Update on Radiation Measurements on the Martian Surface with MSL/RAD

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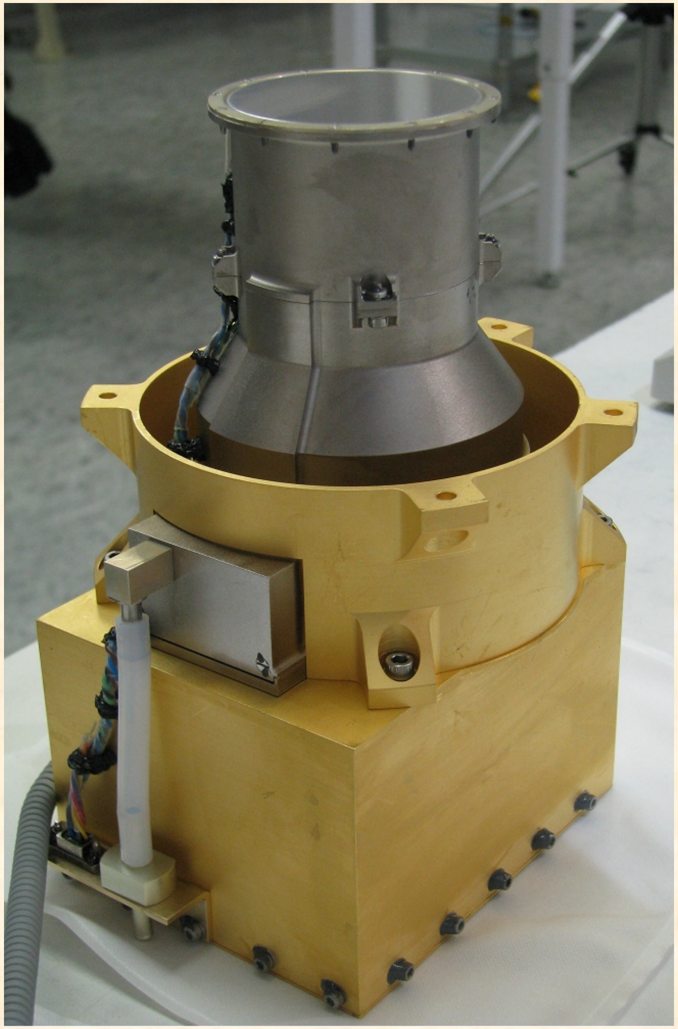
for the MSL/RAD Team

WRMISS 2014
Krakow
September 9 – 11, 2014

The Radiation Assessment Detector (RAD) Instrument

RAD is a combined ***Charged Particle*** and ***Neutral Particle*** Radiation Analyzer comprised of:

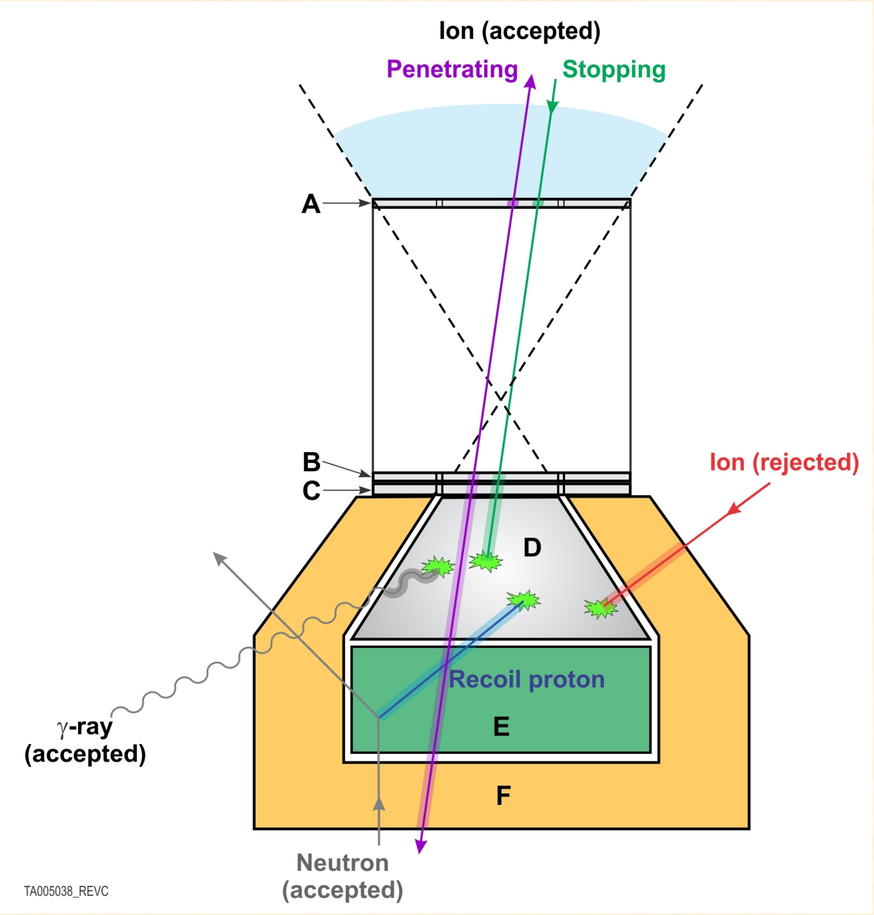
- Solid state detector telescope and CsI calorimeter with active coincidence logic to identify charged particles.
- Separate scintillators w/ anticoincidence logic to detect neutrons and γ-rays.



- Mass = 1.56 kg
- Power = 4.2 W
- Volume = 10.3 x 12.2 x 20.4 cm^3
- Field-of-View = 65 deg. (view cone)
- Geometric Factor = 1 cm^2 x sr

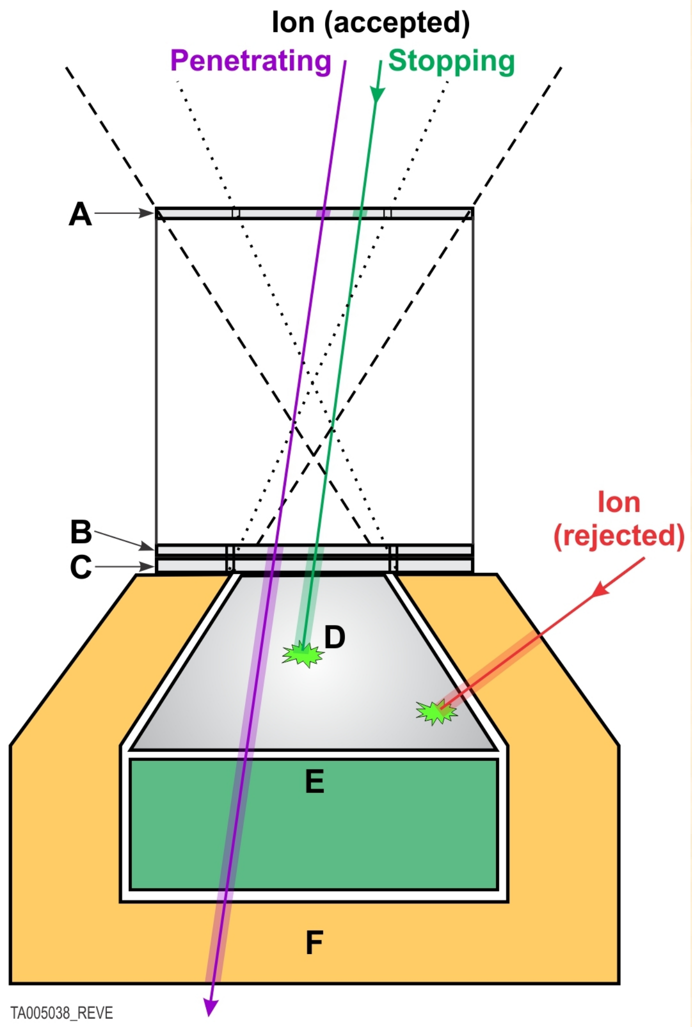
RAD Sensor Head Schematics & Measurement Capabilities

- The ***RAD sensor head*** consists of 3 Si detectors (***A***-***C***), a CsI scintillator (***D***), and a plastic scintillator (***E***); as well as a further plastic scintillator (***F***) acting as anti-coincidence.
- The ***absorbed dose*** is recorded in the Si detector ***B*** and the plastic scintillator ***E*** (tissue-equivalent) as a function of time and energy
- By recording the Linear Energy Transfer (***LET***) spectra in Si (0.3-1000 keV/µm), ***quality factors*** can be derived to convert absorbed dose into ***dose equivalent***



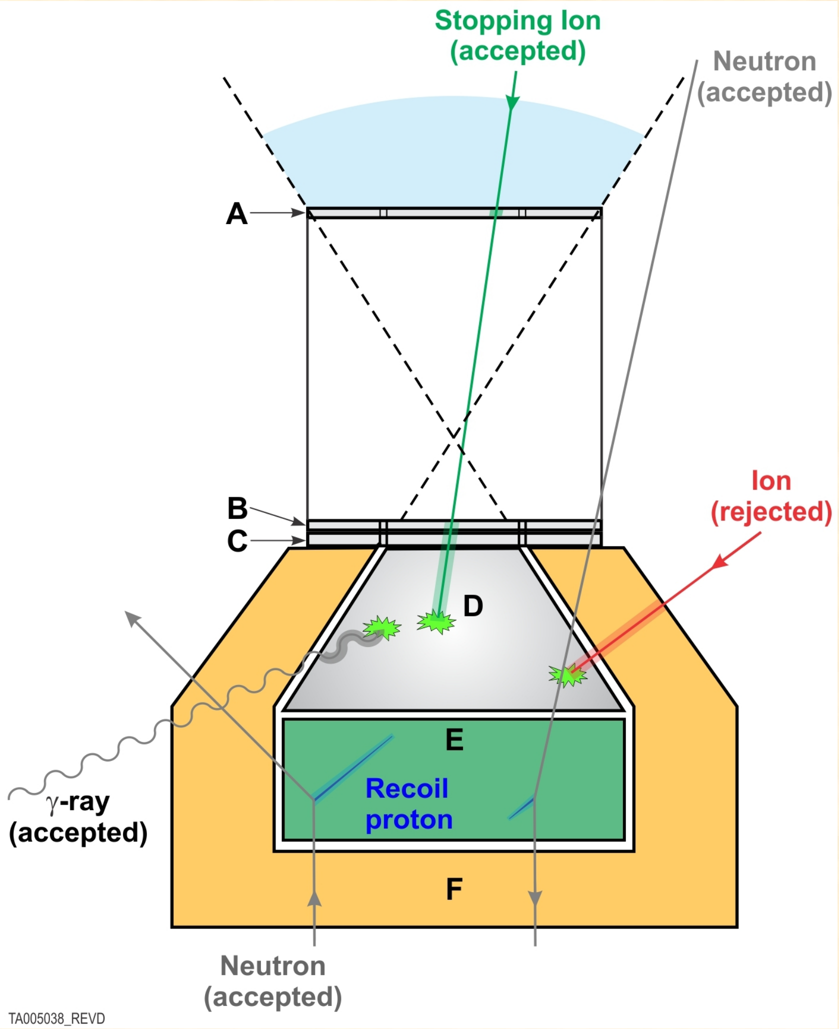
RAD Sensor Head Schematics & Measurement Capabilities

- ***Charged particles*** (protons and heavier ions up to Fe; charges 1 ≤ Z ≤ 26) are distinguished into penetrating and stopping particles
- *Penetrating* means that a particle passes through all detectors (depositing energy in ***A*** through ***F***)
- *Stopping* means a particle deposits all of its initial energy in detectors ***A*** through ***E***
- Maximum energy of stopping particle depends on ion species, ranging from ~100 MeV/nuc (H, He) to ~400 MeV/nuc (Fe)
- Field-Of-View (FOV) for charged particle detection defined by detectors ***A*** and ***B***

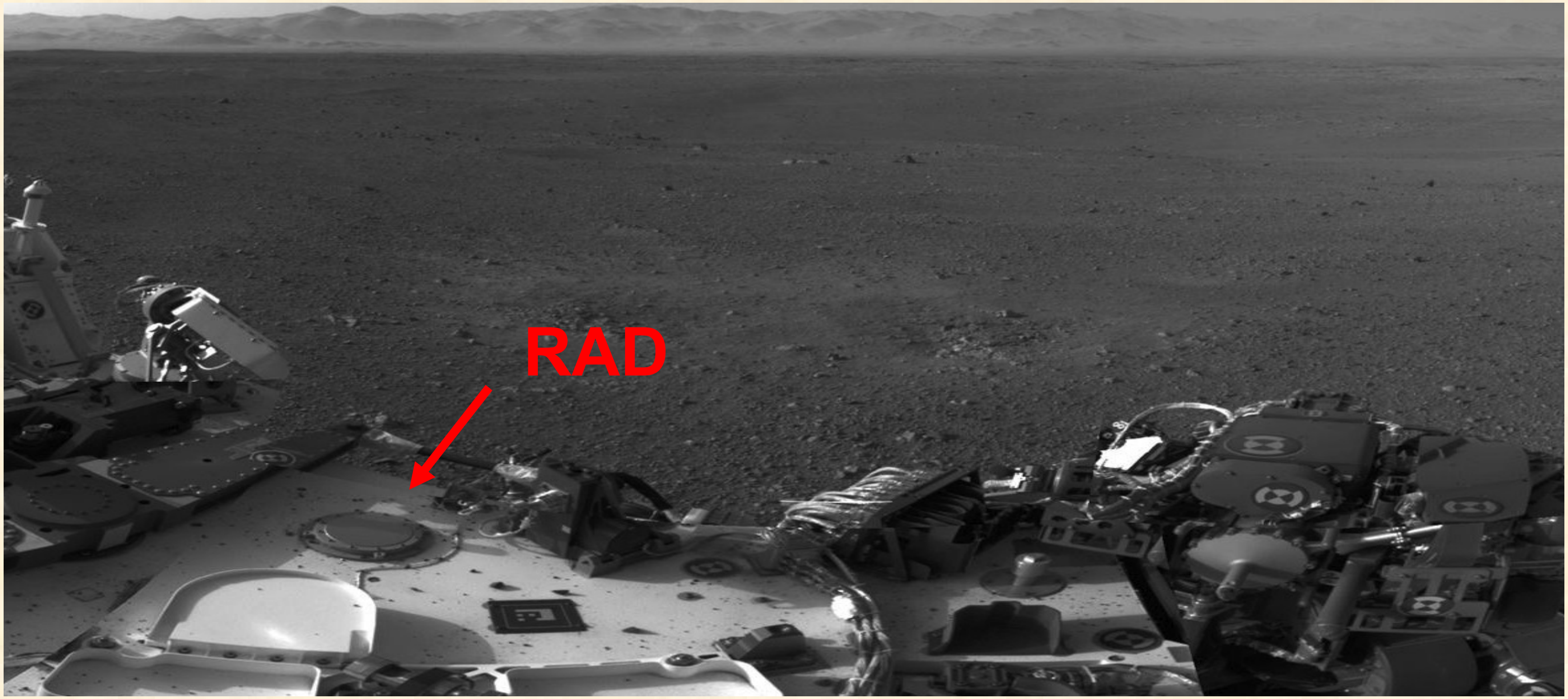


RAD Sensor Head Schematics & Measurement Capabilities

- ***Neutral particles*** are detected both in ***D*** and ***E*** (***C*** and ***F*** are used as anti-coincidence)
- Differences in detector response functions of ***D*** and ***E*** allow further separation into ***neutrons*** and ***γ-rays***
- ***D*** has a high Z → effective for γ-ray detection
- ***E*** has a high proton content → high cross section for neutron interaction
- Inversion method allows reconstruction of initial neutron and γ-ray energy spectra from 10 to several hundred MeV

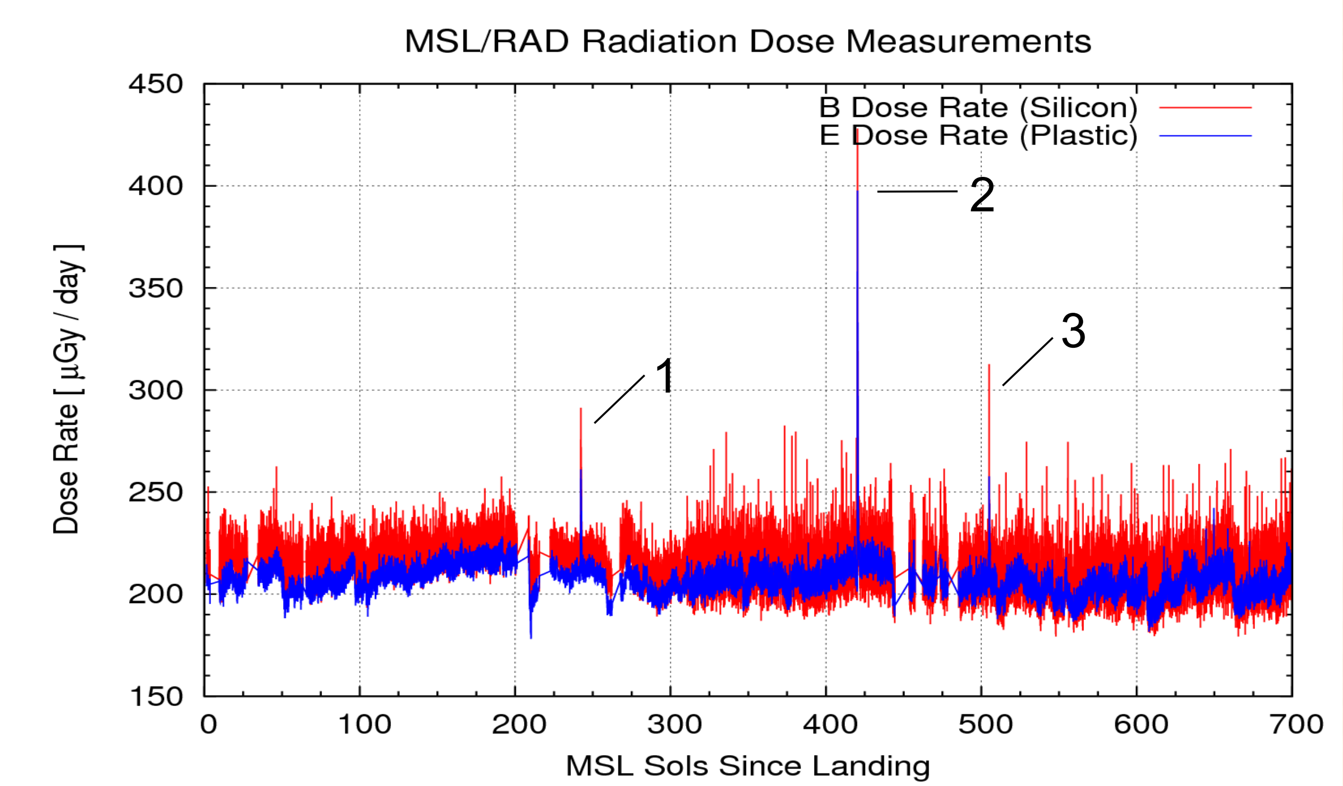


First-ever Radiation Measurements on the Surface of Mars



The Curiosity rover successfully landed in Gale crater on August 6, 2012. Situated on board the rover, RAD is the first-ever instrument to measure the Martian surface radiation environment.

RAD Dose Rate Measurements on the Surface of Mars



RAD has now been measuring the surface radiation for more than one Mars year (> 2 Earth years). So far, only 3 SEP events have been directly observed (as well as several Forbush decreases)!

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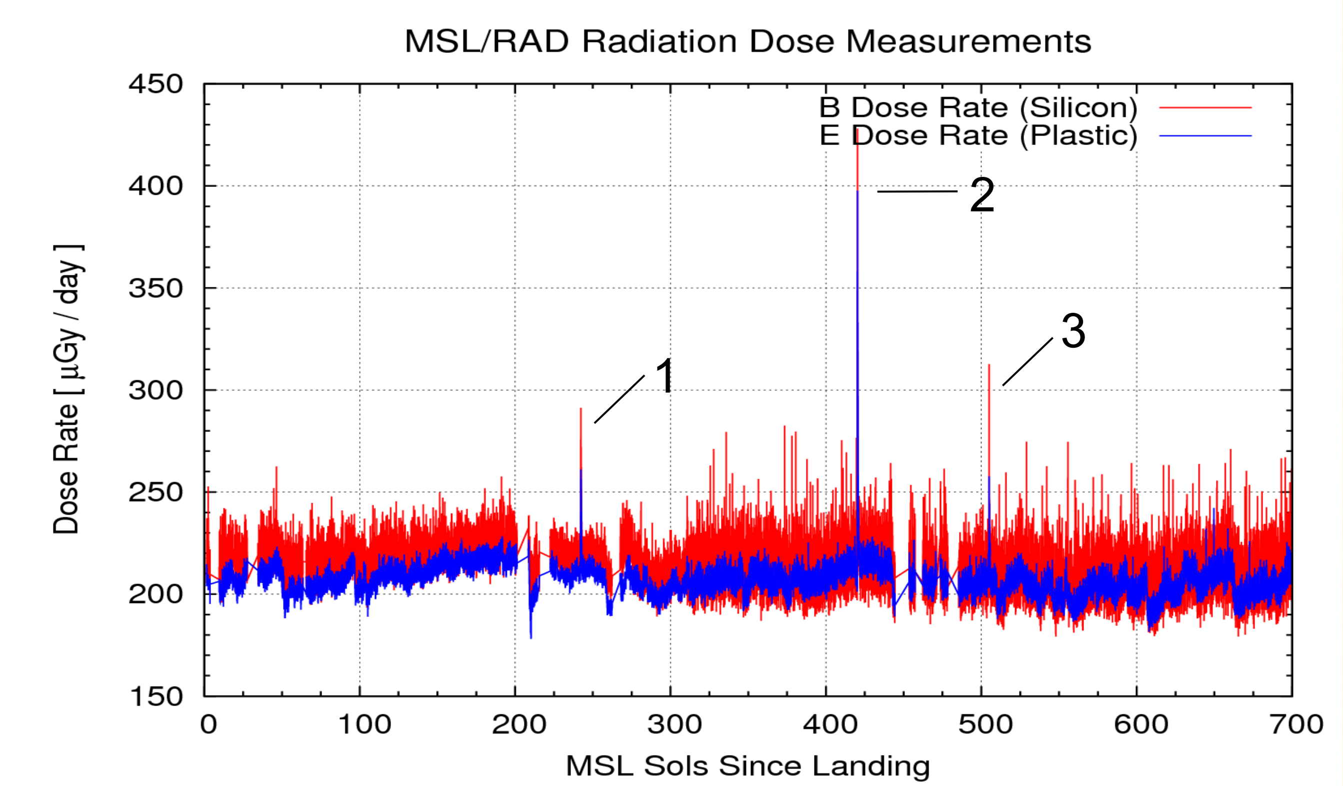
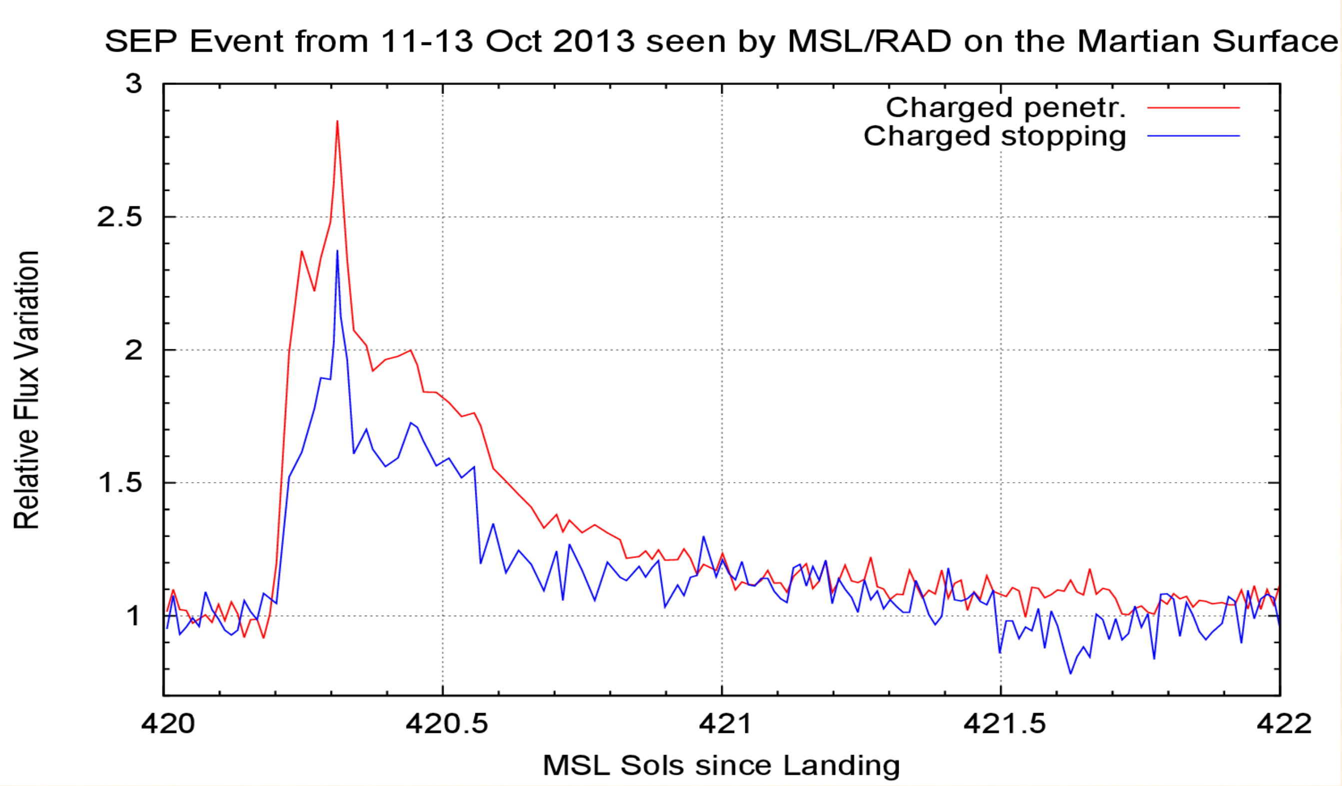


The observed SEP events have been comparatively weak → maximum dose rate increase by a factor of 2!

RAD Charged Particle Counter during SEP events



The largest event so far (Sol 420 / Oct 11 2013) saw an increase in charged particle flux by a factor of 2 – 3.

Current Status of RAD Research

The RAD team has already published several research articles about the measurement during the MSL surface mission phase:

- Hassler et al., Science (343), 2014. RAD overview paper over the surface mission phase
- Ehresmann et al., JGR Planets 119 (3), 2014. Charged particle fluxes
- Koehler et al., JGR Planets 119 (3), 2014. Neutral particle fluxes
- Kim et al., JGR Planets 119 (3), 2014. Comparison of RAD dose measurements and HZETRN calculations
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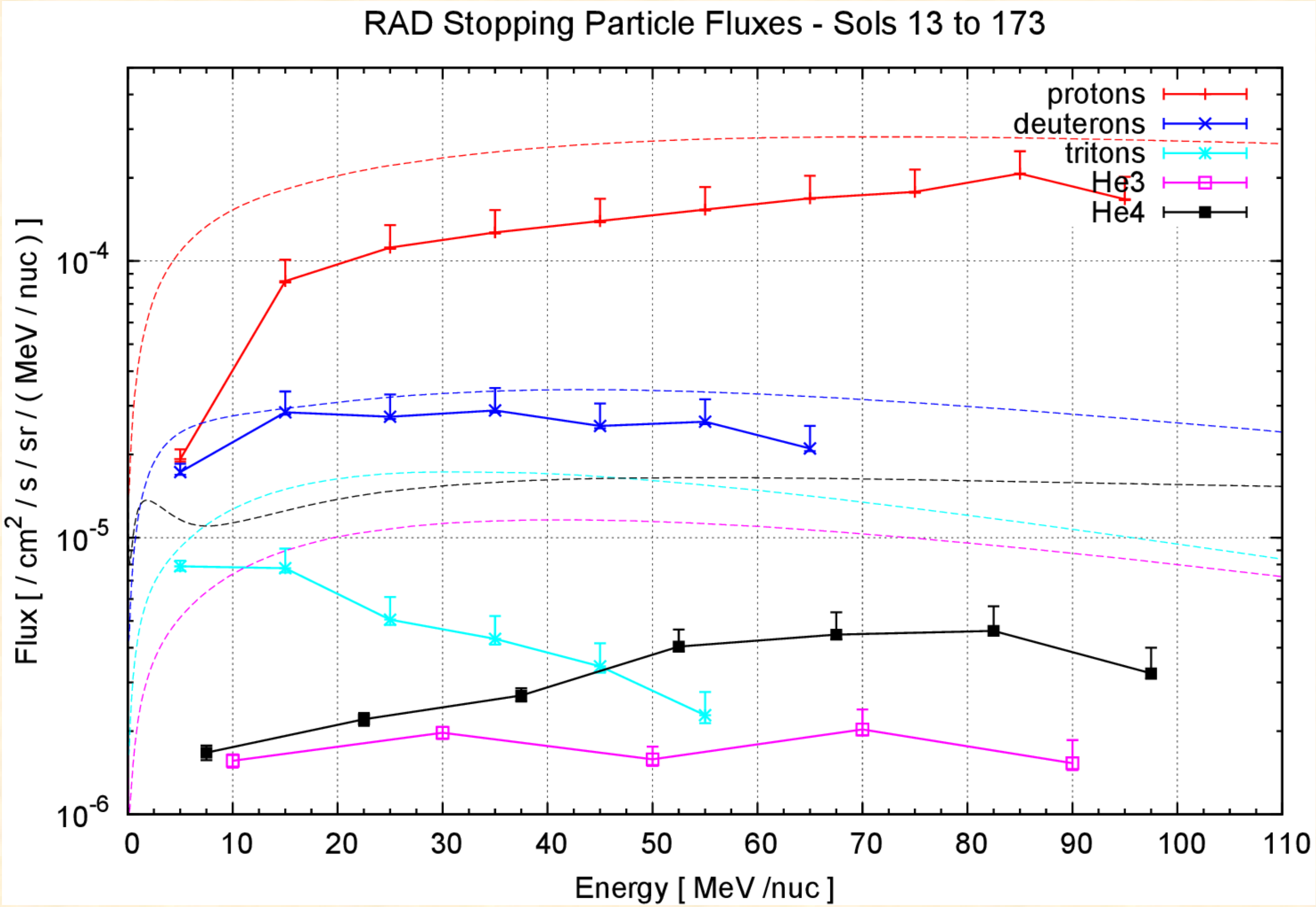

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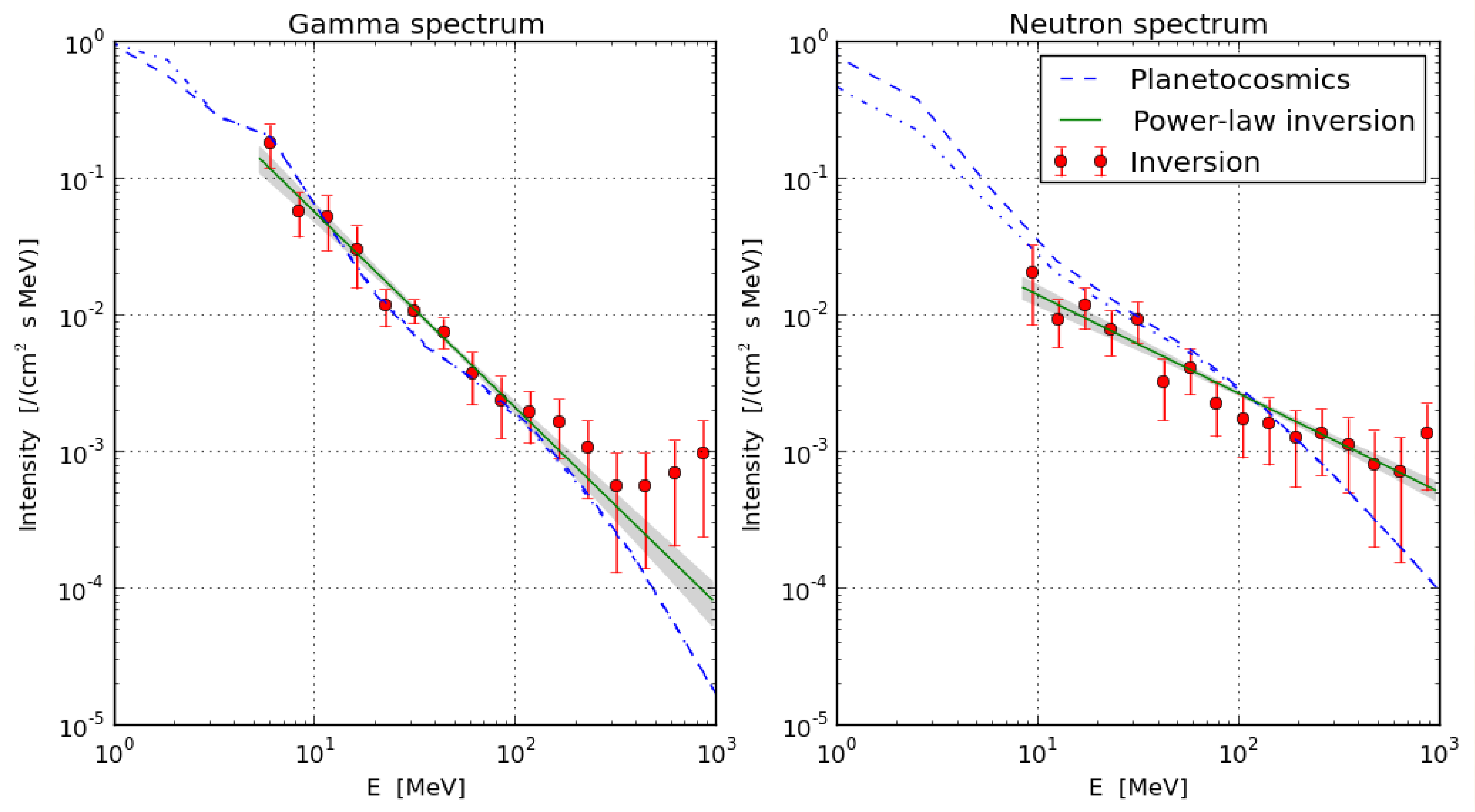

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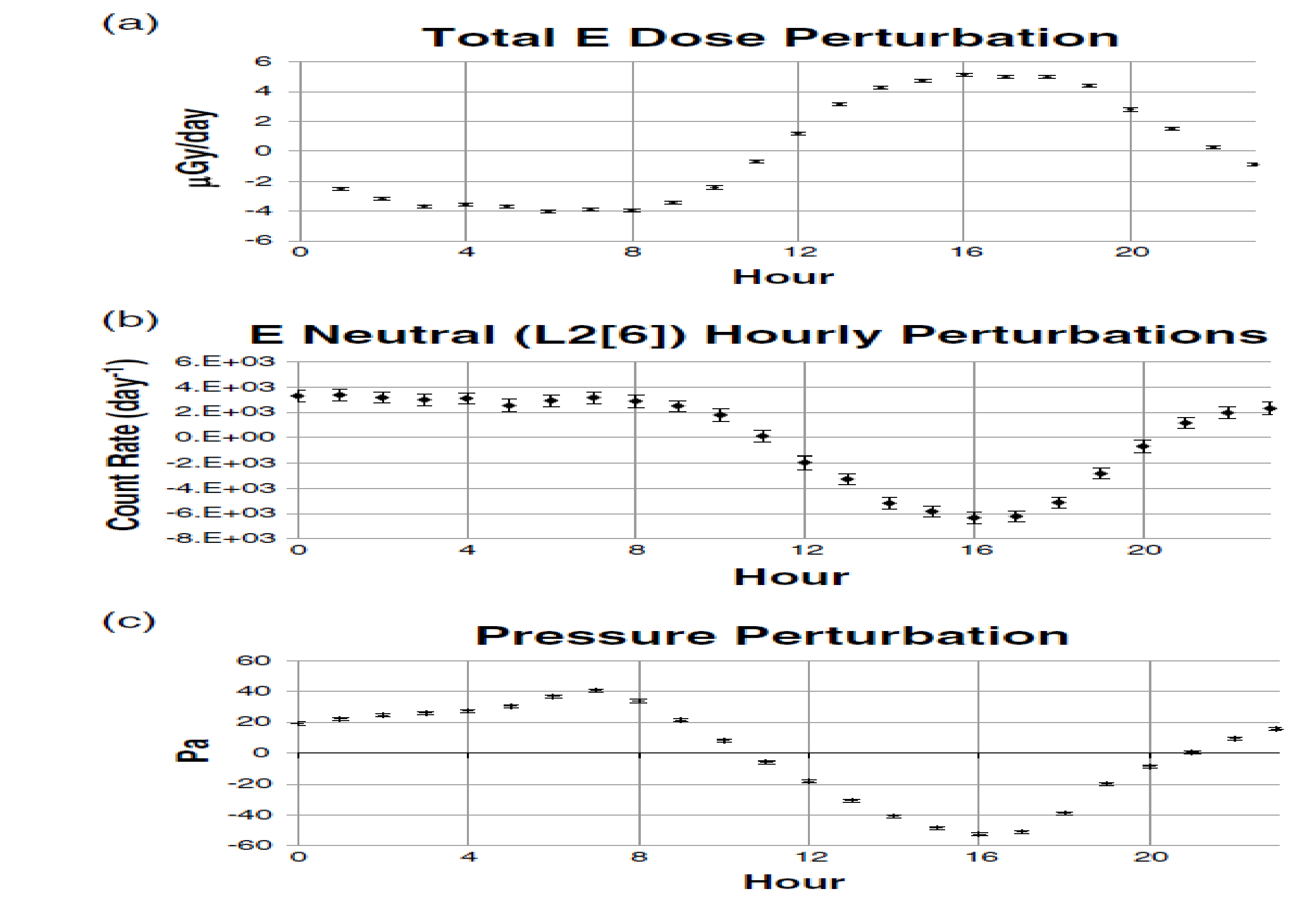

