Recent Results from the Surface of Mars with RAD

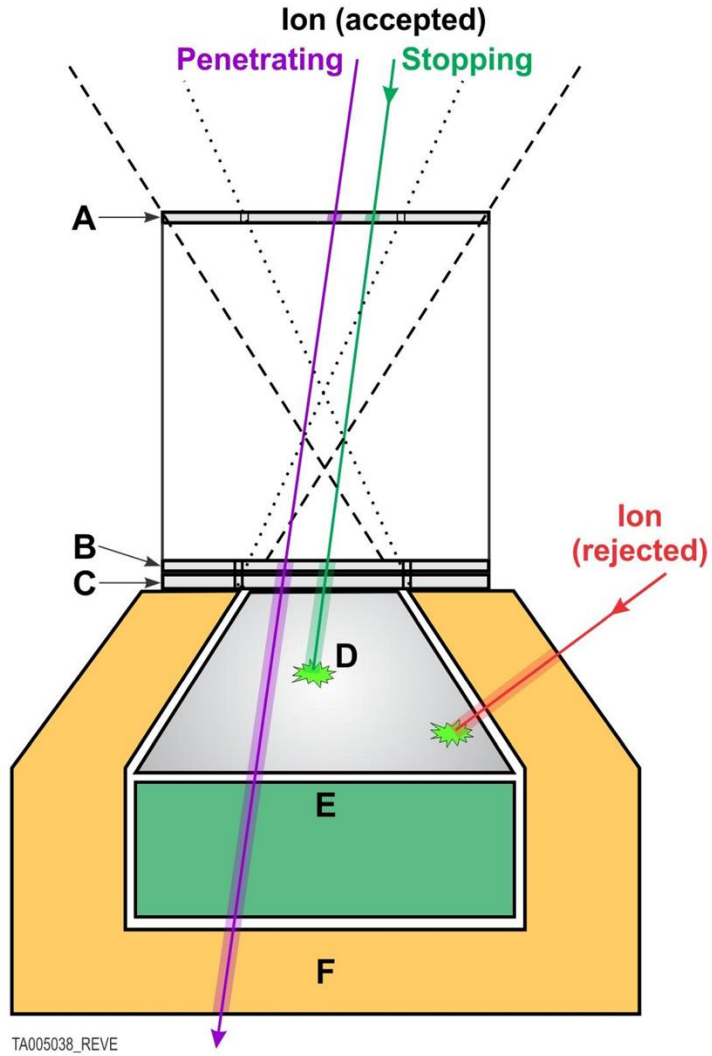


Bent Ehresmann, Don Hassler and the MSL/RAD Team

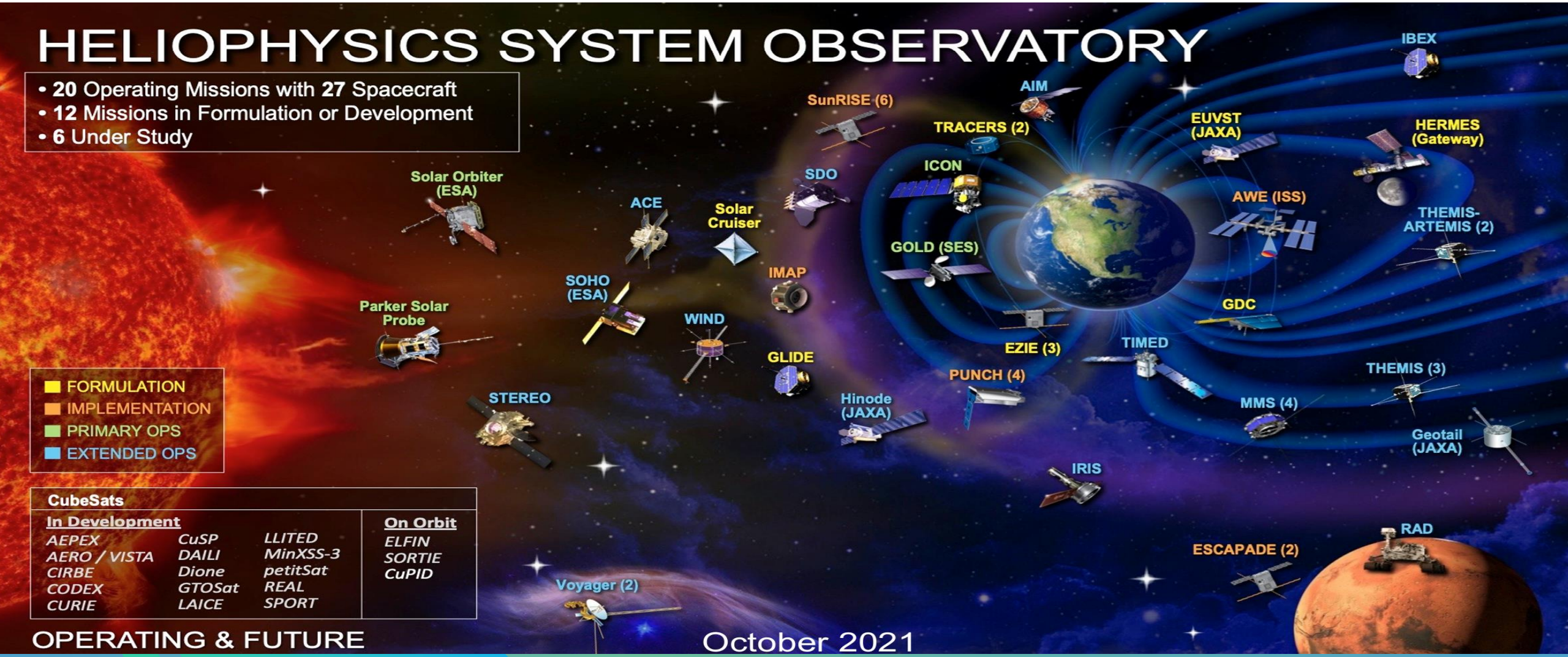
29th WRMISS
2 September, 2026

The Radiation Assessment Detector (RAD)

- RAD has been operating on board the *Curiosity* rover as part of NASA's Mars Science Laboratory (MSL) mission in Gale crater on Mars since landing in August 2012 -> **more than one solar cycle of continuous measurements!**
- RAD sensor head consists of 5 active detectors:
  - Three 300 micron thick silicon detectors (A, B , C)
  - CsI scintillator D
  - Tissue-equivalent plastic scintillator E
  - … + one plastic anti-coincidence scintillator F
- RAD can measure energy spectra for both charged & neutral particle species
- RAD measures absorbed ***dose rate*** in the ***silicon B*** & ***tissue-equivalent plastic E*** detectors (with 4π acceptance angle)

