Updates 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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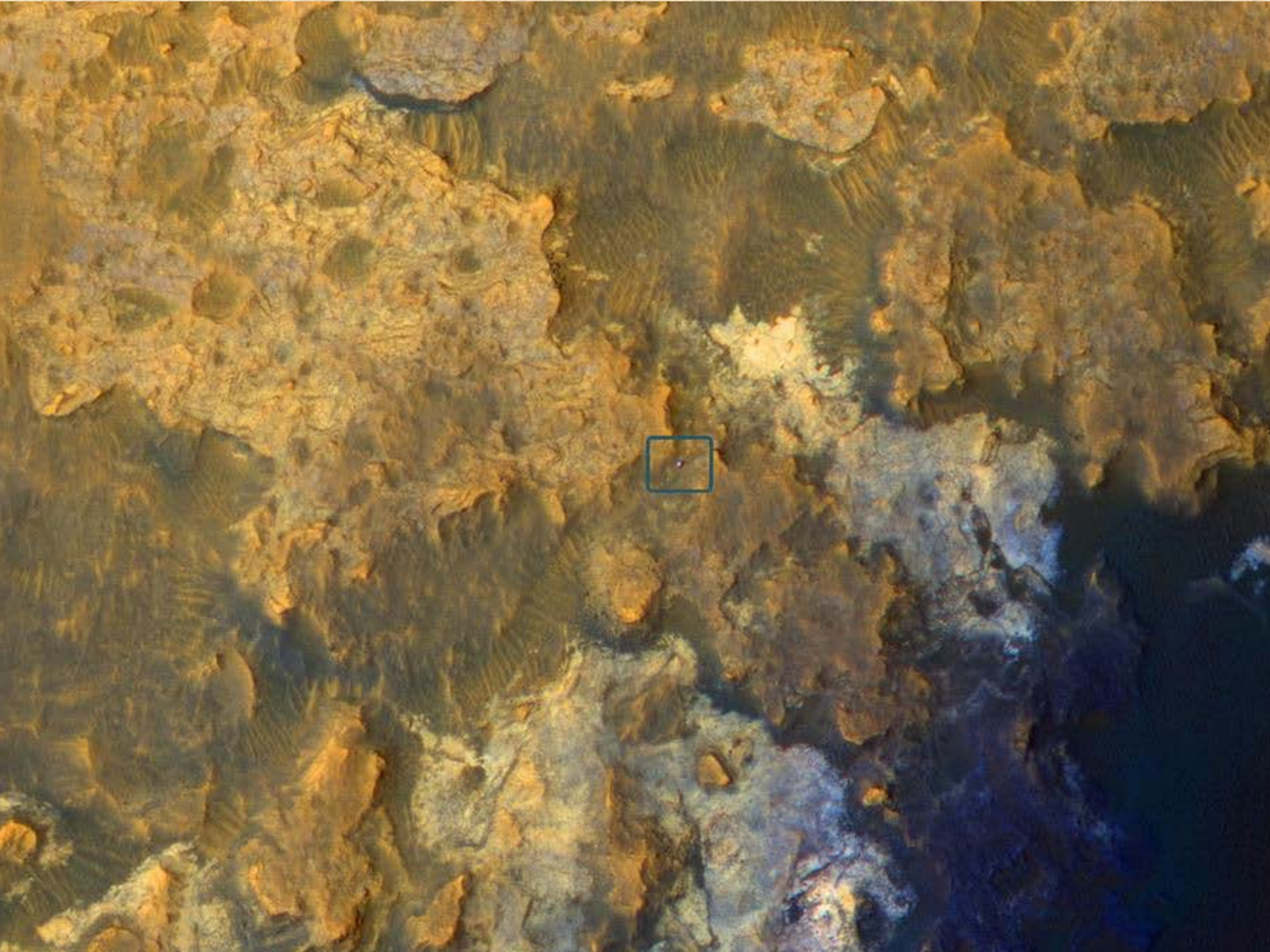
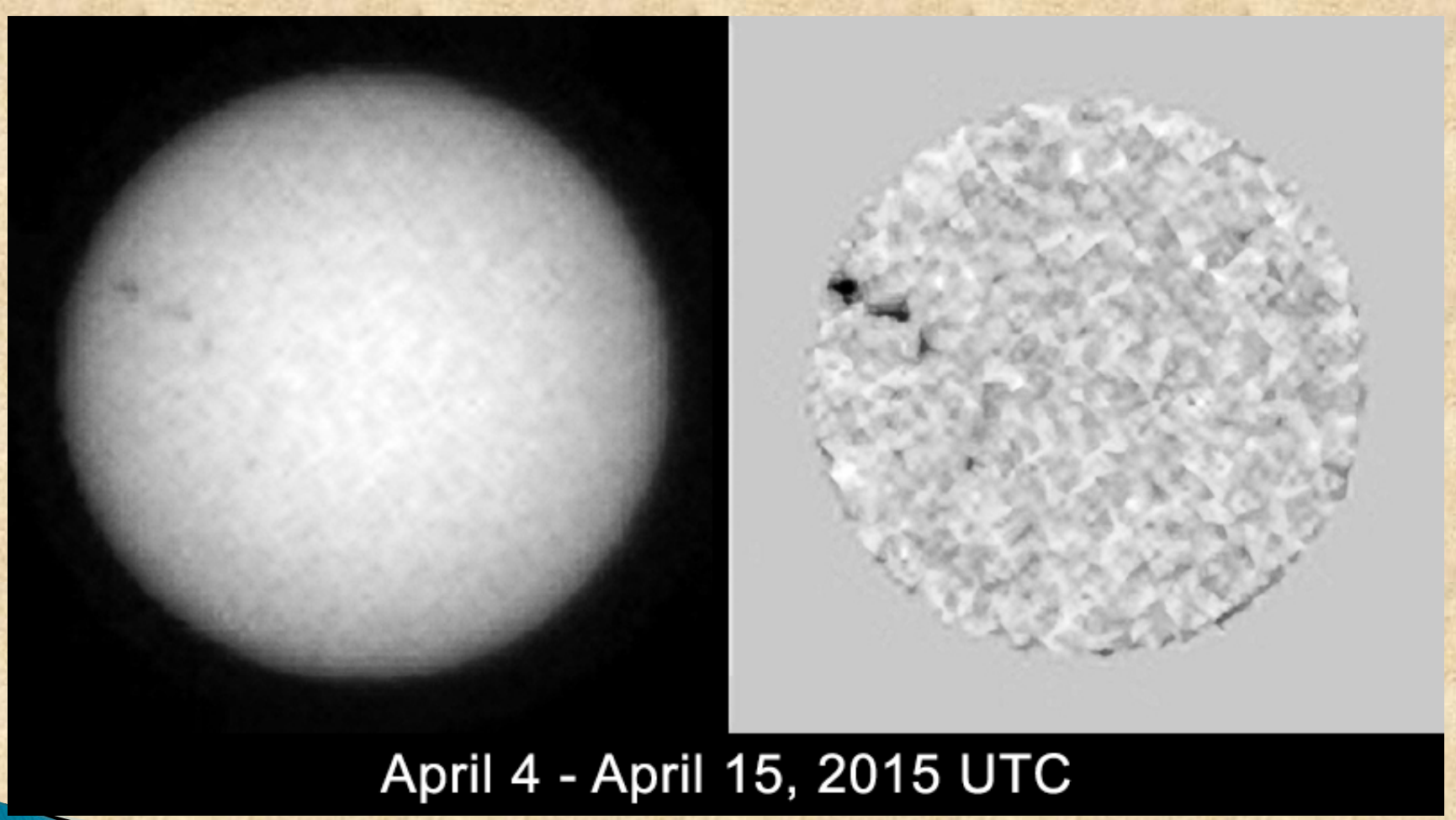
Curiosity Mission Update

