The Cosmic Ray Telescope for the Effects of Radiation (CRaTER) Investigation for the Lunar Reconnaissance Orbiter

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35-WORD ABSTRACT

We describe an investigation to measure linear energy transfer spectra in lunar orbit. The measurements and improvements to radiation transport models will address the effects of the lunar radiation environment on human and technological systems.

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INTRODUCTION

A top priority of the NASA Lunar Reconnaissance Orbiter (LRO) mission is the "characterization of the global lunar radiation environment and its biological impacts and potential mitigation, as well as investigation of shielding capabilities and validation of other deep-space radiation mitigation strategies involving materials" [1]. LRO is the first mission in the NASA Robotic Lunar Exploration Program and is currently planned for launch in late 2008. The overall mission objective is to prepare for and support future human exploration of the moon. To achieve the mission objective, LRO includes investigations that will characterize the lunar radiation environment, develop a high-resolution geodetic grid of the lunar surface for selection of future landing sites, assess the resources and environments of the lunar poles, and map the surface composition. The operational orbit will be 50 ± 20 km altitude polar orbit. The spacecraft will be 3-axis stabilized with a primary mission duration of 1 year [2].

We present here a summary of the preliminary design of the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) sensor for LRO. The CRaTER investigation will address the effects of ionizing energy loss in materials due to solar energetic particle events and galactic cosmic rays, specifically in silicon and in an analogue to human tissue. Our investigation focuses on understanding the linear energy transfer (LET) spectrum inside materials through direct measurement in the space radiation environment, particularly ions with energies above 10 MeV/nucleon, combined with models of radiation transport through materials. The CRaTER results will have direct application to the biological effects of the lunar radiation environment as well as the environmental effects on electronic systems. The details of the LET spectra will have direct use in evaluating Single Event Effect vulnerabilities.

INVESTIGATION GOALS AND APPROACH

The CRaTER investigation goals are to:

• Measure and characterize that aspect of the deep space radiation environment, LET spectra of galactic and solar cosmic rays (particularly above 10 MeV), most critically important to the engineering and modeling communities to assure safe, long-term, human presence in space.

• Develop a simple, compact, and comparatively low-cost instrument, but with a sufficiently large geometric factor needed to measure LET spectra and its time variation, globally, in the lunar orbit.

• Investigate the effects of shielding by measuring LET spectra behind different amounts and types of areal density, including tissue-equivalent plastic.

• Test models of radiation effects and shielding by verifying/validating model predictions of LET spectra with LRO measurements, using high-quality galactic and solar particle spectra available contemporaneously on ongoing/planned NASA spacecraft (e.g. ACE & STEREO) and other agency spacecraft (e.g. NOAA-GOES).

There are several alternatives for measuring the radiation environment near the Moon. For example, a dosimeter is a low-cost option that demands minimal spacecraft resources. However, a total dose measurement provides neither information about the spectral shape of the deposited energy nor information on the particle distribution with ion mass. It is well known that different energies and different ion populations produce different effects in electronic materials and in human tissue. A dosimeter provides only an integrated measure of total absorbed energy; all useful information on how the energy was deposited is lost. In principle, modeling of the particle transport through the dosimeter could recover information about the deposition, but only after significant modeling efforts with attendant uncertainties.

Another alternative is to measure the incident particles with a cosmic ray spectrometer. High-resolution measurements of the galactic and solar energy spectra (above 10 MeV/nucleon) with elemental composition are ideally required to fully understand the deep space radiation environment. From fully resolved energy spectra of individual ion species, one could use models to transform the incident fluxes into net LET spectra behind a given areal density of material. However, the instrumentation required to resolve these populations (including the important Z>2 ions above ~100 MeV/nucleon) typically demands large resources.

