Modeling Energetic Particles Transport in The Inner Heliosphere with

Earth-Moon-Mars Radiation Environment Module (EMMREM)

Kamen Kozarev **Wednesday, Feb. 24 2010**

Outline

- Motivation for the EMMREM project
- Introduction to the EMMREM framework
    - Primary Transport
    - Secondary Transport
- Validation of EPREM
- Coupling EPREM to MHD models
- EMMREM web interface
- Summary

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The EMMREM Objective

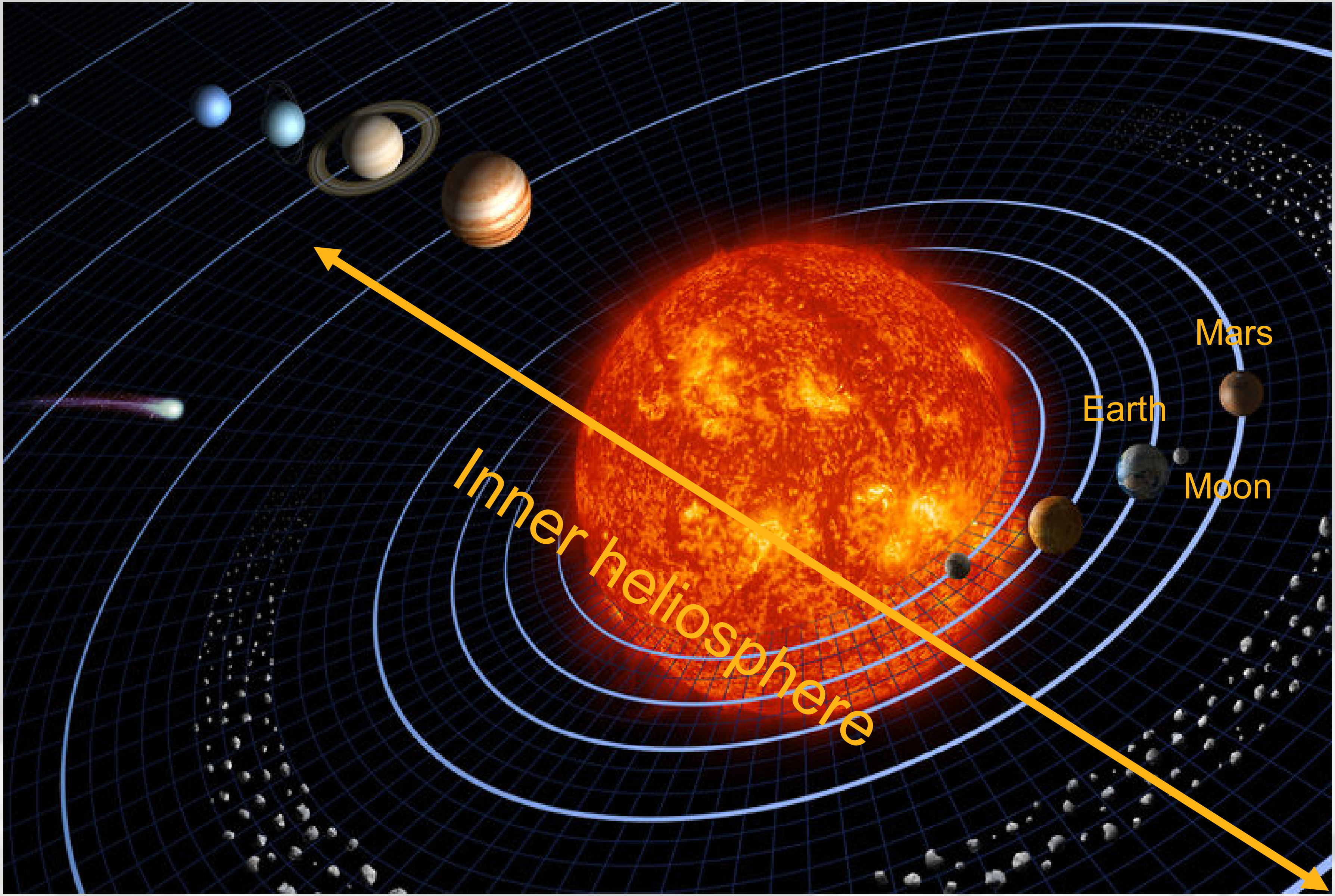
Central objective of EMMREM is to develop and validate a numerical framework for characterizing time-dependent radiation exposure in the Earth- Moon-Mars and interplanetary space environments.

Connect observations and theory in solar and heliospheric physics with radiation studies.

Completed EMMREM framework will be capable of performing radiation calculations that account for time-dependent positions, spacecraft and human geometry, spacesuit shielding, atmospheres and surface habitats.

The EMMREM Heliosphere

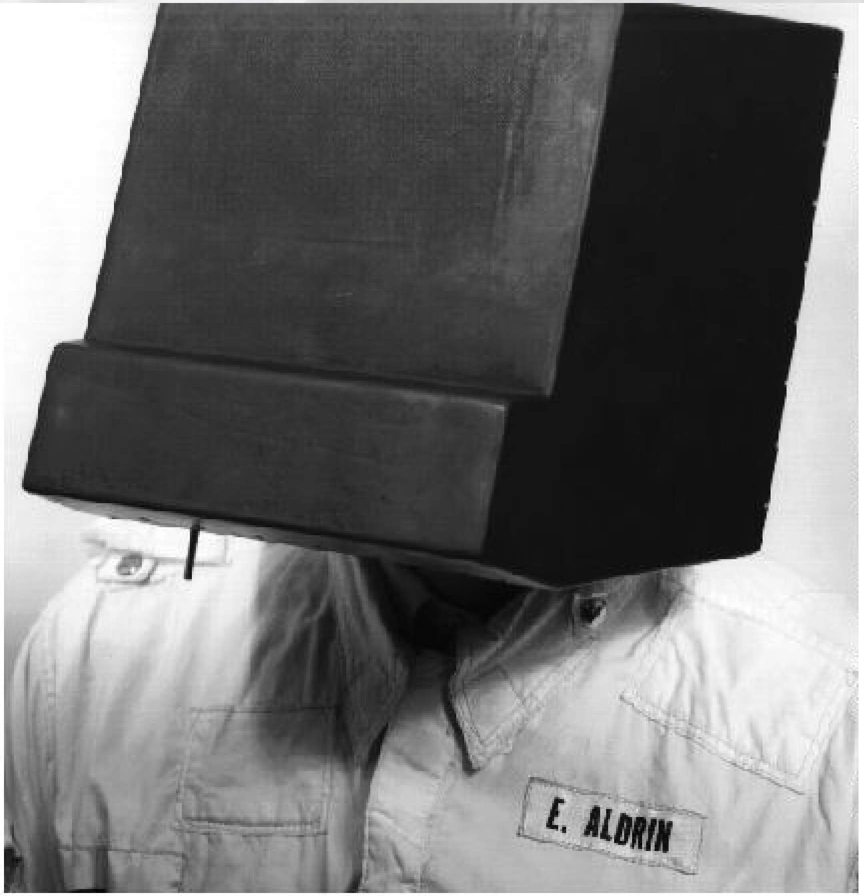
distances NOT to scale (slightly)...



http://boston.grubstreet.com/Solar%20System.jpg

Energetic Particle Hazards

- Need to characterize interplanetary particle radiation
- Need to plan for protection of crews and spacecraft for short- and long-duration missions
- Hazards to astronauts
- Hazards to spacecraft

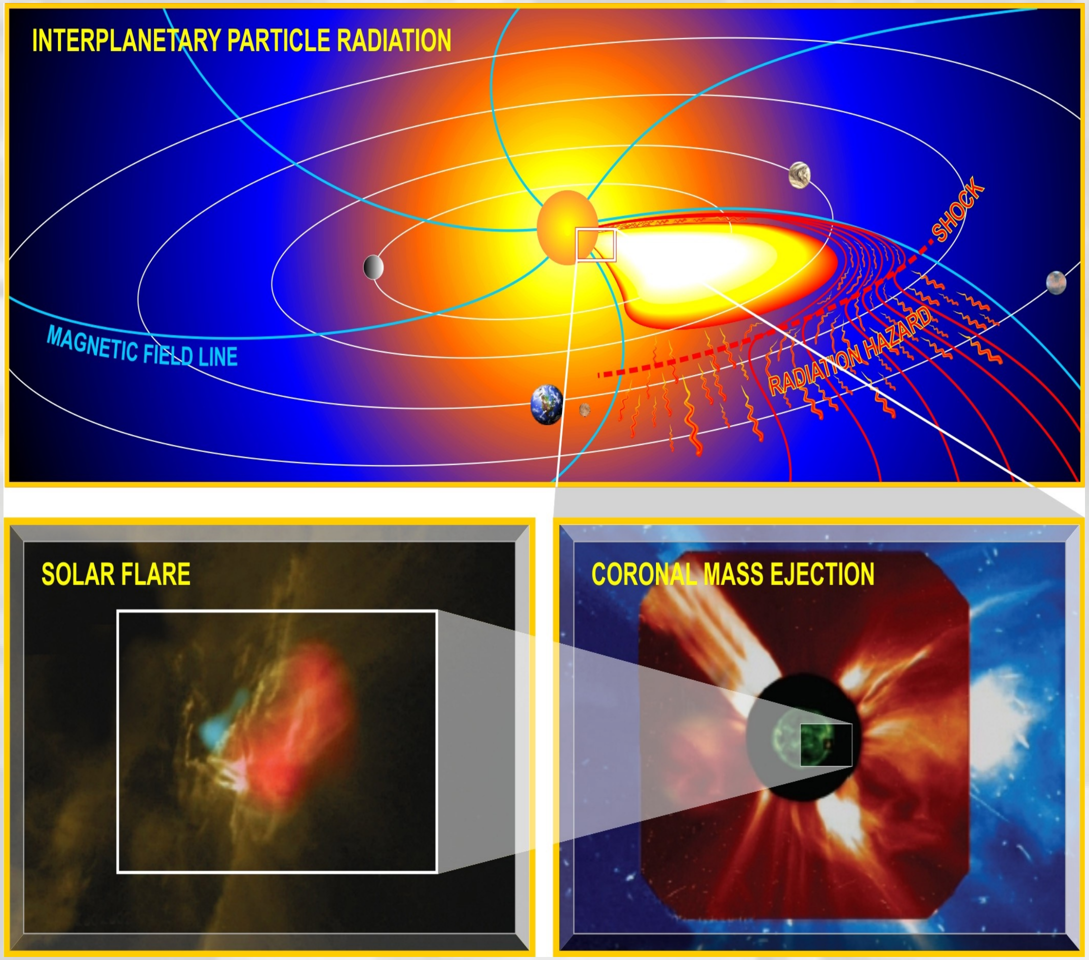


Source: NASA

Sources of particle radiation

Galactic Cosmic Rays (GCRs)
- Extra-heliospheric origin
- Steady Background in fluxes
- Modulated by Solar activity

Solar Energetic Particles (SEPs)
- Energies ~ 1MeV-1GeV
- Episodic in time
- Associated with Solar Flares and Coronal Mass Ejections (CMEs).



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EMMREM Framework

Primary Transport

Interplanetary Sources and Primary Transport of GCR, ACR, SEPs:
Energy Spectrum,
Composition
Angular Distribution

Observed Events & Conditions
- Event Catalogue
- Time series Database

Simulated Events & Conditions
- Event List &Time series
- Solar Cycle Dependence

User-specified Input
- Convert energy spectra and time series to req. input.

