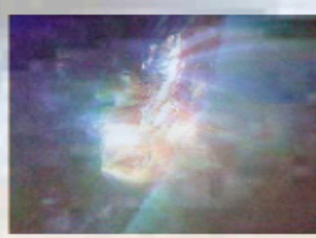
E M M R E M

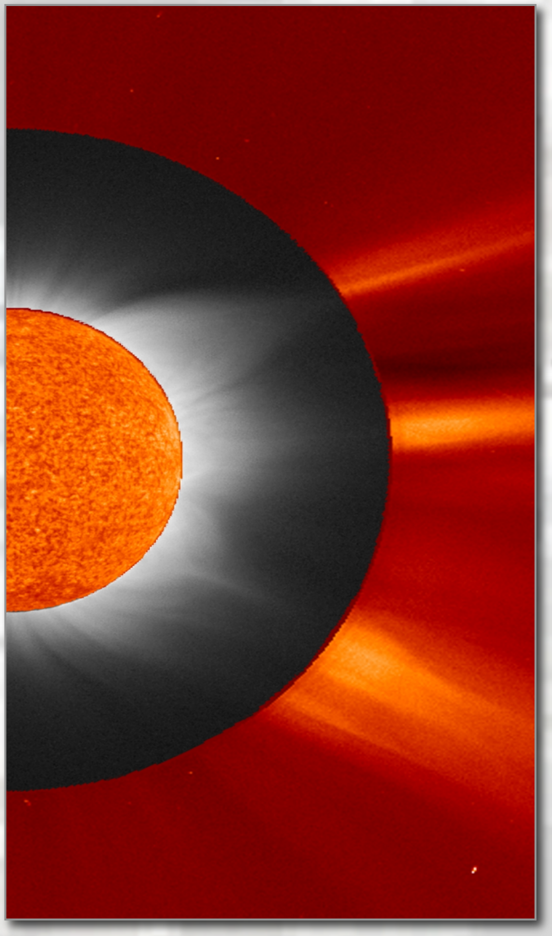
Earth-Moon-Mars Radiation Environment Model

N. A. Schwadron, K. Kozarev, L. Townsend, M. Desai, M. A. Dayeh, F. Cucinotta, D. Hassler, H. Spence, M. Pourars, E. Wilson, K. Korreck, X. Ao, G. Zank

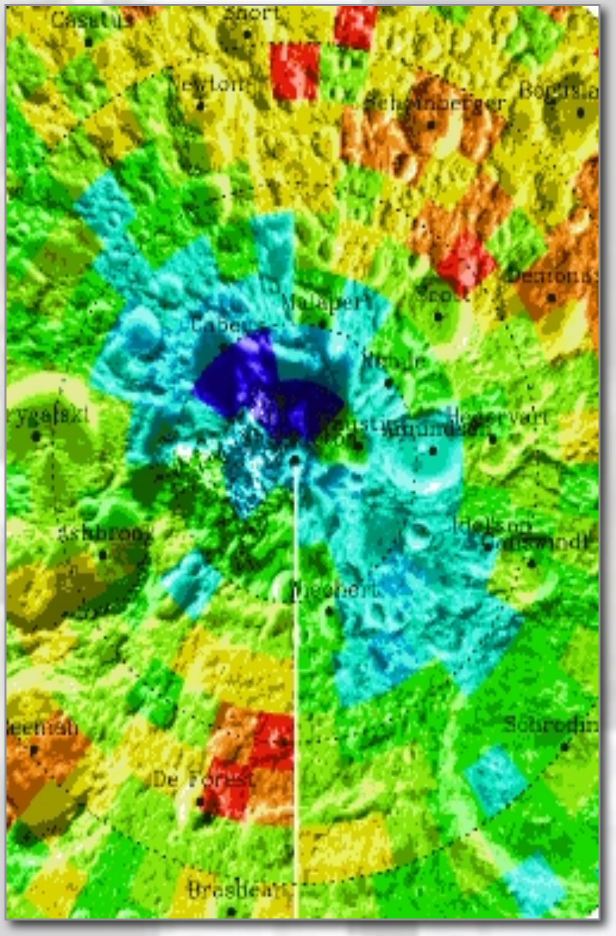
Exploration & Discovery → Radiation Exposure

