

AN INVESTIGATION OF THE SUB-mm-SCALE SPECTRAL DIVERSITY OF THE $\sim 3\ \mu\text{m}$ OH/H₂O ABSORPTION FEATURE IN CM2 CARBONACEOUS CHONDRITES. C. D. Schultz¹, B. A. Anzures¹, R. E. Milliken¹, T. Hiroi¹, ¹Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI 02906. Email: cody_schultz@brown.edu

Introduction: CM carbonaceous (C) chondrites are part of the CM-CO clan and are the most abundant group of C chondrites [1]. Among the most interesting components of CM chondrites are their hydrated minerals, which are primarily phyllosilicates and to a lesser extent include sulfates, oxides, and hydroxides. These minerals record past aqueous processes that likely occurred on the parent bodies from which the CM chondrites are derived. Understanding the spatial distribution of volatiles and their host phases in these meteorites, and how this affects their spectral properties, can provide important information on how to better interpret remotely sensed data of asteroids.

H₂O and OH are readily detect in hydrated minerals in CM chondrites via reflectance spectroscopy due to their characteristic vibrational absorptions at infrared wavelengths. Specifically, symmetric and asymmetric stretching modes of OH and H₂O and the first overtone of the H₂O bending mode give rise to a series of overlapping absorptions in the $\sim 2.7\text{--}4\ \mu\text{m}$ wavelength region that is commonly referred to as the “ $3\ \mu\text{m}$ feature”. The potential diagnostic capacity of the $3\ \mu\text{m}$ feature has inspired workers to propose taxonomical schemes to organize meteorites and asteroids based on the wavelength position and shape of the absorption feature, e.g. [2, 3, 4]. Significant work has been carried out on bulk powder samples to understand their spectral, chemical, and mineralogic attributes as they relate to the hydration of these samples. Despite these advances, it is yet unclear how much the spectra of CM2 chondrites might vary within individual intact meteorite chips and how such resolved spectra relate to bulk spectral data.

With this in mind, the goals of this study are to: (1) assess the sub-mm spatial heterogeneity of the $3\ \mu\text{m}$ absorption feature within individual CM2 chondrites, and (2) to determine the extent to which bulk spectroscopic measurements might “smear out” or destroy important information about the $3\ \mu\text{m}$ feature below the spatial scale of individual components.

Methods: To achieve this, we measured and mapped the sub-mm spatial scale reflectance spectra of individual CM2 chondrite chips from $1\text{--}16\ \mu\text{m}$ with $4\ \text{cm}^{-1}$ spectral resolution under dry-air using a Bruker LUMOS microscope FTIR (μFTIR) spectrometer with spot sizes of $125\ \mu\text{m} \times 125\ \mu\text{m}$. These spectra were then compared to “bulk” IR spectra collected on the same meteorites using a Nicolet NEXUS 870 FTIR with a spot size of $\sim 1\text{--}2\ \text{mm}$. The reflectance spectra were then further contextualized by determining the bulk modal

mineralogy of each meteorite via Rietveld refinement of powder X-ray diffraction (XRD) patterns acquired with a Bruker D2 Phaser XRD.

The meteorites selected from this study come from a suite of 44 CM chips collected from the United States Antarctic meteorite collection and were chosen to sample the range of $3\ \mu\text{m}$ band shapes and minimums. The meteorites chosen for spectral analysis include Allan Hills (ALH) 84031, ALH 84048, Elephant Moraine (EET) 83226, EET 83389, Meteorite Hills (MET) 00630, and Queen Alexandra Range (QUE) 97077. The same meteorites, except for MET 00630 which was swapped with MET 00639 (paired to MET 00630), were also used for XRD analysis.

Results & Discussion: The position of the $3\ \mu\text{m}$ absorption band minimum was calculated on the continuum-removed spectra for each spot for every meteorite [Fig. 1] and revealed two apparent groups within our samples: the spectrally homogeneous group (ALH 84031, ALH 84048, MET 00630) and the spectrally heterogeneous group (EET 83226, EET 83389, QUE 97077).