- Just passed 3-year anniversary of landing.
- All instruments functioning well.

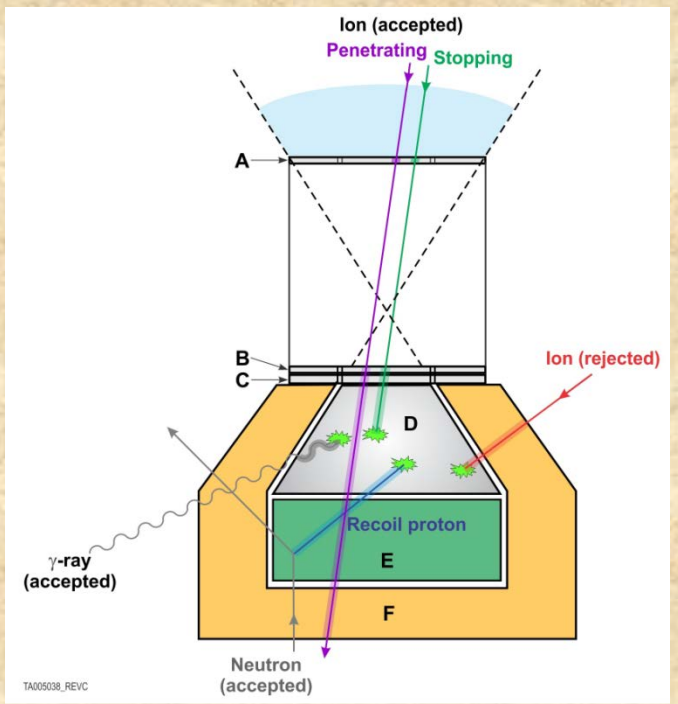


Sunspot Observations by Mastcam



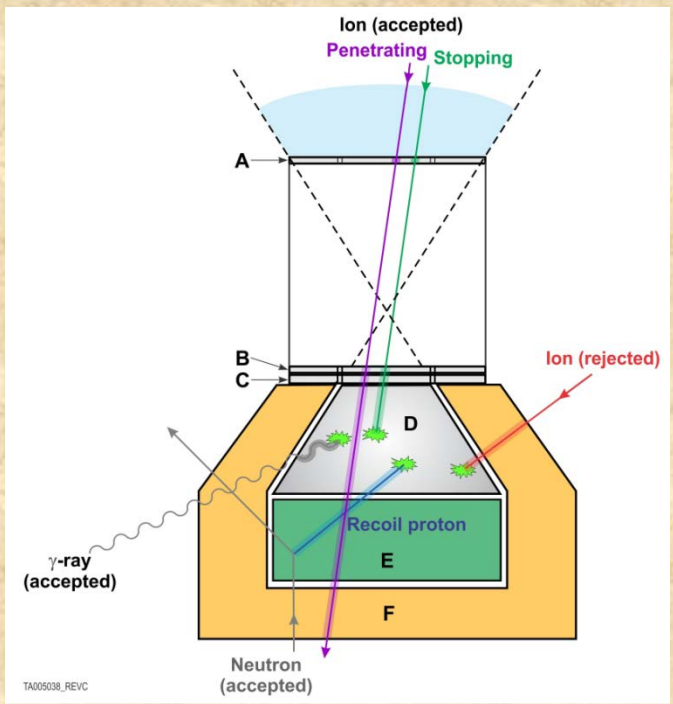
MSL-RAD

- 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.

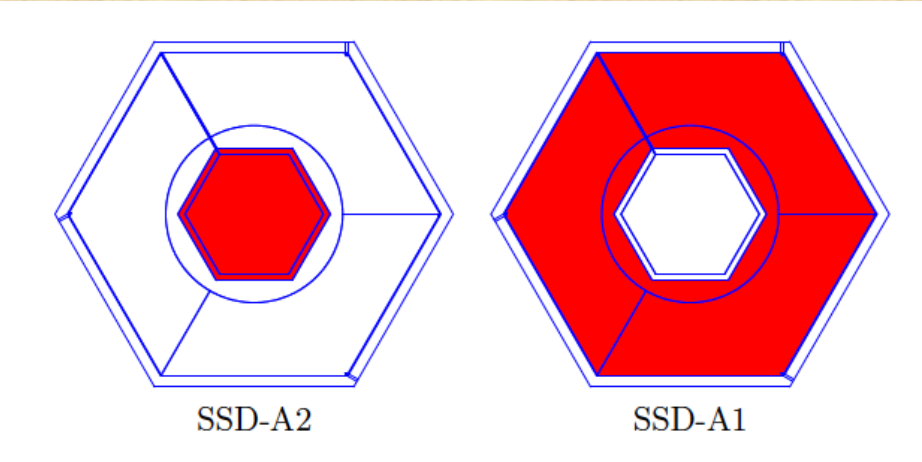


MSL-RAD

- 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.

