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Illumination conditions within permanently shadowed regions at the lunar poles: implications for *in-situ* passive remote sensing

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1. Introduction

H_2O water ice has long been predicted to exist within cold, permanently shadowed regions (PSRs) near the north and south pole of the Moon [1]. Now, after decades of exploration, the preponderance of data from a host of remote sensing and in-situ investigations bear evidence for its existence [2]. Deposits of water ice constitute a valuable resource for both science and exploration and remain important targets for study in planetary science.

Due to its location within perennially shadowed craters, locating the presence of frost on the lunar surface presents a difficult challenge to future landed, ice-seeking missions. Passive remote imaging using diffuse starlight and scattered sunlight as illumination sources may provide a low-mass, power efficient means of locating frost from a distance. Due to strong absorption features of water in the far-UV (0.121 μm) and the IR (1.5 and 2.0 μm), the search for surficial frost can be most effectively carried out using multispectral imaging with either UV/Vis or IR/Vis filter pairings. Both UV (passive) and IR (active) illumination have been used to search for ice on the lunar surface [3,4]. The optimal filter pairing, however, will depend on the available photon flux, instrument sensitivity, as well as the relative reflectance of water-ice and regolith within these wavelength regimes. Improved understanding of the geographic, temporal and spectral distribution of light received to the PSRs may therefore help to guide instrument design for future landed missions.

In this work, we quantify the temporal variation in FUV (0.115–0.180 μm), optical (0.50–0.60 μm) and IR (1.45–1.55 μm) illumination received to PSRs from a variety of sources and explore its implications for passive remote imaging of lunar water-ice deposits.

2. PSR Illumination Sources

2.1 Scattered Sunlight

The largest source of optical and IR radiation reaching PSRs is sunlight that is singly- or multiply-scattered from the surrounding terrain. [5] provided initial estimates of scattered sunlight for selected points within northern and southern hemisphere PSRs, finding significant local and broad-scale geographic variation. Here, we extend the work of [5] in order to provide more detailed maps of the scattered solar flux reaching PSRs.

Scattered flux is modelled for large, contiguous PSR regions for which orbital remote sensing data provide evidence of exposed frost on the surface. We use polar topographic data (240 meters-per-pixel) from the Lunar Orbiter Laser Altimeter (LOLA) instrument on board the Lunar Reconnaissance Orbiter (LRO) spacecraft to model the visible and IR irradiance at the crater wall over a time span of one draconic year (346.6 days) using a 48-hr time step. The radiance emitted from the surface is approximated using the Lommel-Seeliger scattering model with a single scattering albedo of 0.3 for the visible band [6] and 0.6 for the IR band [7]. Additionally, a Henyey-Greenstein double-lobed single particle phase function is applied. The flux received to the permanently shadowed regions of the crater is determined by computing the line-of-sight between the illuminated terrain and each PSR pixel.

2.2 IPM and FUV Starlight

The largest source of FUV light to the PSRs is that of Ly-α photons from the interplanetary medium (IPM) and nearby UV-bright stars in the Milky Way galaxy. While faint, these diffuse sources of light provide enough illumination to observe ice at low concentrations (1-2%), as has been shown by Lyman

Alpha Mapping Project (LAMP) instrument on board LRO [3].

Here, we model the spatial and temporal variation of FUV PSR illumination using data from the Solar Wind Anisotropies (SWAN) instrument on the Solar Heliospheric Observatory (SOHO) spacecraft which acquires daily intensity background maps covering the entire sky within the 0.115–0.180 µm spectral range.

3. Results and Discussion

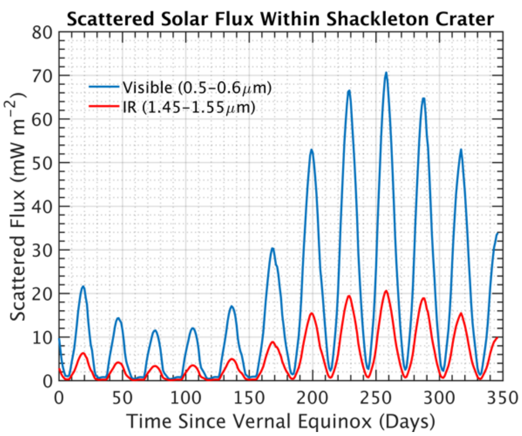

Figure 1: Seasonal variation in scattered solar flux reaching the PSR area of Shackleton crater (a 21-km diameter crater near the south pole). Data at each time step represent a mean of the entire crater floor.

Figure 1 displays the singly-scattered visible and IR flux reaching the PSR area within Shackleton crater as a function of time, beginning at the northern vernal equinox; the flux varies on diurnal timescales as well as seasonal timescales due to the obliquity of the Moon (< 1.59°). The peak flux occurs at the summer solstice (time = 250 days) and is ~6 times greater than the peak during the winter. Due to enhanced solar output at visible wavelengths, the visible flux exceeds the IR flux by a factor of ~3.5.

As shown in Figure 2, the illumination reaching Shackleton's PSR area is highly heterogeneous. While none of Shackleton's PSR regions are permanently doubly-shadowed, areas centrally located within the crater receive on average ~6 times less than the pole-ward facing PSR slopes on the outer edge of the crater.

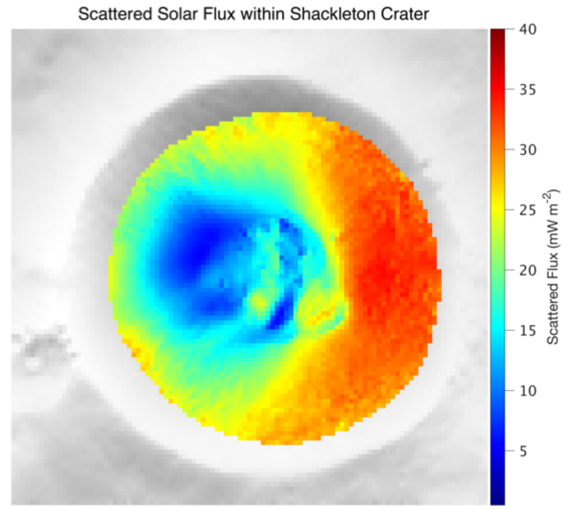

Figure 2: A map showing the reflected sunlight (in the visible regime, 0.50-0.60 µm) received to the permanently shadowed area at the floor of Shackleton crater. Data are averaged over one year.

The FUV illumination received to Shackleton from the IPM and starlight is very faint in comparison to the IR, amounting to only 2.8 µW m^{-2} when averaged across the year, or about 2,000 times less than the average IR flux.

The radiation that is received to PSRs and is available for remote sensing is only one component to the detection of water-ice. Instrument sensitivity, as well as the scattering properties of frost and regolith, are equally important in determining the feasibility of ground-based PSR frost detection. Future work will consist of expanding the scattering model to different PSR craters in order to understand the latitudinal and longitudinal variations in scattered sunlight. These results will be used to estimate the SNR of a surface imager using UV/Vis and IR/Vis filter pairings. Results for this analysis will be available by the commencement of the conference.

References

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