Space Weather at Mars: Energetic Particle Measurements on the Surface of Mars

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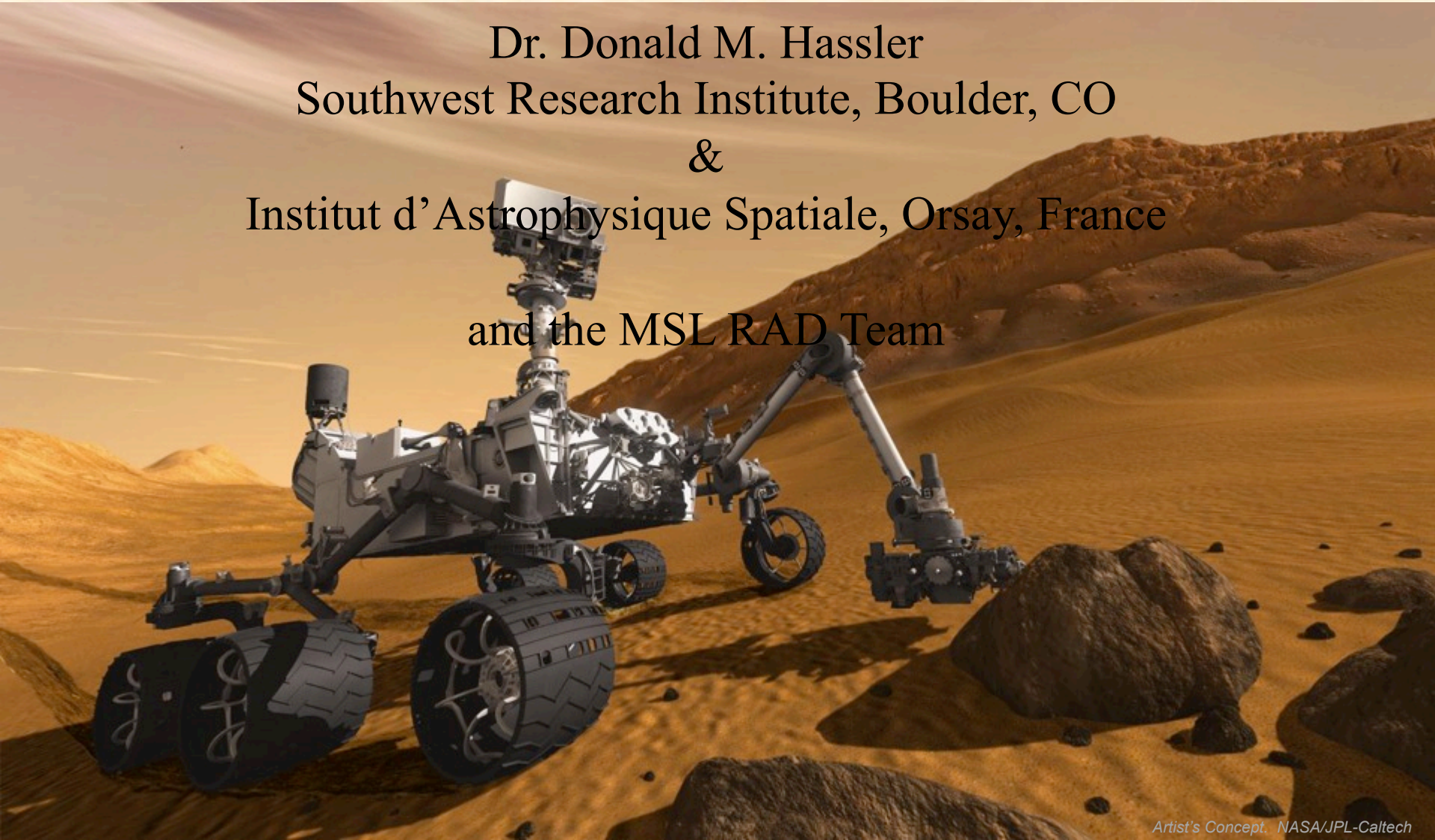
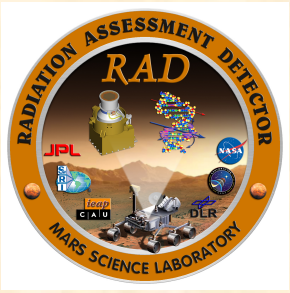
and the MSL RAD Team



Artist's Concept. NASA/JPL-Caltech

Space Weather at Mars (…and Interplanetary Space Weather)



Why is it interesting? Why is it important?

- 1) The Heliophysics system is a ***complex system of coupled processes & phenomena***. Understanding the interactions of the Solar Wind with other planets as ***comparative analogs*** to Earth helps us ***better understand these processes at Earth***.

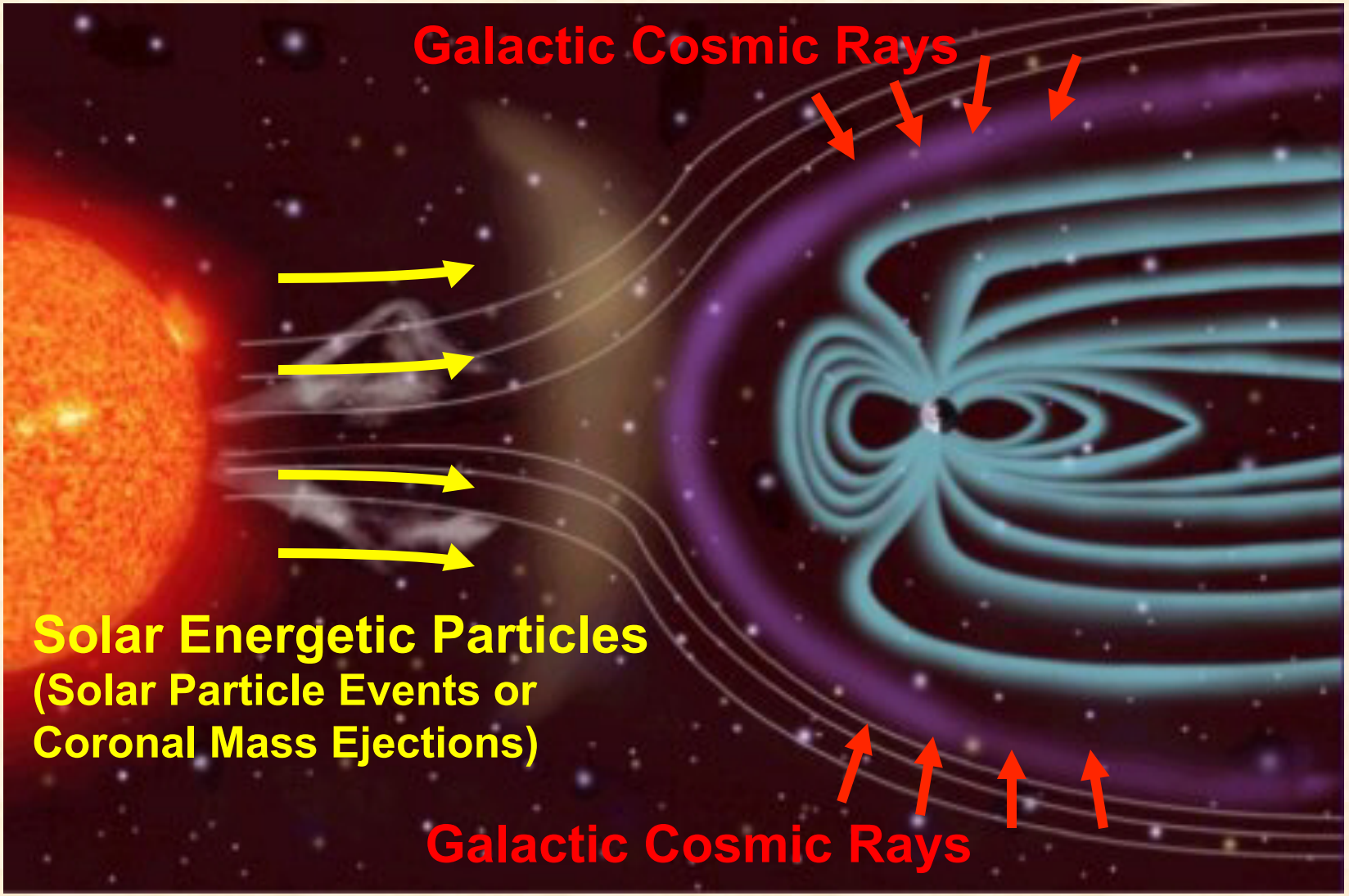
- 2) To understand the initiation, onset, eruption & propagation of Solar Storms, we need to have ***multi-point observations to improve & validate our models and improve prediction***.

- 3) ***To support, enable & ensure Human Exploration to Mars & deep space***, we need to be able to monitor & provide space weather predictions & warnings remotely, at locations away from the Earth-Sun line.

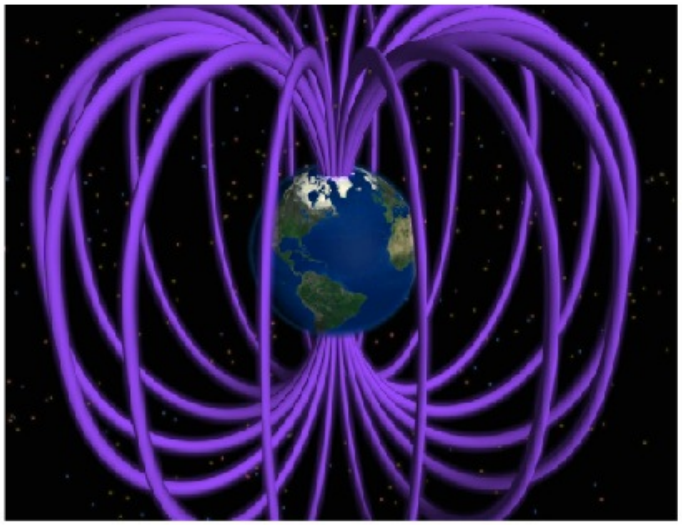
Scientific understanding IS an enabling technology!

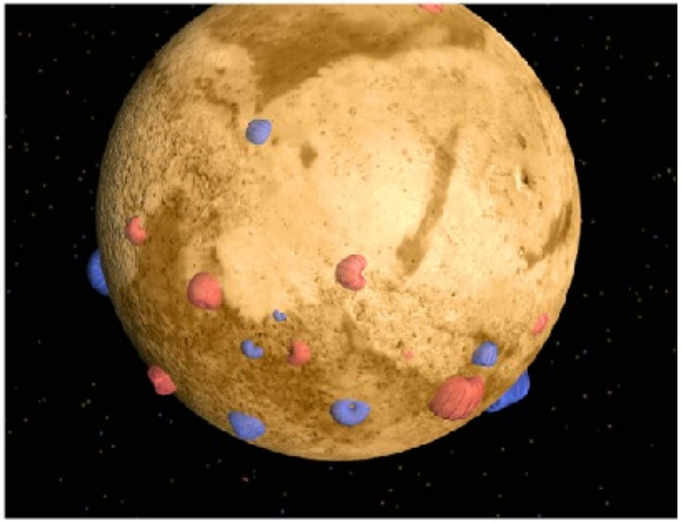
Space Radiation Overview

(View from Earth's perspective)



The Radiation Environment at Mars…





- The surface of Mars is much more exposed to space radiation than is the surface of Earth, for two reasons:
  - Mars lacks a global planetary magnetic field (magnetosphere)
    - Only weak, local, remnant magnetic fields
  - Mars atmosphere is much thinner
    - ~1% of thickness of Earth's atmosphere

RAD (Radiation Assessment Detector) Overview

- ***MSL/RAD is a collaboration between NASA SMD & HEOMD and internationally between the US (NASA) and Germany (DLR).***
- …RAD is characterizing the **changing Radiation Environment on Mars over the Solar Cycle…**, due to Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs) originating from Solar Flares.

