Recent RAD Results:
The Oct 28, 2021 & Feb 16, 2022 Solar Storms & Radiation Shielding at Paraipetuy Pass

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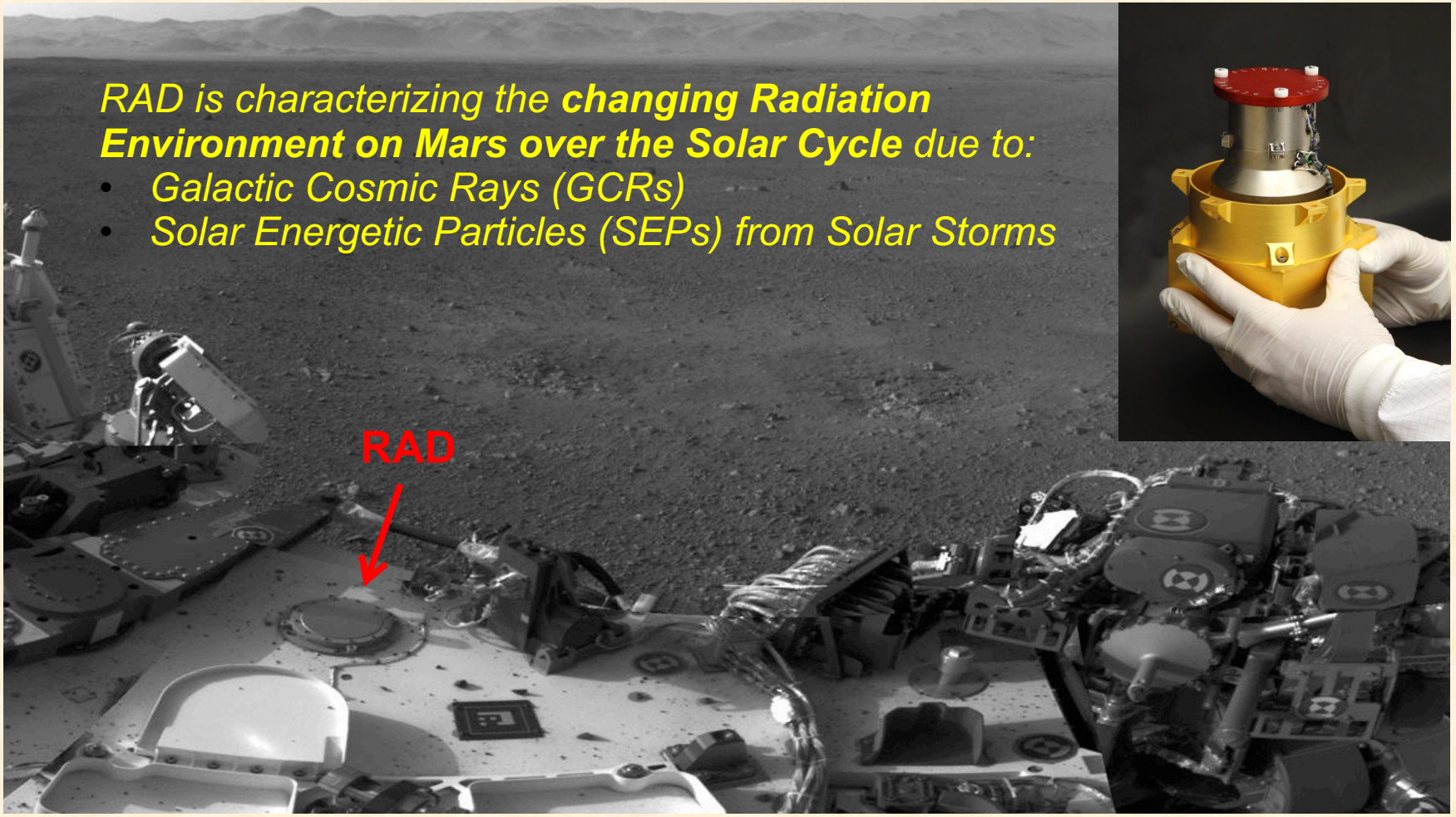
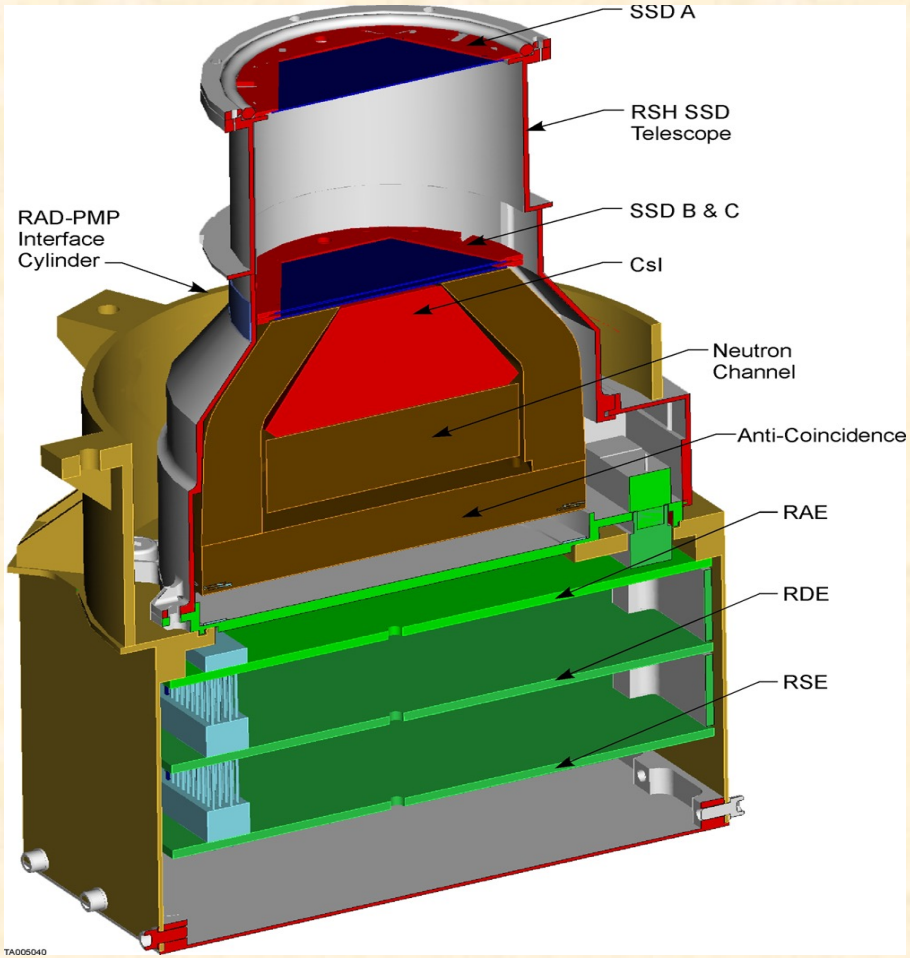
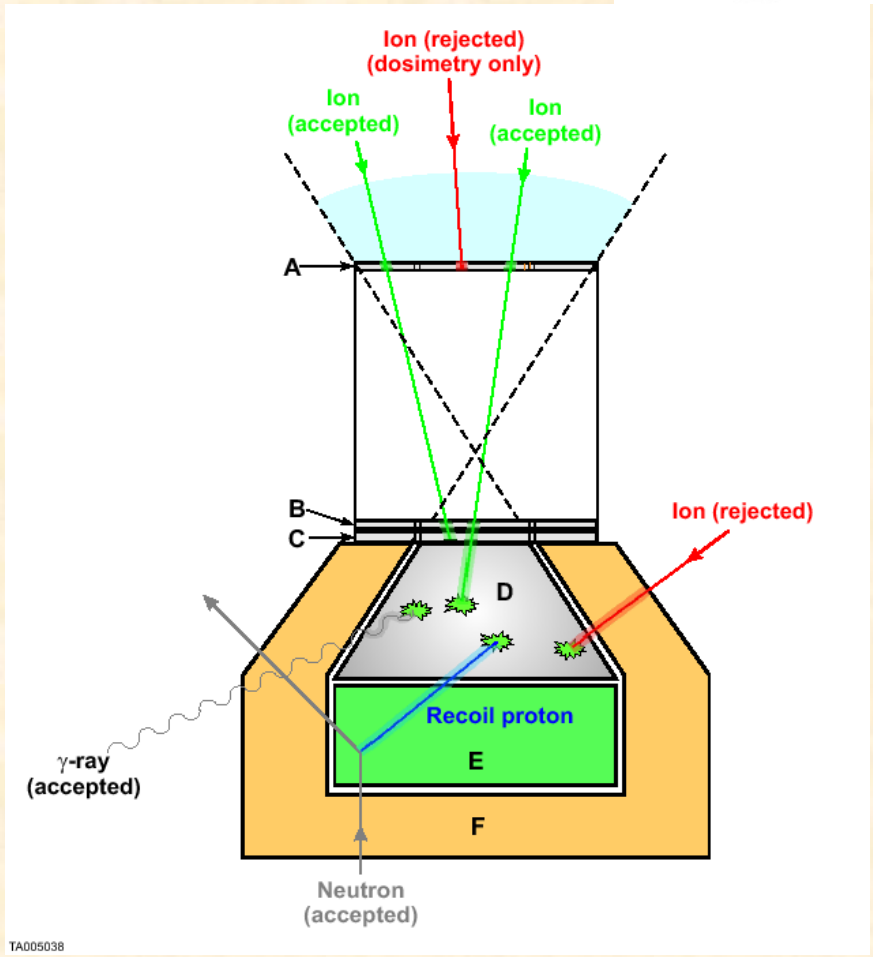
RAD on the Mars rover *Curiosity* is a working Asset on the Surface of Mars...