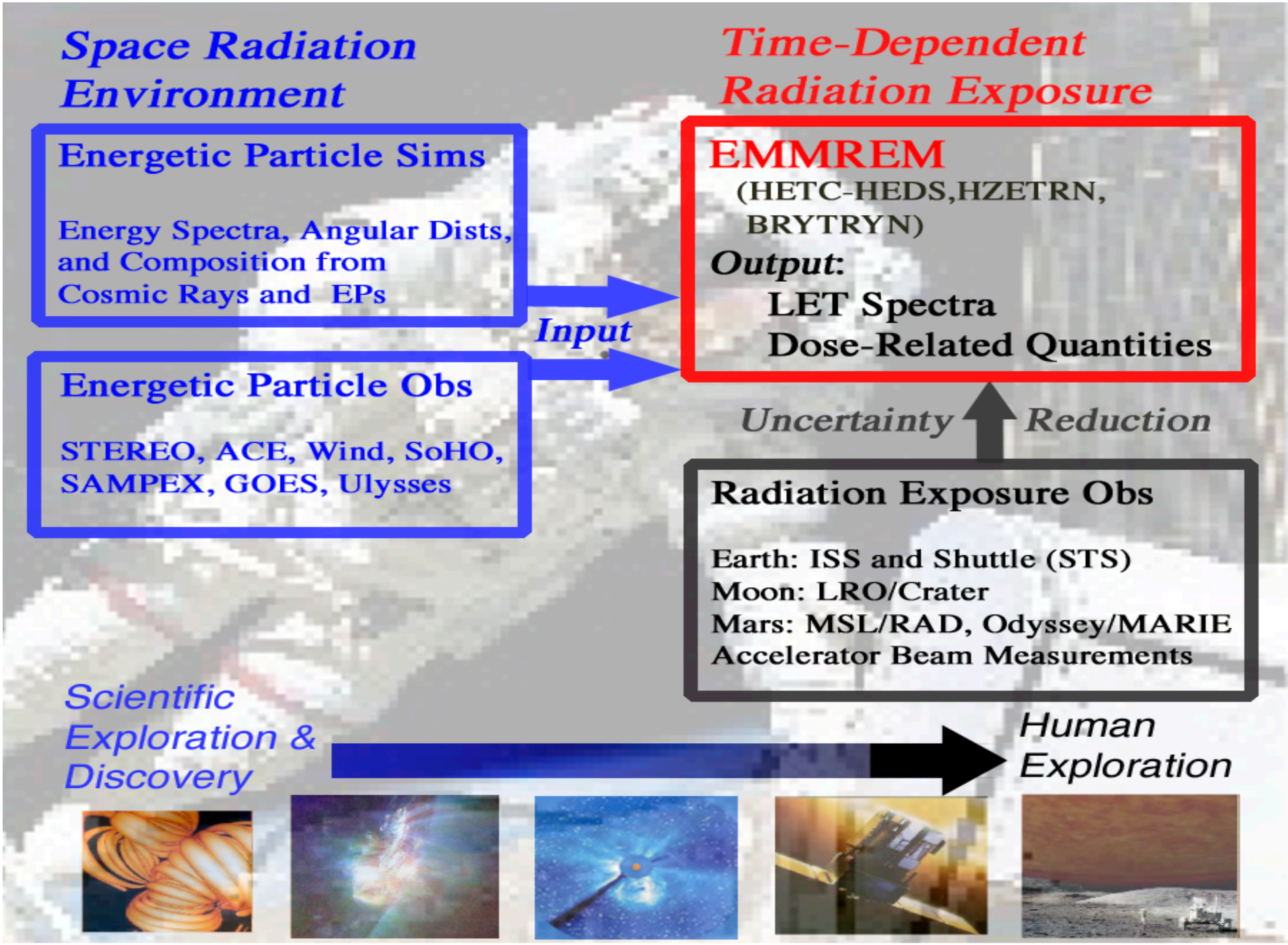

Space Weather, Safeguarding the Journey



Space weather impacts on robotic and human productivity



Radiation bombardment on the lunar surface and subsurface


Space Radiation Environment
Time-Dependent Radiation Exposure
Energetic Particle Sims
Energy Spectra, Angular Dists, and Composition from Cosmic Rays and EPs
Input
Energetic Particle Obs
STEREO, ACE, Wind, SoHO, SAMPEX, GOES, Ulysses
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
Accelerator Beam Measurements
Scientific Exploration & Discovery
Human Exploration

