Charged Particle Measurements during Cruise and on Mars with the Radiation Assessment Detector (MSL/RAD)

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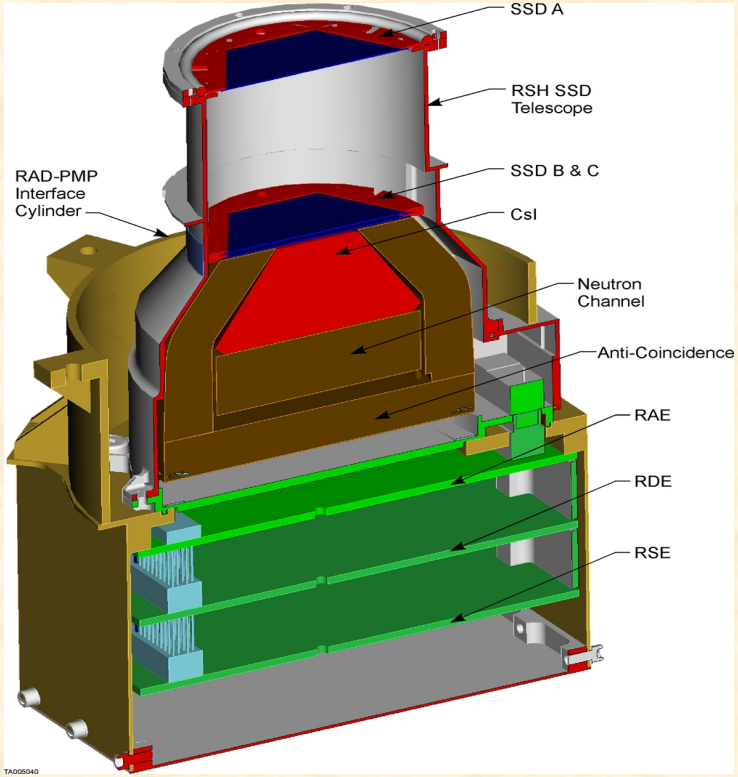
Artist's Concept. NASA/JPL-Caltech

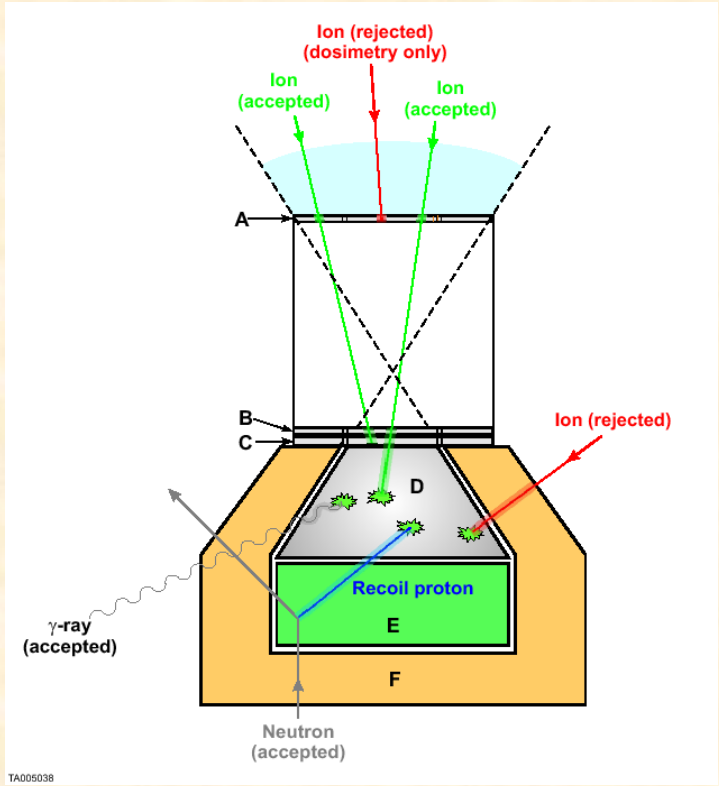
The Radiation Assessment Detector (RAD) Overview

First Radiation Measurements on the Surface of Mars

- **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 currently characterizing the radiation environment on the surface of Mars as part of the Mars Science Laboratory (MSL) mission onboard the *Curiosity* rover.

