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Photoprocessing of Organic Material on Ceres: Laboratory Studies on Chemical Evolution of the Inner Dwarf Planet

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Introduction: Ceres is the largest object of the Solar System main belt with a complex geological and chemical history, which experienced extensive water related processes and geochemical differentiation [1]. Ceres' surface is characterized by dark materials, phyllosilicates, ammonium-bearing minerals, carbonates, water ice, and salts. In addition to a global presence of carbon-bearing chemistry, local concentration of aliphatic organics has been detected by Dawn mission [2]. The mission, thanks to the data collected by the Italian instrument VIR [3], showed clear evidence of a high amount of aliphatic organic material on the surface of Ceres [4, 5, 6]. This has raised new questions about the origin and preservation of this material, especially when considering its high estimated abundance (Fig 1).

We started a series of laboratory studies on physicochemical evolution of organic material interacting with minerals thought to be present on Ceres. The goal is to understand the transformations induced on these samples by processing with ultraviolet radiation.

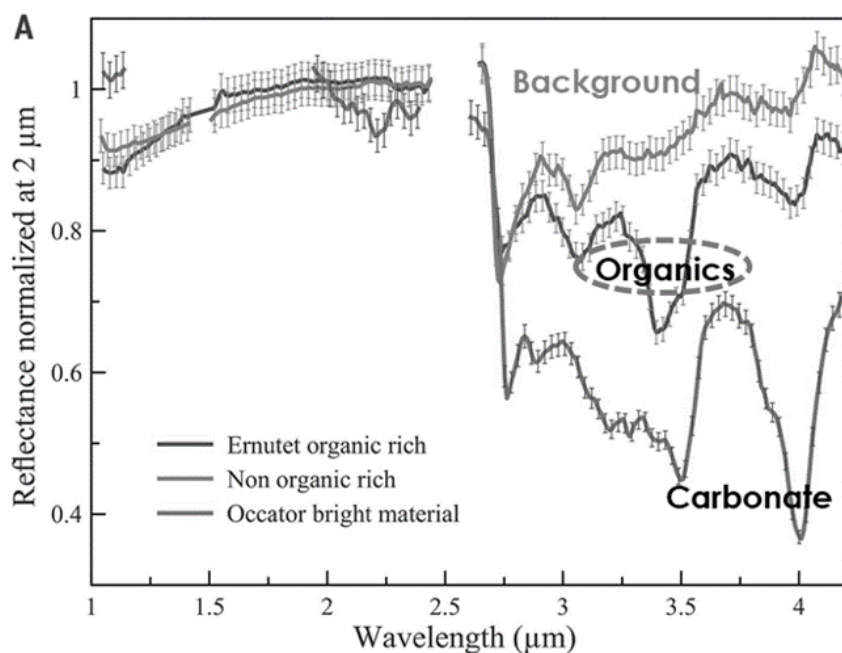


Fig. 1 Ceres spectra of the organic-rich area in Ernutet crater (label "Organics"); of a background organic-poor area from a region southeast of Ernutet (label "Background"); and Occator bright material (label "Carbonate") [4].

Results: In this study, we mixed organic material with a mixture of minerals considered a spectral analog of the Ceres surface. Specifically, we mixed undecanoic acid and solid material made of serpentine, magnetite, carbonate and ammonium bearing montmorillonite with a ratio of 1:80 (organic:mineral).

Diffuse FTIR reflectance spectra were acquired in vacuum. Spectra of simulant are resembling the Ceres surface composition (Fig. 2) organic rich area, even if the proportions between the bands of clays, carbonates and organics are not the same as seen on Ceres. We irradiated the sample in the vacuum chamber at room temperature using an UV lamp to simulate the solar radiation. The photon flux was 2.75×10^{17} ph. $\text{cm}^{-2}\text{s}^{-1}$ in the 200-400 nm spectral range as measured through a single monochromator Spectro 320 spectrometer. The simulant was irradiated at increasing fluence up to irradiation time of about 7 hours and the degradation process was monitored in real time with FTIR spectroscopy by measuring the changes in the spectral features (band areas). In Fig. 4 the reflectance spectra of the simulant as prepared and after UV irradiation at 180, 2280, and 21180 s are showed. The bands area of NH_3 at 3 μm and aliphatic CH_2/CH_3 at 3.4 μm are decreasing as the irradiation fluence increases with time.

