

INVESTIGATING THE 1- μm FEATURE IN THE REFINED AVERAGE SPECTRUM OF CERES

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Introduction: The Dawn NASA mission represented a breakthrough for the investigation of Ceres. Dawn's payload included the Visual (0.25–1 μm) and InfraRed (1–5 μm) mapping spectrometer (VIR) [1].

The first findings from the VIR-IR channel have shown Ceres' average surface is composed of a dark component (carbon and/or magnetite); Mg-carbonates such as dolomite, confirming some of the previous studies from ground-based observations [2]; the detection of a strong absorption at 2.7 μm was assigned to Mg-phyllsilicates such as antigorite; the 3.06- μm absorption was attributed to NH_4 -phyllsilicates [3].

The elemental data from the Gamma Ray and Neutron Detector (GRaND) instrument onboard Dawn [4] provided additional constraints on the abundance of C, H, K, and Fe, [5,6], establishing that the dark material that makes up most of Ceres' surface should resemble carbonaceous chondrite material [7,8].

The recent improvement in the VIR-VIS channel calibration [9,10] allows taking advantage of the full VIS spectral range, including the shorter wavelengths down to 0.25 μm , previously affected by calibration residuals. Following [9] and [10], IR channel calibration was also refined [11]. The combined VIR data of the VIS and IR channels have shown a clear absorption at 1 μm confirming previous ground observations [2]. The interpretation of such feature, in the context of the average spectrum of Ceres, provides new constraints on Ceres mineralogy.

Refined calibration: The calibrated dataset, used to perform the average Ceres spectrum, was refined with the procedure described in [12] and [9], to correct for the odd-even effect and systematic artifacts [12], and spurious spectral variations due to the detector temperature in the VIS channel [10]. Data were then photometrically corrected to standard viewing geometry (incidence angle = 30°, emission angle = 0°, phase angle = 30°) by means of Hapke modeling [13] according to the photometric parameters derived by [14]. Moreover, a correction factor, derived from ground-based observations, was applied to remove fictitious slopes on VIS-IR spectra. These correction factors were first derived by [12]. In the present work, we used the updated version for the VIS and IR channels derived by [10], and [11].

Merging the global average spectrum obtained in the VIS and IR channels, we obtained a single global

average spectrum of Ceres in the range of 0.25–5.0 μm . Then, we removed the thermal emission affecting the spectrum longward of 3.5 μm , as discussed in [11]. The resulting spectrum is shown in Figure 1.

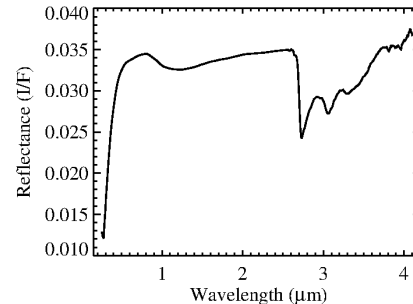


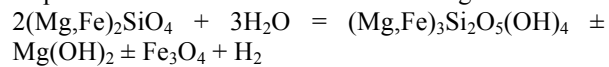
Fig.1 Refined average spectrum of Ceres (VIS-IR).

The 1- μm band: Ceres' average spectrum (characterized by a shallow and broad band centered at about 1.2 μm). This spectral feature can usually be found in the spectra of different types of carbonaceous chondrites, (e.g., Ivuna CI, MAC87300 C2-ung, and DAV92300 CK4) (Fig. 2).

