WHAT’S NEW ON MARS?

Cary Zeitlin (NASA JSC/Leidos), Don Hassler (SwRI)

and

the MSL-RAD Science Team

The MSL-RAD Science Team is:

- D.M. Hassler[1], R.F. Wimmer-Schweingruber[2], J. Appel[2], T. Berger[3], E. Böhm[2], S. Böttcher[2], S. Burmeister[2], B. Ehresmann[1], J. Guo[2], H. Lohf[2], C.Martin[2], D. Matthiä[3], S.C.Rafkin[1], G. Reitz[3], C. Zeitlin[4]
    1. Southwest Research Institute, Boulder
    2. Christian Albrechts University, Kiel
    3. German Aerospace Center
    4. Leidos, NASA JSC

Overview

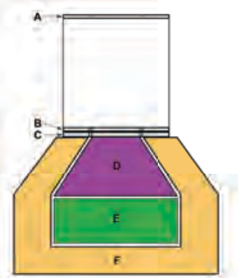
- Picking up where we left off: the September 2017 SPE and after-effects.
- The Great Dust Storm of 2018 – do Martian dust storms affect the radiation environment?
- Does RAD see altitude effects as Curiosity climbs Mount Sharp?
- Changes in GCR LET spectrum as solar cycle progresses?

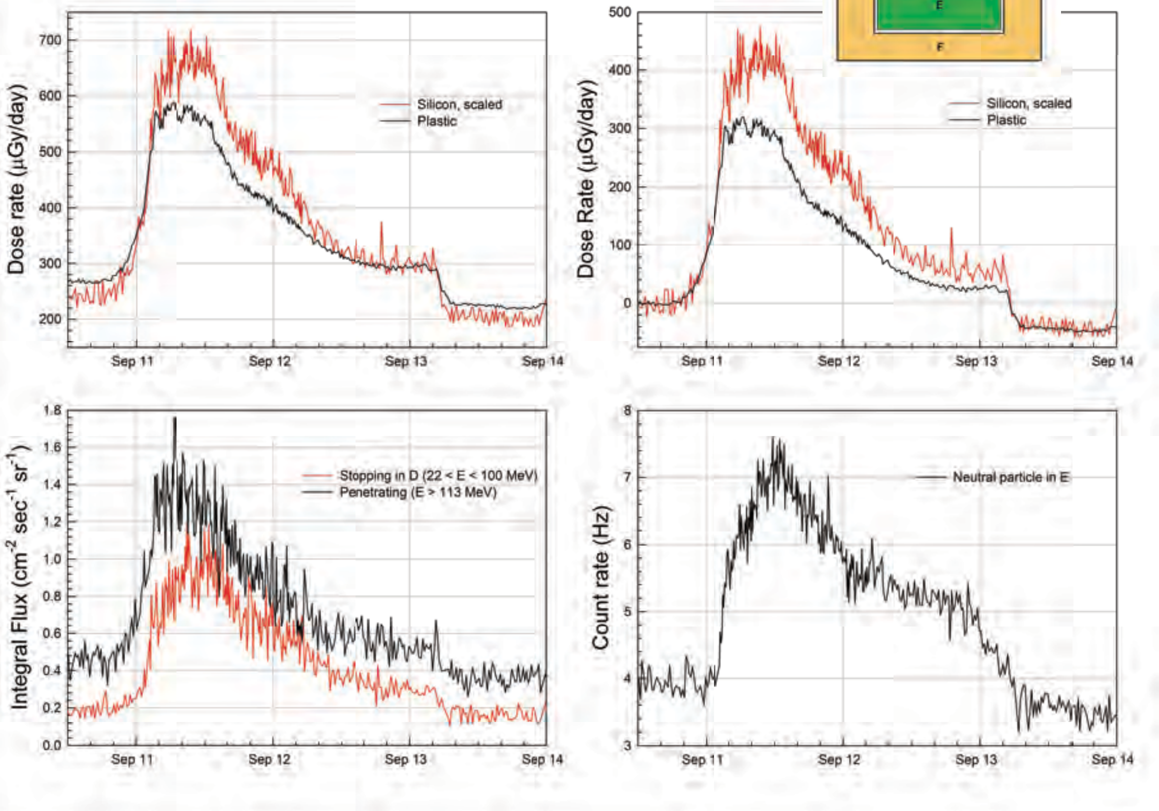
The September 2017 SPE
(“The Hungry Ghost Festival Event”)

- Detailed analysis in *Geophysical Research Letters* special issue:
  - Ehresmann et al., DOI:10.1029/2018GL077801
  - Zeitlin et al., DOI:10.1029/2018GL077760
- Modeling work & Overview published in *Space Weather* Special Issue:
  - Guo et al., DOI:10.1029/2018SW001973
  - Hassler et al., DOI:10.1029/2018SW001959

