Recent Results from the MSL-RAD Experiment on the Curiosity Mars Rover

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On behalf of the MSL-RAD Science Team

RAD Science Team

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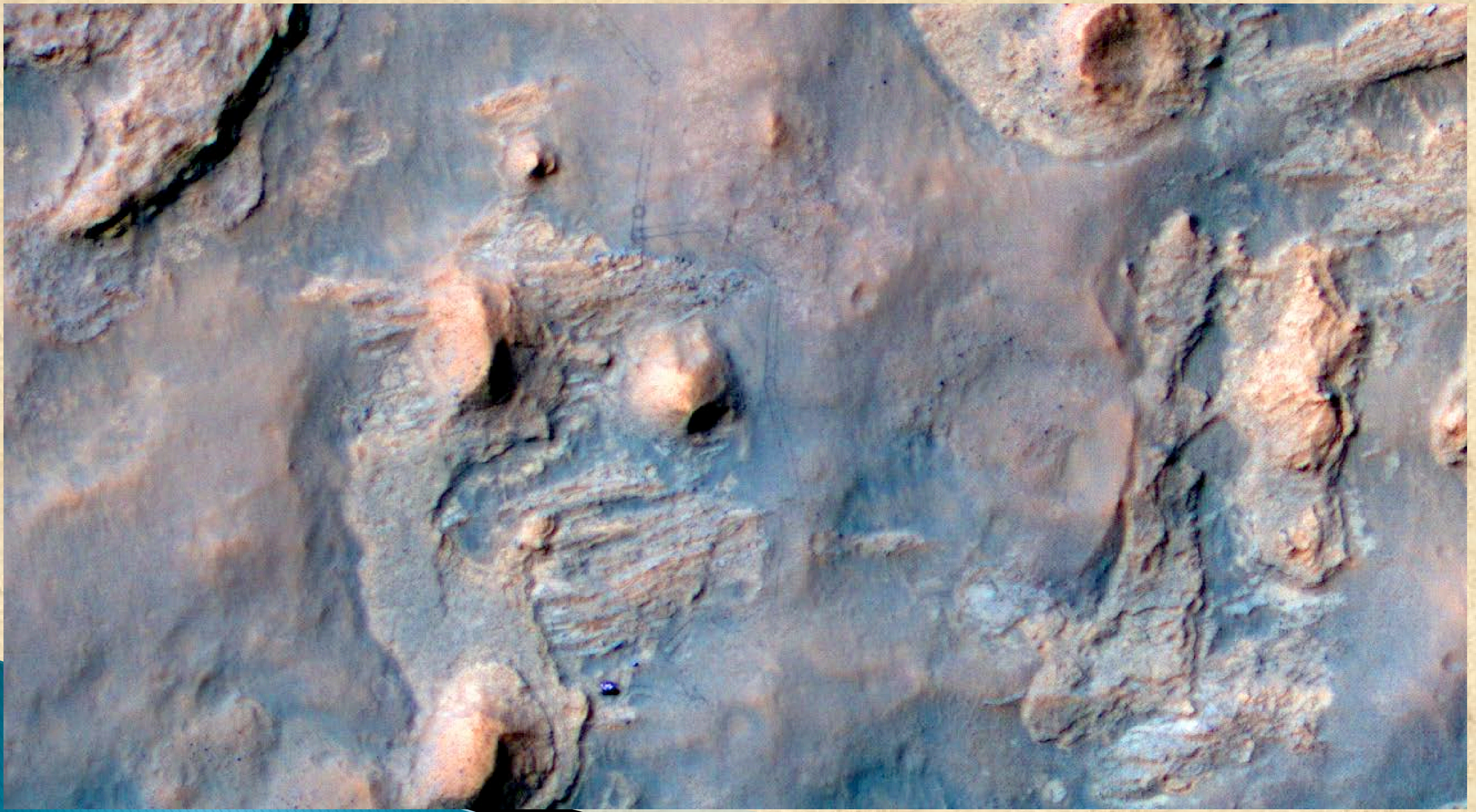
Curiosity Mission Update

- Reached base of Mt. Sharp yestersol.
- On schedule – goal was to reach Mt. Sharp at end of prime mission.
- Driving slower than expected at first, surprising wheel damage.

Path As Seen From Orbit



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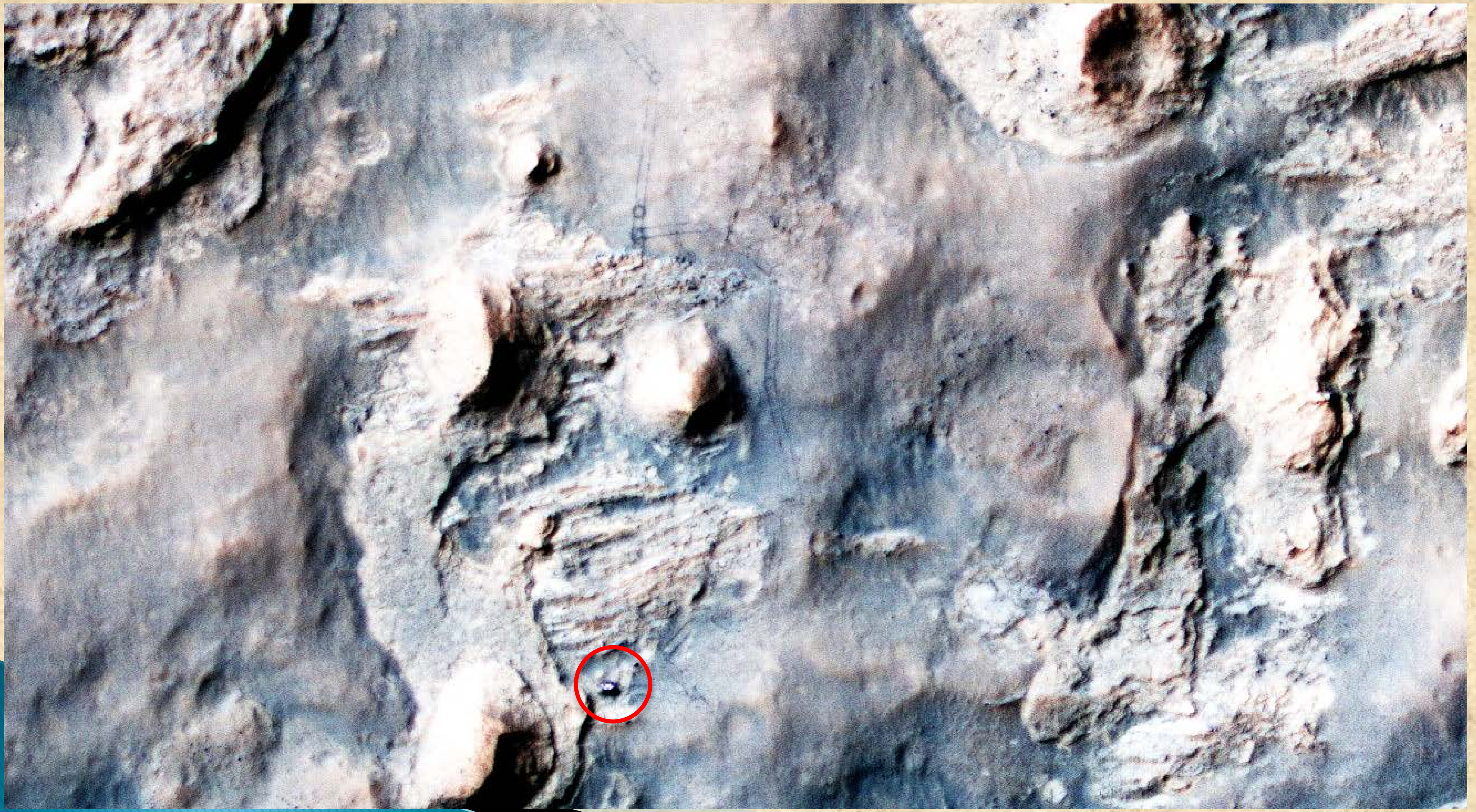
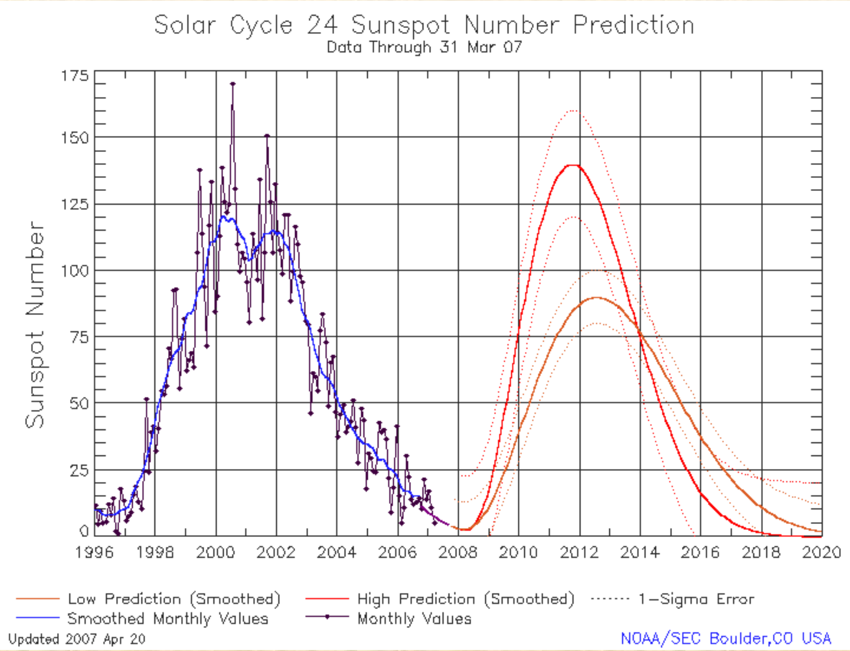
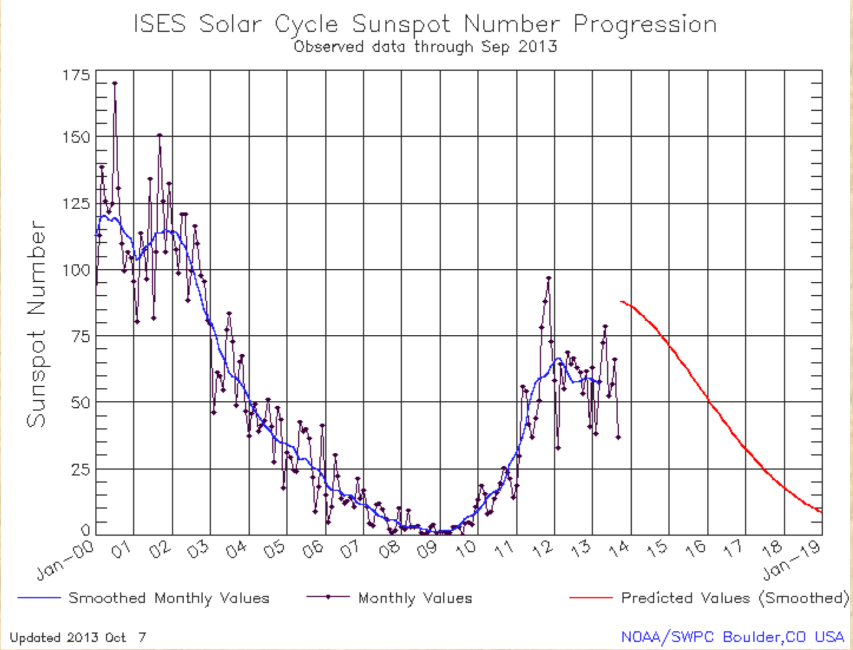


Solar Cycle Predictions

Cycle 23 Data + 2007 Predictions



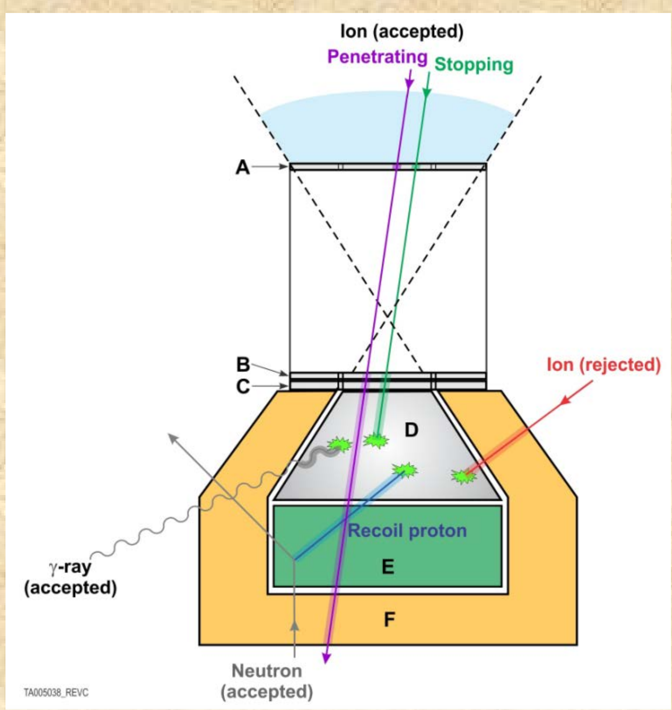
Actual Cycle 24



Cycle 24 is weakest in ~ 100 years (not predicted).

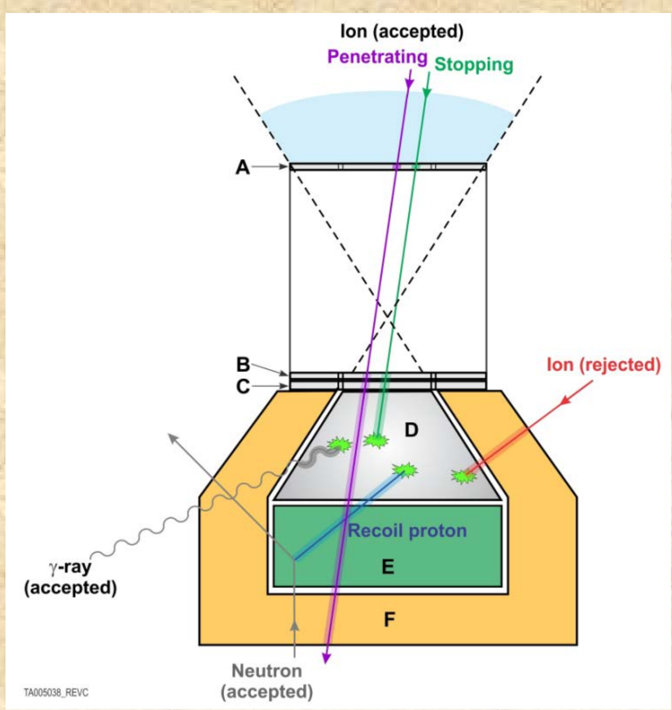
MSL-RAD

- Silicon detector telescope with 3 elements (A, B, C).
- CsI scintillator = D.
- Plastic scintillators: E = 1.8 cm, F = 1.2 cm.
- F = anticoincidence, upper (F1) and lower (F2).
- D & E each have 3 readout photodiodes attached.

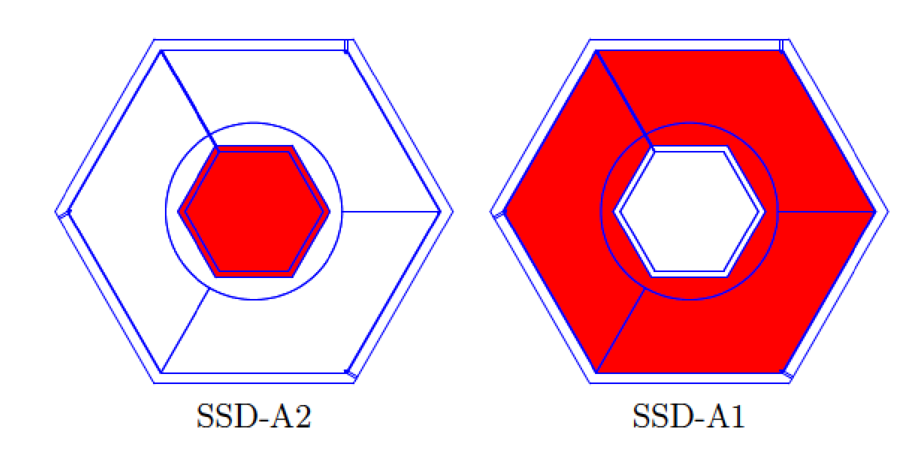


MSL-RAD

- Scintillator readout diodes are used in coincidence in triggers (avoids triggering on γ-rays that make a direct hit in diodes).
- DH*DM*!F*!C = neutral
- EH*EM*!F*!C = neutral
- EH*EM = E dosimetry
- BU = B dosimetry
- Dosimetry triggers accept omnidirectional radiation.

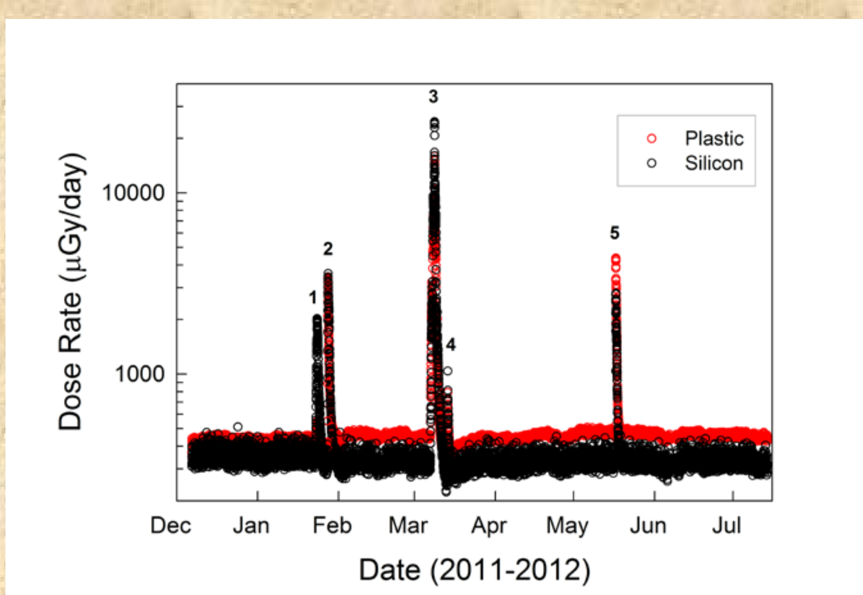


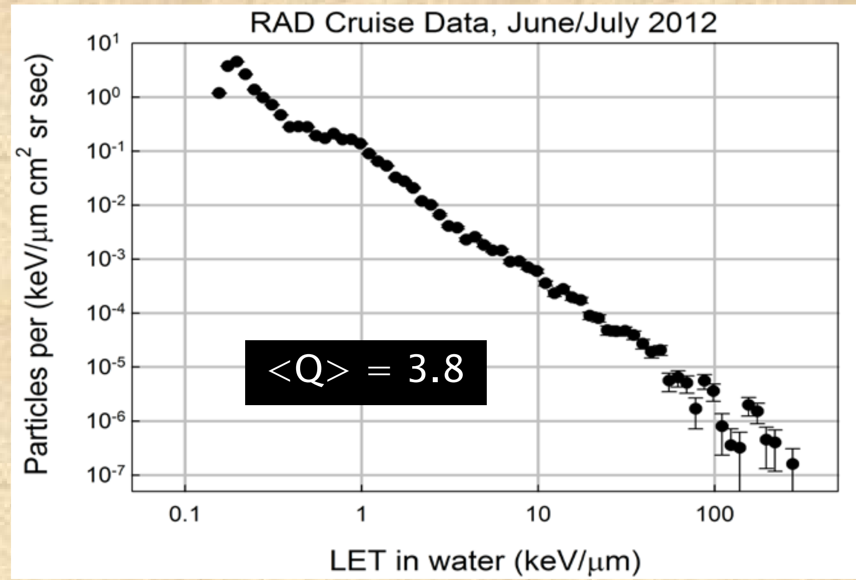
Diode Segmentation & FOV



- A2, B, C use inner segment of diodes, A1 uses outer.
- Two fields of view, two geometry factors.
- A2*B cone has half-angle ~ 18°, G=0.17 cm^2 sr.
- A1*B cone ~ 30°, G=0.72 cm^2 sr.
- Use A2*B events for LET spectrum.

