# The Moon in a Box: Thermal Infrared Spectroscopy of Silicate Mineral Mixtures in a Simulated Lunar Environment

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**Abstract**

A planetary surface's thermal infrared (TIR) emissions provide insight into the surface's composition. Different minerals can be identified by their characteristic TIR spectral signatures. Therefore one can retrieve surface mineral composition by comparing TIR observations of a planetary surface against a library of known mineral TIR spectra measured on Earth. However for airless bodies such as the Moon, creating such a spectral library poses a challenge: minerals exhibit different TIR characteristics when measured in typical terrestrial conditions versus in lunar surface-like environments. We work to overcome this challenge by measuring TIR emission spectra of mineral samples in a chamber that simulates the lunar environment. The Simulated Airless Body Emission Laboratory (SABEL) chamber heats particulate samples under vacuum to generate a thermal gradient akin to that found in the upper regolith (i.e. epiregolith) of airless bodies. The presence of this thermal gradient—modeled to be as steep as ~60K/100 µm for the Moon—is due to airless bodies lacking the convective heat transfer provided by an atmosphere. This thermal gradient is responsible for the altered TIR spectral emission characteristics of the lunar surface, so simulating it in SABEL allows us to measure TIR spectra that are directly comparable to remotely sensed TIR observations from the Diviner Lunar Radiometer (Diviner) instrument aboard the Lunar Reconnaissance Orbiter (LRO). The work presented here focuses on one particular application of SABEL: characterizing the TIR emission spectra of silicate mineral mixtures with the endmembers plagioclase, pyroxene, and olivine. These endmembers bound the typical mineral compositions of the lunar surface. By understanding the TIR characteristics of these endmembers' mixtures, and in particular how the wavelength position of the Christiansen feature—an emissivity maximum sensed by Diviner—changes for different mixtures, we can better interpret TIR data and their implications for surface composition.

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Abstract # P23C-3460

## Highlights:

- We are creating a spectral library of thermal infrared emissions of mineral mixtures in a simulated lunar environment.
- In particular, we are characterizing shifts in wavelength of the Christiansen Feature (CF) with changing mixture composition.
- This will aid in interpreting CF observations of the Moon's surface from the Diviner Lunar Radiometer instrument, helping us better understand lunar surface mineral composition.

## I. Background

Knowledge of lunar surface composition is valuable for understanding the formation mechanism of the lunar crust [1]. We can retrieve this compositional information from multispectral observations of the lunar surface made by the **Diviner Lunar Radiometer (Diviner)**, an instrument aboard the Lunar Reconnaissance Orbiter [2] (Figure 1). Diviner is sensitive to the **Christiansen Feature (CF)** [3, 4], an emissivity maximum in the **thermal infrared (TIR)** whose wavelength position correlates to mineralogical composition [e.g. 5].

However, to accurately extract surface mineralogy from Diviner CF data, we must better constrain the relationship between CF wavelength position and mineralogy. To that end we are creating a spectral library of TIR emissions of lunar-like mineral mixtures to determine how CF position shifts with composition.