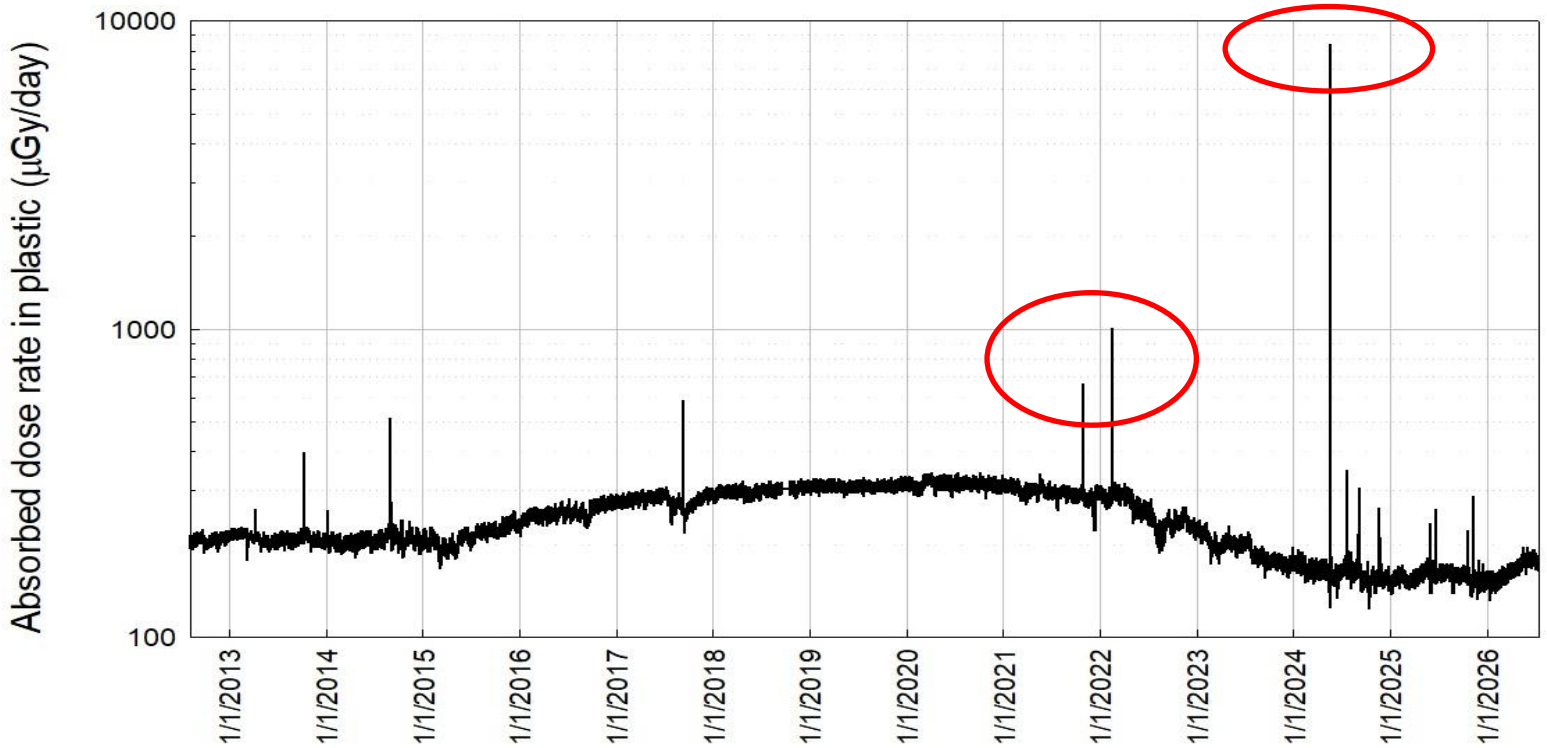


MSL/RAD: Part of NASA's Heliophysics System Observatory (HSO)



RAD Absorbed Dose Measurements Span More than one Solar Cycle

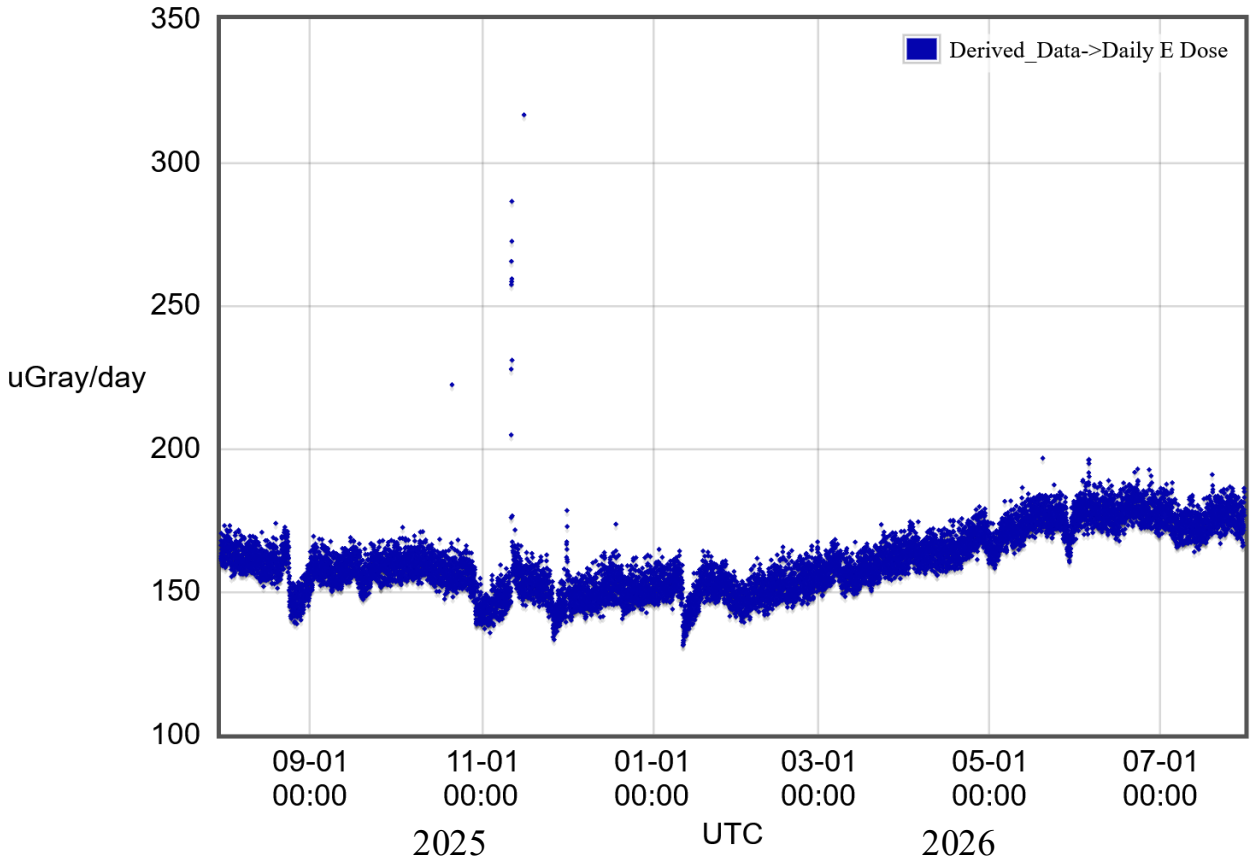
- Measured RAD dose rates range from ~200 µGy/day (start of mission, waning solar max) to ***>340 µGy/day*** in deep ***solar min***, and then down to ***150 µGy/day*** during the current ***solar max***…
- … showing a difference of a ***factor of >2*** between solar max and min



- RAD also directly measured >20 ground-level Solar Energetic Particle (SEP) events (examples in red circles), as well as measured many more SEP events indirectly via the detection of subsequent Forbush decreases

