# Modeled Albedo Proton Surface Emission Spectra for the CRaTER Instrument at Nadir and Limb Orientations

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## Background

The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument is a linear energy transfer (LET) spectrometer aboard the Lunar Reconnaissance Orbiter (LRO), which is currently in a polar lunar orbit. The telescope consists of three consecutive silicon detector pairs. In order to cover a broad range of LET, each pair is made up of one thin detector and one thick detector separated only by the vacuum of space. The two regions between the three detector pairs contain tissue equivalent plastic material[1]. Employing coincidence conditions between observed detections allows CRaTER to differentiate between primary galactic cosmic radiation particles entering from the free-space end, and albedo ions entering from the lunar end of the telescope. In the standard operation configuration, the LRO spacecraft is oriented such that the telescope axis is directly nadir-pointing. Periodically, the spacecraft's orientation is manipulated such that the outer boundary of the lunar field of view is at the limb. Previous work suggests a strong angular dependence on albedo particle spectra in both energy and magnitude[2]. Therefore, the two spacecraft orientations each provide a unique cross-section, in angle and energy, of the entire albedo particle emission spectrum. In this work, we present a comparison of modeled results to determine the expected surface emission spectra of albedo protons for each orientation.

## Lunar Regolith Model

The spectrum of albedo protons being emitted from the lunar surface was calculated using the MCNP6 radiation transport code. The source term representing the incident galactic cosmic radiation (GCR) spectrum was constructed using the Badhwar-O'Neill 2014 model[3]. All GCR species from Z=1 to Z=26 were sampled in the source spectrum. Source particles were inserted isotropically in incident angle at a point just above a semi-infinite lunar surface. The resulting albedo proton spectrum exiting the lunar surface was tallied as a function of energy and angle from the surface normal. Figure 1 illustrates the resulting albedo proton spectrum binned as a function of emission angle for all energies. A more complete representation of the albedo proton spectrum as a function of energy and angle is shown in Figure 2. These results are subsequently used to calculate the expected albedo proton spectrum observed by the CRaTER instrument by folding in the D6/D4 angular response function for each orientation calculated in the next section.

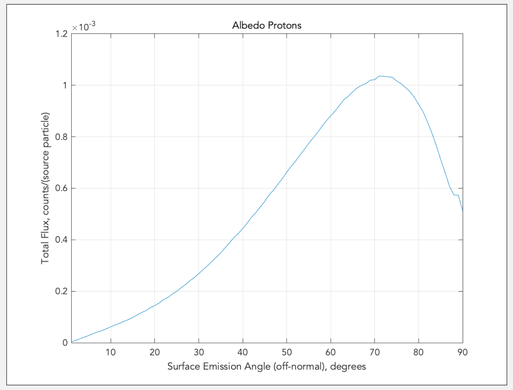


Figure 1. The lunar albedo proton surface emission spectrum binned as a function of emitted angle.

## CRaTER Response Model

The angular surface emission spectrum for particles observed via D6/D4 coincidence in the CRaTER instrument changes with spacecraft orientation. The angular responses for both the limb-pointing and nadir-pointing orientations were calculated independently using the MCNP6 Monte Carlo radiation transport code. The normalized representations of the albedo angles sampled by the CRaTER instrument for each orientation are shown in Figure 3. The angular response functions (Figure 3) are folded into the albedo proton emission distribution (Figure 2), to obtain the expected albedo proton spectrum observed by the CRaTER instrument. Figures 4 and 5 illustrate the expected distributions of albedo protons for the limb and nadir orientations, respectively. Integrating the two distributions in Figures 4 and 5 over albedo particle emitted angle yield the energy distributions shown in Figure 6.

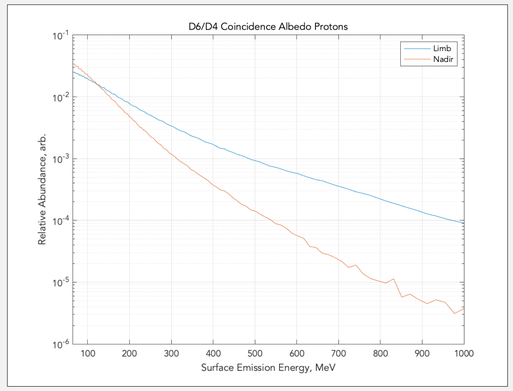


Figure 6. The normalized expected albedo proton spectrum binned as a function of energy observed by the CRaTER instrument via D6/D4 coincidence for both the limb and nadir orientations.

