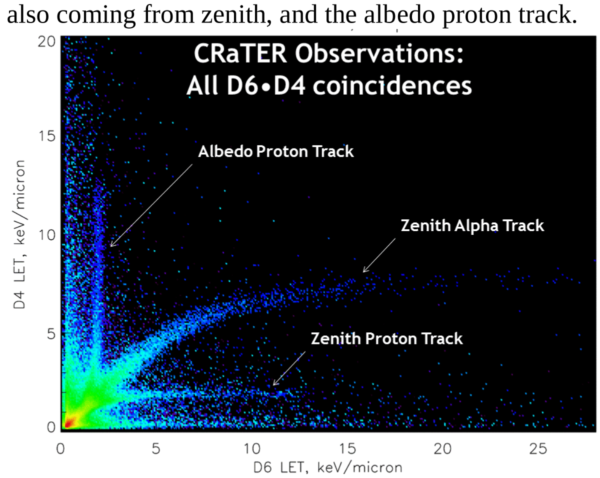
LUNAR ENERGETIC PROTON ALBEDO: MEASURED AND MODELED ENERGY SPECTRA AND OTHER PROPERTIES. H. E. Spence[1], J. B. Blake[2], A.W. Case[3], M. J. Golightly[1], C. Joyce[1], J. C. Kasper[3], M. D. Looper[2], J. E. Mazur[2], N. A. Schwadron[1], S. Smith[1], L. W. Townsend[4], and C. J. Zeitlin[5], [1]Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH 03824, Harlan.Spence@unh.edu, [2] The Aerospace Corporation, El Segundo, CA 90009, [3] Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, [4] Department of Nuclear Engineering, University of Tennessee, Knoxville TN 37996, [5] Southwest Research Institute, Boulder, CO 80302.

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 (denoted D1, D3, and D5) and their thick detector pairs are even numbered (denoted 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 the LET and dose [3] from 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 blue: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.



In this work, we use CRaTER observations to quantify the energy spectrum of this newly-discovered proton albedo. We use multiple-detector energy deposits of all those particles identified as proton albedo and invert these energy deposits to infer the incident proton albedo spectrum. This technique allows us to reconstruct the incident spectrum between ~65 and ~125 MeV.

Data/Model Comparisons: We demonstrate through numerical modeling, using GEANT4, that the proton albedo is produced through nuclear processes and interactions of GCR with the lunar regolith. The albedo spectrum inferred from measurements validates the modeled spectrum; we use the model spectrum, which extends over a broader energy range, to estimate other physical quantities. Finally, we discuss these other aspects of this 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:

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