Dosimetry and Counter Data

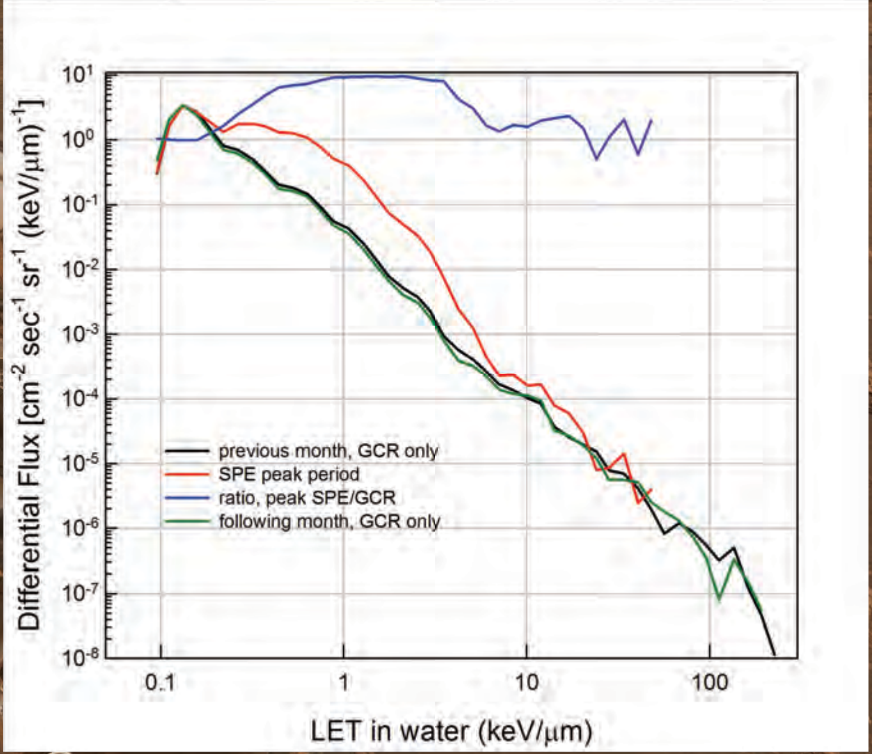
- B dose rate (silicon) is scaled to water.
- E dose rate (plastic) is smaller due to soft spectrum and self-shielding – vertical protons only reach E if they have kinetic energy > 100 MeV at the top of RAD, which means > 275 MeV at the top of the atmosphere.
- Counter data show onset and peak earlier in “penetrating particle” channel.
- Possible delay in onset of neutral particle signal in E – not understood.





LET Spectrum
Before, During & After

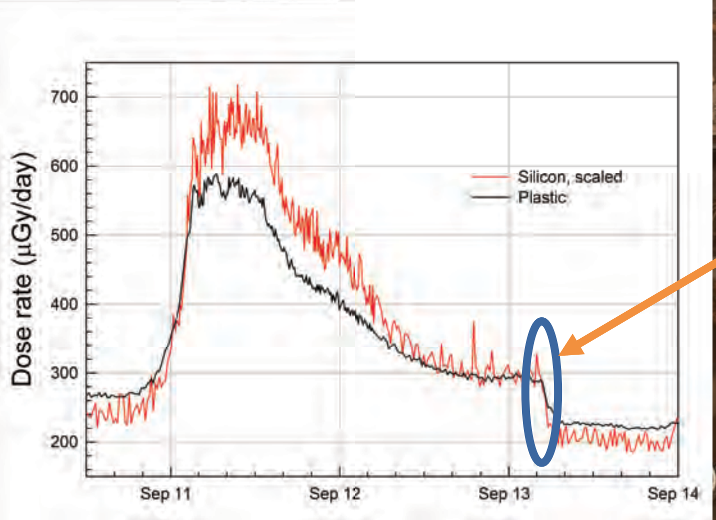
- Looking at 30 days before (black line) and 30 days after (green), there is no difference in GCR-only LET distributions.
- During SPE, MIP peak unchanged (GCR's kept coming), flux enhancement is all in the range from ~ 0.2 to 20 keV/μm as expected for a proton event.



Forbush Decrease & Net Effect

Dose and Dose Equivalent Rates and Totals

	Average rates 5-day pre-SPE	Peak rates during SPE	Average rates during SPE	Average rates 5-day post-SPE	Totals, 30 days before SPE	Totals,30 days starting 11/9/17
B, omnidirectional	240 µGy/day	718 µGy/day	464 µGy/day	208 µGy/day	7.3 mGy	7.7 mGy
E, omnidirectional	265 µGy/day	588 µGy/day	417 µGy/day	232 µGy/day	8.1 mGy	8.2 mGy
Dose equivalent using B	543 µSv/day	841 µSv/day	543 µSv/day	480 µSv/day	16.5 mSv	16.6 mSv



Shock arrival at Mars → GCR dose rate dropped by ~ 15-20% compared to rate prior to SPE.