Secondary Transport

Radiation Transport
Interaction and production of secondary radiation from incident particles transported through atmospheres, shielding material and tissue

Components & Options
- Atmosphere, if appropriate
- Shielding Material
- Spacecraft
- Spacesuit
- Habitats
- Surface

Models
BRYNTRN & HZETRN
- Light ions
- Heavy ions
- LET + dose-related quantities

HETC-HEDS (3-D)
- Light ions
- Energy-dep (dose, LET)
- Secondaries + detailed histories

Scenario/Environment
Several scenarios exist for obtaining **Dose-related quantities** for different environments

Scenario Options

Moon
- Orbit, spacecraft, shielding, spacesuit, surface, habitats

Mars
- Orbit, spacecraft, spacesuit, atmosphere, surface, habitats

Earth-Moon-Mars Transit
- Full spectrum of GCR, ACR & SEP, spacecraft, spacesuit

Earth
- Various orbits, spacecraft, spacesuit, atmosphere, surface

Prediction & Validation

Output, Validation and Presentation
Comparison with observations, online data base

Dose-Related Quantities time series
- Dose
- Dose Equivalent
- Organ Dose
- Effective Dose

Intensity time series

Validation & Presentation
- Event Catalogue
- Online Time Series Database
- Case studies with observations from LRO/CRaTER, MSL/RAD, other spacecraft

EMMREM Framework

• Numerical simulations written in C/Fortran

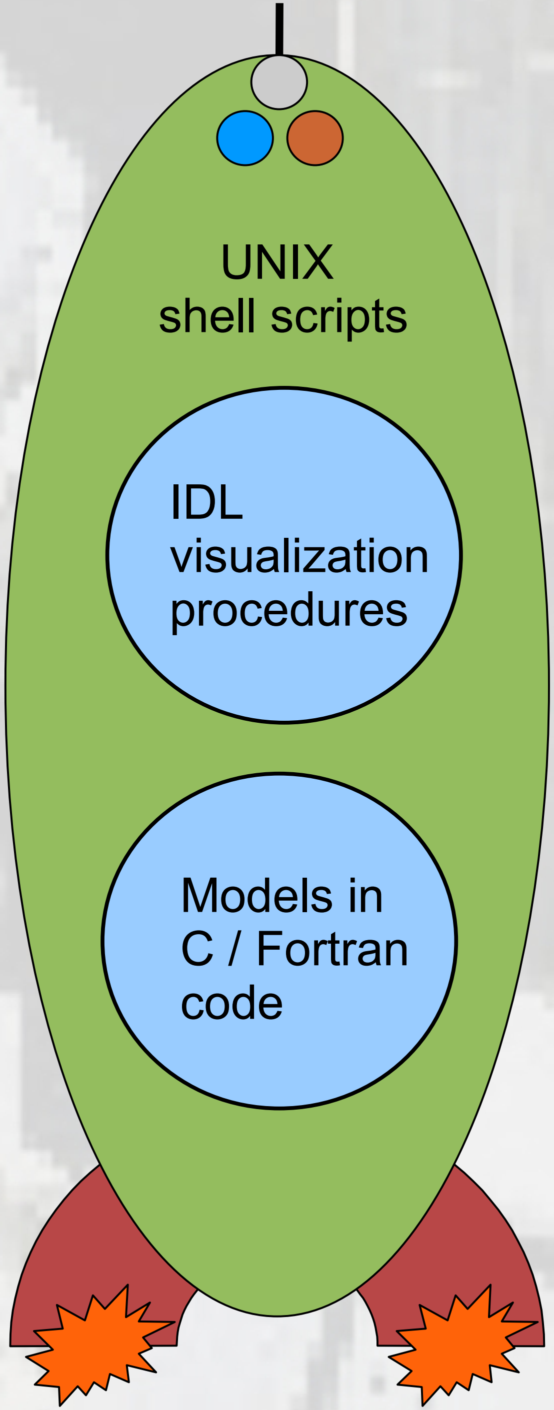
• Visualization tools in IDL

• Automatic generation of plots for analysis

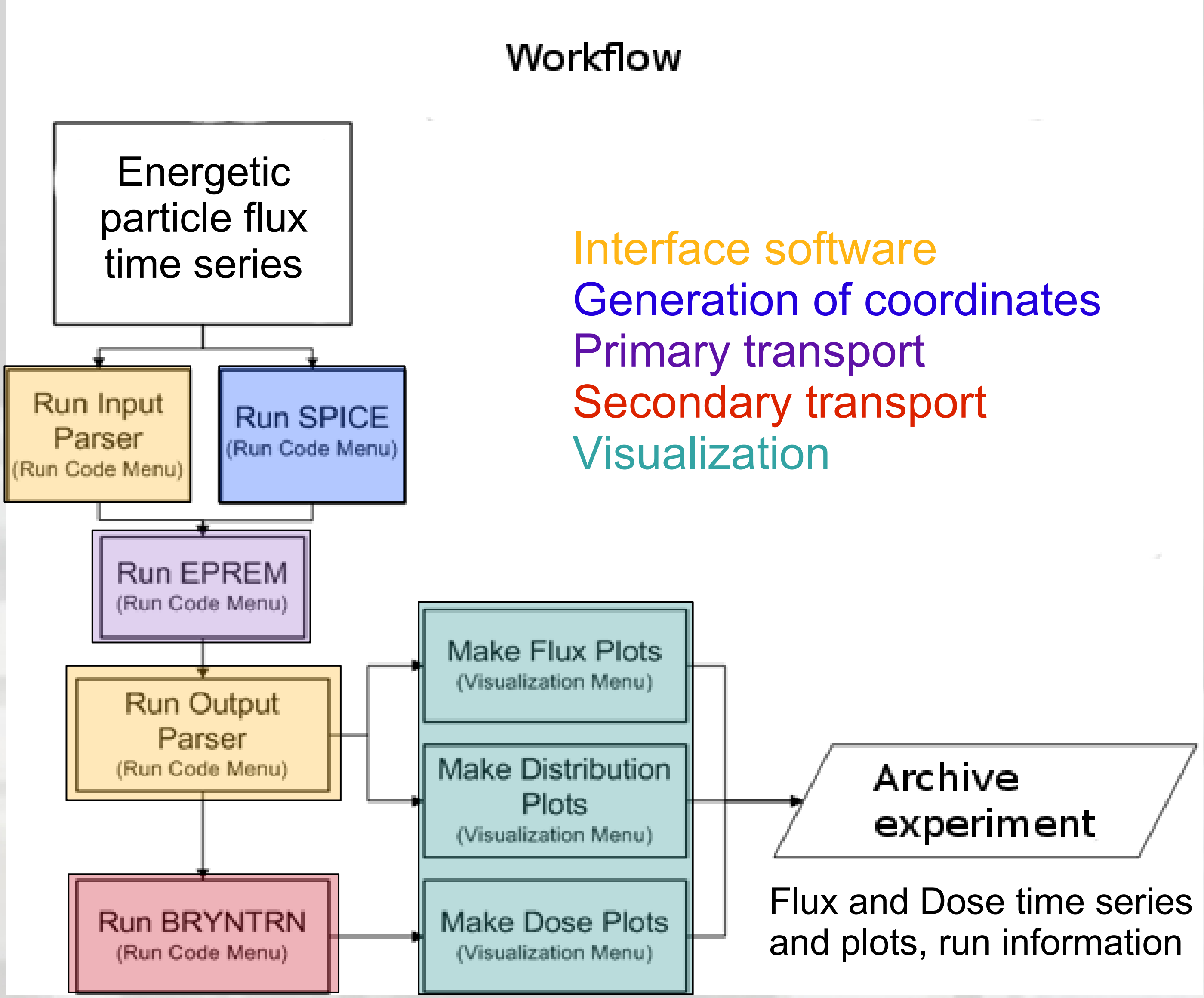
• All codes wrapped in UNIX scripts

• Scripts also control integrated framework

• Codes execution in terminal or via web interface



EMMREM Framework



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EMMREM: Primary Transport

Energetic Particle Radiation Environment Module (EPREM):

- Kinetic model for the heliospheric transport of energetic particles from solar events (flares, CMEs)

- Developed by Prof. Schwadron and Richard Squier (Georgetown University)

- Capable of simulating interplanetary transport of protons, electrons, and heavier ions.

- Currently run on an event-by-event basis

EPREM model

EPREM advantages

- Robust model, written for parallel execution on multiple computers
- Runs faster than real time
- Interfaces allow direct input from particle observations – meant to simulate real events
- 3D structure of model allows to explore perpendicular transport of particles
- Model parameters can easily be modified by users
- Open source, available on request

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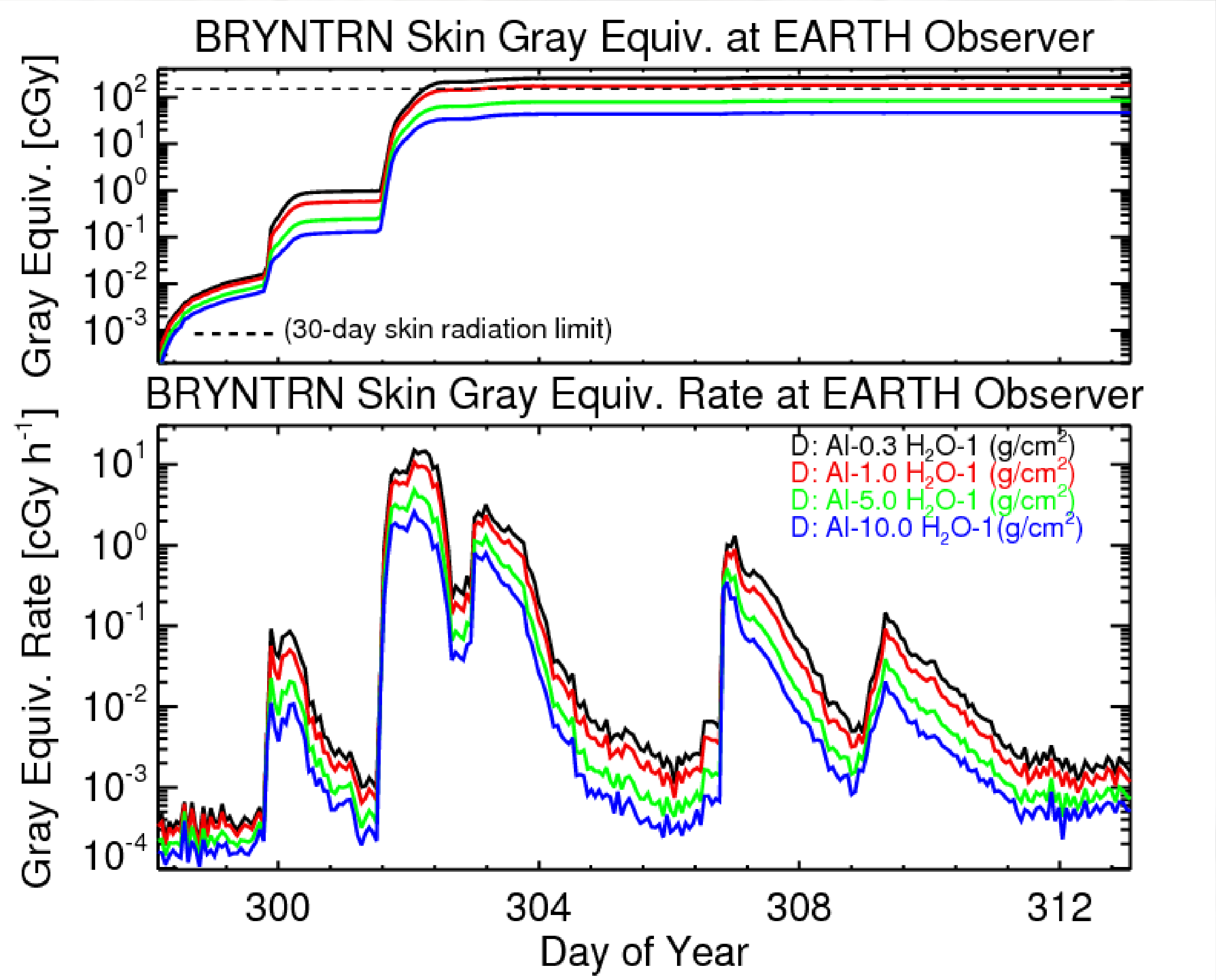
Secondary Transport: BRYNTRN

- BaRYoN TraNsport code, developed at NASA
- For light ions, primarily for SEP calculations;