Previous studies [15,16,17] have shown that these carbonaceous chondrites are characterized by the presence of mafic silicates (e.g., olivine, pyroxene, Fe/Mg-phyllsilicates) and magnetite, which are often the main constituents of their fine-grained matrix along with low-crystallinity materials. In the VIS-NIR range, the main bands of mafic silicates are between 0.9 and 1.1 μm . These absorption features are caused by Fe^{2+} , whose coordination within the crystalline structure determines the position of the bands. Ferrous oxides, such as magnetite, show a very shallow absorption in the VIS-NIR range. Iron-bearing carbonates also have a broad band close to 1 μm but also show several other vibrational bands between 1.7 and 2.6 μm , which allow them to be distinguished with certainty from silicates and oxides. The band near 1 μm linked to the presence of the iron is evident even in spectra of the Fe-bearing low-crystalline material like tektites and volcanic glasses (Fig. 3). In this case, the 1 μm -band depth depends on the amount of iron in octahedral coordination [18].

Discussion: From a mineralogical point of view, the possible presence of magnetite on Ceres' surface as one of the agents responsible for the low albedo of the dwarf planet, can be supported by the mineral assemblage as detected by the VIR instrument, and is predicted by geochemical modeling [19,20]. In fact,

the simultaneous presence of Mg-serpentine could suggest that most of the magnetite may have formed during the serpentinization process following a serpentinization reaction like the following:



which starting from an (Mg/Fe) olivine, returns (Mg/Fe) serpentine, and a variable amount of brucite and magnetite depending on the Fe-Mg lattice diffusion in olivine and other specific parameters [21]. The simultaneous presence of magnetite and serpentine could cause an attenuation of the band depth of any residual olivine. In fact, olivine on Ceres' surface could be present as a mineral of the partially serpentinized primary crust. The presence of olivine was also identified in by heating serpentine samples in laboratory experiments [22]. These demonstrate that the incipient re-crystallization of "prograde olivine" changes the spectral properties introducing a peak close to 0.8 μm , which resembles that observed in Ceres' average spectrum. This does not prove that Ceres has undergone a high-temperature thermal process, but it may be an indication of the presence of olivine that has survived the serpentinization. During the serpentinization process, the olivine dissolution is also correlated with the formation of low-crystalline phases [23] that represent metastable precursors to crystalline serpentine. Amorphous and nanocrystalline material was also found in the matrix of several carbonaceous chondrites [24]. Spectral data obtained on mixtures of crystalline olivine and iron-bearing glass indicates that, by increasing the content of the amorphous component, the band at 1 μm becomes shallower [25]. A similar effect can be obtained also adding a dark material like carbon black or magnetite to a Fe^{2+} bearing mineral.

Further complication in the interpretation of the 1- μm band in the average spectrum of Ceres can be introduced by the presence of a fine-grained coating of iron-bearing material that can add spectral features [26] consistent with the VIR data.

Conclusions: Magnetite, unaltered olivine, and/or iron-bearing low-crystallinity phases can all explain the 1- μm band in the average spectrum of Ceres. Further spectral modelling and laboratory activities will enable a better understanding of the 1- μm feature.

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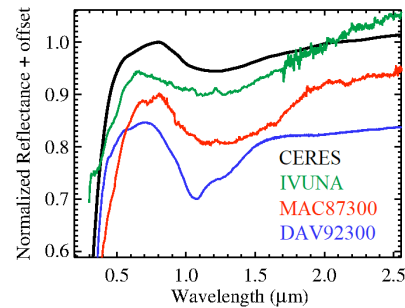


Fig.2 Ceres average reflectance spectrum (black) compared with reflectance spectra of different types of carbonaceous chondrites.

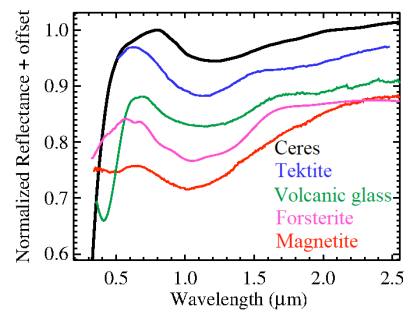


Fig.3 Ceres average reflectance spectrum (black) compared with reflectance spectra of different types of natural iron-bearing glasses (volcanic glass and tektite) and minerals.

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