The RAD instrument in a nutshell

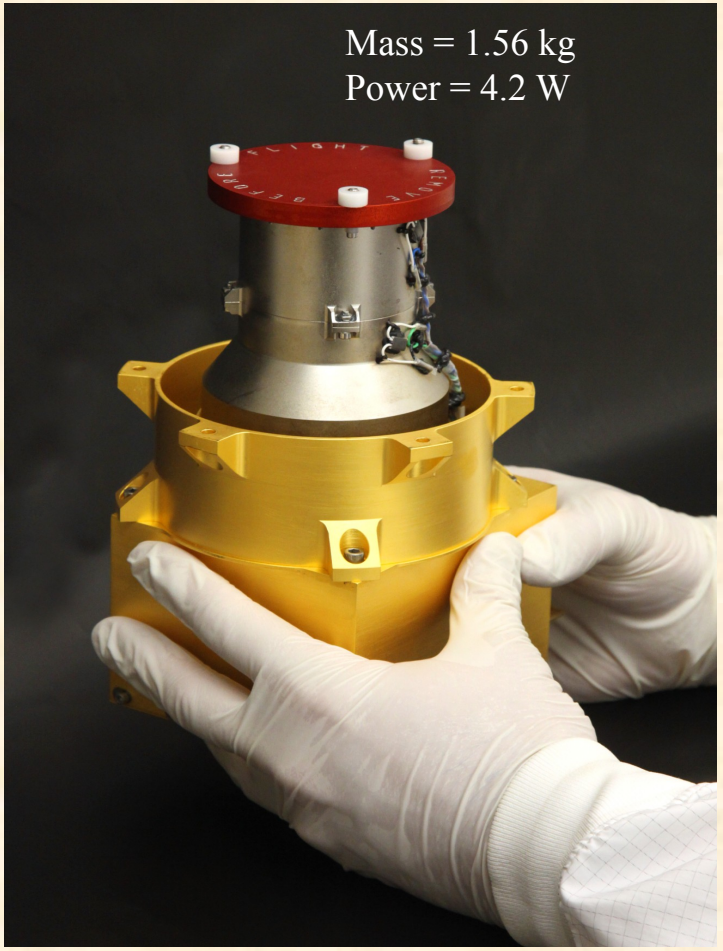
- RAD is a compact, highly capable radiation analyzer to *characterize the full spectrum of space radiation* (both charged & neutral particle).

- RAD can be used as an "area detector*" inside a spacecraft*, or as an "environment monitor" *outside of a spacecraft* to measure the space environment.

RAD is comprised of:

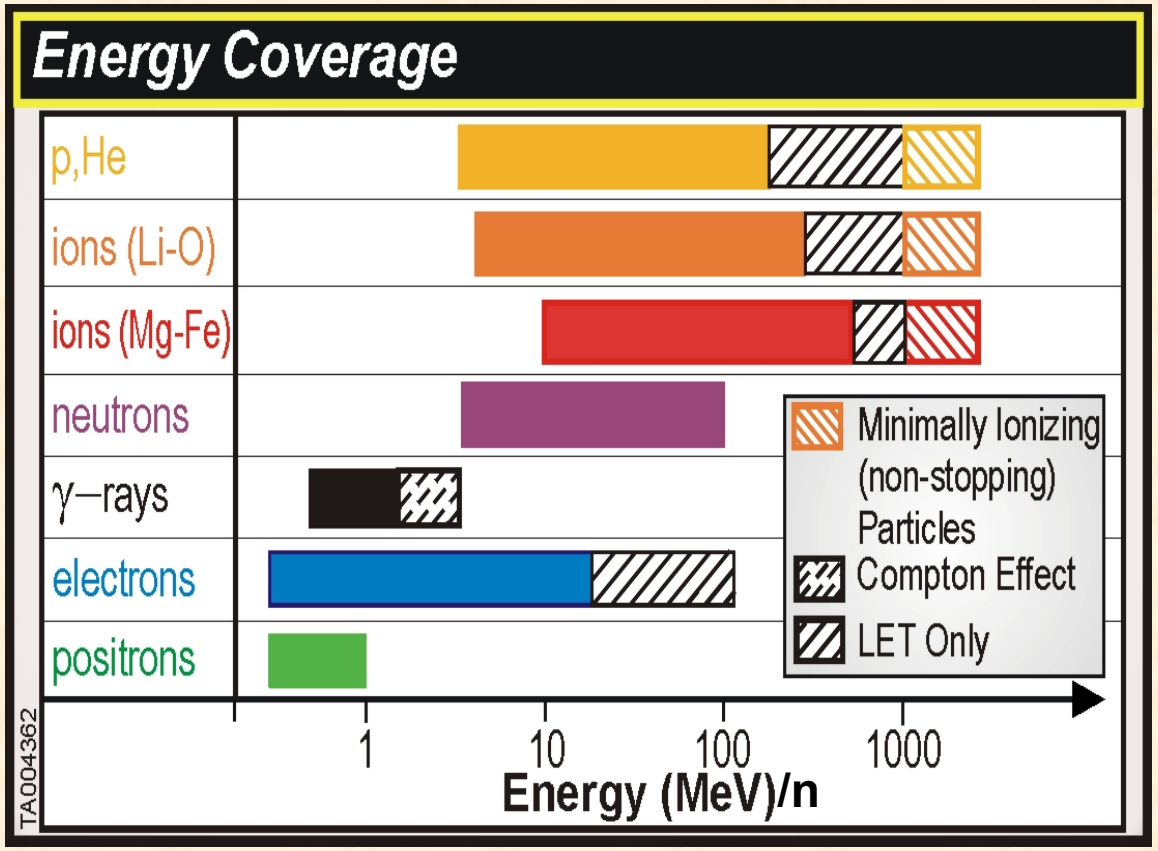
•Solid state detector telescope and CsI calorimeter with active coincidence logic to identify *charged particles*.

•Separate scintillators w/ anti-coincidence logic to detect *neutral particles (neutrons and γ-rays)*.

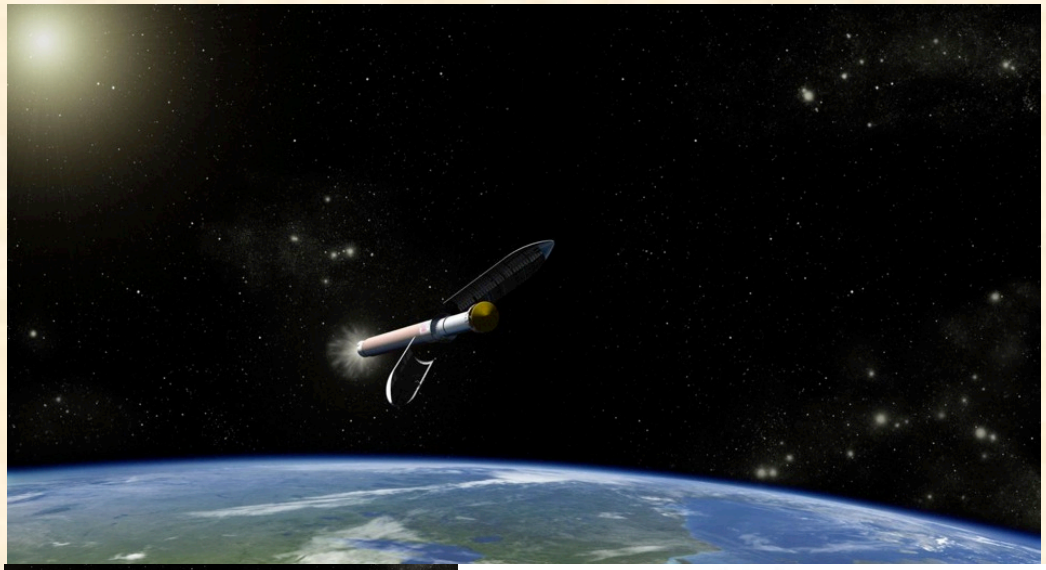


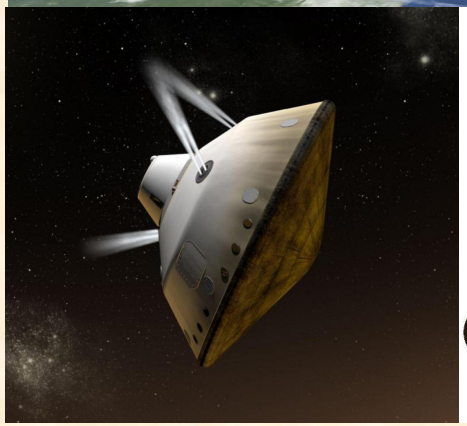
RAD Measurement Capability (Overview)

- ***Charge particles*** (protons and heavy ions up to Fe) ($1 \leq Z \leq 26$) vs energy & time
- ***Neutral particles*** (neutrons and γ-rays) (1-100 MeV neutrons) vs energy and time
- ***Absorbed Dose*** *and* ***Dose rate*** (LET of 0.3 to 1000 keV/μm) as a function of time
- ***Dose Equivalent*** (time-resolved Si LET spectra to determine LET-based Quality Factors)

