



Publication Year	2022
Acceptance in OA	2024-05-08T13:34:30Z
Title	Photoprocessing of Organic Material on Ceres: Laboratory Studies on Chemical Evolution of a Wet Small Body
Authors	BRUCATO, John Robert, DE SANCTIS, MARIA CRISTINA, PAGNOSCIN, Silvia, POGGIALI, GIOVANNI, FERRARI, MARCO, DE ANGELIS, Simone, PALUMBO, Maria Elisabetta, BARATTA, Giuseppe, MENNELLA, Vito, FULVIO, Daniele, POPA, IONUT CIPRIAN, STRAZZULLA, Giovanni, SCIRE` SCAPPUZZO, Carlotta
Handle	http://hdl.handle.net/20.500.12386/35110
Serie	LPI CONTRIBUTION
Volume	2678

PHOTOPROCESSING OF ORGANIC MATERIAL ON CERES: LABORATORY STUDIES ON CHEMICAL EVOLUTION OF A WET SMALL BODY. Brucato J.R.¹, De Sanctis M.C.², S. Pagnoscin^{3,1}, Poggiali G.^{4,1}, Ferrari M.², De Angelis S.², Palumbo M.E.⁵, Baratta G.⁵, Mennella V.⁶, Fulvio D.⁶, Popa C.⁶, Strazzulla G.⁵, Scirè C.⁵; ¹INAF - Osservatorio Astrofisico di Arcetri, Firenze, Italy (john.brucato@inaf.it); ²INAF-IAPS Istituto di Astrofisica e Planetologia Spaziali, Roma, Italy; ³Department of Physics and Astronomy, University of Firenze, Firenze, Italy; ⁴LESIA-Observatoire de Paris, Université PSL, CNRS, France; ⁵INAF - Osservatorio Astrofisico di Catania, Catania, Italy; ⁶INAF-Osservatorio Astronomico di Capodimonte, Napoli, Italy

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]. In the main frame of a national program of the Italian National Institute of Astrophysics INAF, 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, neutral atoms, and fast ions, under experimental conditions that simulate the environment of Ceres. Thanks to the combined experimental activities and through the comparison with the observations of the VIR spectrometer aboard the Dawn mission, we aim to understand the origin and evolution of organic material observed on Ceres. The Dawn 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 evidence has raised new questions about the origin and preservation of this material, especially when considering its high estimated abundance and the mineralogical context (Fig 1).

With this project, we intend to study, through dedicated experiments, the interaction between minerals, water, and organic material in laboratory simulating the environmental conditions of Ceres. Making a synergistic use of complementary and indispensable skills present within INAF laboratories we are investigating a complex issue such as that concerning the origin and preservation of organic molecules on planetary surfaces. Within INAF, complementary and unique realities coexist which, thanks to joint and coordinated work, can give a new interpretation of the physical-chemical processes active on Ceres.

Results: In this study, we mixed organic material with a mixture of minerals that can be 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).

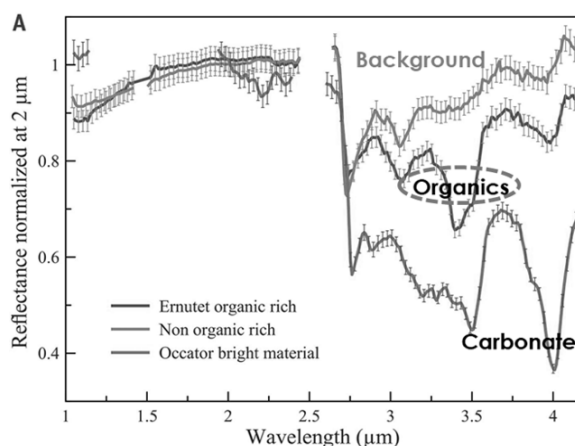


Fig. 1 Ceres spectra of the organic-rich area in Ernutet crater (label “Organics”); of a background organic-poor area from a region southeast of Ernutet (label “Background”); and Occator bright material (label “Carbonate”) [4].