RAD Cut-away View and Principle of Operation

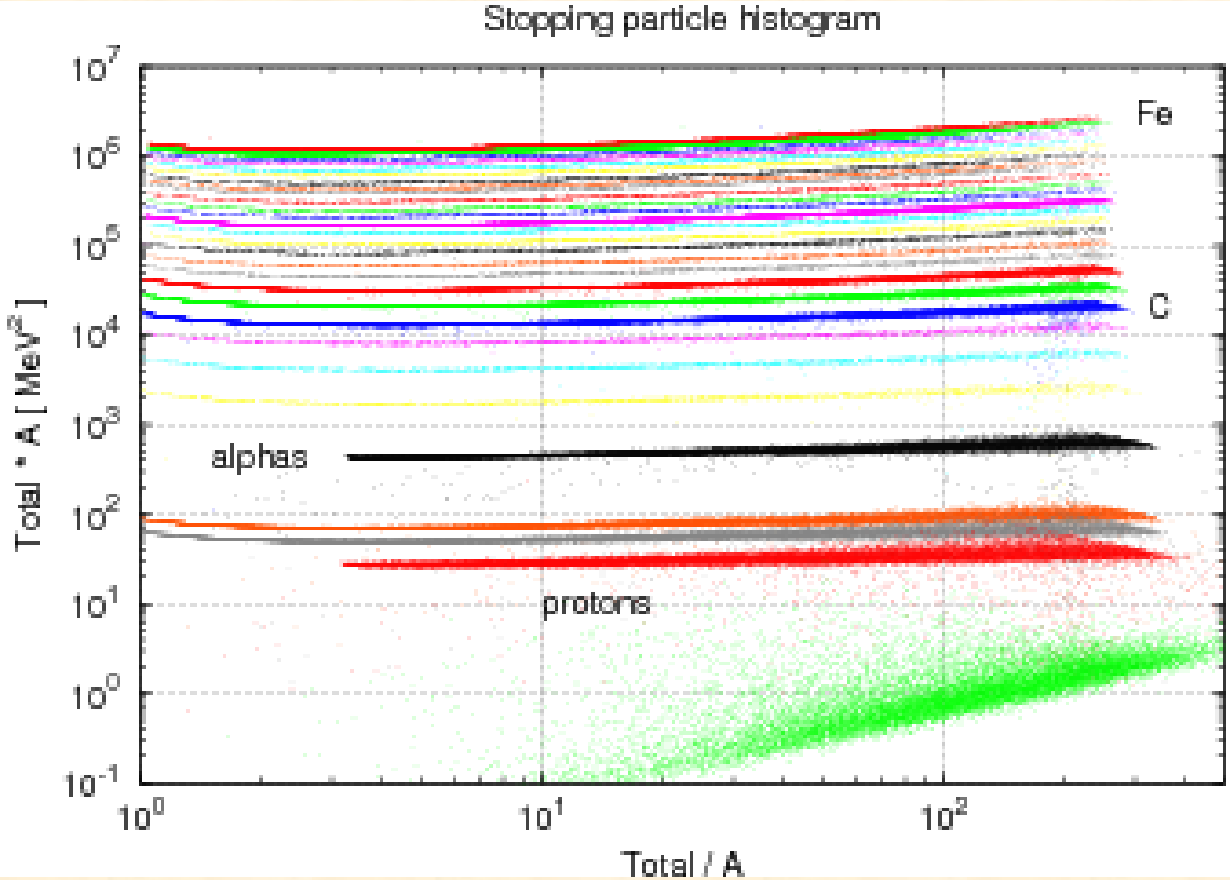




A Solid State Detector (SSD) A
B SSD B
C SSD C
D Cesium Iodide (CsI)
E Plastic Scintillator (Bicron 432M)
F Anti-coincidence Shield (Plastic)

Particle Species Identification

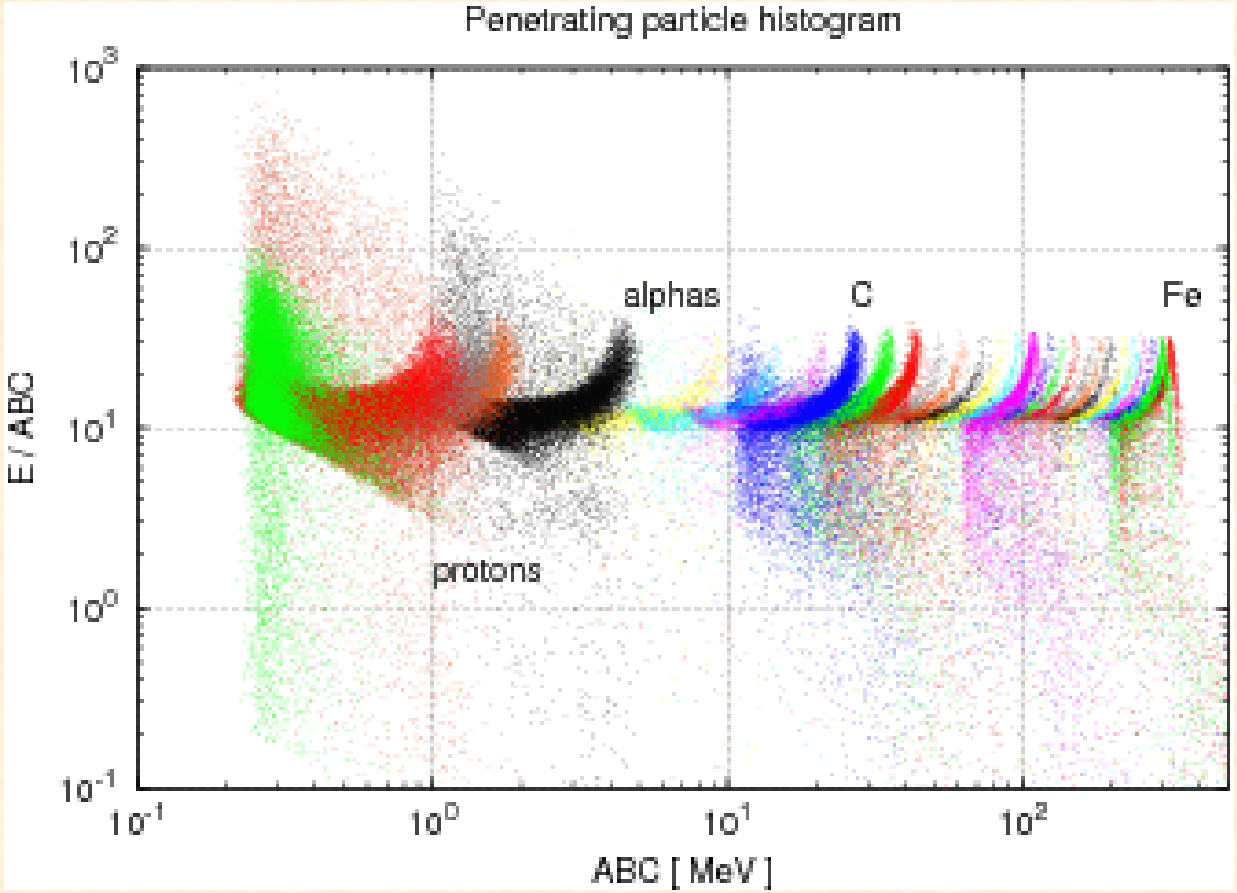
Stopping Particles



- Stopping particles can be identified using a E-dE/dx method
- For low-Z particles (Z=1-2) different isotopes can be distinguished
- For higher-Z ions some species with high abundances can be identified individually