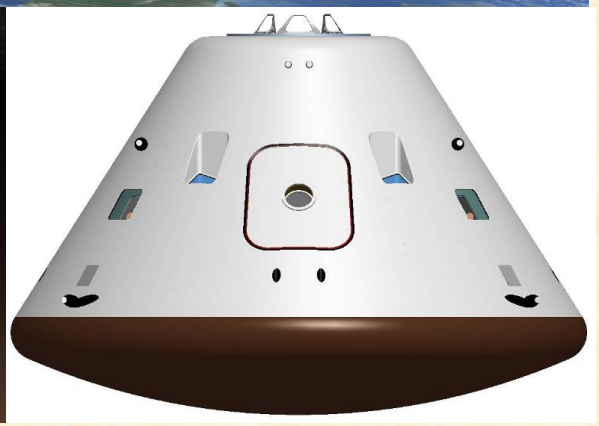


During Cruise: RAD Observations Inside the MSL Spacecraft





MSL Spacecraft during Cruise

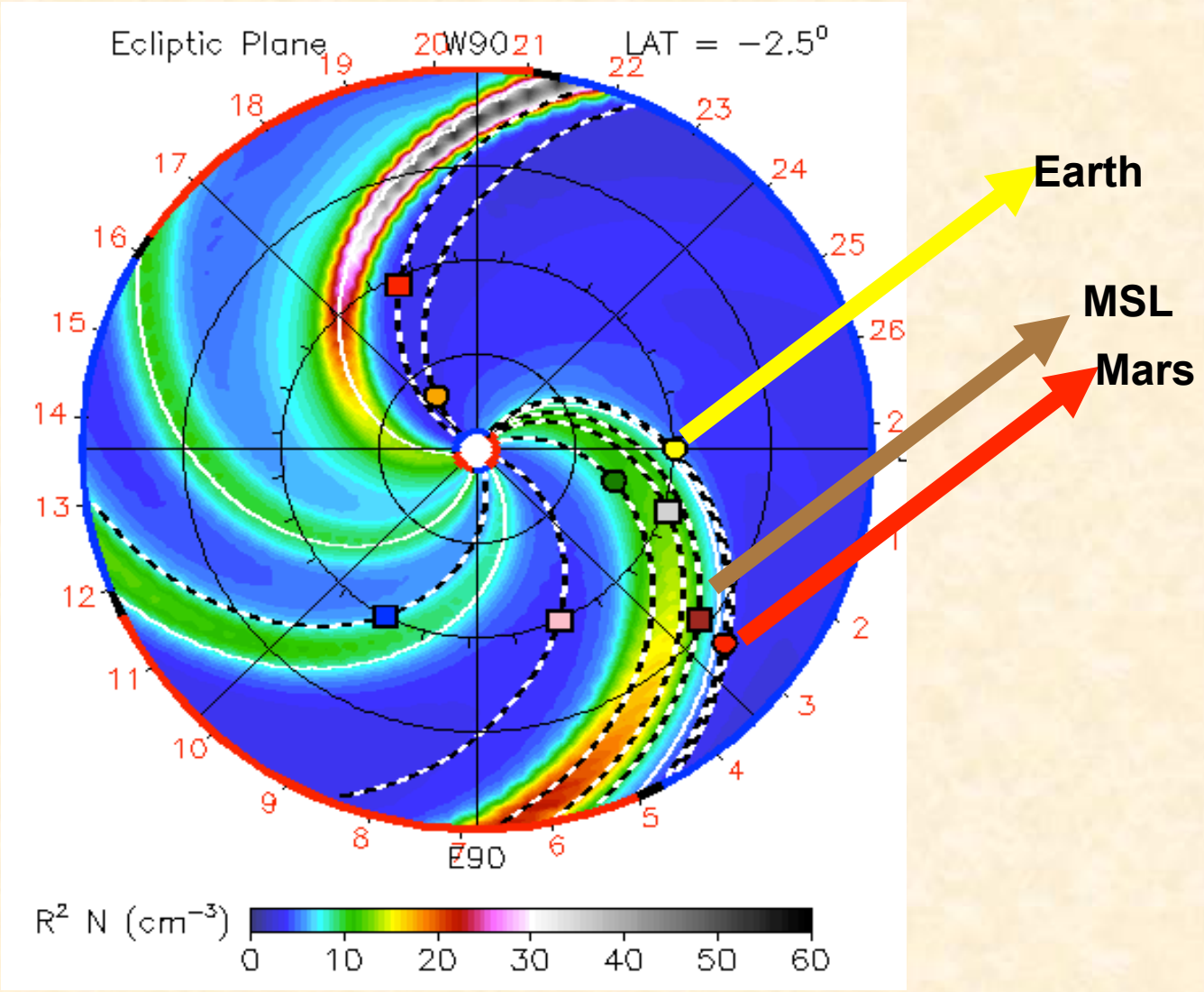


Manned Crew Exploration Vehicle (*Orion)*

On its way to Mars, inside the MSL Spacecraft…,

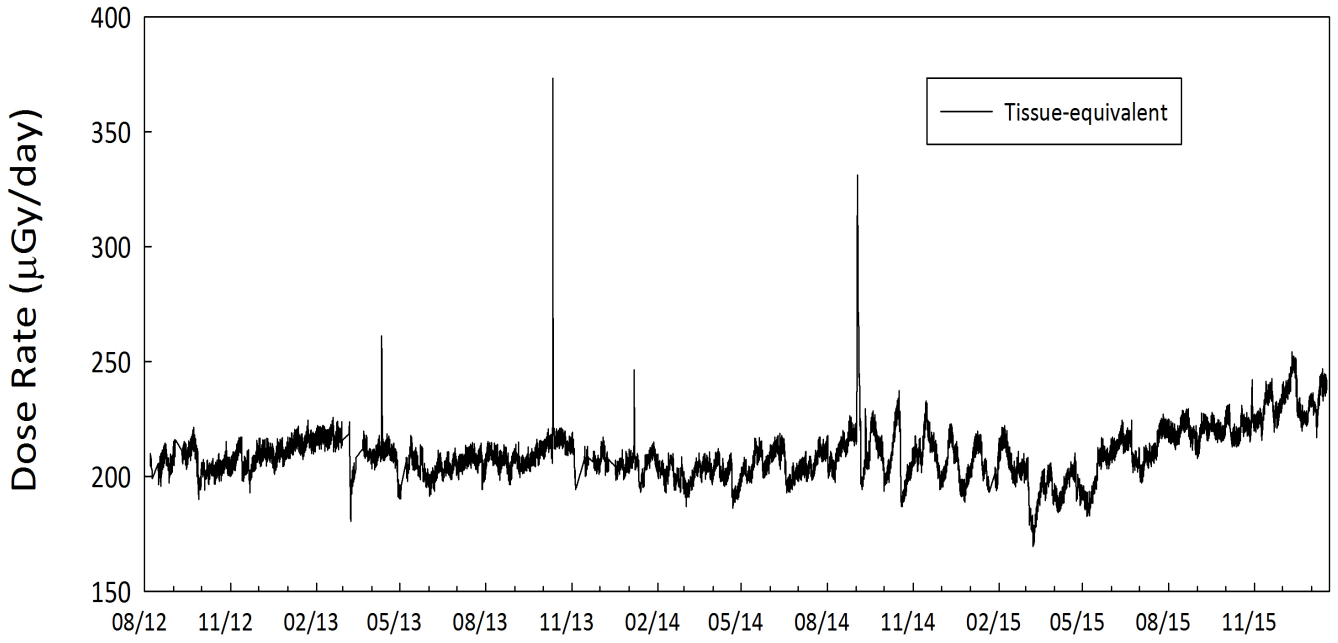
RAD served as a proxy to help validate models of the radiation levels expected inside a spacecraft that future astronauts may experience…

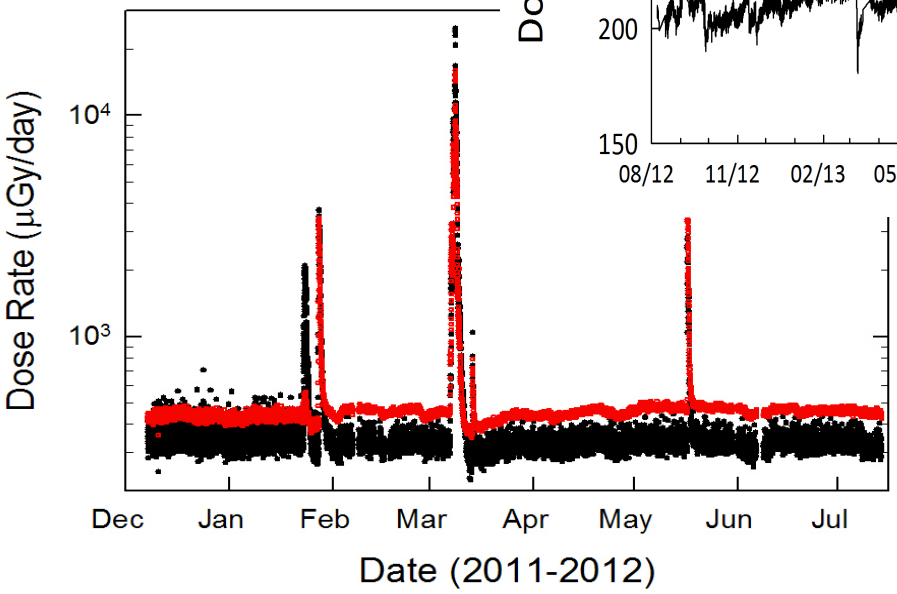
During Cruise: MSL was magnetically well connected with Earth



RAD total Dose Rate Summary (cruise & on the surface of Mars)

During Cruise… several medium size SPEs observed.

