

Low-temperature reflectance spectra of brucite and the primitive surface of 1-Ceres?



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ARTICLE INFO

Article history:

Received 23 March 2015

Revised 27 May 2015

Accepted 28 May 2015

Available online 3 June 2015

Keywords:

Mars, surface

Meteorites

Mineralogy

Spectroscopy

ABSTRACT

The surface of Ceres, the most massive asteroid, presents a peculiar absorption band at 3.06 μm . This feature has been attributed to a number of candidate phases, including a magnesium hydroxide, brucite ($\text{Mg}(\text{OH})_2$). In order to gain insights into this possibility we have investigated the evolution of brucite reflectance spectrum under decreasing temperature (down to 93 K). Following early observation of brucite infrared spectra in transmission, a strong evolution of the reflectance spectrum of brucite is found under decreasing temperature. Small shifts of the band positions are found in particular at 1.36 and 1.39 μm , while the most important evolution is a decrease in intensity of the features at 2.82 and 3.06 μm . These observations can be seen in the light of the nature of these modes, which are transitions from excited states (difference bands) that are less populated under low-temperature. Such results provide a major test for the presence of brucite on Ceres from forthcoming DAWN observations, by searching for a possible evolution of the band with local time and then surface temperature. Based on the fact that the equivalent summation bands are not observed in Ceres spectra, brucite is not favored as the major constituent to the 3.06 μm feature. The possibility that this feature rather corresponds to ammoniated minerals (phyllosilicates or salts) is discussed.

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1. Introduction

As seen from the ground, the population of small bodies is spectroscopically diverse (DeMeo and Carry, 2014). This is particularly true for asteroids, whose telescopic observations suggest a major compositional diversity, which echoes the menagerie of meteorite types that are found on Earth (Brearley and Jones, n.d.). However, the exact connection between specific meteorite groups and asteroid families is still debated, and so is the representativeness of meteorite types with respect to asteroid classes. In the case of S-type asteroids, meteorites (ordinary chondrites) with similar reflectance spectra are commonly found on Earth (Gaffey et al., 2002; Vernazza et al., 2008) and the link between these two groups is now well established. Some of the spectral differences between ordinary chondrite and S-type spectra is most likely due to space weathering processes (Brunetto et al., 2006; Clark et al., 2002; Strazzulla et al., 2005; Vernazza et al., 2009, 2008) and the success of the Hayabusa sample return mission has provided the definite evidence for the link between S-types and ordinary chondrites (Nakamura et al., 2011).

In the case of C-type asteroids, absorption features are weak and often absent in their visible and near-infrared (VNIR) spectra. Space weathering effects on these objects are more moderate (Brunetto et al., 2014). Overall, the lack of absorption features in the VNIR makes the connection with meteorites and/or minerals more subtle and debatable. The use of the 3- μm region has shown great success in this case (Rivkin et al., 2002), where fundamental and harmonic vibrations of water and hydroxyl groups are located, and that were observed to be widespread among C-types. Four major classes of absorption features have been described without at present specific meteorite analogs (Takir and Emery, 2012), except in the case of a “Pallas-type” feature which resembles laboratory spectra of hydrothermally altered carbonaceous chondrites.

Among the shapes of the 3- μm features without meteorite analogs identified at present, there is the one measured for 1-Ceres (Takir and Emery, 2012). Ceres is the largest asteroid, it represents about a third of the mass of the main belt, and it does not seem to have an asteroid family (Rivkin et al., 2014). The spectrum of Ceres around 3 μm shows three distinct absorptions, a relatively narrow absorption at 3.06 μm , and two other features around 3.25–3.60 μm and 3.70–4.00 μm . This “feature-rich” spectrum

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has been interpreted in a variety of ways, and the most recent suggestion, which generates an excellent fit from 2.80 to 4.00 μm , is a mixture of carbonates and brucite (Milliken and Rivkin, 2009). Such a mineral assemblage has not been observed in carbonaceous chondrites and requires very specific environmental conditions including a high water–rock ratio (Zolotov, 2014). In this paper, in order to gain insight into the possibility that brucite occurs at the surface of Ceres, which has strong implications for Ceres external cycles, we measured the reflectance spectra of brucite under temperature relevant for Ceres surface, i.e. down to 93 K.

2. Sample and methods

All spectra were measured at the Institut de Planétologie et d'Astrophysique de Grenoble (IPAG) with a home made spectro-gonio-radiometer (Brissaud et al., 2004). This instrument measures bidirectional reflectance spectra in the range 0.40–4.80 μm . Spectra were acquired from 0.50 to 4.00 μm using an incidence angle of 0° , and an emission angle of 20° , at a spectral sampling of 20 nm. Spectralon[®] and Infragold[®] (Labsphere Inc.) were used as references. Corrections were applied to take into account the standards' spectral behavior and photometry.

The spectro-gonio-radiometer was coupled with the CARBONIR environmental chamber (Grisolle et al., 2014; Philippe et al., 2014). This chamber is made of a large closed isothermal copper cell (diameter of 8 cm) inserted in a stainless steel chamber. The copper cell is cooled with an He-cryostat and optical access is permitted through sapphire windows. This setup enables measurement of reflectance spectra at temperatures down to 50 K. In order to ensure efficient thermal coupling of the sample, a few mbar (monitored during the experiment) of air were kept in the cell. The cell temperature is monitored during the experiment and the error on sample temperature is estimated to be of the order of 1 K.

