

3- μ m REFLECTANCE SPECTROSCOPY OF CARBONACEOUS CHONDRITES UNDER ASTEROID-LIKE CONDITIONS. D. Takir¹ (driss.takir@nasa.gov), K. R. Stockstill-Cahill², C.A. Hibbitts², Y. Nakauchi³. ¹JETS/ARES, NASA Johnson Space Center, Houston TX 77058-3696, ²Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland 20723, ³JAXA Institute of Space and Astronautical Science, Sagami-hara, Japan.

Introduction: We measured 3- μ m reflectance spectra of 21 meteorites that represent all carbonaceous chondrite types available in terrestrial meteorite collections, including CI, CM, CR, CV, CO, CH, CB, CK, and C2-ung chondrites. This investigation completes work begun under [1] that explored the 3- μ m band under asteroid-like conditions of 10 samples of CM and CI carbonaceous chondrite types. With this complete investigation, we can better infer the mineralogy and understand the association of hydrated minerals with organics (and other chemical compounds) on the surface of carbonaceous asteroids, and therefore provide valuable constraints on the current dynamical and thermal theories of the formation and evolution of the early solar system. The measurements were conducted at the Laboratory for Spectroscopy under Planetary Environmental Conditions (LabSPEC) at the Johns Hopkins University Applied Physics Laboratory (JHU APL) under asteroid-like conditions (vacuum at room temperature after slight overnight heating at $T < 400$ K; i.e., asteroid-like conditions). This is the most comprehensive 3- μ m dataset of carbonaceous chondrites ever acquired in environments similar to the ones experienced by asteroids. The 3- μ m reflectance spectra are important for direct comparisons with and appropriate interpretations of reflectance data from ground-based telescopic and spacecraft observations of small bodies.

Methodology: Bidirectional reflectance spectra (*incidence* = 15°, *emission* = 45°, *phase angle* = 60°) of carbonaceous chondrites were measured at the Laboratory for Spectroscopy under Planetary Environmental Conditions (LabSPEC) at the Johns Hopkins University Applied Physics Laboratory (JHU APL) under vacuum- and thermally-desiccated conditions following the methodology used in [1]. Spectra were measured from ~0.8 to ~8 μ m using a high-vacuum chamber system (10^{-7} to 10^{-6} torr) with a Bruker Vertex 70 FTIR spectrometer and an external liquid-nitrogen cooled MCT detector. Samples were placed in the copper sample holder and retained in place with a 1 mm-thick MgF₂ window. A diffuse gold plate mounted immediately below the sample holder was used as the IR reflectance standard, and a thermocouple embedded in the sample provided an accurate temperature measurement. After placing the sample in the holder and securing the window over the sample, the holder was installed onto the cryostat inside the chamber. After installing the holder with sample in it into the chamber, a spectrum is obtained under ‘ambient’ conditions, with the sample

exposed to the laboratory environment. Next, the chamber was sealed and evacuated, and spectra of the initially desiccated sample were obtained. However, much adsorbed water generally remained in samples, so they were baked out. While under vacuum, a resistive heater warmed the back of the copper holder and thus the sample for removing adsorbed water. Sample temperature reached ~ 375K (which is consistent the warmest temperature near-Earth and Main Belt asteroids experience) for ~ 10 to 12 hours overnight. Then in the following day, the heater was turned off, and spectra were taken again under vacuum after the sample had cooled.

Results and discussion: This work revealed that the 3- μ m band in the spectra of the desiccated meteorites is diverse for the 21 studied carbonaceous chondrites, suggesting their parent bodies experienced distinct secondary process environments (aqueous alteration, metamorphism). We found an agreement between the 3- μ m spectral characteristics of carbonaceous chondrites and carbonaceous chondrite classifications. CI chondrites have a very narrow 3- μ m-band centered at ~2.71 μ m, consistent with Mg-serpentine and clay minerals. CI chondrites were found to be affected by substantial amount of adsorbed water from laboratory atmospheric contamination that desorbed under vacuum and heating to ~ 375K for several hours. This adsorptive behavior is likely due to the high abundances of oxyhydroxides and complex clay minerals in these chondrites (e.g., [2]). In addition, we attribute the high abundances of organics revealed by 3- μ m spectra of CI chondrites (higher than all other chondrite types) to the mineralogy of CI chondrites (oxyhydroxides- and clay-rich). CM chondrites have a less intense 3- μ m band than CI chondrites, suggesting they experienced less aqueous alteration. The 3- μ m band of CM chondrites is centered ~2.80 μ m, more likely due to the presence of Fe-serpentine (cronstedtite). The measured 3- μ m spectra of CR chondrites revealed that the degree of aqueous alteration in these chondrites is moderate (moderate phyllosilicate abundances) relative to CI and CM chondrites. CV chondrites, except for Efremovka, have a very shallow 3- μ m band, consistent with their lower phyllosilicate proportions and their experienced metamorphism environments. Like CV chondrites, CO chondrites have a very shallow 3- μ m band that suggest they experienced minor aqueous alteration. The 3- μ m band in CH/CBb is deep and broad centered ~ 3.11 μ m, possibly due the high abundance of FeNi metal

and presence of heavily hydrated clasts in these chondrites. The 3- μm spectra of Essebi (C2-ung) and EET 83226 are more consistent with CM chondrites' spectra. 3- μm spectra of Tagish lake (C2-ung), on the other hand, are consistent with CI chondrites. These spectra show substantial change between ambient and asteroid-like conditions due to the significant amount of adsorbed water. This spectral change in Tagish Lake is more likely associated with the presence of oxyhydroxides and clays. None of these spectral details in carbonaceous chondrites could have been resolved without removing the adsorbed water before acquiring spectra.

