DEGRADATION OF ORGANIC MATTER ON CERES: RESULTS FROM LABORATORY EXPERIMENTS ON IRRADIATED SAMPLES. M.C. De Sanctis[1], G.A. Baratta[2], J.R. Brucato[3], S. De Angelis[1], Ferrari M.[1], D. Fulvio[4], M. Germanà[2], V. Mennella[4], M.E. Palumbo[2], S. Pagnoscin[3,5], G. Poggiali[3,6], C. Popa[4], C. Scirè[2], G. Strazzulla[2], R.G. Urso[2]
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Introduction: Ceres is the largest object in the Solar System asteroid belt and experienced extensive water-related processes with a complex geological and chemical history [1]. Its surface is characterized by dark materials, phyllosilicates, ammonium-bearing minerals, carbonates, water ice and salts. Aliphatic organics have been detected by Dawn mission [2-4] in addition to a global presence of carbon [5] (Fig.1). The origin, evolution, and persistence of the organic matter on Ceres is a matter of debate, given the strong spectral signature observed, corresponding to a "large quantity of aliphatic material (up to 10% according to some modelling [4]) mixed with phyllosilicates, carbonates, and salts.

Hence, in this study we conducted a series of laboratory measurements of physicochemical interactions of organic material and other minerals present on Ceres, investigating the transformations induced by ultraviolet radiation, neutral atoms and fast ions in conditions that simulate the environment of Ceres.

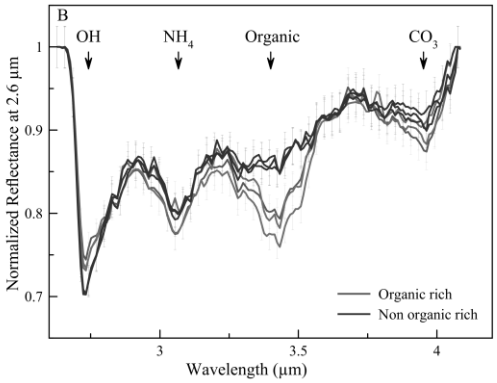

Fig.1 Example of organic rich area vs background material on Ceres from VIR on Dawn mission.

Laboratory studies: We prepared mixtures of materials resembling the Ceres surface composition using an Mg-phyllosilicate, a carbonate, a darkening agent, and an NH_4-bearing clay. The latter was produced following the procedure described by [6]. Spectral proprieties of the ammoniated clays were fully characterized in previous works [6,7]. In this work, we added aliphatic organic molecules to the mixture to understand how organic molecules degrade on Ceres. We investigated how aliphatic molecules degrade by energetic processing with fast ions (keV-MeV) and UV photons [8,9]. Moreover, the physico-chemical properties of the materials exposed to flux of neutral atoms were examined [10].

The project is carried out by several INAF institutes and laboratories. INAF-IAPS (Institute for Space Astrophysics and Planetology) is in charge of preparation of analogues mineral mixtures and comparison with observations. INAF-Astrophysical Observatory of Arcetri subsequently doped the mixture with several organics. They also investigated UV photostability in Ceres'conditions and the influence of temperature. INAF-Astronomical Observatory of Naples studied irradiation with atoms and temperature effect and INAF-Catania Astrophysical Observatory performed irradiation with fast ions. Finally, results of laboratory measurements will be compared with data obtained by VIR instrument on board Dawn mission.

Results: In this section we report the main results found after having irradiated the samples representative of the Ceres surface rich in aliphatic organics.

UV radiation: We mixed undecanoic acid (aliphatic organic) and Ceres analogue sample (ratio 1:80 organic:mineral). We irradiated the sample in the vacuum chamber at room temperature using an UV-enhanced Xenon lamp to simulate the solar radiation. The simulant was irradiated at increasing fluence up to irradiation time of about 7 hours and the organic degradation process was monitored in real time with diffuse FTIR spectroscopy. In Fig.2, 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 and aliphatic CH_2/CH_3 at 3.4 μm is decreasing as the irradiation fluence increases with time. 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 5.85×10^{-21} cm^2. 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.