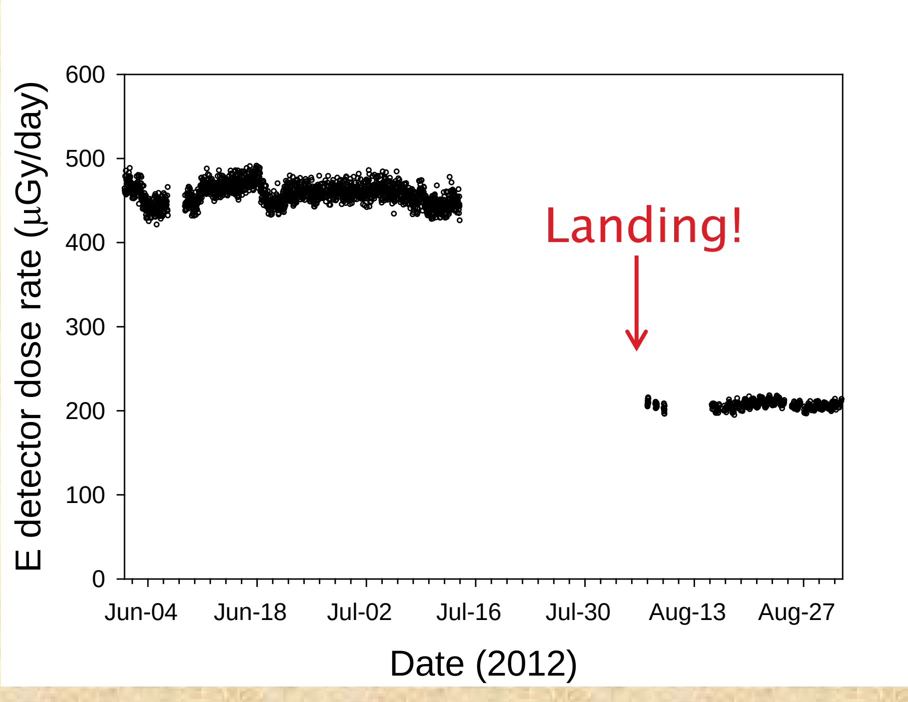
RAD Cruise Results





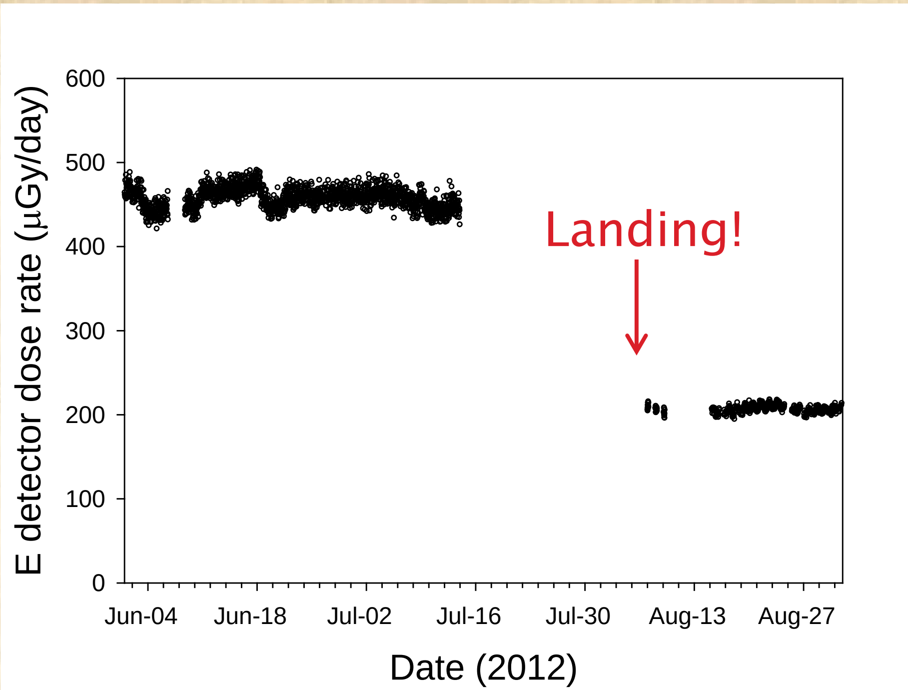
- Tissue dose rate = 0.48 +- 0.08 mGy/day
- Dose equivalent rate = 1.8 +- 0.3 mSv/day
- SEP event contribution ~ 14 days of GCR.

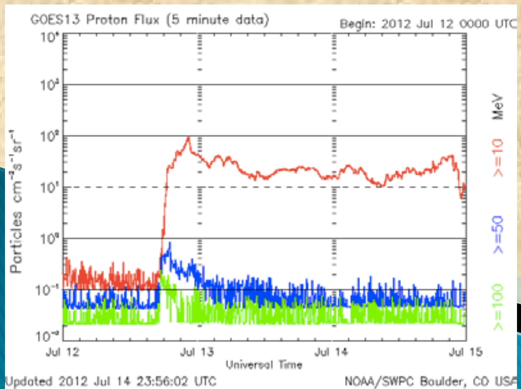
RAD Surface Results

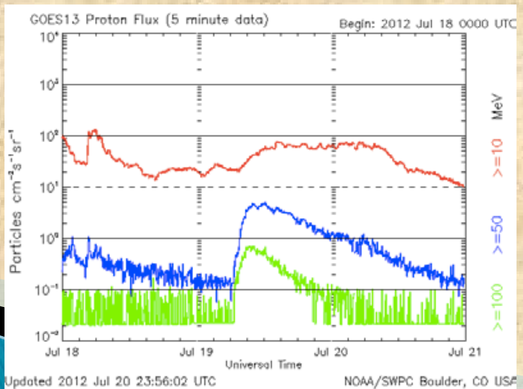


- Average E dose rate ~ 210 μGy/day, ~40% of the cruise dose rate.
- On an airless body, expect dose rate to be 50% of free space.
- $\langle Q \rangle = 3.05 \pm 0.05$, ~30% lower on surface than in cruise.
- Atmospheric shielding & increased modulation decrease dose rates compared to cruise.

RAD Surface Results







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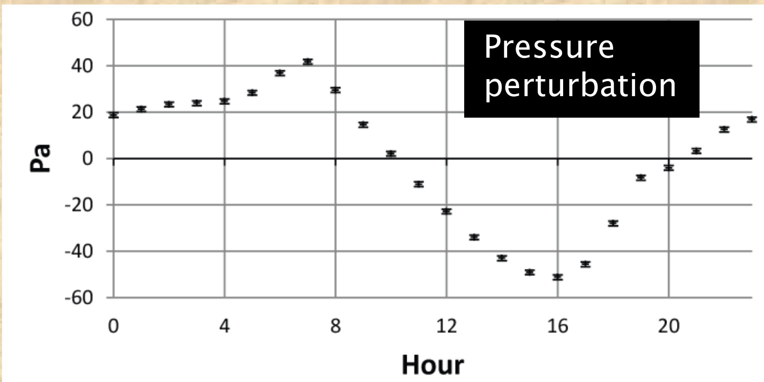
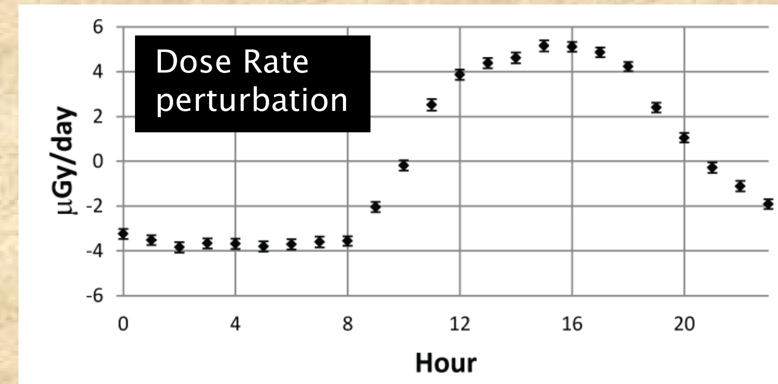
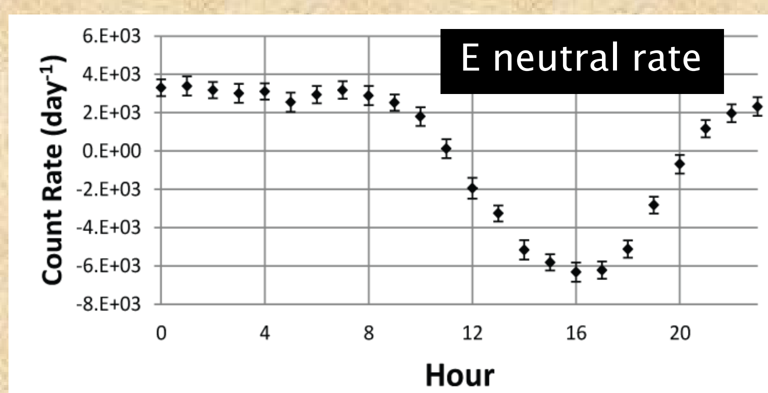
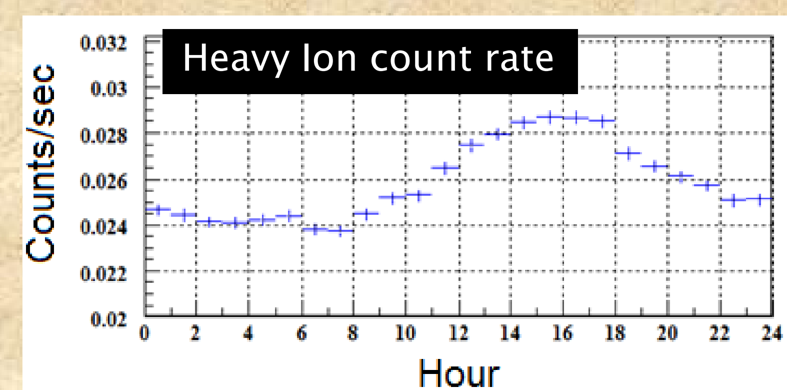
Diurnal Variations

S. Rafkin





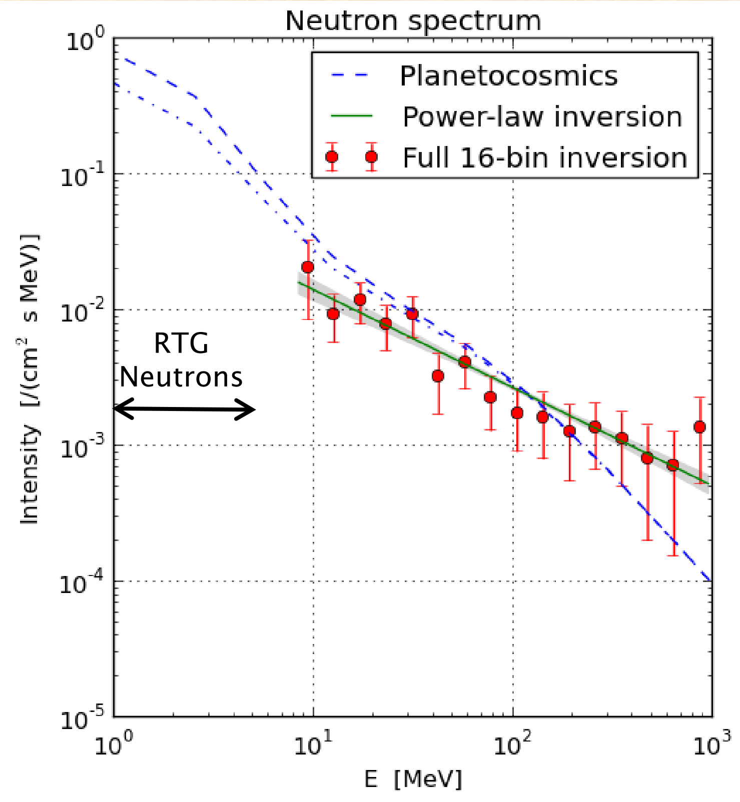




- "Thermal tide" → +- 5% daily variations in pressure → +- 2% variation in radiation dose rate, inversely correlated with P.
- Thinner atmosphere → fewer neutrons made + more heavy ions survive traversal → higher dose rate.
- Pressure data from the REMS team.

