THERMAL EMISSION SPECTROSCOPY OF ORDINARY CHONDRITES AT SIMULATED ASTEROID CONDITIONS WITH IMPLICATIONS FOR ASTEROID THERMOPHYSICAL AND COMPOSITIONAL INTERPRETATIONS.

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Introduction: Thermal infrared spectroscopic measurements record not only compositional information about the properties of a target but also about the environmental conditions in which the measurement was acquired. Spectral variations resulting from different environmental conditions are less apparent when measurements are acquired at terrestrial or martian conditions [1–4]. However, spectral variations resulting from the cold and vacuum environment of airless planetary surfaces can be significant and can greatly influence interpretations of physical and chemical properties of those surfaces when using emissivity spectra [e.g., 1, 2, 4–7]. The absence of interstitial gasses at vacuum conditions can lead to the formation of intense near-surface thermal gradients in particulate (regolith) materials that results in changes in emission spectral features [e.g., 1, 2, 4–7]. Once such category of airless planetary surfaces that is of great interest to the asteroid and planetary defense communities is S-type asteroids, a group that represents the most abundant objects in the inner main belt and near-Earth object populations [e.g., 8]. Through their paring with the ordinary chondrite (OC) meteorites, we can measure the latter under controlled asteroid-like conditions to probe how thermal and emissivity properties respond due to a cold and vacuum environment to better understand the compositional and thermophysical properties of OC parent bodies and other S-type objects.

We report here on a broad suite of environmental chamber measurements focused on anhydrous silicates, mixtures of silicates and metal, and ordinary chondrite samples, and we discuss how their thermal/emissivity properties vary between ambient and simulated asteroid environment (SAE) conditions. Understanding how thermal emission characteristics of relevant planetary materials are altered in an airless environment is important to advance our quantification of thermal reradiation forces such as the Yarkovsky effect, and an improved understanding of the thermal properties of OCs under asteroid-like conditions can lead to better estimates of the forces that govern how objects move from the main belt to the near-Earth population.

Methods: A suite of OCs spanning the three groups (H, L, and LL) and at each thermally metamorphosed petrologic type (4–6) was acquired through the US Antarctic Meteorite Collection, and single mineral phases and mixtures chosen to mimic OC mineralogy were also measured for comparison. These samples were crushed, ground, and sieved into <25, 25–125, and 125–250 μm aliquots and thermal emission measurements were acquired at (1) ambient and (2) cold, vacuum conditions. Measurements were made with the Asteroid and Lunar Environment Chamber (ALEC) at Brown University [9]. The SAE conditions were produced in a vacuum ($<10^{-4}$ mbar) with samples heated from below in sample cups and irradiated from above by a 200 W quartz-halogen lamp. A liquid N_2 cooled, rotary mounting platform holds heated sample holders each surrounded by an aluminum radiation shield that forms an enclosed ~85 K environment. Spectra were collected over a wavelength range of 2.5–25 μm (400–4000 cm^{-1}) through an emission port on a Thermo Nexus 870 FTIR spectrometer equipped with a DTGS detector. FTIR emission spectra were reduced to radiance, emissivity, and brightness temperature spectra using the absolute radiometry method developed for the ALEC system [9].

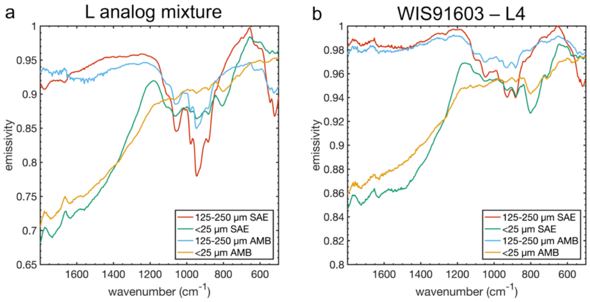

Figure 1: Emissivity spectra measured with ALEC of (a) an analog mineral mixture to the L chondrites and (b) the L4 Wisconsin Range 91603 OC at two particle sizes: <25 μm and 125–250 μm. All spectra were collected with heated cup temperature of 353 K and either at ambient (AMB) or simulated asteroid environment (SAE) conditions.

Results: Our emissivity spectra of OCs and mineral analogs display the expected spectral alterations due to the transition to SAE conditions based on results of previous studies of silicates in this environment [4–7, 10, 11]. Notably, the spectral contrast between the Christiansen feature (CF, an emissivity maximum) and the reststrahlen bands (RB) increases, and the CF position shifts towards higher wavenumbers for the SAE (Fig.1).

