

THERMAL INFRARED CHARACTERIZATION OF ORDINARY CHONDRITE ANALOGS IN A SIMULATED ASTEROID ENVIRONMENT WITH IMPLICATIONS FOR THE REMOTE ANALYSIS OF ASTEROID MINERALOGY. M. S. Bramble¹, R. E. Milliken¹, W. R. Patterson III¹, and J. F. Mustard¹, ¹Brown University, Providence, RI, USA (michael_bramble@brown.edu).

Introduction: Radiance and emissivity spectra derived from thermal infrared (TIR) measurements in a laboratory setting or of planetary surfaces can be used to provide constraints on the mineralogical and physical properties of planetary materials [1–3]. However, laboratory studies have shown that intense near-surface thermal gradients can arise for particulate materials radiating into the cold, vacuum environment of airless planetary surfaces [4–7]. These thermal gradients can significantly alter TIR emission characteristics, indicating that such effects must be better understood through well-controlled experiments in order to accurately interpret remote data of airless bodies. S-type asteroids, which exhibit silicate spectral features, are among the most abundant asteroids in the main belt and near-Earth object (NEO) populations [8]. A link between S-type asteroids and ordinary chondrites, the most common meteorite type, has been established [9,10]. As such, measuring the TIR characteristics of ordinary chondritic materials and analog mixtures at cold, vacuum conditions is needed to fully understand the emissivity properties of one of the most common asteroid regolith types and it is the focus of this work.

Understanding how the TIR emission characteristics of relevant planetary materials are altered in the airless environment is also key to advancing our understanding and quantification of thermal re-radiation forces such as the Yarkovsky effect. Improved understanding of the thermal properties of ordinary chondrite analogs under asteroid-like conditions can lead to better estimates of the forces that govern how objects move from the main belt to the NEO population.

Methods: A suite of single mineral phases and mixtures mimicking ordinary chondrite mineralogy were measured in a cold, vacuum environment. Single mineral phase powders were selected to match bulk ordinary chondrite mineralogy and were sieved into <25, 25–125, and 125–250 μm aliquots. The mineral phases included well-characterized forsterite, enstatite, diopside, bytownite, and iron metal. The mineral phases were mixed proportionally to match the average modal mineralogy of H, L, and LL ordinary chondrite meteorites. Spectral data were collected with the Asteroid and Lunar Environment Chamber (ALEC) at Brown University [11]. The simulated asteroid environment (SAE) was produced in a high vacuum ($<10^{-4}$ mbar) with samples heated in sample cups set to 400 K and irradiated from above by a 200 W quartz-halogen lamp. A liquid N₂

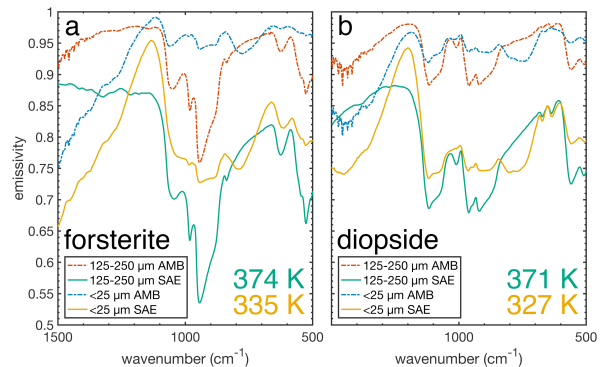


Figure 1: Emissivity spectra of representative single mineral phases (a) forsterite and (b) diopside measured at ambient (AMB) laboratory or a simulated asteroid environment (SAE) conditions. Sample temperatures calculated from the measured sample radiance for the SAE samples are displayed in colors coordinated with the spectra.

cooled, rotary mounting platform holds six heated sample holders each surrounded by an aluminum radiation shield forming an enclosed ~ 85 K environment for that sample. 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.

We have derived a new technique for reducing thermal emission spectra to emissivity using measurements of the emitting components of our system based on a detailed characterization of the system's radiometry [11]. This method yields results similar to the method of [12], with a key difference being we estimate radiance values for each sample and can thus estimate sample temperature.

Results and Discussion: Our TIR emissivity spectra confirm the presence of strong near-surface thermal gradients due to the vacuum environment. We observe an energy shift in the Christiansen feature (CF), an emissivity maximum diagnostic of composition, to higher wavenumbers, and a significant increase in spectral contrast around this feature (Figure 1). The spectral contrast increase around the CF is less intense for the ordinary chondrite mixtures (Figure 2) than the single mineral phases, as was hypothesized by [1].

