

## Matrix materials of carbonaceous chondrites: Characterization using synchrotron-based IR reflectance microspectroscopy

L. V. Moroz (1,2), M. Schmidt (3,4), U. Schade (3), and M. A. Ivanova (5)

(1) Institute of Planetology, University of Münster, Germany (Ljuba.Moroz@dlr.de/Fax:+49-30-67055303) (2) German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany, (3) BESSY GmbH, Berlin, Germany, (4) MPI for Colloids and Interfaces, Potsdam, (5) Vernadsky Institute, RAS, Moscow, Russia

### Introduction

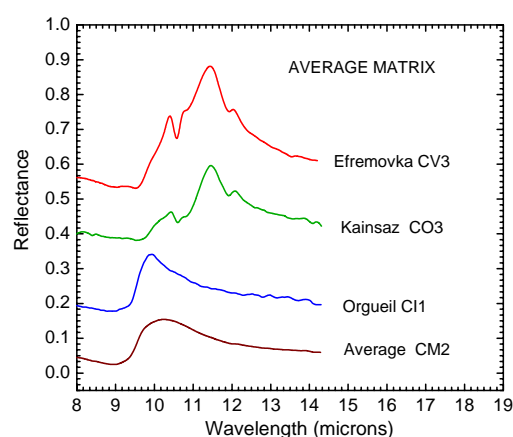
Synchrotron-based IR microspectroscopy allows the acquisition of IR spectra from extremely small samples. The use of a synchrotron IR source significantly increases the signal-to-noise ratio and lateral resolution compared to a conventional global source [1]. This technique has been used in transmission mode to acquire IR spectra of IDPs and meteorite components [e.g., 2, 3]. Here we demonstrate the diagnostic potential of reflectance IR microspectroscopy for nondestructive characterization of matrices of carbonaceous chondrites (CCs) *in situ* using conventional polished sections. This method is particularly useful for analysis of hydration states of the matrix materials [4].

### Experimental procedures and samples

Polished sections of Orgueil (CI1), Kainsaz (CO3), Efremovka (CV3), Mighei (CM2), Cold Bokkeveld (CM2), Murray (CM2), Isheyev (CH-CB<sub>b</sub>), metamorphosed carbonaceous chondrites (MCCs) Dhofar 225, Dhofar 735, and NWA 4757 were used in this study. The IRIS infrared beamline at the electron storage ring facility BESSY [5] is equipped with a Thermo Nicolet Continuum IR microscope coupled to a Nexus 870 FTIR spectrometer. We used an LN<sub>2</sub>-cooled HgCdTe (MCT) detector, a KBr beam splitter and a 32x Cassegrain objective with a numerical aperture of 0.65. We acquired reflectance spectra in the range between 1.4 and 14  $\mu\text{m}$ . The spectral resolution applied was 8  $\text{cm}^{-1}$ . We probed meteorite matrices with a spot size of 15 x 15  $\mu\text{m}^2$  and 20 x 20  $\mu\text{m}^2$ . To provide gold-plated surfaces for standard measurements, we deposited gold layers 1mm wide and 100 nm thick directly onto the samples. It is also possible to deposit gold onto a polished epoxy next to the polished meteorite surfaces.

### Results and Discussion

Two spectral regions are particularly useful for IR spectral characterization of matrix materials of carbonaceous chondrites. IR measurements between 2.5 and 3  $\mu\text{m}$  allow one to detect spectral signatures due to O-H vibrations in structural OH and/or bound H<sub>2</sub>O in hydrated minerals [6]. Synchrotron-based IR reflectance microspectroscopy in this spectral range has been applied by Moroz et al. [4] to detect hydrated phases in several non-metamorphosed and metamorphosed CM2 chondrites. It has been

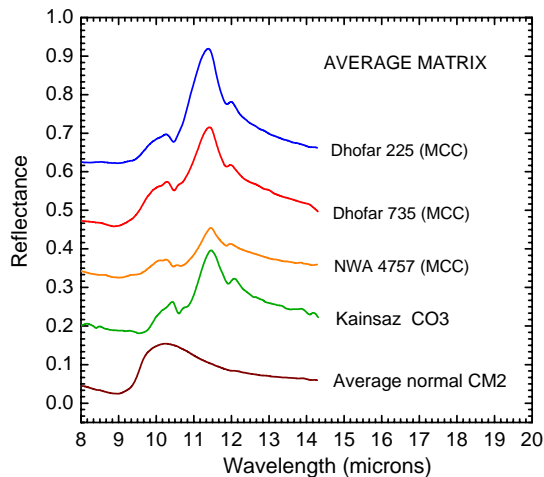


**Fig. 1** Average IR reflectance spectra of matrices of several CCs belonging to the CI1, CM2, CO3 and CV3 groups. Each spectrum is offset for clarity from the previous one.

shown in [4] that the spectral range between 8 and 13  $\mu\text{m}$  has significant diagnostic potential for characterization of hydration states of CC matrices. In the present study we focused on the latter spectral range. In this spectral range, silicate spectra show strong characteristic features caused by asymmetric stretching of Si-O bonds [6]. In reflectance spectra of smooth surfaces and powders these strong bands are seen as reflectance maxima (Reststrahlen bands) [7].