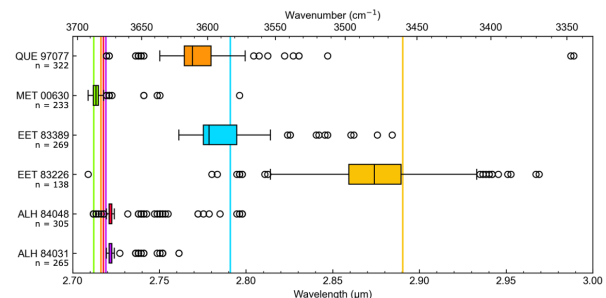


Figure 1: The medians, interquartile ranges, and outliers of $3\ \mu\text{m}$ band position were calculated from the μFTIR spectral maps for each meteorite and are shown as a box-and-whisker plot. The $3\ \mu\text{m}$ band position calculated from the FTIR spectra of the “bulk” chip is shown as a solid vertical line.

The spectrally homogeneous group is characterized by $3\ \mu\text{m}$ features with band minimums positioned at shorter wavelengths ($\sim 2.71\text{--}2.72\ \mu\text{m}$) and that show much less variance in position, as measured by the interquartile range (IQR). When considering outliers, the $3\ \mu\text{m}$ band position of the spectrally homogeneous group exhibited a more dramatic range, from $\sim 2.71\text{--}2.80\ \mu\text{m}$. In contrast, the $3\ \mu\text{m}$ band position of the spectrally heterogeneous group tended to be positioned

at longer wavelengths ($\sim 2.75\text{--}2.90\ \mu\text{m}$) and showed an IQR that was an order of magnitude larger.

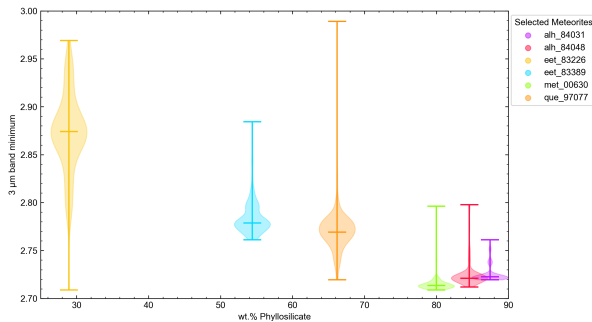


Figure 2: The distribution of the $3\ \mu\text{m}$ band positioned measured via μFTIR are shown as a function of the total overall abundance of phyllosilicates.

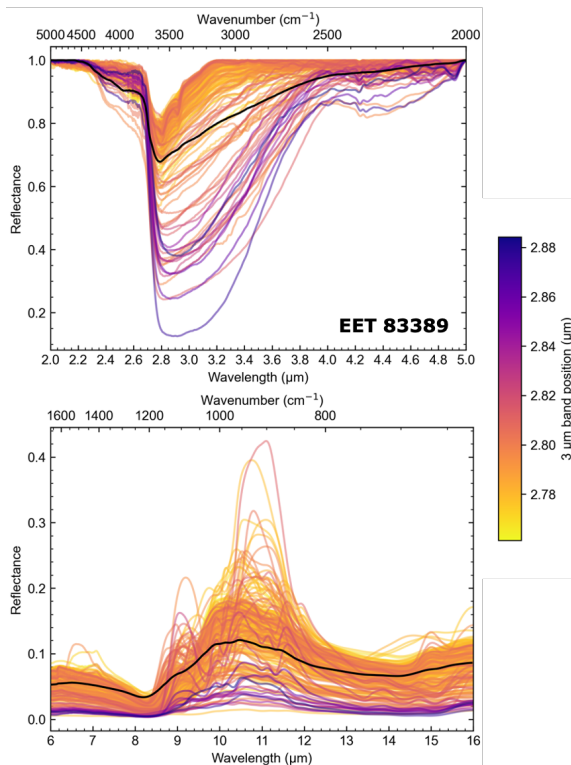


Figure 3: μFTIR IR spectra collected from EET 83389 from are shown with colors corresponding to the wavelength position of the $3\ \mu\text{m}$ band minimum. Spectra collected via FTIR is plotted in black.