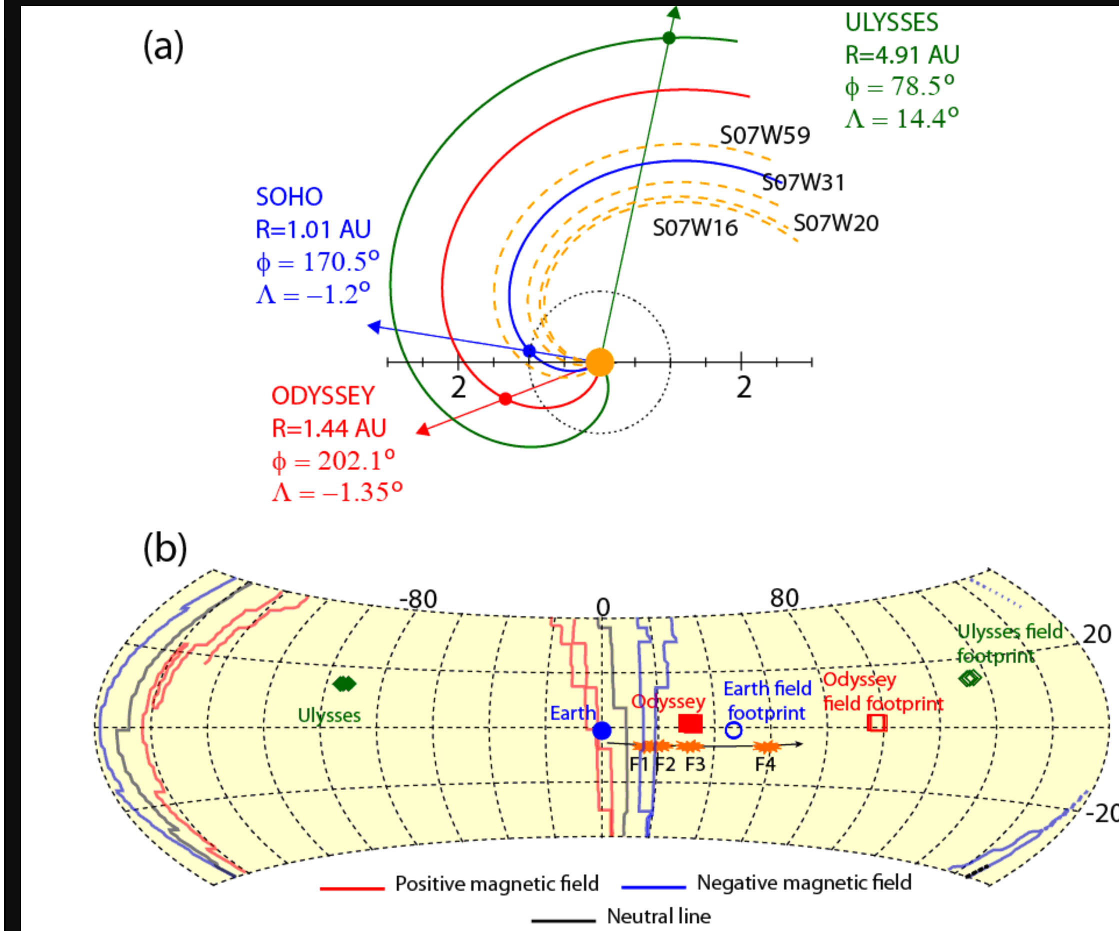
Accomplishments

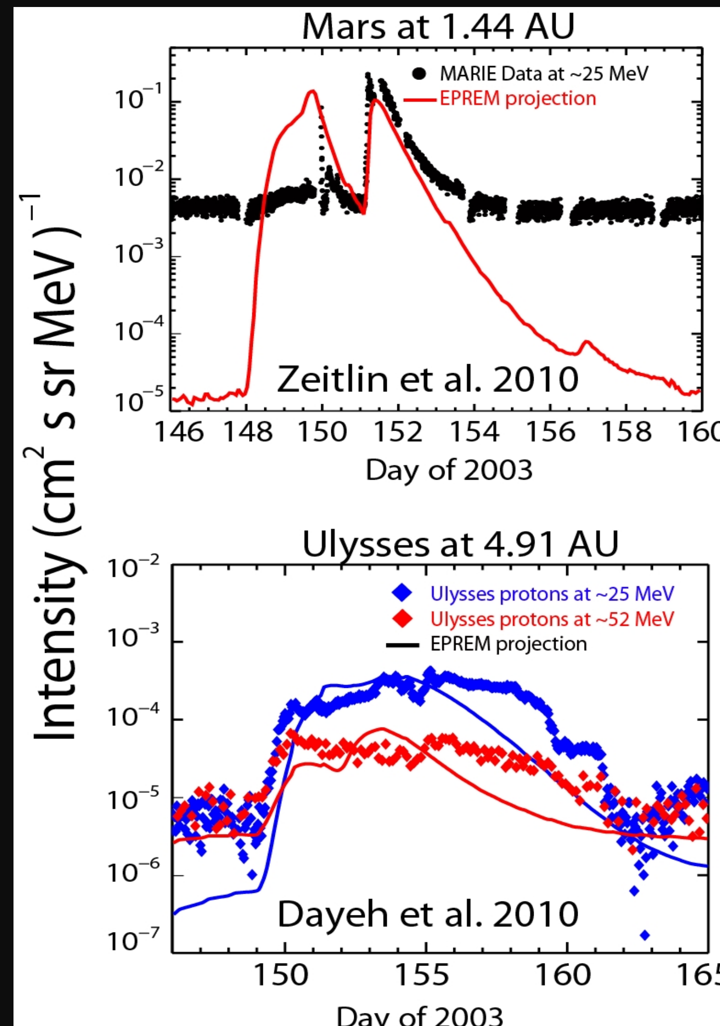
- *Radiation Biology*
  - Risk models
  - Radiation Transport
    - Interplanetary Space
    - Earth, Moon, Mars
- *EPREM*
  - Transport Particle Acceleration
  - Particle radiation throughout inner helioshere
  - Earth, Moon, Mars
- *EPREM-MHD*
  - Transport Effects
  - Particle Acceleration
- Validation
  - 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
- PourArsalan 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, *Spacweather, 8,* 2010
- Kozarev et al., Modeling the 2003 Halloween Events with EMMREM: Energetic Particles, Radial Gradients and Coupling to MHD, Spaceweather, 8, 2010
- Cucinotta et al., Space Radiation Risk Limits and Earth-Moon-Mars Environmental Models, *Spaceweather, 8,* 2010
- Zeitlin, C., et al., Mars Odyssey measurements of GCRs and solar particles in Mars orbit, *Spaceweather, 8,* 2010
- Dayeh, et al, Modeling proton intensity gradients and radiation dose in the inner heliosphere using EMMREM: May 2003 events, *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.



