RADIOMETRIC CALIBRATION OF THERMAL EMISSION DATA FROM THE ASTEROID AND LUNAR ENVIRONMENT CHAMBER (ALEC).

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Introduction: Radiance and emissivity derived from thermal infrared (TIR) measurements can provide valuable constraints on the chemical and physical properties of planetary surfaces [1–6], but laboratory studies have shown that thermal emission spectra are greatly affected by strong near-surface thermal gradients produced in a vacuum environment [1,7]. To accurately interpret TIR data of airless bodies, it is necessary to first understand how the thermophysical properties of planetary materials affect emissivity spectra under cold, vacuum conditions in a controlled laboratory setting. This is achieved through careful analysis of candidate planetary materials in chambers mimicking the environment of airless planetary surfaces [*e.g.*, 8,9]. Here we report on the ongoing calibration of TIR data collected from the Asteroid and Lunar Environment Chamber (ALEC) at Brown University. We aim to show the correspondence of an in-house blackbody to a commercial one and use the resulting data to reproduce emissivity spectra.

ALEC can simulate pressures and temperatures similar to those experienced in the uppermost regolith of airless bodies. A vacuum ($<10^{-4}$ mbar) environment can be produced, and samples can be heated from below via heated sample cups and/or irradiated from above by a 200 W quartz-halogen lamp. Liquid N_2 is pumped through a network of cooling tubes welded to the bottom of the sample rotation stage, cooling the stage and an aluminum radiation shield sitting on top of it to form an enclosed ~85 K environment. A cooled radiation shroud painted with highly absorptive paint (Nextel) surrounds each sample cup to produce a low-emission environment. Spectra are collected through a KBr emission port window with a Thermo Nicolet Nexus 870 Fourier Transform Infrared (FTIR) spectrometer. Data are collected with a DTGS detector over a spectral range of 2.5–25 µm (400–4000 cm^{-1}). ALEC has been successfully employed in previous investigations of the TIR characteristics of Apollo lunar soil samples and single-phase mineral spectra [10–12].

Methods: Calibration was pursued by comparing data collected from two blackbody targets at a range of temperatures. ATK Mission Research, the system vendor, provided a cavity blackbody, and the other blackbody was built in-house. It consists of a hollow 316 stainless steel cylinder bead-blasted with alumina and coated with Zynolyte (Aervoe Industries, Inc.) high temperature black paint. The cylinder is heated by two cartridge heaters in its base and the temperature is controlled by proportional-integral-derivative (PID) feedback from a thermocouple (TC) that is fixed inside a TC well by a setscrew against the TC weld. We have seen no vacuum change or material degradation upon operating the Zynolyte blackbody up to 300 °C.

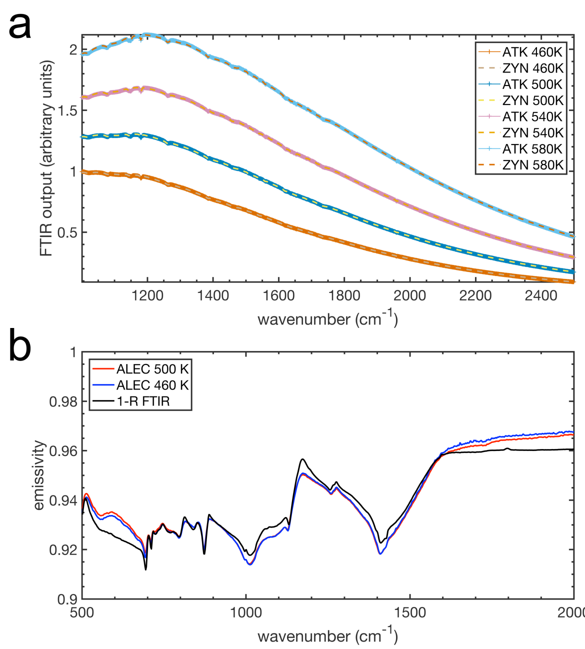

Figure 1: (a) Comparison of the FTIR output of the ATK and in-house (ZYN) blackbodies at several temperatures. (b) Comparison of emissivity spectra of a flat heated Zynolyte surface collected using ALEC under cold, vacuum conditions and 1 – R collected in ambient conditions.

We calculated and compared instrument response functions in two ways. The first uses measurements at two source temperatures, similar to previous studies [9,13]. The second uses an absolute radiometry method in which the signal contributed by radiation from the instrument itself is estimated by measuring a liquid N_2 cooled cylindrical cavity painted on the inside with Nextel paint. The FTIR spectrum of this 'background' is added back to each sample spectrum, and the result is then divided by a Planck function calculated at the blackbody temperature.