Plotting the distribution of $3\ \mu\text{m}$ positions as a function of total abundance of phyllosilicates [Fig. 2], determined via XRD, revealed an interesting negative correlation. Meteorites having lower overall abundances of phyllosilicates ($\sim 30\text{--}68\ \text{wt.}\%$) tended to exhibit $3\ \mu\text{m}$ features positioned at longer wavelengths and showed more variance in position (spectrally heterogeneous group). This may be due to the presence

of highly hydrated phases produced by terrestrial weathering (e.g., sulfates). In contrast, meteorites having higher overall abundances of phyllosilicates ($\sim 80\text{--}89\ \text{wt.}\%$) exhibited $3\ \mu\text{m}$ features positioned at much shorter wavelengths that showed much less variance (spectrally homogeneous group). Fig. 3 shows an example of the diversity of spectra measured via μFTIR versus FTIR for EET 83389.

To investigate the spatial scales at which the observed spectral heterogeneity beings to “smear” or average out, we assumed linear checkerboard mixing and averaged together multiple spectra to resample the nominal $125\ \mu\text{m} \times 125\ \mu\text{m}$ spot measurement size to $250\ \mu\text{m} \times 250\ \mu\text{m}$, $500\ \mu\text{m} \times 500\ \mu\text{m}$, $1\ \text{mm} \times 1\ \text{mm}$, and $2\ \text{mm} \times 2\ \text{mm}$. These spectra were then randomly sampled from the entire population 1000 times, from which we calculated the $3\ \mu\text{m}$ absorption band position for each averaged spectrum. As an example, Fig. 4 shows the statistical results for EET 83389. In general, a marked decrease in variability occurred from the transition from $250\ \mu\text{m} \times 250\ \mu\text{m}$ spot sizes to $500\ \mu\text{m} \times 500\ \mu\text{m}$ spot sizes, marking the approximate size of the largest constituents in these meteorites.

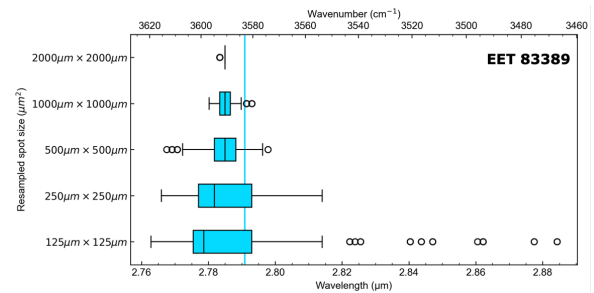


Figure 4: The $3\ \mu\text{m}$ band positions were calculated on spectra resampled from the original μFTIR spectra to artificially create larger measurement spot sizes.

Conclusion: Microscope FTIR data reveal remarkable spectral diversity in position and shape of the $3\ \mu\text{m}$ absorption feature in matrix of individual CM2 chondrites, while preserving the petrographic context of this spectral variation. In some cases, $3\ \mu\text{m}$ features of ‘bulk’ samples are dominated by non-matrix components that can be traced to terrestrial weathering, whereas in other cases the $3\ \mu\text{m}$ band is quite homogenous and reflects the nature of the CM matrix.

References: [1] Weisberg M.K. et al. (2006) *Meteorites and the Early Solar System II*, 943, 19-52. [2] Takir D. et al. (2013) *Meteoritics & Planet. science*, 48, Nr 9, 1618-1637. [3] Rivkin A. S. et al. (2012) *European Planet. Sci. Congress 2012*, EPSC2012-359. [4] Osawa T. et al. (2001) *Antarct. Met. Res.*, 14, 71-88.