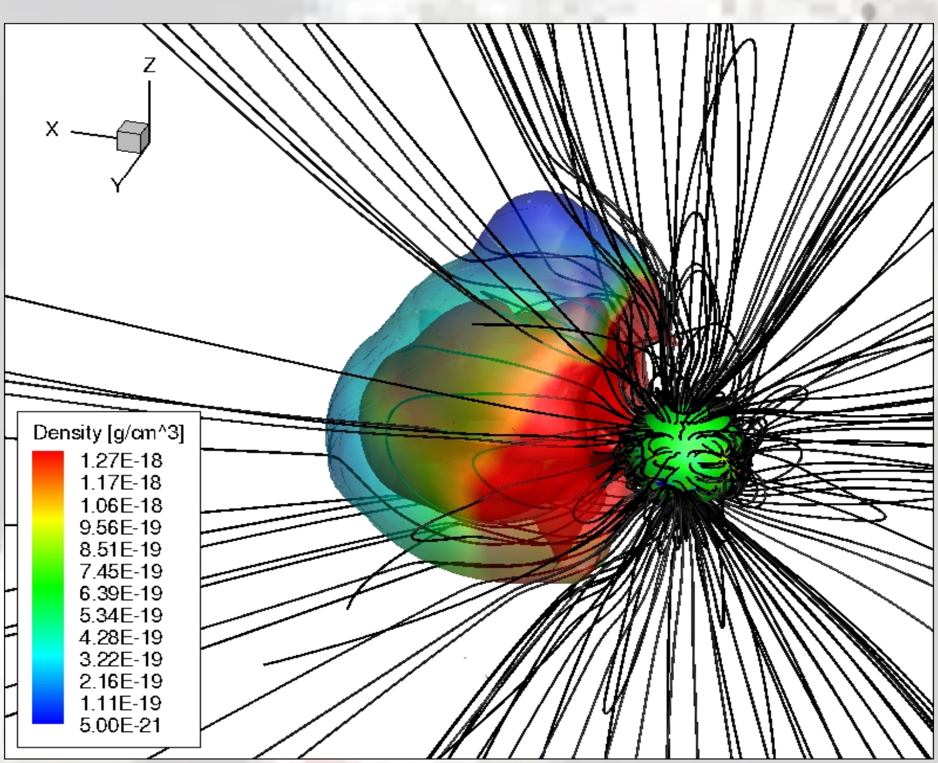


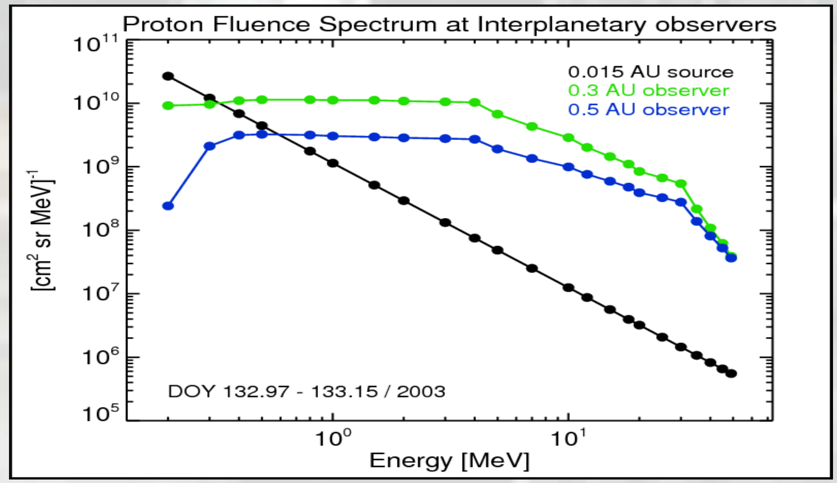
Dayeh, M. A., et al, Space Weather, 8, S00E07, doi:10.1029/2009SW000566

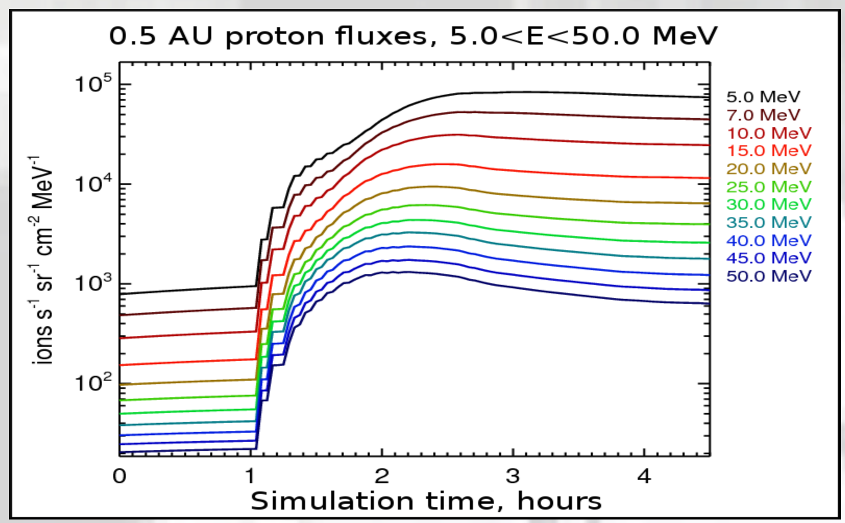
Zeitlin, C., et al., Space Weather, 8, S00E06, doi:10.1029/2009SW000563.