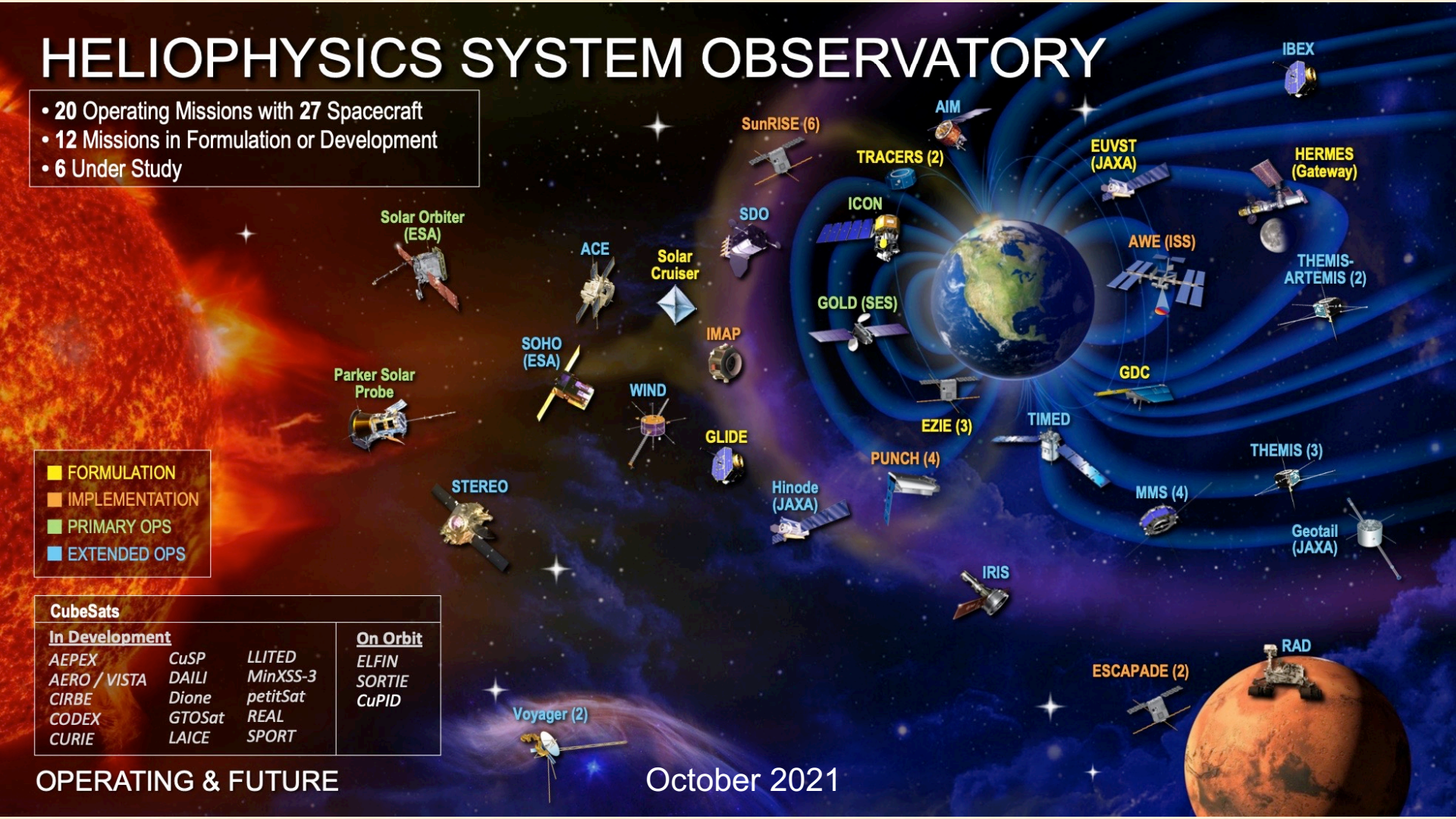
RAD Cut-away View and Principle of Operation