1 Gy = 1 J / 1 kg
for acute
radiation by protons

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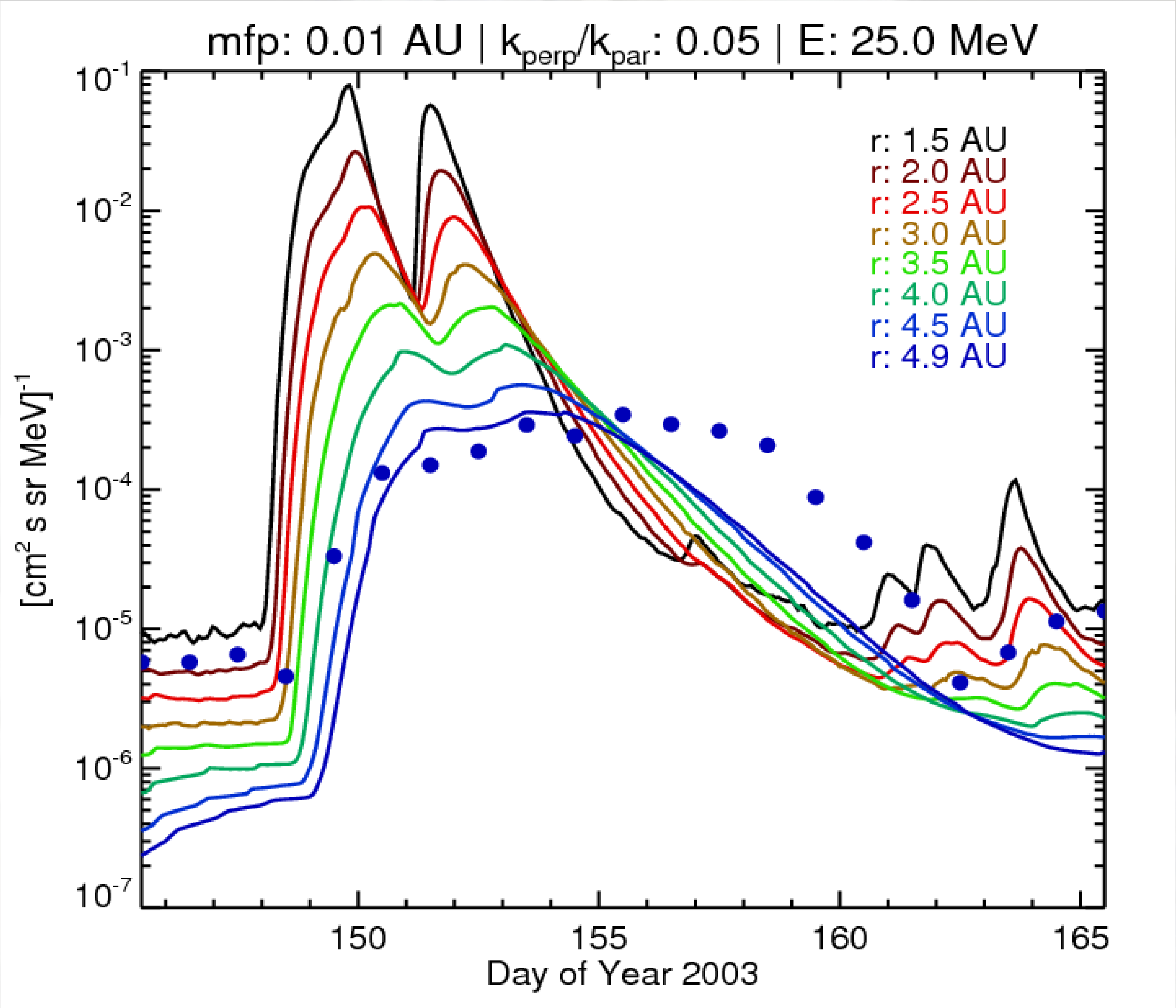
Validation and Verification

Verification - “Are you building the thing right?”

Validation - “Are you building the right thing?”

- EPREM verification and validation underway
- Perform multiple runs to explore the effects of varying parameters in the model.
- Vary parallel mean free path and amount of perpendicular diffusion.
- Examine model output at eight locations between 1.0 and 5.0 AU

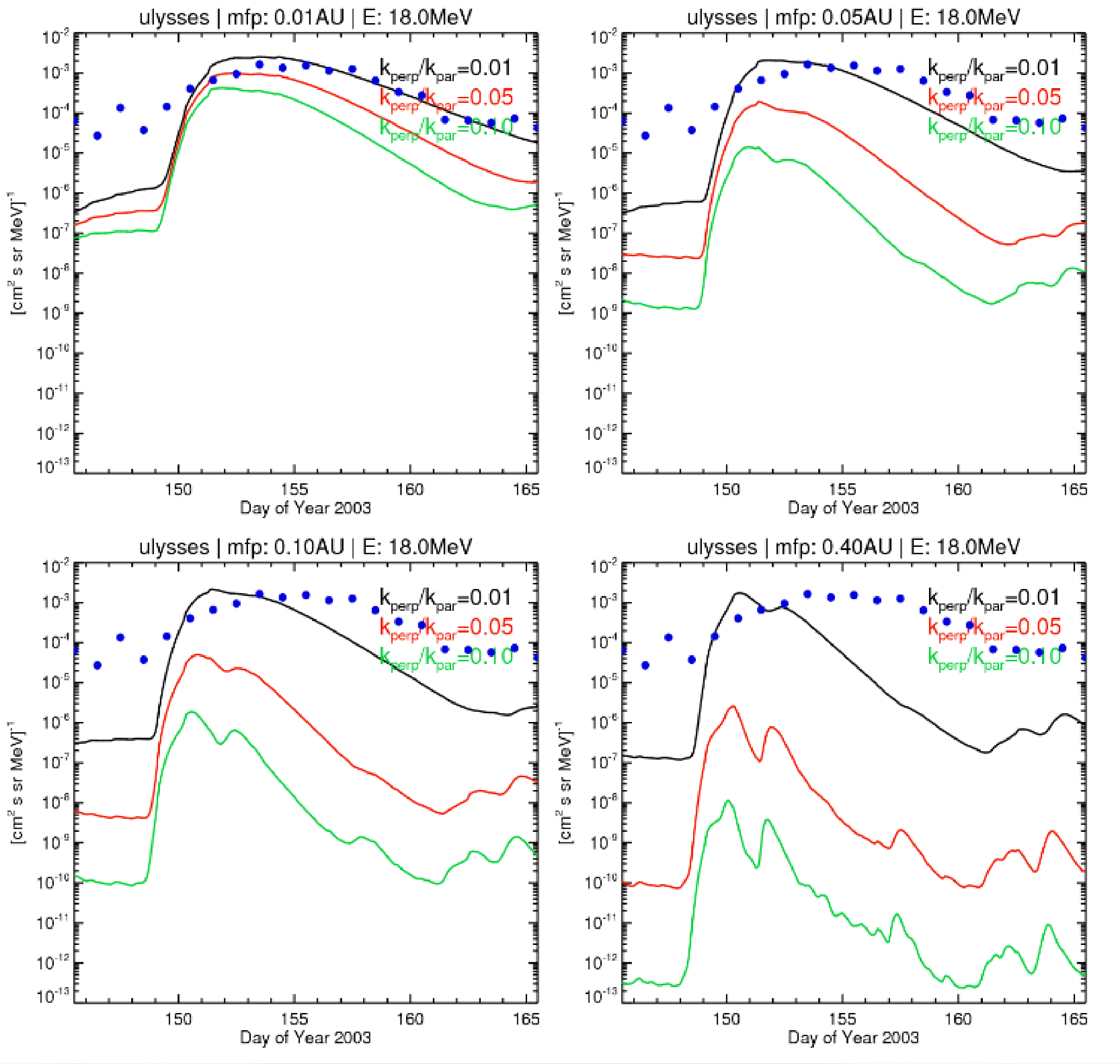
EPREM – V&V



EPREM results for one combination of parameters (blue dots correspond to Ulysses at 4.9 AU)

EPREM – V&V

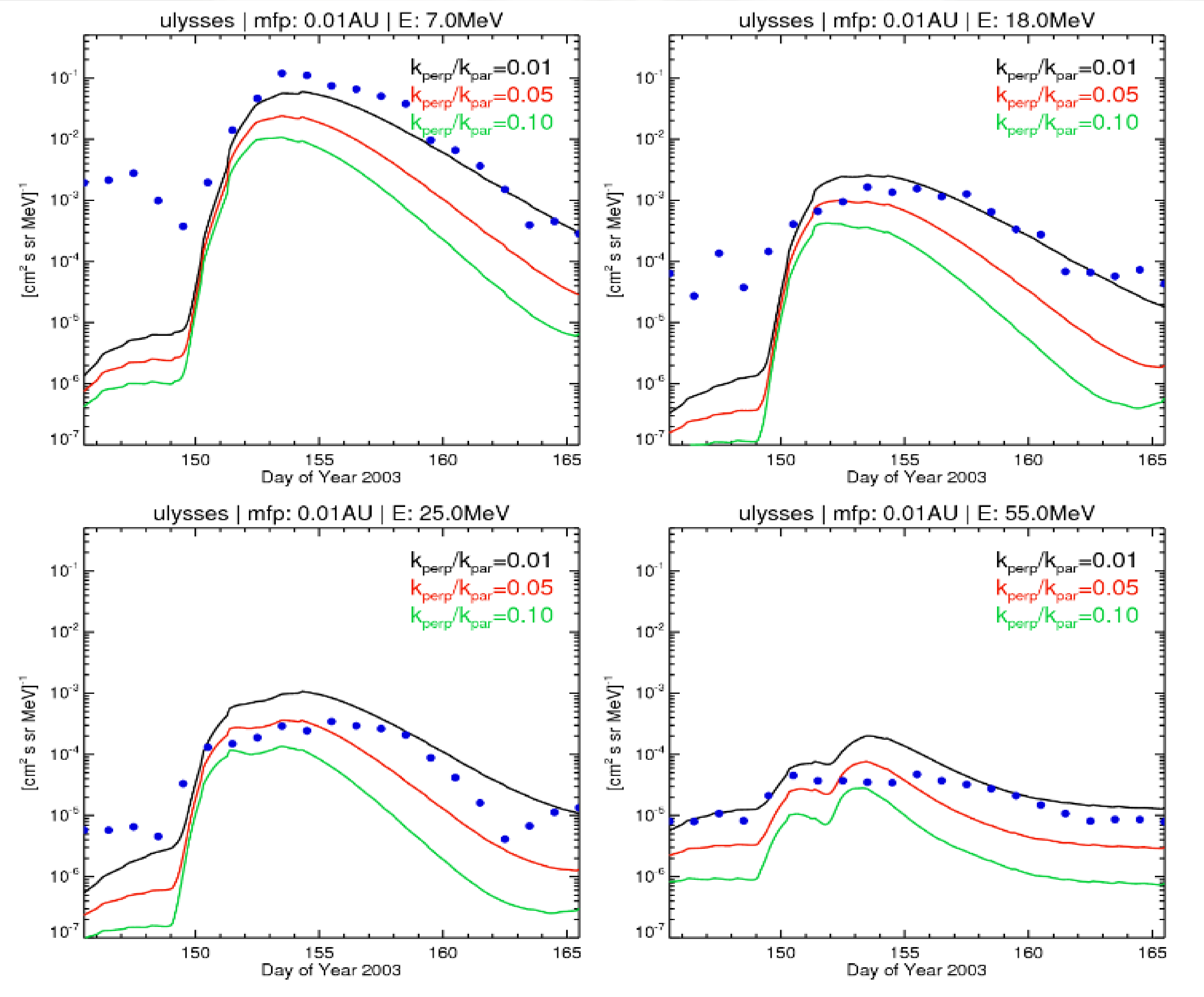
- Dependence on scattering at 5 AU



E = 18 MeV (protons)