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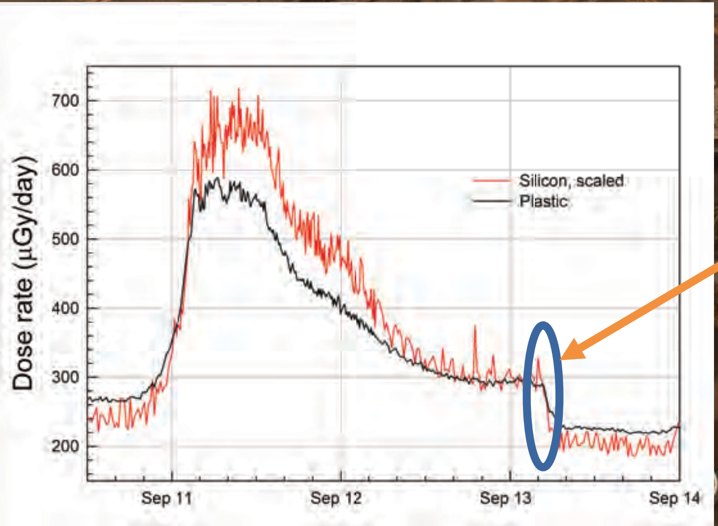

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2018 Dust Storm & Radiation Environment

- Dust storm began to engulf Mars in mid-June.
- Standard way to measure dust conditions is atmospheric opacity – here, derived from sky images using Mastcam on Curiosity.
- Curiosity is in its 3rd Mars year, Mars Year 34.
- No storms seen in previous years, just small increases in dust.

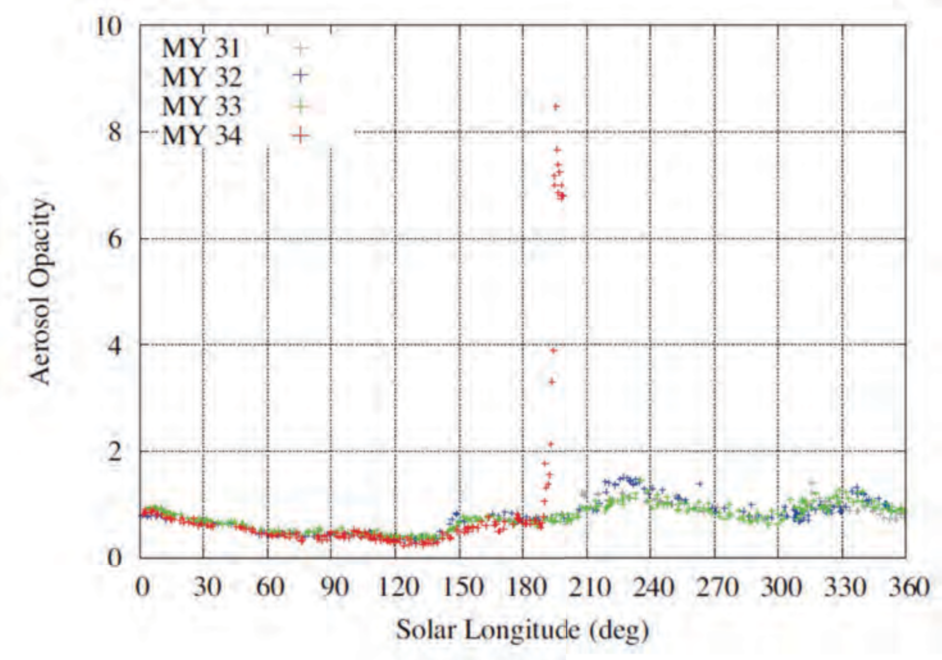


Figure courtesy of German Martinez, REMS team, UMich

2018 Storm Seen from Orbit

Early June Mid June Late June

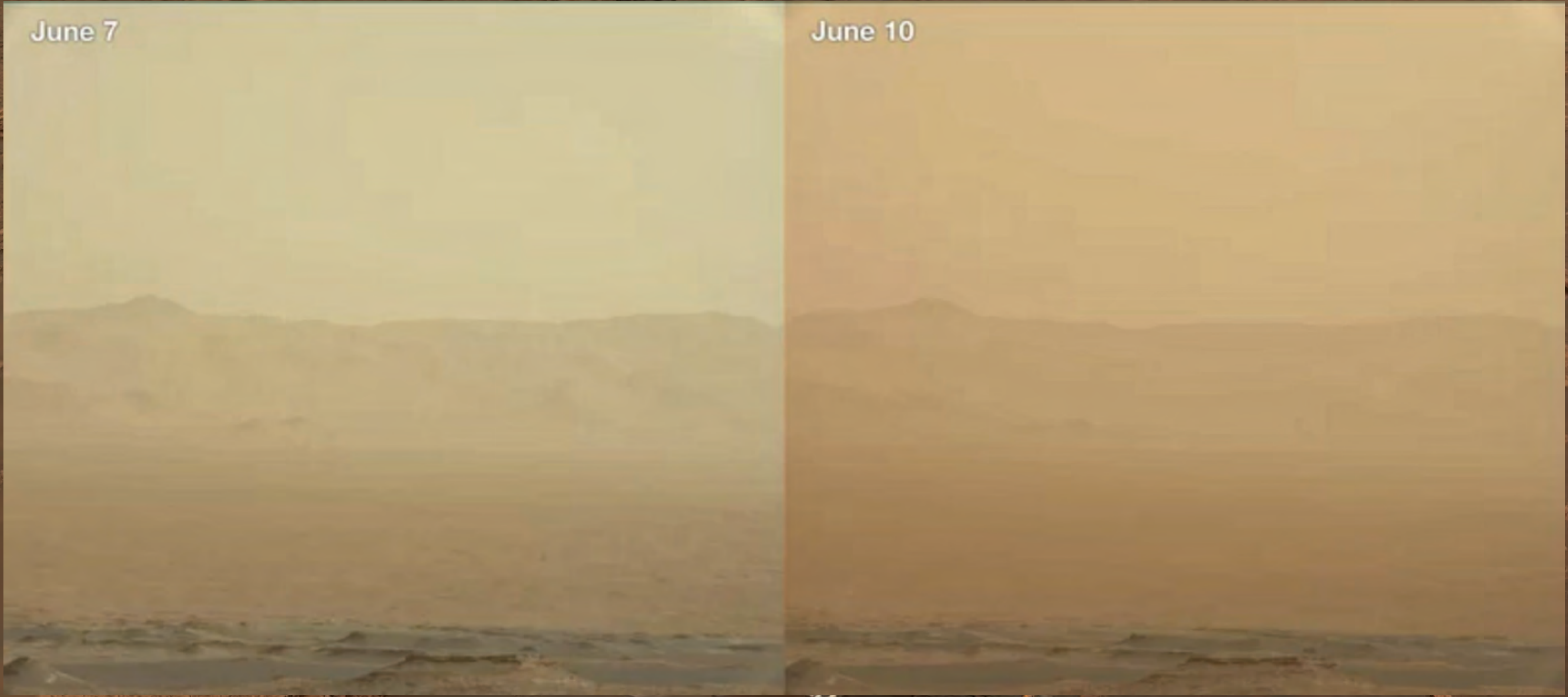
Do Martian Dust Storms Affect the Radiation Environment?

