VOLATILE STABILITY IN PERMANENT SHADOWS AT ARTEMIS III CANDIDATE LANDING REGIONS

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Introduction: The unique thermal environment at the lunar poles enables the sequestration of volatile species via cold-trapping within permanently shadowed regions (PSRs) [1,2]. The Artemis III science definition report [3] prioritizes characterizing the nature and spatial distribution of surface or subsurface volatiles. Thus, PSRs represent high-priority science and exploration targets (e.g. [4, 5, 6]). The current Artemis III Candidate Landing Regions (A3CLR) announced in August 2022 [7] are located within 6° of the south pole and either overlap or are proximal to multiple PSRs. The local thermal conditions in these PSRs are mainly influenced by secondary illumination (light scattered by local topography) [8,9], which is time-varying and can have a decisive impact on extravehicular activity (EVA) planning at the A3CLRs [10].

Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) [11] observations characterize the sunlit portion of the landing regions at exploration scales. Complementary high-resolution images of the PSRs within the A3CLRs are now being acquired by ShadowCam [12], a PSR imaging system onboard the Korea Pathfinder Lunar Orbiter. ShadowCam uses secondary illumination for imaging and enables the analysis of secondary illumination at fine pixel scales (2m or better). In our previous work [10] we discussed the dynamic nature of the secondary illumination and related thermal behavior for four selected PSRs within the 13 A3CLRs. Here, we compare the maximum radiance measured from ShadowCam images and the maximum summer temperature measurements from Diviner for all PSRs (> 1 km²) that overlap the A3CLRs to identify landing regions that are better choices concerning volatile stability within PSRs.

Methods: The 13 A3CLRs overlap with 28 unique PSRs larger than 1 km². Out of these, 12 are relatively small (< 2 km²) while four are considerably larger (> 50 km², near Nobile, Faustini, and Spudis). ShadowCam images for each PSR (Figure 1, 60 m/pixel) represent the maximum radiance map, i.e. for each PSR, the pixel shows the maximum radiance that ShadowCam observed between Jan 2023 and December 2023. Our calibration procedure [13] converts raw observations to radiance (Wm⁻²sr⁻¹μm⁻¹) images. Maximum temperatures at the PSRs are available from LRO Diviner observations binned onto 240 m pixel scale polar stereographic maps [14]. We computed the average maximum values for each PSR from the temperature and radiance maps.

Results and Discussion: Secondary illumination controls PSR temperatures thus PSRs that are brighter (in ShadowCam maximum radiance maps) tend to be hotter (in Diviner summer maximum maps). Secondary illumination varies diurnally and for smaller PSRs (< 5 km²), the average illumination can drop signifi-

Figure 1: ShadowCam maximum radiance maps for PSRs (> 1 km²) at the (A) de Gerlache Rim, de Gerlache Rim 2, Connecting ridge and Connecting ridge extension (B) Faustini Rim A and (C) Nobile Rim 2 and Amundsen Rim A3CLRs
Figure 2: Maximum surface temperatures (Y-axis left) and ShadowCam observed (Jan. 2023 to Dec. 2023) maximum radiance (Y-axis right) for the PSRs (> 1 km$^2$) overlapped by A3CLRs. PSRs corresponding to same A3CLRs are grouped together.

significantly for over 20% of the diurnal cycle (e.g., PSR in de Gerlache Rim 2,[10]). Consequently, surface temperatures drop considerably, even during peak summer, but increase rapidly at the end of the low illumination period. Sublimation rates are expected to fluctuate with secondary illumination and not all PSRs present stable conditions for cold trapped surficial volatiles.

Our analysis identifies the coldest, darkest PSRs – five A3CLRs host colder (< 125 K) and dimmer (< 0.15 W m$^{-2}$ sr$^{-1}$ µm$^{-1}$) PSRs compared to the other eight regions. These 14 PSRs are located at Haworth (4), Faustini Rim A (5), Nobile Rim 2 (2), Peak near Shackleton (1), and Leibnitz beta plateau (2) (Figure 2). PSRs at the other A3CLRs have higher peak temperatures (> 125 K) and brighter (radiance > 0.15 W m$^{-2}$ sr$^{-1}$ µm$^{-1}$) and thus have lower probabilities of harboring surface frost/ice. The coldest and dimmest PSR is in Faustini Rim A (PSR ID 8820400958360 in PSR Atlas [15]). The A3CLRs Faustini Rim A and Peak near Shackleton host relatively cold, dim PSRs where stable conditions for volatiles exist. Faustini Rim A has six PSRs, offering multiple choices of EVA design within the same region surrounded by sunlit regions of long continuous periods of direct illumination. A preliminary analysis shows slopes around the PSRs are between 5° and 15° and four of the six PSRs can be traversed with slopes < 10°. The Peak Near Shackleton region has a relatively large PSR (6 km$^2$), most of which is cold enough to cold trap water [10] but also has an illumination peak that receives persistent solar illumination (~ 80% of the time, [16]).

Conclusion: ShadowCam and Diviner observations uniquely enable the analysis of the correlated thermal and secondary illumination conditions that affect the stability and concentration of volatiles cold-trapped within the PSRs. The Faustini Rim A and Peak near Shackleton regions are better choices with lower temperatures, co-located to sunlit regions enabling access during EVAs. In contrast, PSRs within the A3CLRs near de Gerlache rim are all relatively bright and hot offering low probability of volatiles stable at the surface.

References: