THE THERMAL EMISSION OF ORDINARY CHONDRITES AND ANALOG MIXTURES AT SIMULATED ASTEROID CONDITIONS.

M. S. Bramble[1] and R. E. Milliken[1], [1]Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI, USA (michael_bramble@brown.edu).

Introduction: Thermal infrared spectroscopic measurements can be used to determine compositional and thermophysical properties of a target, but such data may also contain spectral variations resulting from the environmental conditions in which the measurement was acquired. Spectral variations resulting from the cold and vacuum environment of airless planetary surfaces are much more significant than for surfaces modulated by atmospheres, and this can greatly influence interpretations of physical and chemical properties of those surfaces when using emissivity spectra [e.g., 1–7]. 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 spectral emission features [e.g., 1, 2, 4–7]. S-type asteroids are one such category of airless planetary surfaces that is of great interest to the asteroid and planetary defense communities because they represent the most abundant objects in the inner main belt and near-Earth object populations [e.g., 8]. As the S-types have been linked with ordinary chondrite (OC) meteorites, we can measure the latter and other representative planetary materials under controlled asteroid-like conditions to probe how thermal and emissivity properties respond due to a cold and vacuum environment. This will lead to a better understanding of the compositional and thermophysical properties of OC parent bodies.

We report here on a broad suite of environmental chamber measurements focused on anhydrous silicates, mixtures of silicates and metal, and OC samples, with a focus on the influence that metal content has on the thermal emission properties of the samples. Constraining how the thermal emission characteristics of planetary materials are altered in an airless environment is an important step in improving our quantification and understanding of thermal reradiation forces such as the Yarkovsky effect, which can improve estimates of the forces that govern how objects move from the main belt to the near-Earth population.

Methods: A suite of single mineral phases and mixtures were chosen to mimic OC mineralogy and measured alongside a suite of OC samples that spanned the H, L, LL groups and petrologic types (4–6). The OCs (from the US Antarctic Meteorite Collection) were crushed, ground, and sieved into <25, 25–125, and 125–250 µm aliquots and thermal emission measurements were acquired at ambient and simulate asteroid environment (SAE) conditions. Measurements were made at Brown University with the Asteroid and Lunar Environment Chamber (ALEC) [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 method developed for the ALEC system by [9].

Results: Emissivity spectra of OCs and mineral analogs exhibit the expected spectral alterations due to the transition to SAE conditions based on results of previous studies of silicates in this environment [4–7, 10–12]. Interestingly, the expected changes in emissivity spectral features due to SAE conditions are not as significant in the OC meteorites or mixtures as they are for the

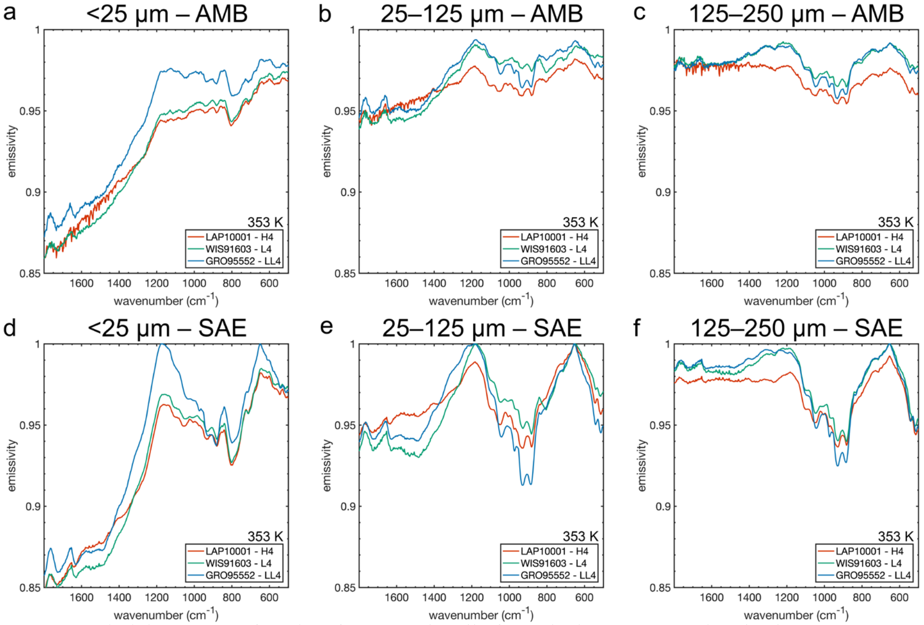

Figure 1: Emissivity spectra of a suite of OC samples all of petrologic type 4 spanning the three OC groups at three particle sizes measured under ambient (AMB) and simulated asteroid environment (SAE) conditions.

single mineral silicate phases. This was interpreted to be the result of interactions between silicates and metallic/opaque components in the polymineralic samples.

For a given petrologic type, we observe trends in spectral conditions as a function of group in our OC samples and the analog mixtures. Silicate vibrational bands associated with olivine and pyroxene increase in band depth with a decrease in metal to silicate ratio from H to LL groups. Noteworthy trends in spectral conditions are not observed within a group as a function of petrologic type, rather spectra within a group display remarkable similarity (Figure 1).