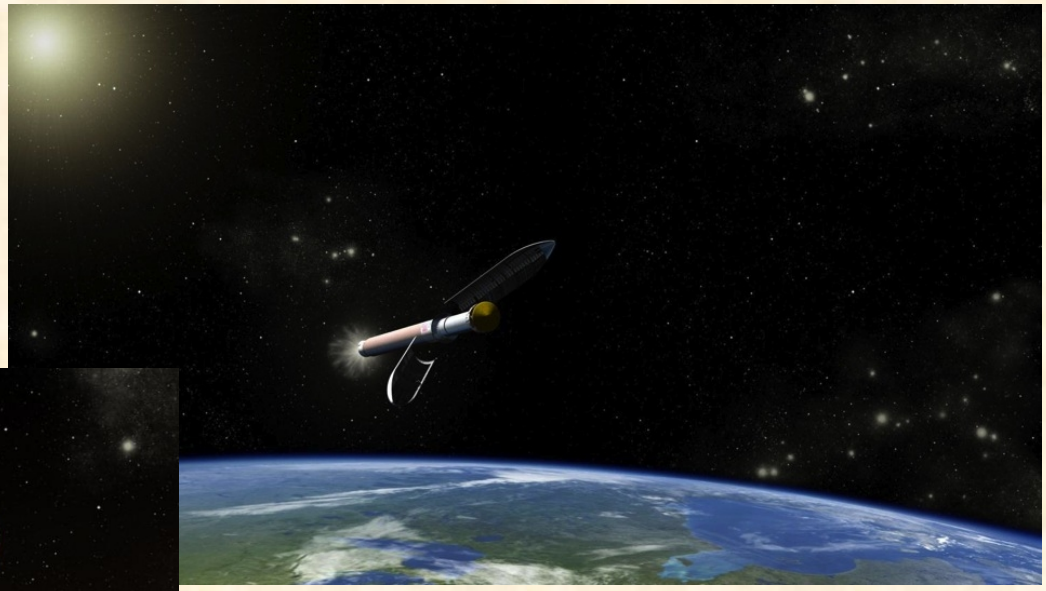
Particle Species Identification

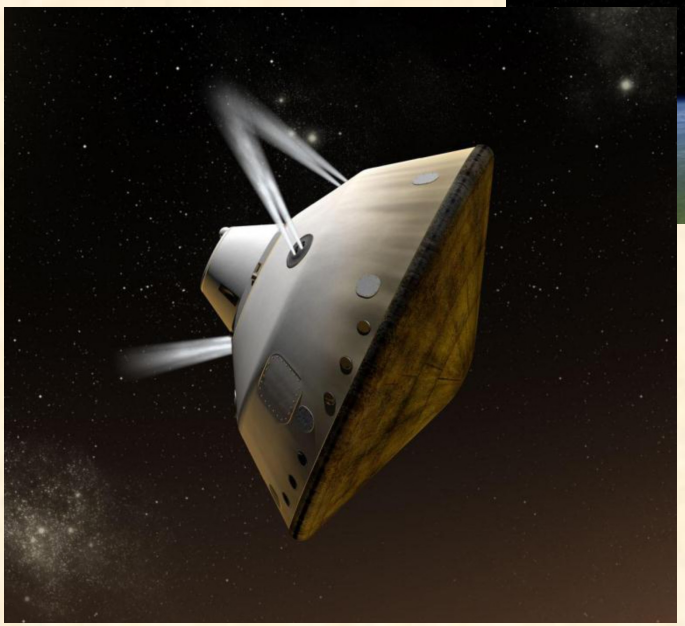
Penetrating Particles



- Penetrating particle species are identified by their dE/dx
- Resolution allows for separation of different charges
- Penetrating particles can be separated in to lower- and higher energy ranges