Recent RAD Dose Measurements During Solar Maximum

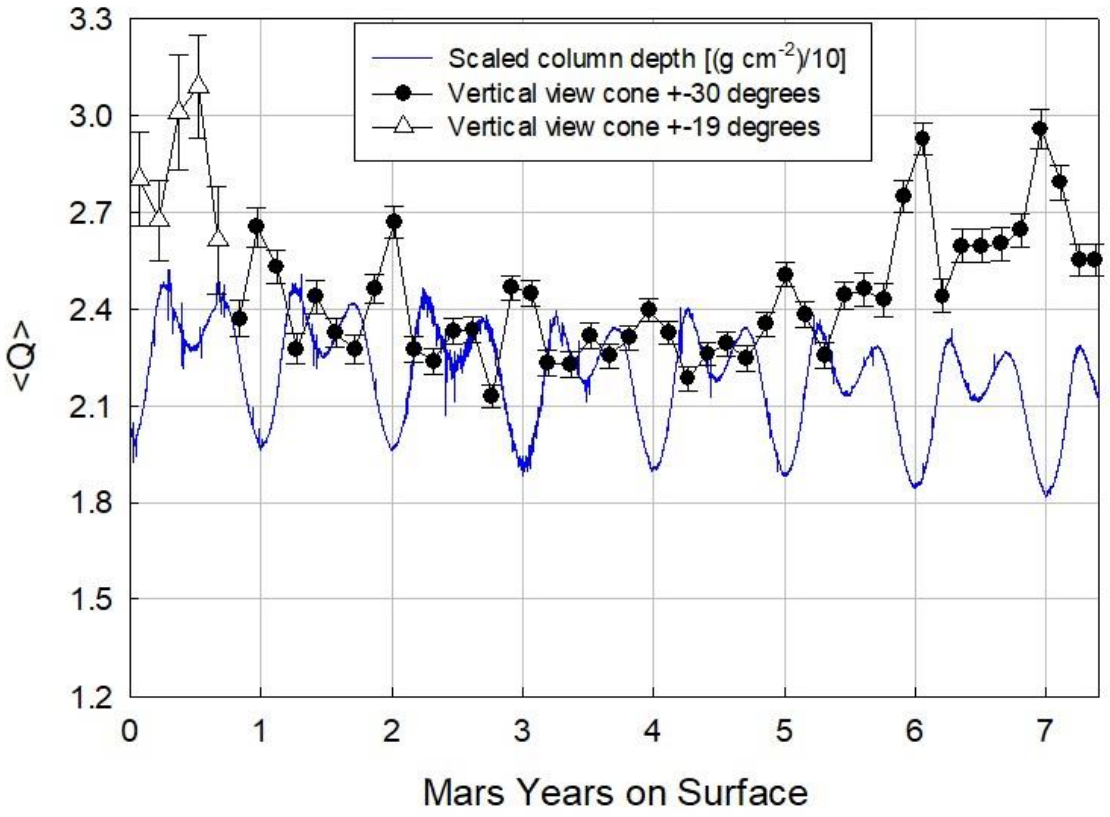
- Dose rates reached a minimum of ~150 µGy/day between November 2025 and February 2026…
- … indicating the peak of solar maximum
- Since then, dose rates have slowly started to increase again, currently reaching ~175-185 µGy/day…
- … indicating that we might be slowly leaving this current solar maximum



Radiation Quality Factor <Q>

Radiation Quality Factor <Q>

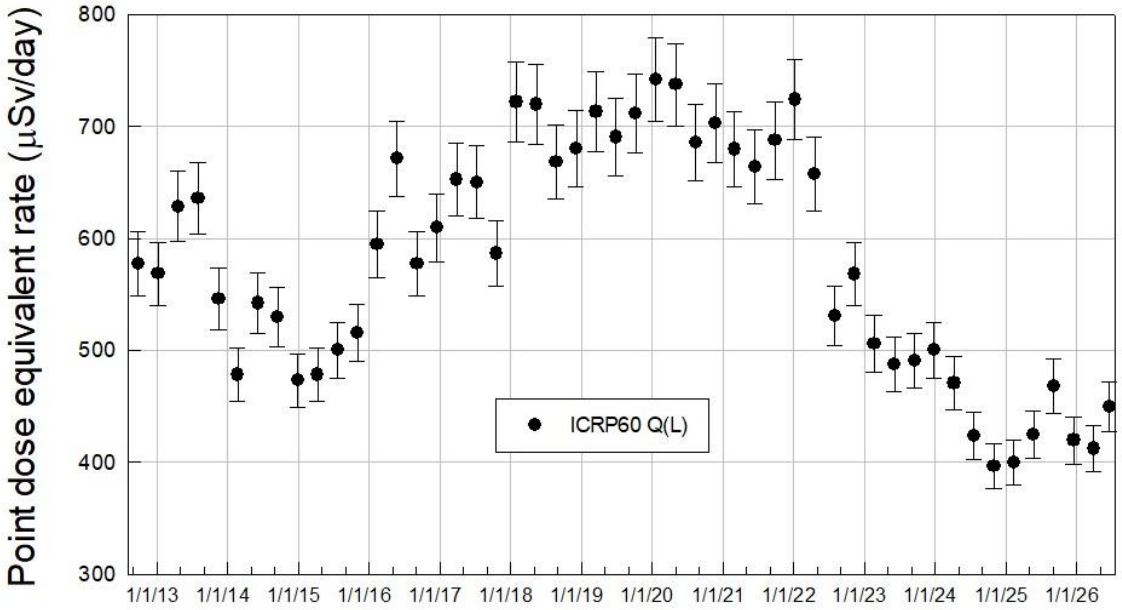
- <Q> is a measure for the biological effectiveness of the radiation field
- <Q> (or Q(LET)) can be derived from the measured LET spectrum (in detector B in coincidence with detector A)
- In general, higher <Q> -> more hazardous for astronauts
- On Mars, <Q> is dependent on both the solar modulation of the incoming GCR flux and the seasonally-changing atmospheric pressure
- <Q> has ranged from ~2.1 in solar minimum to ~3 in solar maximum



Dose Equivalent H

Dose Equivalent H

- The dose equivalent H is an instrumental measurement quantity in space dosimetry
- It is defined as the product of the measured absorbed dose ***D*** multiplied by the derived quality factor ***Q*** (H = D x Q)…
- … and gives insight into the biological effectiveness of the measured space radiation field
- Dose equivalent rates have ranged from <400 µSv/day in solar maximum to >750 µSv/day during solar minimum



SEP Events directly detected by RAD

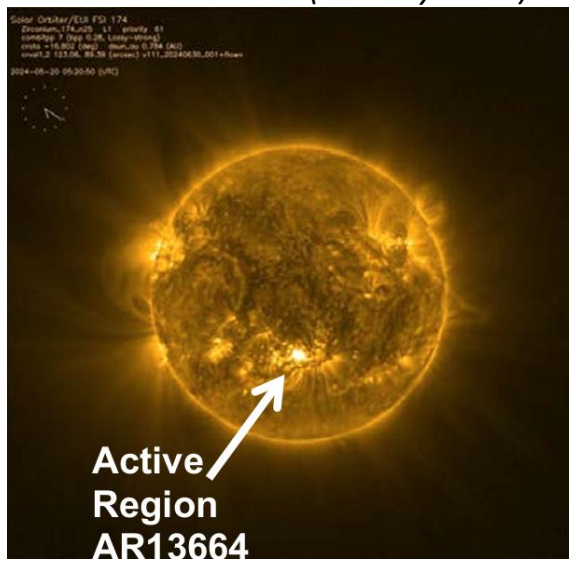
- RAD has directly detected 23 SEP events on the surface of Mars to date
- Note: To reach the surface in Gale crater, protons need an initial energy of at least ~150-165 MeV…
- … due to the protons losing energy in the atmosphere in interactions with the atmospheric nuclei
- RAD SEP measurements are particularly informative when Earth and Mars are separated by large degrees (e.g., when Mars is connected to the far side of the Sun)…
- … when RAD can provide critical insight into SEP propagation inside the inner heliosphere

MSL/RAD SEP Event List		
#	Date	Peak Dose in E [µGy/day]
1	2013-04-10	268.5
2	2013-10-10	395.7
3	2014-01-05	283.1
4	2014-08-31	341.6
5	2014-09-10	258.3
6	2017-09-10	586.7
7	2021-10-28	665.6
8	2022-02-15	1008.6
9	2022-03-14	311.5
10	2023-03-12	282.1
11	**2024-05-20**	**8355.6**
12	2024-07-22	348.5
13	2024-07-26	186.9
14	2024-08-04	189.1
15	2024-09-02	215.9
16	2024-10-09	303.3
17	2024-11-22	262.8
18	2025-05-31	233.6
19	2025-11-12	286.3
20	2025-12-01	178.3
21	2025-12-18	173.5
22	2026-02-28	170.2
23	2026-06-05	196.1