The H meteorite samples exhibit higher brightness temperatures than L or LL samples at uniform conditions, and the brightness temperatures are observed to systematically decrease for the LL meteorite samples with increasing petrologic type. These trends are best exhibited in the well-controlled analog mixtures (Figure 2). Spectral trends associated with the bulk mineralogy of the different groups or the mineral chemistry of the constituent phases appear to be obfuscated by spectral variations due to the physical properties and environmental conditions. This results in a high degree of similarly across the OC groups and petrologic types. The spectral similarity across the meteorite samples suggests significant variation in thermal emissivity is not expected for OC parent bodies (e.g., S-type asteroids) as a result of compositional differences.

Discussion: We observed a high degree of spectral similarity amongst the OCs and analog mixtures, as well as weaker spectral variations due to the change to SAE conditions, than seen for single mineral samples. This spectral similarity is exemplified by reducing the signal-to-noise ratio by 5% by adding white Gaussian noise (Figure 3). These results suggest it may be difficult to use telescopic and spacecraft thermal emission spectra to distinguish between H, L, and LL compositions based solely on bulk mineralogy estimated from those data.

Conversely, our results do display spectral variations under SAE conditions that are likely due to the bulk metal content. These results underpin that sample composition may be more important for near-surface heat transfer at SAE conditions than ambient. As the metal content of the mixtures (10–25 wt. %) increased, the measured brightness temperature of the sample increased for a given experimental setup at SAE conditions. With increasing metal content, the particulate mixtures were able to heat more efficiently, leading to higher thermal emittance.

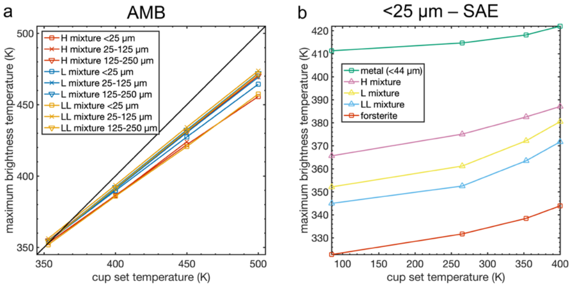

Figure 2: Maximum brightness temperatures (BT) of mixtures and mineral samples compared to the set point temperature of the sample cup heaters. (a) Max BT of H, L, and LL mixtures at three particle sizes measured under ambient (AMB) conditions. (b) Max BT of the <25 μm H, L, and LL mixtures and two minerals measured under simulated asteroid environment (SAE) conditions.

The laboratory spectra presented here hint at other data analysis techniques that may offer promise for probing the geological history of airless small bodies. For example, relationships between the difference in measured and expected brightness temperature versus composition may prove useful for future remote compositional studies. The increase in metal content increases the overall thermal conductivity of the sample and overcomes the comparative inefficiency of thermal transfer in the silicates under vacuum conditions. More laboratory spectra are needed to identify if mixing ratios between these factors and the rate at which a target surface heats and cools at different wavenumbers can be used to identify bulk composition and thus differentiation history of a body.

Conclusion: The thermal emission characteristics of OCs change under the cold, vacuum conditions that characterize airless planetary surfaces when compared with ambient lab conditions, and composition (metal content) appears to have a more significant impact on thermal emission at SAE than ambient conditions. Ongoing measurements are working towards advancing thermal emission spectroscopy as a tool for mineralogical analysis of airless planetary surfaces and improving the modeling of asteroid thermophysical properties to further inform the evolution of asteroid orbits.

References: [1] Henderson B. G. and Jakosky B. M. (1994) *JGR*, 99, 19063–19073. [2] Henderson B. G. and Jakosky B. M. (1997) *JGR*, 102, 6567–6580. [3] Christensen P. R. et al. (2001) *JGR*, 106, 23823–23871. [4] Donaldson Hanna K. L., et al. (2012) *JGR*, 117, E11004. [5] Logan L. M. et al. (1973) *JGR*, 78, 4983–5003. [6] Donaldson Hanna K. L. et al. (2012) *JGR*, 117, E00H05. [7] Donaldson Hanna K. L. et al. (2017) *Icarus*, 283, 326–342. [8] Binzel R. P., et al. (2019) *Icarus*, 324, 41–76. [9] Bramble M. S. et al. (2019) *RSI*, 90, 093101. [10] Donaldson Hanna K. D., et al. (2019) *Icarus*, 319, 701–723. [11] Bramble M. S. et al. (2019) *LPSC L*, Abstract #2101. [12] Bramble M. S. et al. (2019) *Asteroid Science 2019*, Abstract #2139.

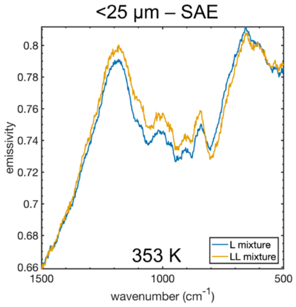

Figure 3: Emissivity spectra of the <25 μm OC analog mixtures measured under simulated asteroid environment (SAE) conditions with 5% noise added.