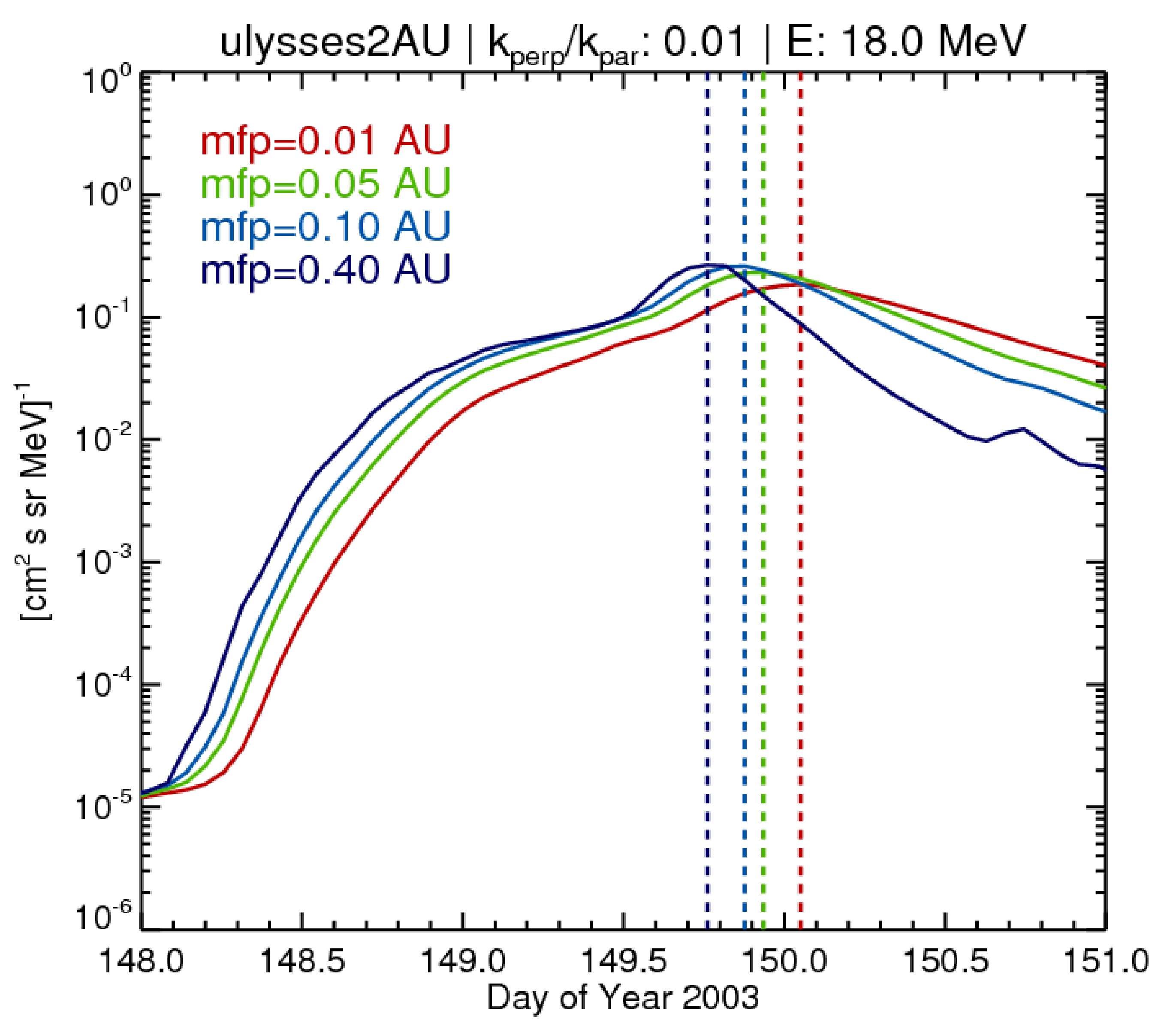
EPREM – V&V

Same mfp, different energies



EPREM – V&V

mfp vs. arrival time



V&V Summary

- Model robust over wide ranges of:

energies (3-82 MeV),

mean free path (0.01-0.4 AU)

perpendicular diffusion (1-10 %)

- Performing as expected:

lower mean free path -> more scattering, higher fluxes

higher perp. diffusion -> lower fluxes along field lines

higher energies -> lower fluxes

increasing radial distance -> more scattering along field lines, delay in particle arrival

high mean free path -> earlier arrival of particles

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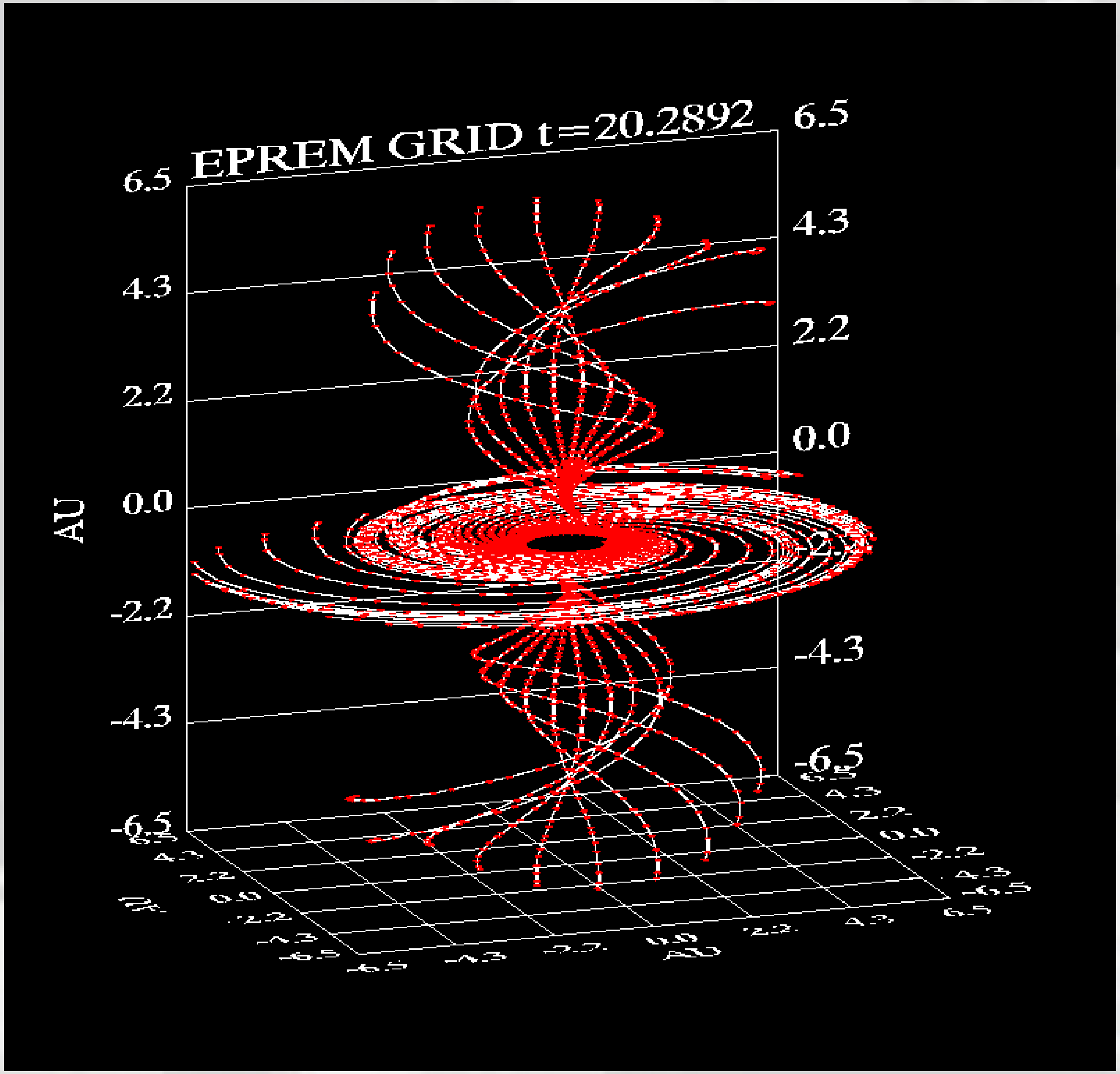
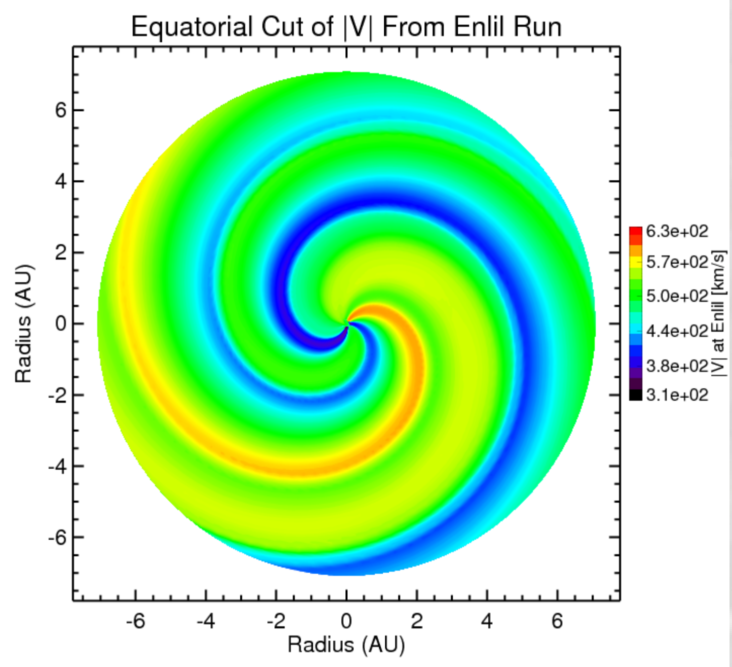
Coupling to MHD

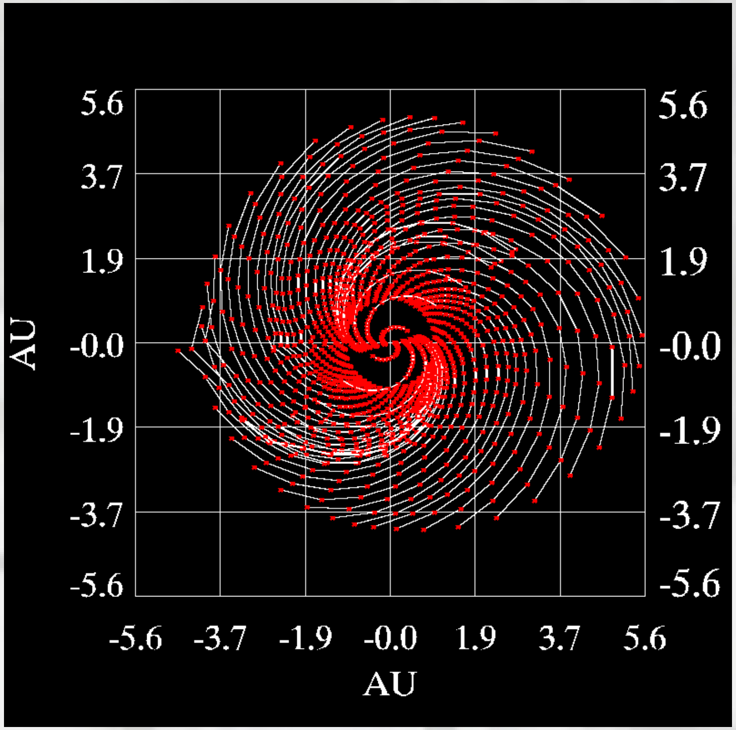
- Used Enlil MHD heliospheric model.
- Modified the EPREM code to ingest Enlil model results.
- Goal - achieve more realistic solar wind conditions.
- Test coupling and EPREM response on a real event.
- Picked big Halloween events of October/November 2003