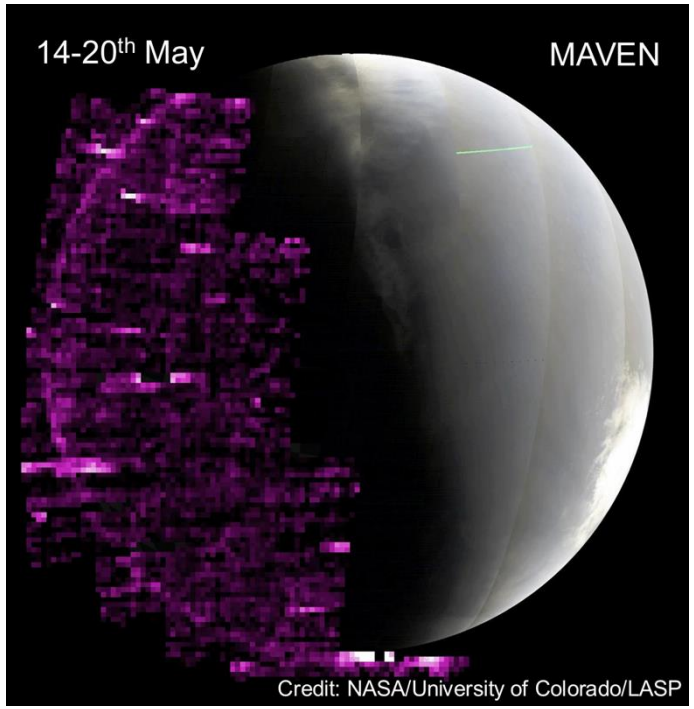
Based on Loewe et al. (2025), https://doi.org/10.1029/2025SW004372

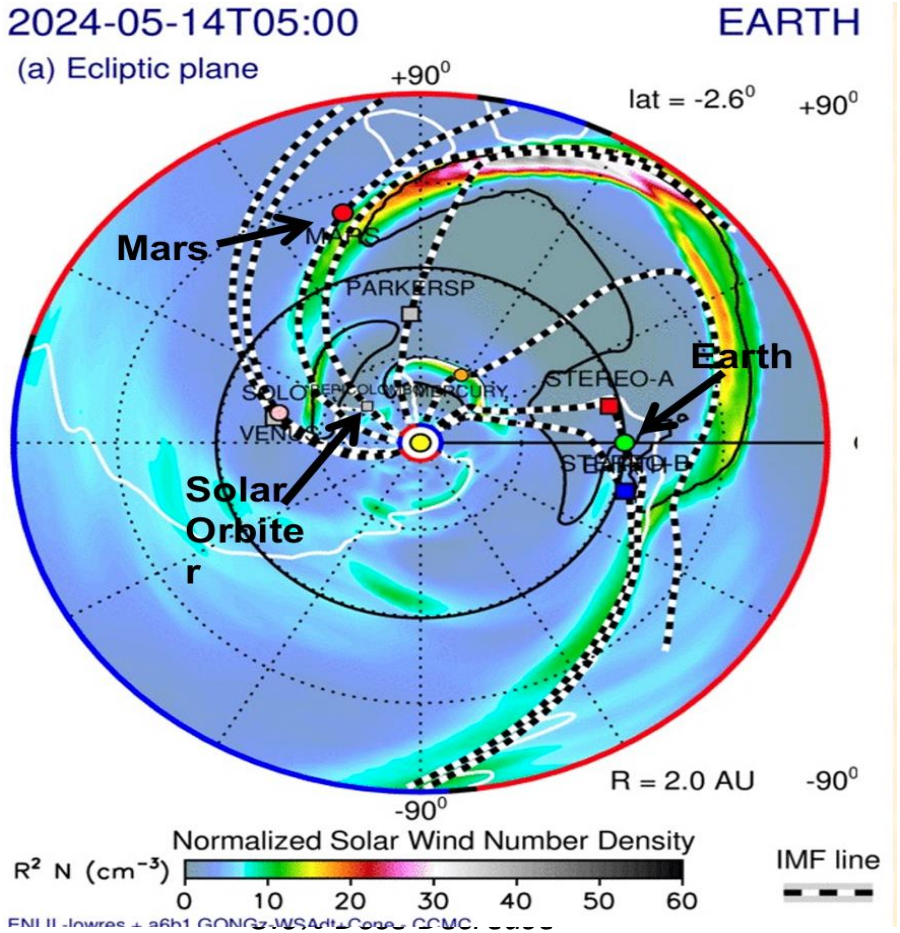
The May 2024 Solar Storms –
The largest Event ever recorded by RAD in more than a Solar Cycle

Solar Orbiter EUI (20 May 2024)



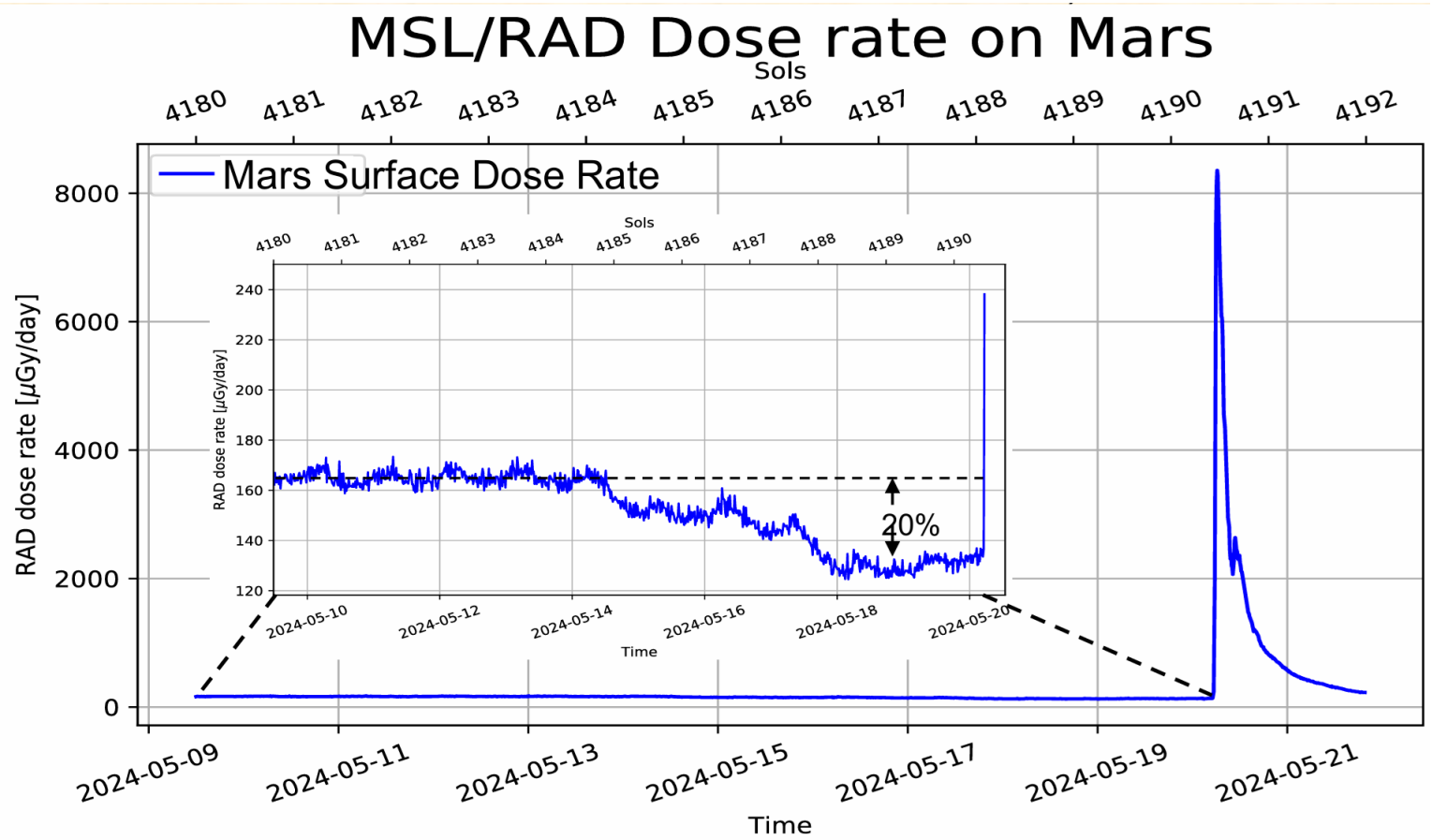
- May 2024 saw prolonged activity from AR 13664
- Earth-Mars separation ~95°





