Long-Term Observations of Galactic Cosmic Ray LET Spectra in Lunar Orbit by LRO/CRaTER

M. D. Looper, J. E. Mazur, J. B. Blake, H. E. Spence, N. A. Schwadron, J. K. Wilson, A. P. Jordan, C. Zeitlin, A. W. Case, J. C. Kasper, L. W. Townsend, and T. J. Stubbs

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GCR Observations Outside Earth's Magnetosphere



- Cosmic Ray Telescope for the Effects of Radiation (CRaTER)
- Aboard LRO at moon since 2009
- Six silicon solid-state detectors
- D1-D6 from zenith to nadir
- Odd numbers 148μ , evens 1mm
- Thick detectors measure low LET and thin detectors measure high



Photo courtesy of NASA



- Energy-deposit spectra normalized by detector thickness available for arbitrary time periods (solar particle events separately) at http://crater-web.sr.unh.edu
- Calibration: Case et al., Space Weather (2013) (doi 10.1002/swe.20051)

GCR H Contributions to LET Signal - Simulations



GCR H Contributions to Background - Simulations



GCR Heavy Ion Contributions to LET - Simulations D1-6 events, all GCRs, all directions 500 normalized energy deposit, keV/micron 400 Main track (Fe) Fragmentation upstream 300 200



Components of Low End of Simulated LET Spectrum



Normalized energy deposit, keV/µ

Components of High End of Simulated LET Spectrum



Normalized energy deposit, keV/µ

Components of Simulated LET Spectrum, D1-D6



Normalized energy deposit, keV/µ

Simulated LET Spectrum With & Without D1 & D3



Normalized energy deposit, keV/µ



Ratio of LET spectrum for each day vs. average of 2009-2010 solar minimum value (red bar at bottom of plot), with days having solar particle events blacked out.

Time Variations of LET Spectra – 6-Month Averages Ratio of spectra to solar minimum value Normalized energy deposit, keV/micron 1.1 100 0.9 Ο С 10 E 0.7 0.5 He 0.3 Η 2008 2010 2012 2014 2016 2018 2020 Year

More detailed analysis reported by Zeitlin et al., Space Weather, submitted (2019)

Observations of Secondary Protons from Moon



From Looper et al., Space Weather (2013) (doi 10.1002.swe.20034)

Summary

- CRaTER has measured GCR LET spectra in lunar orbit for nearly a complete solar activity cycle. Spectra are available over the mission to date online, on demand. LET observations cover all significant GCR species, from about 0.2 to 3000 keV per micron in silicon.
- Geant4 simulations of the sensor response allow us to identify contributions to these measurements from GCRs arriving both inside and outside the nominal geometric acceptance cone defined by detector coincidence. Efforts to use this information to improve background rejection in the observations are ongoing.
- Comparing LET spectra over time with that measured during the deep solar activity minimum at the start of the mission in 2009, we see the expected pattern of reduction of GCR intensity during solar maximum, with less energetic ions being reduced more strongly than relativistic ones. As of early 2019, the intensity has recovered nearly to the level during the previous solar minimum.
- Geant4 simulations will also prove useful in subtracting GCR-induced background from CRaTER's measurements of secondary "albedo" protons coming up from the lunar surface.