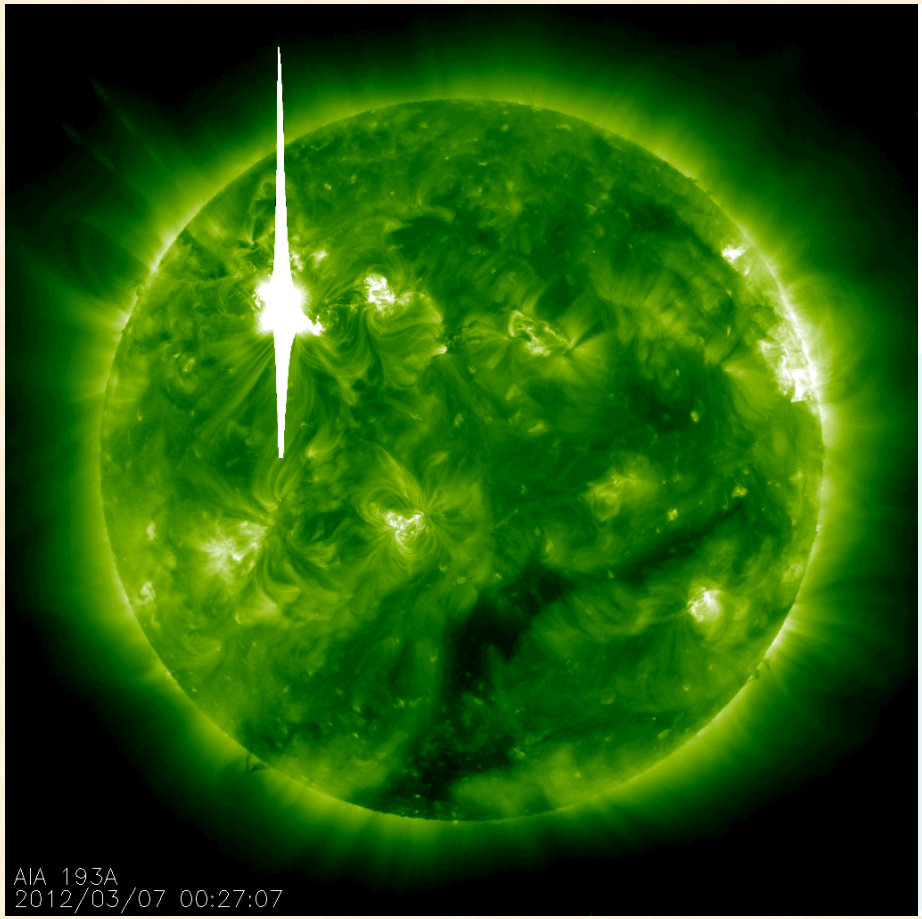


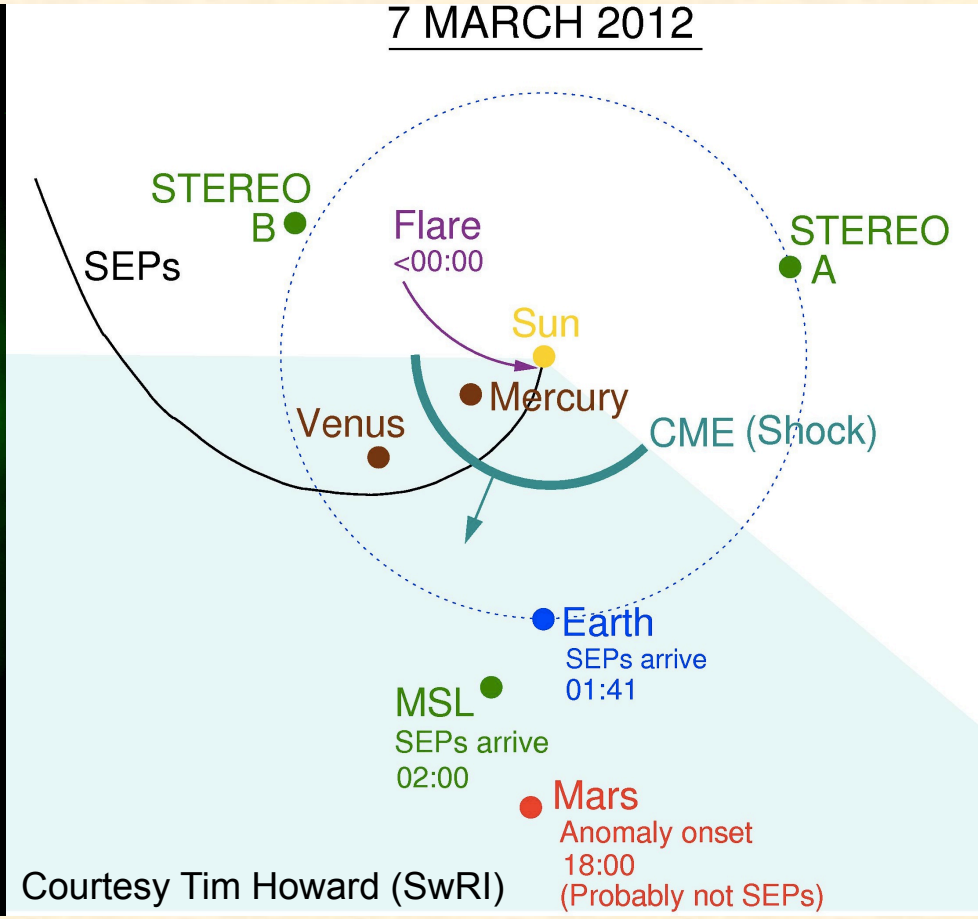


On the Surface…variability on all time scales…only small SPEs observed so far…

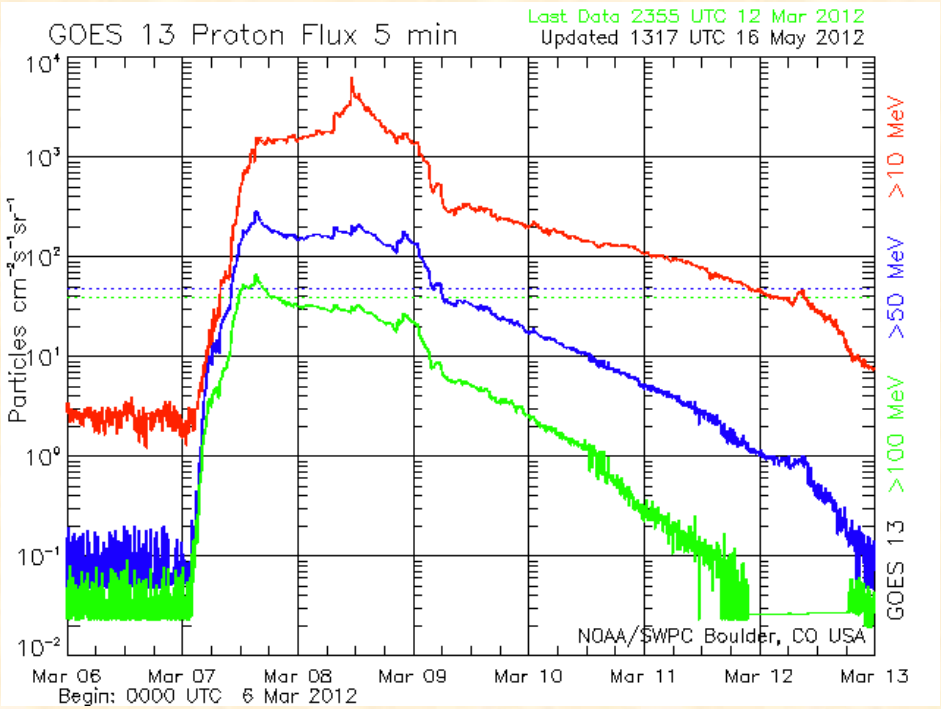
RAD saw several medium to large SEP Events during Cruise…

Flare & SEP Event on March 7, 2012



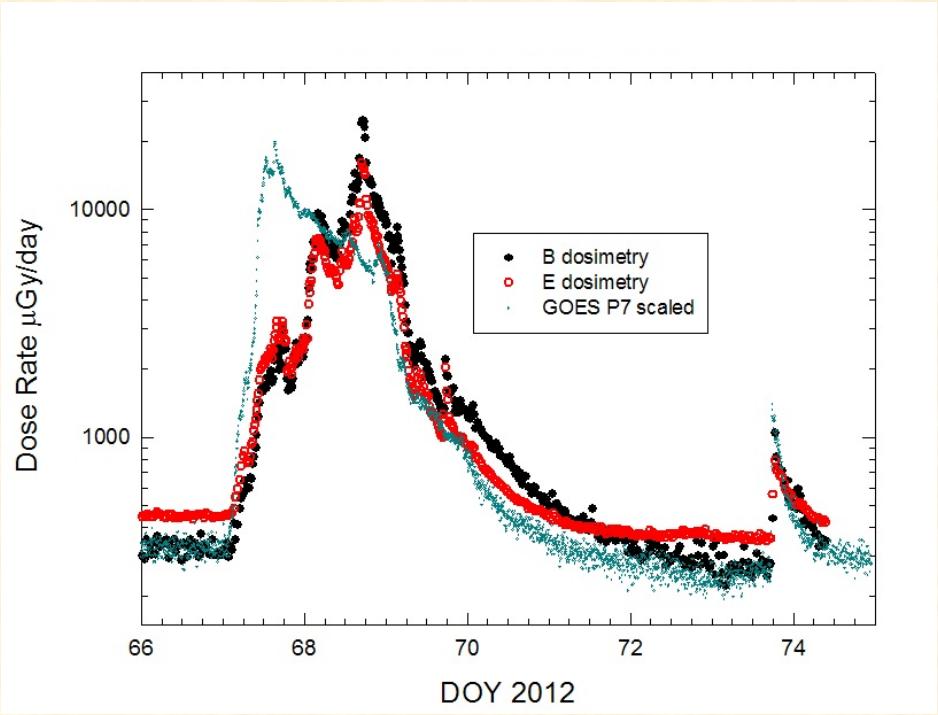


RAD & GOES 13 observations of the same event – RAD is shielded…!



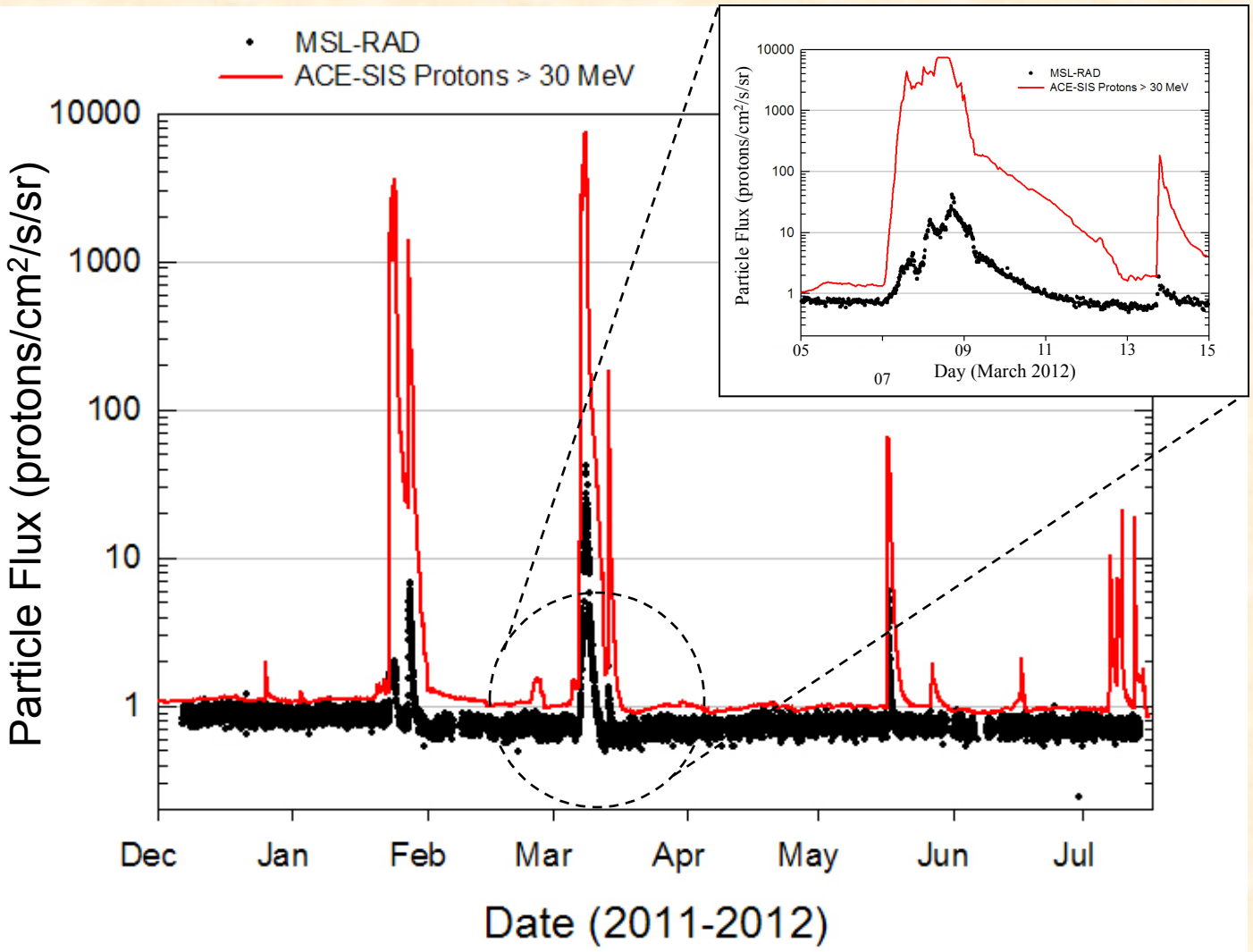
GOES Satellite (Earth Orbit)

SEP Event on March 7, 2012



RAD (Inside MSL Spacecraft)

Shielding to Solar Particle Events (SPEs) Provided by the MSL Spacecraft



The spacecraft structure provides significant shielding from the deep space radiation environment…, reducing significantly the particle flux observed by RAD.

Particle flux observed by RAD is several orders of magnitude less than that observed by the SIS instrument on ACE.