We tested the conformity of our Zynolyte blackbody to true blackbody emission by comparing it to the ATK blackbody. The comparison focused on minimizing the mean square error (MSE) over 800–3000 cm^{-1}

between the ATK and the Zynolyte signals using two free parameters, a scaling constant and a temperature for the in-house blackbody that is used in a ratio of Planck functions. To further investigate possible emissivity corrections of ALEC data, we used a three-step process to measure the emissivity of a flat, stainless steel plate coated with Zynolyte. First, we used the instrument response to convert the measured FTIR output into radiometric units. The result was then compared with an emissivity (E) spectrum based on ambient (air at 22 °C) reflectance (R) measurements of the Zynolyte target (*i.e.*, E = 1 – R; Kirchoff's Law). The latter was converted to radiance by multiplying the emissivity spectrum by a Planck function in which the target's temperature was a free parameter used to minimize the MSE. Finally, the response-corrected radiance data were divided by the Planck function at the estimated temperature to derive the sample emissivity.

Results: Our calibration method is able to match the FTIR output of the Zynolyte blackbody to the ATK blackbody, confirming the blackbody nature of the in-house blackbody (**Figure 1a**). A temperature differential of ~5 K applied to the set temperature of the Zynolyte blackbody is required to achieve the best agreement. This is consistent with a similar temperature differential found between a TC affixed to the top of a similar heater and block structure that showed a temperature gradient between the heater and the surface.

The second test reproduced the 1 – R derived emissivity spectrum of the Zynolyte surface using data reduced by the procedure described above (**Figure 1b**). A temperature correction of ~5 K to the nominal heater set temperature of the sample was again required. The ALEC emissivity spectra calculated using this method match the 1 – R values with root mean square (RMS) deviations of ~0.5 %. Instrument response functions derived by both techniques differed from their mean by 0.34 % RMS over 500 to 3000 cm^{-1} (**Figure 2a)**.

Discussion: Our methods are able to reproduce the signal of the ATK blackbody with the Zynolyte blackbody. Measurements of the ATK blackbody output are consistently ~25 % of the apparent intensity of the Zynolyte blackbody, which is a result of the ATK blackbody cavity not filling the field of view of the optics. The greatest uncertainty in our analyses appears to be the effective temperature of the in-house blackbody. This is difficult to measure directly, though methods applying Wien's law or fitting Planck functions to the radiance curves agree with comparison to the commercial blackbody within a few Kelvin.

With these methods, we are able to produce calibrated TIR spectra of geological materials (**Figure 2b**), and the emissivity spectra measured in ALEC are similar to independent measurements measured in the University of Oxford's MoonBox2 instrument. Additional inter-lab comparisons for emissivity measurements acquired under cold vacuum conditions are ongoing.

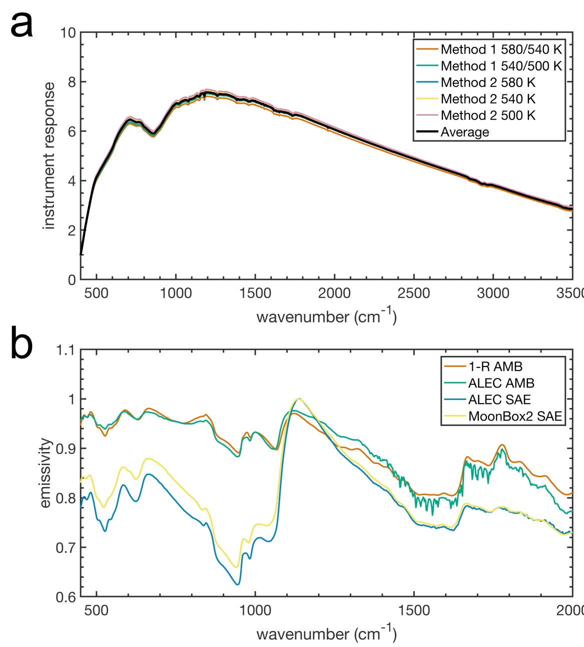

Figure 2: (a) Instrument response calculated using the in-house blackbody. Method 1 is the two-temperature method [9,13] and Method 2 is the absolute radiometry method. (b) Emissivity spectra of <75 µm San Carlos olivine measured under ambient laboratory conditions (AMB) and in a simulated asteroid environment (SAE) under cold, vacuum conditions, heated below to 353 K, and illuminated from above using the 200 W lamp. The calculation of emissivity used ambient 1 – R data and the method described for the Zynolyte emissivity. A spectrum of the same sample collected with Oxford's MoonBox2 is shown for comparison.

Conclusions: We have demonstrated the correspondence between our in-house blackbody and a commercial blackbody source. We have also demonstrated the ability to reproduce emissivity spectra acquired with ALEC that are similar to those acquired in another lab (*i.e.*, Oxford). Future work will address additional outstanding nuances within our processing pipeline to increase the spectral precision and radiometric accuracy.

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