Update for the MSL/RAD Investigation

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and the MSL/RAD Team

WRMISS
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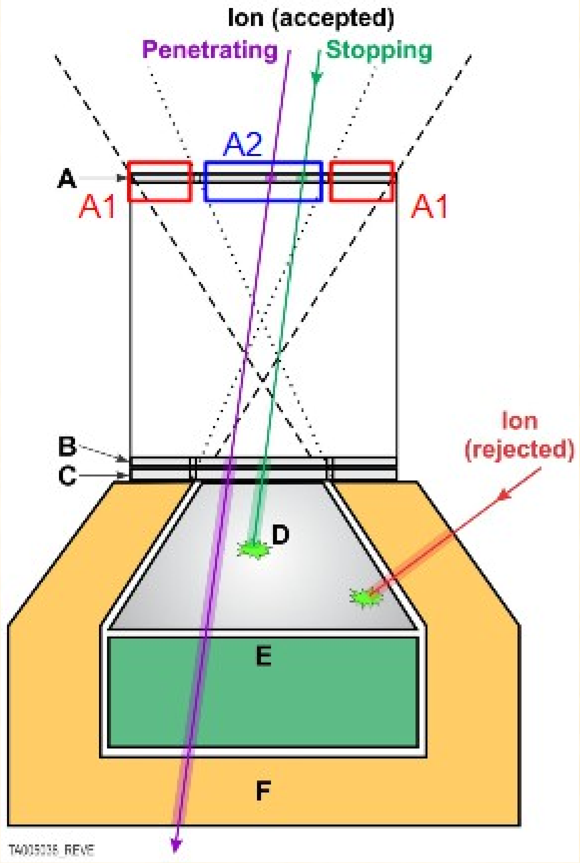
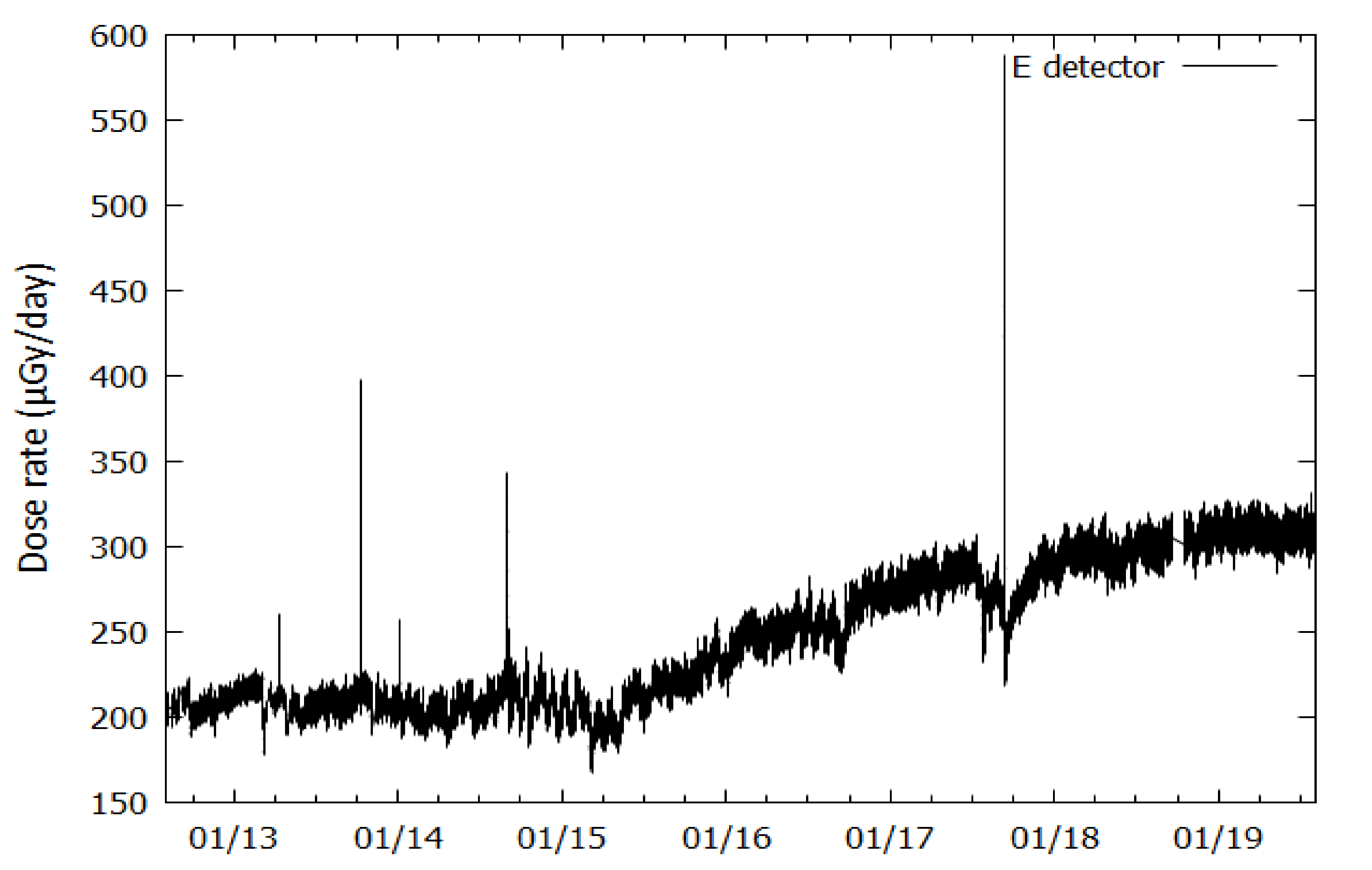
RAD High-Level Overview