Diffuse FTIR reflectance spectra were acquired in vacuum at 5×10^{-6} mbar using Bruker VERTEX v70 interferometer. Spectra of simulant are resembling the Ceres surface composition (Fig. 2). We irradiated the sample in the vacuum chamber at room temperature using an UV-enhanced Newport Xenon lamp (wavelength range 185 - 2000 nm) to simulate the solar radiation. The radiation emitted by the lamp was collimated through an optical fiber directly to the sample. 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. 3 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.

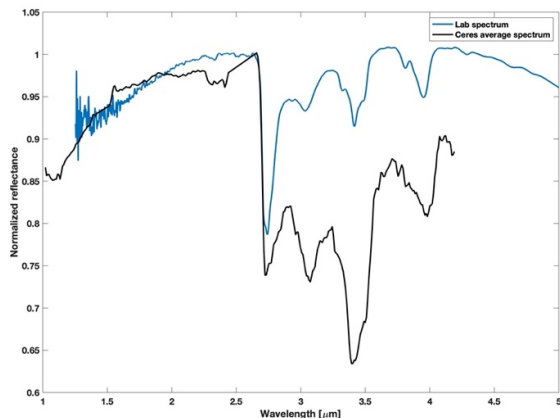


Fig. 2 Average spectrum of Ceres Ernutet organic-rich areas (black) compared to laboratory simulant (blue). Spectra are normalized at 2.6 μm .

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. The degradation cross section of the aliphatic band at 3.4 μm , which is the probability that chemical bonds are broken by UV radiation was $5.85 \times 10^{-21} \text{ cm}^2$.

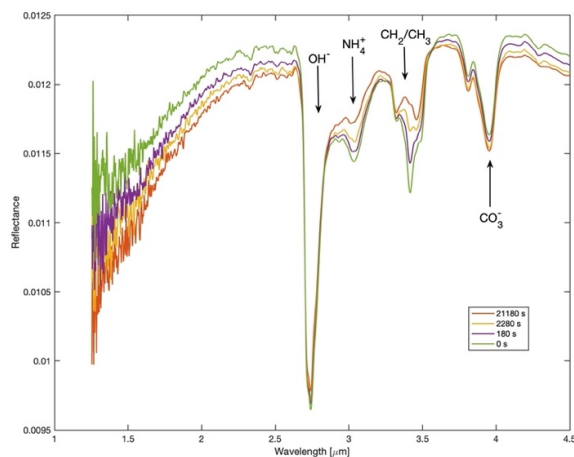


Fig. 3 Diffuse reflectance spectra of the simulant as prepared (0 s) and after UV irradiation at 180, 2280, and 21180 s

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

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. Further experiments are planned to investigate the photodegradation processing at cryogenic temperatures.

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. In fact, the half-lifetime obtained in this work is too short compared the resurfacing processes that are estimated to act on Ceres in millions of years. However, the photodegradation act 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 that acts on a much shorter time scale than the geological one. Diffusion of organic matter and ammonia towards the surface coming from the deeper unprocessed layers of the order of meters cannot be excluded. This could occur by thermal conductivity due to diurnal and annual solar irradiation. This is a first result of a broader work that we are conducting within various INAF institutes with the aim to understand the effects of irradiation processes with UV, ions and hydrogen atoms on Ceres surface.

Acknowledgements: This work is supported by INAF Main Stream program, grant "Evolution and alteration of organic material on Ceres".

References:

- [1] De Sanctis et al., 2016, Nature 536, 54–57
- [2] Marchi et al., 2019, Nature Astr. 3, 140–145
- [3] De Sanctis et al., 2011, Space Science Reviews 163, 329–369.
- [4] De Sanctis et al., 2017, Science 355, 719–722
- [5] Pieters et al., 2018, Meteoritics and Planetary Science 53 (9), 1983–1998
- [6] De Sanctis et al., 2019, MNRAS 482 (2), 2407–2421