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Reflectance spectra of primitive chondrites

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Abstract

We are studying a wide sample of pristine carbonaceous chondrites from the NASA Antarctic collection in order to get clues on the physico-chemical processes occurred in the parent bodies of these meteorites. We are obtaining laboratory reflectance spectra of different groups of carbonaceous chondrites, but here we focus in CM and CI chondrites. We discuss the main spectral features that can be used to identify primitive carbonaceous asteroids by remote sensing techniques. Two different spectrometers were used covering the entire 0.3 to 30 μm electromagnetic window. Only a handful of Near Earth Objects (NEOs) exhibit bands or features clearly associated with aqueous alteration. Among them are the target asteroids of Osiris Rex and Marco Polo-R missions.

1 Introduction

Parallel studies of mineralogy and reflectance spectra of meteorites have allowed the identification of the parent bodies of several meteorite groups [3]. Distinctive mineralogy of some asteroids, differentiated or undifferentiated, can be used to infer clues on the complex collisional and dynamical history of asteroids [9]. The relevance of obtaining reflectance spectra of asteroids was the identification of the Howardite, Eucrite, and Diogenite (HED) suite of achondrites as samples delivered from asteroid 4 Vesta. The characteristic olivine and pyroxene absorption bands of this group of achondrites was essential to establish the link (for a review see e.g. [13]). To identify other asteroidal candidates as source of terrestrial meteorites has remained elusive due to several factors. First one is related with the intrinsic spectral diversity of asteroid surfaces. Space weathering is the second negative factor because asteroidal surfaces are subjected to cosmic rays, and meteoroid bombardment that cause surface gardening and changes in their reflectance patterns that are in general bad constrained. Finally, asteroid spectra taken by remote techniques are taken in non-ideal observing circumstances, subjected to geometrical and phase angle effects that make absolute calibration not always feasible. Due to all these circumstances, meteorite spectra obtained in laboratories might differ significantly from the spectral appearance of their respective parent asteroids, increasing our puzzle [3]. Despite the intrinsic problems previously mentioned, a significant progress in asteroid taxonomy has been achieved by comparing meteorite and asteroidal spectra [4, 5, 12, 6]. Meteorite spectra obtained in terrestrial laboratories allow to identify diverse bands and reflective patterns also noticed in asteroidal spectra.

Antarctic collections are a scientific opportunity as they offer direct access to scarcely represented chondrite groups, or even ungrouped meteorites that could be sampling pristine asteroids or even comets. Including these in our current meteorite studies could help to increase our general knowledge on the reflective and thermal properties of dark and primitive objects. It is important to remark that some of these minor bodies are future targets of space based missions like e.g. Osiris Rex or Marco Polo-R [10, 1]. We have already said that asteroid taxonomy is complex and doesn't allow identifying the source of most of the different meteorite groups. In the case of primitive meteorites the scenario is still more complex. Due to this, we have been working in the context of Marco Polo-R Space Weathering Group. In the framework of this proposed ESA mission we are obtaining a complete meteorite spectra catalogue of pristine chondrites inside a wide wavelength range from 0.2 to about 30 μm. We have recently completed a 2 years project to identify the main spectral feature in such window for a representative number of pristine chondrites from the NASA Antarctic collection [18]. Our final goal is developing a database, and creating new software of general use.

Asteroids of the C-class are mostly characterized by their low albedos, and flatten and feature-poor spectra [8, 7]. The C class was first temptatively associated with the CI and CM groups of carbonaceous chondrites (hereafter CCs) [19]. Later on, some researchers noticed the presence of water absorption features in about half of the C complex asteroids, particularly at 0.7 and 3 μm [11, 19]. Here we basically introduce the reflectance spectra of pristine CI and CM chondrites. The specimens were selected to be among the most primitive groups of carbonaceous chondrites, and are sampling the materials available in the outer part of the planetary disk where ices and organic compounds were available at the time they accreted. CI and CM are rich in organic and opaque phases that make their parent asteroids the darkest objects in the solar system.

2 Experimental procedure and instruments

Several sections and chips of primitive carbonaceous chondrites were chosen from the NASA Antarctic collection and other from fresh available falls. The meteorites selected for this preliminary study are listed in Table 1. The UV to NIR reflectance spectra were obtained using a Shimadzu UV3600 UV-Vis-NIR spectrometer. This instrument allows the measurement of the transmission, absorbance and reflectance spectra of powder, solid, or liquid samples. The standard stage for the spectrometer is an integrating Sphere (ISR) with a working range of 0.28 to 2.60 μm. The spectrometer uses multiple lamps, detectors and diffraction grates to work over a wide range of wavelengths. For calibration a standard baseline was created using a conventional $BaSO_4$ substrate that provided $\sim$ 100% reflectance signal better than 1 σ over the entire electromagnetic spectrum. The sampled area was a slot of $\sim$ 2$\times$1 cm^2, that was smaller than the common size of the analyzed samples.

