THERMOPHYSICAL BEHAVIOR OF LUNAR COLDSPOTS FROM DIVINER HIGH TIME-RESOLUTION, POST-SUNSET OBSERVATIONS. P.S. Russell[1], D. A. Paige[1], and B. Greenhagen[2], [1]Dept. EPSS, UCLA, Los Angeles CA, [2]APL/JHU, Laurel MD, patrick.s.russell @ epss.ucla.edu.

Introduction: Lunar "cold spots" are areas around small fresh craters that are colder than their surroundings in nighttime regolith temperature [e.g., 1, 2] (Fig. 1). The size of cold spots in Diviner data typically extend several crater radii beyond the visible crater ejecta. However, recent findings based on LROC photometry suggest subtle surface modification extends still further beyond the thermal cold spot [3]. At a basic level, Diviner data illustrates that the thermophysical properties of the surface in the cold spot region have somehow been altered by the impact process. The differences observed by Diviner and LROC suggest that cold spot formation is a complex process that may affect shallow but varying depths to different degrees.

Intriguingly, this cold anomaly does not appear in Diviner observations during eclipses when the sun has been blocked for only a short period of time [4]. Likewise, in the half hour just after sunset, there is some evidence that the cold spot area may in fact be warmer than the surroundings. This peculiar short-period response of cold spots to the cessation of solar heating would suggest that the very uppermost layer may be altered such that thermal inertia/density is increased rather than deacreased by cold spot formation (as underlying material must be to give the typical nighttime regolith cold spot signature).

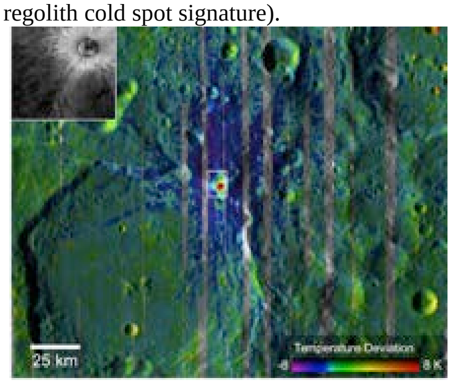


Figure 1. From [1]. Visual image and temperature anomaly at a cold spot.

Observation Campaign: We broaden and generalize the investigation of the immediate reaction of cold spots to the cessation of solar heating into a comprehensive "twilight" imaging campaign, in which we specifically target and aquire observations of surface features in the post-sunset, or twilight, period (i.e., ~18:00-19:00 local time). Analysis of this time period focuses specifically on variability in the thermophysical structure of the upper ~1 cm of lunar surface, whereas standard, previous analyses of nighttime temperatures (well after sunset) typically speak to the upper 10s of cm. It is not yet known whether other features or materials besides cold spots exhibit high-frequency temperature change in response to sunset/eclipse. Importantly, it is the uppermost portion of the surface that largely influences what is detected by a host of other remote-sensing techniques. Constraining the thermal intertia of the very surface would also benefit thermal models of the near- and sub-surface.

Unlike eclipses, which are rare and very narrowly limited geographically, a large fraction of the moon (roughly half) will be observable at least once within the 18:00-19:00 local twilight period every ~6 months. Local coverage for the most recent, Oct 2017, opportunity is given in (Fig. 2). Over 2016-2018, there are six opportunities for twilight observation, each lasting about 4 weeks to cover +/- 60° latitude**.** Any given location can be observed multiple times at moderate emission angles (<40°) during a twilight period, typically every ~7 lunar minutes on 3-5 sequential orbits, depending on latitude (and spacecraft activity). By acquiring co-located observations of target locations over successive orbits over multiple twilight opportunities, we are building up a high-resolution time series of post-sunset thermal evolution of the uppermost surface. Prior to this campaign, Diviner measurements within this time period for many locations were few, scarce, or absent. Features included besides cold spots are: Irregular Mare Patches (IMPs), impact rays, swirls, pyroclastics, impact melts, landing sites, and a few others.

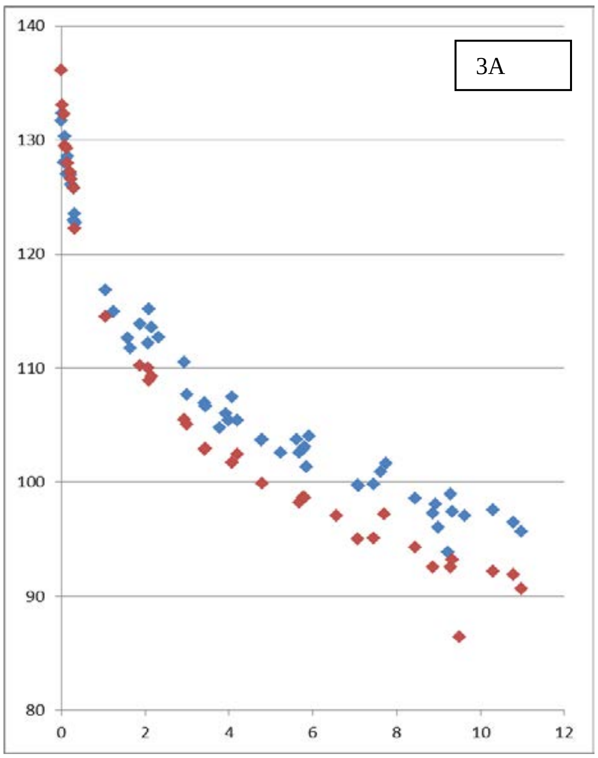
Results: To-date we have competed four periods of twilight observation (Table 1). The number of visible targets varies because most targets are on the lunar nearside, and each twilight period covers a different part of the Moon. In two years, we have collected 688 twilight observations, which is an increase of 320% over what existed prior to the campaign.