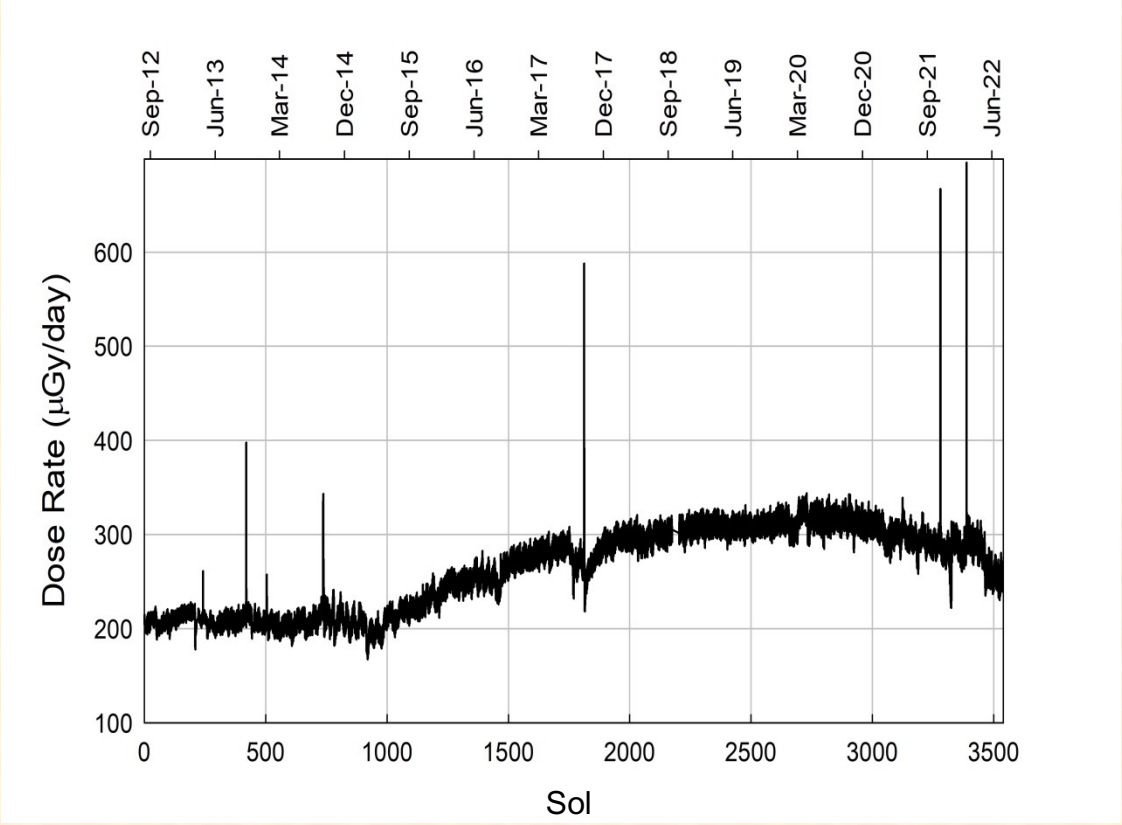
A	Solid State Detector (SSD) A	D	Cesium Iodide (CsI)
B	SSD B	E	Neutron Channel (Bicron 432M scintillating plastic)
C	SSD C	F	Anti-coincidence Shield