To obtain the IR spectra, the received chips of each meteorite sample were grinded using an agate mortar. Few minutes after the samples were transformed in powder were placed in between a diamond detector of the Smart Orbit ATR (Attenuated Total Reflectance) IR spectrometer. The ATR spectrometer is ideal for the analysis of hard materials of very different nature, but particularly meteorites because it is inert and extremely strong to deal with tough chondritic materials (e.g. metal grains or refractory inclusions). At the same time, this diamond-based detector has a wide spectral range and good depth of penetration, which makes it a good choice for meteoritic samples. This spectrometer provides high resolution internal reflection spectra of meteorite powders following standard procedures [18]

Table 1: CM and CI chondrites selected for this work

Meteorite name	Chondrite group	Weathering degree	Spectra obtained
Cold Bokkeveld	CM2	A	IR
LEW 87148	CM2	Ae	IR
MET 01070	CM1	Be	UV-NIR+IR
MIL 07689	CM1	C	UV-NIR+IR
Murchison	CM2	A	UV-NIR+IR
Murray	CM2	A	IR
Orgueil	CI1	B	IR
QUE 97990	CM2	Be	UV-NIR+IR
QUE 99355	CM2	B	UV-NIR+IR
SCO 06043	CM1	B	UV-NIR+IR

3 Results and discussion

The CM and CI groups of carbonaceous chondrites studied here are coming from transitional bodies (comets/asteroids) that have suffered more pervasive aqueous alteration [20, 2, 15]. The reflectance spectra of CM chondrites discussed here reflect a significant diversity as consequence of different degrees of aqueous alteration in their parent asteroid [16, 14]. Quite limited data is available in the literature for spectral regions below 0.4 μm and over 1.4 μm, although the RELAB comprehensive database sometimes reaches 2.5 μm. Our data extends this window until 0.18 μm in the lower limit and to 2.6 μm in the upper one. This is particularly interesting as absolute reflectivity measurements in those windows are rare. We have found e.g. that below 0.4 μm the samples reflectivity tends to converge into a 5 to 10% range. Longward of 2.4 μm the reflectivity diversifies slightly over 10%.

Polished sections of the selected meteorites were measured using the UV-Vis-NIR spectrometer. The reflectance spectra were obtained at least two times to get an average value for the reflectance in each wavelength, and not significant differences were found either rotating the sections. The slot size was chosen to almost cover the size of the section, just following

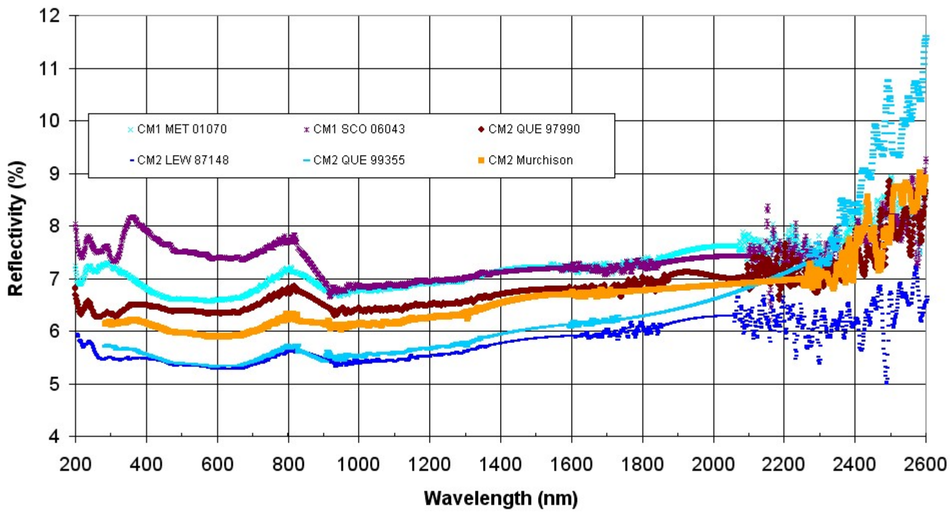

Figure 1: UV-NIR spectra of the CM carbonaceous chondrites discussed here

the same procedure explained in [17, 18]. Our meteorite reflectance measurements, performed at 8^o of phase angle, are close to the 0^o given by definition to estimate geometrical albedos of asteroids. It is also remarkable that our data in the UV-NIR range provides absolute reflectance values that can be used to compare with relative reflectance values of remote asteroids in selected bands. The reflectance curves of the different CC groups are shown in Fig. 1a,b where the different meteorites are labeled. The reflectance spectra of several analyzed CM chondrites are plotted in Figure 1. We remark the presence of the absorption band in the 0.65 μm region characteristic of CMs attributable to Fe^{3+}-Fe^{2+} charge transfers as also noted by [6]. It suggests that CMs are richer in Fe^{3+} phyllosilicates and aqueous alteration was more extended than in other groups with exception of CIs. Figure 1 also shows weak absorption bands in the $0.9 - 1.3$ μm region as found previously [6, 18]

