Earth-Moon-Mars Radiation Environment Model

Space Weather, Safeguarding the Journey

Space weather impacts on robotic and human productivity

Radiation bombardment on the lunar surface and subsurface
**Space Radiation Environment**

- **Energetic Particle Sims**
  - Energy Spectra, Angular Dists., and Composition from Cosmic Rays and EPs

- **Energetic Particle Obs**
  - STEREO, ACE, Wind, SoHO, SAMPEX, GOES, Ulysses

**Time-Dependent Radiation Exposure**

**EMMREM**
(HETC-HEDS, HZETRN, BRYTRYN)

**Output:**
- LET Spectra
- Dose-Related Quantities

**Uncertainty Reduction**

**Radiation Exposure Obs**
- Earth: ISS and Shuttle (STS)
- Moon: LRO/Crater
- Mars: MSL/RAD, Odyssey/MARIE

**Scientific Exploration & Discovery**

**Human Exploration**
Accomplishments

• **Radiation Biology**
  – Risk models
  – Radiation Transport
    • Interplanetary Space
    • Earth, Moon, Mars

• **EPREM**
  – Transport Particle Acceleration
  – Particle radiation throughout inner heliosphere
    – Earth, Moon, Mars

• **EPREM-MHD**
  – Transport Effects
  – Particle Acceleration

• **Validation**
  – Marie
  – CRaTER

• **Extended Solar Minimum**

• **EMMREM Special Section**
  (Spaceweather Journal; currently, 12 papers)
Select EMMREM Special Section Papers

- Schwadron et al., EMMREM Framework, *Spaceweather Journal, 8*, 2010
- Schwadron et al., GCR Hazard in the extended solar minimum between cycles 23 and 24, *Spaceweather Journal, 8*, 2010
- PourArslan et al., Time-dependent estimates of organ dose and dose equivalent rates for human crews in deep space from the 26 Oct 2003 solar energetic particle event (Halloween event) using EMMREM, *Space Weather 8*, 2010
- Townsend et al., Parameterization of LET for the CRaTER Instrument, *Spaceweather, 8*, 2010
- Kozarev et al., Modeling the 2003 Halloween Events with EMMREM: Energetic Particles, Radial Gradients and Coupling to MHD, Spaceweather, 8, 2010
EMMREM has proved very successful at predicting SEP spectra and radiation dose estimates at different distances in the inner heliosphere. Figures below show two recent papers by which SEP time profiles, onset, and radiation estimates were successfully predicted at Mars (Odyssey) and Ulysses located at 1.44 AU and 4.91 AU, respectively. 1 AU measurement from ACE, SoHO, and GOES.

EMMREM-MHD Coupling – Shock Acceleration from Seed Populations

• Kozarev et al., Fall AGU, 2010
Modeling Large SEP Events with PATH Code

- Zank et al., AGU, 2010
Simulation of Earth-Moon-Mars Radiation Environments for Assessments of Radiation Doses

- Kim et al., AGU, 2010
Doses for CRaTER

Dose on Lunar surface [cGy/year]

Year


Lens Dose - 0.22 g/cm² A1 - HZETRN 2005
CRaTER Sim - D1-D2
CRaTER Obs - D1
CRaTER Obs - D2
CRaTER Obs - D3
Long-term GCR Extrapolation
Lead development of Scenario and Transport code modules

Provided capability, in near-real-time, to calculate radiation doses and LET spectra for tissue and electronics behind spacecraft aluminum shields using “looping” BRYNTRN code

Provided database of human organ radiation exposures for Al shielding thicknesses relevant to vehicle and habitat designs anywhere in free space or in Mars atmosphere for GCR and SEP spectra covering the entire solar cycle

Calculations of doses, dose equivalents and effective dose for GCR and SEP protons at aircraft altitudes in Earth’s atmosphere are completed. Heavy ion component calculations are in progress

Publications (author/coauthor)
- 10 journal articles
- 4 invited paper presentations
- 15 contributed paper presentations

3 graduate students supported
Transition to Prediction & Operations

- New ESMD/LRO Predictive Model

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<tr>
<th>Task Description</th>
<th>Value to ESMD</th>
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<tr>
<td>(1) SEP Prediction Development</td>
<td>Uses CRaTER observations and existing models to improve advanced warning of solar proton events</td>
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<tr>
<td>(2) Radiation Environment Forecasting</td>
<td>Develops analysis and modeling tool combined with CRaTER observations to extend prediction of the radiation environment well beyond low Earth orbit, not only at Moon but also throughout the inner heliosphere, including at Earth, Moon, Mars, Asteroids, and Comets</td>
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Figure from Posner et al. (2009) demonstrating how relativistic electrons racing ahead of SEP ions provide an early warning of the radiation hazard to follow up to one hour later.
Next Steps for EMMREM

• Transition to Operations and Predictive Models
• Development of Comprehensive Risk Models
• Coupling between MHD & EPREM
• Continued development of PATH into a predictive model