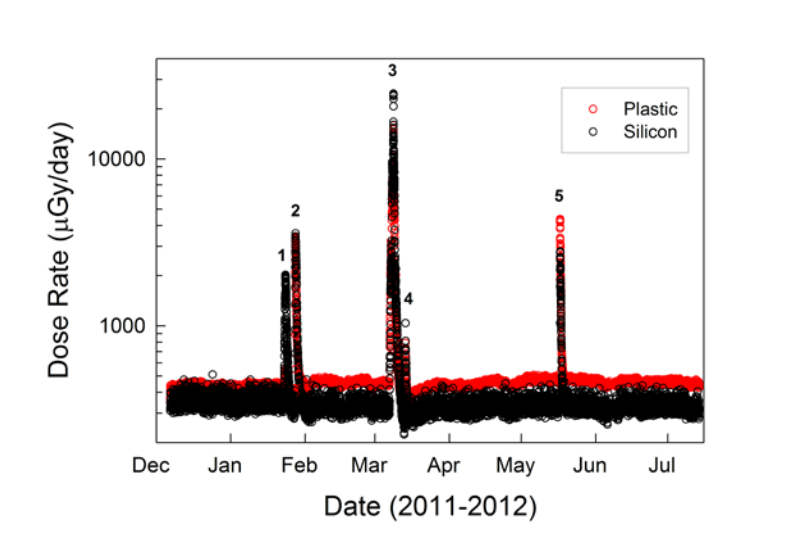


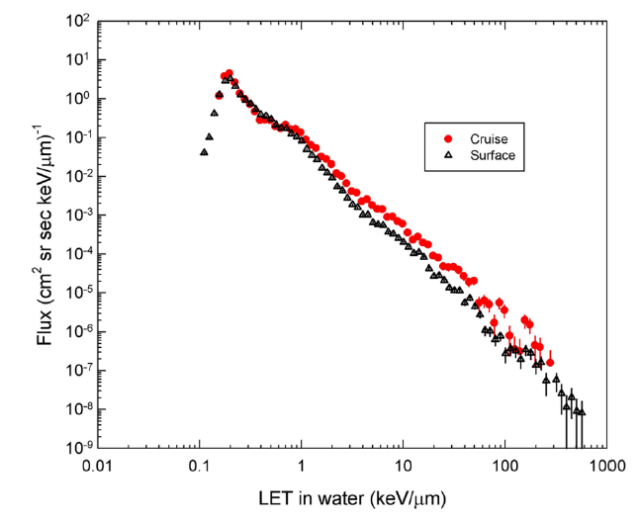
Diode Segmentation & FOV



- 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 Dosimetry Results

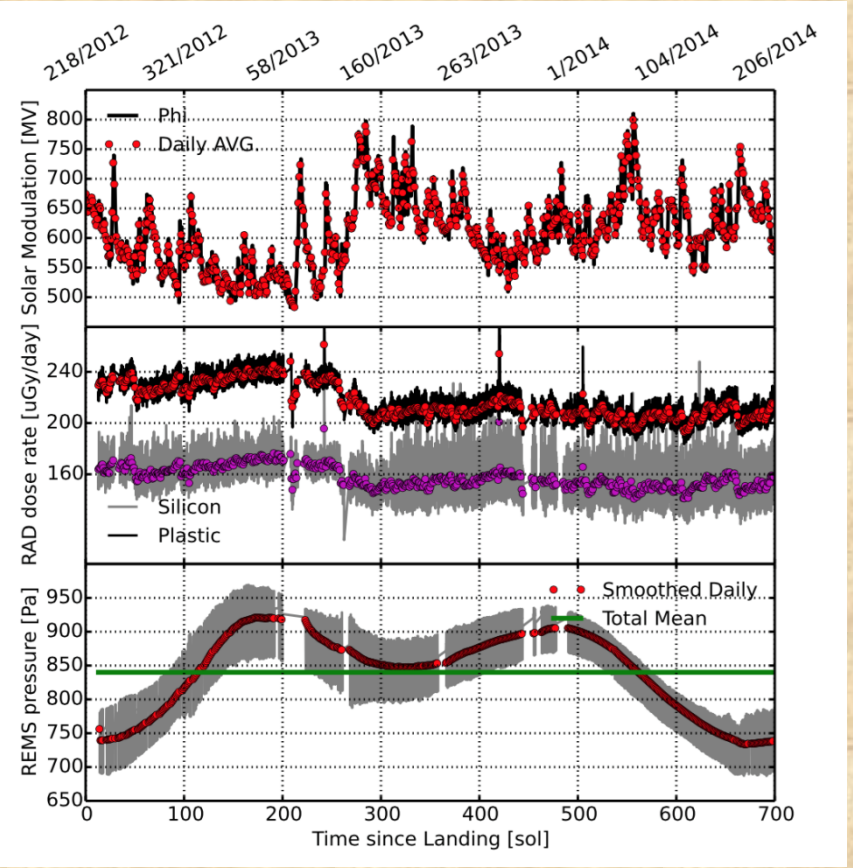




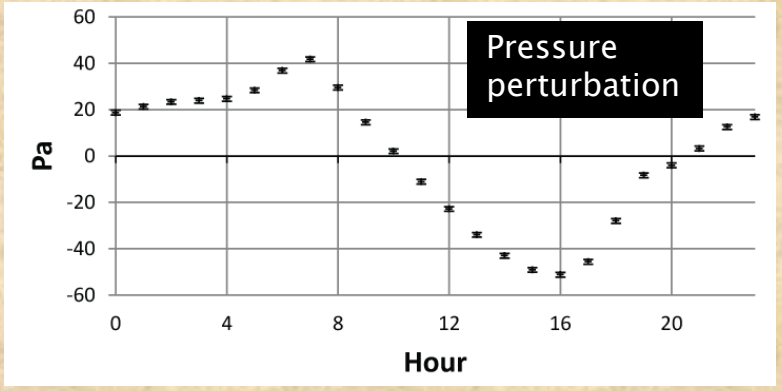
- Cruise:
  - Tissue dose rate = 0.48 +- 0.08 mGy/day, <Q> ~ 3.8
  - Dose equivalent rate = 1.8 +- 0.3 mSv/day
  - SEP event contribution ~ 14 days of GCR.
- Surface:
  - Tissue dose rate = 0.21 +- 0.03 mGy/day, <Q> ~ 3.0
  - Dose equivalent rate = 0.63 +- 0.15 mSv/day
  - SEP contribution ~ negligible.