- A frequently asked question. ☺
- Planetocosmics simulations by Jan Appel (Kiel) suggest there is no effect – as table shows, there is no predicted difference in dose rates, regardless of conditions and modulation potential.
- This is ~ expected since the mass of dust lifted is small compared to the column depth of CO_2.
- Note, “cold” scenario = very clear atmosphere, no dust.

Table 1. Ground-level dose rates for different solar modulation conditions and atmospheric dust scenarios. Dose rates have been computed for particle energies between 1 MeV and 10 GeV.

Φ/MV	quiet / μGy/day	cold / μGy/day	storm / μGy/day
400	$1.34 \cdot 10^{+02}$	$1.34 \cdot 10^{+02}$	$1.33 \cdot 10^{+02}$
650	$1.10 \cdot 10^{+02}$	$1.10 \cdot 10^{+02}$	$1.10 \cdot 10^{+02}$
1500	$3.96 \cdot 10^{+01}$	$3.97 \cdot 10^{+01}$	$3.95 \cdot 10^{+01}$
surface pressure / Pa	960.96	954.50	998.41

The View From Curiosity

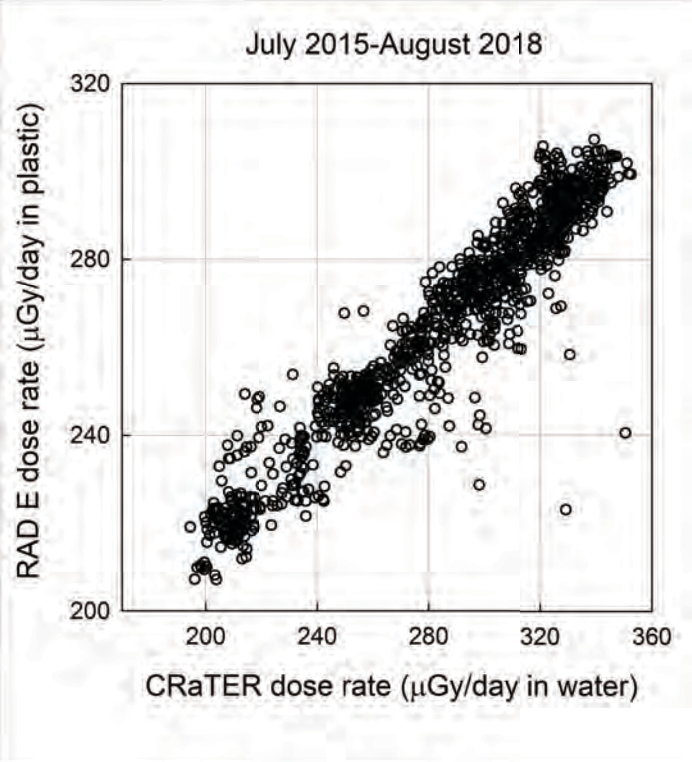


A Dusty Selfie

Good news – no visible dust accumulation on RAD.