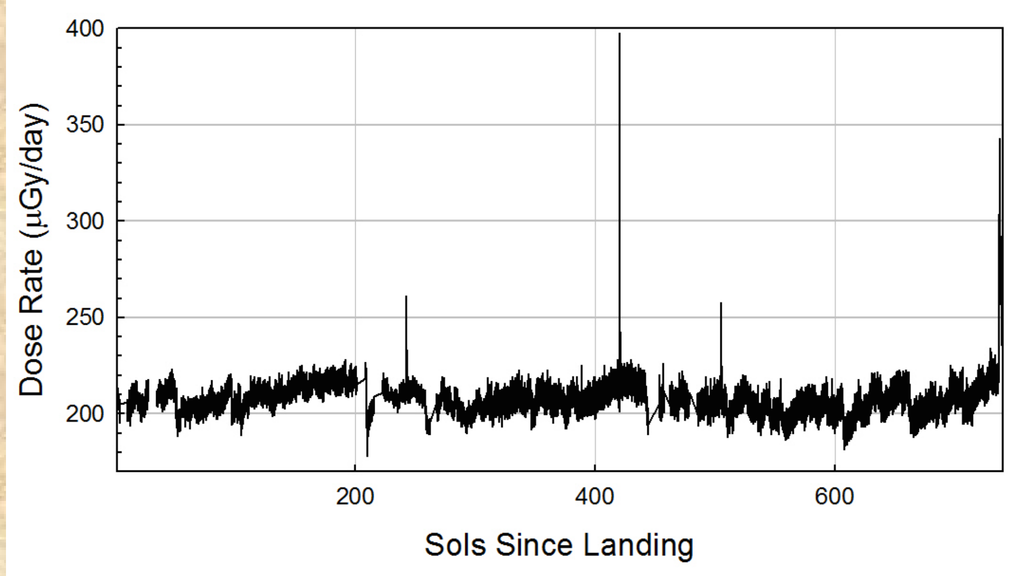
Neutron Spectrum

J. Köhler



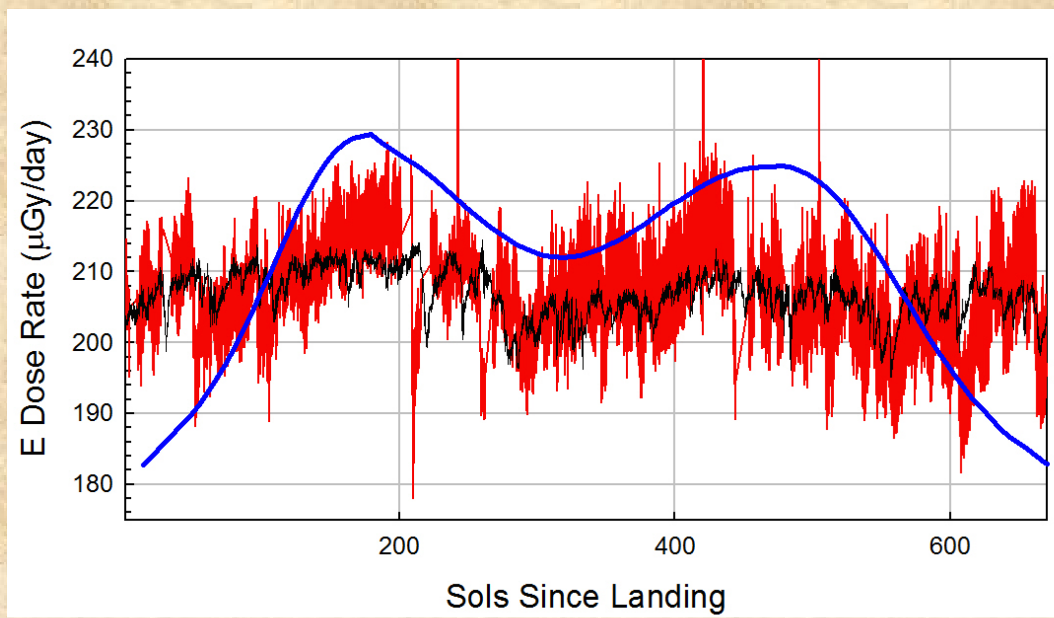
- D, E spectra inverted → γ and neutron spectra.
  - Neutron threshold energy ~ 8 MeV.
- D = 14 ± 4 μGy/day, about 7% of total.
- H = 61 ± 15 μSv/day, about 9% of total.
- E dose rate from RTG < 1 μGy/day in ground test.

E Dose Rate



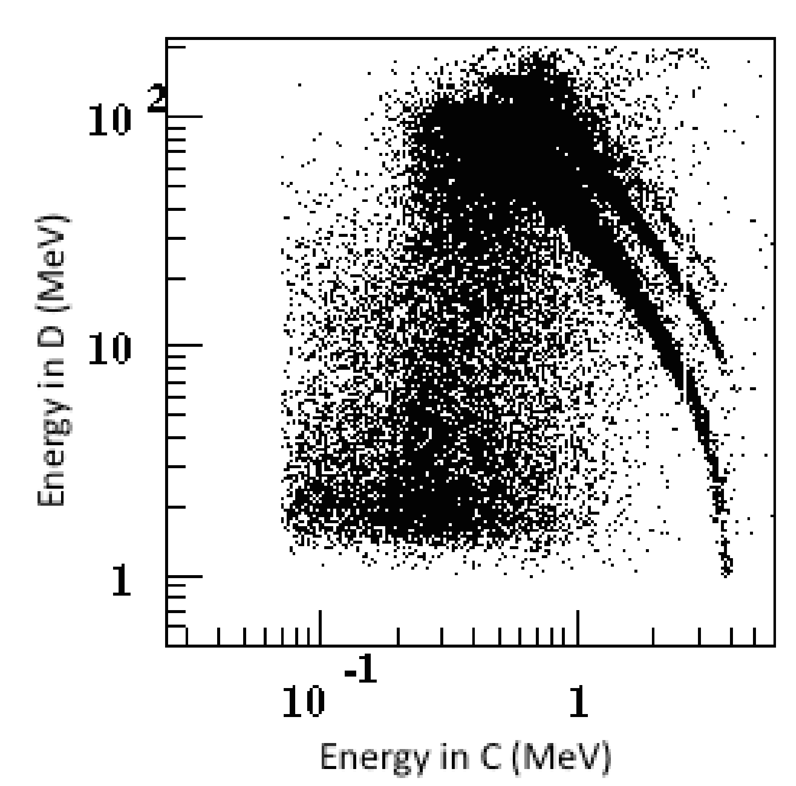
- Four small solar events, including one last week. (Another one on the way??)
  - RAD under avg. 21 g cm^{-2} CO_2 → E_{proton} > 160 MeV
- Many Forbush decreases.
- SEP contribution to total dose ~ negligible.

