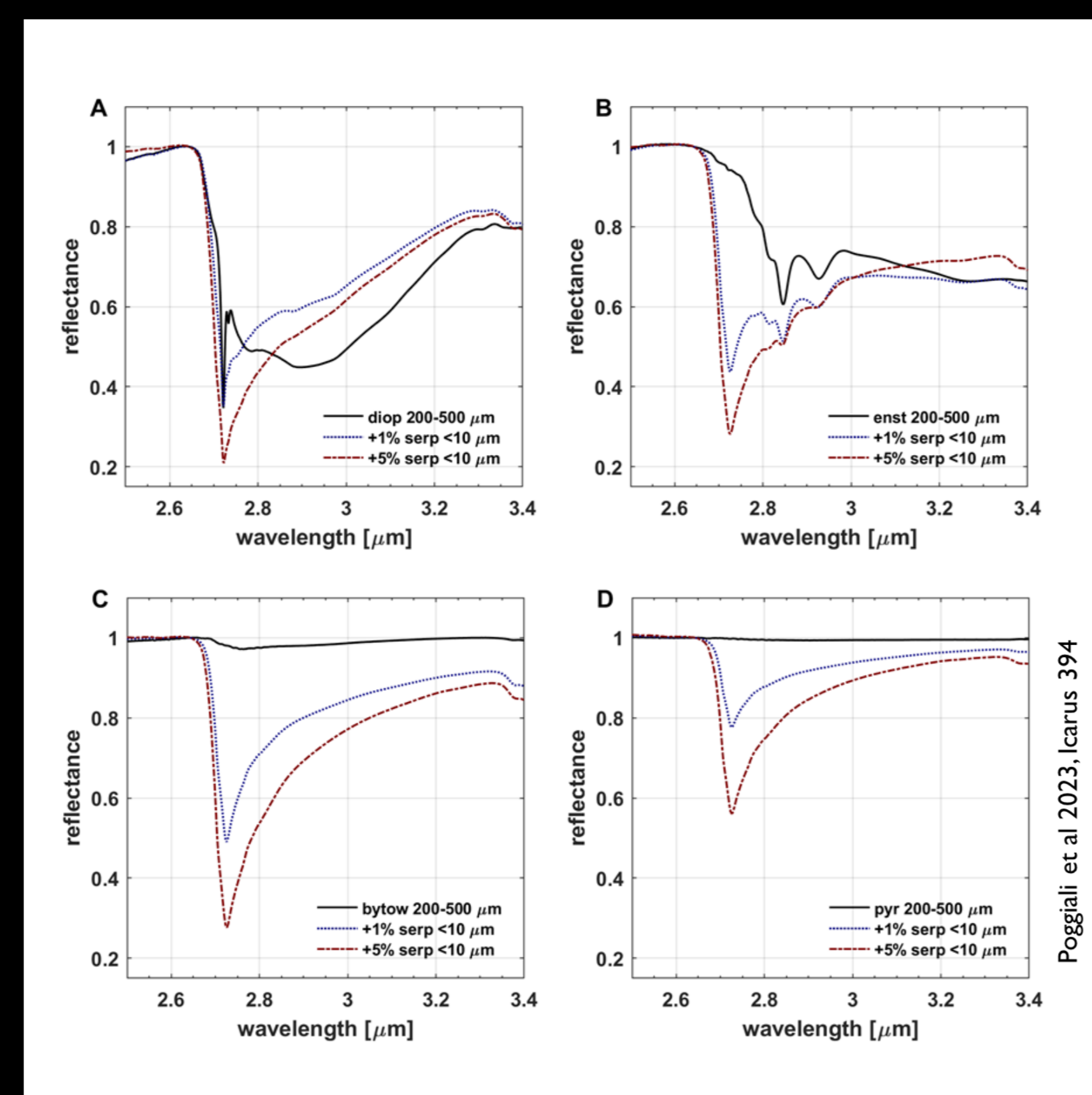
Addition of 1 wt% or 5 wt% of hyperfine hydrate component is sufficient to change the spectrum of anhydrous mineral but in almost all spectra, the major changes concern the appearing of a prominent hydrated band while MIR spectrum is mostly affected for reflectance level.



