The Effects Of Hydrogenated Surface Layers In Lunar Regolith On Galactic Cosmic Ray Induced Proton Albedo Yields

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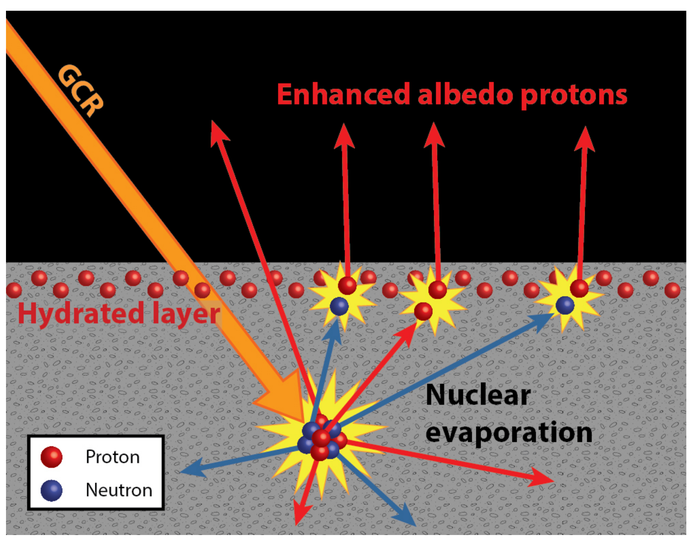
Background

The Lunar Reconnaissance Orbiter (LRO) spacecraft carries an instrument to study the galactic cosmic radiation (GCR) environment in the lunar vicinity: the Cosmic Ray Telescope for the Effects of Radiation (CRaTER).

The Lunar Reconnaissance Orbiter. Photo credit: NASA.

GCR particles collide with stationary nuclei within the lunar bulk, creating secondary particles. The albedo spectrum observed by CRaTER contains directly reflected incident particles and secondary particles that have escaped the lunar surface. Schwadron et al. observe a 40% difference in the proton fluxes measured by the CRaTER instrument when facing the lunar limb vs. nadir, and also report that proton albedo flux is suppressed by a hydrogenated layer within the lunar regolith [1,2].



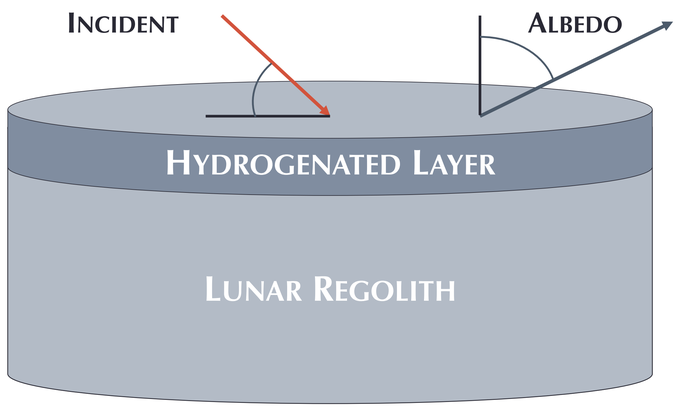
The albedo proton enhancement mechanism.

Objective

Investigate the effects of a surface hydrogen layer within lunar regolith on GCR induced albedo proton spectra as a function of emission angle and hydrogenated layer thickness.

Radiation Transport Model

The interactions of GCR particles within three separate lunar regolith geometries have been modeled using the Monte Carlo Neutral Particle (MCNP6) radiation transport code. An isotropic GCR spectrum comprised of elements ^{1}H through ^{56}Fe representative of a typical solar minimum is used as the boundary condition flux. The resulting albedo proton spectrum is tallied on the outer surface as a function of off-zenith angle.



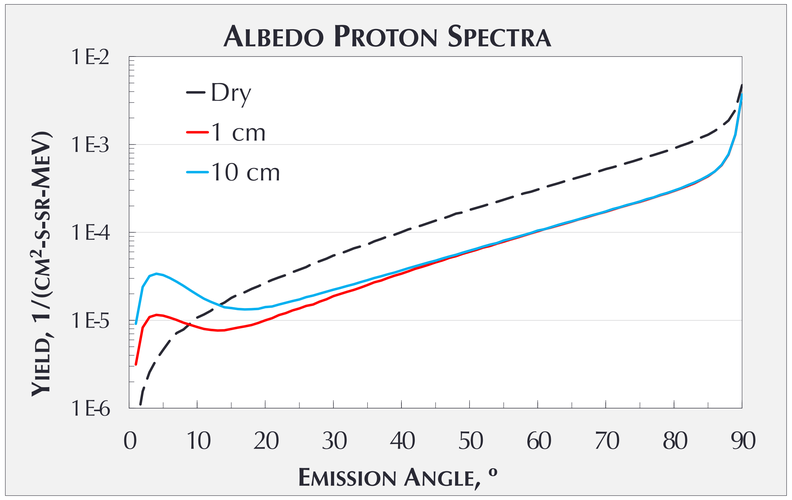
A representation of the transport model geometry.

The tallied kinetic energy range, 60-400 MeV, is selected to be compatible with the observable range of the CRaTER instrument. The albedo proton yield from a reference geometry of dry regolith is compared with the results of regolith geometries containing 1 cm and 10 cm surface layers of water. The calculation was performed independently for each incident element to ensure converged statistics. The results from each element are weighted according to its relative abundance in the incident GCR spectrum and combined to form the final albedo yield spectrum.

Reference

[1] Schwadron, N. A. et al. (2016) Icarus, 273, 25-35.
[2] Schwadron, N. A., et al. (2016) LPS XLVII, Abstract #1583.

Results & Discussion



GCR induced albedo proton emission spectra as a function of off-zenith emission angle for dry regolith, 1 cm water, and 10 cm water.

For the dry regolith case, the albedo proton spectrum has a minimum value at 0° off-zenith, and a maximum value at 90° off-zenith. This behavior agrees with the increased albedo proton flux when observing the lunar limb. As expected, the presence of a hydrogenated layer in the lunar regolith did suppress the overall albedo proton spectrum considerably for most angles. However, at angles approximately less than 10° off-zenith, the proton albedo flux is larger in the presence of hydrogenated layers than for dry regolith. This enhancement is likely the result of protons within the hydrogenated layer being ejected from the regolith via elastic collisions with secondary neutrons produced deeper within the regolith. This explanation is supported by the observation that the enhancement becomes more exaggerated as the thickness of the hydrogenated layer grows.

Furthermore, It is observed that the ^{1}H, ^{2}He, ^{12}C, ^{28}Si, ^{56}Fe components together serve as a sufficient surrogate for the entire GCR source term for the purposes of studying albedo yields in hydrogenated lunar regolith. The average difference for the 1 cm hydrogenated layer albedo flux between the full GCR source spectrum and the surrogate spectrum is 4.97%. For the 10 cm hydrogenated layer case, the difference is 5.08%.