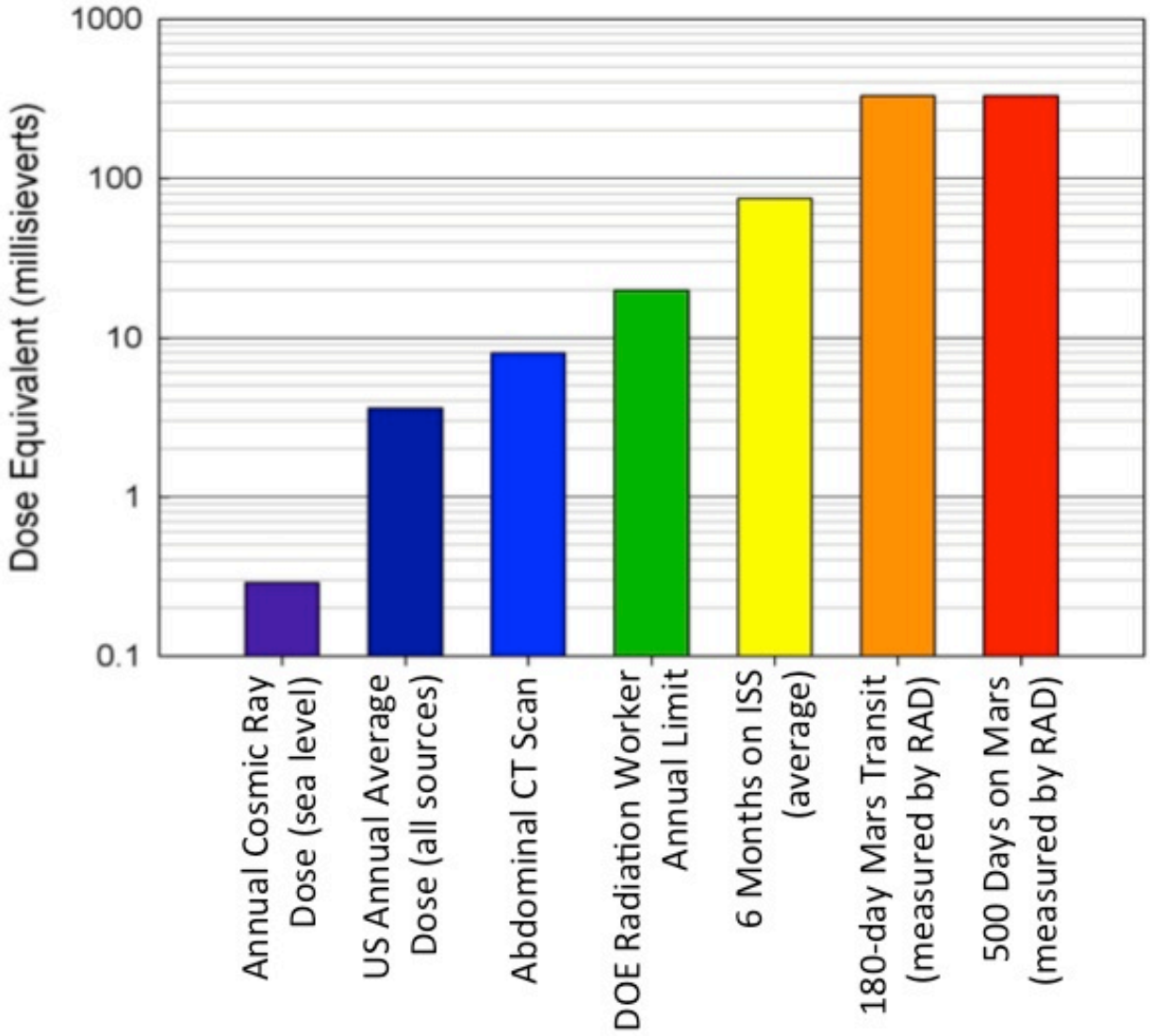
SEP Events Contribute to Total Dose During Cruise…

Time Period (2012)	Integrated Dose Equivalent (mSv)
Total Jan 23-29 SEP	4.0
Total March 7-15 SEP	19.5
Total May 17-18 SEP	1.2
SEP Events Total	**24.7**
GCR average per day	1.84
TOTAL (GCR + SEP) (253 days)	**490**

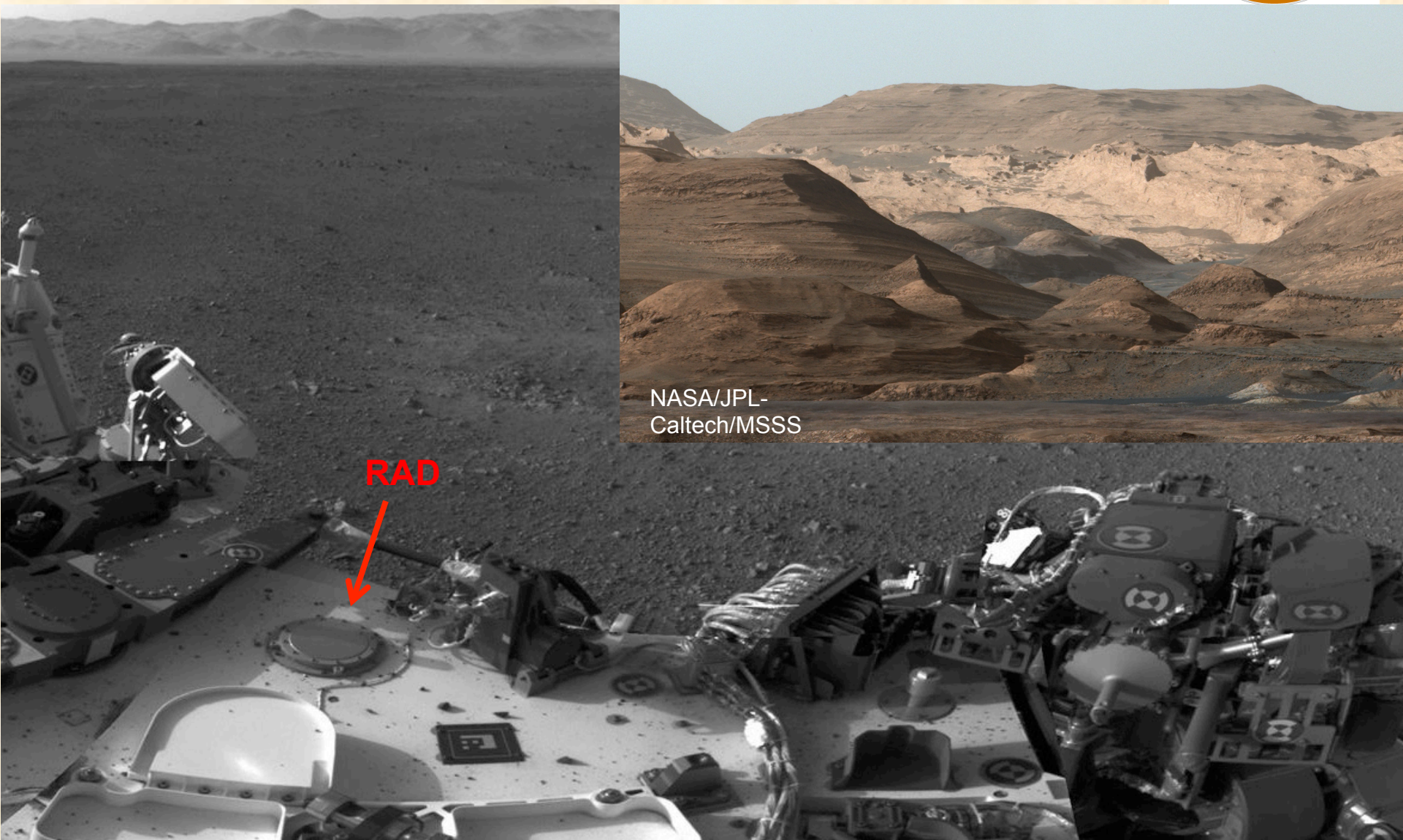
During Cruise, SEP Events contributed ~5% to the Total Integrated Dose Equivalent.

- However, SEP Fluences & Energy Spectra ("Hardness") are highly variable…
- *…a very large SEP Event ("Super-Event" or Carrington Event) (similar to the 1972 SEP event) could potentially contribute substantially more (>order of magnitude) to the total integrated Dose Equivalent.*

Radiation Levels Measured by RAD compared with Common Sources



On the Surface of Mars…
(RAD's new home in Gale Crater)



Sol 1…First Observations on the Surface of Mars!

100 Years after the Discovery of Cosmic Rays on Earth…August 7, 1912…

Credit: Foray (New York Times)

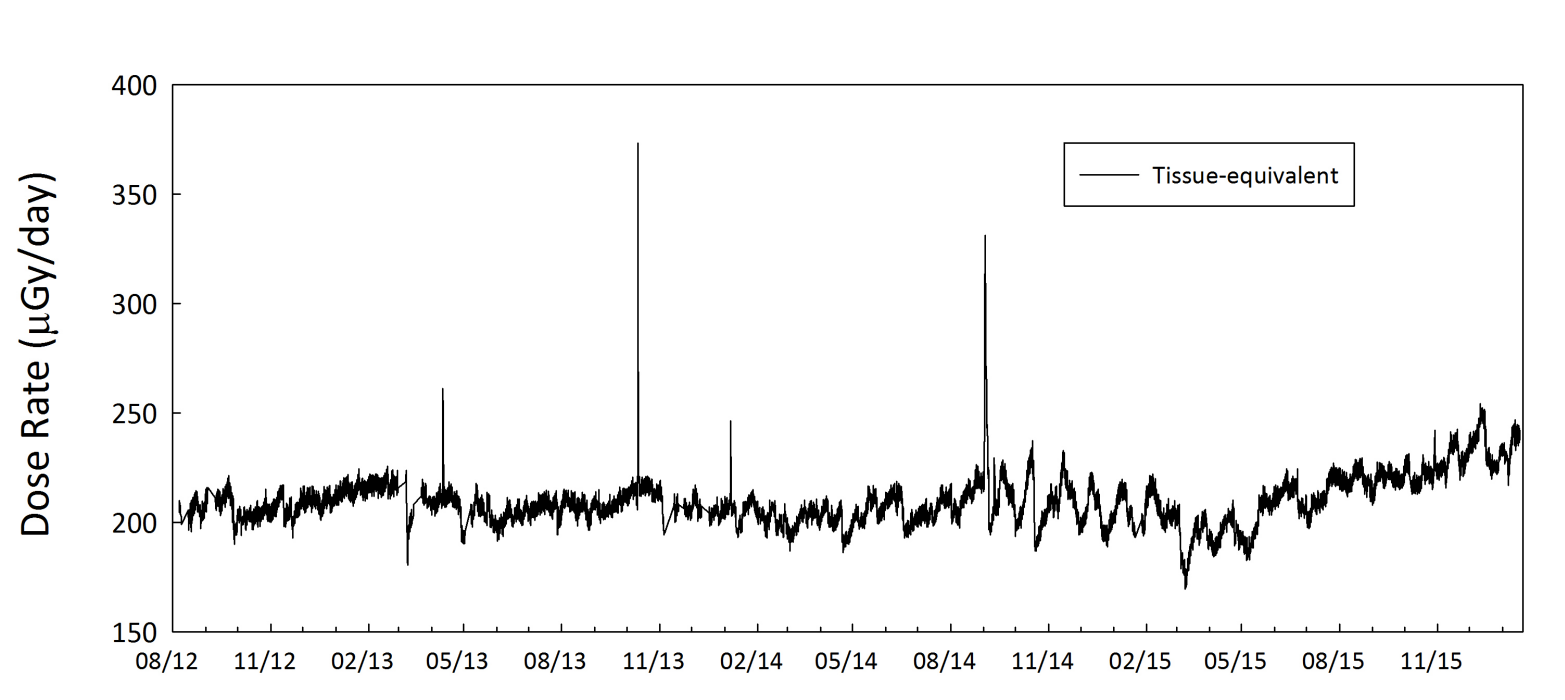
Exactly 100 years after Victor Hess discovered Cosmic Rays from his balloon in Eastern Germany…

…RAD makes the first observations of the radiation environment on the surface of another planet!