Courtesy of C. Lee (UC Berkeley / SSL)

RAD Observations on Mars (May 14-22 2024)

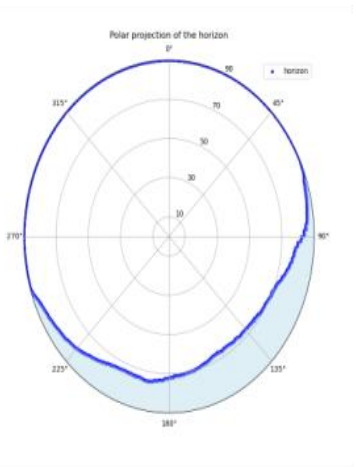


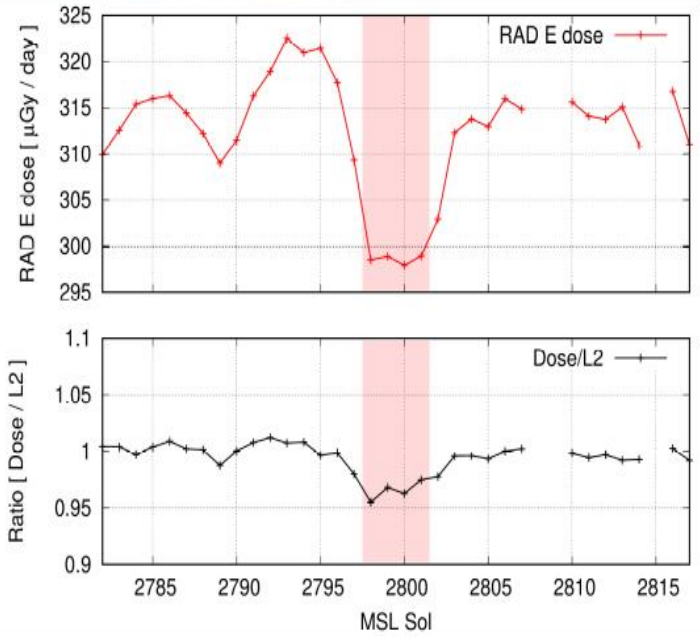
- The initial events hitting Mars were relatively low energy and didn't reach the surface, resulting in two subsequent Forbush decreases suppressing the incoming GCR radiation by up to 20%
- The event on May 20 resulted in the highest ever recorded surface dose rates (x8 higher than previous high)

Natural Terrain Radiation Shielding on Mars

- Natural terrain on Mars (canyon walls, …) can provide shielding from the incoming radiation -> Highly useful for construction of base stations and radiation shelters
- Shielding effect depends on amount of sky blocked out by terrain
- Full study of this effect as measured by RAD under review, in conjunction with:
- Charpentier et al. (2026), JGR Planets, https://doi.org/10.1029/2025JE009336
- Guo et al. (2026), JGR Planets, https://doi.org/10.1029/2026JE009704







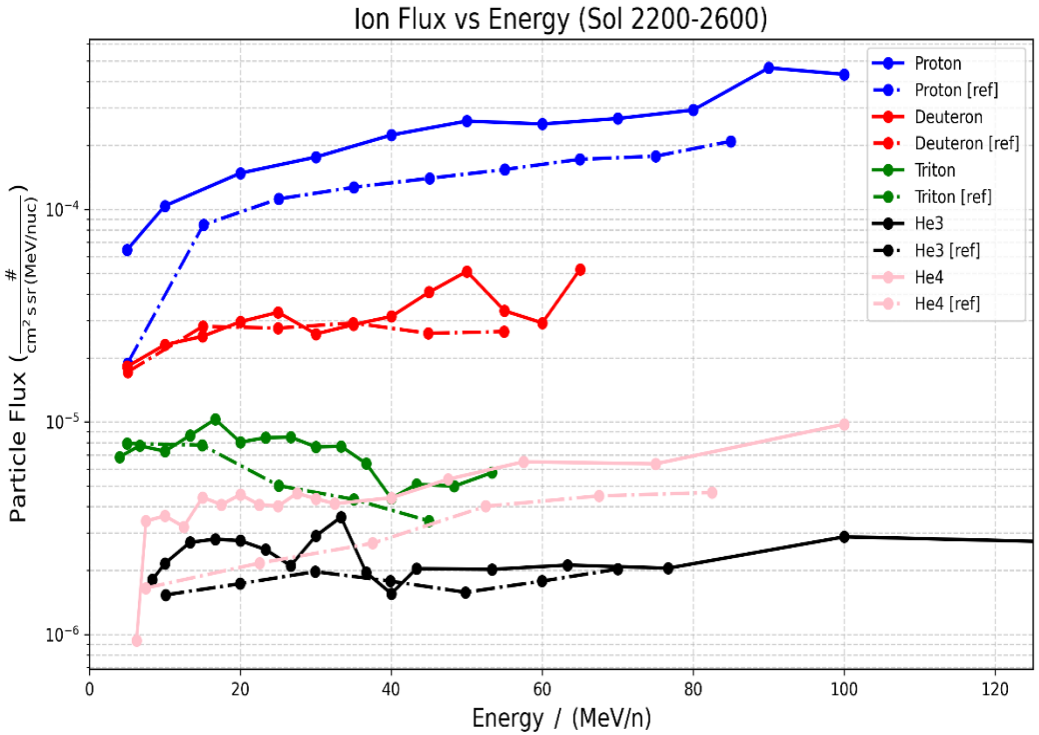
Location	MSL Sol	Dose Rate Decrease	Average Angle of Sky Obstruction	Percentage of 2π Sky Blocked
Hidden Valley	707 – 708	1.5% (±0.7%)	4.9°	8.5%
Murray Butte (a)	1456 – 1467	3.8% (±0.4%)	8.4°	14.3%
Tower Butte – Position 1	2658 – 2691	3.2% (±1.1%)	8.3°	14.4%
Tower Butte – Position 2	2735 – 2741	3.6% (±1.2%)	8.6°	14.8%
Bloodstone Hill	2798 – 2801	3.5% (±0.6%)	7.3°	12.6%
Mt. Mercou 1- Drill Position (position a)	3053 – 3072	3.0% (±1.0%)	6.9°	11.8%
Mt. Mercou 2 - Close Approach (position b)	3073	5.8% (±1.0%)	8.3°	14.2%
Mt. Mercou 3 (position c)	3077 – 3078	3.1% (±1.0%)	6.5°	11.2%
Maria Gordon Notch	3324 – 3325	12.8% (±1.2%)	23.5°	37.8%
Paraipetuy Pass Approach	3551 – 3562	6.6% (±1.3%)	16°	27.0%
Paraitepuy Pass	3563 – 3567	9.2% (±1.3%)	20°	33.3%

(a) recalculated from Ehresmann et al. (2021)

