DIFFERENCES IN FAR-IR EMISSIVITY BETWEEN PERMANENTLY SHADED AND PARTIALLY ILLUMINATED TERRAIN AT THE LUNAR SOUTH POLE E. Sefton-Nash[1], B. Greenhagen[2], J.-P. Williams[3] and D. A. Paige[3] [1]ESTEC, European Space Agency, Keplerlaan 1, Noordwijk 2201AZ, Netherlands (e.sefton-nash@cosmos.esa.int). [2]Applied Physics Laboratory, Johns Hopkins University, MD, USA. [3]Department of Earth, Planetary and Space Sciences, University of California Los Angeles, CA, USA.

Introduction: The northern floor and wall of Amundsen crater, near the lunar south pole, is a permanently shadowed region. We report on results from observations of two targets on the floor of Amundsen, one in the permanently shadowed region (PSR) and the other in the partially illuminated area (NPSR) (Figure 1), with the goal of observing relative differences in their far-IR emissivity in nighttime observations by LRO's Diviner Lunar Radiometer Experiment.

A 3km radius around centers of 93.1047°E, 84.5523°S and 91.2826°E, 83.6889°S define the NPSR and PSR targets, respectively. For the PSR target this radius ensures that only observations from within the PSR boundary are included, but the size is also a balance between minimizing scatter caused by heterogeneous thermal states, while ensuring sufficient data coverage for robust statistics.

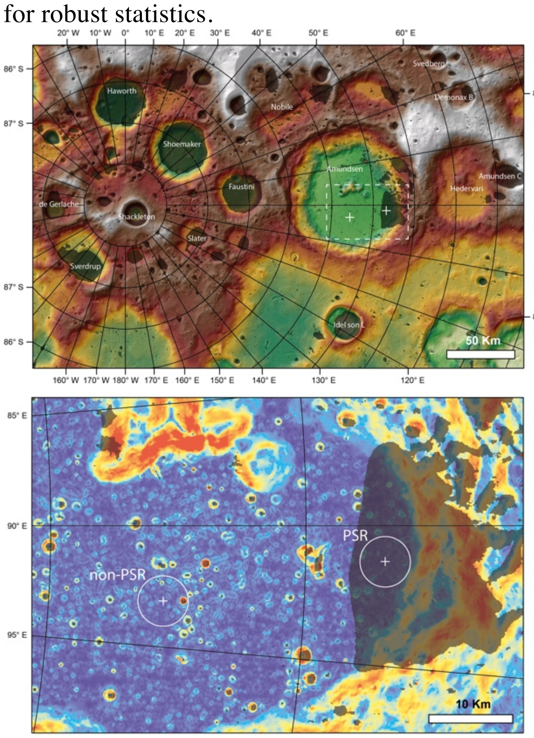

Figure 1: Study area and targets: colorized hillshade (top) and slope (bottom) from LOLA 20m/pixel data. Regions in permanent shadow darkened using 120 m/pixel map [1]. Dashed box marks lower panel. 2 targets in Amundsen crater marked with white '+'s, encircled at 3 km radius.

The permanently shadowed target includes terrain that is reported to indicate generally brighter 1064 nm albedo combined with annual maximum surface temperatures low enough to enable persistence of surface water ice (< 110K). Many permanently shadowed areas with similar LOLA reflectance characteristics do not show this trend [2].

This is consistent with a similar correlation of annual maximum temperature with anomalous ultraviolet radiation as measured by the LAMP instrument [3]. A patchy distribution of areas in the PSR target show a combination of off/on-band ratios > 1.2 and Lyman-α albedo < 0.03, indicating a possible water mass content of 0.1 – 2.0% [4].

Portions of our PSR target therefore indicate annual maximum temperatures, as well as ultraviolet and near-IR signatures that are anomalous compared to other south polar terrain in permanent shadow, and are consistent with the presence of surface water frost. Our method intends to quantify any effect by the presence of water frost, or by ultra-low temperatures, on emissivity in the far-IR, near the PSR terrain's planck peak.