E Dose Rate – GCR



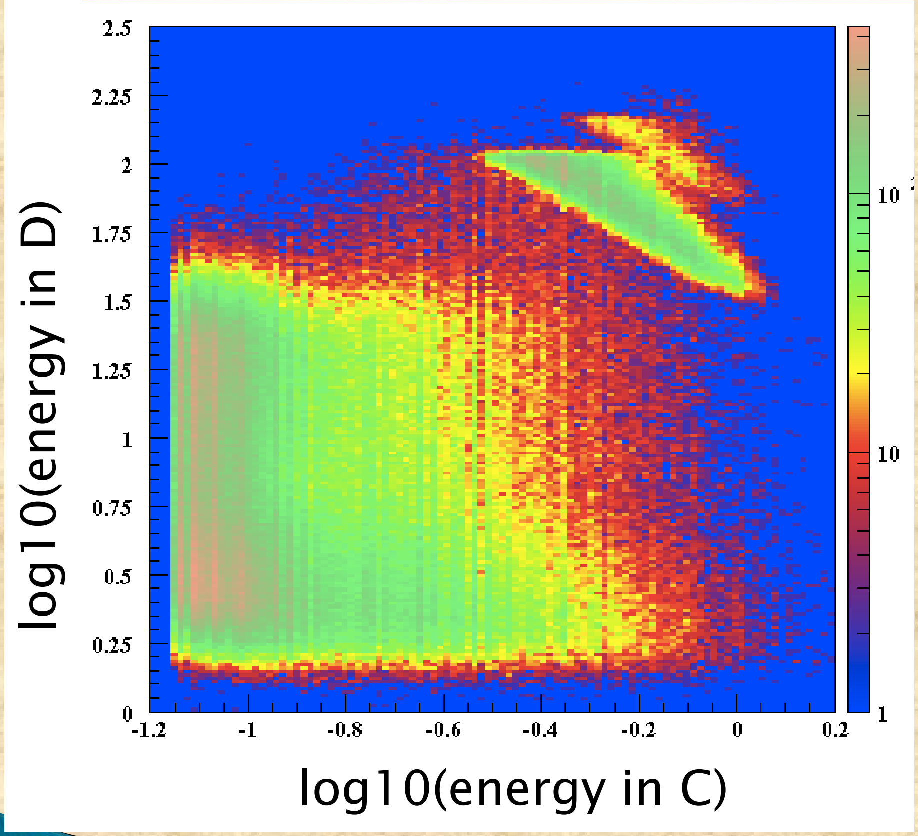
- Look for correlations w/seasonal atmospheric changes (scaled column depth in blue) and with heliospheric changes (scaled Oulu NM count rate in black).
- More influenced by heliosphere.
- Thanks to REMS team for pressure data.

Z = 1 Electrons & H Isotopes



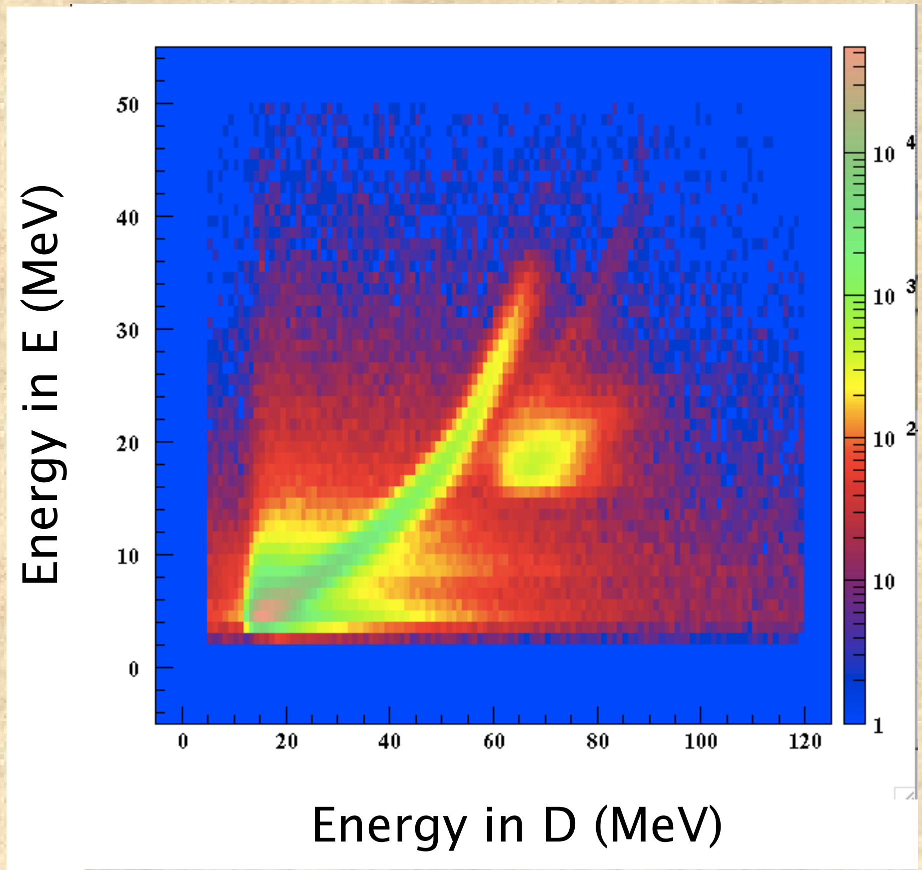
- Calorimetry useful for particle id.
- Select slow Z=1 particles that stop in D: hits in A2, B, C, D, but no energy in E or F2.
- See p, d, t.
- Electrons below the proton band.

More Stopping Z=1



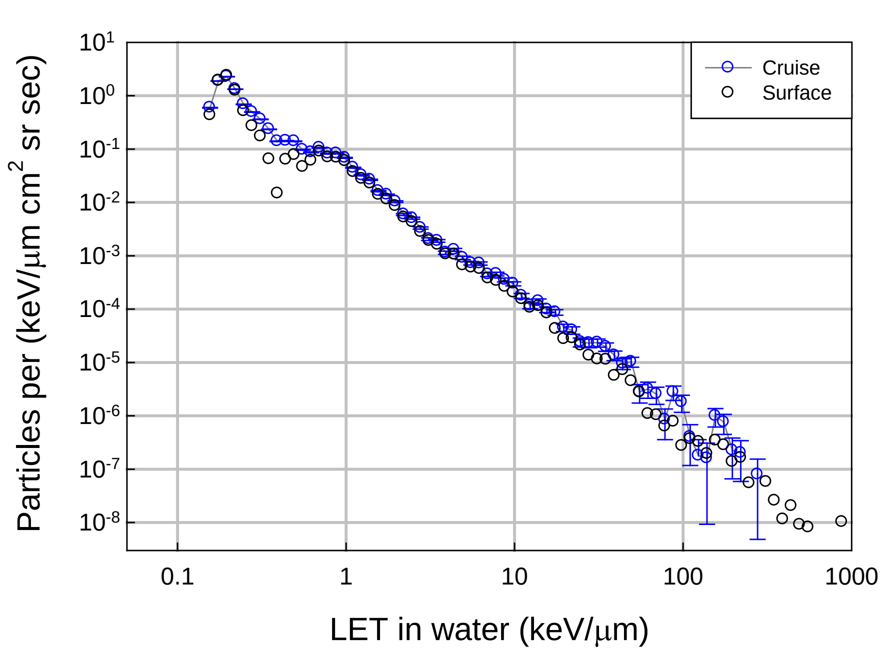
- D vs. C again but now include min-I in ABC.
- See low energy electrons and maybe pions stopping in D.