MSL RAD: NASA's Newest Member of the Heliophysics System Observatory (HSO)



RAD Radiation Dose Rate Measurements over the Course of the MSL Mission

- We are now past Solar Minimum and on our way into the Maximum of Cycle 25
- Peak GCR dose rates were observed in March / April of 2020
- As the sun gets more active on its way to Solar max, large solar storms are more likely
- RAD saw its two biggest solar events to date in October 2021 & February 2022

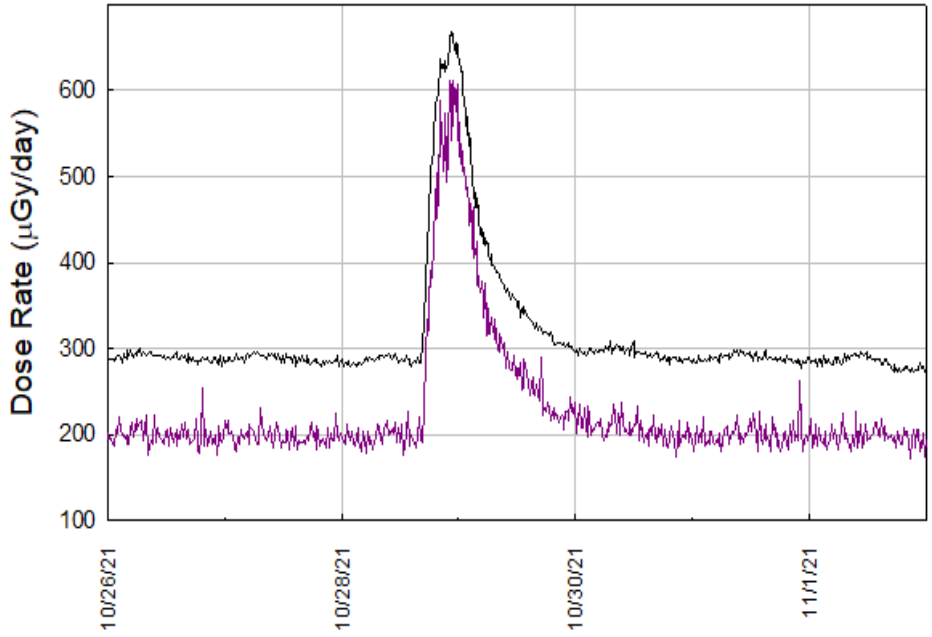


RAD Outlook for Curiosity's fourth extended mission (2023-25):

- complete an entire 11-year solar cycle of observations
- characterize potentially large/extreme events which can occur during Solar Max

The Solar Storm of Oct 28, 2021

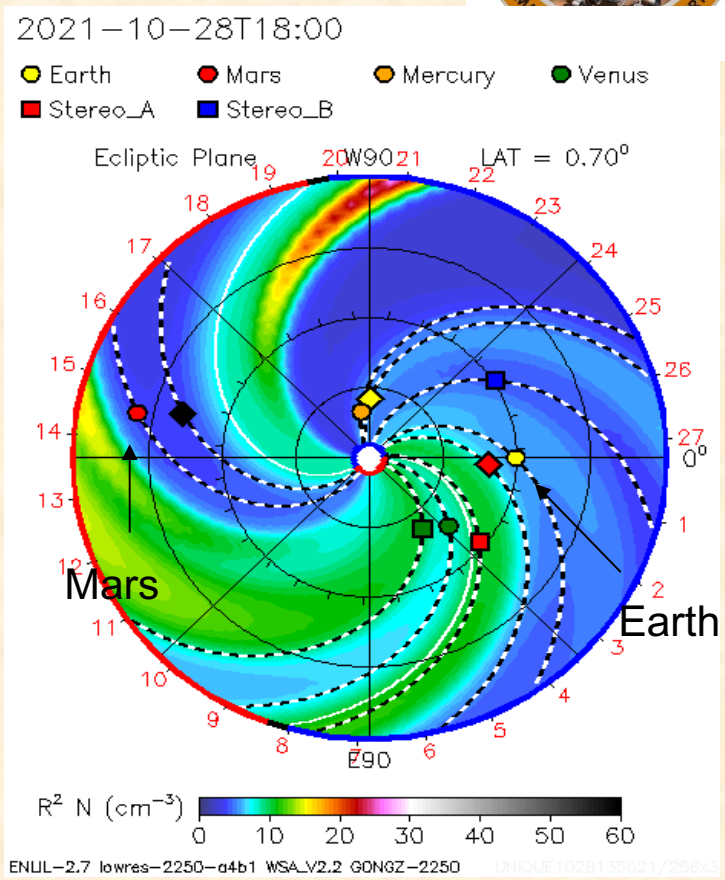
- Dose rates in ***E*** increased by ~350 uGy/day (factor of ~2.25) over the course of a few hours, reaching a peak dose of ~670 uGy/day
- ***B*** dose rates increased by ~400 uGy/day (factor of ~3)
- ***B*** is less shielded, so more lower-energy protons can reach the detector (compared to ***E***)
- *This shows the event was stronger than the biggest previous event seen by RAD in Sep 2017*