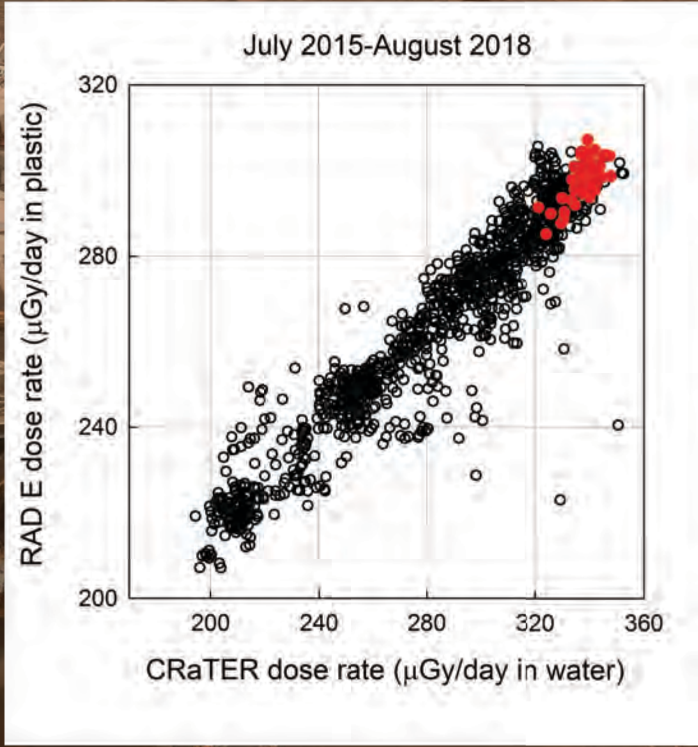
Did the 2018 Dust Storm Produce Measurable Effects?

- Compare MSL-RAD data to data from CRaTER (lunar orbit), since we know CRaTER is not affected.
- Generally see beautiful correlation between data sets – outliers from the correlation line occur sometimes due to FD's when there are large differences in heliospheric longitude.
- These are daily average dose rates, CRaTER shielding is 9 g cm^{-2} of tissue-equivalent plastic.



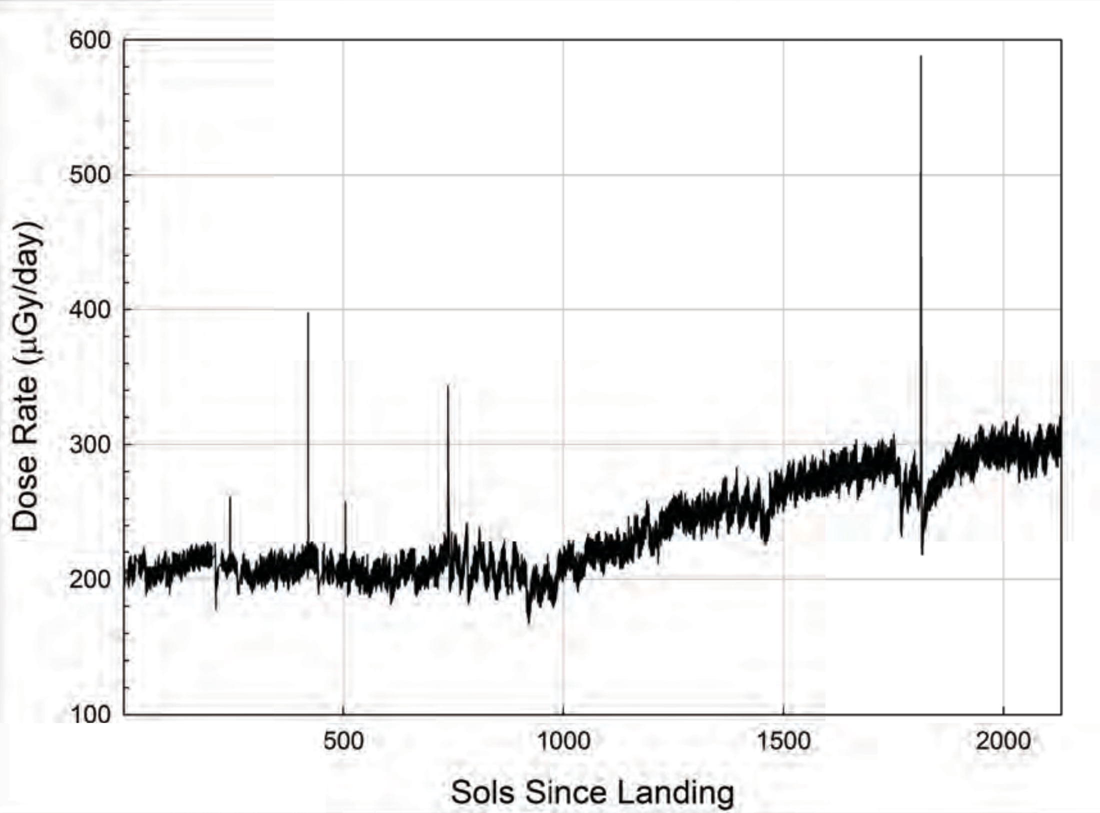
Did the 2018 Dust Storm Produce Measurable Effects?

- Highlighted data (in red) from dust storm period show no significant deviations from the correlation line.
- There may be more subtle effects lurking in the data, but to first order, it looks like there's no effect, as expected.