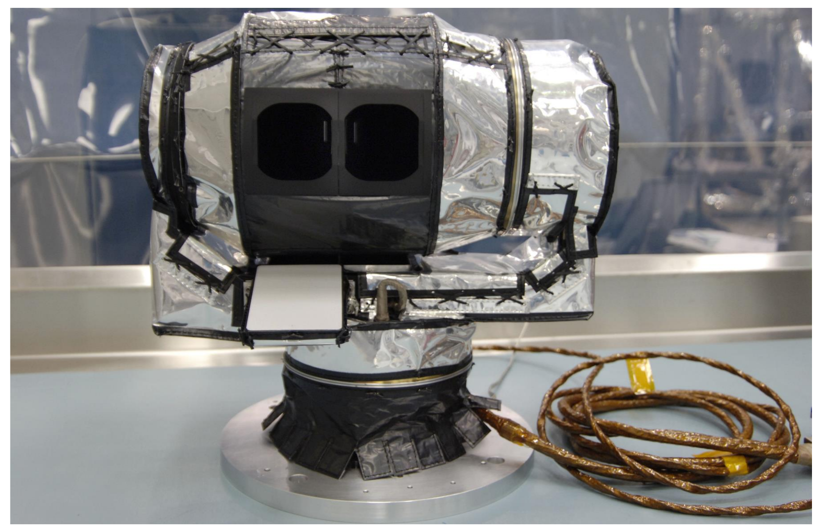


**Figure 1:** The Diviner Lunar Radiometer, one of seven instruments on NASA's Lunar Reconnaissance Orbiter spacecraft. Image credit: NASA / JPL / UCLA.

## II. Lunar-like Mineral Mixtures

We are measuring mixtures of the silicate minerals bytownite (a plagioclase), enstatite (a pyroxene), and forsterite (an olivine). These minerals were chosen because the mineral groups plagioclase, pyroxene, and olivine dominate the lunar surface [6]. We must measure mixtures across the ternary space bounded by these minerals because, based on [7], we do not expect the CFs of intimate mixtures to be approximated by linear mixing of endmember CFs.

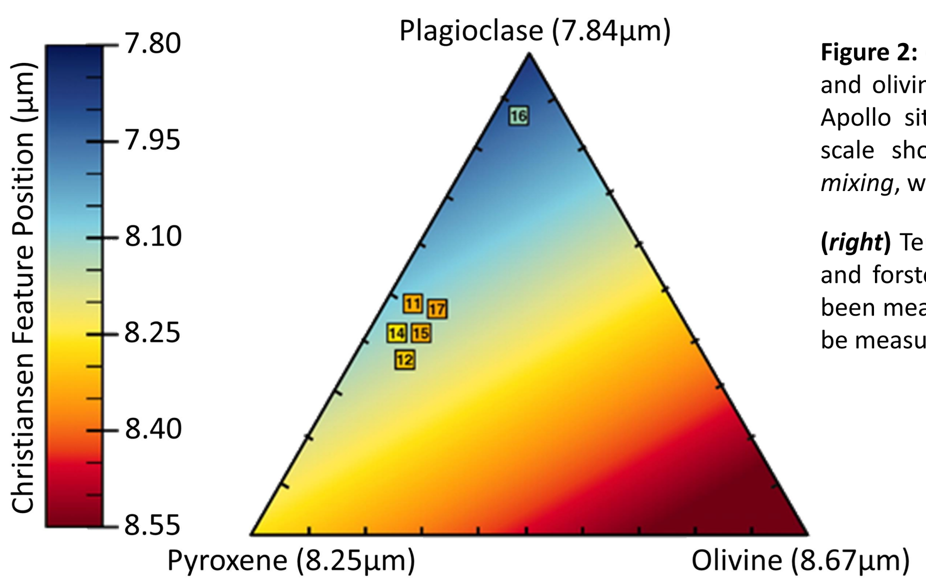
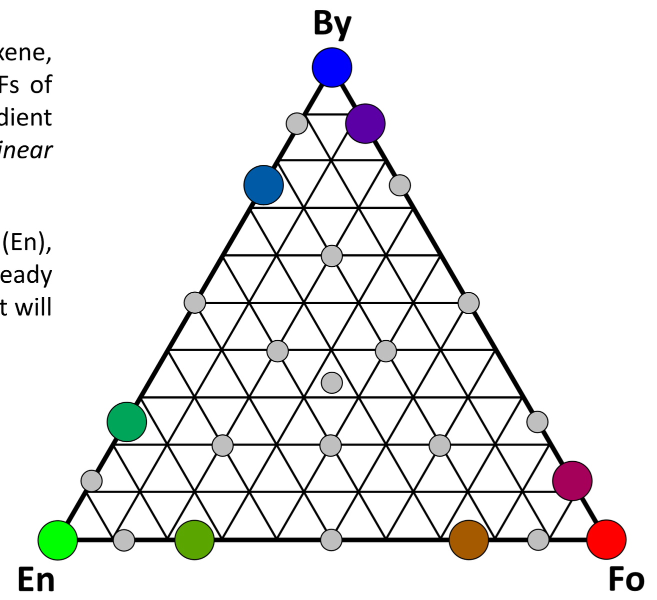