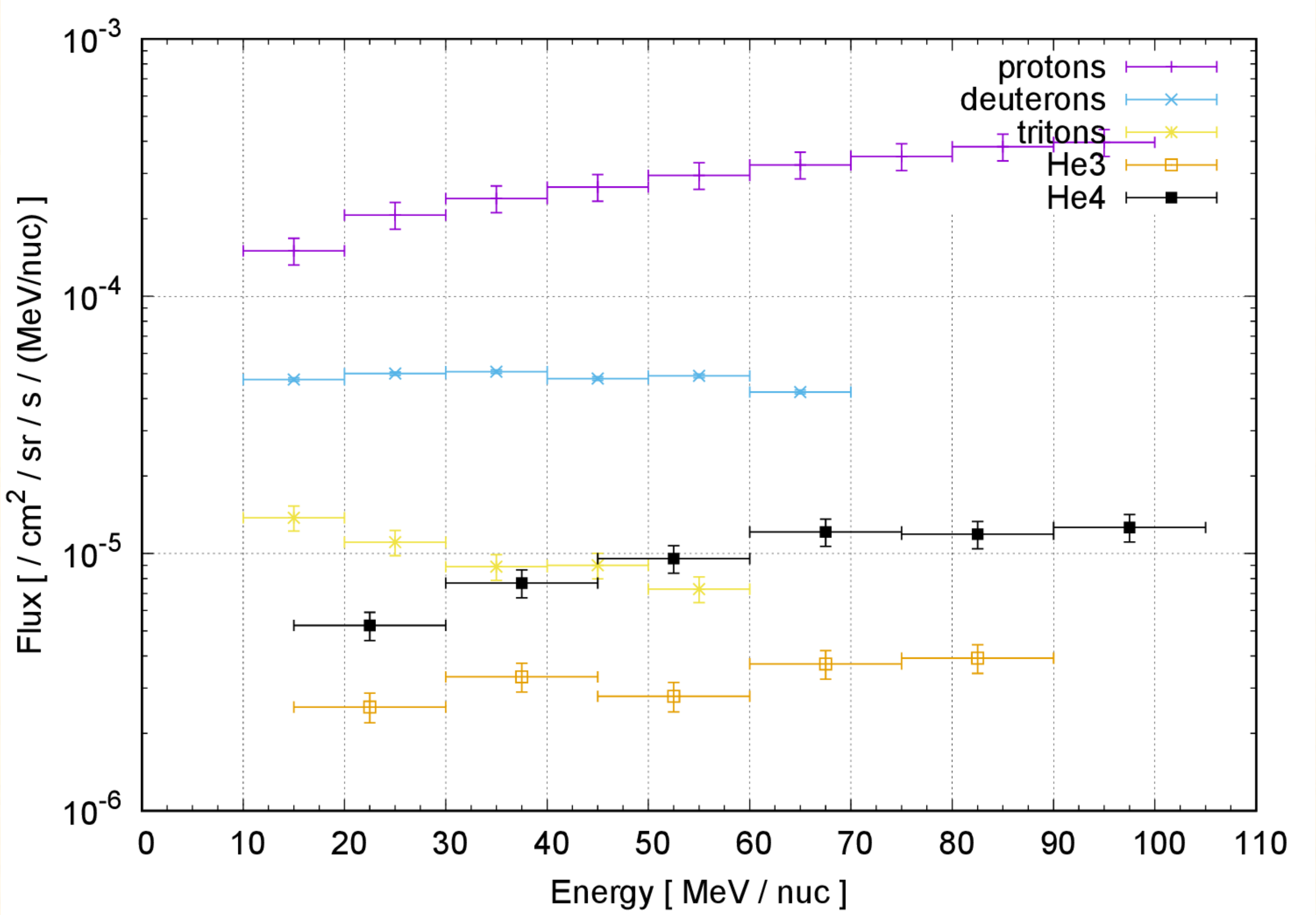
- RAD is part of ***NASA's MSL mission*** and is measuring the Martian surface radiation environment in Gale crater on board Curiosity since ***August 2012***
- The RAD sensor head consists of 3 Si detectors (***A***-***C***), a CsI scintillator (***D***), and a plastic scintillator (***E***), as well as a further plastic scintillator (***F***) acting as ***anti-coincidence***.
- RAD measures:
  - ***Neutral Particle spectra*** (neutrons and γ-rays) in D and E (in AC with F) & ***Charged particle spectra*** and ***integral fluxes*** distinguished into separate isotopes (H & He) or groups of ion species (higher Z)
  - ***LET(Si)*** spectra are measured in ***B*** & ***dose*** in ***B*** (Si) and ***E*** (plastic / tissue-equivalent)