Method: For each orbit we bin observations onto a triangular mesh representation of a digital elevation model (DEM) derived from LOLA 60m/pixel topography (Figure 2), incorporating effective field-of-view (EFOV) considerations [5].

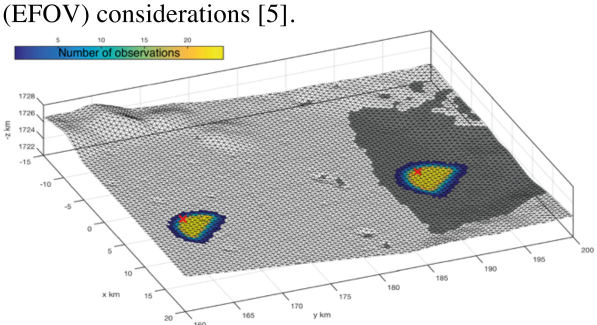

Figure 2: Cumulative Diviner ch. 9 EFOVs ray-traced onto terrain model in Amundsen crater for NPSR (left, orbit 30516) and PSR (right, orbit 34194) targets. The PSR is grayed and red crosses mark target centers. Note for these orbits, mean boresight emission angles w.r.t. lunar sphere are 36.3° and 28.9° for NPSR and PSR tragets, respectively. The vast majority of observations are ~nadir emission angles (< 5°).

Radiance received in a channel, c, is described by: $\Re_c = \int \varepsilon(\upsilon)\, f_c(\upsilon)\, B(T_s, \upsilon)\, d\upsilon$. Where $f_c(\upsilon)$ and $\varepsilon(\upsilon)$ are the quantum efficiency and emissivity at frequency υ, respectively, and B is the black body radiance emitted at frequency υ, by a surface of temperature, T_s. This formulation ignores emission angle effects, which are unimportant for night observations. For fixed T_s and known f_c, only emissivity varies. We select data from Diviner channels 7, 8 and 9; which are sensitive to photons between ~25-41, 50-100 and 100-400 µm respectively, and most representative of surface brightness temperatures between 69-178, 43-69, and < 43K respectively [6]. These data provide sufficient spectral coverage of radiance emitted at the expected nighttime temperatures (Figure 3).

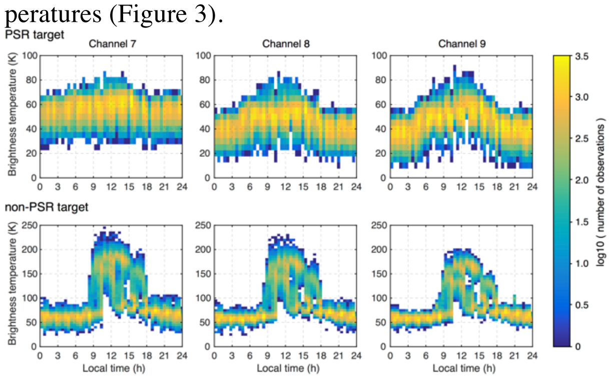

Figure 3: Brightness temperatures observed for PSR (top) and NPSR (bottom) targets between Jul. 2009 – Aug. 2017 plot over local mean solar time.

We estimate the surface kinetic temperature by retrieving bolometric brightness temperature, T_{BOL} [7], for each terrain element where observations in all 3 channels are present. Therefore, using each observed terrain element in each orbit swath, i.e. triangle in the DEM, and over many orbits, we generate a large list of data points to populate a parameter space with dimensions: T_{BOL}, $\mathfrak{R}_7$, $\mathfrak{R}_8$, $\mathfrak{R}_9$, local time and emission angle.

We model the band ratio $\mathfrak{R}_{8/9}$ as a function of surface temperature (Figure 4), because these long wavelength channels are most sensitive to PSR-relevant temperatures.