**Figure 2:** (*left*) Ternary diagram for plagioclase, pyroxene, and olivine from [4]. Numbered boxes represent CFs of Apollo sites based on Diviner data. Note the gradient scale shows CF wavelength position *assuming linear mixing*, which may not be accurate.

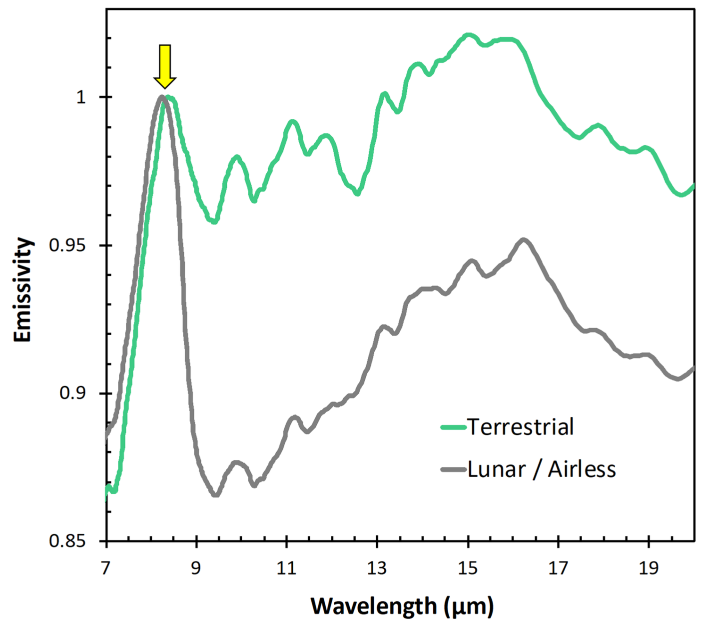
(*right*) Ternary diagram of bytownite (By), enstatite (En), and forsterite (Fo), showing mixtures that have already been measured (large, colored circles) and those that will be measured (small, gray circles).




## III. Spectroscopy in a Simulated Lunar Environment

We want to create a library of spectra comparable to Diviner CF data. However we cannot do so by measuring spectra in typical terrestrial conditions, as minerals exhibit different TIR emissions in the lunar environment [8, 9]; for airless bodies such as the Moon, lack of the heat transfer provided by an atmosphere effects a steep thermal gradient in the upper regolith (i.e. epiregolith) that alters TIR spectral emission characteristics [e.g. 9] (Figure 3).

Therefore we conduct measurements in **simulated lunar environment (SLE)** conditions in the **Simulated Airless Body Emission Laboratory (SABEL)** chamber (see SABEL panel for details). This generates a thermal gradient as in the lunar epiregolith, yielding TIR spectra directly comparable to Diviner's remotely sensed CF data.



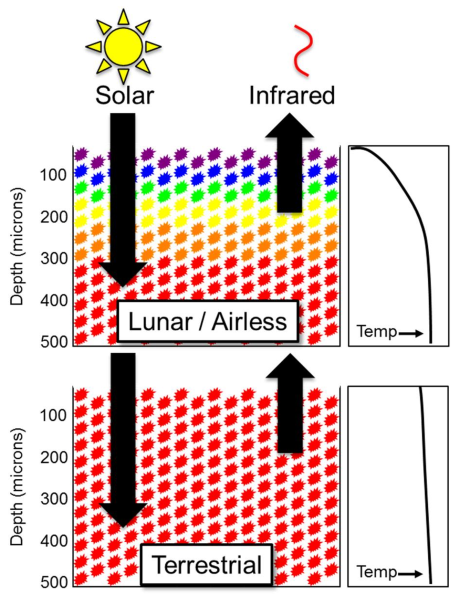




**Figure 3:** (*left*) Thermal infrared spectra of a <30µm enstatite sample, measured in SABEL in both terrestrial and lunar conditions. Note the major differences: a shift in CF position (arrow) and a change in spectral contrast.