RAD Dose Rate Measurements So Far



RAD Stopping Particle Measurements / Energy Spectra – Z = 1 and 2

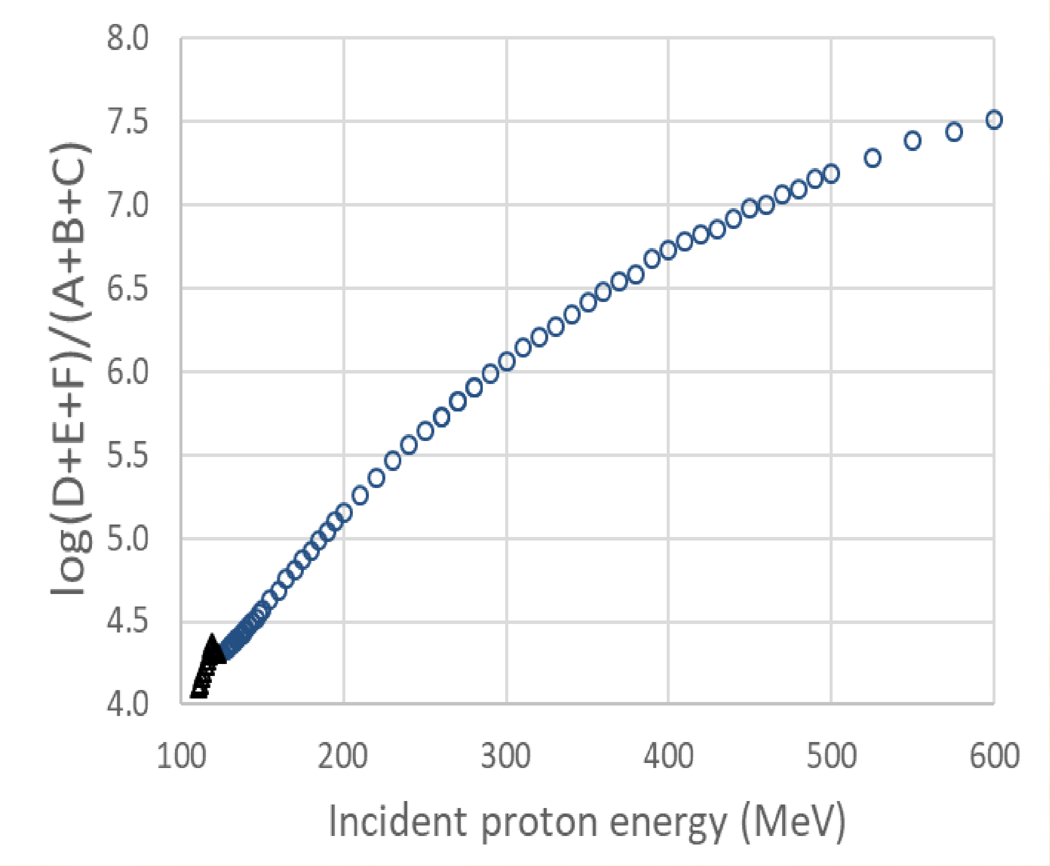


Extending the RAD Proton Energy Range

- Can we increase the proton spectra (differential fluxes) with a combination of RAD data, simulations, and first order calculations?

Empirical Approach

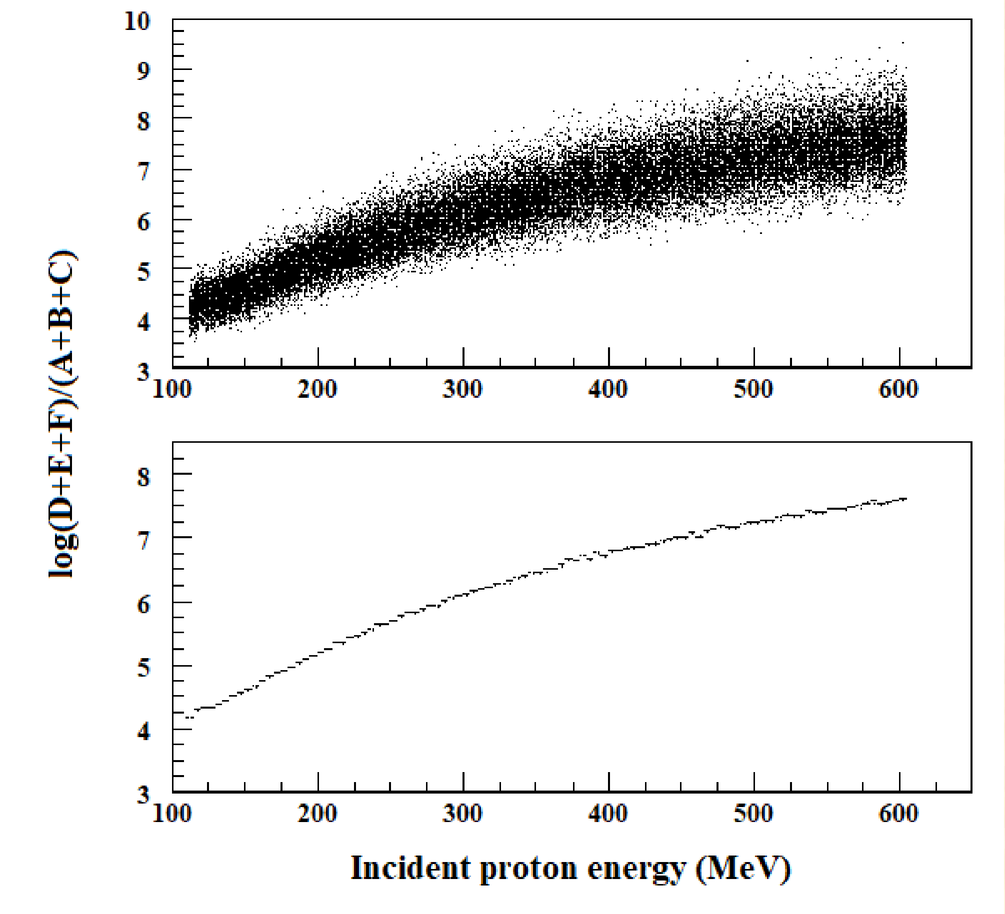
- Started with spreadsheet of Bethe-Bloch energy deposition calculations for various proton energies in MSL-RAD
- Noticed that log(D+E+F)/(A+B+C) showed some correlation with the true incident proton energy.
- Not really linear but maybe ok in restricted ranges, i.e., piecewise.



Extending the RAD Proton Energy Range

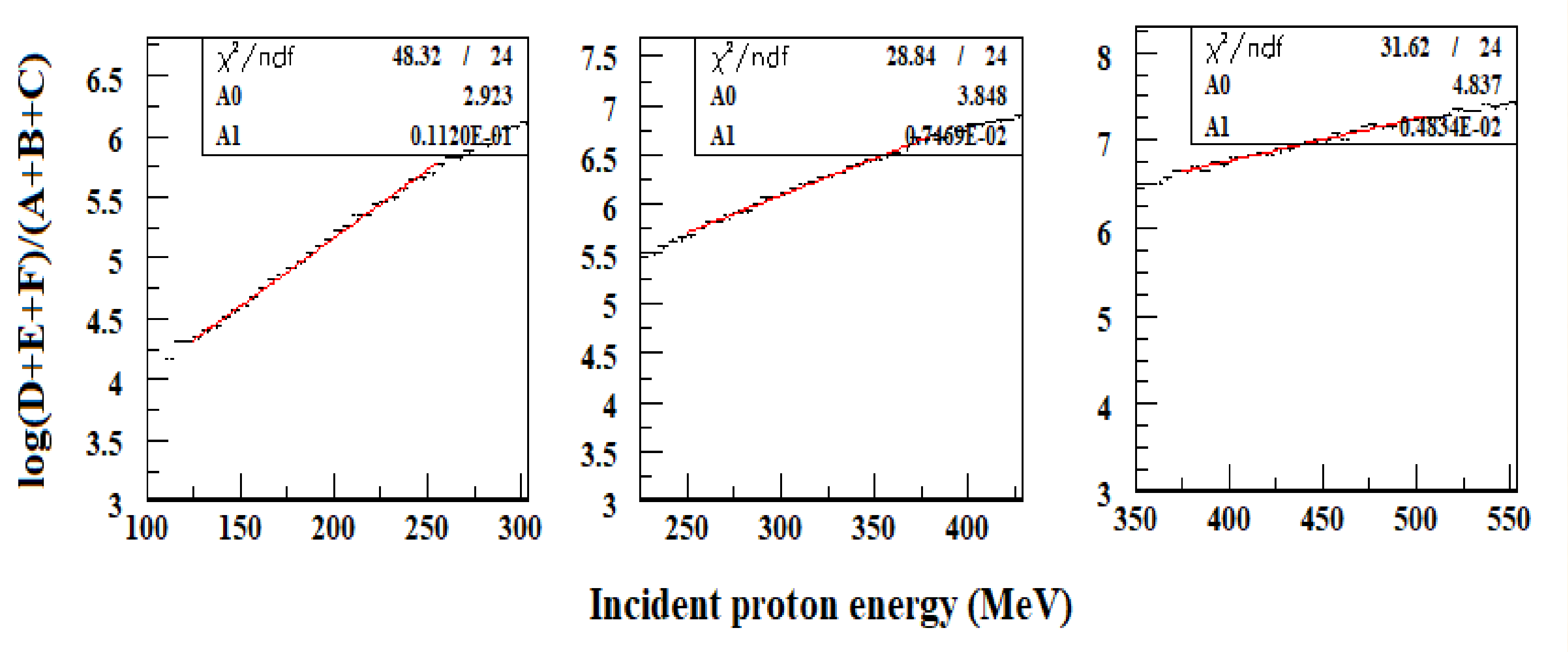
Energy Loss Simulation

- MSL-RAD stack simulated.
- Smearing is probably too large.
- Top plot is scatter, bottom plot is average of “thing” (y-axis unit) vs. proton energy.
- Looks a lot like the plot on the previous page, which it should, because it all uses the same implementation of Bethe-Bloch.



Extending the RAD Proton Energy Range

Piece-Wise Linear Fits

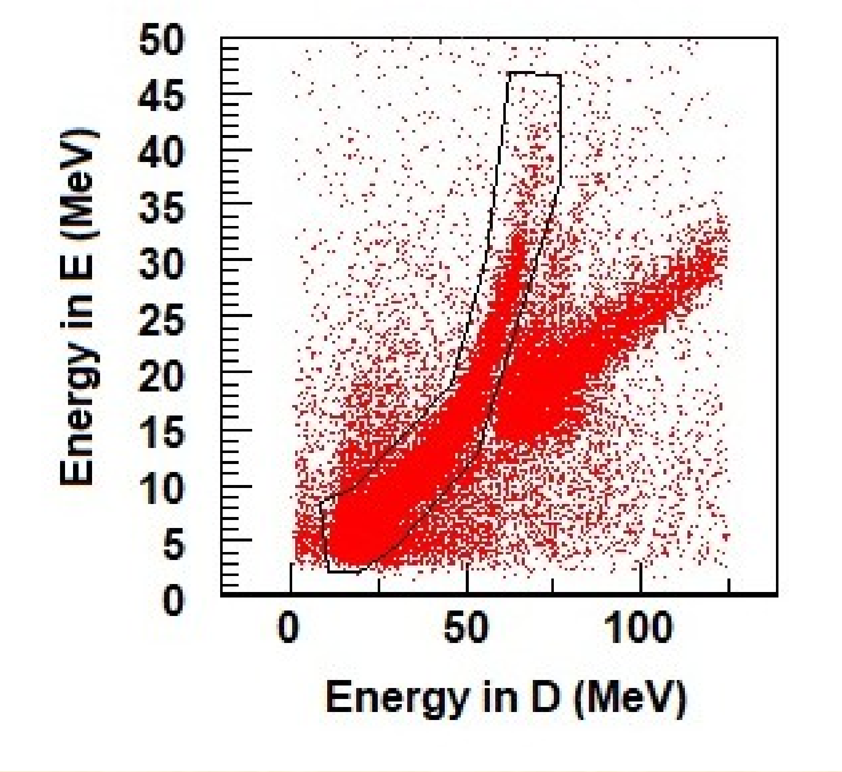


- Break into 3 ranges on y-axis: 4.25 to 5.5, 5.5 to 6.5, 6.5 to 7.15.
- These more or less map into broad but nonetheless discrete energy bins – not perfectly, but not terribly.

Extending the RAD Proton Energy Range

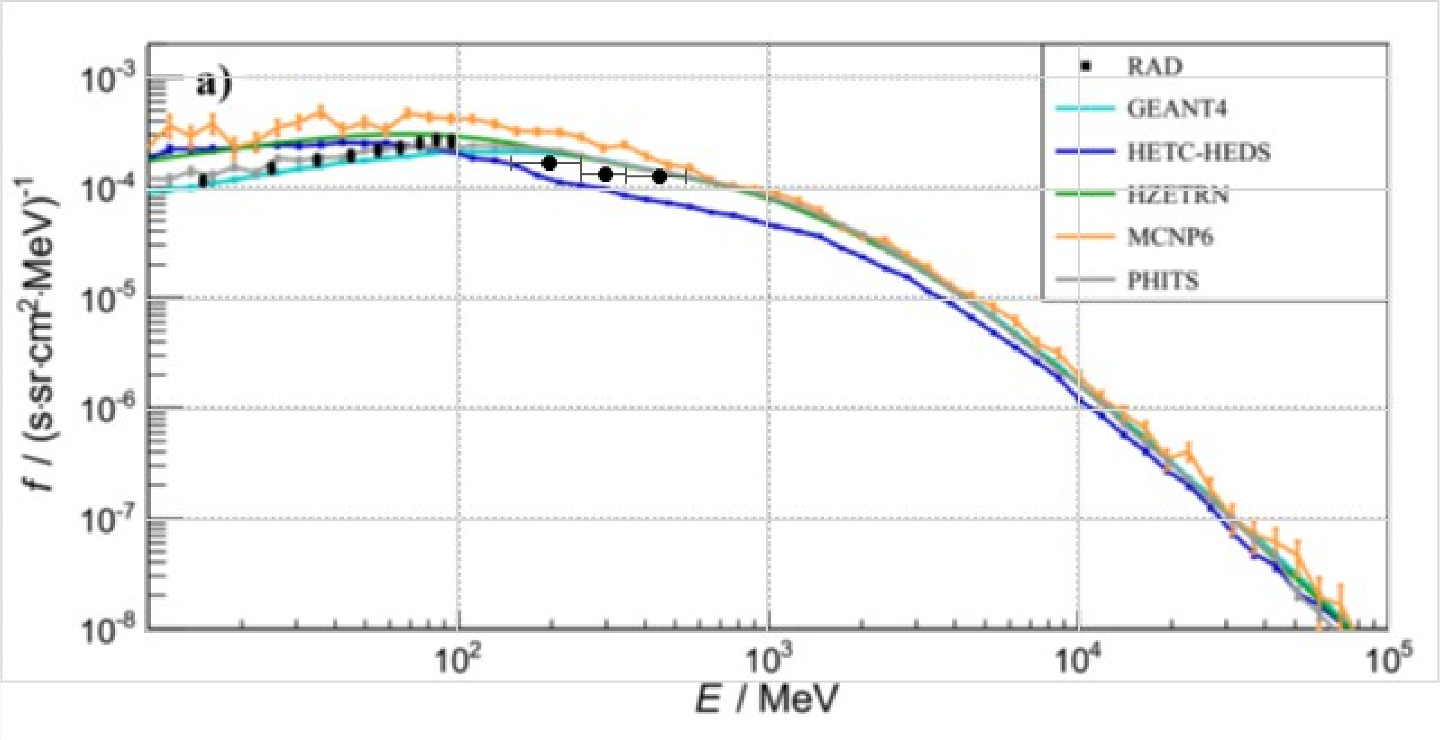
Apply to Real Data with Cuts to Select Penetrating Protons

- A2*B coincidence (L2[1] and/or L2[3] trigger).
- A2 energy deposit > A1 energy deposit.
- C, D, E, F2 all have slow tokens set.
- B and C both have between 120 and 450 keV energy deposited.
- D has between 15 and 62 MeV energy deposited.
- E has between 4 and 30 MeV energy deposited.



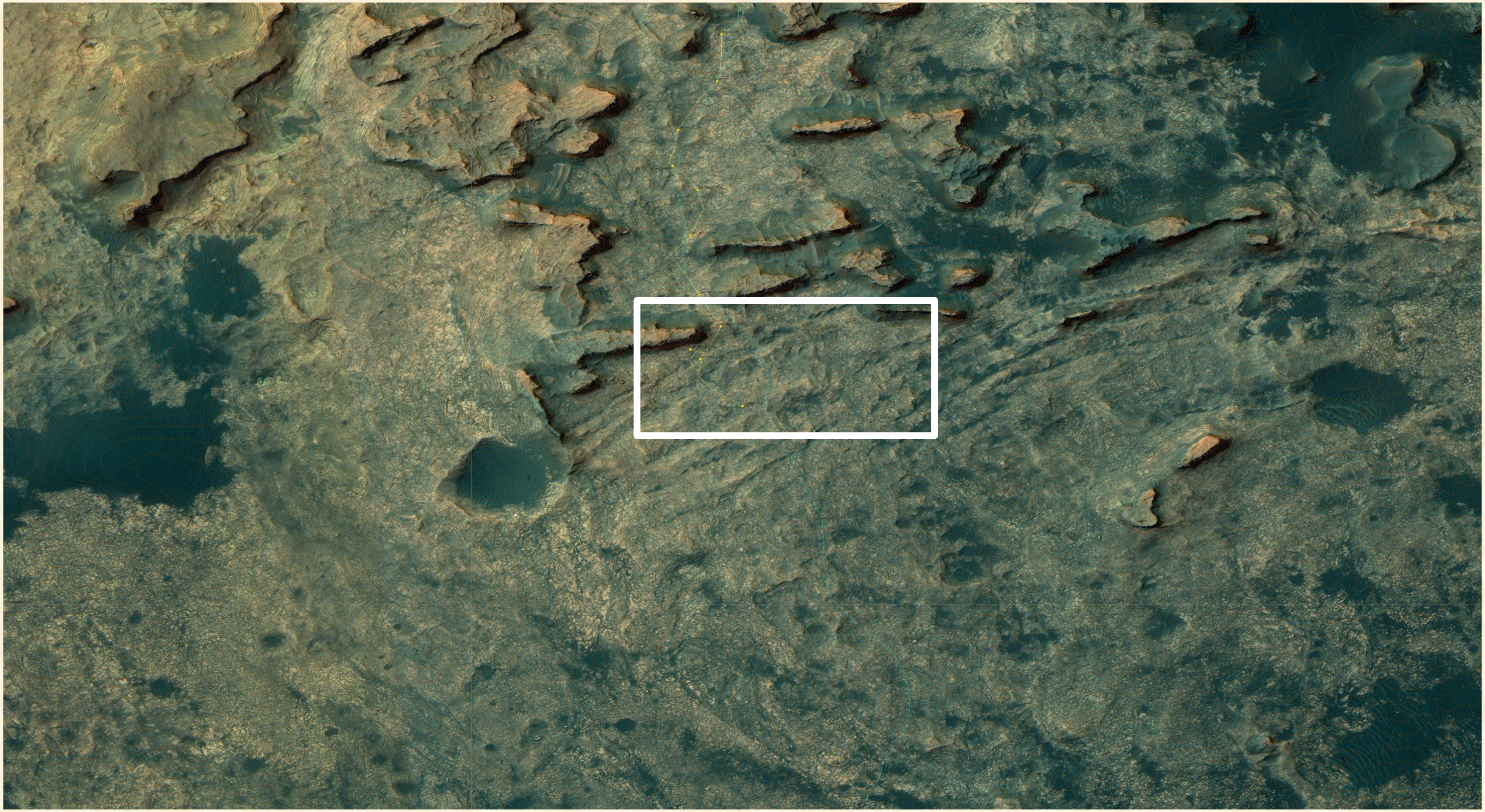
Extending the RAD Proton Energy Range

Results



- Look at data period for first MSL-RAD Modeling Workshop, since we have this nice plot from Daniel Matthiae.
- Overlay 3 new points – encouraging.
- Work in progress → Potential 10% upward correction identified.

RAD at the Murray Buttes – Radiation Sheltering from Natural Formations



On sol 1455, Curiosity drove up close to a location, called Murray Buttes, where it parked for 13 sols.

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RAD at the Murray Buttes – Radiation Sheltering from Natural Formations

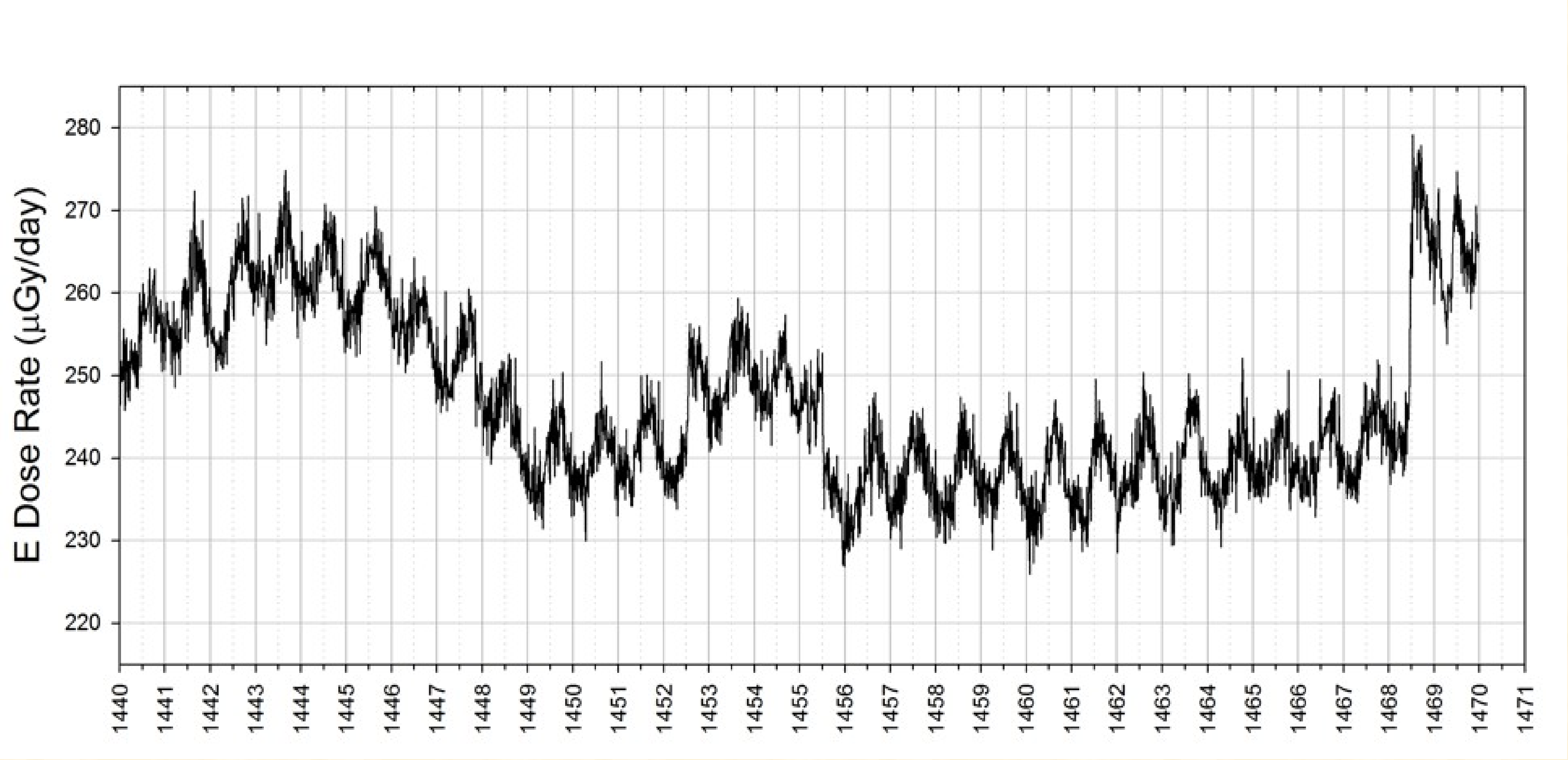
MSL Mastcam mosaic of Murray Buttes

RAD at the Murray Buttes – Radiation Sheltering from Natural Formations

Astronaut inserted for scale (credit: NASA/JPL)

RAD at the Murray Buttes – Radiation Sheltering from Natural Formations

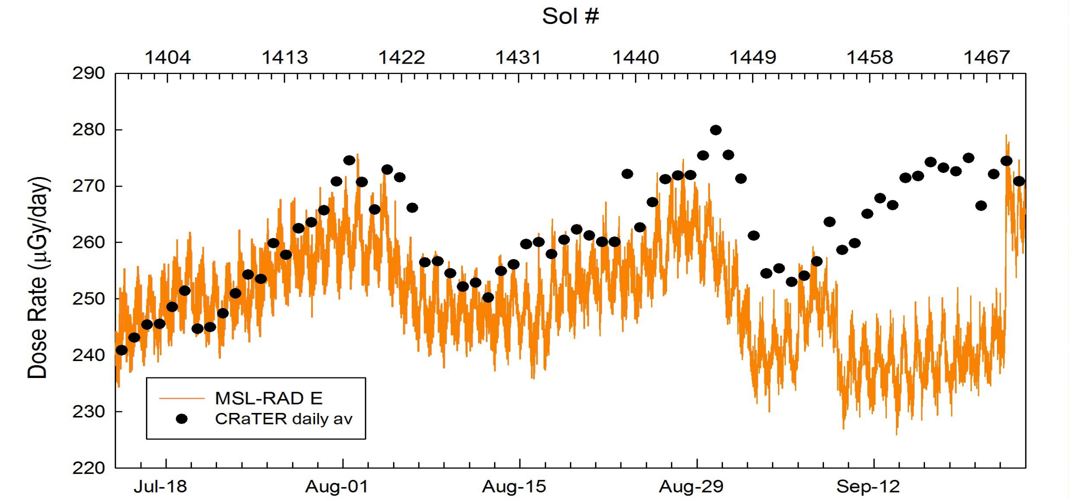
What did RAD see while parked at the Murray Buttes?