We observe an increase in the difference between the setpoint temperature of the sample cup and the calculated temperature (based on the derived sample radiance) as a function of decreasing particle size. This indicates an increased thermal gradient for smaller particle sizes. For all data shown, the sample cup temperature was set to 400 K and the lamp was set to 100%

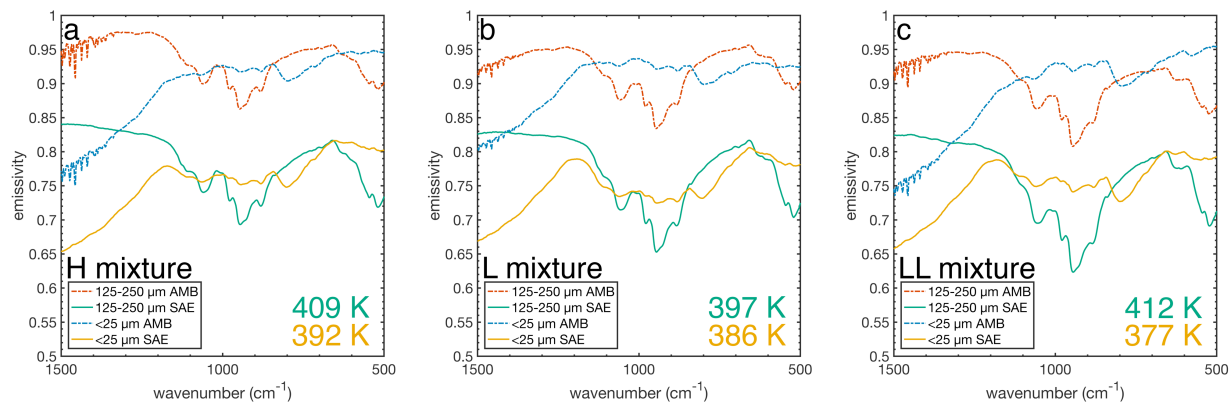


Figure 2: Emissivity spectra of analog mixtures simulating (a) H, (b) L, and (c) LL ordinary chondrites measured at ambient (AMB) laboratory or a simulated asteroid environment (SAE) conditions. Sample temperatures calculated from the measured sample radiance for the SAE samples are displayed in colors coordinated with the spectra.

output for ~25 minutes. During the data reduction to emissivity, sample temperatures were derived by fitting a simulated radiance curve (Planck function multiplied by an ambient reflectance-derived emissivity spectrum) to the measured sample radiance. The temperature corresponding to the best-fit Planck function was taken as the sample temperature. Figure 1 shows that for single mineral phases, the radiating surfaces of the 125–250 μm particulates are ~25–30 K below the set temperature. This temperature differential is greater for the fine (<25 μm) particulates, where the calculated temperatures are ~70 K lower than the set point. The 25–125 μm samples consistently exhibit calculated temperature differentials between these endmembers.

The same general trend is observed for the ordinary chondrite analog mixtures (Figure 2), where the finer particle sizes display lower radiating temperatures in a SAE. The coarse samples (125–250 μm) display temperatures close to or slightly above the set point (400 K). This is likely due to the metallic darkening components of the mixtures that can cause more efficient lamp-induced heating. The finer particulates display an increased temperature differential, but the magnitude (~15 K) is less than that of the single mineral phases.

Our results suggest that careful attention must be paid to the analysis methods used to interpret and/or model TIR data, as spectral alterations caused by near-surface thermal gradients may affect their efficacy. As an example, linear mixing models used to estimate modal mineralogy based on TIR data may break down at fine particle sizes due to a loss of spectral contrast and changes in scattering properties [13]. However, near-surface thermal gradients produced under asteroid-like conditions leads to an enhancement in spectral contrast. Therefore, we are examining whether linear mixing models may be able to retain effectiveness for particulate mineral assemblages measured under cold, vacuum conditions. Preliminary results demonstrate that linear mixing models applied to spectra of the coarse-grained mixtures yield similar fits and root mean square

errors whether samples are measured at ambient or SAE conditions. In contrast, spectral unmixing results for the finer-grained samples acquired at ambient and SAE conditions are poor, and we are investigating possible increases in modeling accuracy for mixture and meteorite data collected in a SAE benefiting from the increased spectral contrast.

Conclusion: A new emissivity reduction method can provide an independent assessment for characterization of materials at cold, vacuum conditions. Our results suggest emissivity values of regolith materials on airless planetary surfaces may be lower than expected when compared with spectra derived from methods that assume unity emissivity at a user-defined CF position. Therefore, attention must be paid to the specific methods used to derive thermal emissivity spectra when making interpretations of airless planetary surfaces or modeling their physical properties.

Ongoing work with these data is investigating how different analysis techniques, including linear unmixing methods, are influenced by spectral alterations in the cold, vacuum environment in comparison with data acquired at ambient conditions. Additionally, specimens of each type of thermally metamorphosed ordinary chondrite are being measured to investigate their emission characteristics in a SAE and for comparison to our synthetic mixtures.

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