(*right*) Surface temperature profiles in upper 500µm. In lunar/airless conditions the upper layers radiate away much more heat than received from lower layers, establishing a thermal gradient (modeled as high as 40–60K/100µm for the Moon) [10, 11]. In terrestrial conditions the soil contains interstitial gases that conduct heat, resulting in a more isothermal profile [11].

## The Simulated Airless Body Emission Laboratory (SABEL):

In the SABEL sample chamber, particulate samples are held under vacuum and heated via conductive heating elements and/or by lamp illumination. This generates a thermal gradient in the sample, simulating the epiregolith of an airless body. A spectrometer then measures thermal emission spectra.

**SPECTRAL RANGE:** 5-25 µm (at 0.45 $cm^{-1}$ resolution)
**CAPACITY:** up to 6 samples, each 1.5-3.0 g (approx.)

**ATMOSPHERE:** high vacuum ($10^{-6}$ mbar), low vacuum (5 mbar), or atm. pressure (air or $N_2$)

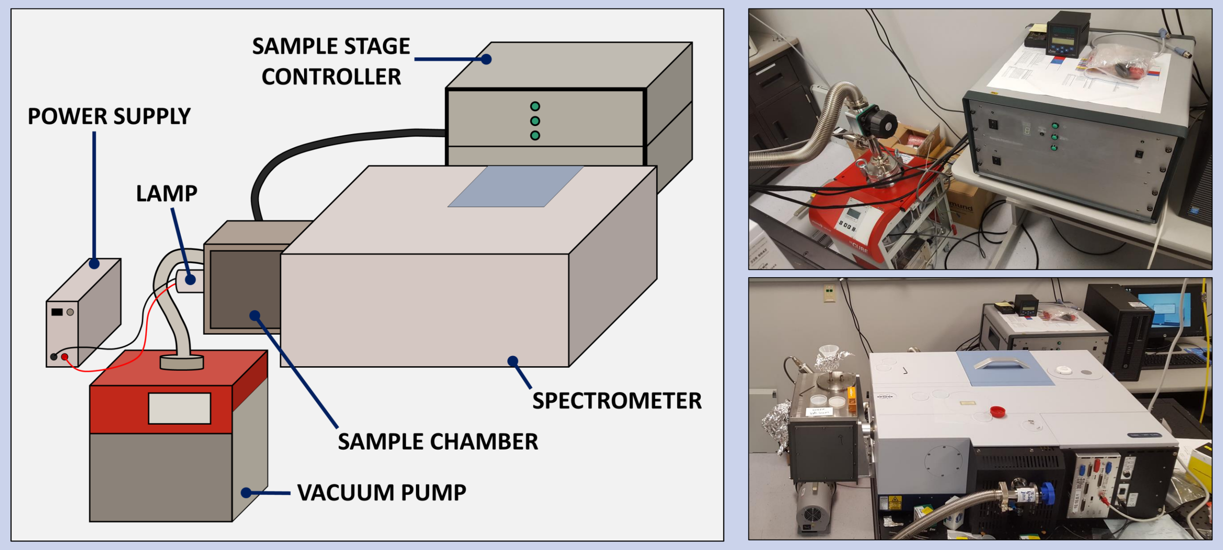



