TOWARD AN UNDERSTANDING OF PHYLLOSILICATE MINERALOGY IN THE OUTER MAIN BELT REGION. D. Takir[1,3], J.P. Emery[2,3] ,and H.Y. McSween Jr[2], [1]Department of Physics, Ithaca College, Ithaca, New York 14850, USA (dtakir@ithaca.edu), [2]Department of Earth & Planetary Sciences and Planetary Geosciences Institute, University of Tennessee, Knoxville, TN 37996-1410, USA. [3]Visiting Astronomer at the Infrared Telescope Facility under contract from the National Aeronautics and Space Administration, which is operated by the University of Hawai'i, Mauna Kea, HI 96720, USA.

Introduction: Carbonaceous chondrites exhibit evidence for past reactions with liquid water in the form of hydrated minerals, including water- and hydroxyl-bearing minerals [1]. Several attempts have been made to link spectra of outer Main Belt asteroids with spectra of carbonaceous chondrites on the basis of the analyses of spectral slope and albedo and the 0.7 µm absorption feature [2]. In addition, analyses of the 3-µm absorption feature that include the band depth and the intensity have been used to characterize spectra of CM and CI carbonaceous chondrites [3]. However, these meteorite spectra were measured under ambient laboratory conditions and are consequently contaminated by adsorbed water.

Recently, [4] identified from high-quality near-infrared (NIR: 0.7-4.0 µm) spectra of 35 outer Main Belt asteroids ($2.5 < a < 4.0$ AU) four 3-µm spectral groups, each of which is, presumably, related to distinct surface mineralogy. Additionally, [5] measured reflectance spectra of CM chondrites under dry (vacuum) conditions and recognized three spectral groups (in addition to the CI chondrite Ivuna) on the basis of the 3-µm band center and shape of spectra, showing that distinct parent body aqueous alteration environments experienced by different carbonaceous chondrites can be distinguished using reflectance spectroscopy.

The goal of the present study is to apply the 3-µm spectral indicators (e.g., band center band shape, band depth) in CM and CI chondrites to outer Main Belt asteroids spanning the $2.5 < a < 4.0$ AU region in order to constrain the nature and location of aqueous alteration, and to provide more details on the alteration state and phyllosilicate mineralogy of these asteroids.

Methodology: Reflectance spectra of CM and CI carbonaceous chondrites used in the present study were measured by [5] under dry conditions (vacuum and elevated temperature) to remove adsorbed water, for subsequent comparison with reflectance spectra of asteroids. [5] also investigated degree of hydration in these chondrites, using previously defined alteration parameters, including the Mineralogical Alteration Index (MAI) [6] and petrological subtype [7].

In addition to asteroid spectra that were presented in [4], the present study includes additional spectra, which were also observed using the long wavelength cross dispersed (LXD: 1.9-4.2-µm) mode of the SpeX spectrograph/imager at the NASA Infrared Telescope Facility (IRTF). The band depth, D_λ, at a given wavelength λ in both meteorite and asteroid spectra was calculated relative to the continuum that is defined as the regression line across the (k-band: 1.95-2.50-µm) region. Further details on the observational and data reduction techniques as well as the analysis of the 3-µm band can be found [4].

To characterize the shape of the 3-µm absorption feature in meteorites and asteroids, we chose representative wavelengths at 2.90 µm and 3.20 µm for nominal band depth calculation. We used a chi-squared test to quantitatively compare spectra of meteorites and asteroids and to determine the best matches. The calculated chi-squared is the sum of three chi-squared of the linear regression order polynomial fits across three representative regions: the 1.95-2.50 µm, 2.85-3.25 µm, and 3.50-4.00 µm (Figure 1):

$$\chi^2 = \chi^2_{1.95-2.50} + \chi^2_{2.85-3.25} + \chi^2_{3.50-4.00}.$$

The representative regions exlude the 2.50-2.85-µm region because asteroid spectra are affected by strong absorptions in Earth's atmosphere, and the 3.25-3.50-µm region because some meteorite spectra exhibit strong organics abosprtions. In this chi-squared test, the predicted data are the meteorite data and the observed data are the asteroid data. The lowest chi-squared value represents the best match between spectra of an asteroid and a meteorite. In addition to comparisons with individual meteorites, we also determined the average χ^2 for each meteorite group (Group 1, Group 2, Group 3, and Ivuna).

Results & Discussion: All analyzed meteorites were found to be similar to the "sharp" asteroids [4], which are located in the $2.5 < a < 3.3$ AU region. We used the 3-µm band shape as a spectral indicator to provide more details on the alteration state and phyllosilicate mineralogy on these asteroids. The band center, on the other hand, is very difficult to calculate in asteroid spectra because of the strong absorptions in Earth's atmosphere. The 3-µm band shape was characterized on the basis of the band depths at 2.90 µm and 3.20 µm, as well as chi-squared tests in the 3.0-µm region.