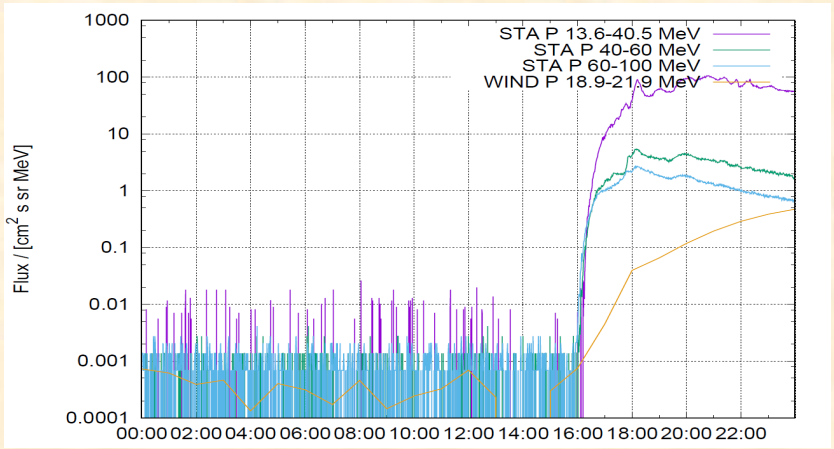


Black: Dose Rate in E (tissue-equivalent)
Magenta: Dose Rate in B (Silicon)

The Solar Storm of Oct 28, 2021

- The event was caused by the first X-class flare of the solar cycle, followed by a halo CME
- Mars & Earth were magnetically well-separated by ~ 180°, but the event was still seen at both planets
- ENLIL forecasting didn't predict such a widespread event
- Flux increases were seen by several spacecraft throughout the heliosphere
- Understanding these widespread events is crucial for space weather prediction

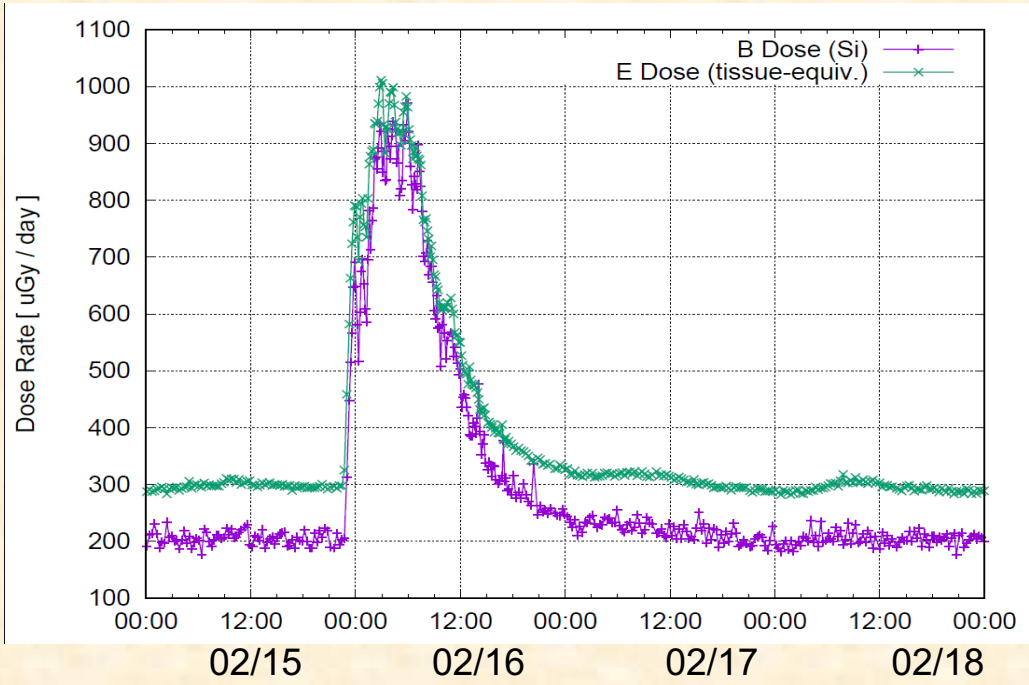




- RAD provides highly important measurements from Mars to cross-compare with the fleet of particle detectors in the heliosphere

The Solar Storm of Feb 16, 2022

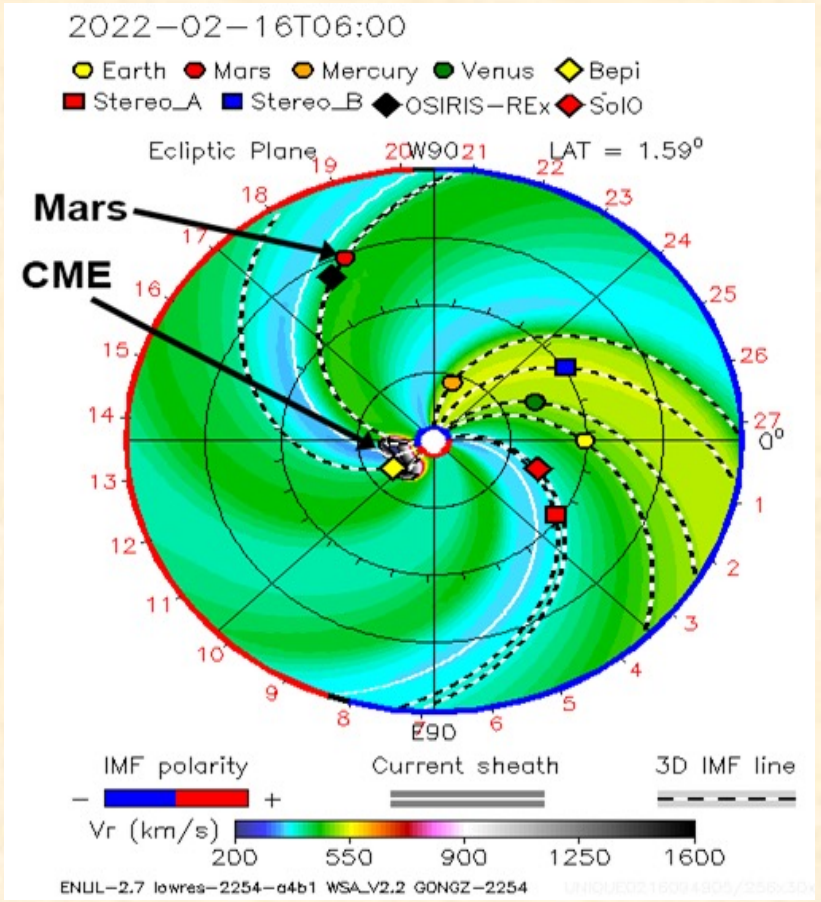
- The 16 February solar storm was the biggest event detected by RAD to date
- It marks the first time RAD measured dose rates **>1000 uGy/day** on the Martian surface
- Dose rates increased by factors of x3.4 (in the E detector) and x4.5-5 (in the B detector)