RAD Observations Inside the MSL Spacecraft During Cruise

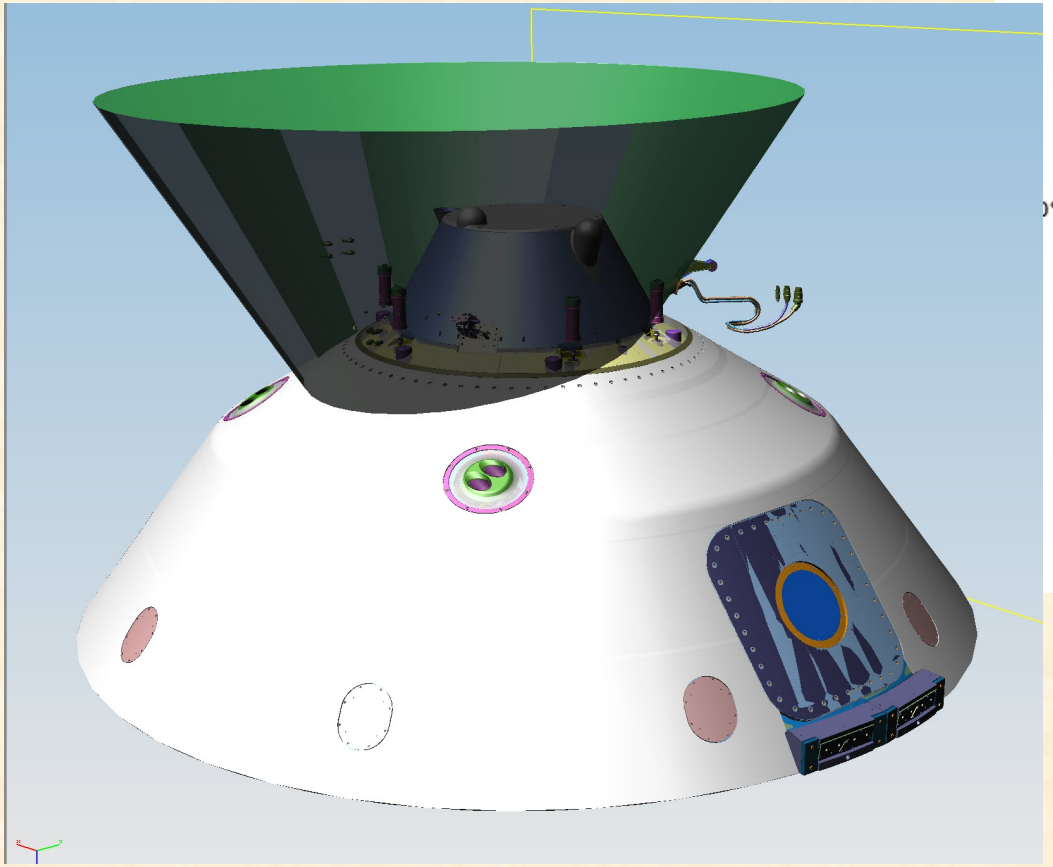


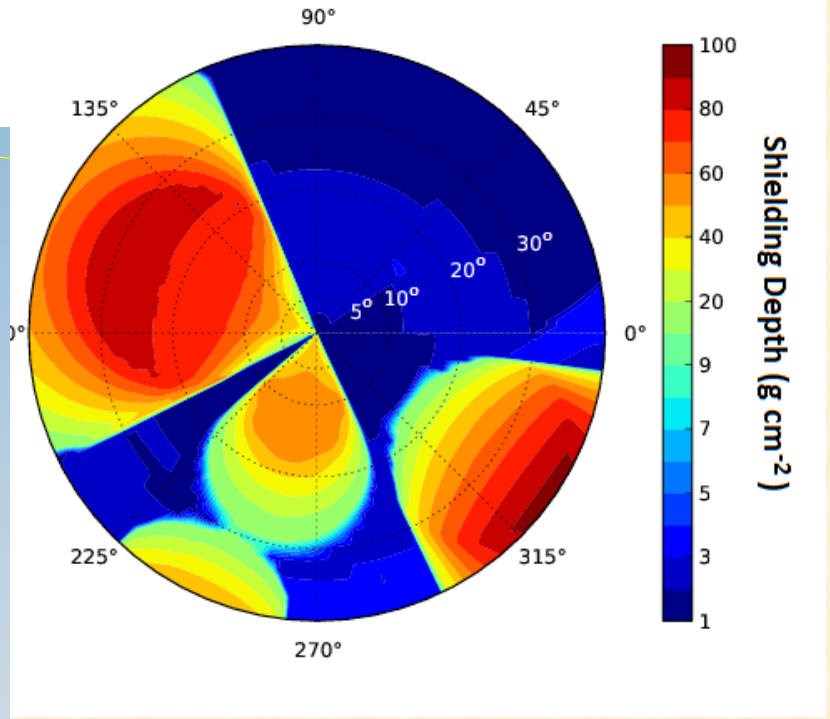


MSL Spacecraft during Cruise

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…

RAD's Field of View From Inside the Spacecraft

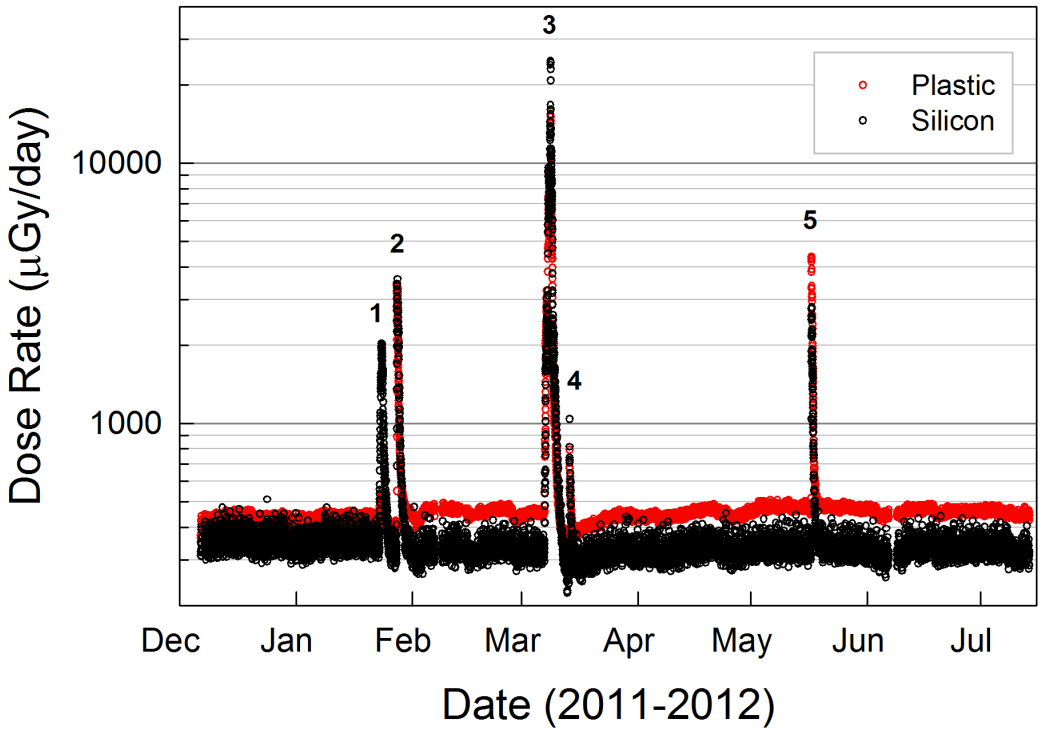




During the cruise phase, the shielding in RAD's Field-of-View was very inhomogeneous (~23 g/cm2)

RAD Observations During Cruise

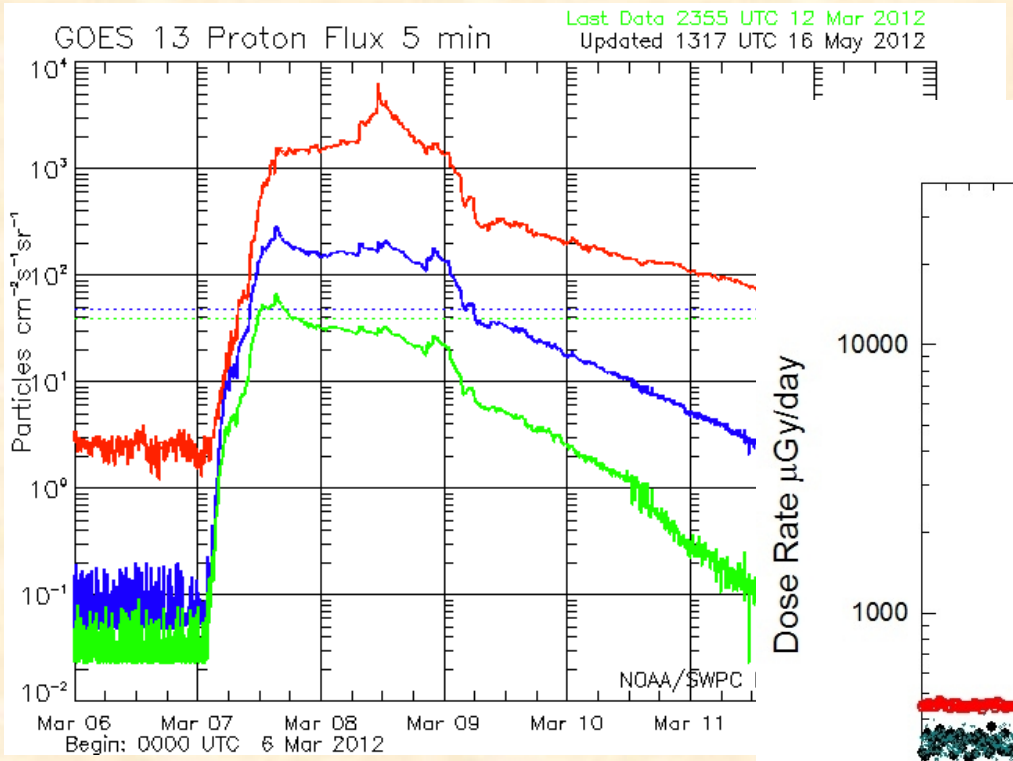
RAD observations during ~7 months of cruise included contributions from 5 solar energetic particle events.