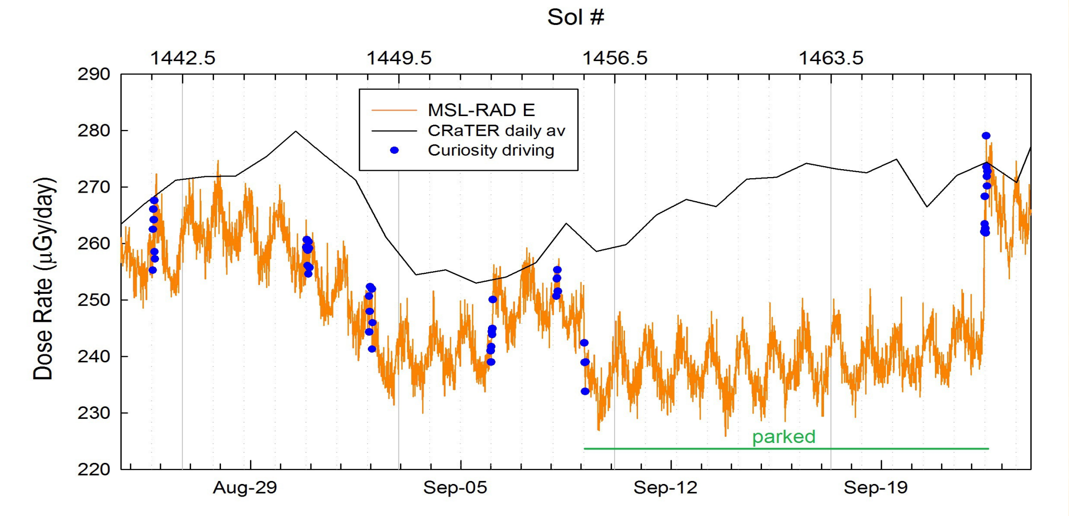


Murray Buttes blocked out a part of the upper hemisphere above RAD, resulting in a decrease in radiation

RAD at the Murray Buttes – Radiation Sheltering from Natural Formations

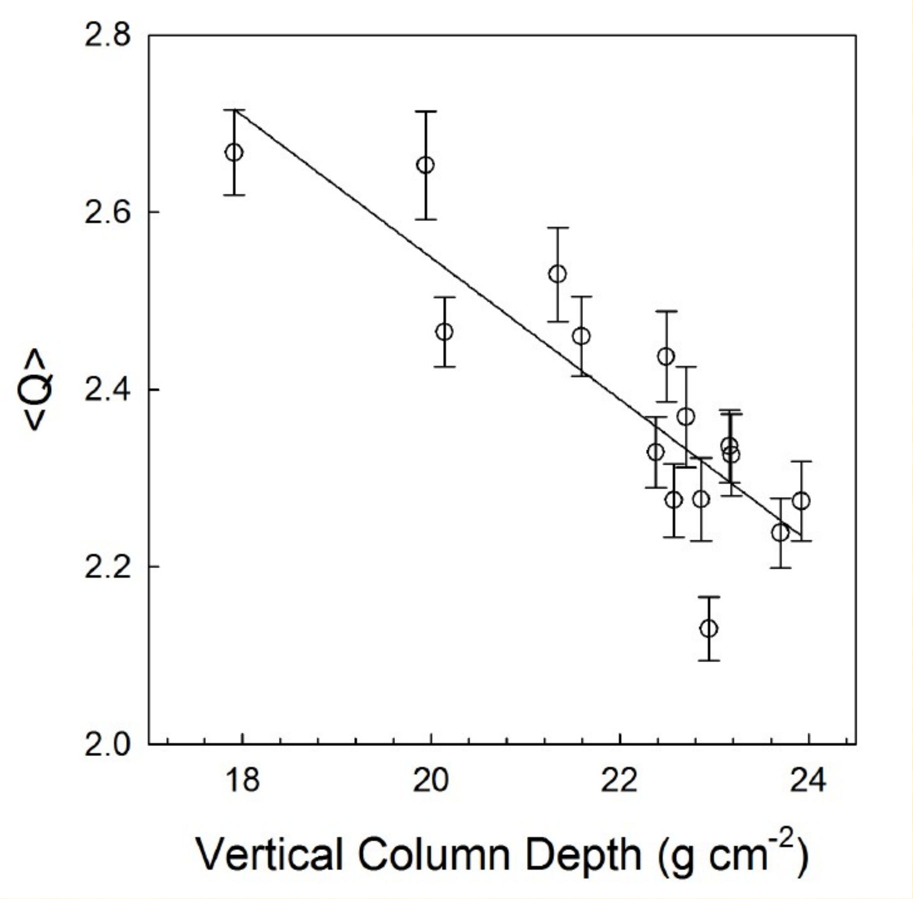
- Initial analysis from Cary
- Before Murray Buttes CRaTER and RAD track each other well
- Can we use this to calculate the “missing” dose?
- Can L2 counters reveal interesting information about the “quality” of the drop in dose
- Counters with AxB trigger shouldn’t show any drop in dose but could be used as sanity check
- What do neutral counters show? (drop due to lower primary flux? / more secondaries created in the Buttes near RAD?)
- Do heavy ions show bigger drop due to fragmentation?





