ENERGY SPECTRAL PROPERTIES AND IMPLICATIONS OF THE LUNAR ENERGETIC PROTON ALBEDO.

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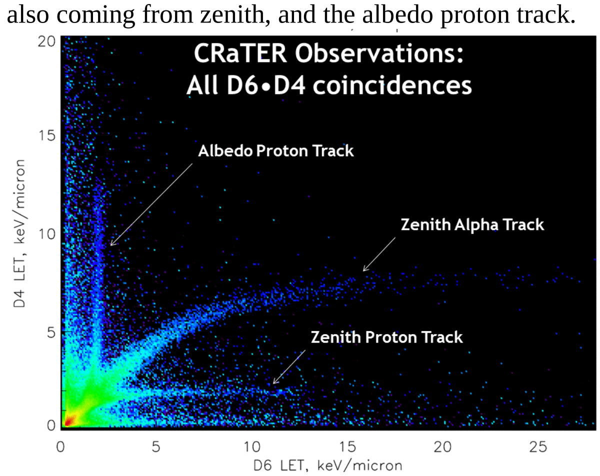
Background: The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) [1] has been immersed in the radiation environment of the Moon since its launch on NASA's Lunar Reconnaissance Orbiter (LRO) [2] in June 2009. CRaTER measures the linear energy transfer (LET) of extremely energetic particles traversing the instrument, a quantity that describes the rate at which particles lose kinetic energy as they pass through matter. A significant portion of the kinetic energy converts into deleterious ionizing radiation through interactions with matter, thus posing a radiation risk for human and robotic space explorers subjected to deep space energetic particles. CRaTER employs strategically placed solid-state detectors and tissue equivalent plastic (TEP), a synthetic analog for human tissue, to quantify radiation effects pertinent to astronaut safety.

LET Spectra: The CRaTER instrument measures the LET spectrum of ionizing radiation near the Moon using solid state detectors (SSDs) sandwiching two pieces of TEP. CRaTER employs a bi-directional telescope to measure the energy loss in three thin-thick pairs of SSDs (see Figure 5 of [1]). Thin detectors are odd numbered (D1, D3, and D5) and their thick detector pairs are even numbered (D2, D4, and D6). During normal operations, the D1-D2 detector pair is directed toward zenith while the D5-D6 detector pair is directed toward nadir (lunar center). Each detector operates independently through six separate electronic chains, each identifying ionizing radiation events above threshold in each detector, producing shaped electronic pulse heights related through calibration to deposited energy. When any one electronic chain identifies a pulse height above threshold, then its pulse height (energy) and the remaining five detector pulse heights (and hence energies) are determined for that ionizing radiation event. CRaTER's primary data product thus comprises a time-tagged series of energy deposits in each of six detectors whenever any single detector registers an ionizing event above a set threshold.

Proton Albedo: Though designed to measure galactic cosmic rays (GCR) and solar energetic protons coming from zenith and deep space, CRaTER observations can and have been used also to discover an energetic proton albedo coming from the lunar surface [3]. Particles moving through CRaTER at high energies lose fractionally little energy, but then lose more and more energy as they slow and potentially even stop in the matter they are traversing. Within CRaTER, we can thus establish ionizing radiation directionality in a statistical sense by exploring energy loss in detector pairs, particularly those pairs separated by an amount of intervening matter that slows them substantially (i.e., between D2 and D4 in the zenith direction and between D4 and D6 in the nadir direction) .

The figure below shows a D4 versus D6 LET spectrogram in which color indicates number of events (red:highest to purple:lowest), over the ranges of LET (keV/micron) that cover CRaTER's response to incident protons and alpha particles. We identify three "tracks": protons traversing the CRaTER instrument from zenith, alpha particles (doubly-ionized helium) also coming from zenith, and the albedo proton track.



We use CRaTER observations to quantify the energy spectrum of this newly-discovered proton albedo and demonstrate through preliminary numerical modeling that this it is produced through nuclear processes and interactions of GCR with the lunar regolith. Finally, we discuss other aspects of this unanticipated secondary source of ionizing radiation near the Moon, including quantifying its contribution to radiation dose and implications for similar interactions with other airless planetary objects.

References:

[1] Spence H. E.. et al. (2010) *Space Sci. Rev., 150(1-4),* 243-284. [2] Chin G. S. et al. (2007) *Space Sci. Rev., 129(4)*, 391-419. [3] Wilson J. (2012) *LPSC XXVIII (this meeting)*.