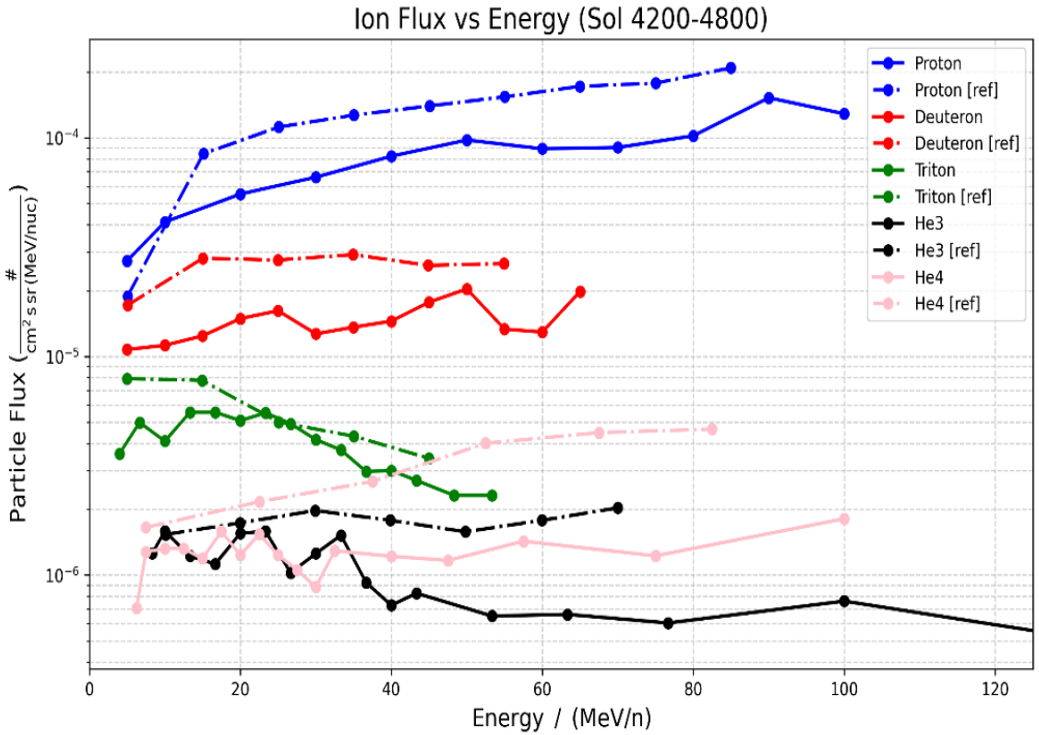
RAD Charged Particle Spectra on the Surface of Mars – 14 Years of Measurements

- RAD can measure differential energy spectra for charged particles stopping in the RAD detectors -> divided into separated isotopes (H, He) or groups of ion species
- RAD can also measured integrated particle fluxes for penetrating charged particles, divided into groups of ion species

Solar Minimum

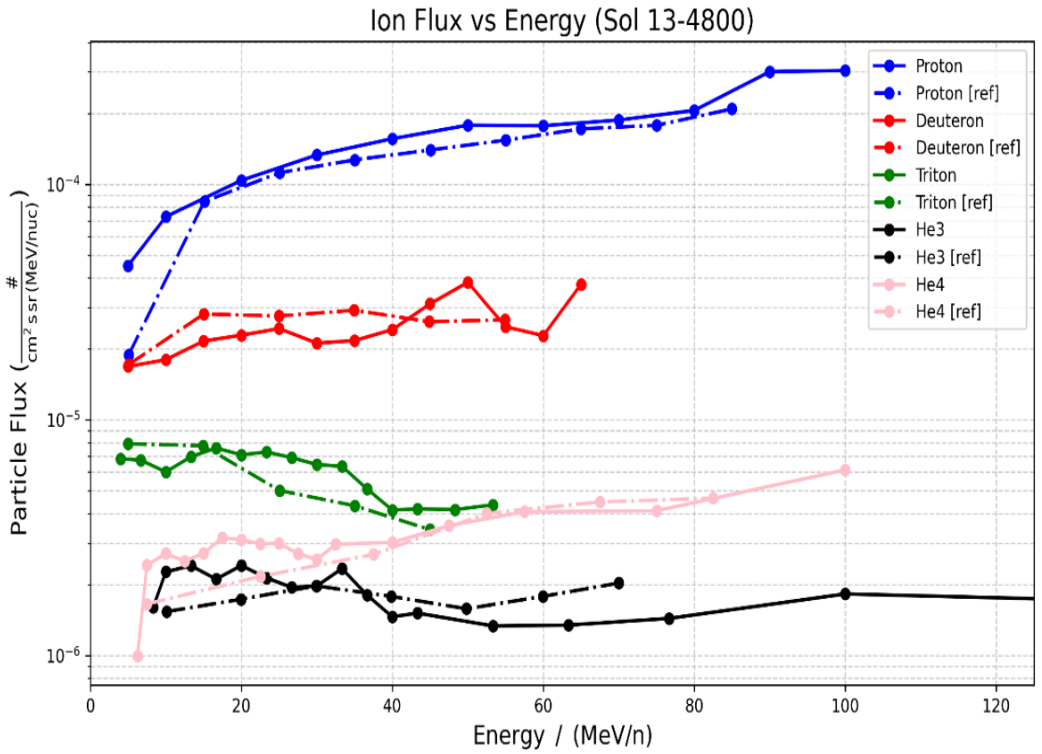


Solar Maximum

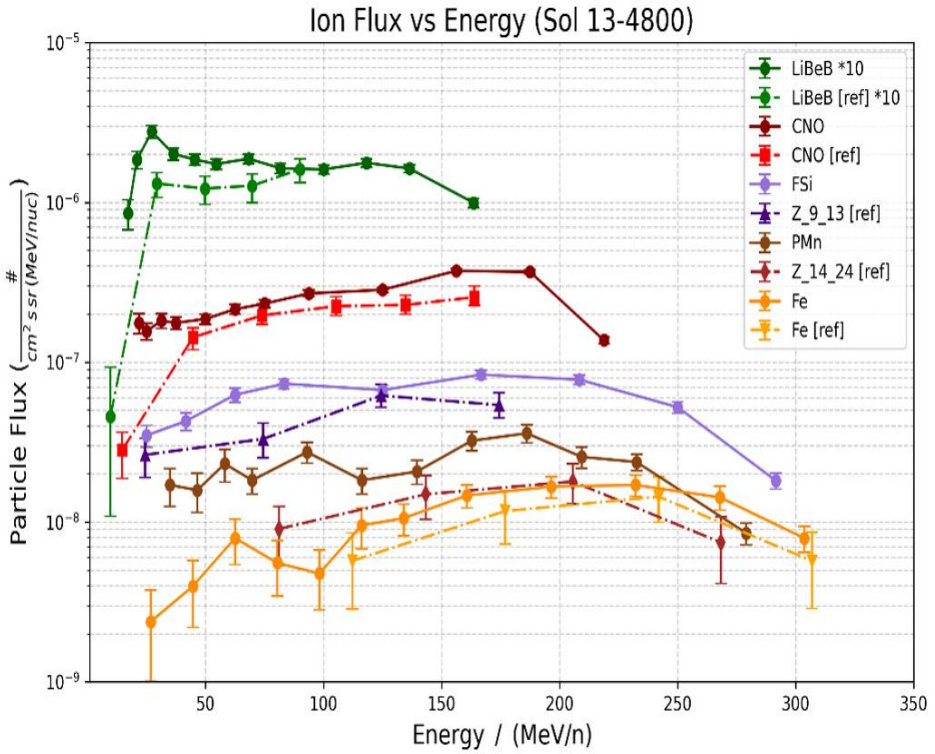


RAD Stopping Particle Spectra over the Whole Mission (Aug 2012 – Aug 2026)