EMMREM-MHD Coupling – Shock Acceleration from Seed Populations

- Kozarev et al., Fall AGU, 2010

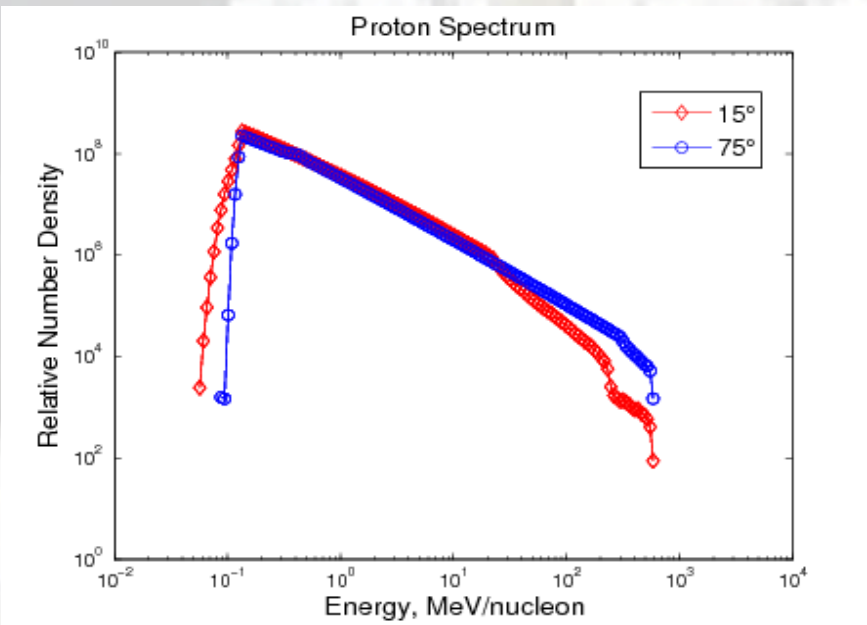