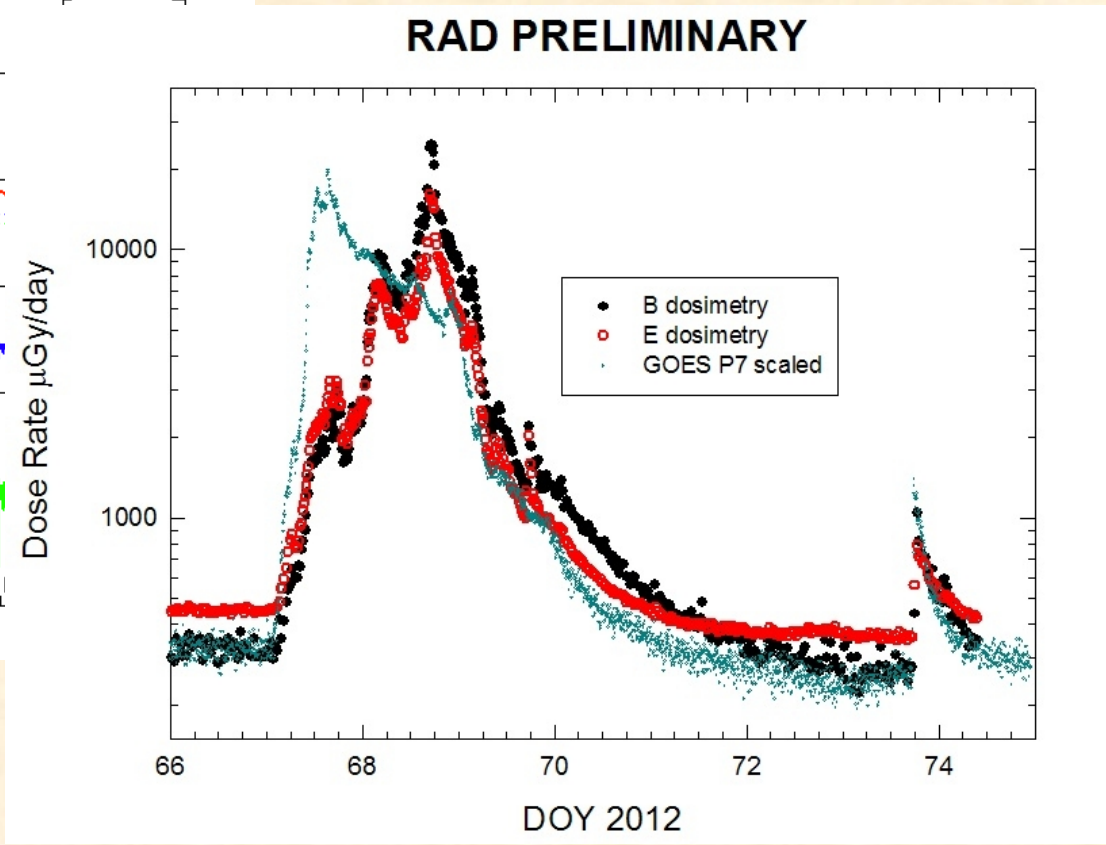
- RAD operated with >90% duty cycle since Launch+10 days (6 Dec 2011).
- In terms of Dose Equivalent the five SEP events contributed ~5% to the total dose encountered during cruise.

Figure from *Zeitlin et al. 2013*

RAD & GOES Observations of the SEP Event on March 7, 2012



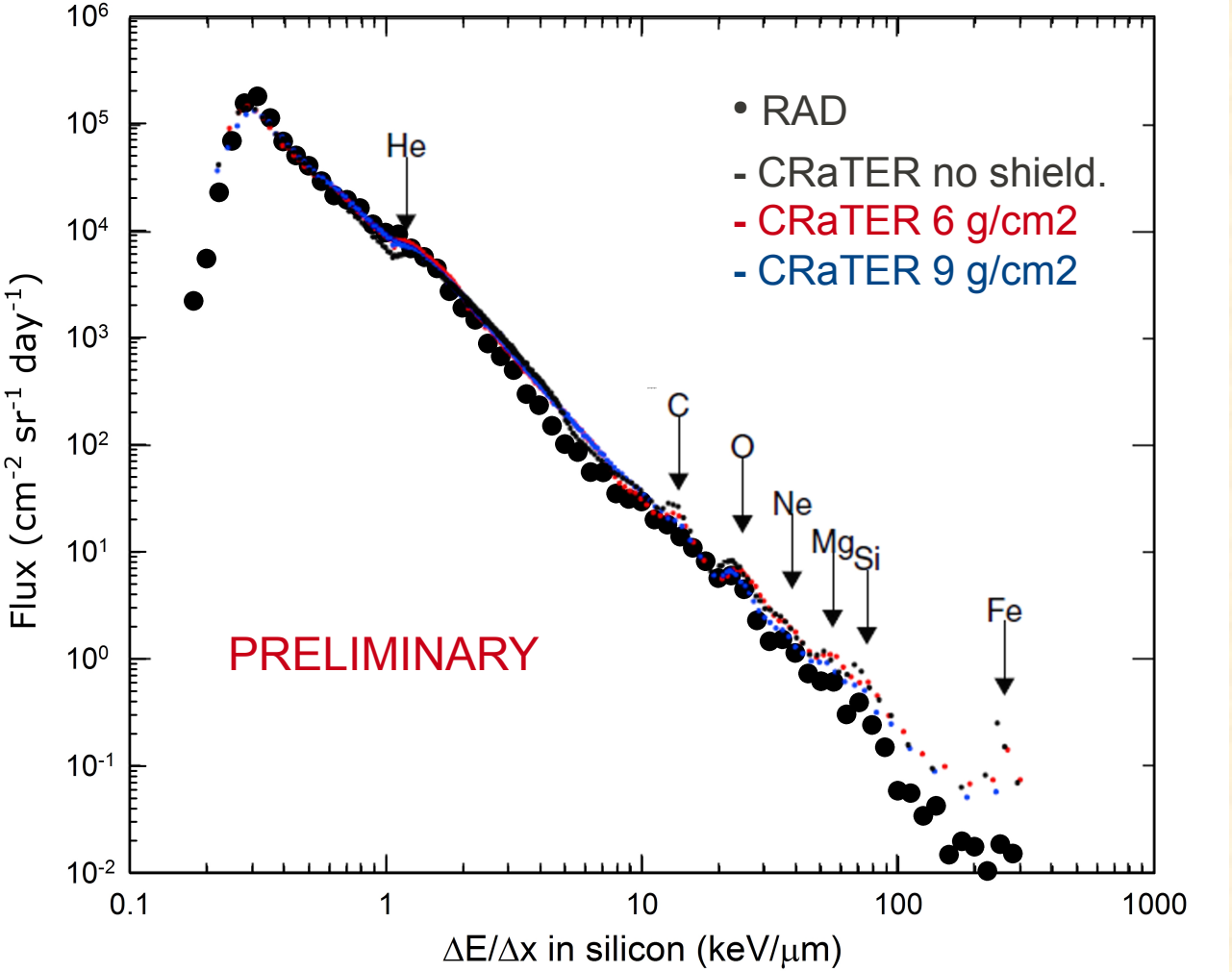
GOES Satellite (Earth Orbit)