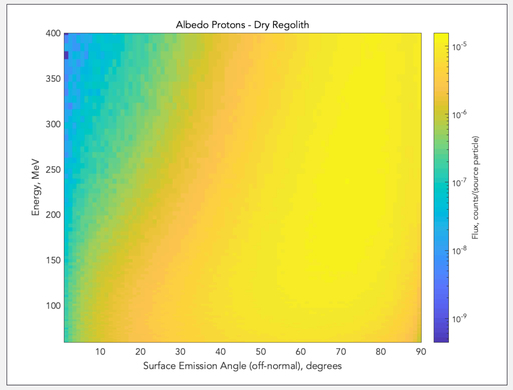


Figure 2. The lunar albedo proton surface emission spectrum binned as a function of both energy and emitted angle. No CRaTER response function has been applied.

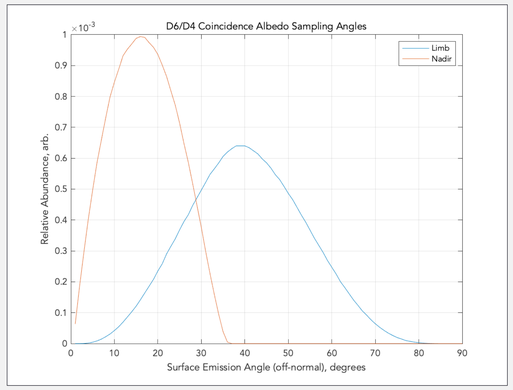


Figure 3. The normalized distributions of albedo particle surface emission angles sampled by CRaTER via D6/D4 coincidence for both limb and nadir orientations.

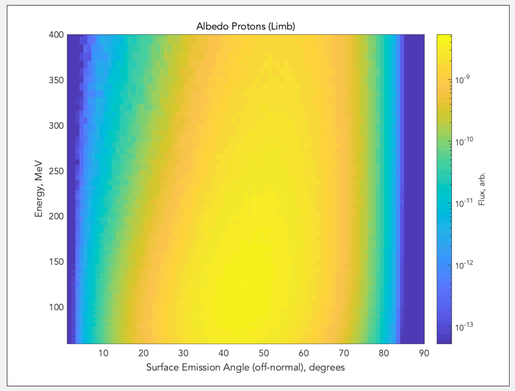


Figure 4. The expected albedo proton spectrum binned as a function of both energy and emitted angle observed by the CRaTER instrument via D6/D4 coincidence for the limb orientation.

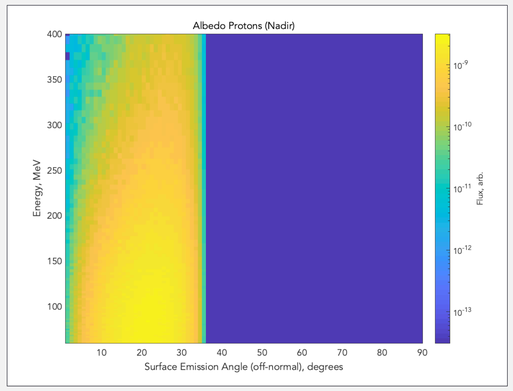


Figure 5. The expected albedo proton spectrum binned as a function of both energy and emitted angle observed by the CRaTER instrument via D6/D4 coincidence for the nadir orientation.

## Results

According to the results presented in Figure 6, the mean energies expected for albedo protons measured by the CRaTER instrument via D6/D4 coincidence are 137 MeV for the limb orientation and 110 MeV for the nadir orientation. The expected distribution of protons observed by CRaTER in the limb orientation falls less rapidly with energy than in the nadir orientation. This is likely due to the higher likelihood of direct reflection of incident GCR protons at glancing angles in the limb observation.

## Conclusions

- Developed methodology for calculating expected albedo proton spectrum measured by CRaTER via D6/D4 coincidence.
- The expected limb and nadir albedo proton spectra observed by CRaTER behave similarly, but with unique rapidity.
- Reproduce this calculation for hydrogenated regolith in order to evaluate the viability of using CRaTER to locate hydrogenated surface/subsurface features.

## References

[1] Spence, H. E. et al. Space Science Reviews 150.1-4 (2010)
[2] de Wet, W. et al. LPSC Meeting. (2018)
[3] O'Neill, P. M. et al. NASA/TP–2015–218569. (2015)

## Acknowledgements

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