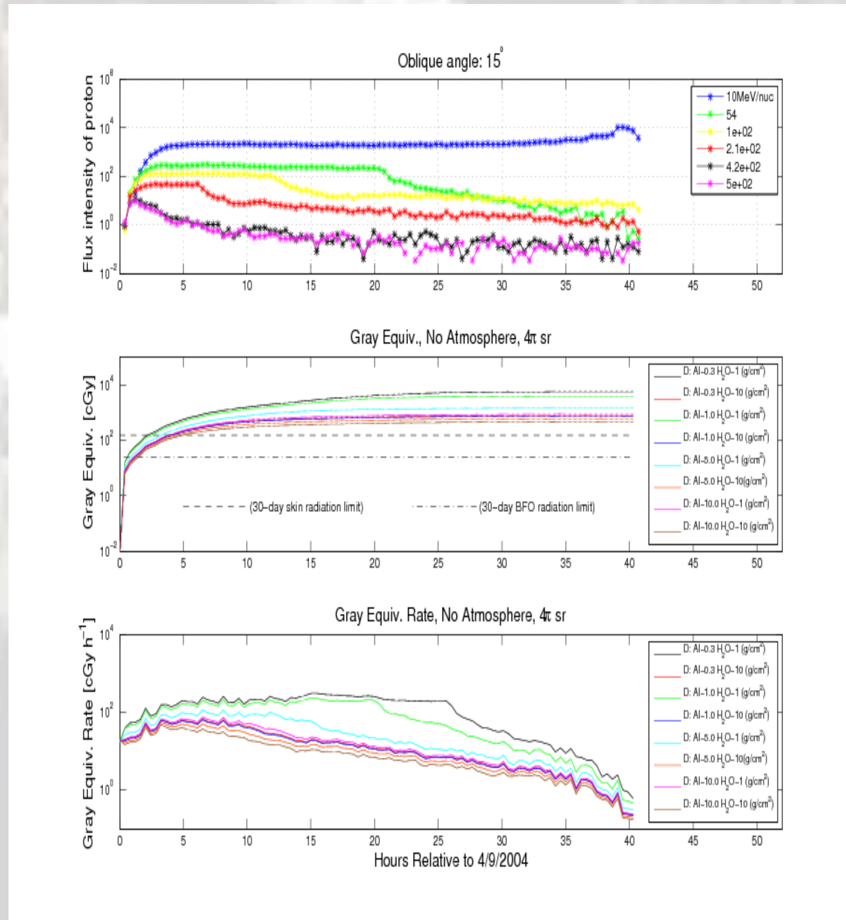




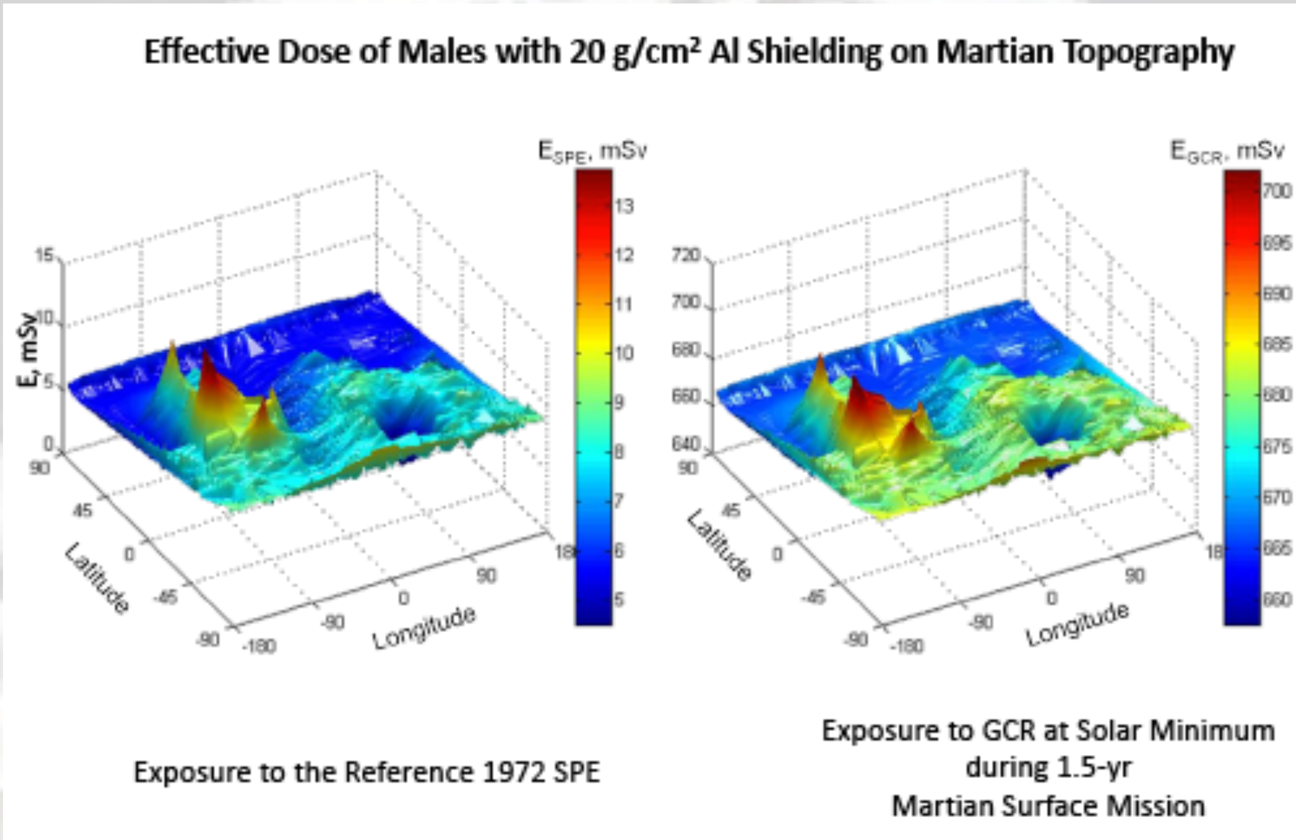
Modeling Large SEP Events with PATH Code