Jim Ryan showed this photo earlier…

Synoptic Observations on the Surface of Mars: the first 1200 days (sols)…

RAD Tissue-Equivalent Dose Rate through mid-Jan 2016

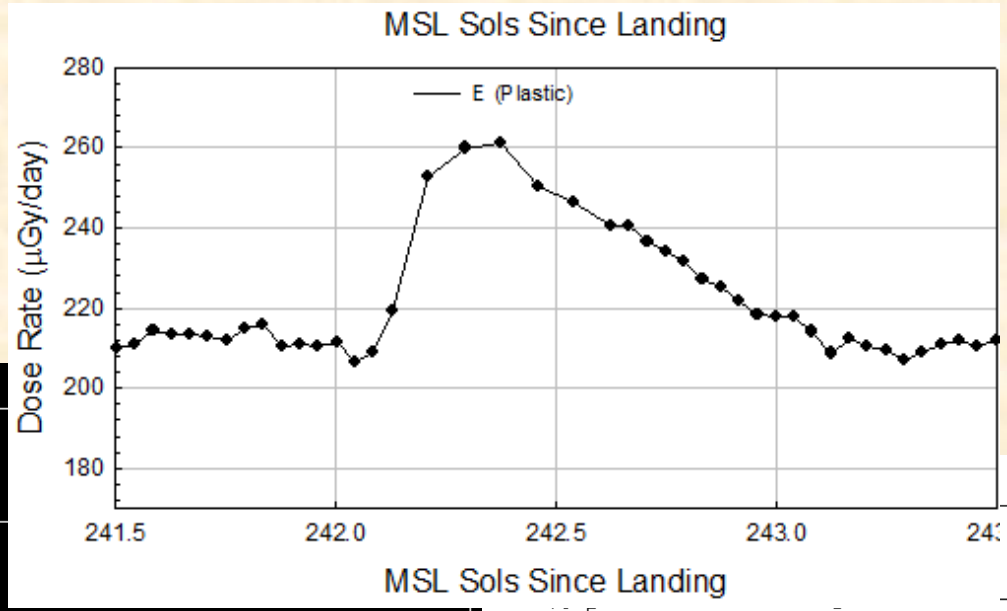


- For a *SEP event* to make it to the surface, it needs to be relatively "hard"… otherwise the only observed effect is a Forbush decrease…
- **Dose Rate trending higher (~10-20%) since June 2015**
- …due to beginning of declining phase of solar cycle?

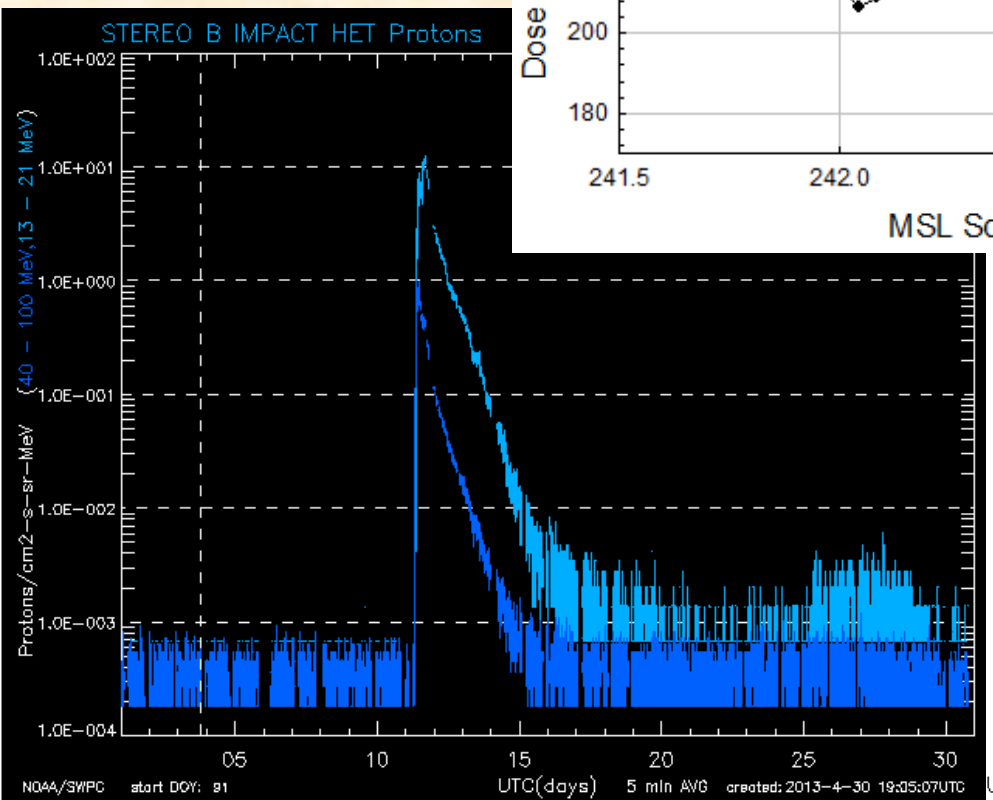
First SEP Event seen on the Surface of Mars…