Our approach for LRO is a cosmic ray spectrometer designed with less capable mass resolution than is achievable with state-of-the-art instruments. Coarse mass resolution allows for a less technically challenging spectrometer. Nevertheless, in order to obtain the important high-energy coverage of the heavy ions, significant solid-state detector material is still required to stop the particles and thus record total energy (e.g. the range of 170 MeV/nucleon Fe is > 8mm in silicon). Fortunately, during the LRO mission, several current and planned NASA spacecraft (ACE, STEREO) as well as spacecraft from other agencies (e.g., NOAA–GOES) will be measuring galactic and solar particle spectra contemporaneously from well above low-Earth orbit. The populations measured at these high-altitude locations will serve as excellent proxies for the population of cosmic rays present at the lunar orbit at the same time (or at some easily calculated propagation time delay in the case of SEP events). Galactic cosmic rays are not considerably localized in space, so that measurements anywhere within several hundred Earth radii of the Moon will be sufficient.

Figure 1 shows an example of the spectra that will be obtained by and made available to our team by ACE and future space science missions. While the parent cosmic ray populations are arguably important for LRO, such high quality measurements will be available in a leveraged manner. Reproducing them on LRO would unnecessarily strain valuable spacecraft resources by duplicating measurements already provided by other spacecraft assets. It is more important to focus on the direct measurements of the ionizing energy loss of these particles, their secondaries, and the improvements in radiation transport models that will result.

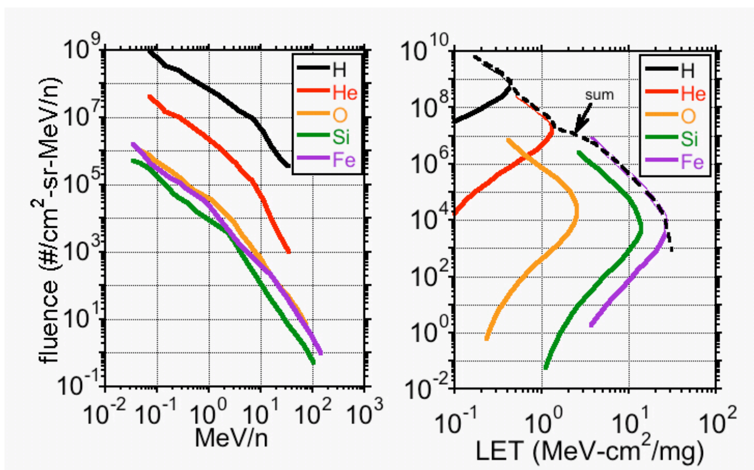

Fig. 1: Left panel shows solar particle energy spectra in the 6 November 1997 solar particle event as measured on ACE. The right panel shows fits to these energy spectra as functions of LET in free space.

INSTRUMENT DESIGN

The investigation hardware consists of a single, integrated sensor and electronics box with simple electronic and mechanical interfaces to the spacecraft. The CRaTER telescope design is based on standard stacked-detector, cosmic ray telescope systems that have been flown for decades, using detectors developed for other NASA flight programs. The telescope is bi-directional and senses and analyzes particles passing through its 6 ion-implant silicon detectors (Figure 2). However, we use sections of tissue-equivalent plastic (TEP) between the detectors as analogues to human muscle. The TEP is 77.5% C and 10.1% H by weight. The charge collected in each detector is amplified and digitized using standard pulse-height processing techniques. We use on-board lookup tables to define multiple coincidence types that can prioritize events that, for example, are incident from the zenith direction and stop in the detector stack, or events that indicate an interaction via scattering or spallation inside the telescope or inside the spacecraft. Table 1 lists the details of the detector and TEP components as well as the instrument's fields of view.

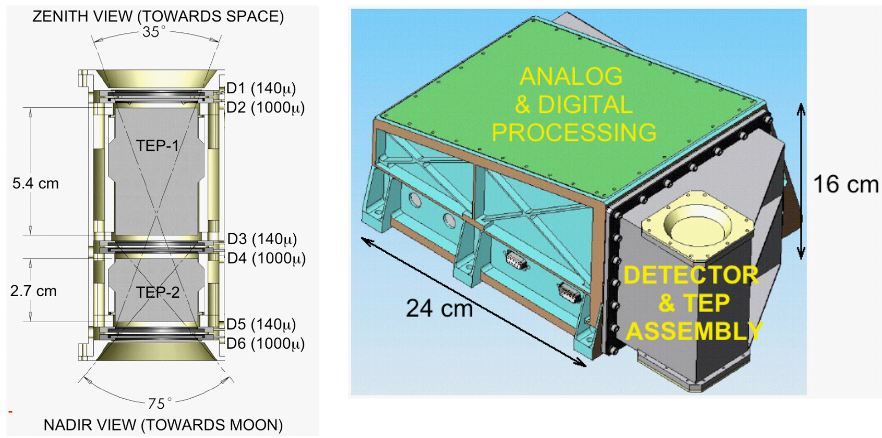

Figure 2. Cross-section of telescope housing showing the detector and TEP spacing and fields-of-view. Entire CRaTER instrument with telescope housing mated to the analog and digital processing assembly.