Change of Quality Factor <Q> with Pressure / Altitude

- As Curiosity continues to climb in altitude, the atmosphere above the rover is, in turn, getting less and less
- Less atmospheric mass means incoming GCRs undergo fewer interactions with the atmosphere
- GCRs lose less energy & lower probability of heavy ions fragmenting → relative fraction of heavy ions in the surface radiation field increases
- As a result the quality factor <Q> of the radiation field increases → more biologically harmful



2nd Mars Radiation Modeling Workshop (16-18 Oct 2018)

- After the highly successful first iteration, the 2nd Mars Radiation Modeling Workshop, supported and encouraged by NASA HEOMD, was held in Boulder in October 18
- Modeling results of the Mars radiation environment showed great improvements from the first workshop
- Modelers were able to use the knowledge gained to identify areas of improvements in model setups and included physical processes, based on the comparison to ***in-situ*** RAD measurements from the Martian surface
- However, there are still discrepancies to be found between the models themselves and between models and measurements
- Hopefully, a future 3rd Workshop can improve the models even better
- The interplay between measurement and model improvements highlights the continued need for in-situ measurements to baseline models against

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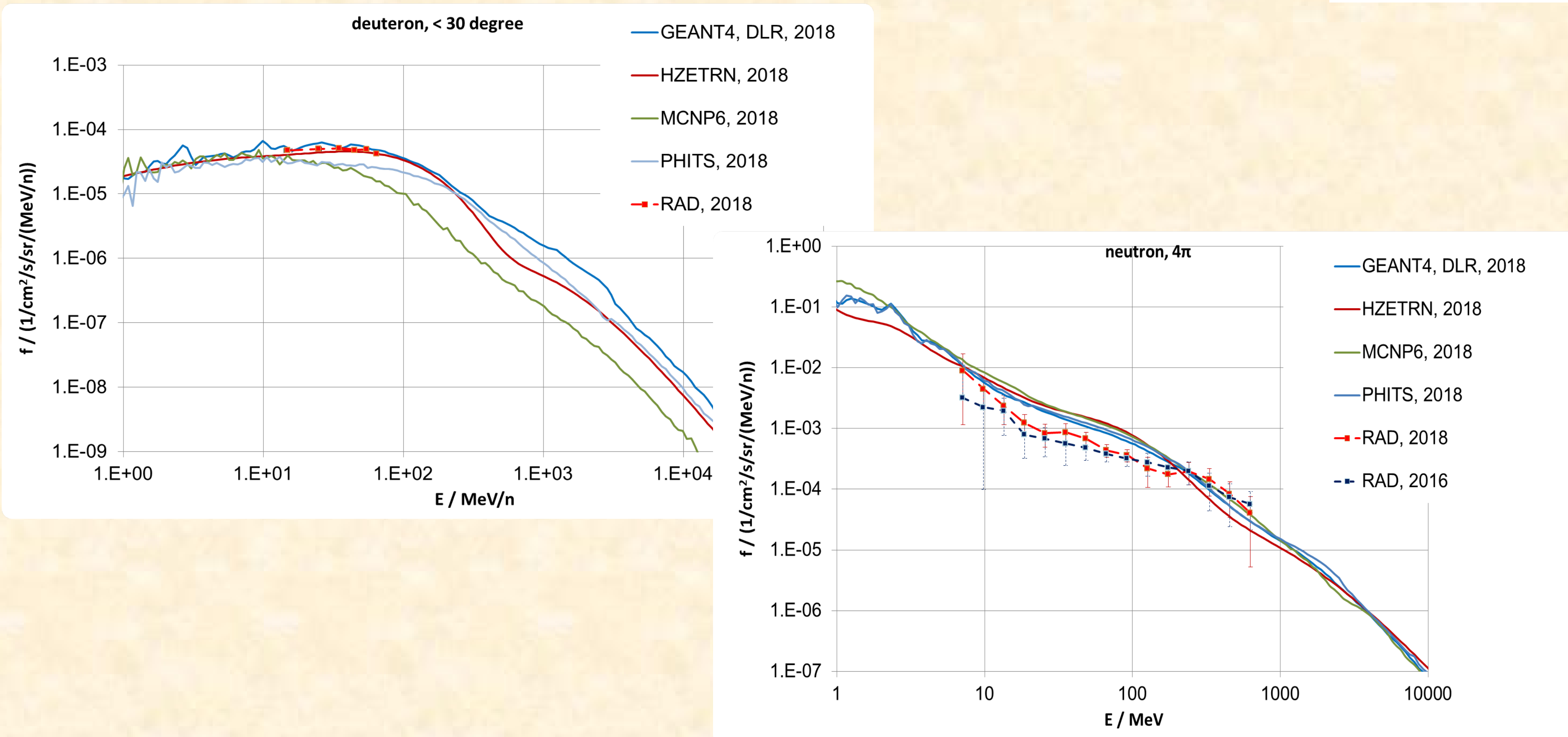

Modeled deuteron and neutron fluxes on the surface of Mars from the 2nd Modeling Workshop (graphs courtesy of Daniel Matthiä (DLR & RAD team))

Summary & Conclusions

- RAD continues its ***highly successful*** measurements of the Martian surface radiation on board NASA's Curiosity rover (***7+ years of operations***), measuring effects of the changing solar modulation, as well as effect from solar sources (SEP events, Forbush decreases, etc.)
- The RAD team is currently working on ***extending*** the energy spectral range for protons from 100 MeV out to > ***500 MeV***. First results look very promising!
- ***"Radiation shadowing"*** from the Murray Buttes, detected by RAD, leads to the interesting question:
  - Can future human explorers ***utilize Mars' natural geological properties*** for radiation protection? (Manuscript in preparation)
- ***2nd Mars Modeling Workshop*** was again a great ***success***, showing how ***in-situ*** RAD measurements are crucial for ***improving*** radiation transport / prediction models
- RAD has only detected 5(!) direct SEP events on the surface of Mars so far (in 7+ years)!
- We need a ***larger data set*** of RAD measurements to reliably assess the ***impact of SEPs*** on future human explorers! In particular, as we have no measurements of SEP spectra in the orbit → Making radiation risk assessments for ***Mars*** based on spectral measurements at ***1 AU*** is highly ***challenging***!

Thank You!

- RAD is supported by NASA (HEOMD/AES) under JPL subcontract #1273039 to Southwest Research Institute.

- … and by DLR in Germany under contract with the Christian-Albrechts-University Kiel.