RAD (Inside MSL Spacecraft)

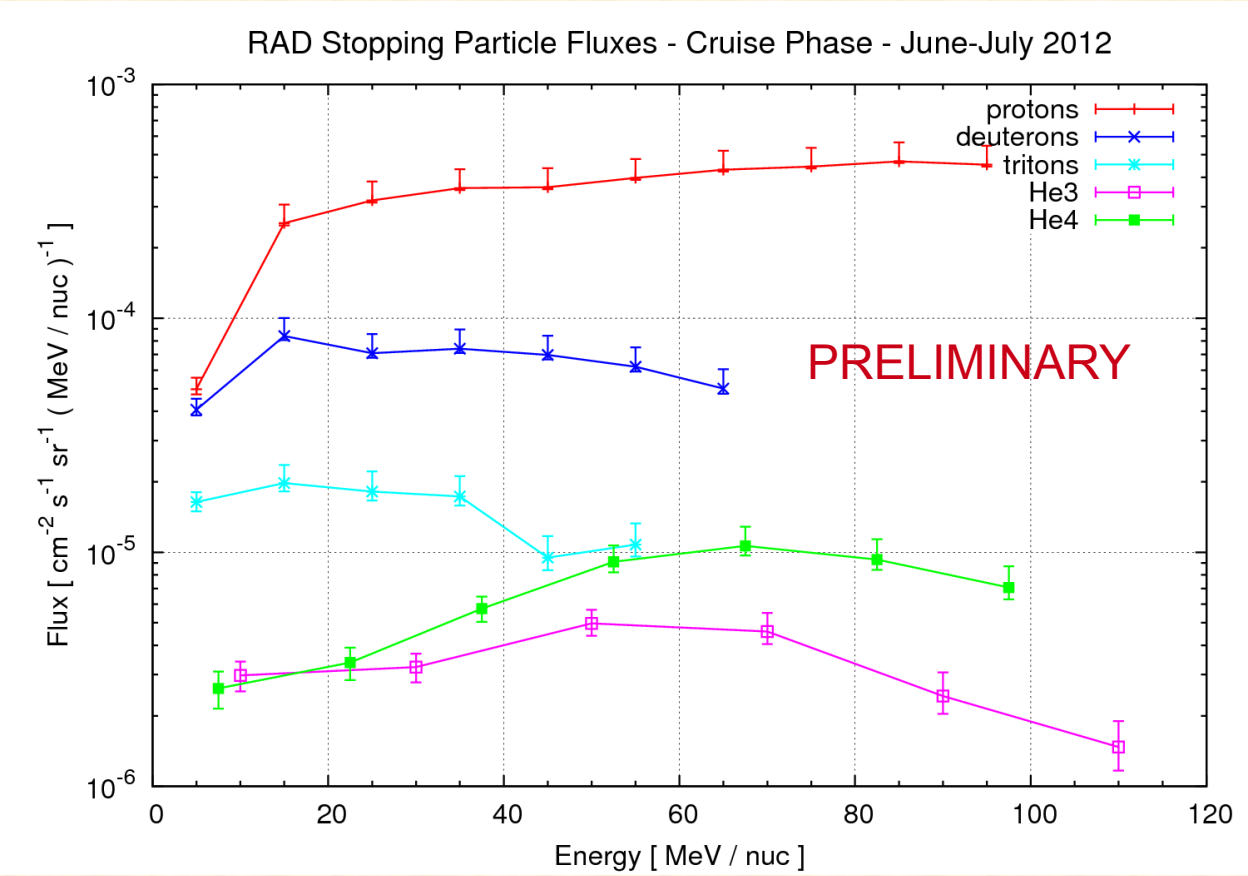
MSL/RAD & LRO/CRaTER Comparison (Preliminary)

Shielding depletes the flux of heavy ions (high LET) seen by RAD.



- The fragmentation products end up at low LET, so RAD sees a higher flux of low LET particles than CRaTER. (RAD is more heavily shielded).
- For the 3 CraTER data sets: heavier shielding → heavy ions depleted, low LET increased
- RAD continues this trend.

RAD Stopping Charged Particle Fluxes (Preliminary)



Charged particle fluxes measured on the Martian surface and during the cruise phase will be published in the near future.

- RAD measurements offer the possibility to identify different ion species and derive fluxes separately.
- Differential (stopping particles) or integrated fluxes (penetrating) can be derived.
- Particle fluxes can be used to validate current transport models for GCRs and the Martian atmosphere.