At ambient conditions (room temperature and pressure), the 2-4 μm spectral region is significantly contaminated with adsorbed atmospheric water, which severely affect the calculations of features' spectral parameters (e.g., band center, band shape, band area), and hence, the mineralogical and chemical interpretation of meteorite spectra and their comparisons with asteroid spectra. In some meteorite spectra, adsorbed water can spectrally mask absorption features (e.g., organics, carbonates). Figure 1 shows IR reflectance spectra of a carbonaceous chondrite, Alais, measured at ambient temperature and pressure (gray curve), in vacuum under ambient temperature (dash dot black curve), and in vacuum and slightly elevated temperature at 375K (solid black curve). This figure clearly demonstrates the effects of removing adsorbed water on the spectral parameters. For example, the 3- μm band area decreased from $\text{BA}=0.341 \mu\text{m}^{-1}$ in ambient conditions to $\text{BA}=0.119 \mu\text{m}^{-1}$ in asteroid-like conditions. In addition, the organic absorption ($\sim 3.4\text{--}3.5 \mu\text{m}$) increased from $\text{BA}=0.007 \mu\text{m}^{-1}$ in ambient conditions to $\text{BA}=0.010 \mu\text{m}^{-1}$ in asteroid-like conditions.

In general, meteorite spectra show three fundamental vibrations of the water molecule that occur near 3 μm (ν_1 symmetric and ν_3 asymmetric OH stretches) and at $\sim 6 \mu\text{m}$ (ν_2 H-O-H bend). The 3- μm band is sensitive to both hydroxyl and molecular water, whereas the 6- μm band is only affected by molecular water. Both bands are significantly affected by atmospheric (adsorbed) water. To ensure that most or all of adsorbed water is removed from our samples, we heated the sample until the 6- μm band went away, and so ν_3 asymmetric OH stretch that is due to water contamination in the laboratory (Figure 2). The fact that heating to only 375K was sufficient to remove all molecular water, implies the molecular water is adsorbed and not bound into the mineral structure and also the ease of desiccation suggests all molecular water is likely terrestrial contamination. Any structural water (i.e., hydroxyl groups) in meteorites is not affected at these temperatures.

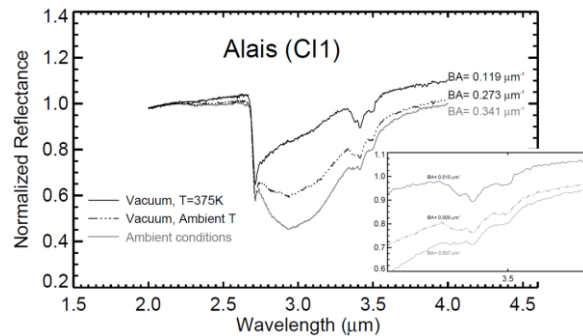


Figure 1. IR spectra of a carbonaceous chondrite, CI Alais, measured under ambient pressure and temperature (solid gray curve), immediately after exposure to vacuum and while at ambient temperature (dash dot black curve), and under vacuum and after thermally desiccated at 375K (solid black curve). The shape and intensity of the 3- μm band, including the organics features around 3.4-3.5 μm , is enormously affected by adsorbed water due to the atmospheric contamination in laboratory at ambient conditions. In vacuum and at $T = 375\text{K}$, the organics features become more pronounced and intense. Note the significant spectral effect of adsorbed water in the sample measured under ambient conditions.

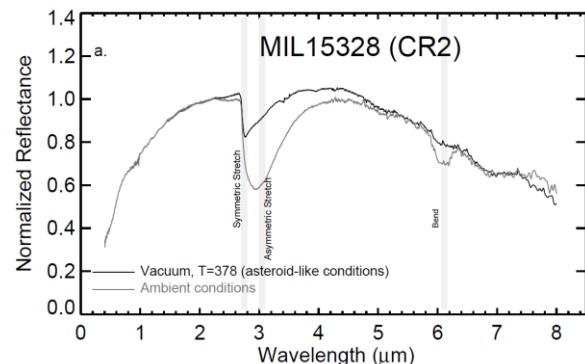


Figure 2. IR reflectance spectra of MIL 15328 measured at JHU APL's LabSPEC, covering the 0.8-8 μm spectral range. There is a significant difference (in the 3- μm and 6- μm water bands) between the spectrum that was measured under ambient conditions (gray curve) and asteroid-like conditions (black curve). For direct comparison with ground- and space-based data, meteorite spectra need to be measured in asteroid-like conditions. For confirming there is no residual molecular water (H_2O), the 6- μm band needs to be measured.

References: [1] Takir D. et al. (2013) MAPS, 48, 1618-1637. [2] Berlanga G. et al. (2016) Icarus, 280, 366-377.

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