- The event was not seen at Earth (no particle flux increase)
- Other spacecraft such as STEREO-A only saw small increases in flux

The Solar Storm of Feb 16, 2022

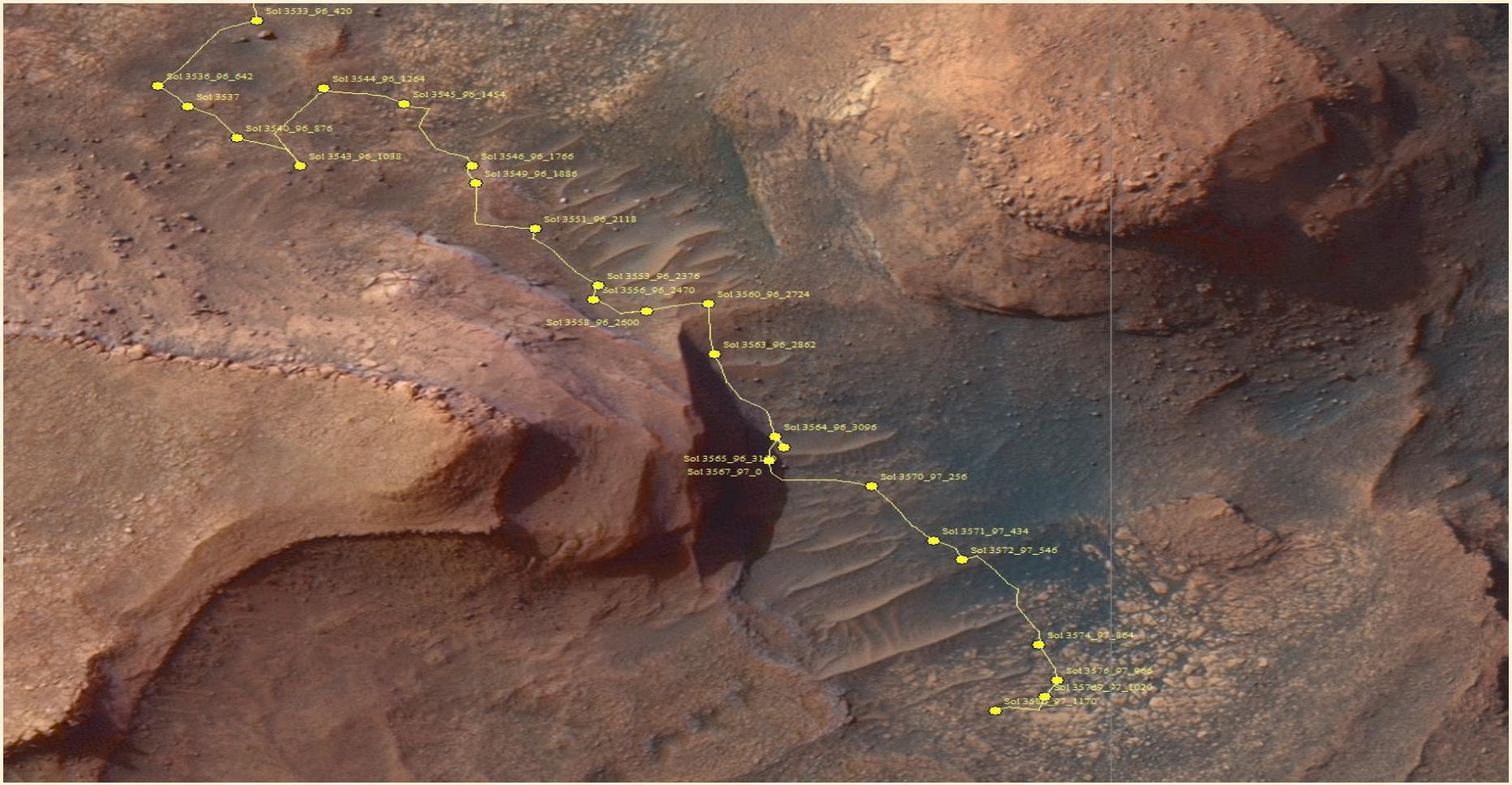
- Mars & Earth were separated by ~135˚
- The event was caused by a CME launched from the backside of the sun
- Mars was still connected to the flank of the CME
- SEP measurements spread-out throughout the heliosphere are highly important to understand the longitudinal spread of these events



- Space agencies planning space station EVAs or off-base Lunar or Martian “sorties”, need to understand if any active regions on the far side of the sun could develop into solar storms that might still reach the astronaut on the near side...