- Zank et al., AGU, 2010

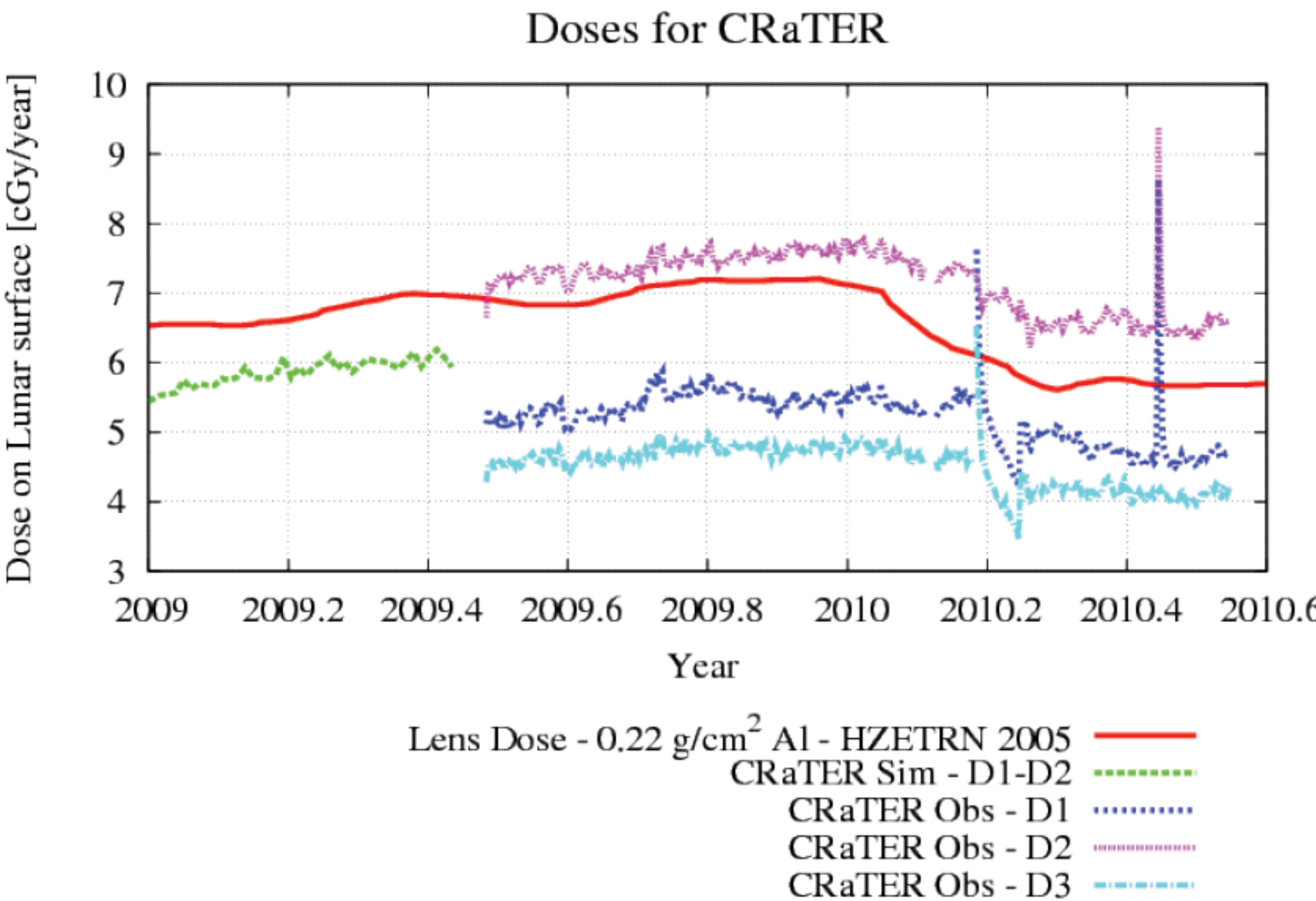




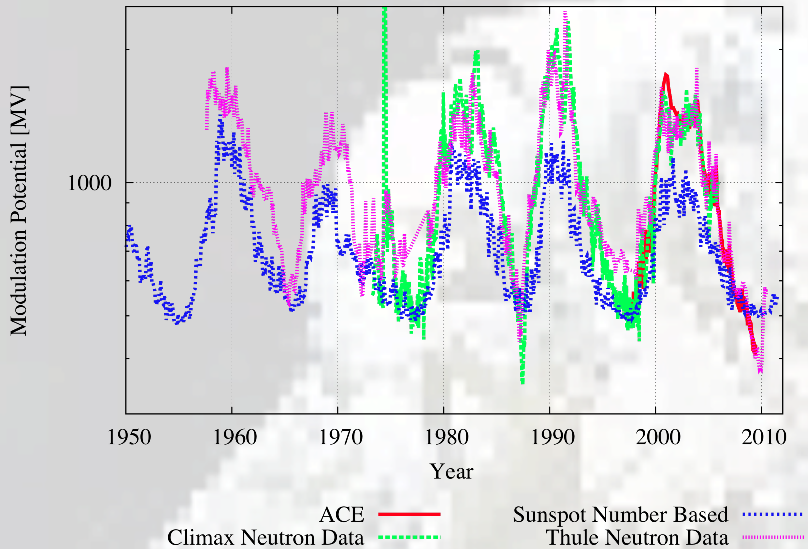
Simulation of Earth-Moon-Mars Radiation Environments for Assessments of Radiation Doses