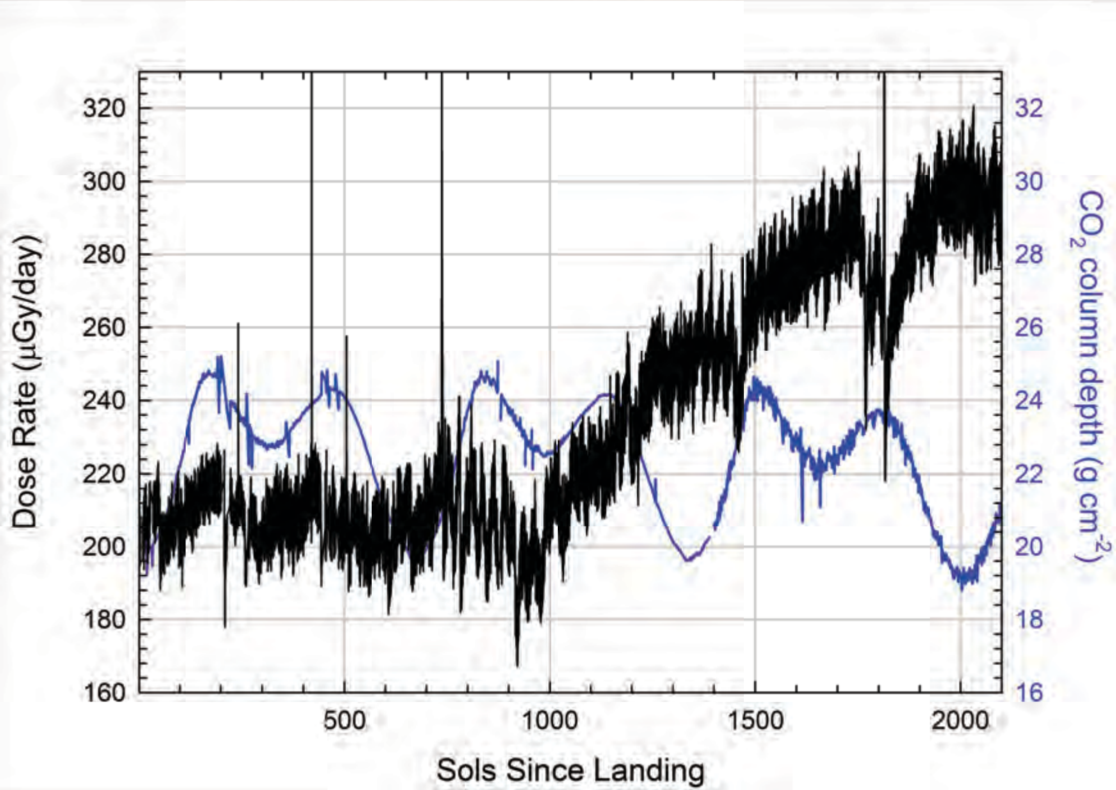
The Big Picture So Far...

- Total exposure is dominated by GCRs.
- GCR dose rate (E detector shown here) has gone up by ~ 50% due to weakening solar modulation, despite occasional large Forbush decreases.
  - Periodicity seen in some quiet time is due to CIRs.



Atmospheric Pressure and GCRs

- Vertical column depth is based on pressure data from the REMS instrument suite.
- 1 Martian sol = 1.027 day. For reference, Sol 2100 was 3 July 2018.
- It looks like pressure is lower in the most recent cycle.



Correlation of Pressure and <Q>

- Pressure (and therefore column depth) really is lower in MY34 by ~ 5%.
    - Note: depth in g cm^{-2} = P(Pa)/37.2
- Curiosity has climbed from 4.4 km below the mean Martian surface (MOLA) altitude to 4.2 km below (5% change).
- Large share of incident heavy ions undergo nuclear fragmentation in the atmosphere, so <Q> increases with decreasing depth.
- Naively expect to see larger <Q> in more recent data.