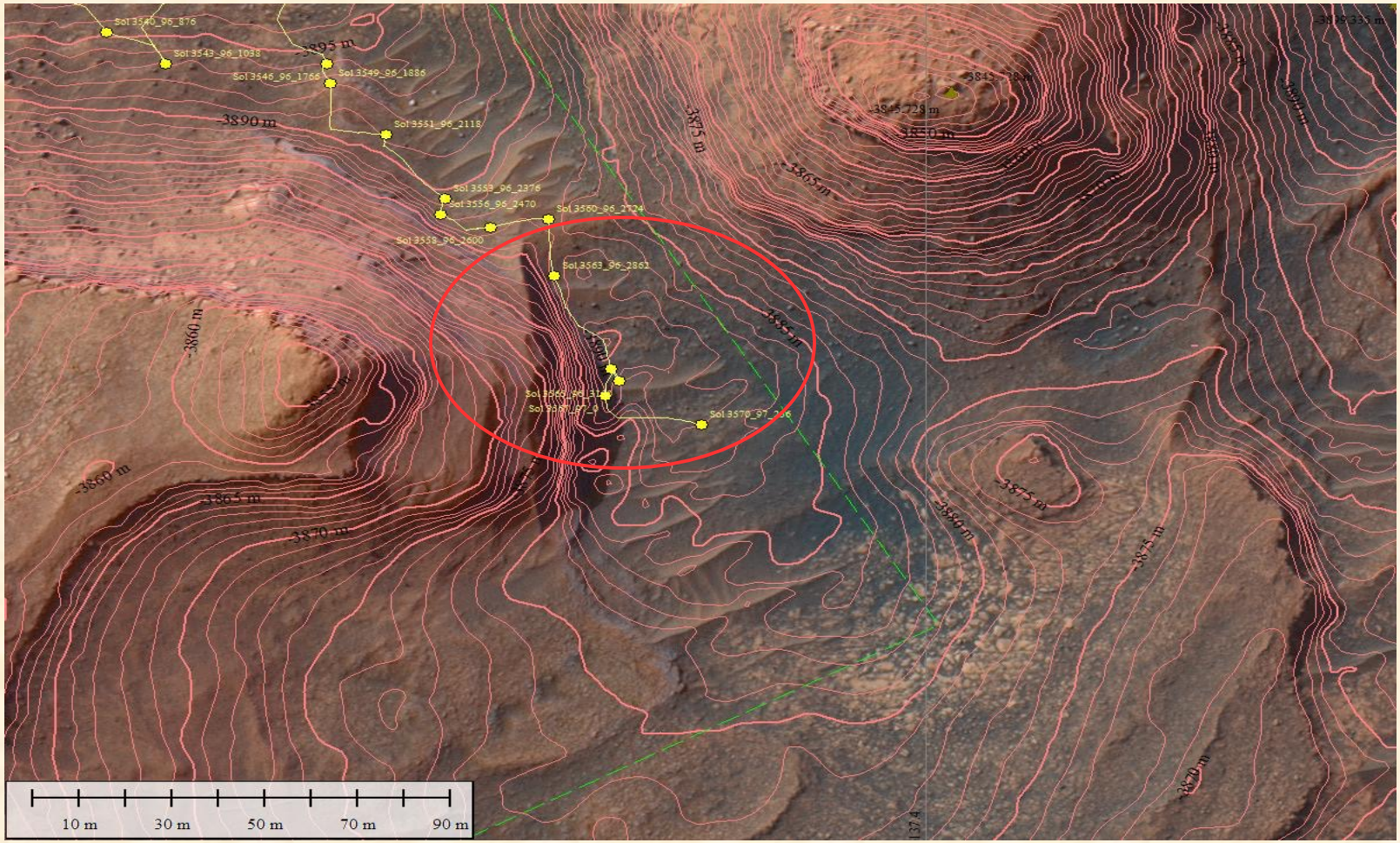
- … to provide a reliable All-Clear forecast

Radiation Shielding at Paraitepuy Pass



The drive through Paraitepuy Pass & particularly the close approach to Bolivar offered a new & exciting opportunity to measure the radiation shielding effect