11 April 2013

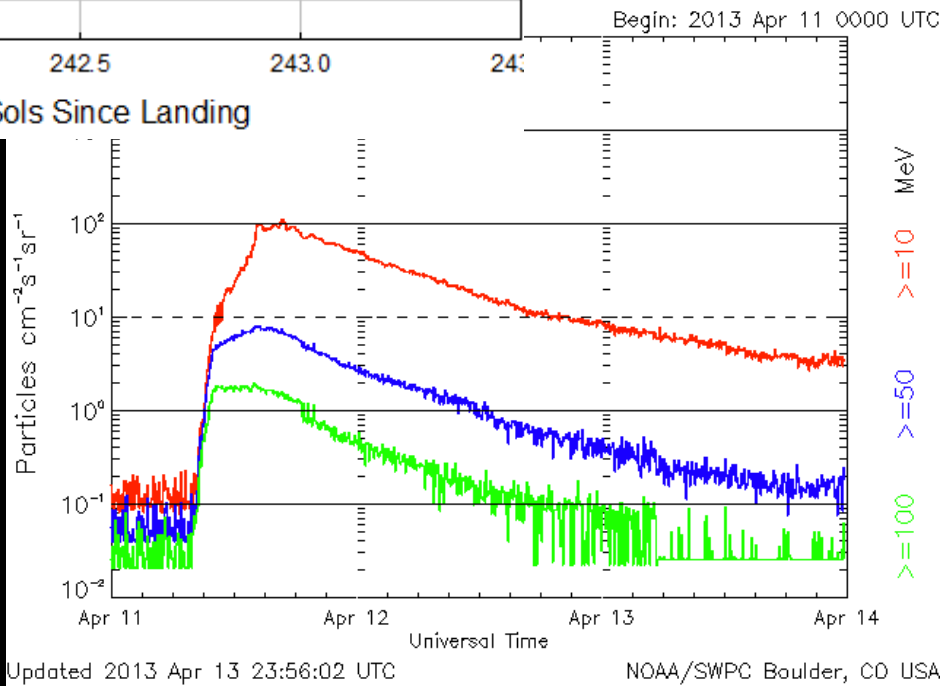
RAD



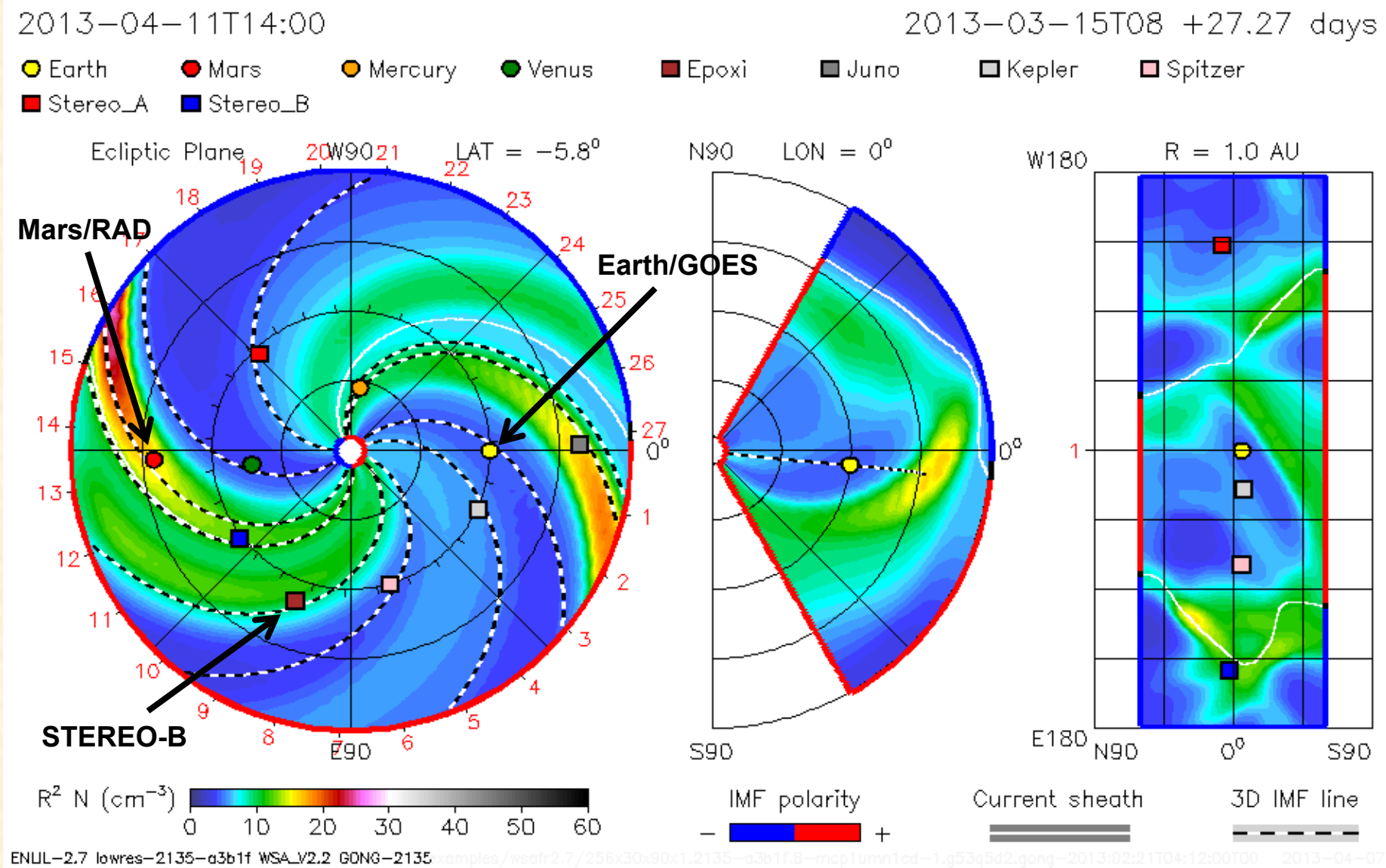
STEREO-B



GOES-13

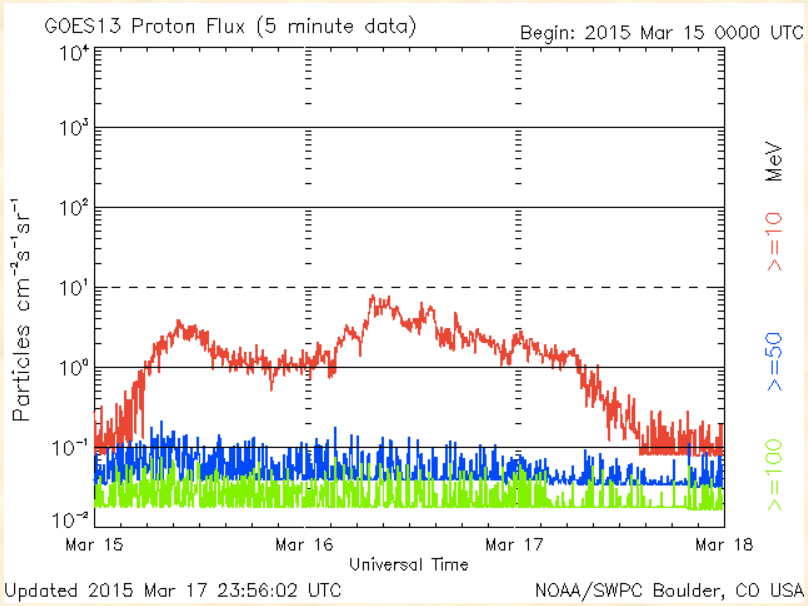


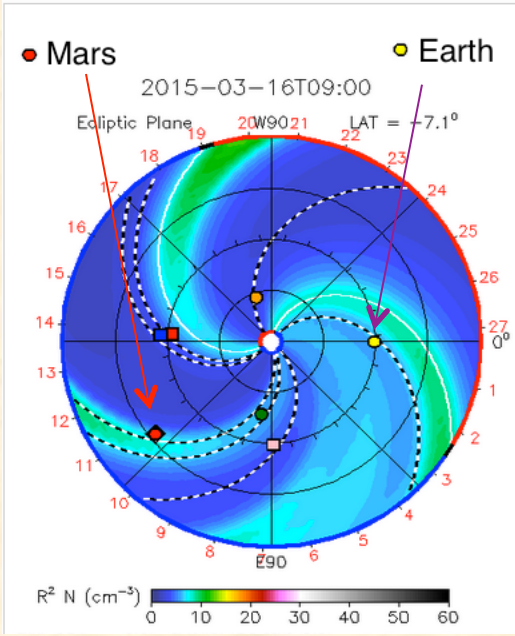
This SEP event was seen over 180 degree longitudinal extent…!



However, not all events are seen over such a wide extent…

- **X-class flare in March, 2015**
- St. Patrick's Day aurora: large geomagnetic storm, lots of media coverage…!
- X-class flare on Earth-facing side of Sun produced low-energy SEPs and associated geomagnetic storm.
- However, no SEP enhancement @ Mars…due to geometry?





The Future:

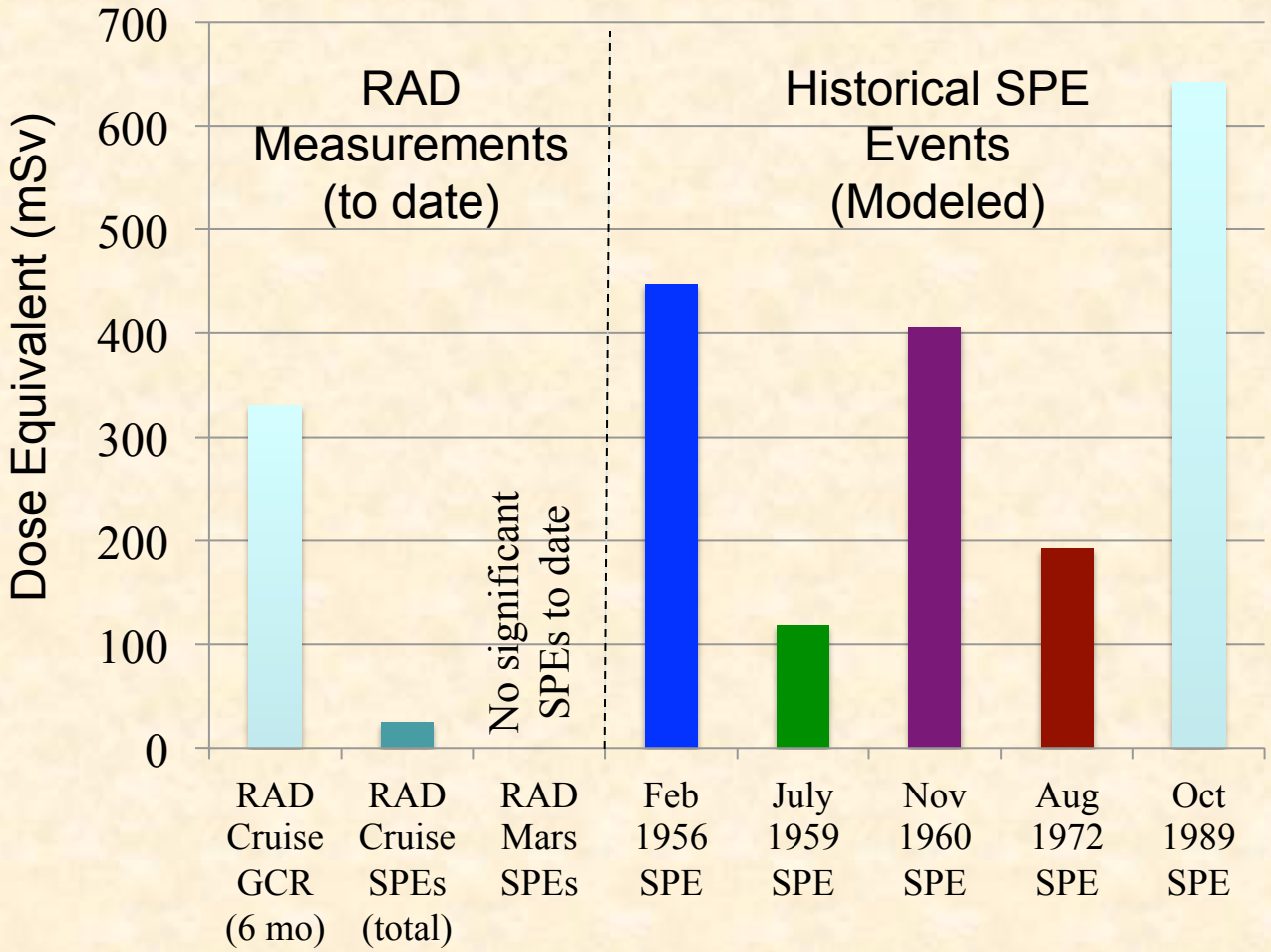
We have not yet seen a large Solar Particle Event since arriving at Mars...

What might we expect from a Carrington Event or Super-Storm?

(What is the worst-case scenario?)

Comparison of Total Radiation Dose measured by RAD to Historic SPE Events

Contribution of SPEs to Total Dose Eq. (mSv) (behind 5 g/cm2 Al shielding)

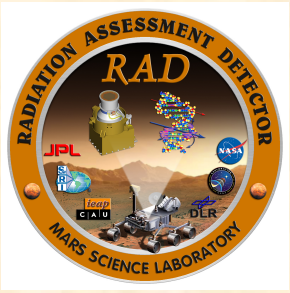


*SPE Dose Equivalent values modeled behind 5 g/cm2 Aluminum by M.-H. Kim, F. Cucinotta, et al. (AGU, 2012).

RAD cruise measurements from Jan-July 2012.

Nov. 1960 SPE includes contributions from 2 events.

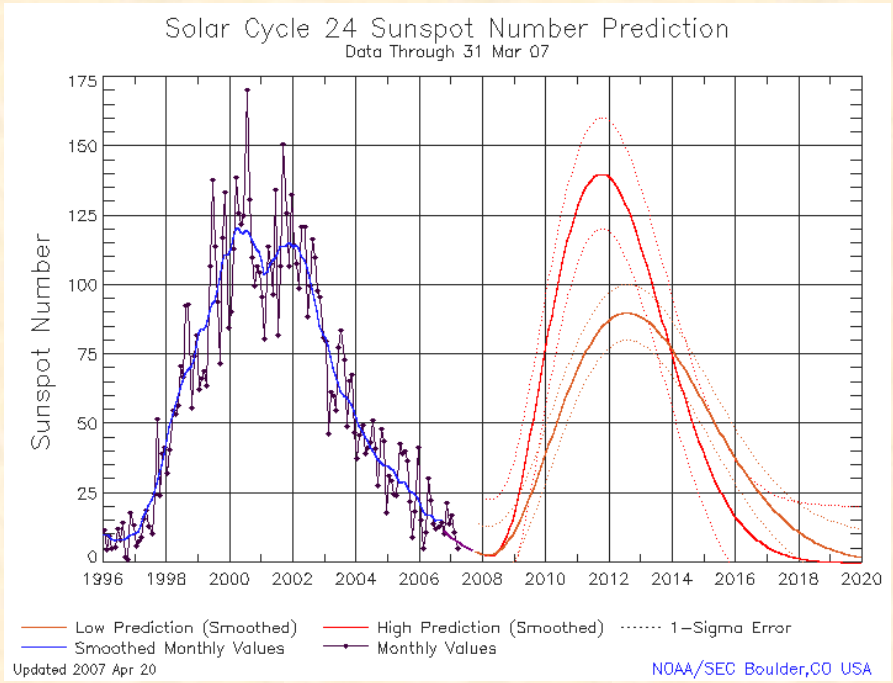
Oct. 1989 SPE includes contributions from 5 events over 1 month.