Using both the spectral contrast between the CF and RBs and variations in brightness temperature as a function of wavenumber, we confirm that the thermal gradients are less intense in both our analog OC mixtures and the suite of OCs compared with single mineral phases, and that gradients become less intense with increasing metal content (LL to H). Additionally, the shift in CF position is less intense in the meteorites and mixtures than the single phases. This confirms a hypothesis by

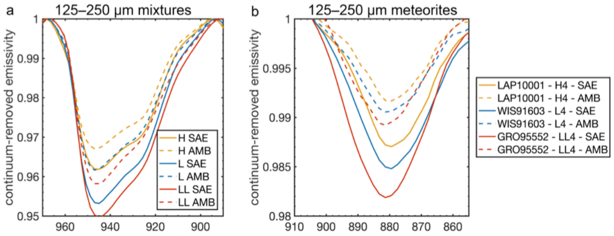

Figure 2: (a) Band depths of the ~945 cm^{-1} spectral feature from a suite of mineral mixtures with a particle size of 125–250 µm that mimic the three OC groups. (b) Band depths of a ~880 cm^{-1} feature in a suite of type 4 OCs spanning the H, L, LL groups (LaPaz Ice Field 10001, Wisconsin Range 91603, Grosvenor Mountains 95552). All spectra were collected with heated cup temperature of 400 K and either at ambient (AMB) or simulated asteroid environment (SAE) conditions.

[12] that the dark and opaque components in OCs would lead to less intense thermal gradients at SAE conditions.

For a given petrologic type, we observe trends in spectral conditions as a function of group in our OC samples. RBs associated with olivine and pyroxene increase in band depth with the decreasing relative metal to silicate ratio from H to L to LL groups (Fig. 2), though the band depth differentiation between the L and LL groups is not strong. This trend is corroborated by the analog mixtures. We also observe a shift in RB position towards lower wavenumbers from H to L to LL for several silicate RB features. The clearest trend is in the olivine RB feature at ~1045 cm^{-1} which is observed to shift by ~10 cm^{-1} towards lower wavenumber from H to LL. This trend likely reflects the relative increase in Fe^{2+} content in the silicates towards the LL group. These trends occur at both ambient and SAE conditions.

We do not observe significant trends in spectral conditions within a group as a function of petrologic type, rather spectra within a group display remarkable similarity. Possible spectral differences within a group due to physical differences for different petrologic type, such as grain coarsening, would be lost in our samples due to our sorting into particle size aliquots. However, it is observed that brightness temperature systematically decreases at all wavenumbers as a function of petrologic type for all three particle sizes.

Discussion: We can investigate how environmental conditions will affect the interpretation of asteroid thermophysical properties by applying the results in spectroscopic variations to thermophysical methods and models. We find that the integrated radiance of our mineral mixtures and meteorite samples decreases with increasing particle size at ambient conditions. This is the result of the reduction in spectral contrast (i.e., higher emissivity values) with decreasing particle size. The transition to SAE conditions results in an increase in spectral contrast at all particle sizes due to the strong near-surface thermal gradient, but the contrast increase is particularly strong for the <25 µm and 25–125 µm samples. As a result, the integrated radiance of these samples is further reduced in comparison with the ambient conditions (Fig. 3a). When applied to modeling temperatures of small bodies [e.g., 13], these trends in environmental conditions and radiance values could result in an underestimation of surface temperature if ambient lab data are used rather than SAE spectra, as lower emissivity values lead to less efficient thermal radiation and thus higher surface temperatures (Fig. 3b).

Conclusion: The thermal emission characteristics of OCs change under the cold and vacuum conditions that characterize airless planetary surfaces when compared with ambient lab conditions. While these variations are not as significant as observed for single silicate phases, presumably due to the role of opaque and metal components, the differences can still affect the interpretation of physical and chemical properties of asteroid surfaces when using remotely sensed thermal infrared data. We identify trends that vary as a function of OC group and petrologic type, though the OCs are remarkably similar in the thermal infrared and may trend toward being indistinguishable depending on the applied spectral sampling and radiance resolution. Ongoing work is further investigating the effect of varying environmental conditions on the modeling of asteroid thermophysical properties to further inform the evolution of asteroid orbits.

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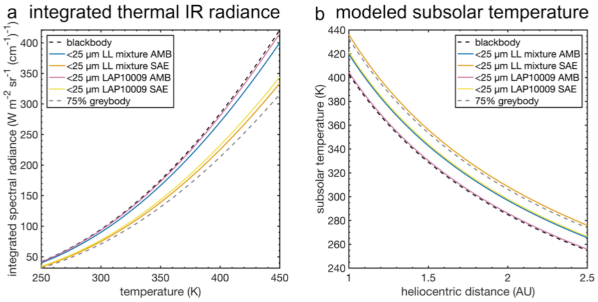

Figure 1: (a) Plot of integrated radiance across the thermal IR region as a function of temperature using emissivity data from an LL analog mineral mixture compared to the LL5 LaPaz Ice Field 10009 sample (both with a particle size of <25 µm). These integrated radiance curves are compared to a blackbody and 75% greybody. All spectra were collected with heated cup temperature of 400 K and either at ambient (AMB) or simulated asteroid environment (SAE) conditions (b) Example subsolar temperatures recalculated using the data as in (a) as a function of heliocentric distance.