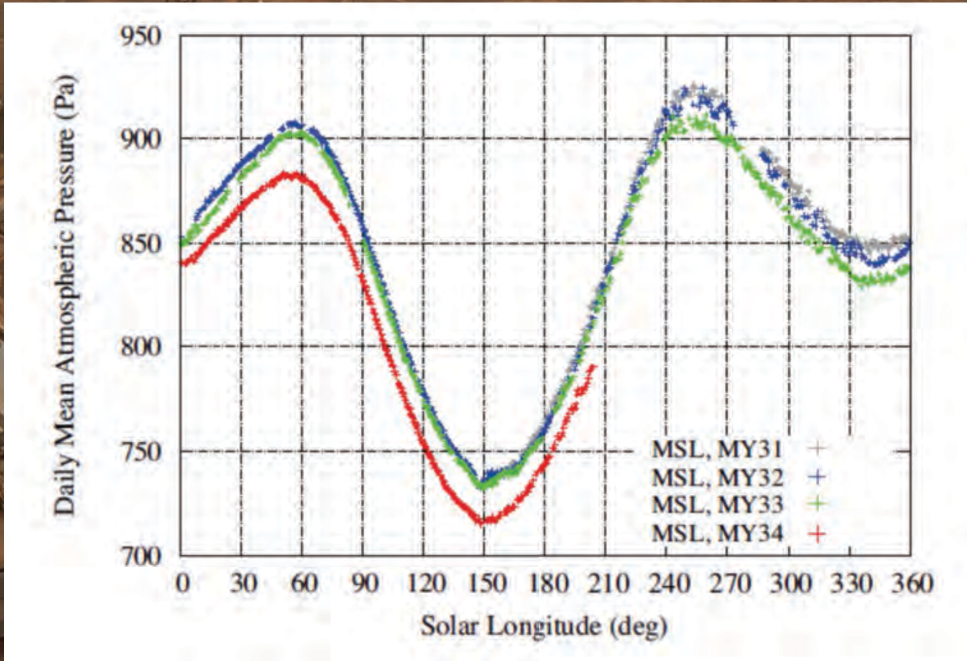
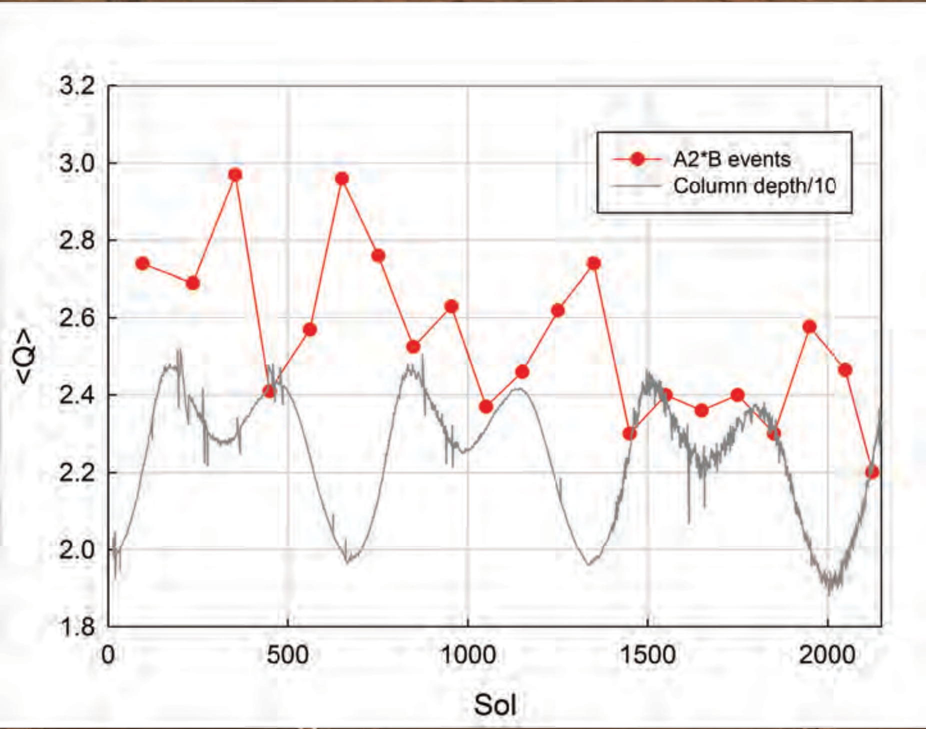


Figure courtesy of German Martinez, REMS team, UMich

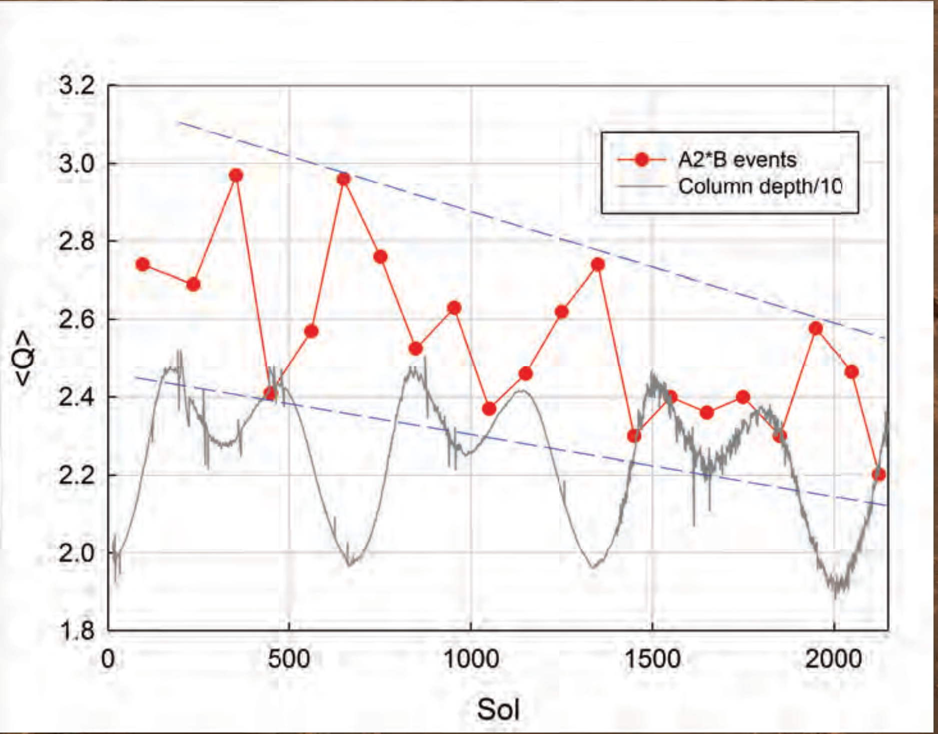
<Q> and Column Depth

- In first 2 pressure minima, <Q> approached 3, but in more recent minima <Q> is 2.5 to 2.7.
- In first few pressure maxima, <Q> was 2.4 to 2.6, but more recently, <Q> is 2.2 to 2.4.