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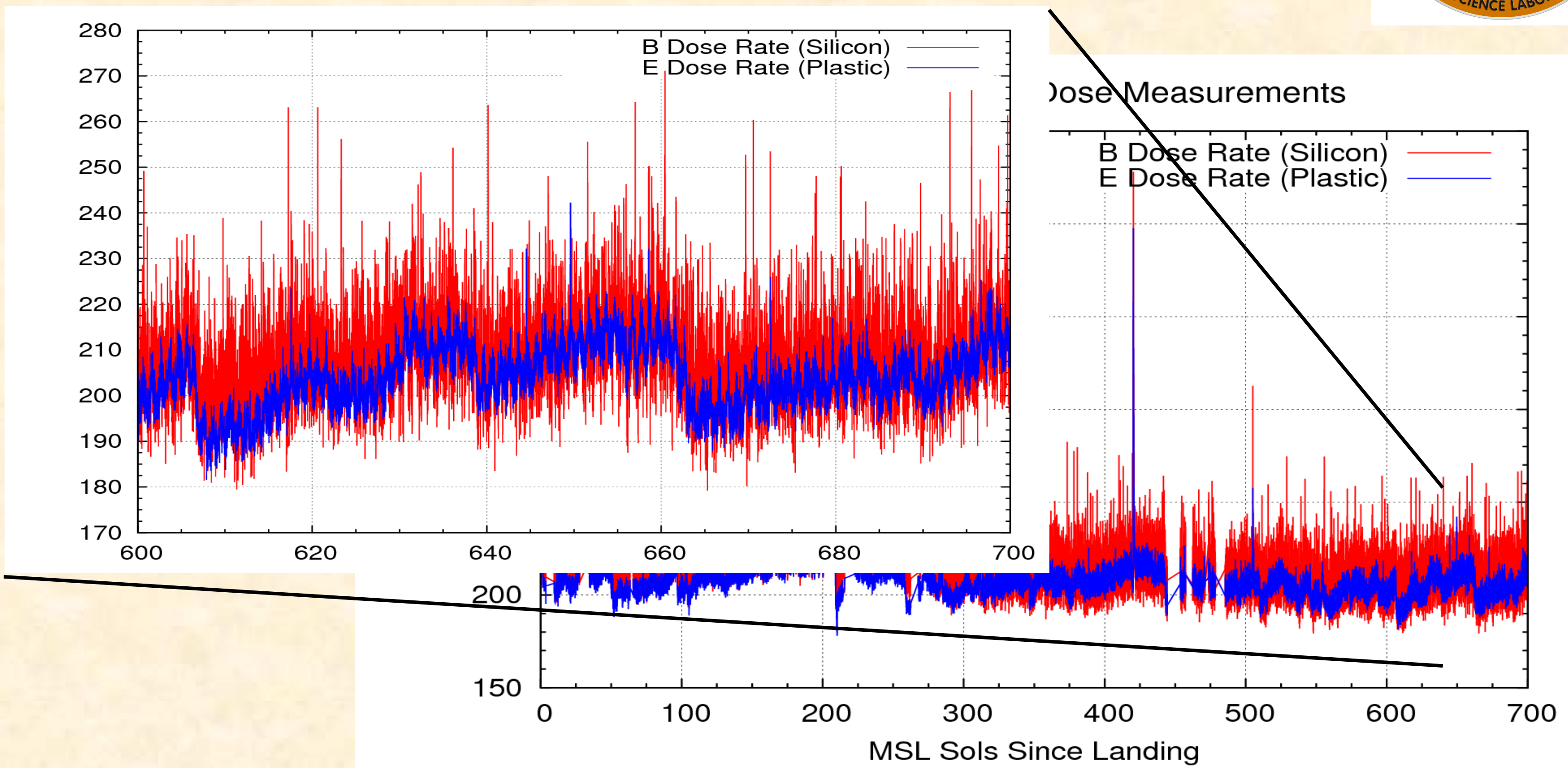
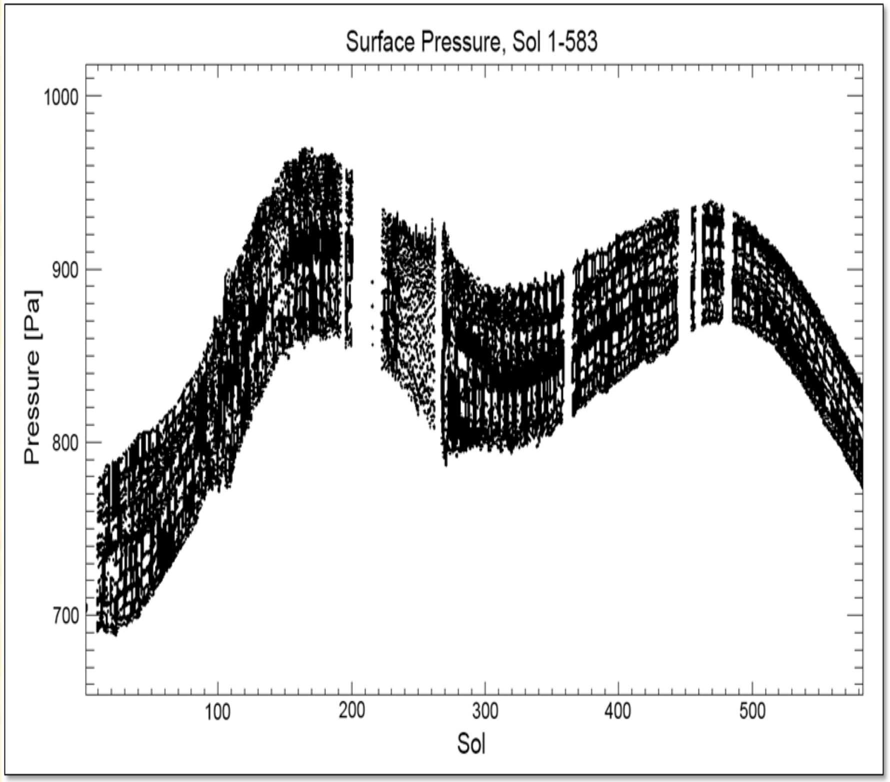
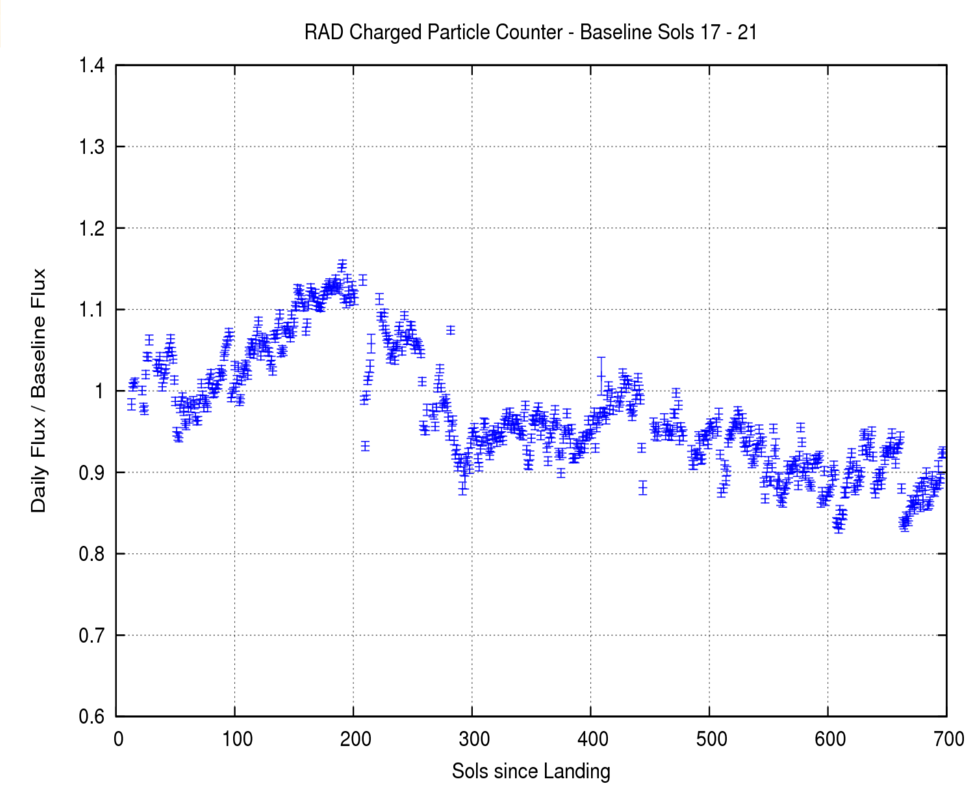
Short-term Variations of Radiation Environment



Besides diurnal variations, the radiation environment is also susceptible to other short-term variations, e.g., the heliospheric rotation → peak-to-peak variations of ~20 % in RAD dose measurements