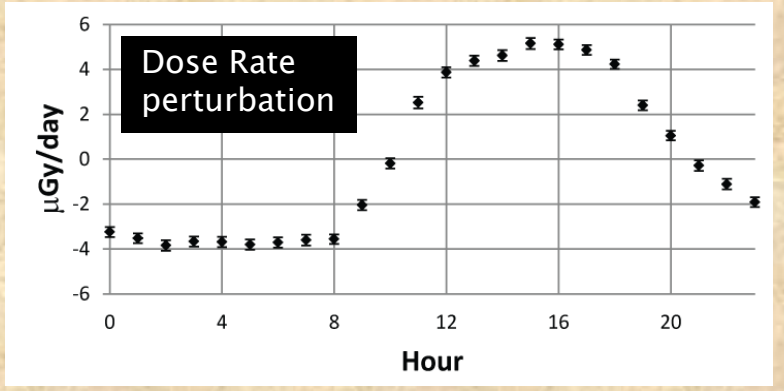
Variations Over the First Mars Year

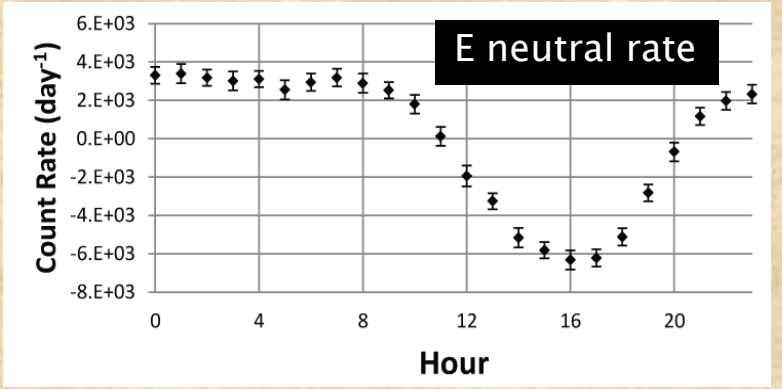
- RAD sees both heliospheric and local effects from the atmosphere (diurnal + seasonal).
- Upcoming talk by J.Guo has details (also paper in ApJ).

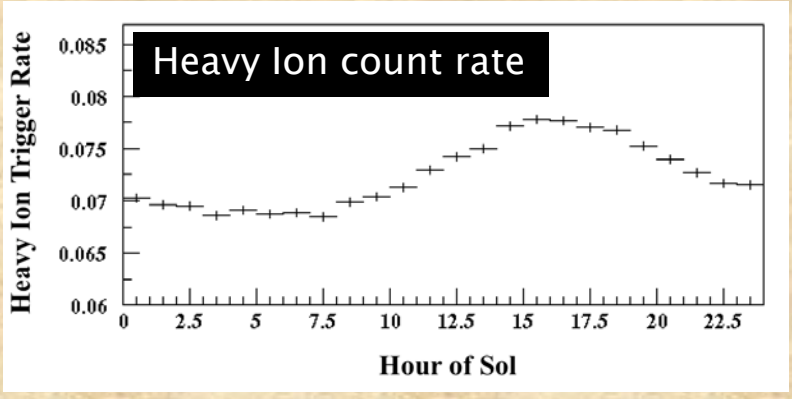


Diurnal Variations





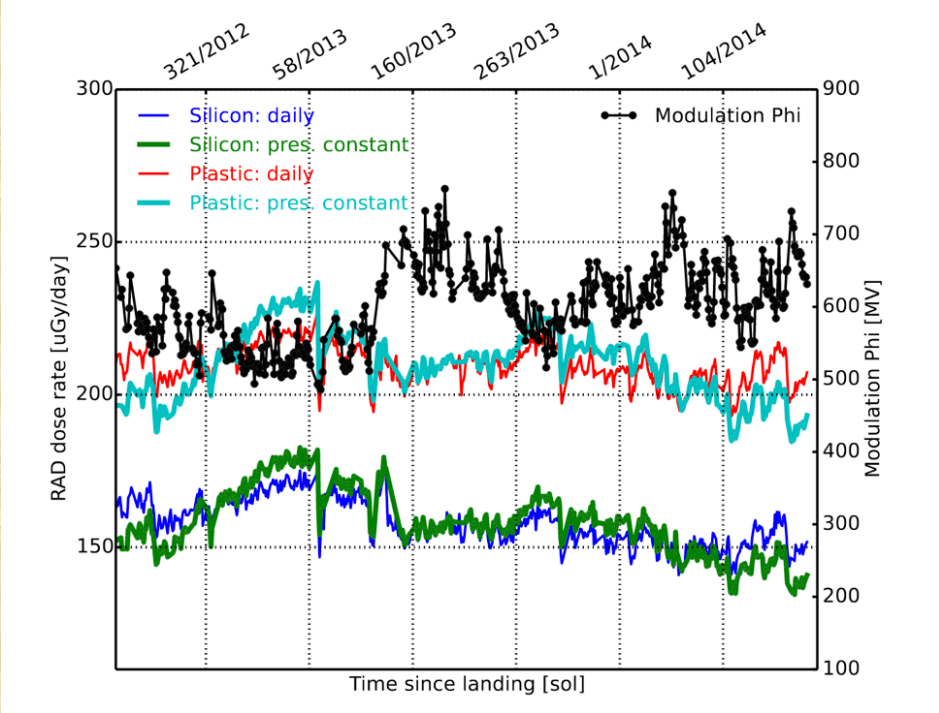




- Dose rate variations are mainly driven by fragmentation of heavy ions in the atmosphere, which undergoes diurnal variations in column depth.

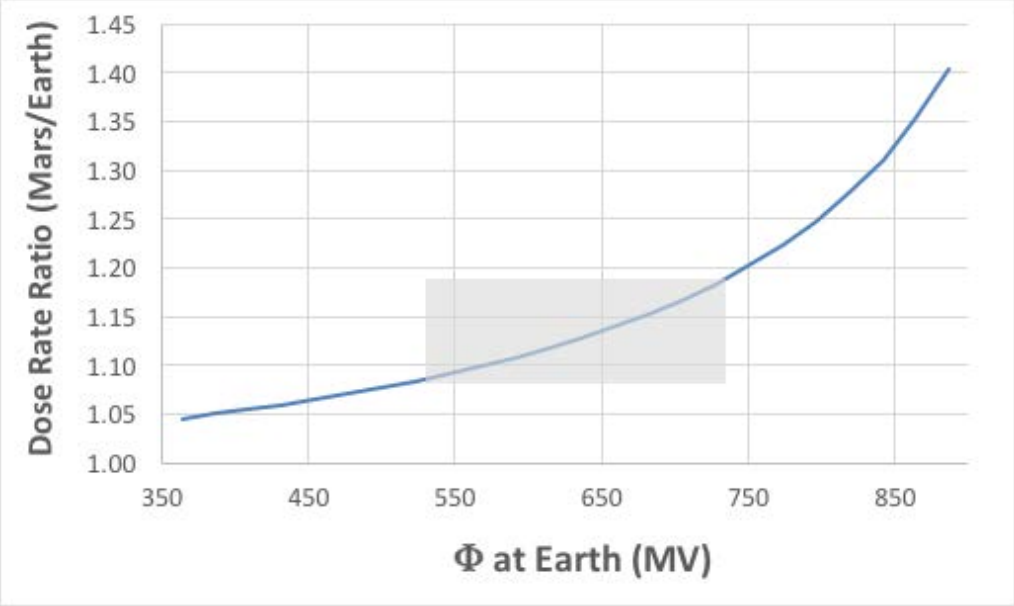
Pressure-Corrected Doses

- Measured diurnal dependence on atmospheric pressure allows us to back out seasonal effect.
- Improves the anti-correlation with Φ.
- Longitudinal separation of Earth & Mars also affects correlation of dose on Mars with Φ.

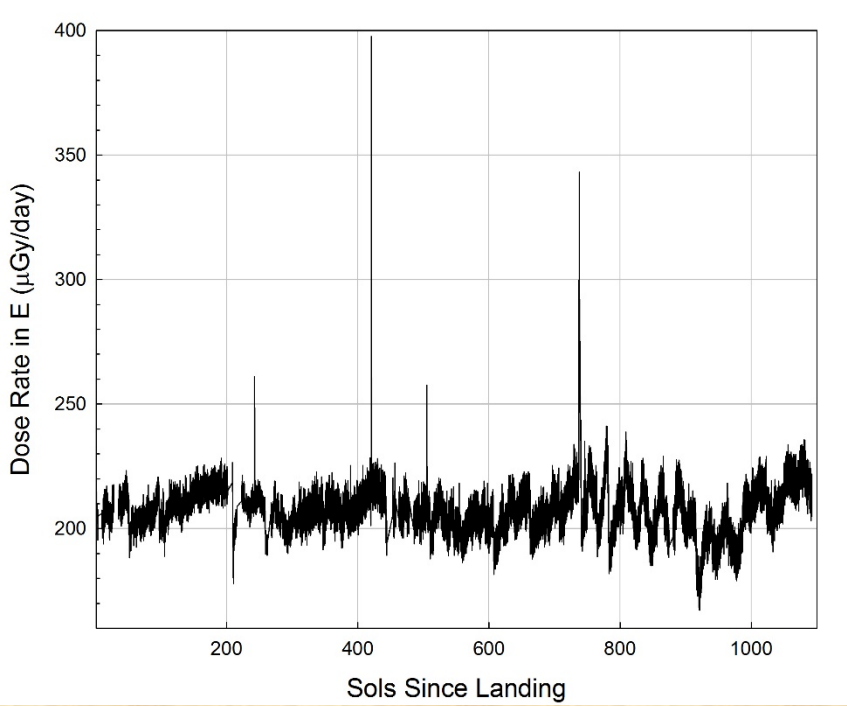


Φ_{Mars} vs. Φ_{Earth}

- Schwadron formula for radial gradient:
  - $\Phi_{Mars} \sim 0.9\ \Phi_{Earth}$.
- Correlate CRaTER dose rates w/Φ_{Earth}, find approximate relation
  - $D \cong 420 - 0.4 \times \Phi_{Earth}$ (μGy/day) when Φ_{Earth} isn't too large.
  - Apply to Mars