Table 1. Twilight imaging campains & metrics to date.

Obs. period	Date range	Targets in database	Targets visible	Observa-tions
Prior	2009-2015	-	-	215
0	Apr 2016	46	43	55
1	Oct 2016	80	75	250
2	Apr 2017	101	57	145
3	Oct 2017	101	75	238

As mentioned, initial observations of the twilight time period at some cold spots suggest that twilight temperatures mimic the behavior of eclipse temperatures (Fig. 3A), in that the cold spot does not become colder until ~half hour after sunset. This suggests that the thermal inertia of the upper ~1 cm is higher than surroundings, while the thermal inertia of the upper 10s of cm may be lower. Initial thermal modeling [5] bears this out in that high-resolution twilight measurements are best fit with a thermal model containing a higher surface density than the surroundings with a greater rate of decrease in density with depth than surroundings. However, most cold spots do not display this behavior - they are cooler than or similar to surroundings just at sunset (Fig. 3B). Here we compare temperature curves of four additional cold spots to the one modeled by [5], also examining radial variation within the cold spots. As demonstrated by the cold spots, it may be unexpected how the relative thermal behavior of different surfaces extrapolates from nighttime behavior back to the period of higher-frequency forcing post-sunset.

References: [1] Bandfield J. L. et al. (2014) *Icarus, 231*, 221–231. [2] Williams J.-P. et al. (2017) *Icarus, 283*, 300-325. [3] Speyerer E. J. et al. (2016) *Nature, 538*, 215–218. [4] Hayne P. O. et al., (2015) *LPSC XLVI*, Abstract #1997. [5] Powell T. M. et al., (2016) *AGU Fall*, Abstract #P21A-2079.



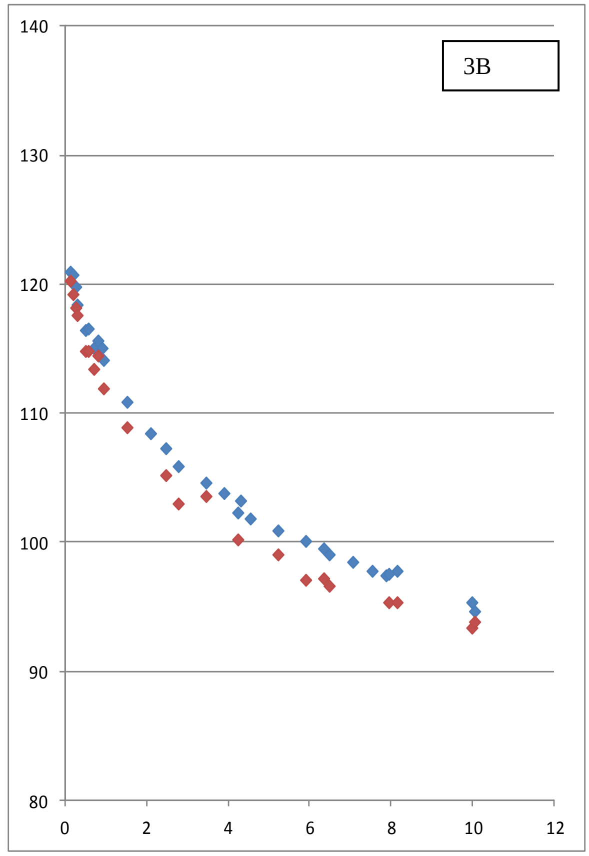


Figure 3. A) termperature of cold spot and surroundings , with cold spot warmer just after sunset. B) Another cold spot at which surroundings are warmer just after sunset, the more typical case.

Figure 2. Map of local times at which the nadir LRO groundtrack crosses the local lunar surface, during the Oct 2017 twilight opportunity. Total colored range: 17:45-19:00 local time. Color contours: yellow=18:00, green=18:15, cyan=18:30, blue=18:45. Faint, dashed, grey lines: 3 example LRO nadir groundtracks crossing the equator at 18:00, 18:15, and 18:30 local time. Letters indicate type of targeted feature listed in inset box.