Influence of Seasonal Pressure Cycle and Solar Modulation





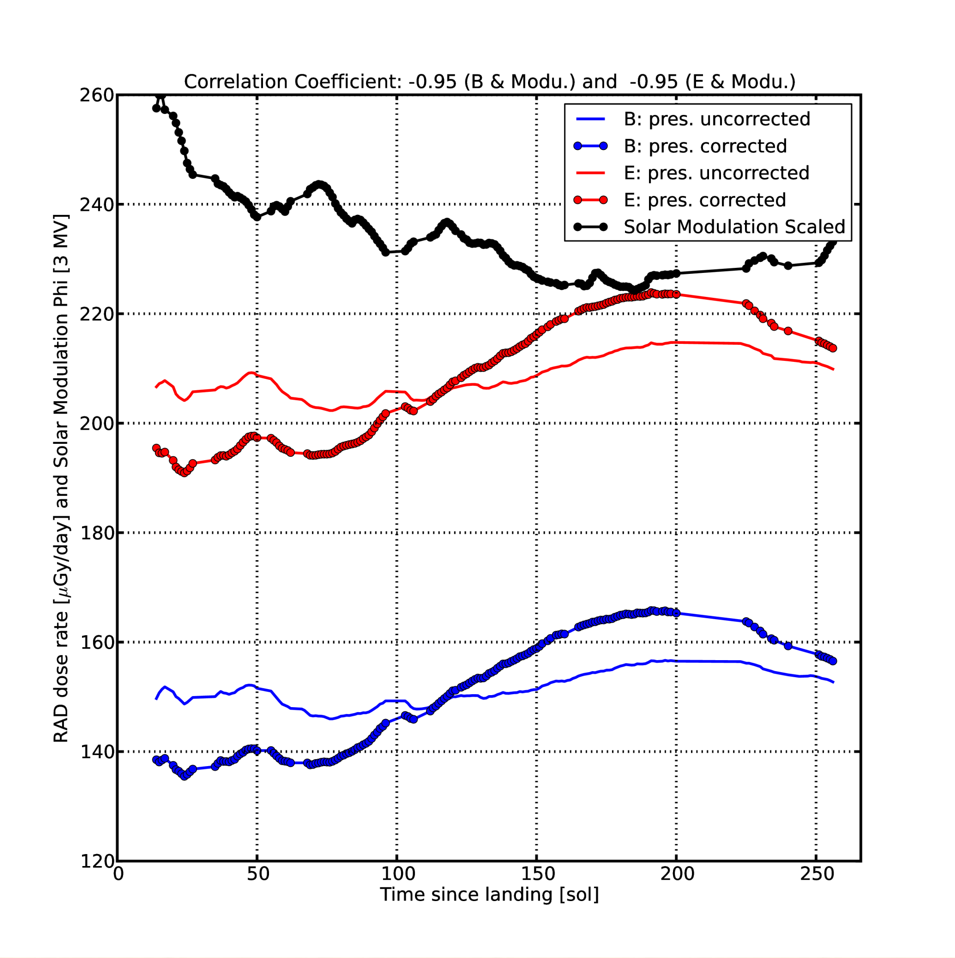
Radiation environment is not only influenced by the seasonal pressure cycle on Mars, but also by the solar modulation → Need to understand these separate influences!

Influence of Seasonal Pressure Cycle and Solar Modulation

On a long-term basis the radiation environment is mainly influenced by two factors:

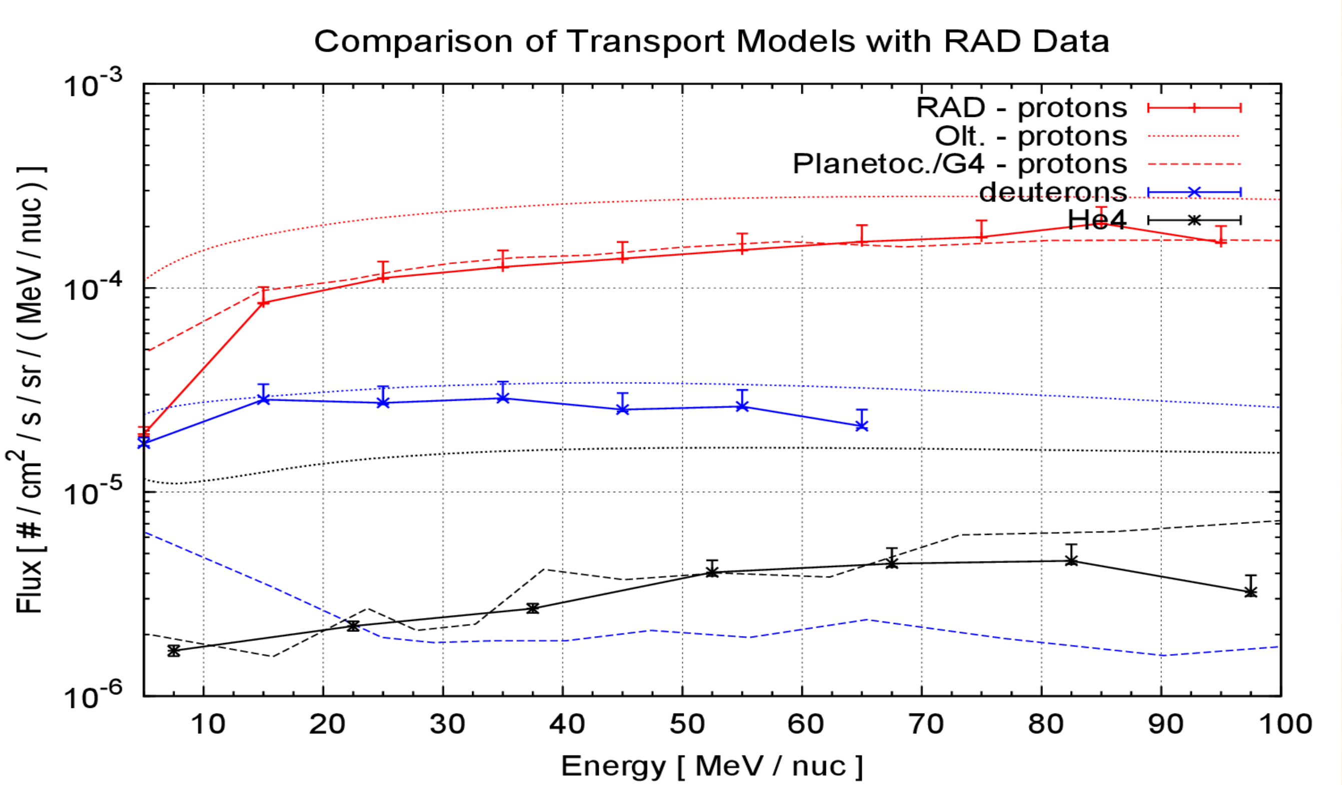
- Solar activity → modulation of incoming GCR flux (anti-correlated with solar activity)
- Seasonal pressure cycle → atmospheric column mass drives attenuation of GCRs in atmosphere + cross section for secondary particle production

These concurrent influences need to be separated to fully understand them!



RAD dose rate after preliminary pressure correction.

Validating Transport Models



RAD data (dose, spectra,...) can now be used to evaluate performance of different transport models (e.g., Oltaris, Planetocosmics, Fluka) → Analysis by *Matthiae, et al.* to be published soon.

Summary & Outlook

- RAD is the first-ever instrument to measure the radiation environment on the surface of Mars (2 years and running)
- Avg. absorbed dose rate: ~***210 µGy/day***; Quality Factor: ***3.05*** → Dose equivalent rate: ***~0.64 mSV/day***
- Only 3 (relatively) weak SEP events detected so far → need larger sample size to understand potential hazards
- Measuring throughout the solar cycle important for full understanding of radiation environment → Radiation environment is highly variable on short- and long-term time scales
- Separation of concurrent influences of solar modulation and seasonal pressure cycle
- How do radiation dose, charged and neutral particle spectra vary throughout the mission phase? (seasonal and solar cycle)
- Cooperation with other MSL instrument teams (e.g., REMS, DAN, SAM) ongoing → complement research