### Matrices of hydrated and anhydrous CCs

Fig. 1 shows that the IR spectra of anhydrous CC matrices - such as CV3 and CO2 matrices - are clearly dominated by fine-grained Fe-rich olivine. Fine-grained Fe-rich olivines in the spectra of CV3 and CO3 matrices are responsible for the Si-O reflectance peaks at 11.45, 10.4  $\mu\text{m}$  and weaker shoulders at 12.07 and 10.75  $\mu\text{m}$  (Fig. 1). The spectra of CV3 and CO3 matrices can easily be distinguished from the spectra of hydrated CM2 and CI1 matrices dominated by Si-O signatures of hydrated silicates, observed near 10  $\mu\text{m}$ . Furthermore, the CI1 matrix spectra can be distinguished from typical CM2 matrix spectra. CM2 matrix spectra exhibit smoother Si-O Reststrahlen bands than CI1 spectra, possibly due to a greater diversity of matrix phyllosilicate compositions in CM2 chondrites compared to CI1 meteorites. Poor crystallinity of CM2 matrix silicates may also be responsible for the smooth character of their



**Fig. 2** The average matrix IR reflectance spectra of non-Antarctic MCCs, “normal” non-metamorphosed CM2 chondrites and CO3 chondrite Kaisaz. Each spectrum is offset for clarity from the previous one.

spectral signatures. Furthermore, the Si-O reflectance peaks of CM2 chondrites are centered at longer wavelengths (~10.2  $\mu\text{m}$ ) than the sharper reflectance peak in the Orgueil (CI1) spectrum (9.9  $\mu\text{m}$ ).

#### Matrices of metamorphosed carbonaceous chondrites

Several non-Antarctic metamorphosed CM2 chondrites have recently been found and characterized [8, 4, 9]. Matrix IR spectra of the MCCs can easily be distinguished from phyllosilicate-rich ones of “normal” CM2 chondrites and are dominated by spectral signatures of fine-grained Fe-rich olivines (Fig. 2). In this respect they strongly resemble the matrix spectra of anhydrous CCs (Fig. 1, 2). However, due to the lower average content of fayalitic component in matrix olivines of the MCCs, the spectral features of olivines are slightly shifted to shorter wavelengths. At ~10  $\mu\text{m}$  some spectral contribution from phyllosilicates to the MCCs matrix spectra cannot be ruled out, especially for NWA 4757 meteorite. Thus, IR microspectroscopy is a good complementary tool for identification of MCCs [4].

#### Hydrated matrix lumps in Isheyev meteorite

Isheyev is a metal-rich CH/CB<sub>b</sub> carbonaceous chondrite composed of Fe,Ni-metal, chondrules, rare CAIs and hydrated matrix lumps [10]. We acquired reflectance spectra of three matrix lumps from Isheyev and found that all of them show different spectral characteristics (Fig. 3). The spectrum of the lump I strongly resembles that of Orgueil (CI1). The lump II spectra are generally similar to those of the lump I (CI1-like) but show signatures of carbonates at 7- $\mu\text{m}$  (red arrow in Fig. 3) absent in the Orgueil spectra. The lump III is significantly dehydrated

compared to the lumps I and II. Its dehydrated state is evident from the Si-O Reststrahlen bands at 11.4 and 12  $\mu\text{m}$  typical of fine-grained olivine. However, some additional silicate phases (possibly hydrated) are present in the lump III as well. These results are preliminary and require further analysis.

#### Conclusions

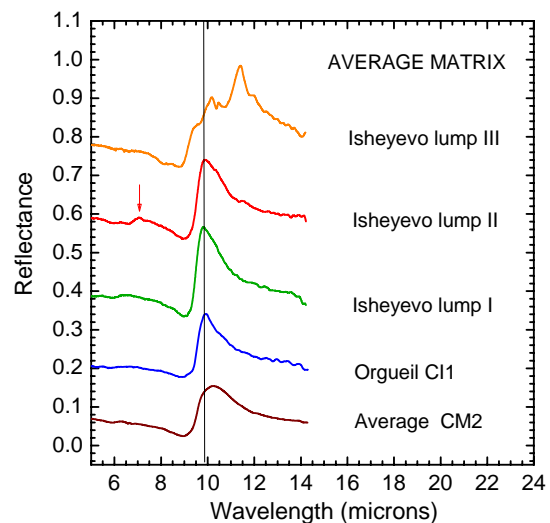
IR reflectance microspectroscopy is a useful tool for characterization of CC matrix silicates in terms of their hydration states. It allows one to distinguish between various types of CC matrix materials.

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**Fig. 3** The average IR reflectance spectra of three different matrix lumps from Isheyev meteorite in comparison with IR reflectance spectra of typical (non-metamorphosed) CM2 matrices and CI1 chondrite Orgueil. Each spectrum is offset for clarity from the previous one.