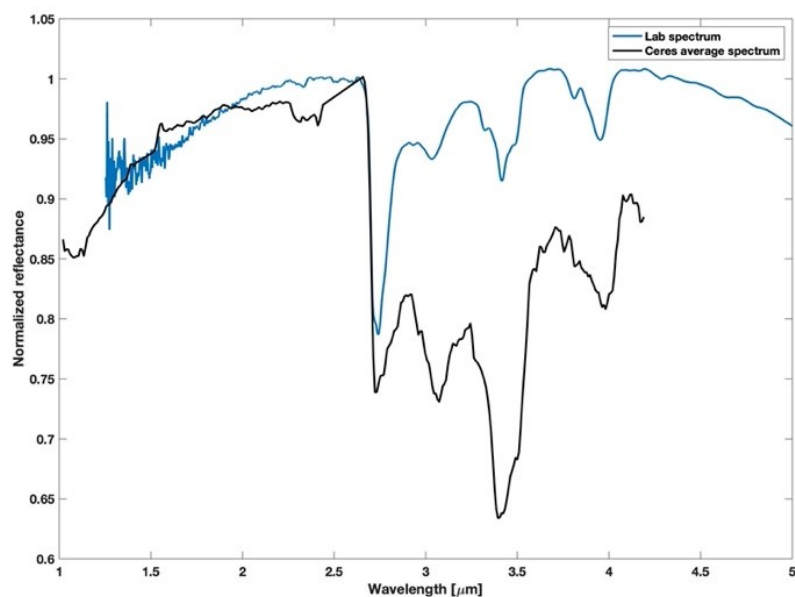


Fig. 2 Average spectrum of Ceres Ernutet organic-rich areas (black) compared to laboratory simulant (blue). Spectra are normalized at 2.6 μm .

Each band area, which is proportional to the number of functional groups, was evaluated at different irradiation time and the degradation rate was obtained by fitting the band areas vs irradiation time using an exponential function. This method permits to determine the degradation cross section of each band, which is the probability that chemical bonds are broken by UV radiation. In particular, for the aliphatic band at 3.4 μm it was possible to obtain the degradation cross section of the whole band, $5.85 \times 10^{-21} \text{ cm}^2$, and of every single band component distinguishing between CH_2 and CH_3 bonds behavior under irradiation.

In presence of mineral simulant, the degradation rate of aliphatic compounds extrapolated to the estimated UV flux at the surface of Ceres gives a half-lifetime of 215 days. This result coupled with resurfacing process time scale of million years could justify the absence of detectable organics on most of the Ceres' surface. However, this result would not be able to explain the presence of organics in the organic-rich area in Ernutet crater. Furthermore, as can be seen from Fig. 3, UV radiation not only degrades the CH bonds but also affects the NH bonds present in the ammoniated silicates. In this latter case the degradation cross section for the whole band is $2.05 \times 10^{-21} \text{ cm}^2$ which is responsible of a less effective photodegradation process giving a degradation half-lifetime of about 613 days. This result also seems to be in contrast with the ubiquity of the presence of ammoniated silicates on Ceres. We have to recall that the experiments reported in this work have been done at room temperature. It is not excluded that photoprocessing at cryogenic temperature typical of Ceres surface can be less effective further reducing the degradation cross sections of CH and NH bonds.

Discussion: As showed by VIR, the ammoniated band is ubiquitous on Ceres, which is in contrast with the fact that we expected the ammoniated band to be completely degraded. However, photodegradation acts on the first molecular layers of the surface exposed to the radiation.

Furthermore, the visible and near infrared spectra detected by VIR are diffused by the first millimeters of the surface at a depth that cannot be affected by UV radiation. Therefore, the spectra are a combination of processed superficial material and underlying layers of the Ceres surface, which may retain the primitive characteristics of material rich in organic. However, it should be noted that in addition to UV, the surface is constantly bombarded by solar energetic particles (SEP) and galactic

cosmic rays (GCR). This radiation also has the effect of breaking chemical bonds such as UV photons, but penetrating meters into the surface can alter deeper layers. These results suggest that there must be a resurfacing mechanism able to expose organic rich material that acts on a much shorter time scale than the geological one.

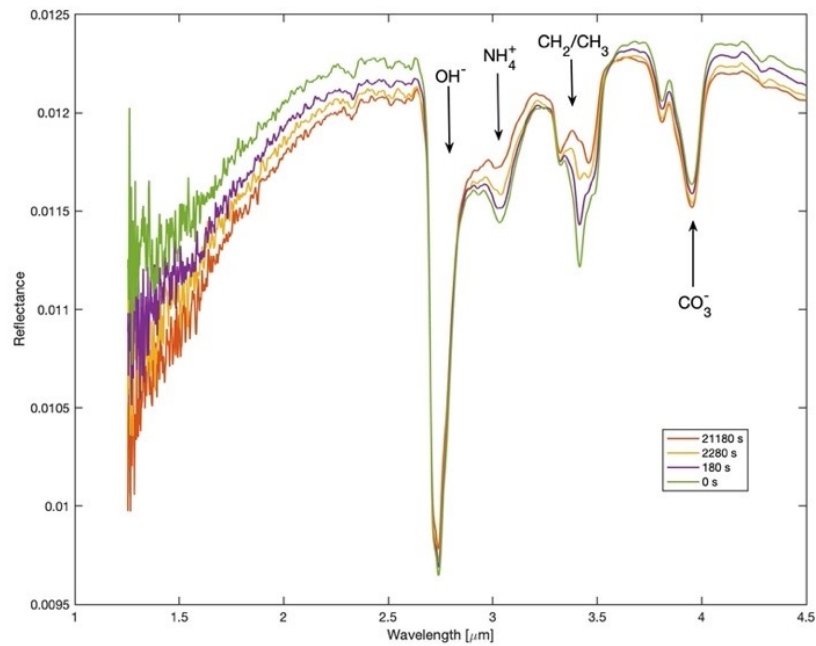


Fig. 3 Diffuse reflectance spectra of the simulant as prepared (0 s) and after UV irradiation at 180, 2280, and 21180 s.

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