**Figure 4:** (**left**) Diagram of SABEL's major components. (**right**) Photographs of SABEL.

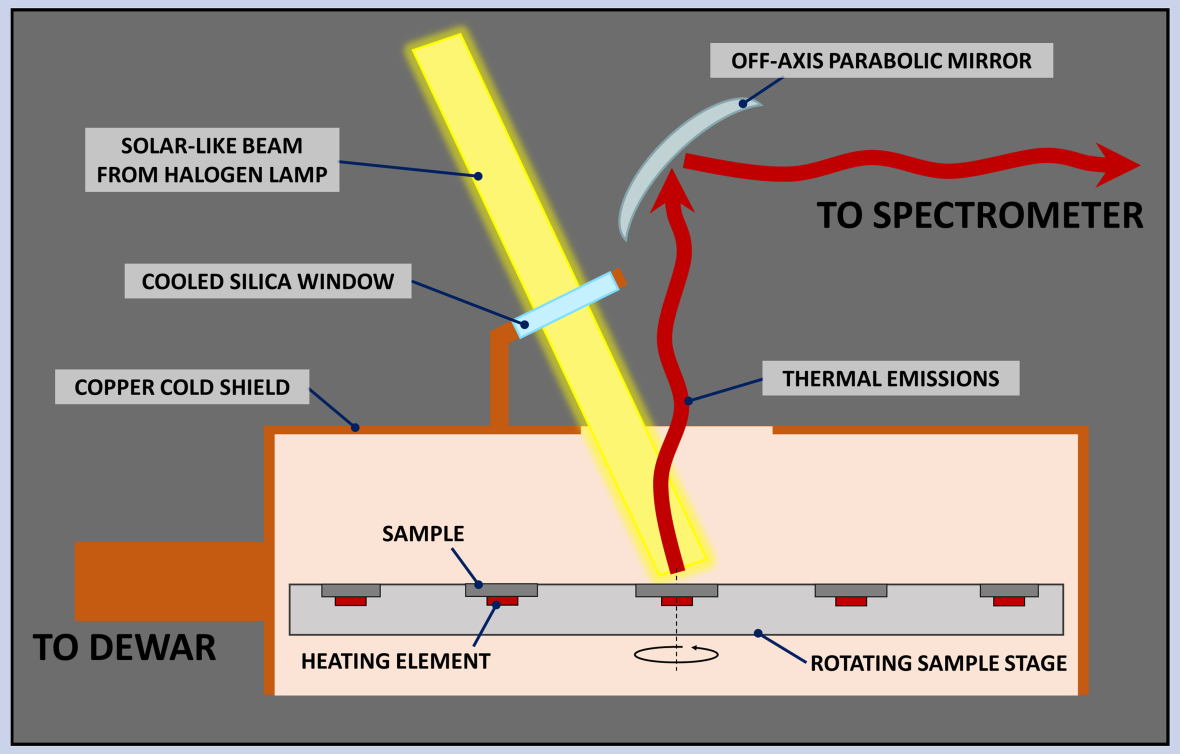



**Figure 5:** Schematic of the sample chamber, showing the method by which samples are heated and their thermal emissions are measured. Some components have been repositioned or omitted for clarity.

## IV. Results

We have made preliminary measurements of TIR spectra for the three pure minerals and for several two-mineral mixtures (Figure 6). Although we see shifts in CF position for the mixtures, we cannot yet say they are solely due to composition. This is because other factors that affect CF position, such as grain size, have not yet been fully controlled for in these initial measurements (Figure 7). In particular, the bytownite-enstatite mixtures were prepared with the samples on hand at the time, <64µm bytownite and <30µm enstatite, which differ significantly in grain size.