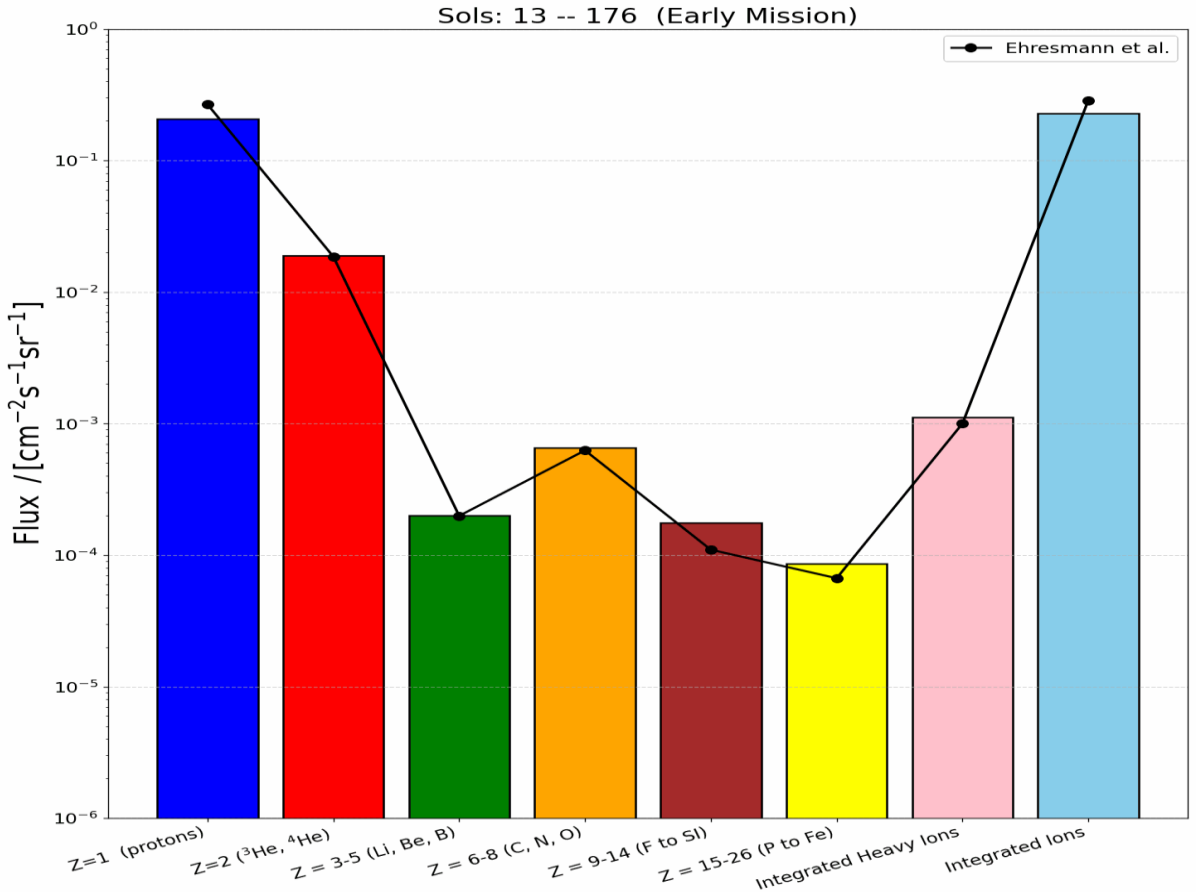
Low-Z Ion Isotopes



HZE Ions

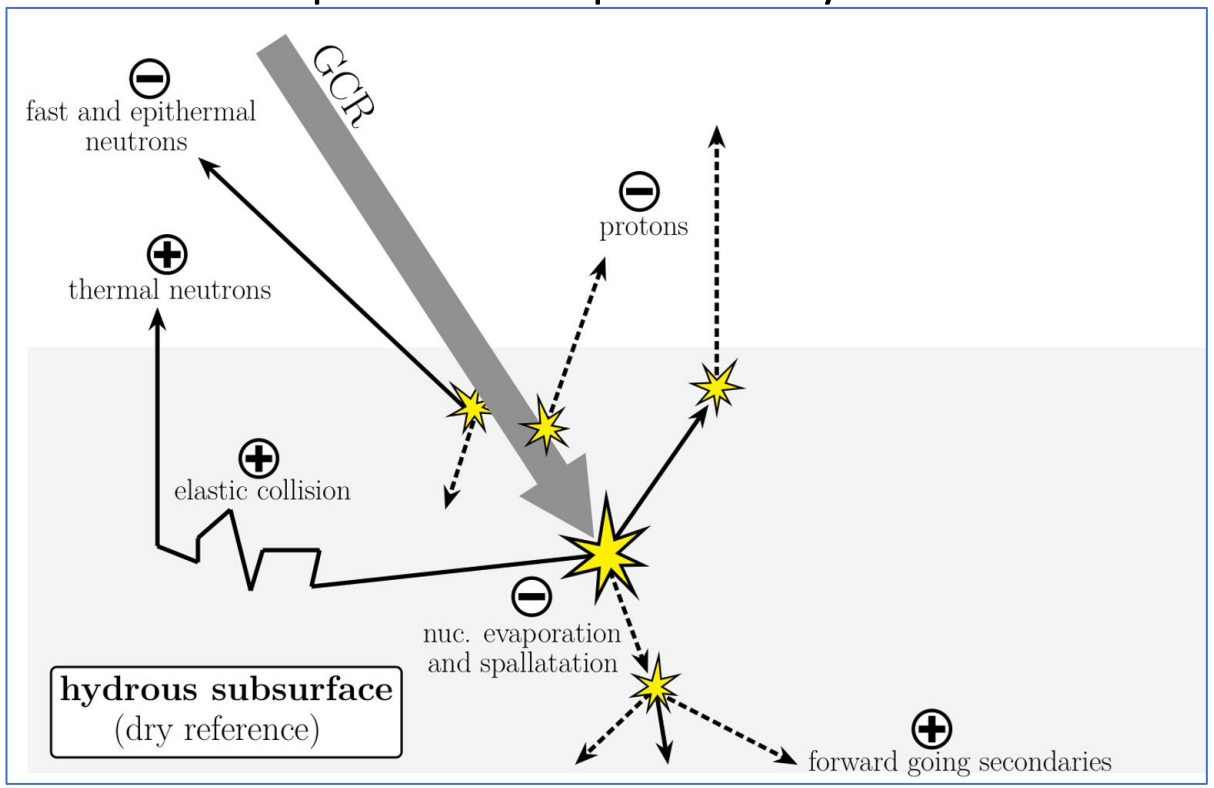


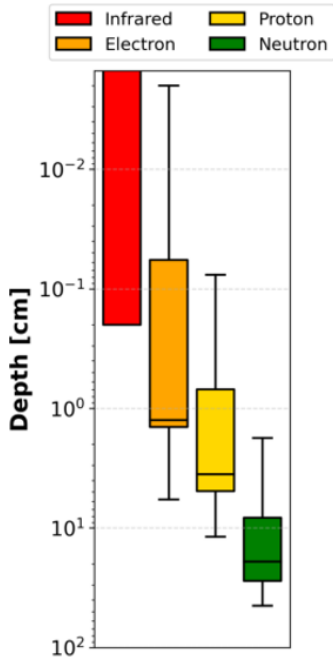
RAD Penetrating Particle Fluxes – Changes over Time