Coupling to MHD

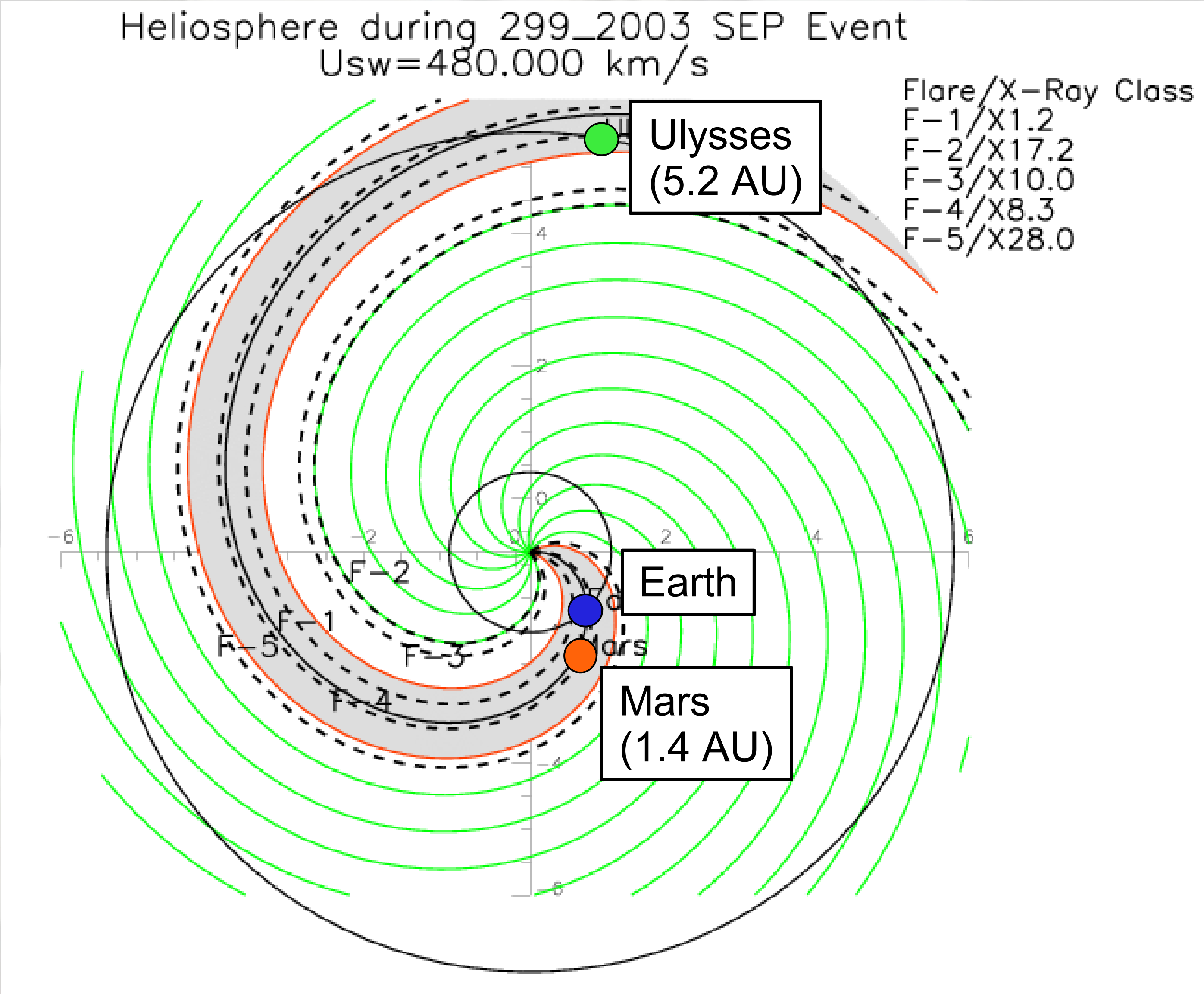
EPREM grid response



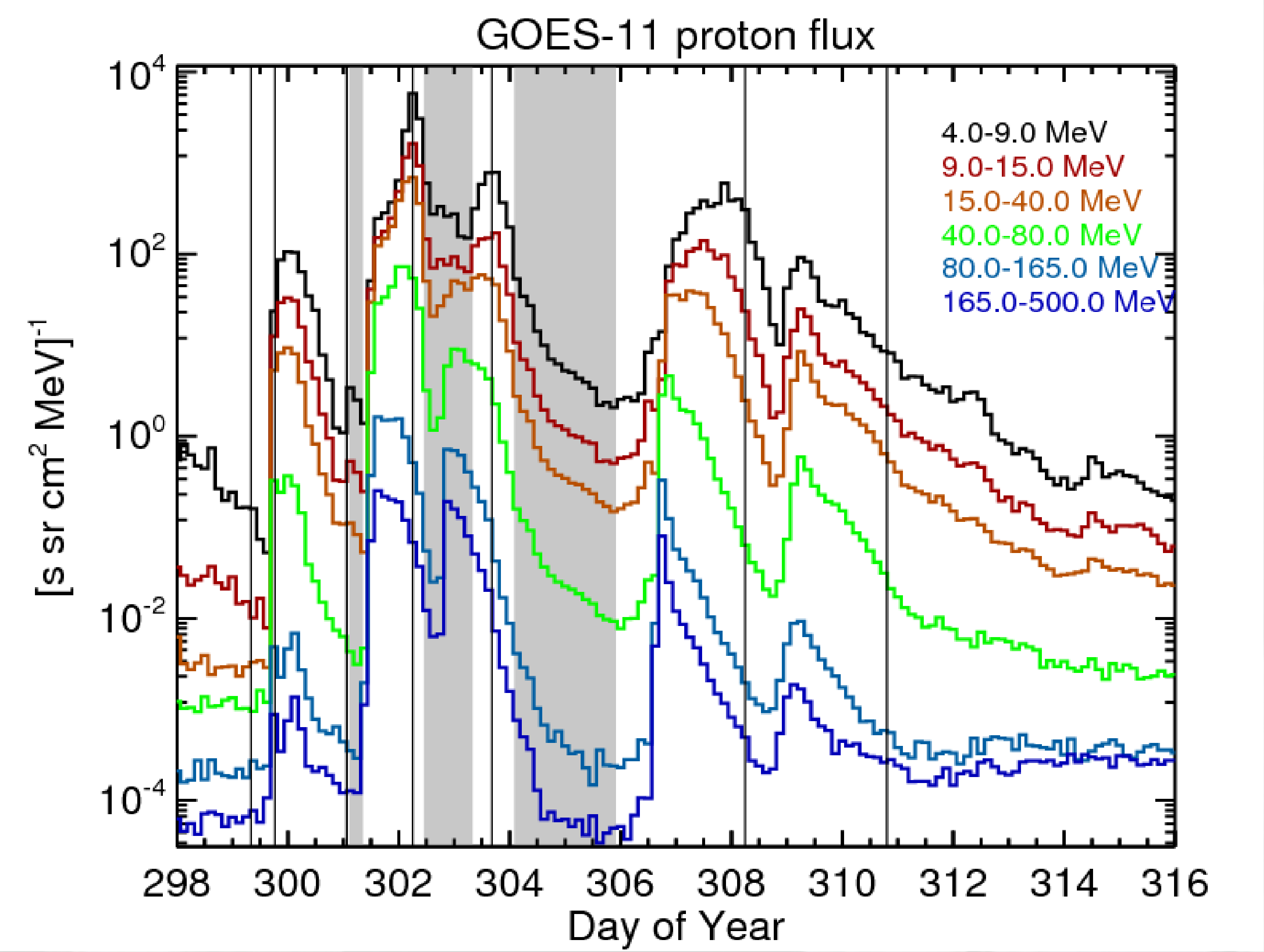




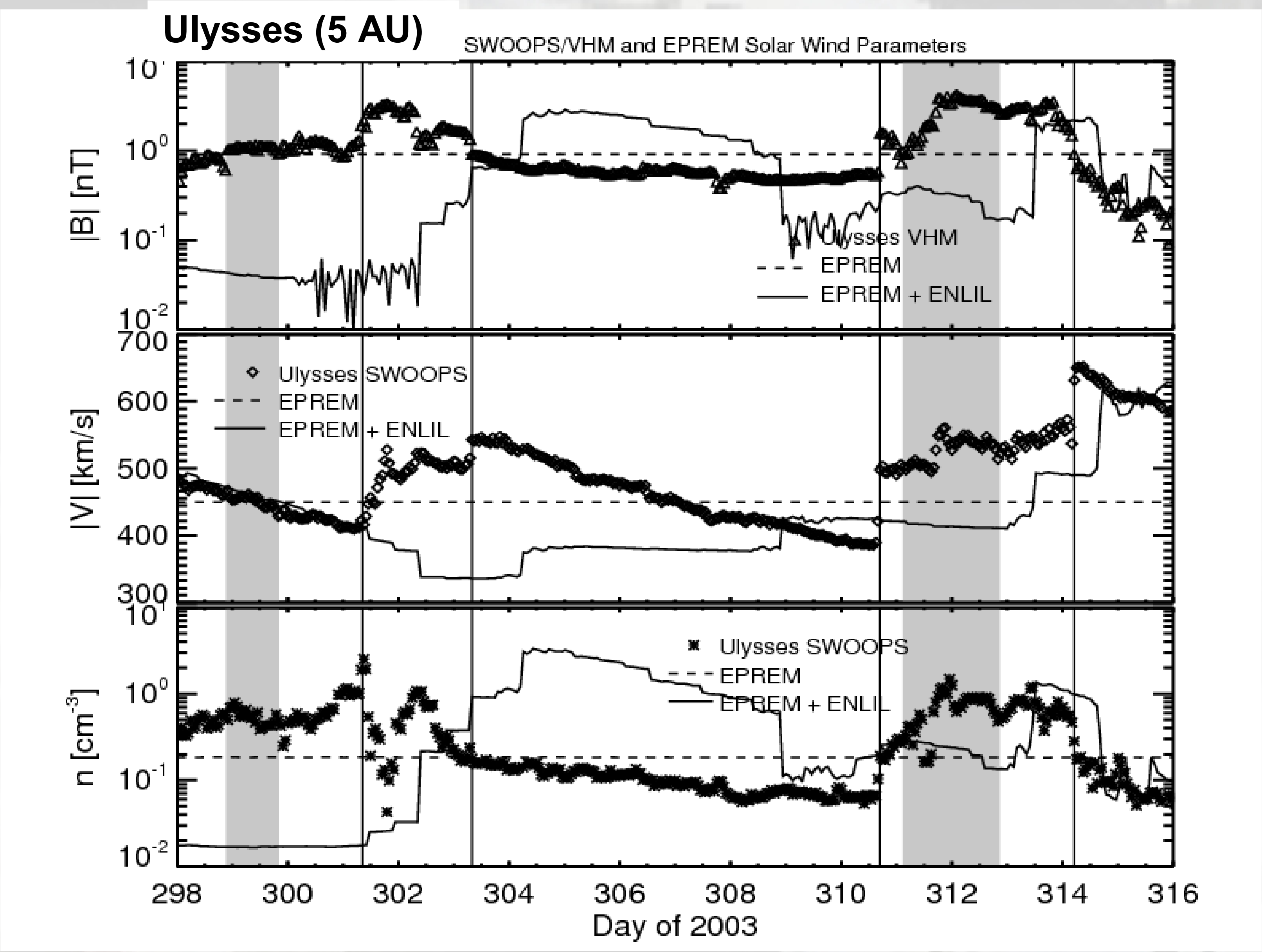
Study of Halloween events (October/November 2003)



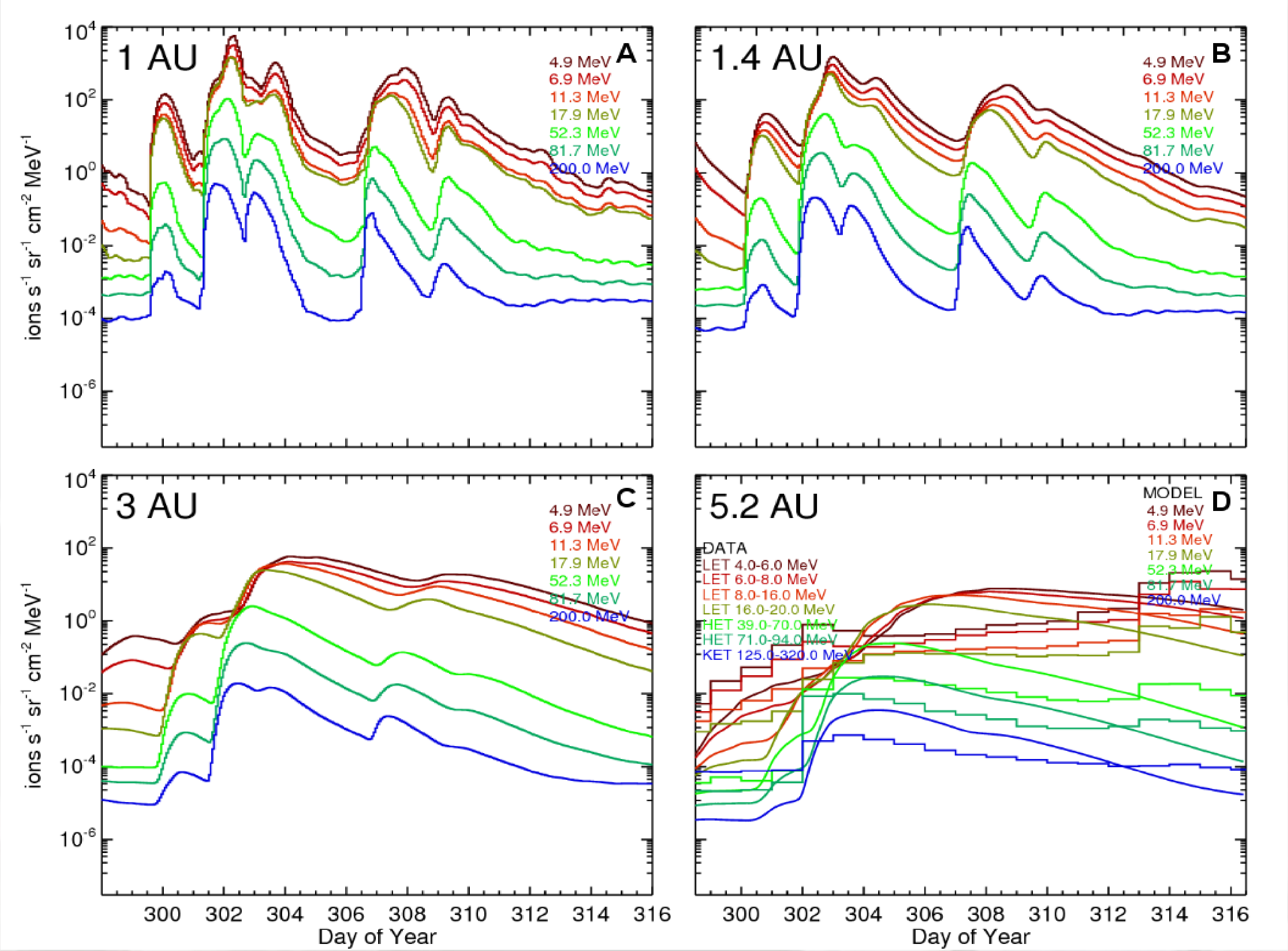
Study of Halloween events (October/November 2003)