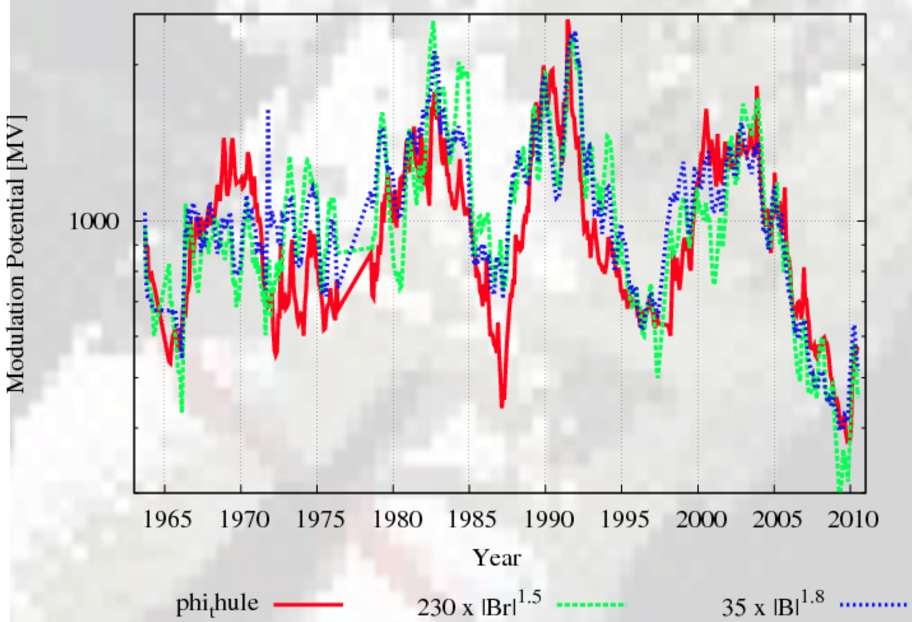


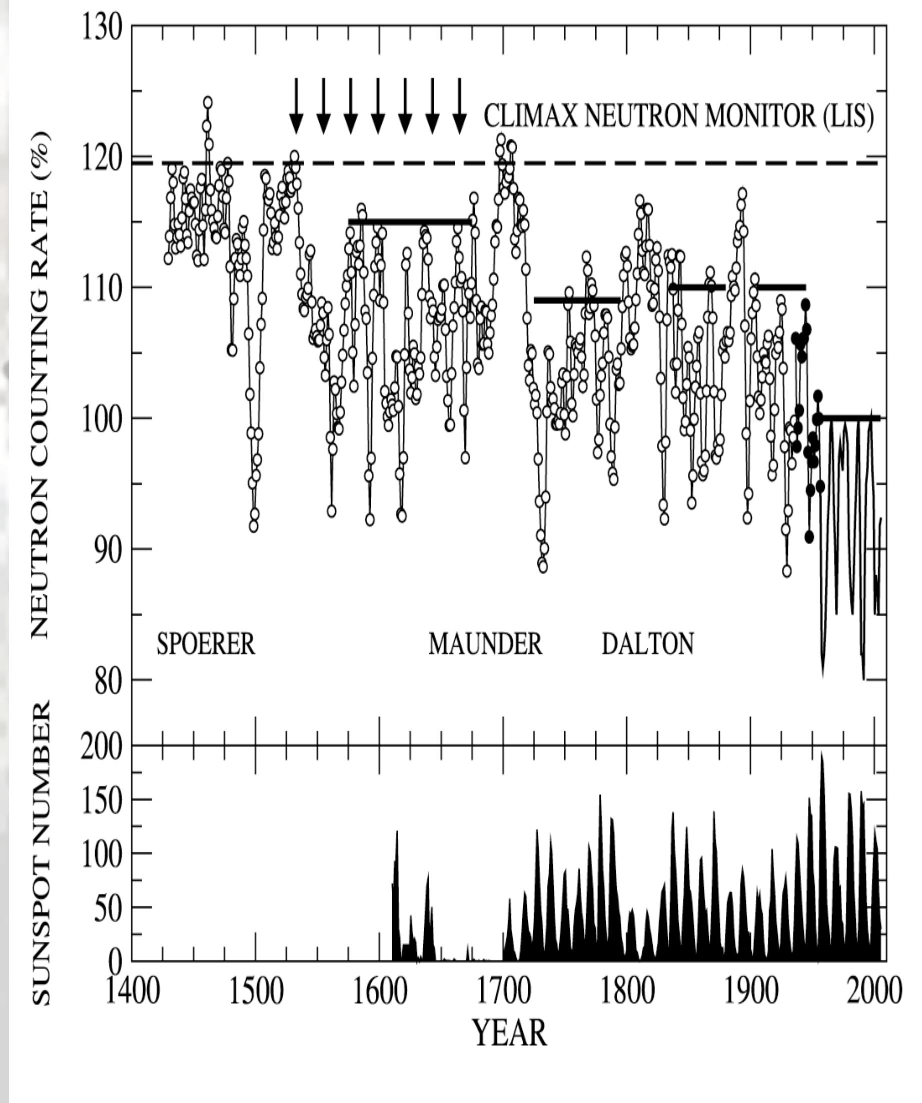
- Kim et al., AGU, 2010


Doses for CRaTER
Dose on Lunar surface [cGy/year]
10
9
8
7
6
5
4
3
2009
2009.2
2009.4
2009.6
2009.8
2010
2010.2
2010.4
2010.6
Year
Lens Dose - 0.22 g/cm2 Al - HZETRN 2005
CRaTER Sim - D1-D2
CRaTER Obs - D1
CRaTER Obs - D2
CRaTER Obs - D3

Long-term GCR Extrapolation







U. Tennessee – EMMREM Accomplishments

NNX07AC14G – L. Townsend

- 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

Task Description	Value to ESMD
(1) SEP Prediction Development	Uses CRaTER observations and existing models to **improve advanced warning of solar proton events**
(2) Radiation Environment Forecasting	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

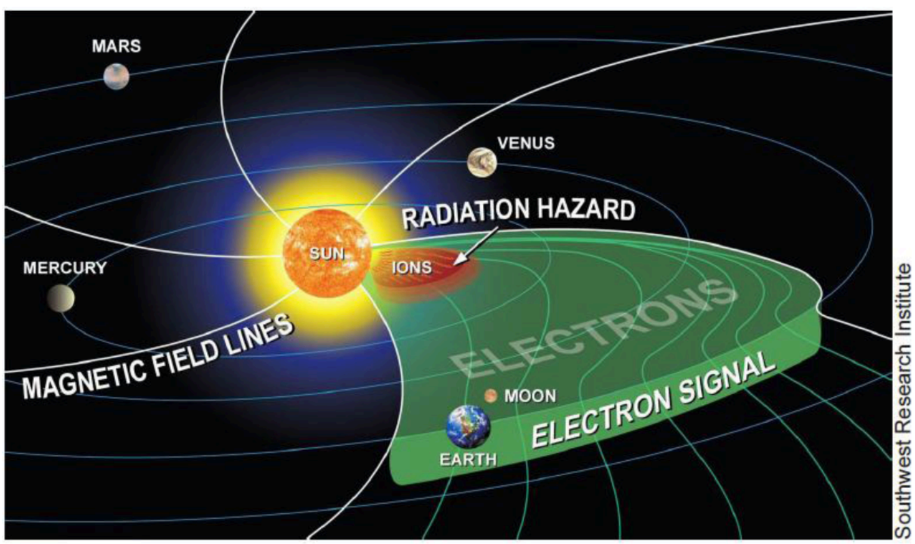


Figure from Posner et al. (2009) demonstrating how relativistic electrons racing ahead of SEP ions provide an early warning of the radiation hazard to follow up to one hour later.

EMMREM

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