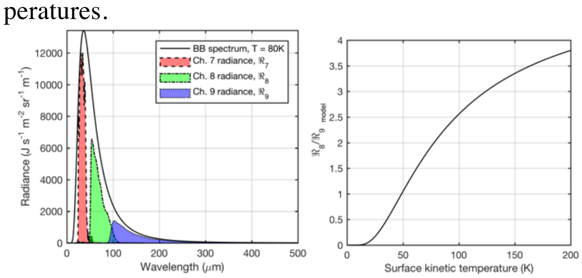

Figure 4: Left – Example of integration of quantum efficiency over wavelength $f_c(\nu)$ for Diviner channels 7, 8 and 9 beneath 80K Planck function to model expected signal at this temperature. Right – Ratio of radiance received in channels 8 and 9 ($\mathfrak{R}_{8/9\,model}$) expected as a function of surface temperature.

This model serves as an instrumental correction, and comparison of it to the observed $\mathfrak{R}_{8/9}$ for each target allows us to plot the signature of changes in apparent emissivity as a function of surface temperature (Figure 5), without assuming a value for emissivity.

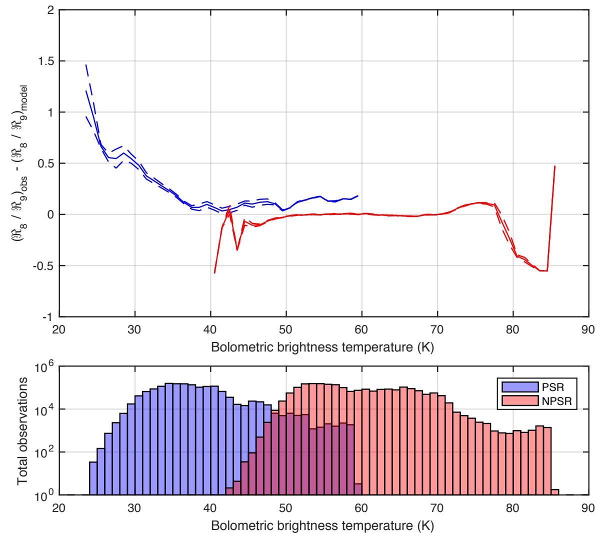

Figure 5: Band ratio model vs observations ±1σ over $T_{BOL.}$

Discussion: The NPSR target is very well predicted by the bandpass model that assumes invariate relative emissivities, implying there is little difference between apparent emissivities of channels 8 and 9 for the NPSR target in the 50-70K temperature regime. A small upturn around 75K and subsequent dramatic downturn from ~77K upwards both coincide with reduced numbers of observations, and therefore we do not interpret these features as having significant physical meaning. The PSR target shows a statistically significant increase from 40 to 30K, implying the model over-predicts $\mathfrak{R}_{8/9}$; meaning channel 8 emissivity increases relative to 9 (or 9 decreases rel. to 8) at very low temperatures.

We also find that $\mathfrak{R}_{8/9}$ does not depend significantly on local time (i.e. differential nighttime cooling rates) or emission angle (i.e. non-lambertian emission).

Conclusions: PSR and non-PSR targets in Amundsen crater differ in band ratio between Diviner channels 8 and 9, after correction for known instrumental effects; implying differential emissive properties in the far-IR. A possible temperature dependance in apparent emissivity is unique to the PSR target. The mechanism for this is not clear, but given the very low temperatures involved (and therefore high sensitivity to instrumental effects and noise sources), further investigation is required to determine if this result is related to the presence of surface volatiles that has been suggested by several other studies, or other low temperature processes.

References: [1] Marzarico et al., (2011), Icarus 211, p. 1066-1081. **[2]** Fisher, E. A. et al. (2017), *Icarus* 292, p. 74-85. **[3]** Gladstone, G. R. et al. (2012), *J. Geo. Res*. 117, E00H04. **[4]** Hayne, P. O. et al. (2015), Icarus 255, p. 58-69. **[5]** Williams, J.-P. et al., (2016), Icarus 273, p. 205-213. **[6]** Paige D. A. et al. (2010), Space Sci. Rev. 150, p. 125–160. **[7]** Paige, D. A. et al. (2010), Science 330, p. 479–482 *(Suppl. Mat.)*.