Using RAD Proton Albedo Measurements to Search for Water

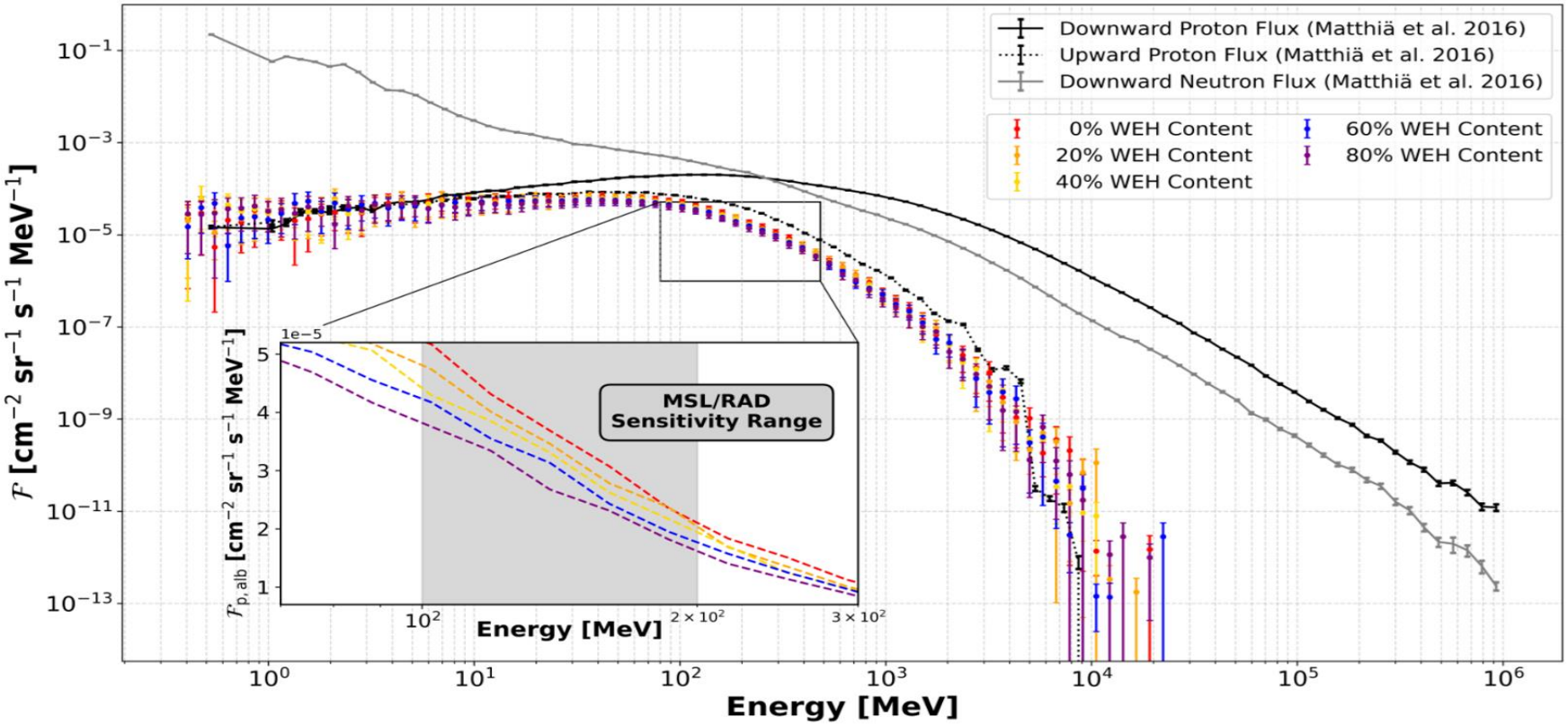
- Production of proton albedo particles depends on hydrogen content of subsurface
- Sensing for hydrogen with albedo proton detection surveys much shallower depths (compared to albedo neutrons)
- Can we use a RAD-like detector to provide complementary measurements when searching for subsurface water?





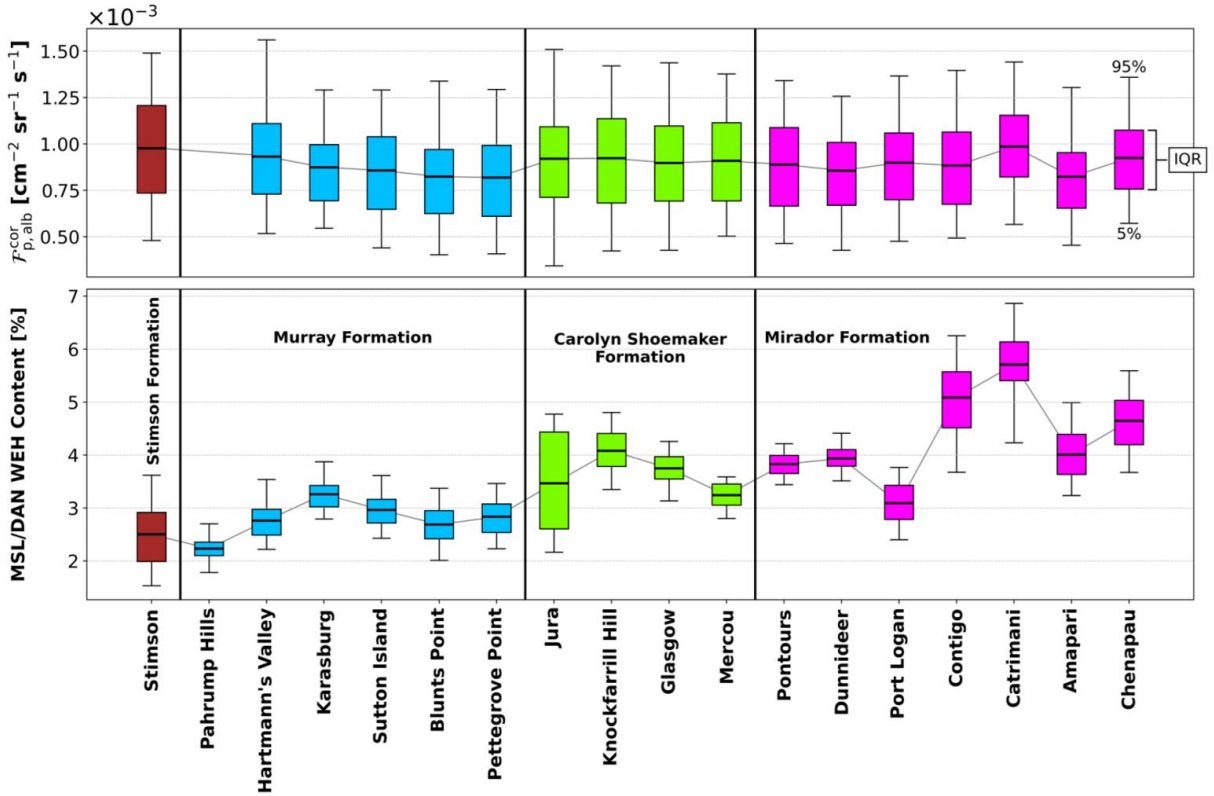
Using RAD Proton Albedo Measurements to Search for Water

- In the relevant proton albedo energy range, simulations show that RAD is sensitive to changes in hydrogen content
- Sensitivity increases with amount of change in hydrogen content



Using RAD Proton Albedo Measurements to Search for Water

- Water content encountered by Curiosity so far (2-6%) is too low for this technique to be effective
- Technique works in theory, but efficiency depends on size of detector, accumulation time & amount of water
- Promising for future missions to provide complementary hydrogen measurement that probe shallower depth than neutron detectors



Summary

- RAD has been conducting detailed measurements of the Martian surface radiation environment since August 2012, ***covering more than one solar cycle***
- These measurements are critical to understand space weather at Mars and its impact on astronauts and future human exploration of the red planet
- RAD measurements of SEP events provide important insight into the propagation of SEP particles throughout the inner heliosphere, especially when Mars is connected to the backside of the sun
- RAD has measured 23 SEP events so far and will continue to monitor the space weather at Mars throughout the declining phase of the solar cycle on the way to the next solar minimum

RAD is supported by NASA (SMD/Heliophysics) under JPL subcontract #1273039 to SwRI ...and by DLR in Germany under contract with Christian-Albrechts-Universitat (CAU).

THANKS FOR YOUR ATTENTION!