Major results of this work are:

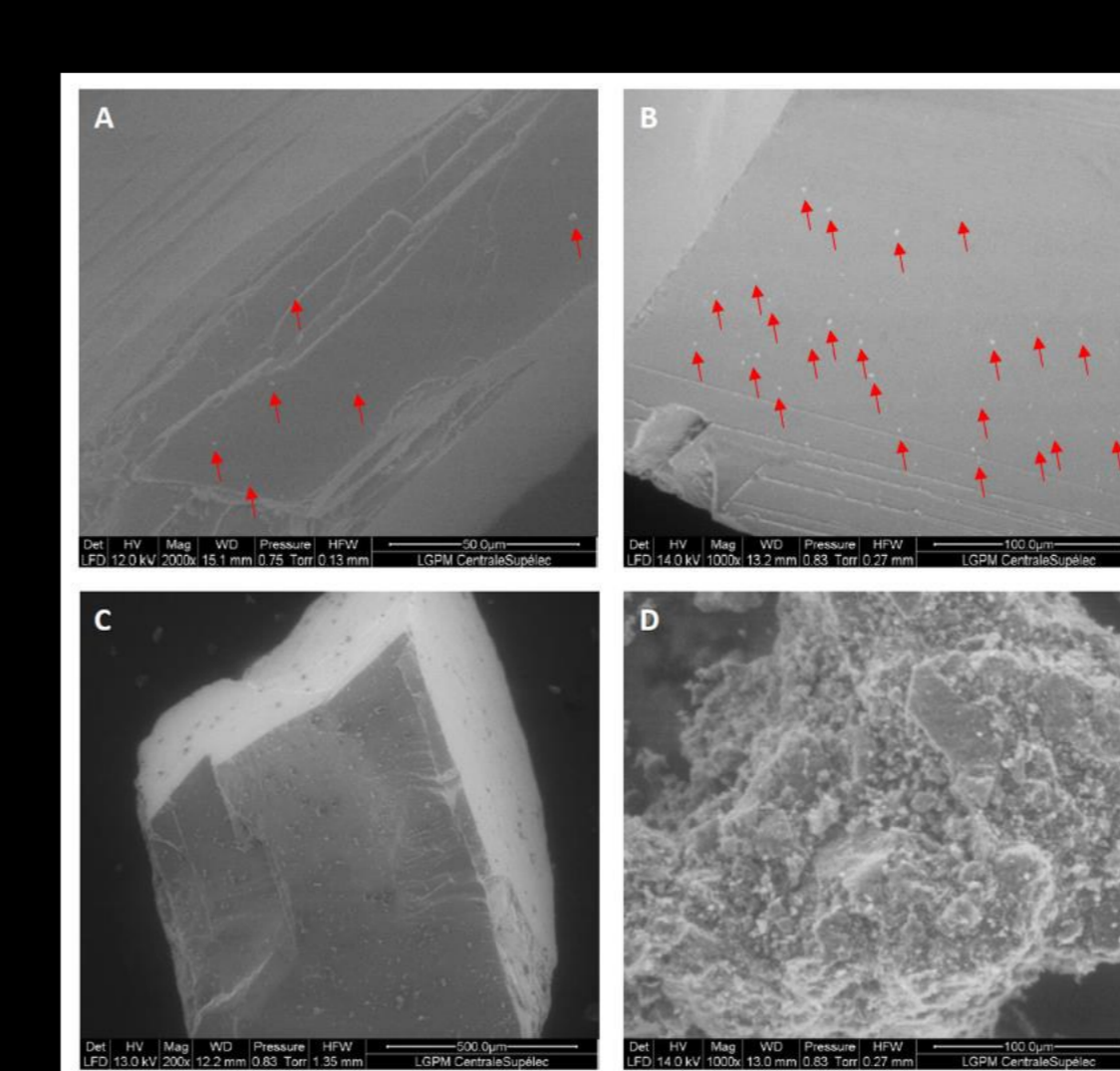
- Near Infrared range shows notable changes due to the addition of hydrated minerals.
- The hydrated OH-stretching band at 2.7 μm appear to be dominant over the anhydrous spectra.
- Mid Infrared range is less affected and anhydrous mineral features are still dominant.

The surface of many rocky bodies is covered with regolith, and these new laboratory data show how even a small amount of hydrated mineral in the composition can influence the overall final spectrum. Therefore, it is of paramount importance to have a very good understanding of the spectroscopic changes induced by small variations in the mineral phases for the correct interpretation of infrared data of planetary surfaces acquired by space missions.



Note that not all pairings between anhydrous and hydrous minerals reproduce typical alteration mineralogy

DARK COMPONENT MIXING



In the second study [9] we mixed anhydrous mineral, bytownite and augite, with grain size < 50 μm , 50–200 μm , 200–500 μm , 500–1000 μm and amorphous carbon < 50 μm .

We used different increasing proportion from 1% to 50% of dark component for the mix to stress out the physical effect even if high percentage are not very representative.