Study of Halloween events: Plasma observations/predictions

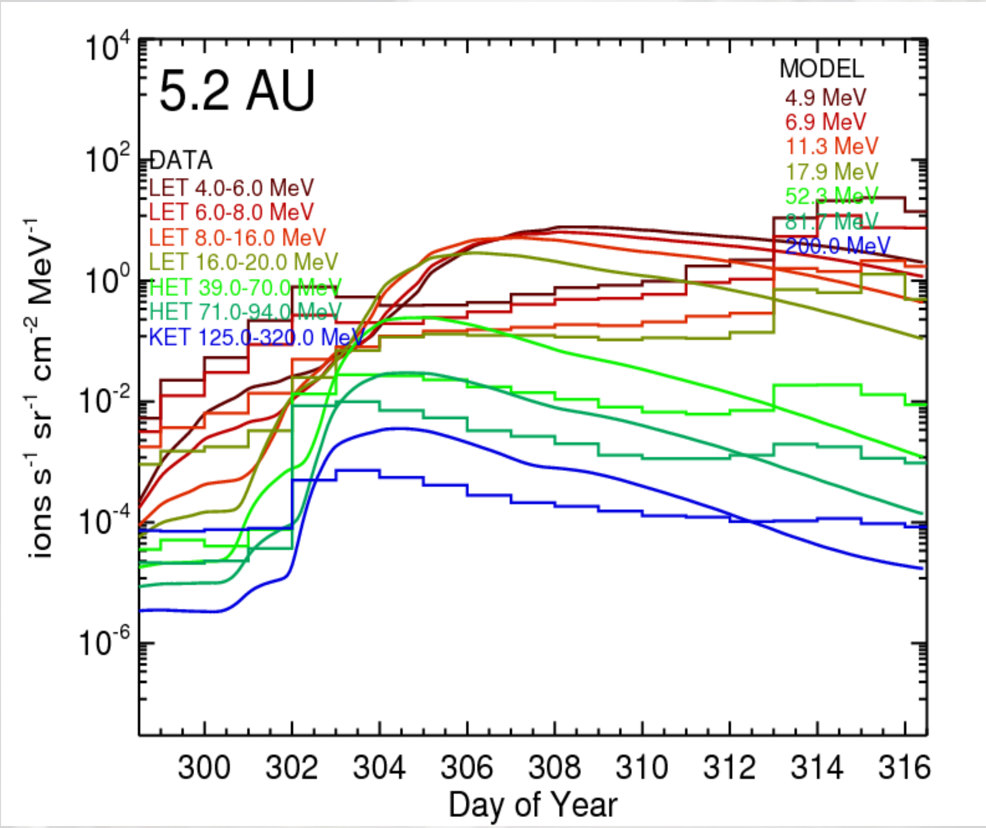


Study of Halloween events: energetic particle predictions

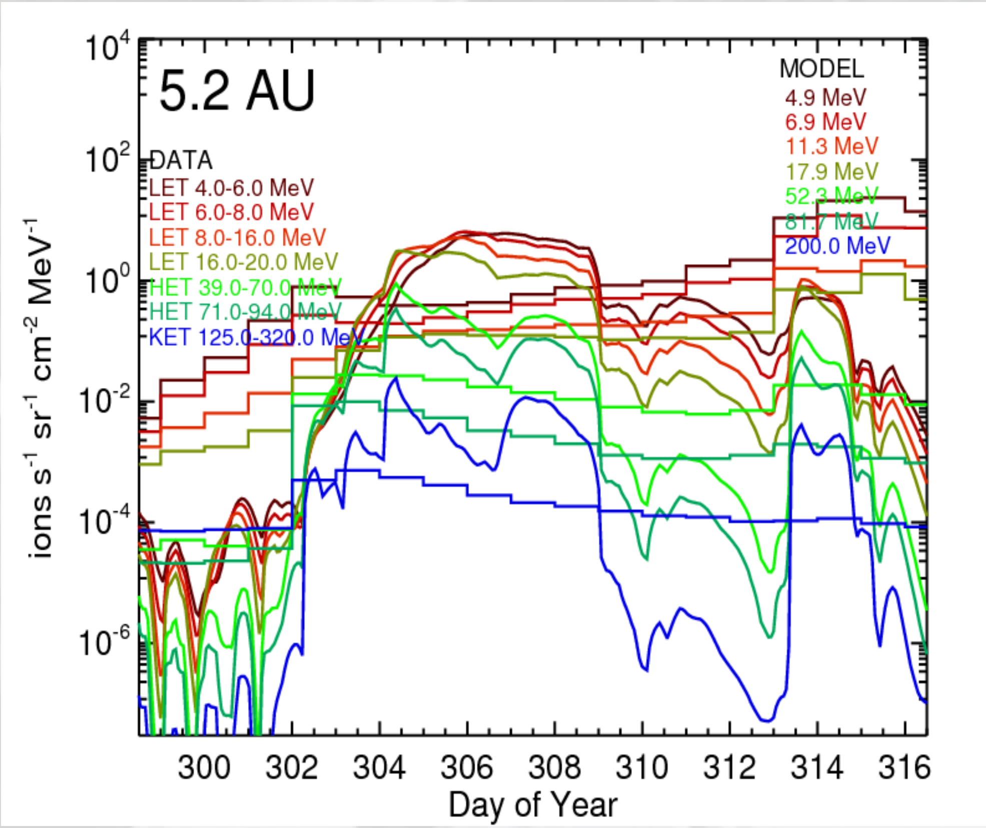


No MHD coupling

Study of Halloween events: energetic particle predictions



Without Enlil

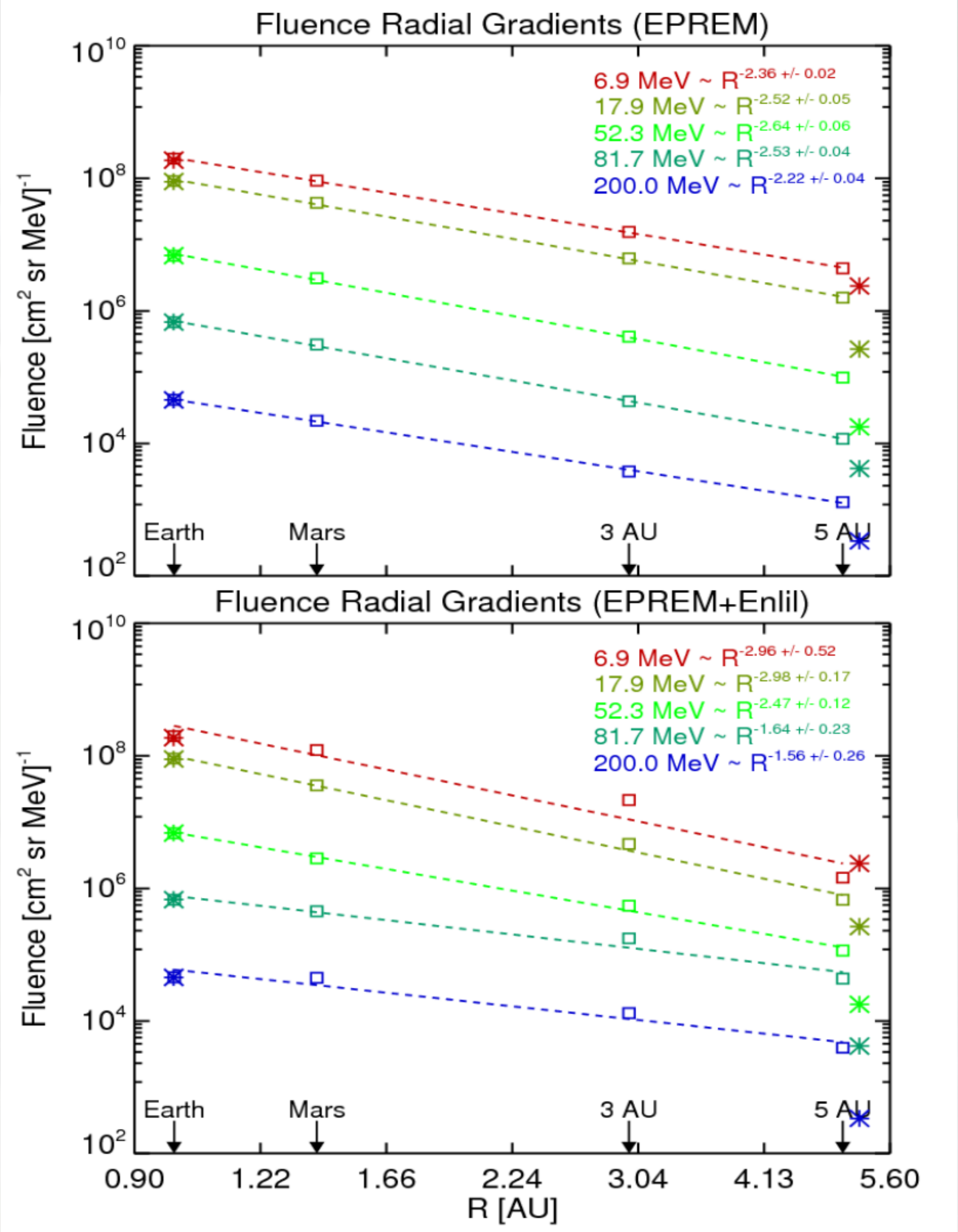


With Enlil

Study of Halloween events: radial gradients

Fluence~R^-2.5

Fluence~R^-2.3



Study of Halloween events summary

- An important link made between transport model and numerical MHD modeling
- EPREM sensitive to time-dependent plasma environment
- EPREM numerically stable against sharp changes in magnetic field/velocity/density
- Performs well out to 5 AU despite:
    - great longitudinal separation between Earth and Ulysses
    - large SEP events
- Overall agreement between the model and observations with time-independent solar wind
- Need improved MHD predictions for similar big events

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EMMREM Web interface

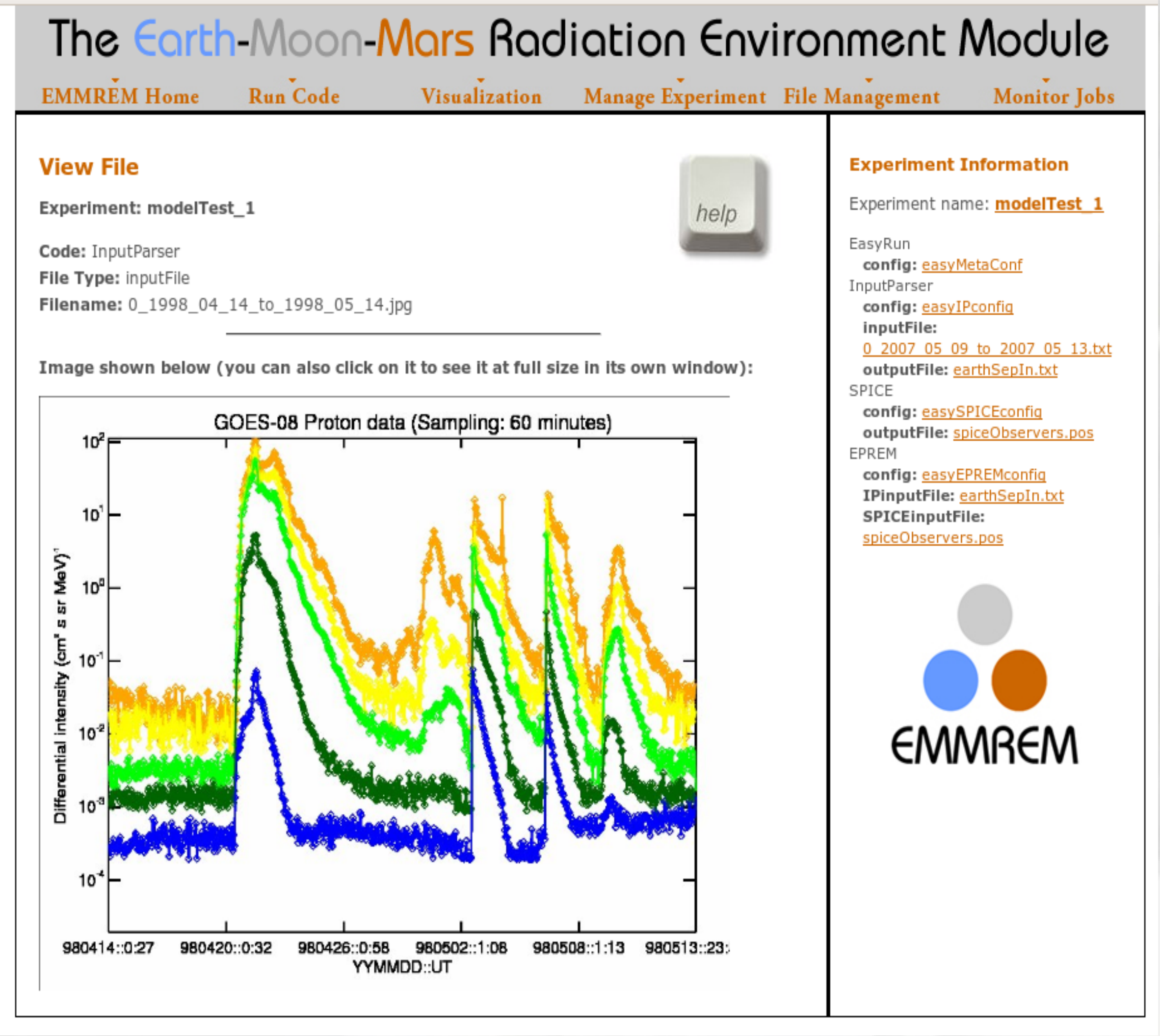
- Proton flux input data from GOES satellite