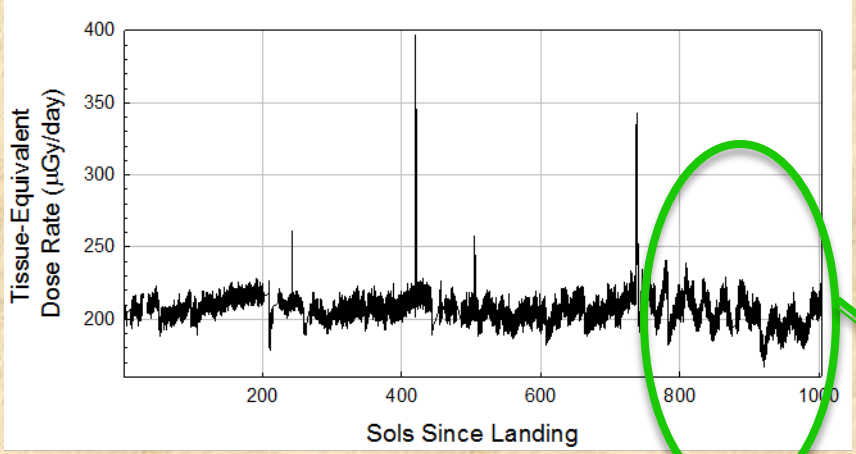


E Dose Rate

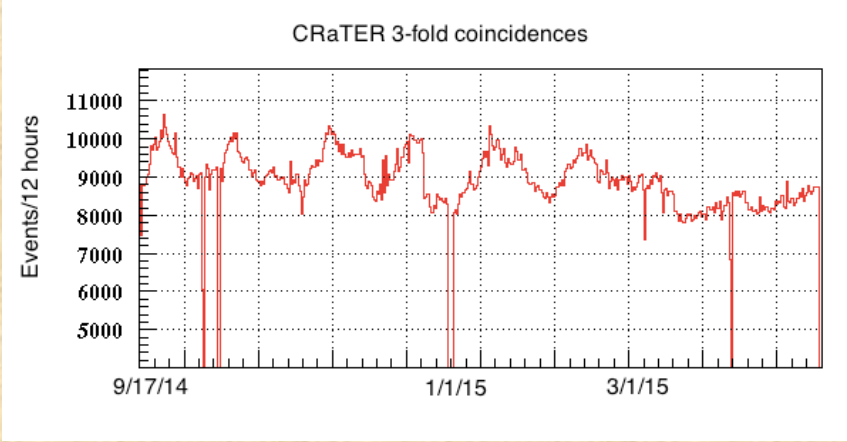


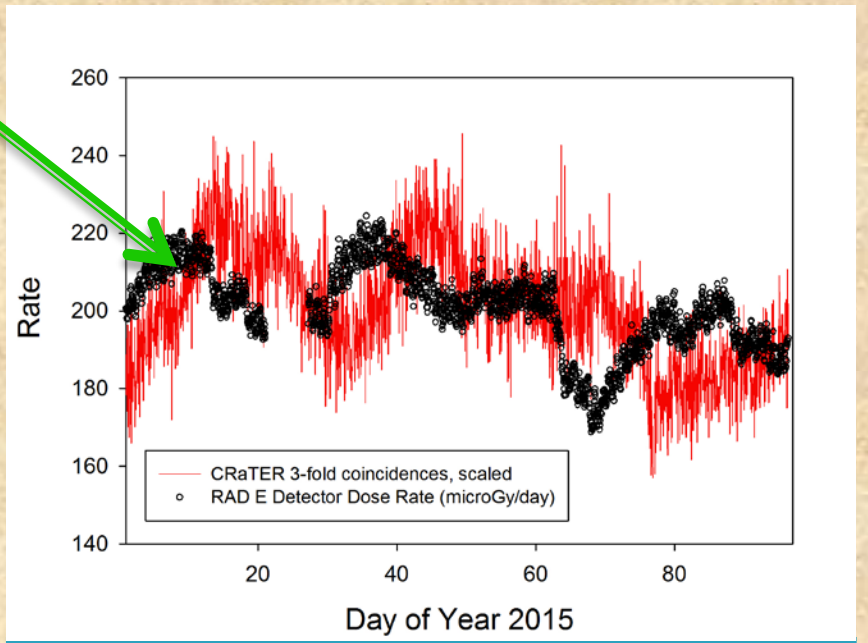
- Four small SPE's seen.
- RAD under average CO_2 column depth of 21 g cm^{-2} → proton E > 160 MeV to be detected.
- Many Forbush decreases.
- SEP contribution to total dose ~ negligible.
- Solar rotations clearly seen starting around sol 750.
- Recent slight increase, is solar max ending?

What Drives the Oscillations?