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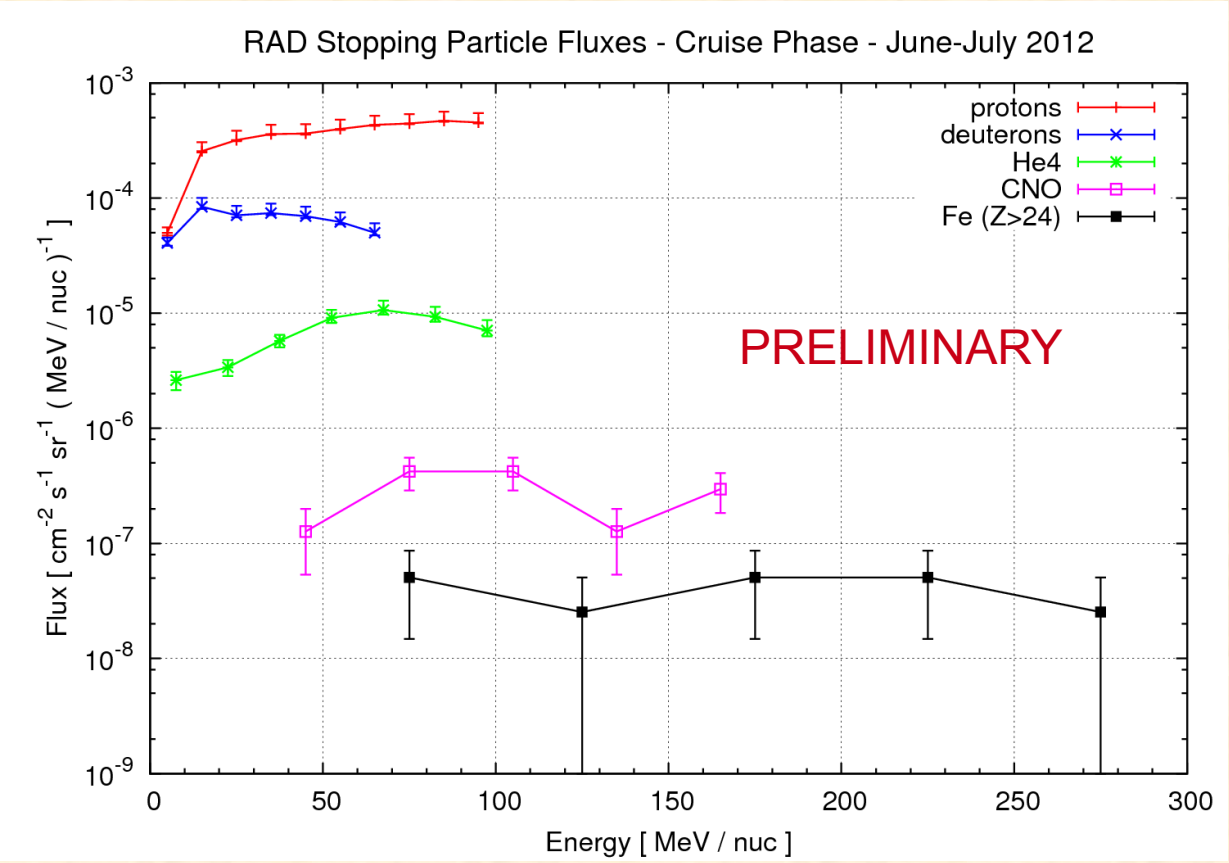

Higher-Energy (Penetrating) Charged Particle Fluxes [/cm^2/sr/s]:

Z=1:	0.242±0.02
Z=2:	0.024±2x10^{-3}
Z=3-5:	2.15x10^{-4}±3x10^{-5}
Z=6-8:	7.3x10^{-4}±5x10^{-5}
Z=9-14:	2.5x10^{-4}±3x10^{-5}
Z=15-25:	2.7x10^{-5}±9.5x10^{-6}
Z=26:	2.35x10^{-5}±9x10^{-6}

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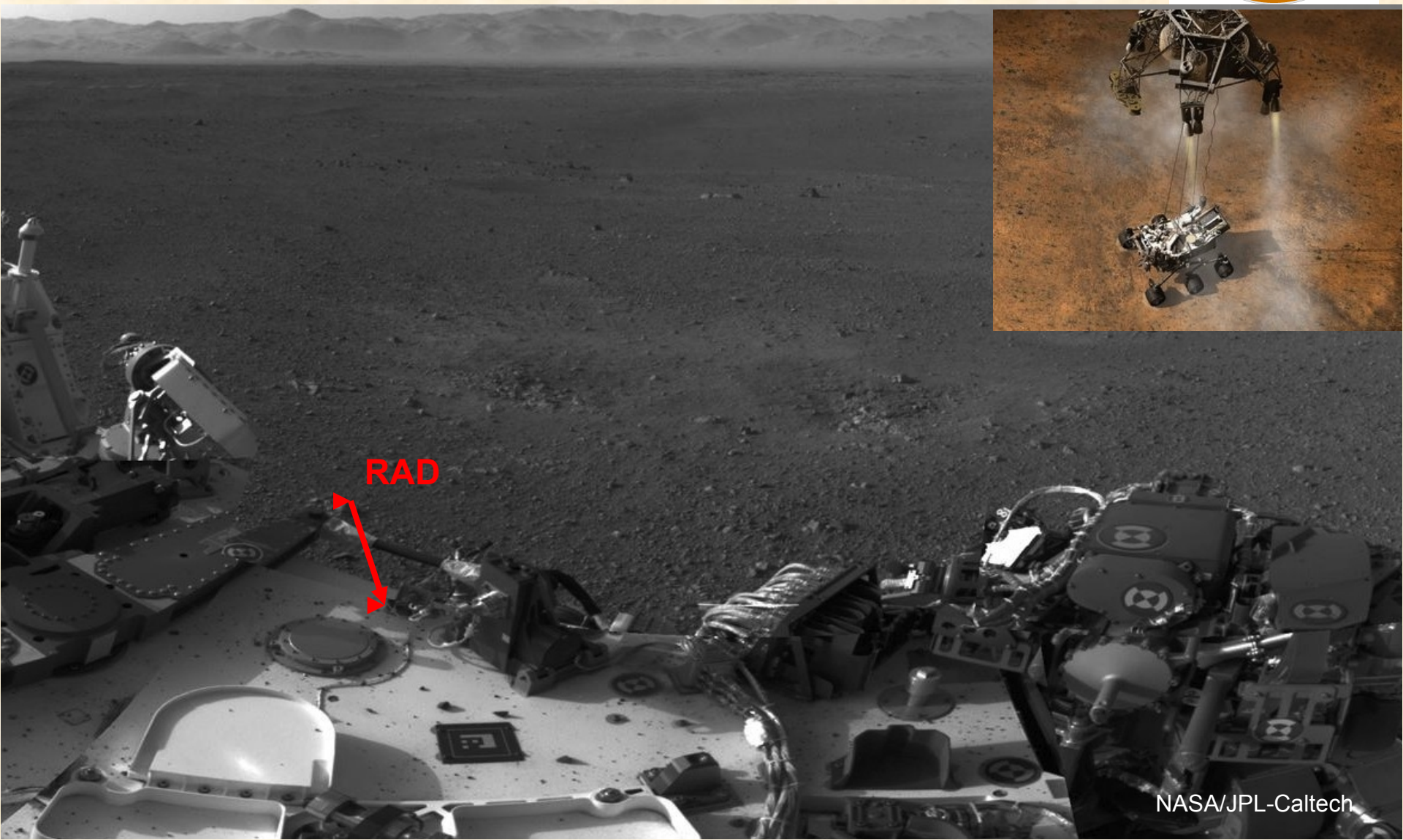
First-ever Radiation Measurements on the Martian Surface