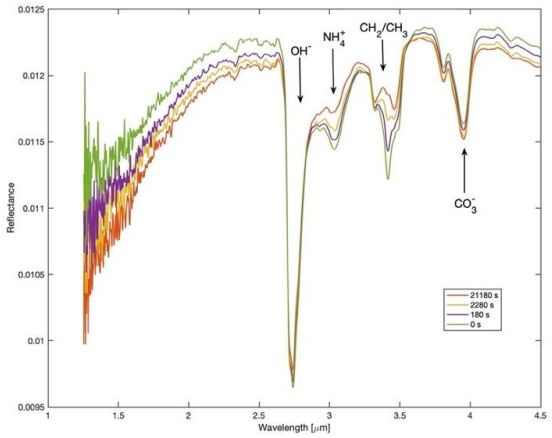

Figure 2: Diffuse reflectance spectra of the simulant as prepared (0 s) and after UV irradiation at 180, 2280, and 21180 s

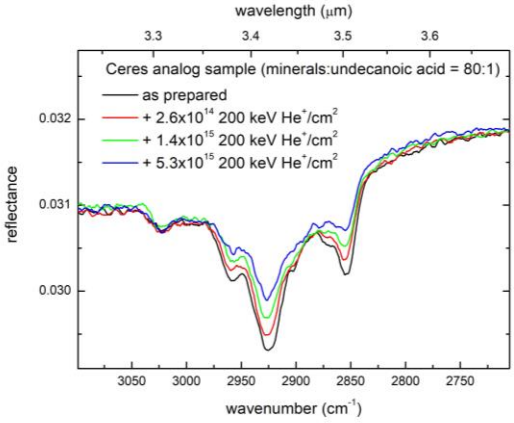

Figure 3: Diffuse IR reflectance spectra of Ceres analog sample after irradiation with 200 keV He+ ions at room temperature.

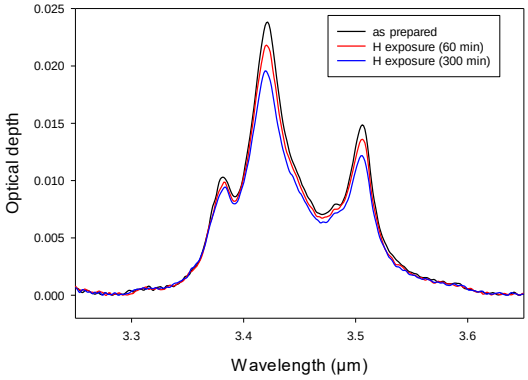

Figure 4: Transmission spectra of the simulant aliphatic bands as prepared (To) and after 60 and 300 min of atomic H exposure.

Energetic ions: At INAF-Catania three pellet samples made of a mixture of minerals and undecanoic acid (80:1) have been irradiated under vacuum at room temperature by 200 keV H+, He+, and N+ ions, respectively. At selected step of irradiation, the samples have been analyzed by diffuse reflectance IR spectroscopy at room conditions using a FTIR Bruker (Vertex 70) spectrometer. The spectra show that the intensity of the 3.4 μm feature decreases as the irradiation fluence (ions/cm^2) increases (Fig. 3). For each experiment, the values of the area of the 3.4 μm feature have been plotted versus the irradiation dose (eV/16u) and were fit by an exponential curve. For the three experiments considered the value of the destruction cross section of the 3.4 μm feature is σ[3.4μm] = 0.04 ± 0.01 16u/eV.

Atomic H treatment: The Ceres analogue was exposed at room temperature to a beam of atomic H with a Maxwellian distribution of temperature at 300 K [11]. The beam was produced by microwave excited dissociation of molecular hydrogen. The sample was exposed to increasing fluence of atomic H and corresponding spectral changes were studied in-situ by FTIR transmission spectroscopy. In Fig. 4, we report the evolution of the organic bands due to C-H bond stretching. The decrease of the band intensity with the atomic H exposure indicates an abstraction of H from the simulant. From the trend of the integrated optical depth as a function of time, a H abstraction rate of 1.4×10-4 s-1 was obtained. Considering the value of the H atomic flux in the experiment the rate corresponds to a cross-section of 8.3×10-19 cm^2. Assuming undecanoic acid as the representative organic material on Ceres' surface, the result of this experiment suggests that atomic hydrogen also contributes to the degradation of organics on Ceres.

Conclusions: The experiments indicate that organic matter should degrade on Ceres, given the radiation environment of the body. However, the signature of the aliphatic organic on Ceres is well detectable, suggesting that the organic matter is extremely recent or is preserved/re-constituted by unidentified processes.

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References: [1] De Sanctis et al., 2016, Nature 536, 54; [2] De Sanctis et al., 2011, Space Sci. Rev.163, 329; [3] De Sanctis et al.,2017, Science, 355, 719;[4] De Sanctis et al., 2019, MNRAS 482; [5] Marchi et al., Nature Astr., 2019. [6] Ferrari et al.,2018, Icarus, 321;[7] De Angelis et al., 2021,JGR, 126;[8] Baratta et al. 2002, A&A, 384, 343-349;[9] Brucato et al. 2006, A&A, 455, 395-399 [10] Mennella et al. 2003, ApJ, 587, 727-738.