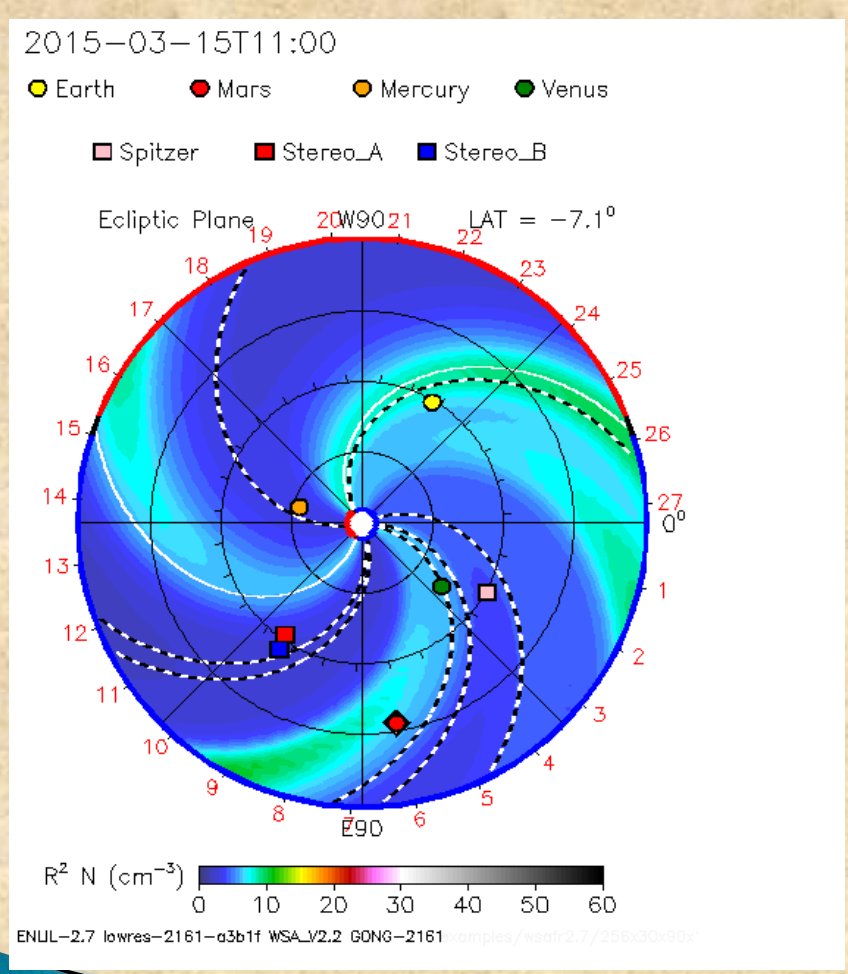


RAD





RAD E, CRaTER on LRO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Earth
Mars
Mercury
Venus
Spitzer
Stereo_A
Stereo_B
Ecliptic Plane
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R² N (cm⁻³)
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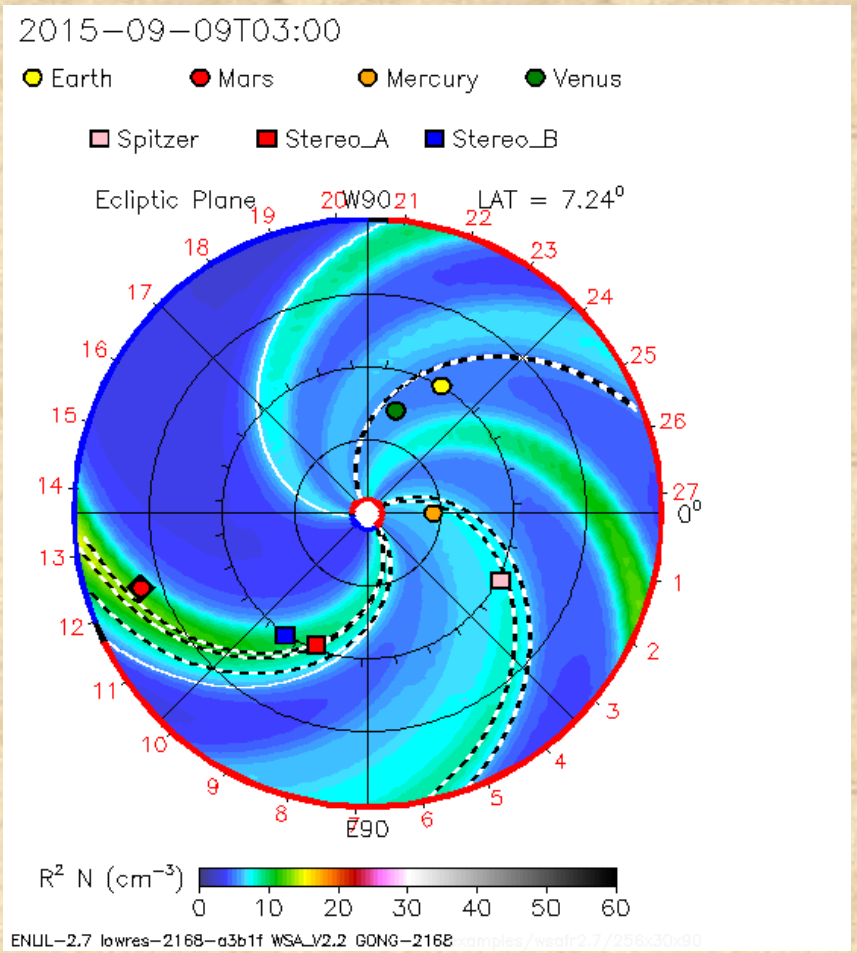
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Mars
Mercury
Venus
Spitzer
Stereo_A
Stereo_B
Ecliptic Plane
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R² N (cm⁻³)
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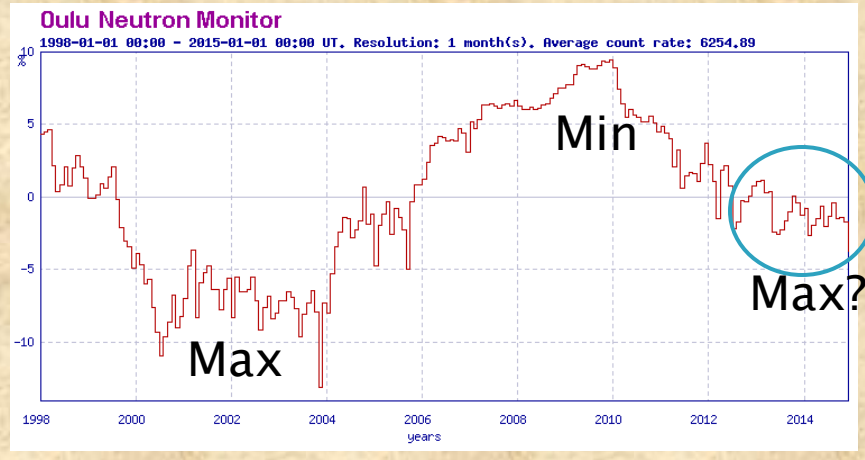
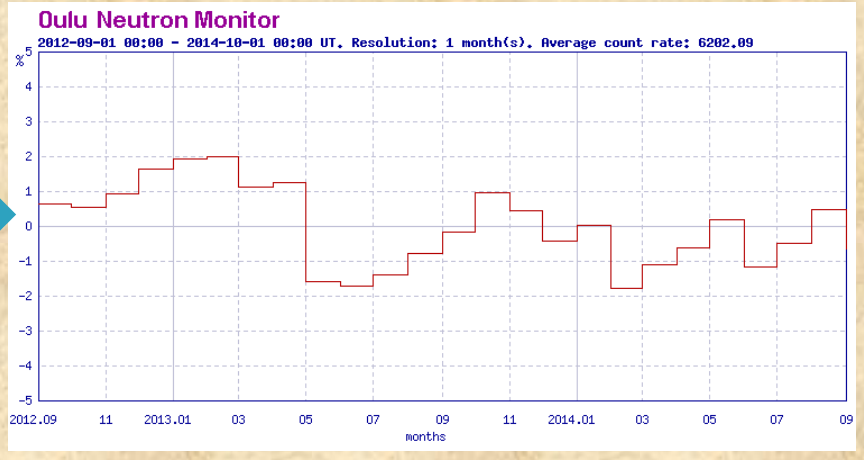
GCR Stability in Cycle 24