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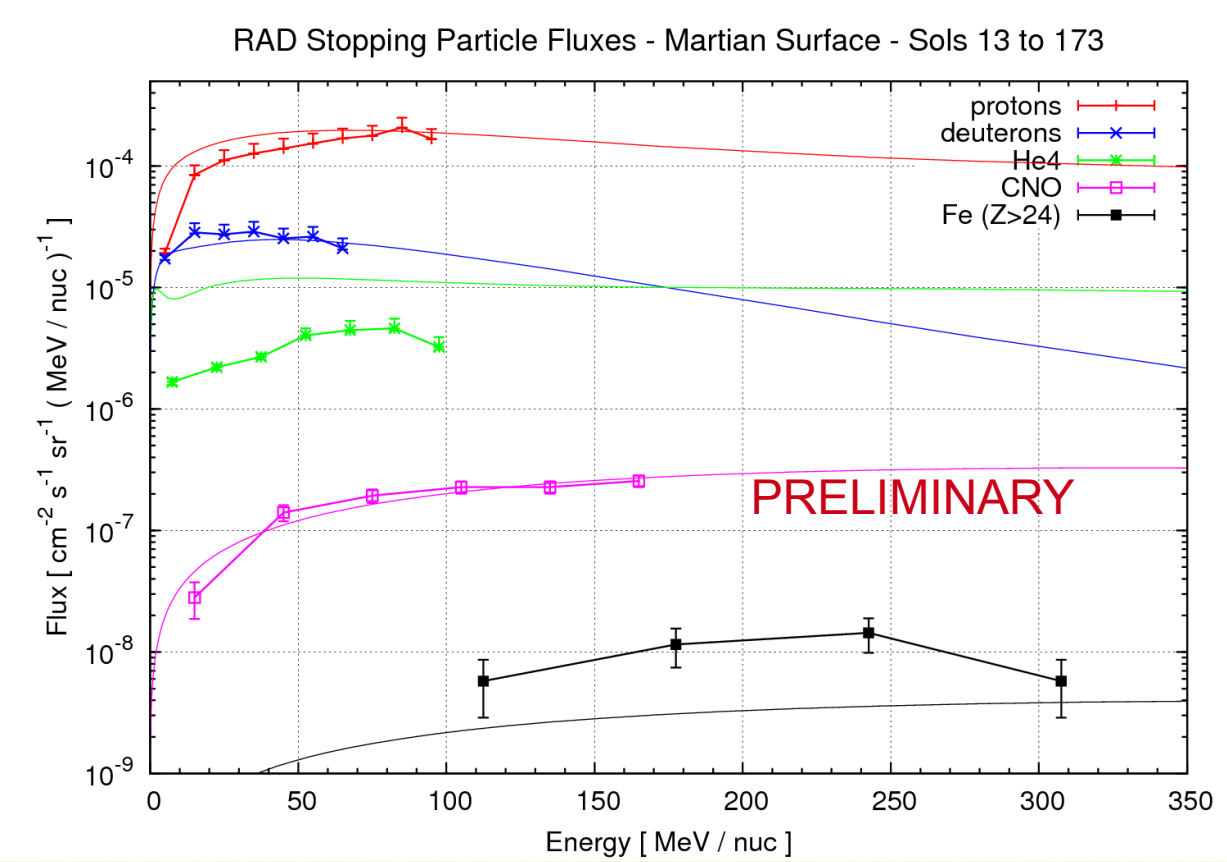

Shown are mean fluxes in the considered time frame (variations from diurnal and seasonal pressure changes, as well as heliospheric rotation and Solar modulation)

High-Energy Charged Particle Fluxes [/cm^2/sr/s]:

Z=1:	0.141±0.01
Z=2:	0.013±1x10^{-3}
Z=3-5:	1.61x10^{-4}±9x10^{-6}
Z=6-8:	5x10^{-4}±1.6x10^{-5}
Z=9-14:	1.3x10^{-4}±8x10^{-6}
Z=15-25:	1.1x10^{-5}±2.3x10^{-6}
Z=26:	9.4x10^{-6}±2x10^{-6}

Measured fluxes (linespoints) are compared to OLTARIS simulations (thin lines) assuming atmospheric shielding of 18.6 g/cm2 and a Solar modulation parameter of Φ = 627 MV.

Summary

- RAD radiation measurements are helpful for the planning of future manned missions to the Red Planet ...by measuring the radiation inside the spacecraft (during the cruise phase) and on the planetary surface
- RAD dose and particle flux measurements provide great input for the validation of GCR modulation and transport models
- Measured charged particle fluxes (He?) show reasonably good agreement with model estimates (more precise modelling needed)
- RAD recently measured its first direct SEP event on the surface (five were seen during cruise)
- Results published for cruise phase: ***Zeitlin et al.***, *Science (340) 2013*.
- Further publications will follow soon:
  - **Hassler**: Radiation environment on the surface of Mars – Overview
  - **Ehresmann**: Charged particle fluxes on the surface and during cruise (2 publications)
  - **Koehler**: Neutral particle fluxes and dose on the surface and during cruise (2x)
  - **Posner**: Hohmann-Parker Effect as measured by RAD during cruise
  - **Rafkin**: Diurnal variations in dose and count rates on the surface

RAD Acknowledgements

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- RAD is supported by NASA (HEOMD) under JPL subcontract #1273039 to SwRI...
- ...and by DLR in Germany under contract with Christian-Albrechts-Universitaet (CAU) zu Kiel.
- Thanks to Shawn Kang from JPL/CalTech for the development of the shielding model for the cruise phase.

Thanks for your attention!

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