In order to minimize undesired water vapor absorption and to improve our SNR in the infrared, the whole setup (CARBONIR + spectro-gonio-radiometer) was kept within a cold chamber at 265 K.

About 5 g of natural brucite ($\text{Mg}(\text{OH})_2$) from Texas, Lancaster Co. PA, were ground in an agate mortar. The sample was ground vigorously to achieve a fine grain size ($<50 \mu\text{m}$) in order to minimize possible crystallographic orientation effects. Indeed, transmission spectra measured on brucite shows a profound dependence on crystallographic orientation (Dawson et al., 1973). The powder was gently poured into the sample holder, and the surface was not compacted.

3. Results

At room temperature, the reflectance spectrum of brucite shows numerous absorption features between 0.50 μm ($20,000 \text{ cm}^{-1}$) and 4.00 μm (2500 cm^{-1}) (Fig. 1). A triplet of relatively narrow absorptions is found at 1.30, 1.36 and 1.395 μm , while at higher wavelength features occur around 2.10 μm , 2.47 μm , 2.70 μm , 2.84 and 3.06 μm (Fig. 1). As will be discussed later all these absorptions are likely related to $-\text{OH}$ fundamental stretching, or its combination with lattice modes. Possible feature observed above 3.20 μm are explained by the presence of carbonates, which on Earth can form very rapidly by gas–solid reaction between atmospheric CO_2 and brucite surfaces (Garenne et al., 2014).

With decreasing temperature, a significant evolution is found in the reflectance spectrum of brucite (Fig. 1). In the case of the triplet around $\sim 1.4 \mu\text{m}$, the relative intensity of the features at 1.36 and 1.39 μm is changed (the 1.36 μm band increasing while the 1.39 μm band decreases). This is possibly related to a modification of the position of the modes.

Changes are also observed at higher wavelength. At 2.10 μm , 2.48 and 2.70 μm , with decreasing temperature, subtle changes appear to occur in the shape of these bands attributable to narrowing. The most visible change in the reflectance spectra of brucite observed under low-T is a modification of the 3.06 μm band. The band broadens under low-T and its depth decreases by about a factor of two. The evolution of this feature is shown in more details in Fig. 1b, where a linear baseline has been subtracted between the two local reflectance maxima surrounding the band.

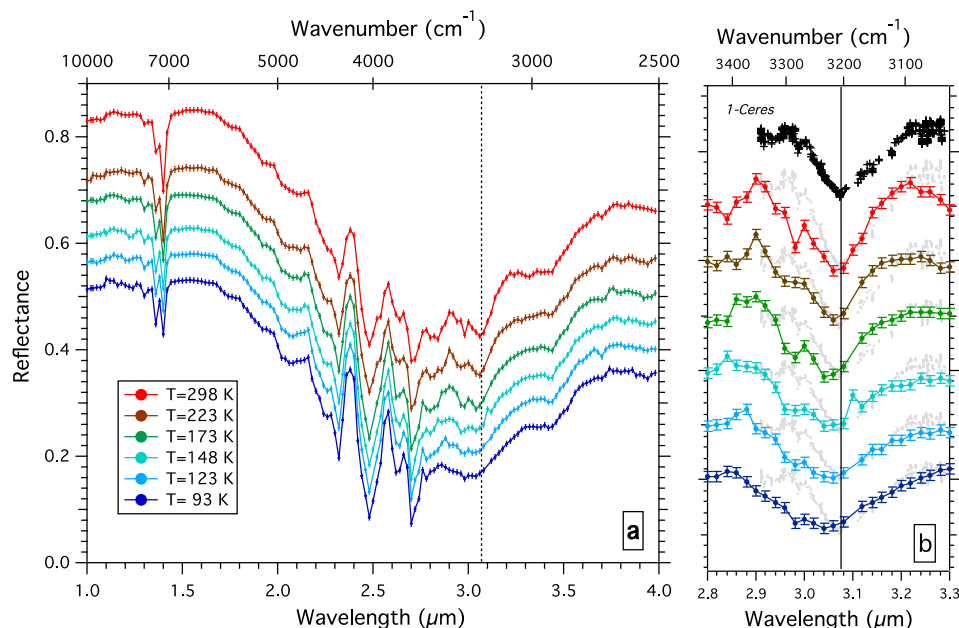


Fig. 1. Reflectance spectra of natural brucite ($\text{Mg}(\text{OH})_2$) measured under decreasing temperature. The left panel shows almost the full spectral range (1.00–4.00 μm) and individual spectra were offset for clarity. The right panel is a zoom on the 3.06 μm feature, and a linear baseline has been subtracted. The gray line in the right panel correspond to Ceres spectra digitized from Milliken and Rivkin (2009). The equilibrium temperature of Ceres is 164 K while the maximum temperature measured is 234 K (Saint-Pe et al., 1993).

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