Using these analyses, we found that the sharp asteroids possibly have similar phylosillicate mineralogy as CM meteorite Group 2 (e.g., Figure 2), suggesting that these asteroids and meteorites experienced similar aqueous alteration processes. These results suggest that CM and CI chondrites are possibly the meteorite analogs for these asteroids. Group 2 was previously found to have a petrological subtype that ranges from 2.2 to 2.1, and to be consistent with intermediate phases between endmembers Fe-serpentine and Mg-serpentine [5].

No meteorite match was found for the "rounded" group, "Ceres-like" group (1 Ceres, 10 Hygiea, and 324 Bamberga), or "Europa-like" group (52 Europa, 31 Euphrosyne, and 451 Patientia). Because the 3-μm feature in the rounded group was attributed to H_2O ice [8, 9], we do not expect to find any meteorite match for this group. For Ceres-like and Europa-like groups, we suggest several possible scenarios to explain the lack of meteorite matches in these groups: (1) The surfaces of these two groups contain mixture of H_2O ice-coated phyllosilicates. The dislodged fragments from Ceres-like and Europa-like groups then experienced H_2O ice sublimation before falling on Earth. (2) The dislodged fragments experienced re-accretion due to the large escape velocity of these two groups, which have larger diameters than the sharp group. (3) Because asteroids in Ceres-like and Europa-like groups have larger diameters than the sharp group, it is possible that they did not experience impacts that exposed the deep interiors that might contain phyllosilicates detected in the sharp group. (4) It is possible that Ceres-like and Europa-like groups are big enough to allow hydrothermal circulation inside the asteroid that causes water to be replenished on the surface [10], interacting with existing phyllosilicates to form the phases spectrally detected on the surfaces (e.g., brucite on Ceres). (5) The products of aqueous alteration on these two groups have not been spectrally recognized in the laboratory. (6) May be that no members of these groups are close enough to resonances to provide a clear pathway for meteorite delivery to Earth.

Hence, laboratory work and spectral analyses of minerals under dry conditions and vacuum, as well as spectral models using new phylosillicate optical constants, are needed to test these hypotheses, and to characterize the spectral compositions of the two groups and possibly identify their meteorite analogs. Also, the Dawn mission, which is on its way to Ceres, will provide some crucial information about the surface composition of this asteroid.

References:

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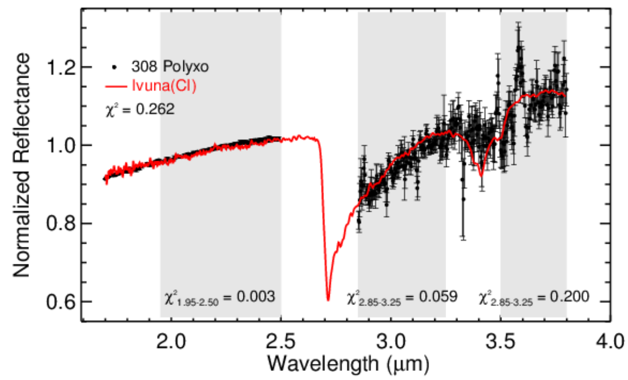

Figure 1. Comparison between the spectra of CI chondrite Ivuna and the asteroid 308 Polyxo, using the sum of three chi-squared of the linear regression order polynomial fits across three representative regions (gray): the 1.95-250 μm, 2.85-3.25 μm, and 3.50-4.00 μm. In this chi-squared test, the predicted data represent Ivuna and the observed data represent 308 Polyxo. The lowest chi-squared value of 0.262 shows that Ivuna is the match for Polyxo.

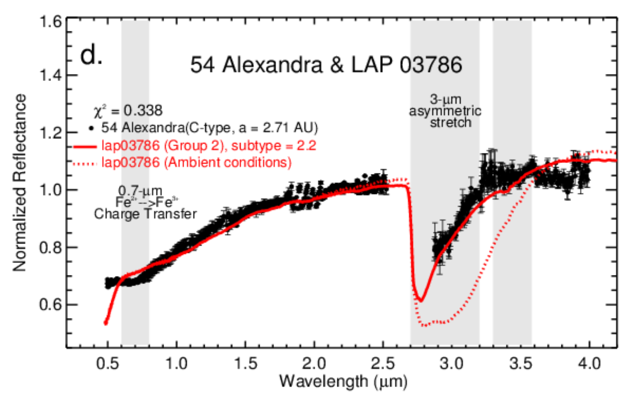

Figure 2. An example of the comparison between CM and CI chondrites and outer Main Belts asteroids with the sharp OH 3-μm feature (2.5 < a < 3.3 AU). Chi-squared tests were used in the 1.95-250-μm region to quantitatively compare spectra of meteorites and asteroids and to determine the best matches, which were determined on the basis of the lowest computed chi-square value.