The IR spectra of CM and CI chondrites are plotted in Fig. 2. Both groups exhibit a distinctive absorption band at 3.1 μm corresponding to OH bonded in minerals. The presence of phyllosilicates in these chondrites is also noticeable from the different depth of the $\sim$ 10.5 μm Al/Si-OH libration absorption band. A very broad band around 16.4 μm due to the Al-O and Si-O out of plane bonds is also shown for CI and CM spectra. In Orgueil, such band extends until 17.6 mm due to the possible action of other minerals perhaps as consequence of pervasive aqueous alteration. Meteorites arriving to Earth have presumably experienced quite complex and peculiar evolutionary histories, important compositional and mineralogical properties among the different specimens exist. To exemplify this, the CM chondrites parent asteroid could have suffered disruptive processes capable to deliver meter-sized meteoroids to Earth's vicinity. It is possible that the observed aqueous alteration degrees are consequence of different meteorites sampling different burial depths [14]. In any case, each chondrite from a same group could have suffered distinctive evolutionary histories forming part of fragments delivered in different ways to the near Earth region.

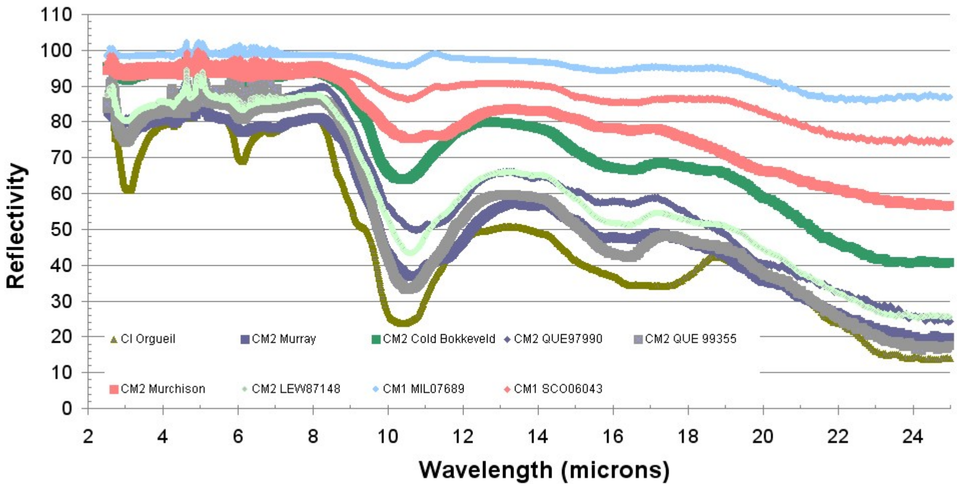

Figure 2: ATR IR spectra of the CM, and CI carbonaceous chondrites discussed here

4 Conclusions

We have presented the main reflectance properties of two of the most primitive groups of carbonaceous chondrites: CM and CI chondrites. They are very dark objects with typical reflectivity from UV to NIR below 10%. Their parent bodies should be among the darkest solar system objects known, and they are mostly composed by aqueously altered minerals. This is evidenced by distinctive bands and features in their reflectance spectra. A careful identification of the location and width of absorption bands (e.g. these placed around 3, 10, 17, and 20 mm) could be used to differentiate between carbonaceous asteroids and establishing more precise relationships between asteroid taxonomy and primitive meteorites arrived to Earth. Our main conclusion are:

1 UV to NIR spectra of pristine carbonaceous chondrites are extremely useful to identify the main patterns and absorption features that can be used to remotely characterize primitive asteroids. A complete spectral characterization from 0.2 to 2.6 μm provides distinctive features that can be used for such purpose.

2 High-resolution ATR IR spectra of CCs are complementary to provide a general assessment of the main mineral bands and organic bonds contained in the grinded powders. Some bands and features can be used to identify similar patterns in dark primitive asteroids at longer IR wavelengths.

3 The OH absorption band characteristic of water bounded into phyllosilicates is usually present in CM, and CI chondrites, but its relative depth is highly variable and probably consequence of different degrees of parent body aqueous alteration.

4 A careful identification of absorption features and their location and relative depth seems particularly useful for remote characterization of asteroids. Particularly the ma-

jor or minor presence of OH bands could be used to quantify the extent of aqueous alteration in targets selected for future spacecraft missions.

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