- EPREM runs on request

- BRYNTRN runs on request

- Visualization tools

- Catalog of events being compiled



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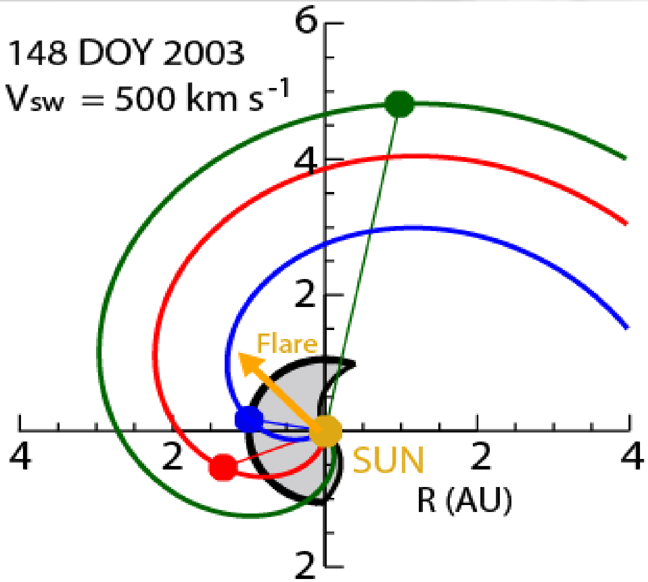
Summary

- **First version of EMMREM developed**
  - Interplanetary charged particle transport with EPREM
  - Coupling to MHD models
  - Radiation transport
  - Integrated models using unix scripts
  - Developed a suite of visualization routines in IDL
- **Ongoing V&V of interplanetary transport model**
  - EPREM stable and robust
  - Being verified against big SEP events and validated
  - **Developed a web interface to EMMREM**
    - Wide access to models and visualization

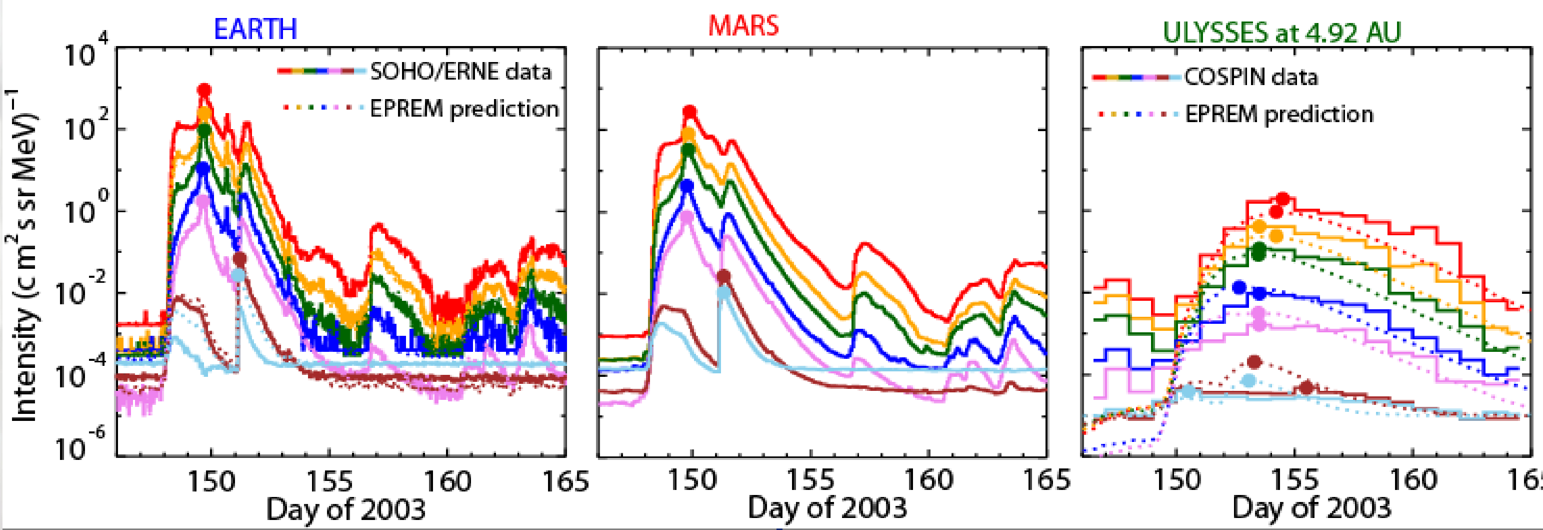
Future Work

- Continue comprehensive EPREM V&V
- Add traveling shocks/sources to particle propagation modeling
- Validate coupling to the LFM-helio model
- Develop a catalog of modeled SEP events

Thank you!



Proton energy ranges (MeV) at all observers		
SOHO/ERNE	ULYSSES/COSPIN	EPREM
2.7 - 3.3	2.0 - 4.0	3.0
4.1 - 5.1	4.0 - 6.0	5.0
6.4 - 8.1	6.0 - 8.0	7.0
10.1 - 12.7	8.0 - 16.0	12.0
16.9 - 22.4	16.0 - 20.0	18.0
50.8 - 67.3	39.0 - 70.0	52.0
80.2 - 101.0	71.0 - 94.0	80.0



Source reveals extremely broad longitudinal distribution

Radiation Quantities Primer

Dose: Mean energy absorbed per unit mass – **1 Gray = 1 J / 1 kg**

Dose Equivalent: Dose multiplied by a quality factor, for long-term radiation effects such as cancer

Organ Dose: Dose averaged over entire mass of a given organ or tissue (T)

Effective Dose: Sum over all irradiated organs of the equivalent doses times a weighting factor for long-term radiation effects

Linear Energy Transfer (LET): Mean energy loss by charged particle per unit distance traveled

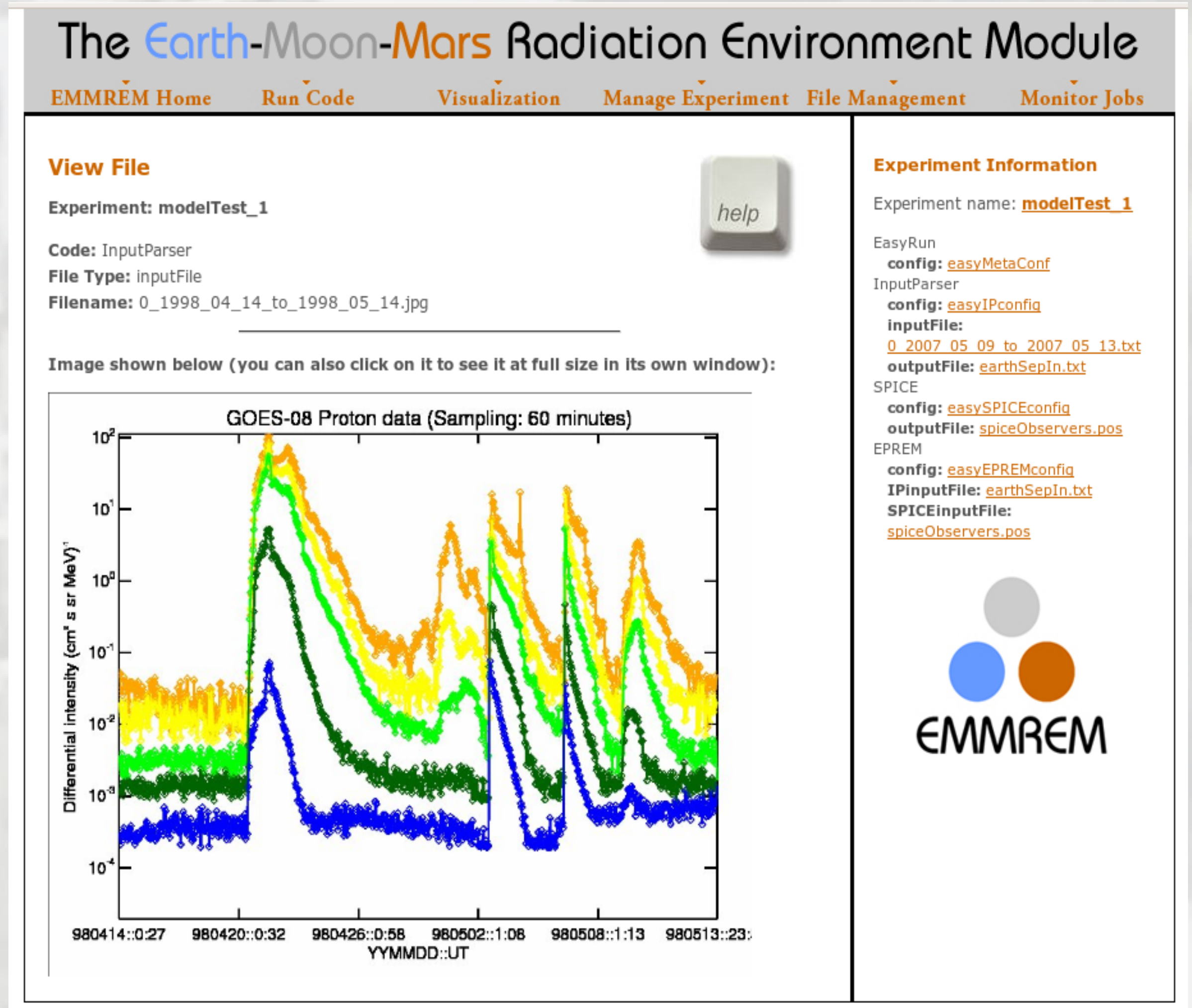
Dose-rate: The radiation dose absorbed per unit time