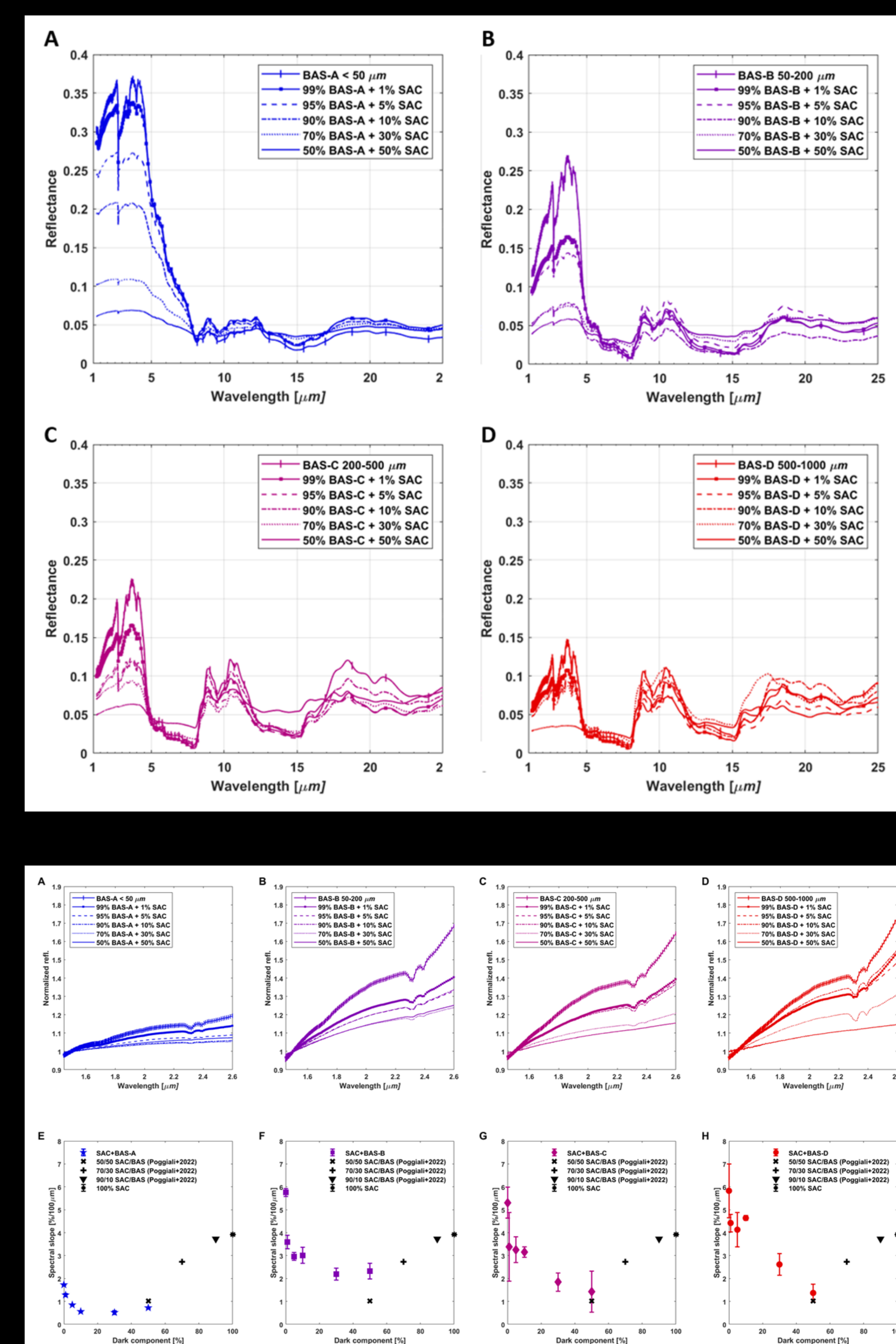
From the combination of basaltic mixtures 50% augite and 50% bytownite in four different grain sizes with amorphous carbon [AC] in five proportions, we obtained 24 spectra.

The addition of AC induces several changes in every feature of the spectrum from NIR to MIR range. These changes combine with the well-known modification induced by grain size reduction

The trend of the slope values observed with the addition of a dark component follow a nonlinear trend with a minimum between 10% and 50% depending on grain size. The trend of modification of the OH band area and peak intensity is influenced by the grain size.

Major results are:

- Smaller percentage of mixing are in general affected by higher variability and irregular trends
- Slope variation shows a minimum and the inversion between reddening and blueing at 10% mixture with dark component (or higher percentage)
- Adding a dark component the OH-stretching band around 2.7 μm shows a trend linear or power law trend of modification depending on the grain size.
- MIR range is generally more affected by grain size than the percentage of dark component added to the mixture.



FINAL REMARKS

Apophis asteroid close approach on Earth will offer a unique opportunity to improve our knowledge on how infrared observation can be linked to regolith properties. Detail observations made by OSIRIS-APEX mission [10] and RAMSES mission will be coupled with ground observations [11]. It becomes clear, then, how possessing in advance a deep knowledge on the whole spectrum from visible to thermal infrared is crucial for a correct interpretation of the data from Apophis. Results will be useful also for support the exploration of Didymos, target of HERA mission [12] ready to be launched this year, following the investigations of DART/LICIACube mission.

Indeed, it is pivotal to increase our knowledge on the link between micro- and macro-scale infrared observation if we want to improve our interpretation of remote sensing data from every kind of planetary surfaces.



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