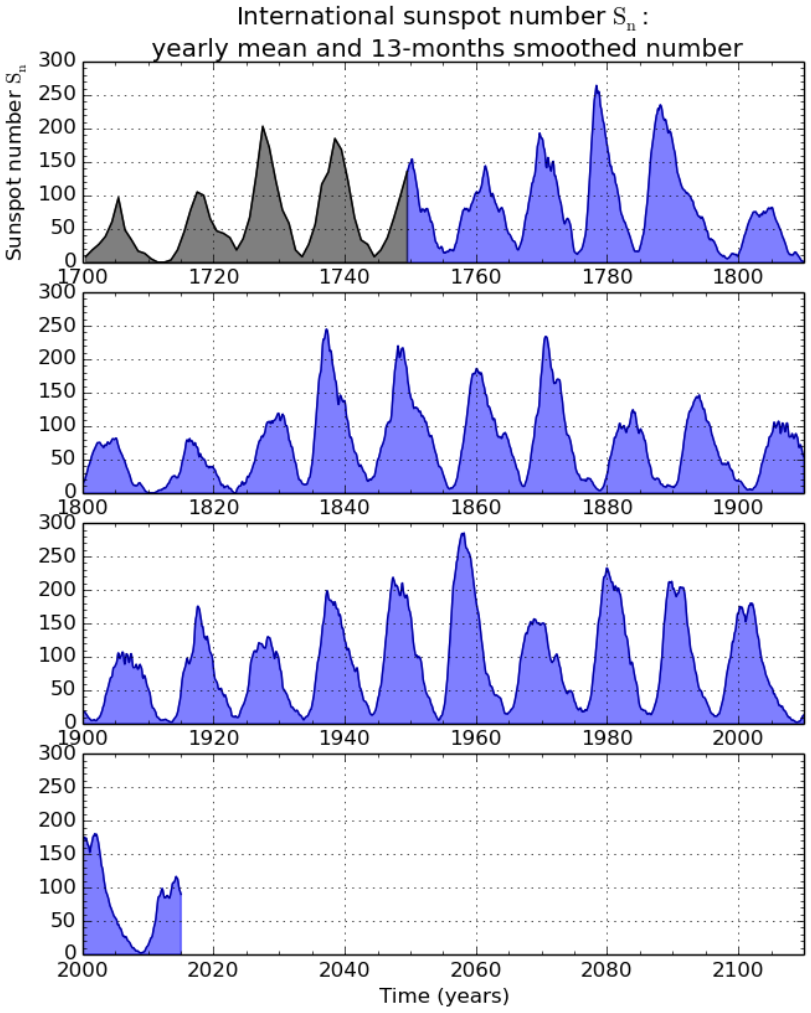


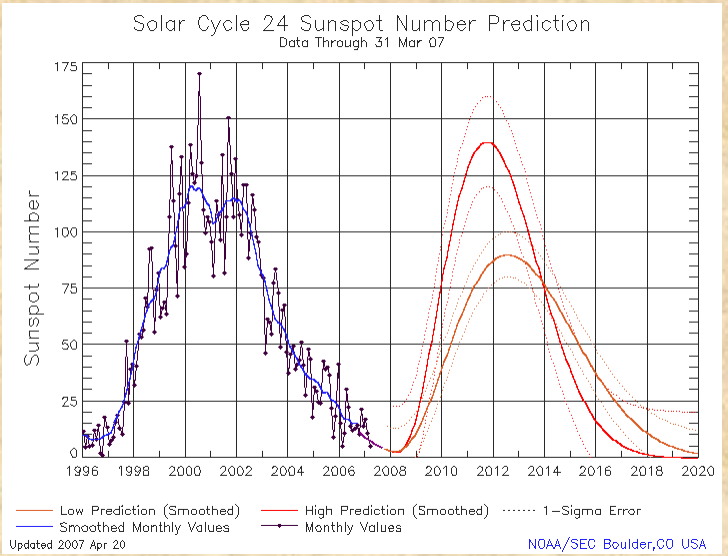


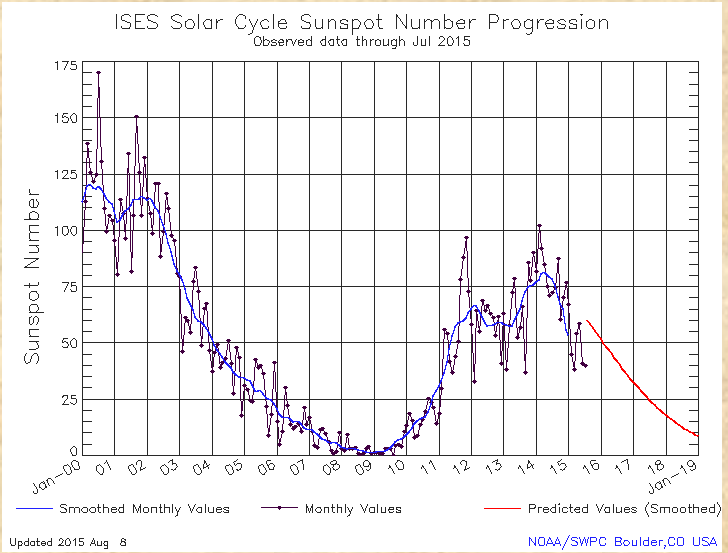
NM Counts Inversely Proportional to Modulation

- Very weak maximum → GCR suppression small compared to typical max.

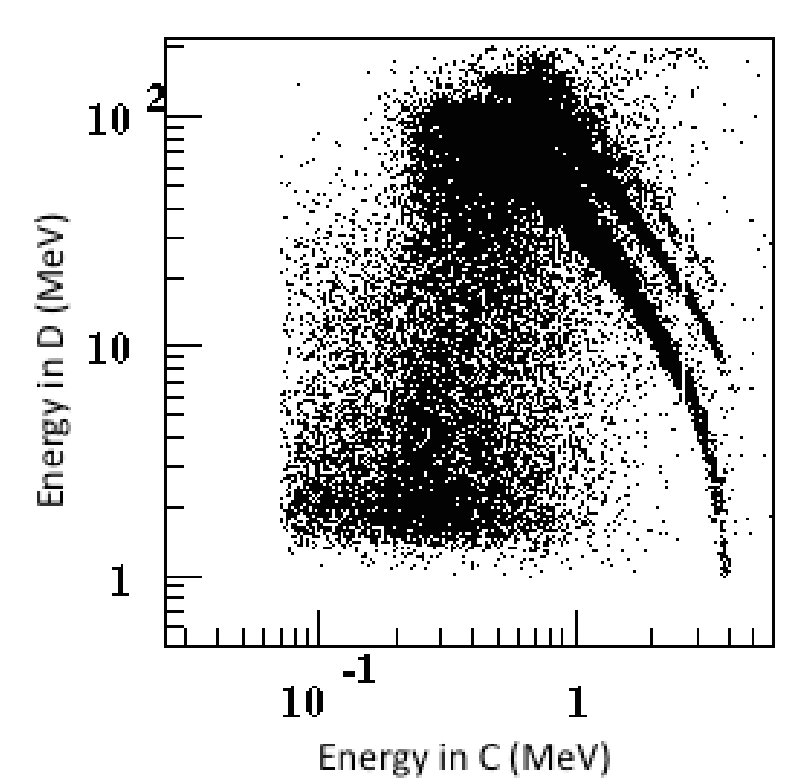
Historically Weak Solar Max







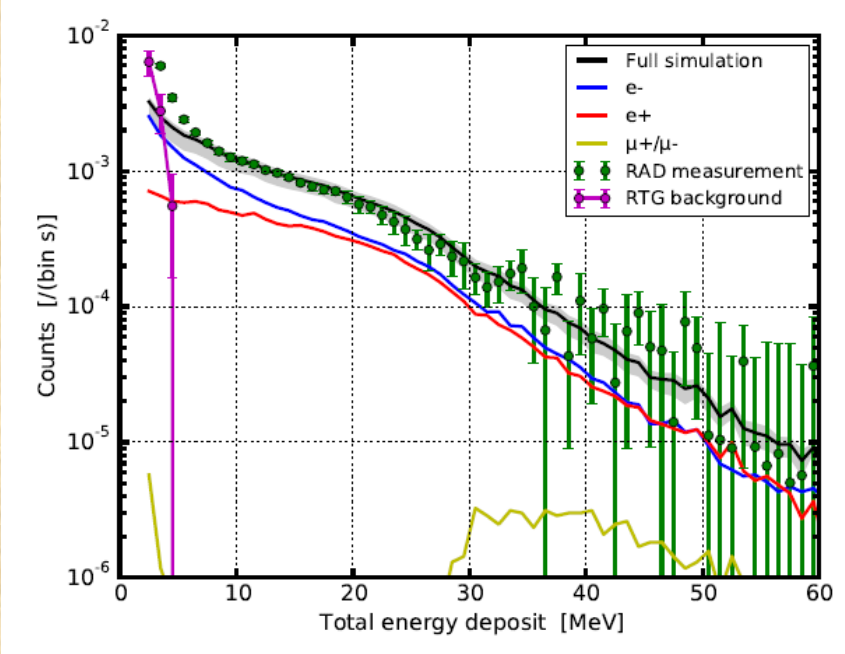
Z = 1 Electrons & H Isotopes



- 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.

e^+ e^- Spectra

- Jan Köhler (Kiel) has extracted electron and positron spectra from the surface data.
- Reasonable agreement with Planetocosmics (uses GEANT4 for transport).



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 has been extremely stable.
  - Daniel Matthiä nearing completion of detailed model comparison paper.

Acknowledgments

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