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Ceres VIS-IR average spectrum from VIR/Dawn suggests pristine and altered silicates, within volatile and carbon chemistry

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Abstract

In this work, we revise the in-flight calibration of both visible and infrared channels of VIR spectrometer onboard Dawn. The resulting average Ceres spectrum is modeled with Hapke radiative transfer model to infer the composition. For the first time we attempt the modeling of the visible part of Ceres' spectrum as measured by VIR in addition to the IR spectral range. Here we confirm previous results on an aqueously altered carbon-rich surface. Moreover, we interpret the visible spectral shape as an indication of a transition phase between primary and altered silicates.

1. Introduction

The infrared average spectrum of Ceres as seen by VIR onboard Dawn [1] has already been the subject of previous works which derived an aqueously altered, volatile rich, and carbon-rich composition [2, 3]. Those results have taken advantage of an inflight calibration of the infrared channel [4] to match the ground observation [5]. Here we refined this calibration on the base of the observation of the star Arcturus by VIR, which represents an independent and absolute reference. Moreover, we add the spectral range covered by the visible channel, taking advantage of a new correction for instrumental effects [6].

2. Calibration refinement

Both VIR-Dawn and VIMS-Cassini observed stars during the cruise phase of their missions. This gives the possibility to compare the flux observed by both instruments to perform an inter-calibration. In particular, we compared four acquisitions of Arcturus performed by VIR-IR with six observations performed by VIMS onboard Cassini [7]. Given its long calibration history, VIMS calibration can be considered a reliable reference. The ratio of the average fluxes observed by the two instruments provides a correction factor as a function of the wavelength, which can be applied over the whole VIR dataset. The same approach has been used by [6] to calibrate the visible channel, using as reference ground observations of the same star.

The average spectrum of Ceres has been simulated according to the photometric parameters derived by [8] at the same viewing geometry of ground observations [5] and applying the derived correction factors. By comparing the VIR spectrum with the ground observation, we obtained a further refinement of the calibration. This was needed to ensure a correct bridging between the two channels (VIS and IR), and to correctly calibrate the VIS detector at longer wavelengths (0.95 – 1.1 µm), whose low sensitivity prevents a calibration with star observations.

3. Spectral modelling

The full disk reflectance of Ceres in the spectral range 0.4 – 4.1 µm as seen by VIR (according to [8] and calibration refinements) have been used as reference to perform spectral modeling with Hapke theory [9]. The simulated composition makes use of endmembers in intimate mixture, similarly to [2] and [3], to fit the IR features at 2.72, 3.06, and 3.95 µm, respectively attributed to Mg-phyllosilicates, NH_4-phyllosilicates and Mg-carbonates. Their abundances and regolith grain size are free parameters in the fitting procedure. Table 1 shows the endmembers used, and the respective abundance retrieved. In order to simplify the model, we assume all endmembers with the same grain size. In this case, the abundances retrieved represent a volume fraction of the endmembers. A complete description of the fitting procedure is described in [10] to which we refer for further details.

4. Results and discussion

The best fit requires an abundant dark and neutral phase in order to match the spectrum of Ceres. A possible analogue of such phase would be represented by amorphous carbon [11]. This strengthen the possibility of a widespread presence of organic material on the surface of Ceres, as suggested by [3]. However, any other neutral, reddish and dark phase could be suitable to produce a good fit.

The novel introduction of the visible spectral range adds new constrains in the fitting procedure: the steep slope in the 0.4 – 0.6 µm range resembles that of spectra of carbonaceous chondrites, showing that a similar material is likely present on the surface as a result of meteoritic bombardment [3]. The small absorption centred at 0.72 µm, also present on CM chondrite spectra [12], would be attributed to Fe^{3+}. However, the lack of such feature on ground observations would cast doubt on its reliability.

The broad absorption centred at 1.2 µm, has been attributed to Fe^{2+}, in dark phases like meteorite MAC87300 and/or magnetite, as suggested by [13]. We produced good fit with these materials, confirming such possible solutions. However, mixing with high concentration of Fe would not match elemental composition derived by GRAND [3]. We obtained an alternative and significantly better fit, including a spectrum of serpentine-lizardite heated in vacuum at 600 °C [14] (see Fig 1). The emergence of a blue slope longward of 0.77 µm at such high temperature can be due to dehydroxilation and oxidation of the silicate, which indicate a transition phase between serpentine and olivine in the laboratory sample. This would suggest that, on Ceres, Mg-serpentine is an alteration product of primary phases like olivine, pyroxene, and low-crystallinity Mg- and Fe-silicates. A few percentages of these pristine silicates could have remained unaltered on Ceres surface.

Table 1: Endmembers and abundances retrieved.
Retrieved grain size: 280 µm.

Reference /Sample ID-RELAB	Endmember	Abundance (%)
[11]	Amorphous Carbon	40
[12]	Carb. Chondrite (CM)	29
[14] / LZ-TXH-006	Heated Lizardite*	12
JB-JLB-189	NH_4-Montmorillonite	8
AA-A1S-002	NH_4-Annite	5
Querry M. R., 1985	Magnetite	3
CB-EAC-003	Dolomite	3

* heated in vacuum at 600°C for one week. The spectrum could indicate a transition phase between serpentine and olivine

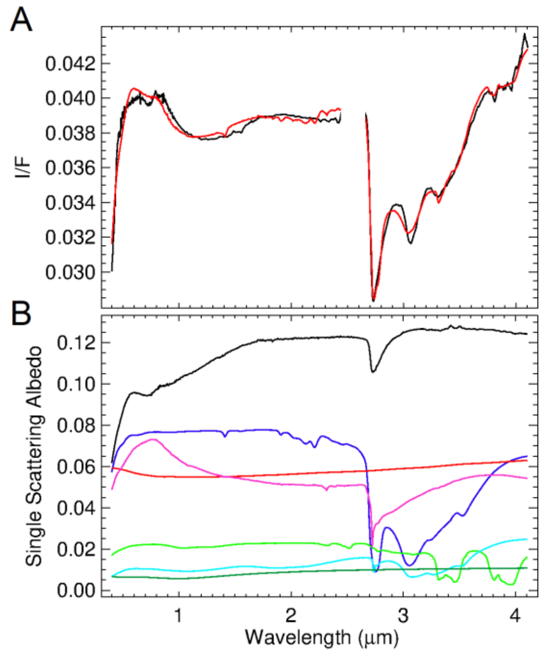

Figure 1. Panel A: VIS-IR average Ceres spectrum (black) and best fit (red). Panel B: albedo of endmembers scaled for the abundance retrieved: amorphous carbon (red), CM (black), heated lizardite (pink), NH_4-mont. (blue), dolomite (light green), magnetite (dark green), NH_4-annite (cyan).

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