Table 1. Telescope components and parameters

Low LET detectors [a]	9.6 cm^2 circular, 1000μ thick 0.2 MeV threshold
High LET detectors [b]	9.6 cm^2 circular, 140μ thick 2 MeV threshold
TEP absorber 1	5.4 cm cylinder
TEP absorber 2	2.7 cm cylinder
Field of view – zenith	35° [c]
Field of view – nadir	75° [d]
Geometry factor	0.7 cm^{2}sr [e]
LET range	0.2 – 7 MeV/μ (Si)
Incident particle energy range [e]	>10 MeV (H) >87 MeV/nucleon (Fe)

[a] D2, D4, D6 in Figure 2
[b] D1, D3, D5 in Figure 2
[c] For 6-fold detector coincidence events
[d] For D3D4D5D6 coincidence events
[e] D1D2 events including 60 mils aluminum shield in zenith view

Table 2 lists the preliminary CRaTER resources. The relatively high data rate takes advantage of the vehicle's 1553B network.

Table 2. CRaTER instrument resources

Mass	5.6 kg
Power	9.0 W
Volume	~6700 cm^3
Data rate	89.4 Kbps

SIMULATION RESULTS

An important component of the CRaTER investigation is the use of state-of-the-art radiation transport codes, not only to guide the design of the flight instrument, but also as a means of code validation through ground-based tests at accelerator facilities and of course during flight. We show in Figure 3 an example of the recently updated HETC code [3] applied to the CRaTER design. This version of the code included an event generator capable of providing nuclear interaction data. The event generator predicts the interaction product yields and production angles and energies using nuclear models and Monte Carlo techniques. Specifically, the simulation followed the primary particles indicated (600 MeV/nucleon Fe and 1 GeV protons, energies near the peak galactic cosmic ray intensity) with normal incidence from the zenith. The code tracks the energy deposits in the telescope components as well as the charge-composition of the secondaries. We see considerable fragmentation in the case of Fe and interactions up to the atomic number of silicon in the case of protons.

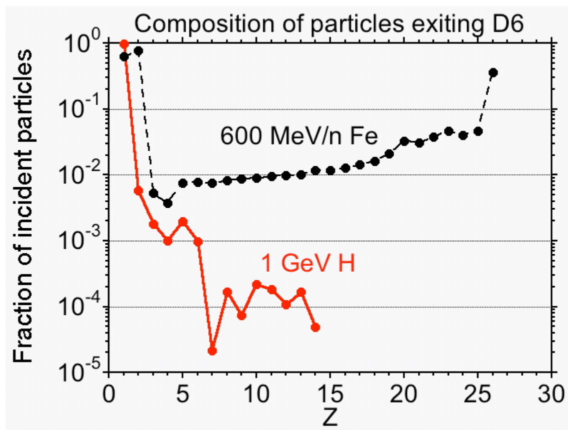

Fig. 3: Charge composition of particles exiting the CRaTER telescope in a recent HETC Monte Carlo simulation.

SUMMARY

The CRaTER investigation will measure and characterize that aspect of the deep space radiation environment - LET spectra of galactic and energetic solar particles and their secondaries - most critically important to the engineering and modeling communities to assure safe, long-term, human presence in space. The investigation involves coordinated efforts on instrument design, ground-based accelerator testing, improvements to transport models, flight data, and concurrent space science measurements.

REFERENCES

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[3] L. W. Townsend, T. M. Miller, and Tony A. Gabriel, "HETC radiation transport code development for cosmic ray shielding applications in space", Radiation Protection Dosimetry Vol. 116, No. 1-4, 135-139, 2005.