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Update on Radiation Dose From Galactic and Solar Protons at the Moon Using the LRO/CRaTER Microdosimeter

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Update on Radiation Dose From Galactic and Solar Protons at the Moon Using the LRO/CRaTER Microdosimeter

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The NASA Lunar Reconnaissance Orbiter (LRO) has been exploring the lunar surface and radiation environment since June 2009. In *Mazur et al.* [2011] we discussed the first 6 months of mission data from a microdosimeter that is housed within the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) instrument onboard LRO. The CRaTER microdosimeter is an early version of what is now a commercially available hybrid that accurately measures total ionizing radiation dose in a silicon target (http://www.teledynemicro.com/product/radiation-dosimeter). This brief report updates the transition from a deep solar minimum radiation environment to the current weak solar maximum as witnessed with the microdosimeter.

The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) microdosimeter is behind about 4.4 g/cm^2 equivalent aluminum, corresponding to the range of ~55 MeV protons. Energetic protons are the dominant source of ionizing radiation at the Moon. The measured dose includes contributions from the low-energy part of the galactic cosmic ray proton spectrum and the high-energy portion of typical solar energetic particle events. Figure 1 is the history to date of the total ionizing dose averaged over 12 h intervals. The figure includes the entire Lunar Reconnaissance Orbiter (LRO) orbital history that ranged from ~50 km circular to more elliptical orbits with aposelene above ~150 km. We did not correct the observed dose rate for the changing amount of solid angle blocked by the Moon in Figure 1 as one would need to do to derive an interplanetary rate. When averaged over 12 h, the variations among the various orbit modes have less than a 5% and 20% effect on the galactic cosmic ray dose rate and peak solar proton dose rate, respectively.

From the mission start in June 2009 to the latest data we saw a decrease in the galactic cosmic ray dose rate by a factor of 2 due to the increasing solar modulation [*Schwadron et al.*, 2012, 2014]. Also note that solar particle events were absent from the first year and a half of the mission, but they began to appear in the dose record in 2011.

The cross-hatched area indicates the ionizing dose rate measured with Apollo Personal Radiation Dosimeters (APRDs) [*Richmond et al.*, 1968] and recently analyzed to infer the dose only in lunar orbit and on the surface using transcripts of the Apollo crew-to-ground verbal communications (cf. E. M. Jones et al., 2014, http://www.workingonthemoon.com, *derived from the NASA Apollo Lunar Surface Journal*, E. M. Jones and K. Glover, The Apollo Lunar Surface Journal, 2014, http://www.hq.nasa.gov/alsj/frame.html). Shielding from the Apollo command module was at least a few g/cm^2 with half of the solid angle from the center seat having at least 10 g/cm^2 (W. Atwell, personal communications, 2014). The CRaTER microdosimeter shielding is therefore on the low end of the Apollo command module mass distribution and is better shielded than the lunar module.

The figure illustrates our two main points. The first is the similarity between the microdosimeter galactic cosmic ray dose rate and the Apollo reports. There was more solar modulation in the 1969 to 1972 era than in the LRO mission, so with similar shielding the similarity is puzzling. The inconsistent reporting of APRD data across the Apollo missions as noted by (E. M. Jones et al., 2014, http://www.workingonthemoon.com) together with the 10 mrad resolution of the APADs may lead to a larger systematic uncertainty in the Apollo data than the figure suggests.

The other main point is the relatively low dose contribution from solar particle events of the current solar maximum. Measurements of solar protons from long baseline missions such as NOAA/GOES indeed show the meager intensity of recent events. Turning to the LRO data, the most intense event behind 4.4 g/cm^2 occurred on 7 March 2012. This event's integral proton fluence above 30 MeV was on the order of 1% of the August 1972 worst case [*Jiggens et al.*, 2014]. As a result, our most intense event contributed only about

10 rads to the LRO mission integrated dose as shown in Figure 1 (bottom), whereas an actual worst case like August 1972 would have added several kilorads to the mission dose.

This continuous environmental monitoring with LRO has high value to several communities. It places historical radiation measurements into current context, which is especially important for designs of new spacecraft with and without human crew. It also provides a reference for the near-Earth radiation environment that upcoming robotic and manned missions might encounter if solar particle events fail to reach historical intensity again.

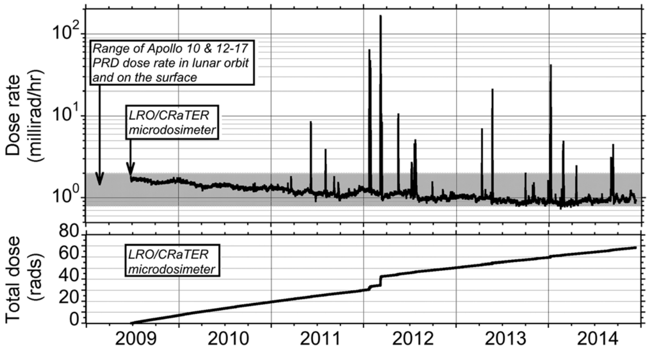

Figure 1. LRO/CRaTER microdosimeter measurements from launch in June 2009 to December 2014. (top) The minimum dose rate, below 2 mrads/h, originated from galactic cosmic rays that slowly varied and was within the range of Apollo measurements on the lunar surface and in lunar orbit indicated by the grey horizontal band (E. M. Jones et al., 2014, http://www.workingonthemoon.com). On this time scale, solar particle events appeared as spikes above the galactic cosmic ray dose rate. (bottom) The integrated total dose was about 70 rads after 5.5 years.

References

Jiggens, P., M. Chavy-Macdonald, G. Santin, A. Menicucci, H. Evans, and A. Hilgers (2014), The magnitude and effects of extreme solar particle events, *J. Space Weather Space Clim.*, *4*, A20, doi:10.1051/swsc/2014017.

Mazur, J. E., W. R. Crain, M. D. Looper, D. J. Mabry, J. B. Blake, A. W. Case, M. J. Golightly, J. C. Kasper, and H. E. Spence (2011), New measurements of total ionizing dose in the lunar environment, *Space Weather*, *9*, S07002, doi:10.1029/2010SW000641.

Richmond, R. G., W. G. Davis, J. C. Lill, and C. S. Warren (1968), Radiation dosimetry for manned space flight, *NASA SP-169*.

Schwadron, N. A., et al. (2012), Lunar radiation environment and space weathering from the Cosmic Ray Telescope for the Effects of Radiation (CRaTER), *J. Geophys. Res.*, *117*, E00H13, doi:10.1029/2011JE003978.

Schwadron, N. A., et al. (2014), Does the worsening galactic cosmic radiation environment observed by CRaTER preclude future manned deep space exploration?, *Space Weather*, *12*, 622–632, doi:10.1002/2014SW001084.

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