EMMREM Web interface

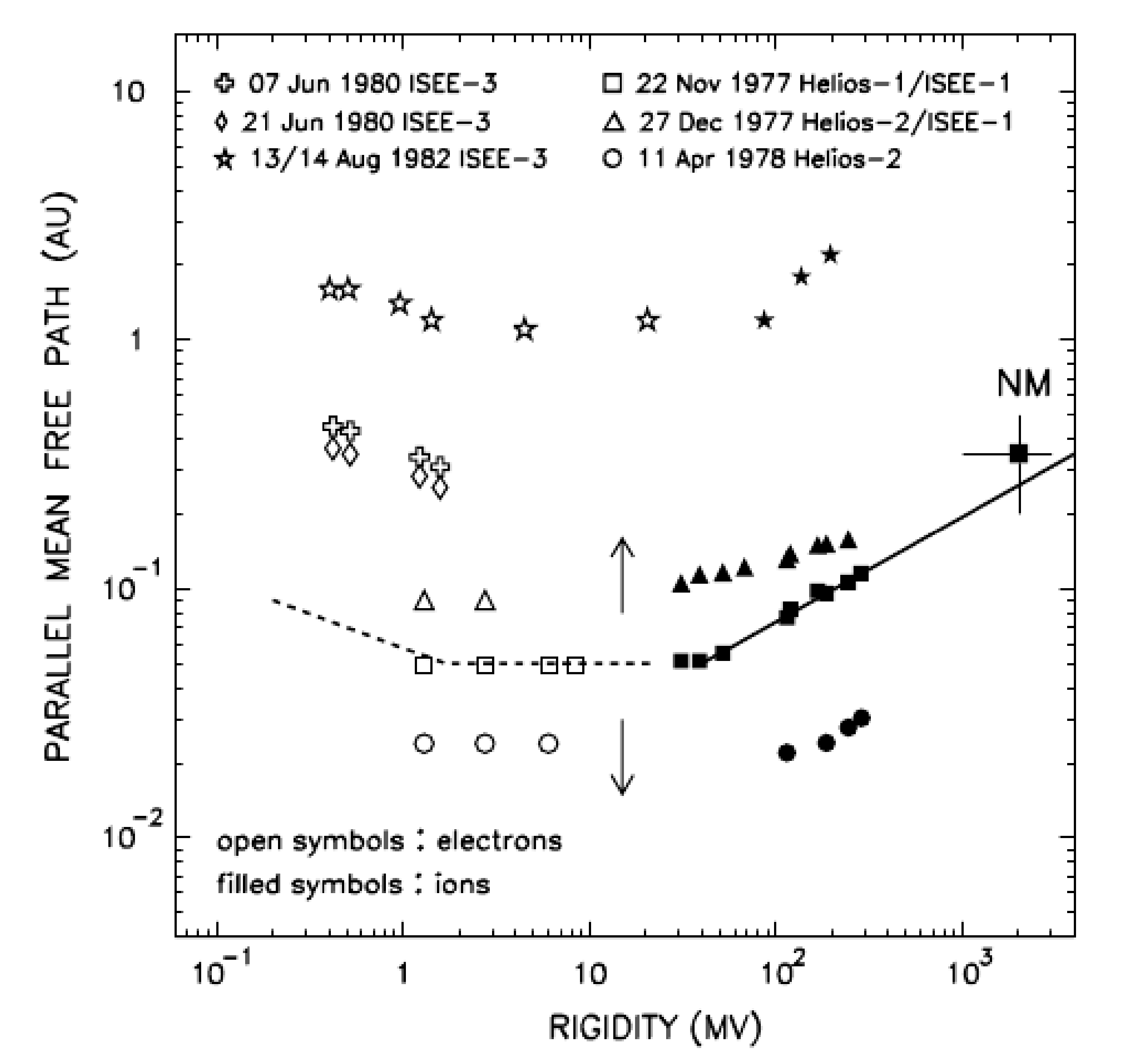
• Developed to allow easy access to models

• Currently available:
- GOES proton input
- EPREM runs on request
- BRYNTRN runs on request
- Sim results visualization

•New functionalities very soon:
- Mars radiation environment
- LET specra for comparison with CraTER
- Earth atmospheric radiation environment
- Catalogue of historical events with radiation environment information



Parallel Mean Free Path vs. Rigidity



Observed mean free paths (Droege, 2000)

Radiation Environment Characterization

The effects of energetic particle radiation on the human body are heavily dependent on the type and energy of the radiation, as well as the tissue being irradiated. These effects include cancer, degenerative tissue diseases, damage to the central nervous system, cataracts, and hereditary risks. The relative ability of energetic particles to cause biological damage is expressed as a quality factor, Q, which is a function of the Linear Energy Transfer (LET), or energy absorbed per distance traveled by a given particle through a medium. (For human tissue, this medium is approximated by water.) The LET is a function of particle atomic mass, charge (A and Z) and energy. For example, heavy elements such as Fe generally have large Q, even at relatively high energies, and therefore pose a serious safety hazard even though they are a fraction of the overall flux.

The following dose-related quantities (EMMREM output) are defined as follows:

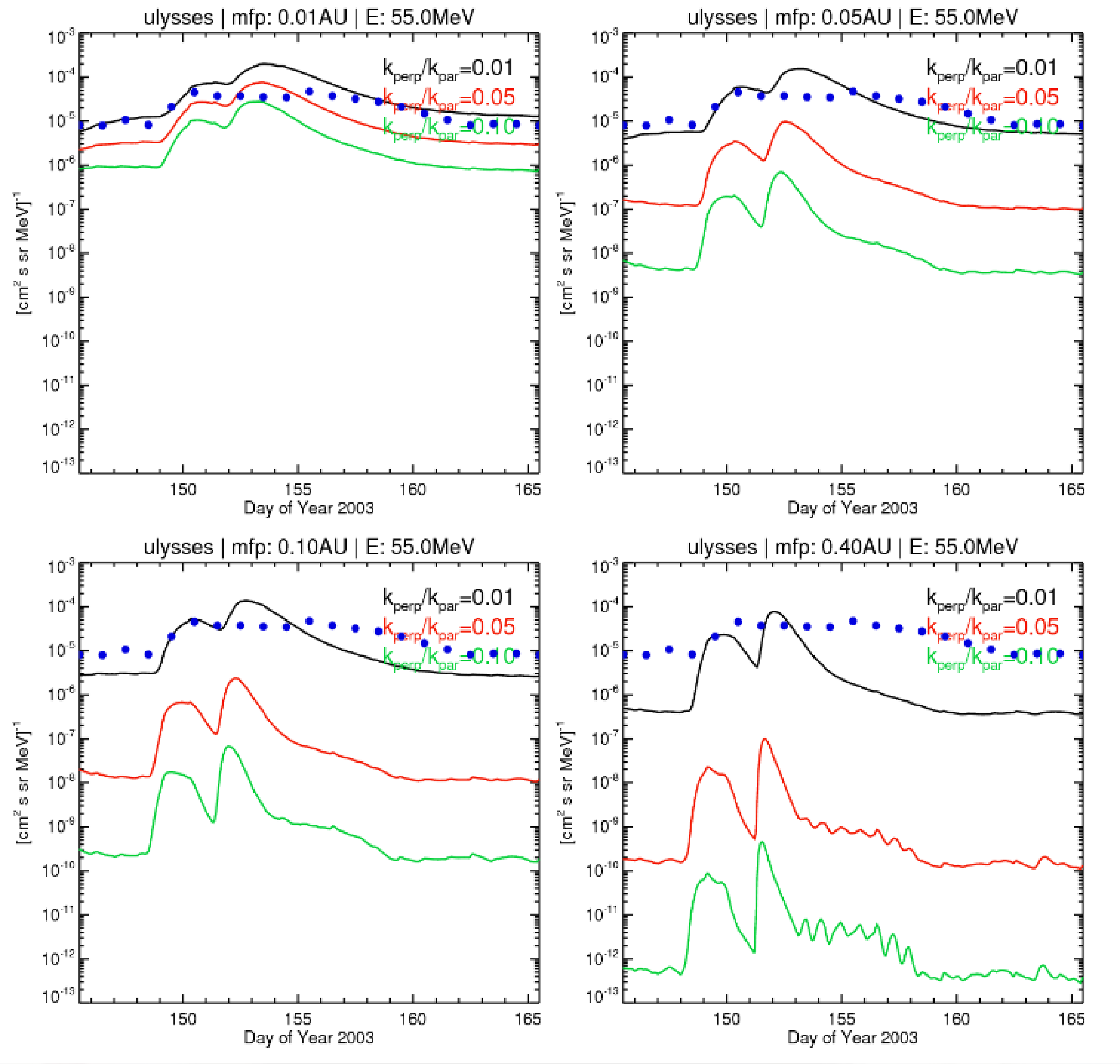
- Dose (D): Mean energy absorbed per unit mass
- Dose Equivalent (H): Dose multiplied by a weighting factor (quality factor, Q) characterizes long-term radiation effects such as cancer

$\dot{D}$

- Organ Dose (D_T): Dose averaged over entire mass of a given organ or tissue (T)
- Equivalent Dose (H_T): Organ Dose multiplied by a weighting factor characterizing long-term radiation effects depending on specific types of radiation (proton, neutron, alpha, etc)
- Effective Dose (E): The sum over all irradiated organs of the equivalent doses times a weighting factor for long-term radiation effects
- Linear Energy Transfer (LET): Mean energy loss by charged particle per unit distance traveled

EPREM – validation

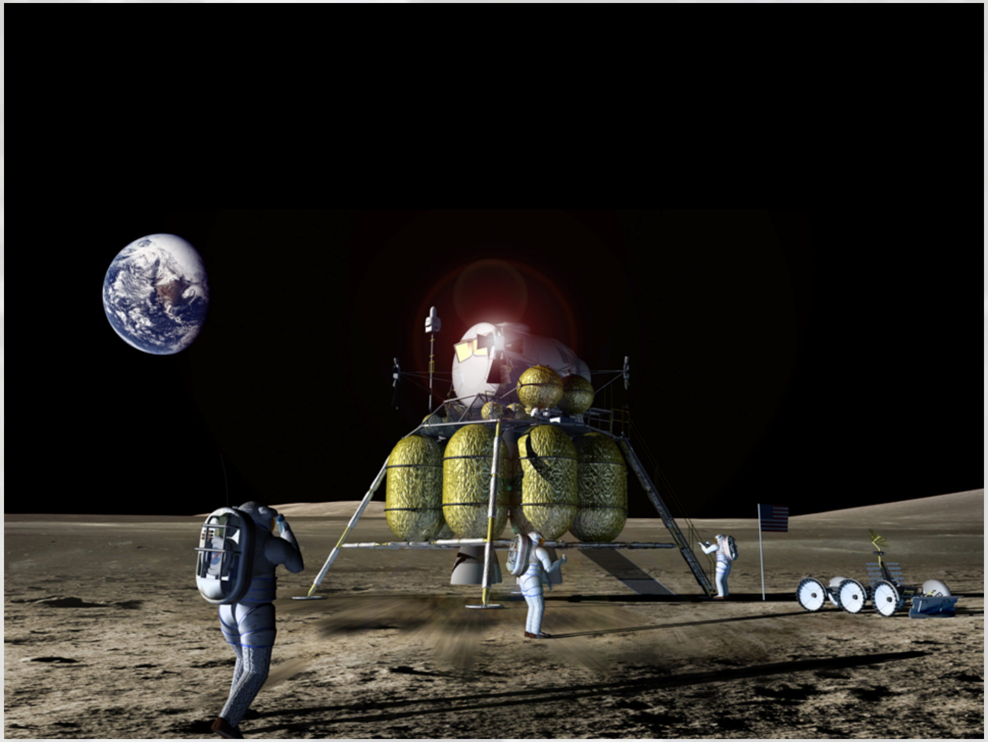
- Dependence on diffusion at 5 AU



E = 55 MeV (protons)

The NASA Vision for Space Exploration

- NASA will carry out missions returning to the moon in next decade
  - Sortie missions ~14 days by 2020
  - Long duration missions up to 240 days by 2022
- Missions to Mars will occur towards 2030 building on the lunar program
- Radiation protection requirements including dose limits for lunar missions are now being formalized
  - Protection against large solar proton events are a major near-term goal
- Proposed NSBRI Acute Countermeasures Team requires Risk initial assessment focus



Cucinotta and Durante, The Lancet- Oncology (06) courtesy of John Frassanito and associates

EMMREM is urgent for the following National, NASA, NSF and LWS Objectives

- Our objective is vital to "*Implement a sustained and affordable human and robotic program to …, and prepare for human exploration*" (a vision established by the **President's Space Exploration Policy Directive**, NPSD31) and directly relevant to the LWS program strategic goal 3: "*The need for a predictive model for radiation exposure anywhere on the surface or in the atmosphere of Earth, on the Moon, on Mars, and in interplanetary space between Earth and Mars*" (in sec 1.1of the NRA).
- Innovative software technology that provides critical knowledge of radiation exposure in support of human and robotic exploration and thus a key element of the **National Objective** to "*Develop innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration*" and **NASA's objective** to "*Develop and demonstrate … other key capabilities required to support more distant, more capable, and/or longer duration human and robotic exploration of Mars and other destinations*".
- Important to **NASA's objective** to "*Explore the Sun-Earth system to understand the Sun and its effects on Earth, the Solar System, and the space environmental conditions that will be experienced by human explorers …*".
- Relevant to the **National Space Weather program**'s goal to *"validate and enhance space weather models to improve specification and prediction capabilities,…"*..
- Complements and enhances **NSF's Science and Technology Center for Integrated Spaceweather Modeling (CISM)** by predicting radiation exposure from the large-scale space weather events simulated as a part of CISM. EMMREM leverages research at the heart of National space weather program for the development of a module important for NASA's Vision for Exploration Program.

Goals of the Project

- Develop central **EMMREM module** for predicting time-dependent radiation exposure based on **BRYNTRN and HZETRN** code developed at NASA Langley and the **HETC-HEDS Monte Carlo code** developed at Oak Ridge National Laboratory and the University of Tennessee.

- Develop **interfaces between EMMREM and direct observations** of particle radiation. Observations used as direct input to predict radiation exposure at the Earth, on the Moon, Mars and in interplanetary space environments.

- Develop **interfaces between EMMREM and models** of particle radiation (energetic particle transport).

- Significantly reduce radiation exposure uncertainties through comprehensive validation