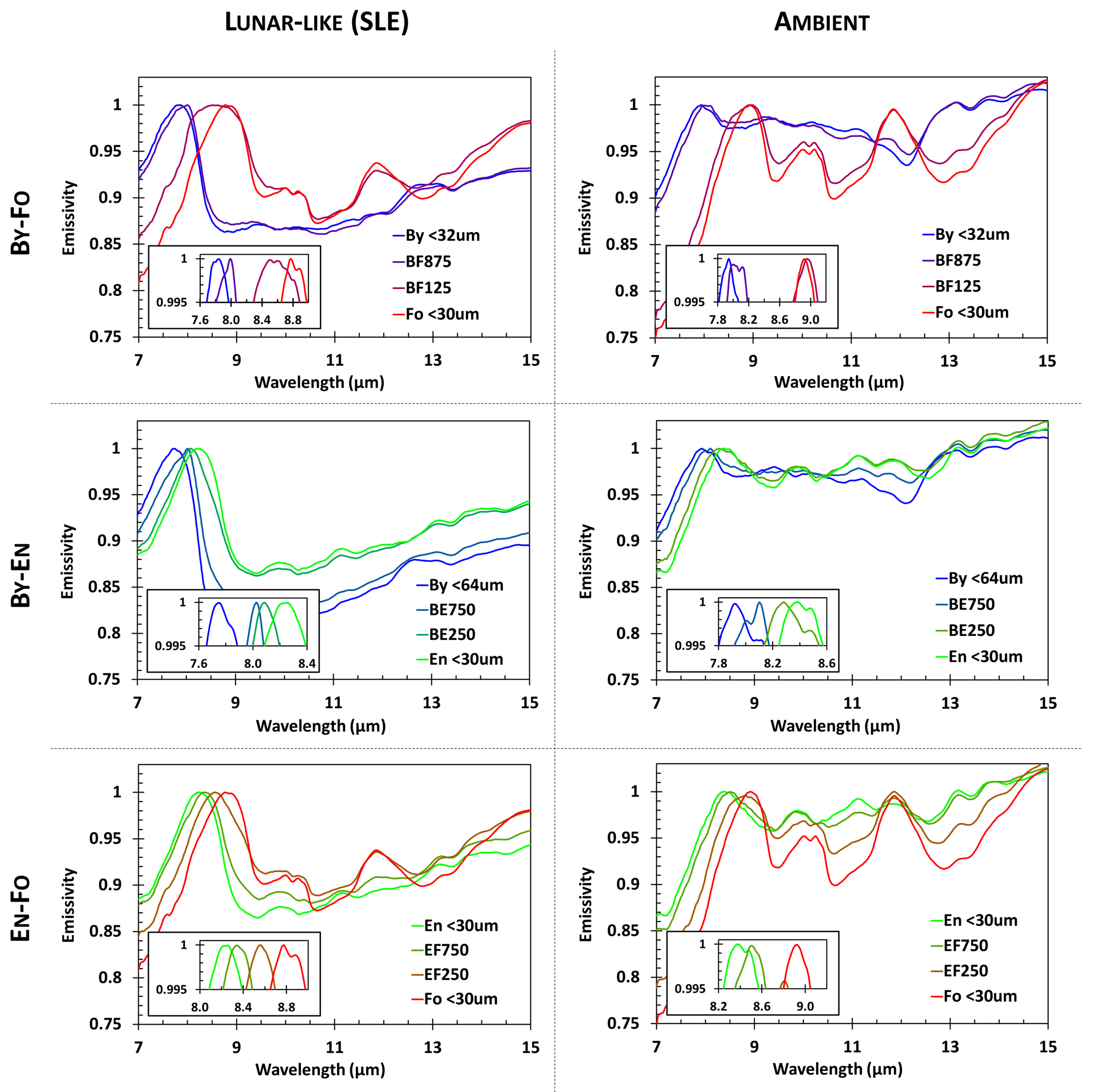



**Figure 6:** Thermal infrared spectra for mixtures of bytownite-forsterite (first row), bytownite-enstatite (second row), and enstatite-forsterite (third row) in SLE and ambient conditions. Inset plots zoom in on variations in CF position.