Penetrating Z=1, 2



- E vs. D, require Z= 1 or 2 in ABC + energy in F2.
- See high-energy protons, deuterons, helium.
- Use to calculate integral fluxes.

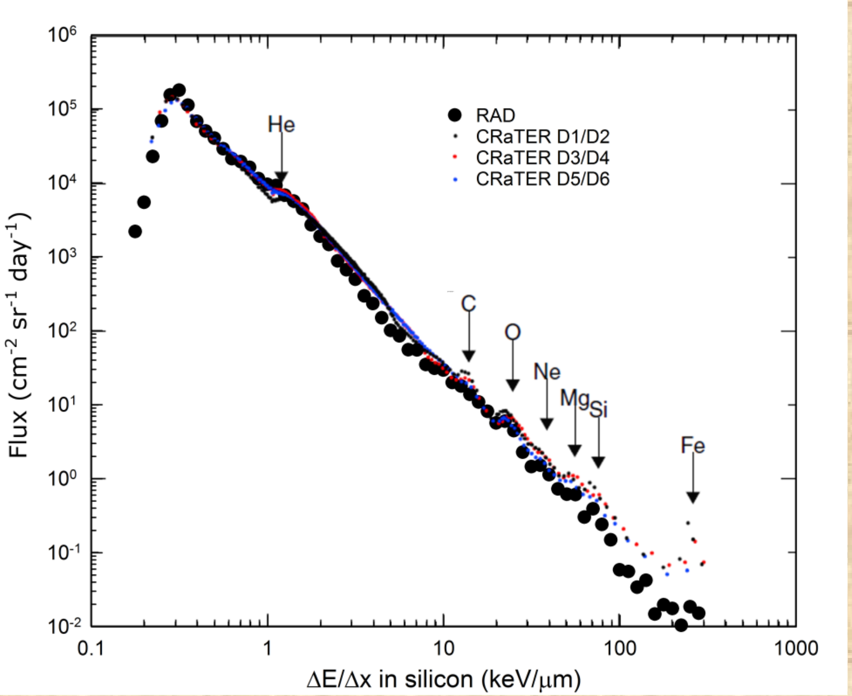
Cruise vs. Surface LET



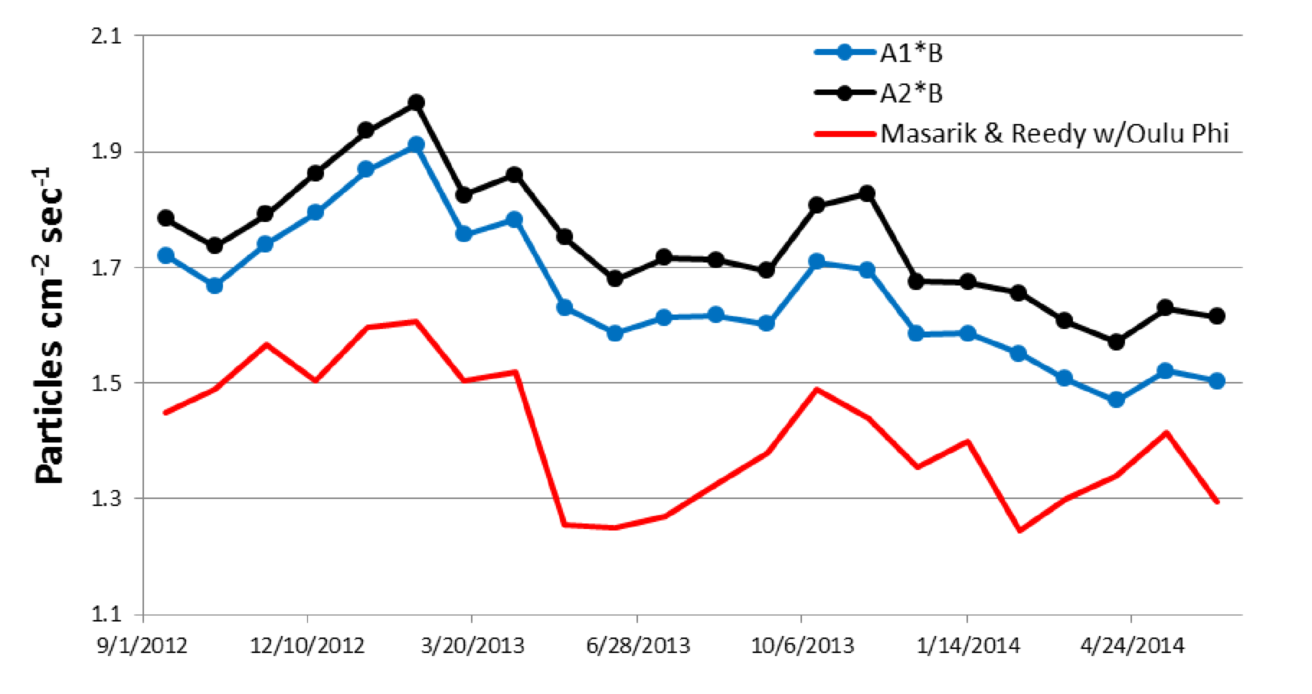
- Both spectra made with A2*B events.
- RTG background subtracted from both but less certain for surface.

RAD LET vs. CRaTER LET

- Compare silicon LET spectra (~21 g cm^{-2} CO_2 shielding) to LET spectra from CRaTER with 0.2, 6, and 9 g cm^{-2} shielding.
- RAD sees slightly more min-I charge 1 particles and fewer heavies, as expected.



Flux Model w/Modulation



- Get Φ from Oulu NM count rates, use as input to Masarik & Reedy GCR flux model (red),compare to coincidence rates in A1*B and A2*B.
- Model is top of the atmosphere flux.

Summary and Conclusions

- RAD made the first measurement of radiation dose on a transit to Mars and continues to work well on the surface.
  - Diurnal and seasonal variations observed.
  - First SEP events observed on another planet.
  - Mars dose rate predictions span a factor of ~4, from about ½ of what RAD is measuring to about a factor of 2 higher.
  - For model validation, need to study spectral details & extend comparisons to include both flux models and transport models.

Acknowledgments

- RAD is supported at Southwest by NASA Advanced Exploration Systems.
- DLR supports Kiel team.
- JPL manages the MSL mission.
- Thanks to all for great support.