<Q> and Column Depth

- In first 2 pressure minima, <Q> approached 3, but in more recent minima is 2.5 to 2.7.
- In first few pressure maxima, <Q> was 2.4 to 2.6, but more recently, 2.2 to 2.4.
- Lines added to guide the eye… <Q> is generally decreasing & range seems to be narrowing.

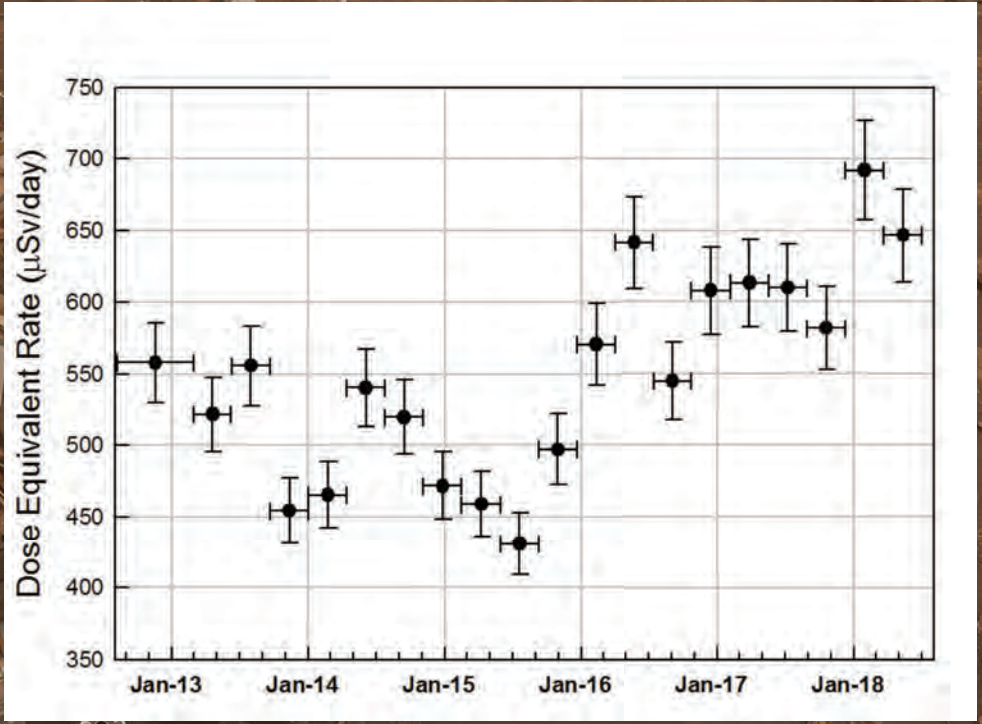


Is Decreasing <Q> Due to Weak Modulation?

- Protons (A/Z = 1) are more modulated than ions with (A/Z = 2) → relative increase in proton abundance.
- Increase in lower-energy heavy ions is not observed on Mars due to atmospheric shielding.
  - E.g., minimum energy for a ^{56}Fe nucleus to penetrate 23 g cm^{-2} of CO_2 is 800 MeV/nuc .
- It should be straightforward to model this effect.

Dose Equivalent Rates

- Surface rates shown here mostly in 100-sol intervals.
- RAD measured 1.4 0.1 μSv/day in cruise to Mars.
- Initial H rate was down by more than a factor of 2 by comparison, recently is factor of ~ 2 below cruise.
- Increasing dose rate with decreasing <Q> tends to keep H fairly constant.



Conclusions

- MSL-RAD has had another successful year of operations – just passed the 6th anniversary of the landing.
- September SPE was largest seen to date on the surface & demonstrates unpredictability of large events and complexity of propagation through the heliosphere.
  - Contribution to dose & dose equivalent (H) was ~ negated by subsequent Forbush decrease.
  - However, it is impossible to draw significant conclusions from a single event. . .more statistics are necessary.
- 2018 dust storm had – at least to 1st order – no effect on the surface radiation environment.
- GCR dose rate continues to rise, but rise appears to correlate with a decrease in <Q>, likely due to changing ion abundances.

MARS SPACE RADIATION MODELING WORKSHOP 2018

16-18 October 2018
Boulder, Colorado

http://www.boulder.swri.edu/rad_modeling_workshop2/workshop.php

The purpose of this workshop is to bring the radiation transport modeling community together to compare their models with each other & with data from MSL/RAD on Mars.

One of the difficulties in comparing model results is often the different assumptions and treatment of boundary conditions. Therefore, the Organizing Committee will specify an initial set of boundary conditions, as well as scope and format of the model outputs (values to be calculated), to allow better comparison of model results.

This year, our Blind Challenge will focus on a model comparison exercise with all input conditions specified, including input GCR spectrum, atmos. pressure, etc. for a 4 month period (March 1 to June 31, 2018). We will also have a Focused Topic Session with Contributed Talks on modeling SEPs under varying heliospheric conditions.

Organizing Committee: Don Hassler, Cary Zeitlin, Daniel Matthiae, John Norbury, Tony Slaba, Guenther Reitz, Bob Wimmer-Schweingruber, Lawrence Heilbronn, Eddie Semones, Bent Ehresmann

Thank you!

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