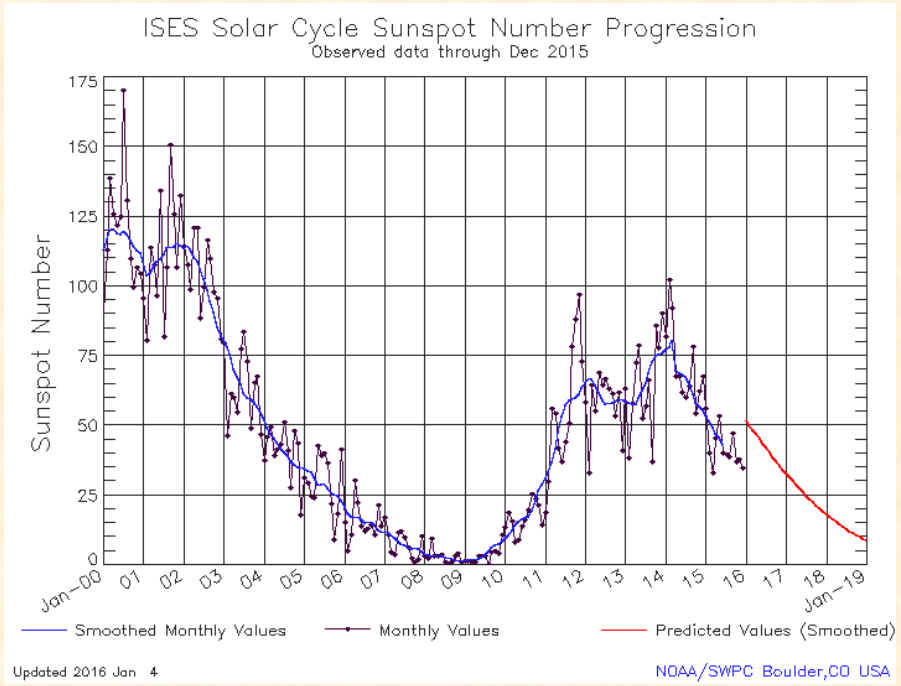
Prospects for the Next Solar Cycle

Predicting the Solar Cycle…

Cycle 23 Data + 2007 Predictions



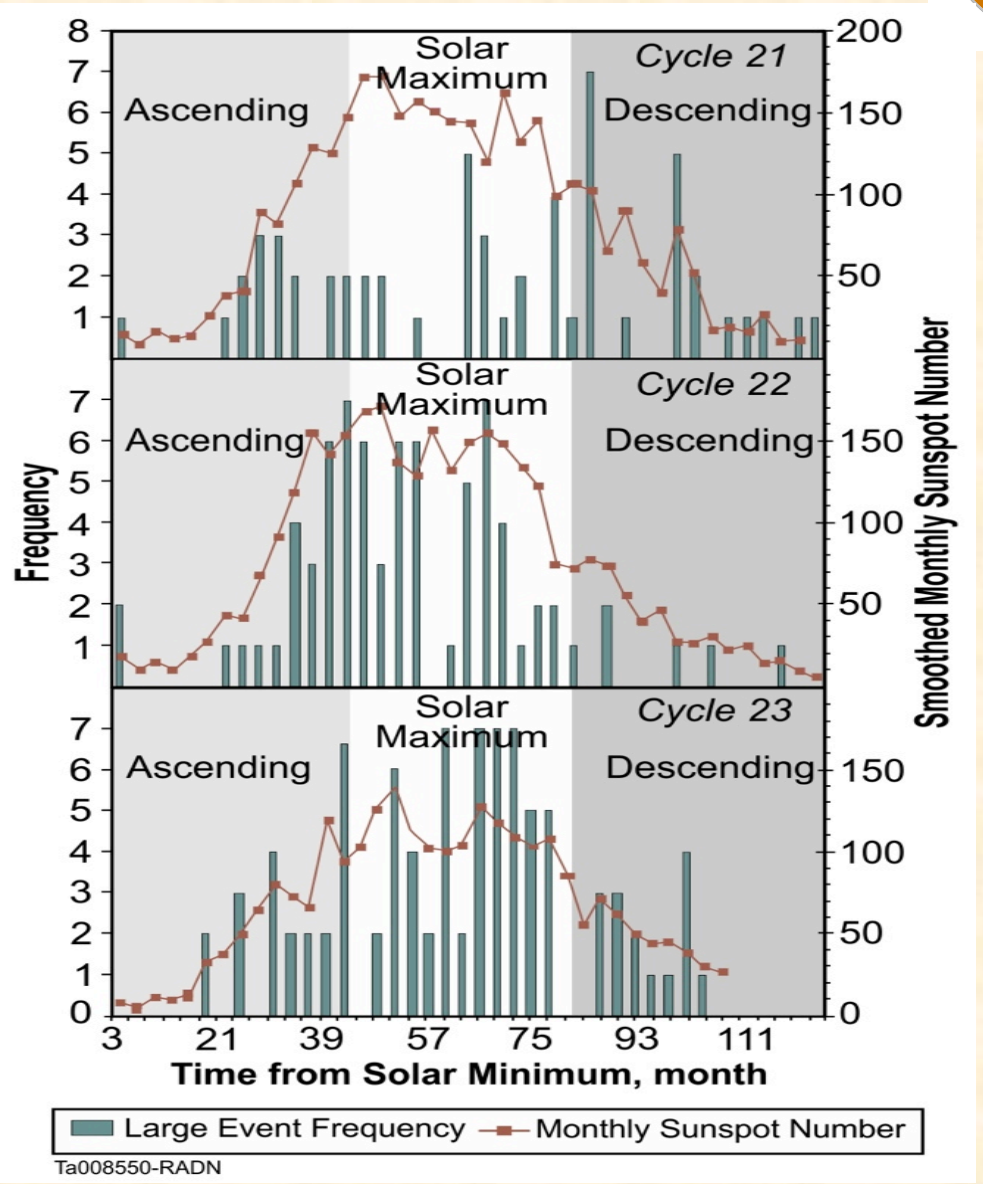
Actual Cycle 24



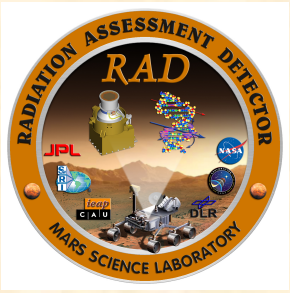
- Deepest minimum of Space Age in 2009…, **not predicted.**
- Cycle 24 maximum occurred late & is weakest in over 100 years…, **again not predicted.**

Large Solar Particle Events are seen throughout the Solar Cycle

- Histogram of large SPEs (green bars) vs time.
- Large events are seen **throughout the solar cycle**.

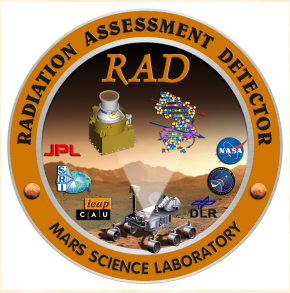


We Need to Characterize Extreme Conditions throughout the Solar Cycle



- Extreme variations in the past 2 solar cycles have shown that ***current models clearly lack sufficient predictive capability***.
- If cycle 24 minimum is as deep as 23's, GCR dose rate will approach worst-case conditions for human expeditions.
  - How bad can it get? We don't really know.
- We need to characterize these Extreme Conditions…
  - 1) Extreme Cycle variations (not just solar max, but solar min!)
  - 2) Extreme SPEs (X-Class flares, GLEs, "Super-Events"…)

Take-Away Points…and Future Needs…

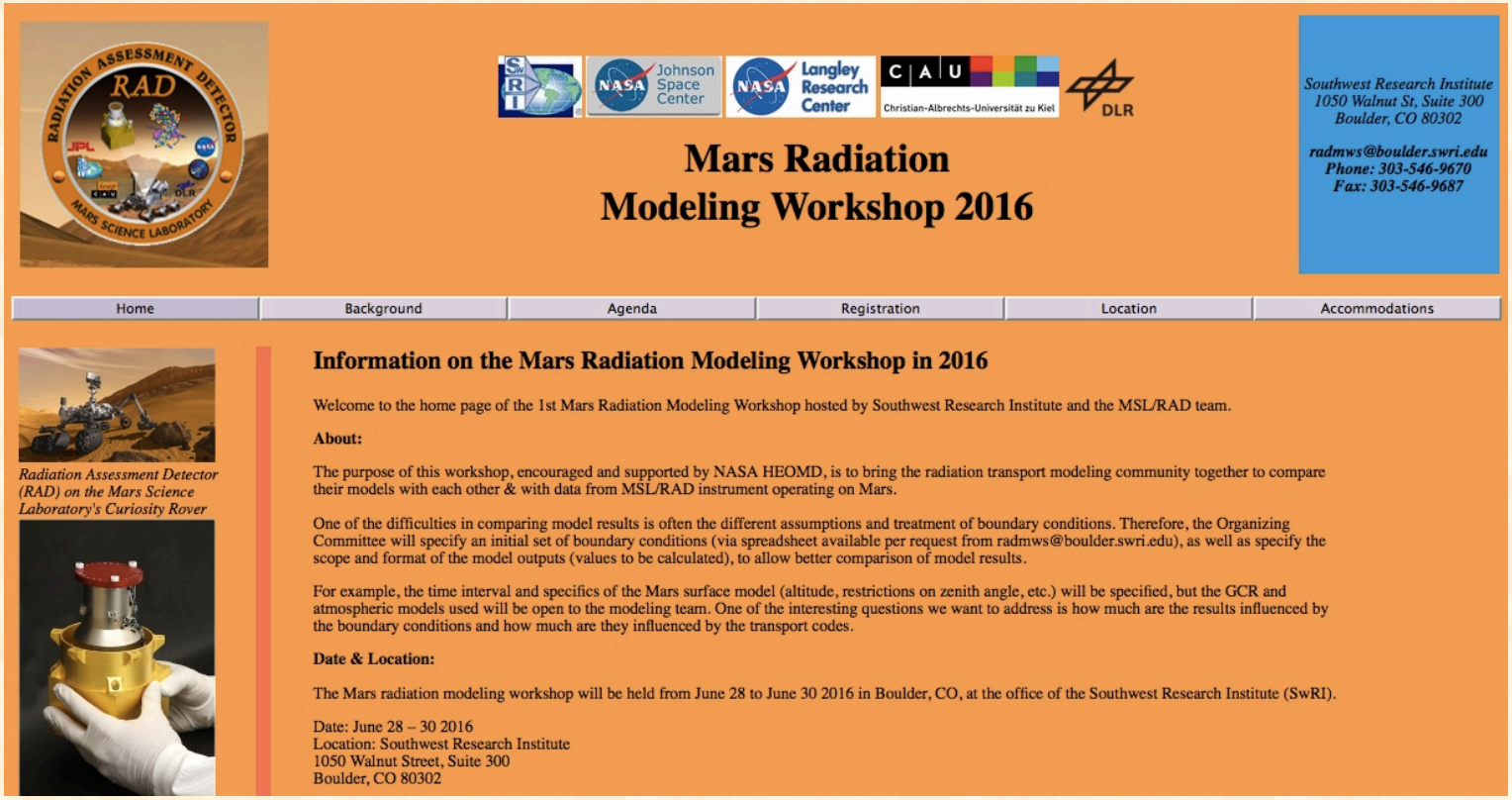


- Additional data points & observations over a **wide longitudinal extent** to improve models and understanding of the **3-D structure and propagation** of CMEs & SPEs throughout the heliosphere.
- Establish **event database** at Mars and throughout the heliosphere to aid prediction & understanding of SPEs.
- Continued program of **synoptic observations** to **characterize extreme conditions** throughout the solar cycle **(both solar max & min),** and from one solar cycle to the next…

- To support **human exploration to Mars and beyond**, we will need to provide *heliosphere-wide space weather monitoring*, prediction & early warning for these missions.
- **RAD is a proven, highly capable, low mass, high TRL, instrument ideal for future resource-constrained operational missions.**

RAD-Sponsored Mars Radiation Modeling Workshop

- Scheduled for June 28-30, 2016 in Boulder, CO
- Models to be discussed & compared with RAD data…
  - Geant4, PHITS, HZETRN, FLUKA, HRTC-HEDS, MCNP6



Johnson Space Center | Langley Research Center | Christian-Albrechts-Universität zu Kiel | DLR

Mars Radiation Modeling Workshop 2016

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Home | Background | Agenda | Registration | Location | Accommodations

Radiation Assessment Detector (RAD) on the Mars Science Laboratory's Curiosity Rover

Information on the Mars Radiation Modeling Workshop in 2016

Welcome to the home page of the 1st Mars Radiation Modeling Workshop hosted by Southwest Research Institute and the MSL/RAD team.

About:

The purpose of this workshop, encouraged and supported by NASA HEOMD, is to bring the radiation transport modeling community together to compare their models with each other & with data from MSL/RAD instrument operating on Mars.

One of the difficulties in comparing model results is often the different assumptions and treatment of boundary conditions. Therefore, the Organizing Committee will specify an initial set of boundary conditions (via spreadsheet available per request from radmws@boulder.swri.edu), as well as specify the scope and format of the model outputs (values to be calculated), to allow better comparison of model results.

For example, the time interval and specifics of the Mars surface model (altitude, restrictions on zenith angle, etc.) will be specified, but the GCR and atmospheric models used will be open to the modeling team. One of the interesting questions we want to address is how much are the results influenced by the boundary conditions and how much are they influenced by the transport codes.

Date & Location:

The Mars radiation modeling workshop will be held from June 28 to June 30 2016 in Boulder, CO, at the office of the Southwest Research Institute (SwRI).

Date: June 28 – 30 2016
Location: Southwest Research Institute
1050 Walnut Street, Suite 300
Boulder, CO 80302

http://www.boulder.swri.edu/rad_modeling_workshop/

Thank you!

RAD Acknowledgements

- RAD is supported by NASA (HEOMD/ AES) under JPL subcontract #1273039 to SwRI.
- ...and by DLR in Germany under contract with Christian-Albrechts-Universitat (CAU).