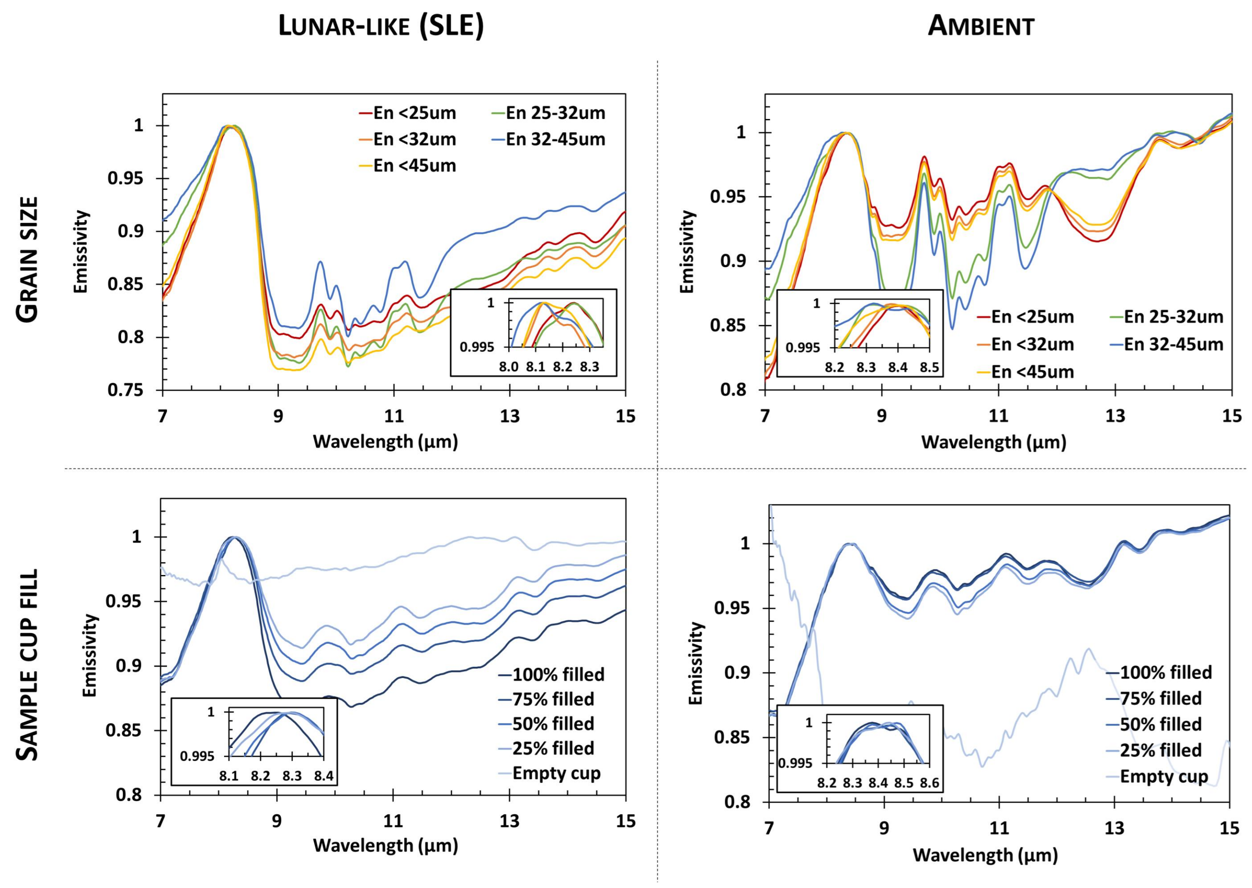



**Figure 7:** Thermal infrared spectra of samples of varied grain size (first row) and varied sample cup fill level (second row) in SLE and ambient conditions. A <30µm enstatite sample was used for the sample cup fill measurements. Inset plots zoom in on variations in CF position.

## V. Future Work

Although bytownite is fairly representative of the plagioclase minerals found on the lunar surface, a more representative mineral is anorthite. Therefore we are crushing and sieving anorthite to use in place of bytownite in the mineral mixtures.

Once we have measured spectra and CF positions for the initial set of mixtures (as indicated in Figure 2), we will identify regions on the ternary diagram where CF shifts are most nonlinear. We will prepare and measure more mineral mixtures corresponding to these regions to better constrain CF behavior.

## References/Acknowledgements:

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