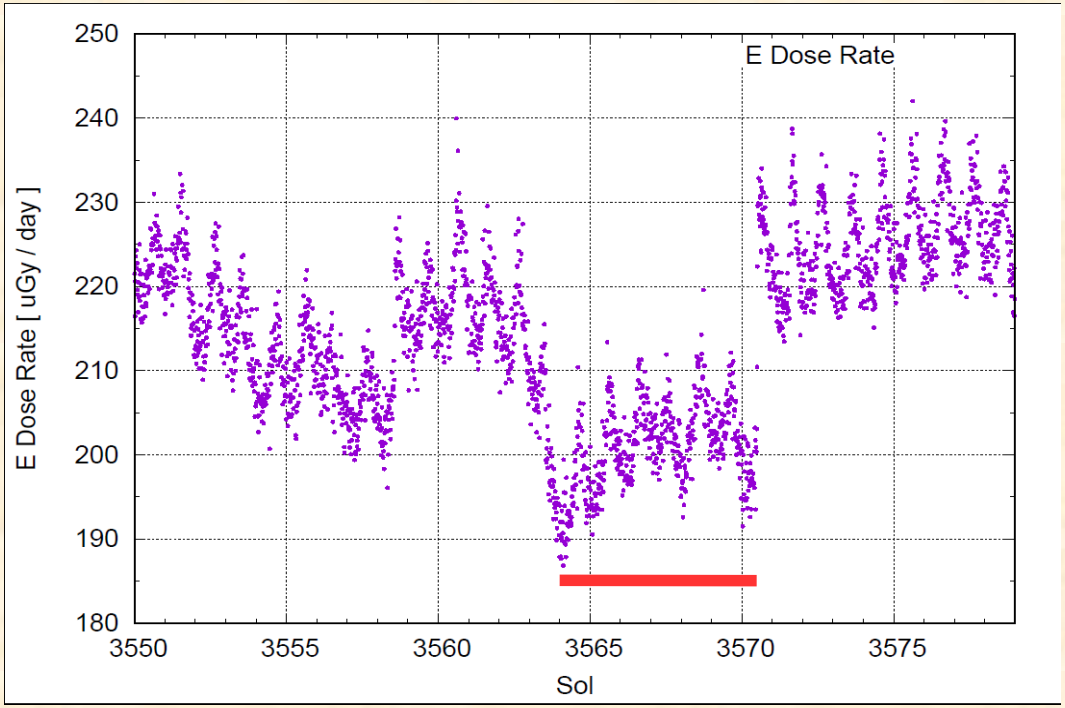
Radiation Shielding at Paraitepuy Pass



From sol 3563 to 3570 in the Pass & in close proximity to Bolivar, RAD measured a distinct decrease in dose rate

Radiation Shielding at Paraitepuy Pass

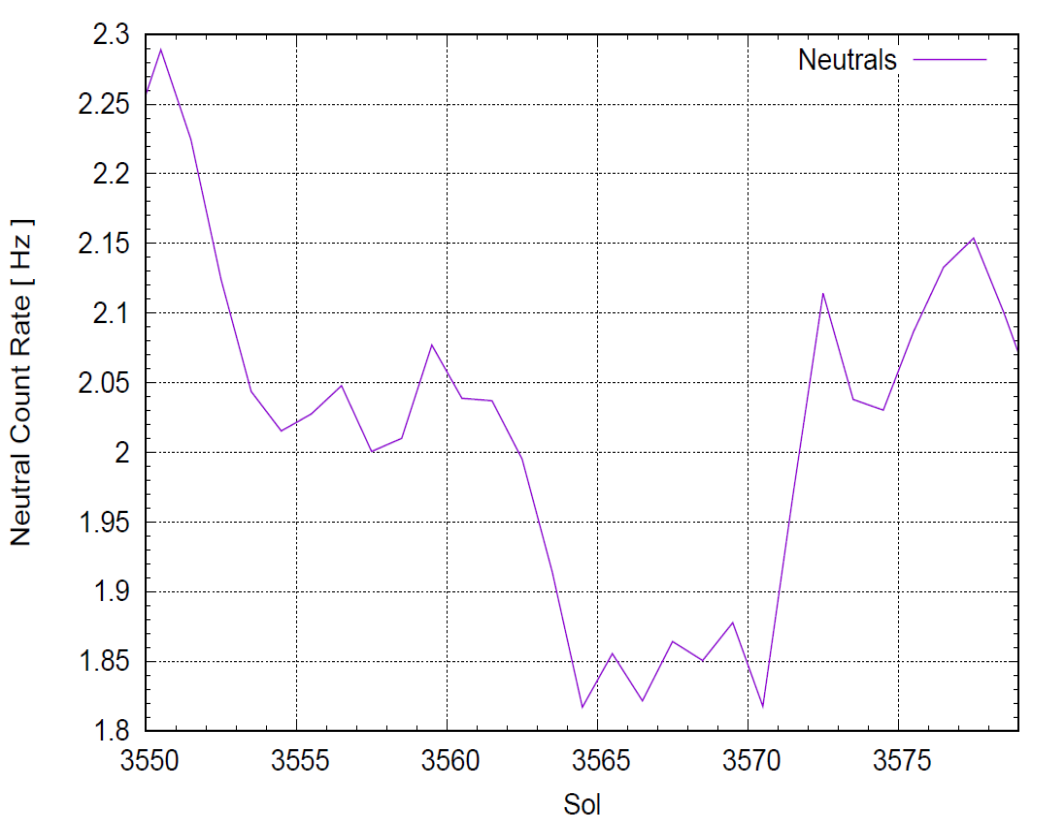
- Dose rate decrease was >11-12%
- Analysis needs to take into account that Curiosity was already traversing close to Bolivar & Deepdale for >20 days before the closest approach...
- … to correctly estimate the expected / unshielded dose rate and thus the decrease from the shielding effect



- Decrease in dose rate in the same order of magnitude (at least ~ 10%) as previous dedicated measurement campaigns at Maria Gordon Notch at Mt Mercou...

Radiation Shielding at Paraitepuy Pass – Neutral Particles

- Decrease in the neutral particle radiation was also >10-11%
- Neutrals here are gamma-rays and neutrons with energies >10 MeV
- (Important when comparing to shielding effects seen by DAN Passive which measures much lower-energy thermal neutrons)



Radiation Shielding at Paraitepuy Pass – Summary

- Making use of available in-situ shielding could be an important aspect to reduce mass & cost requirements for future Mars missions
- Measuring the radiation shielding effect provides input for the planning of radiation storm shelters for future human explorers of Mars
- RAD measurements under different shielding conditions (different occlusion angle & azimuth range) are useful to validate angular-dependent radiation transport models used to estimate the effectiveness of storm shelters
- Additionally, shielding measurements let us also calculate the changing contribution of the MMRTG to the RAD dose rate...
- … by comparing the dose decreases in detectors B (sensitive to RTG) & detector E (insensitive to RTG contribution)
- The RAD team is currently preparing a manuscript summarizing all observed radiation shielding measurements to date...
- … and would like to thank the project for accommodating these highly interesting & important shielding measurements!

Thank you!

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- ...and by DLR in Germany under contract with Christian-Albrechts-Universitat (CAU).