An Overview of a Solar Storm at Mars

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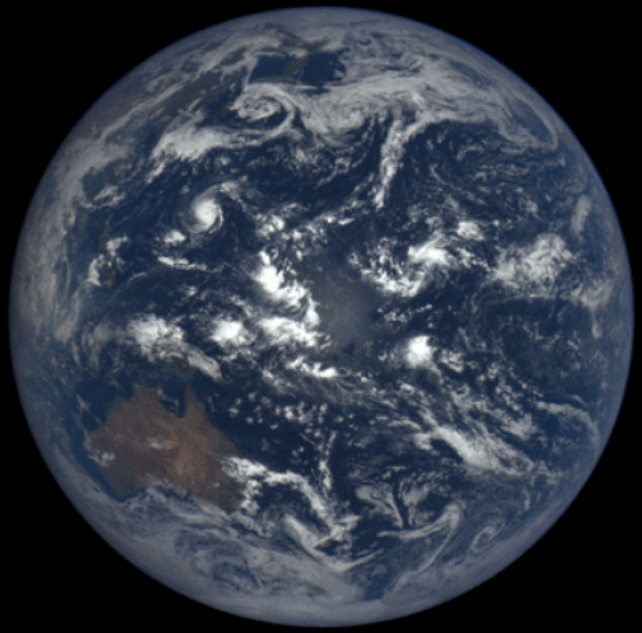
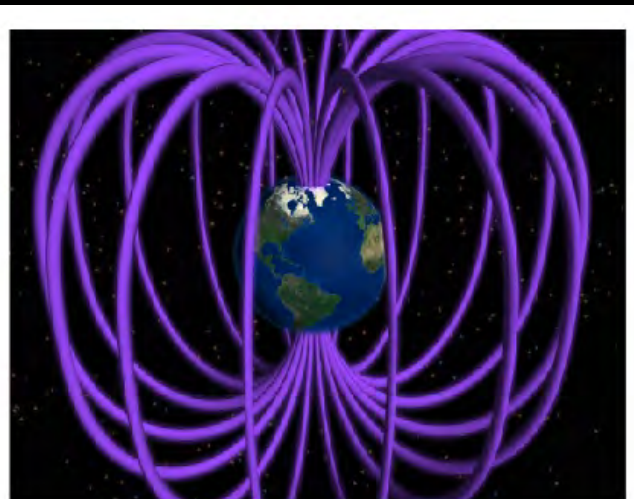
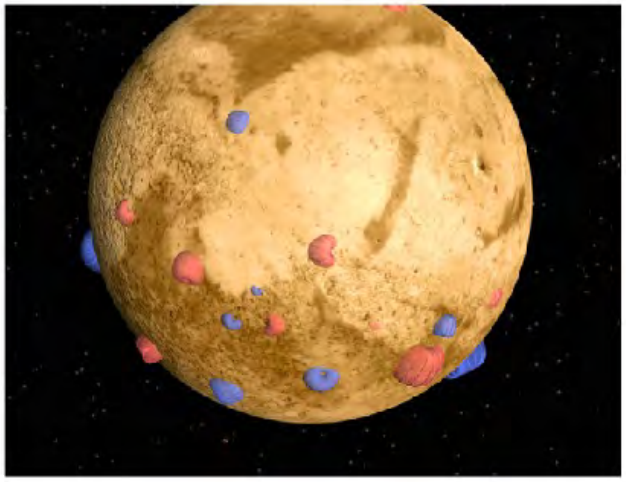
Comparison of Mars with Earth

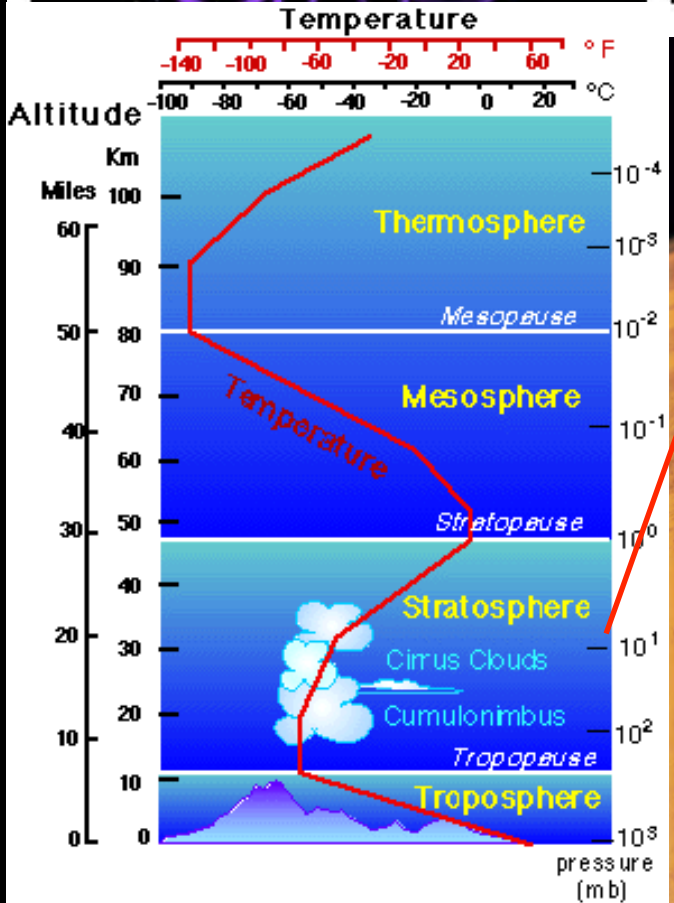


- Diameter: 53%, **Mass**: 10% of Earth. So Mars cooled faster and (mostly) ran out of volcanic activity ~3 billion years ago.
- Gravity: 38% of Earth. Lower escape velocity: 2 km/s vs. 7 km/s. → Gas can escape more easily from Mars.

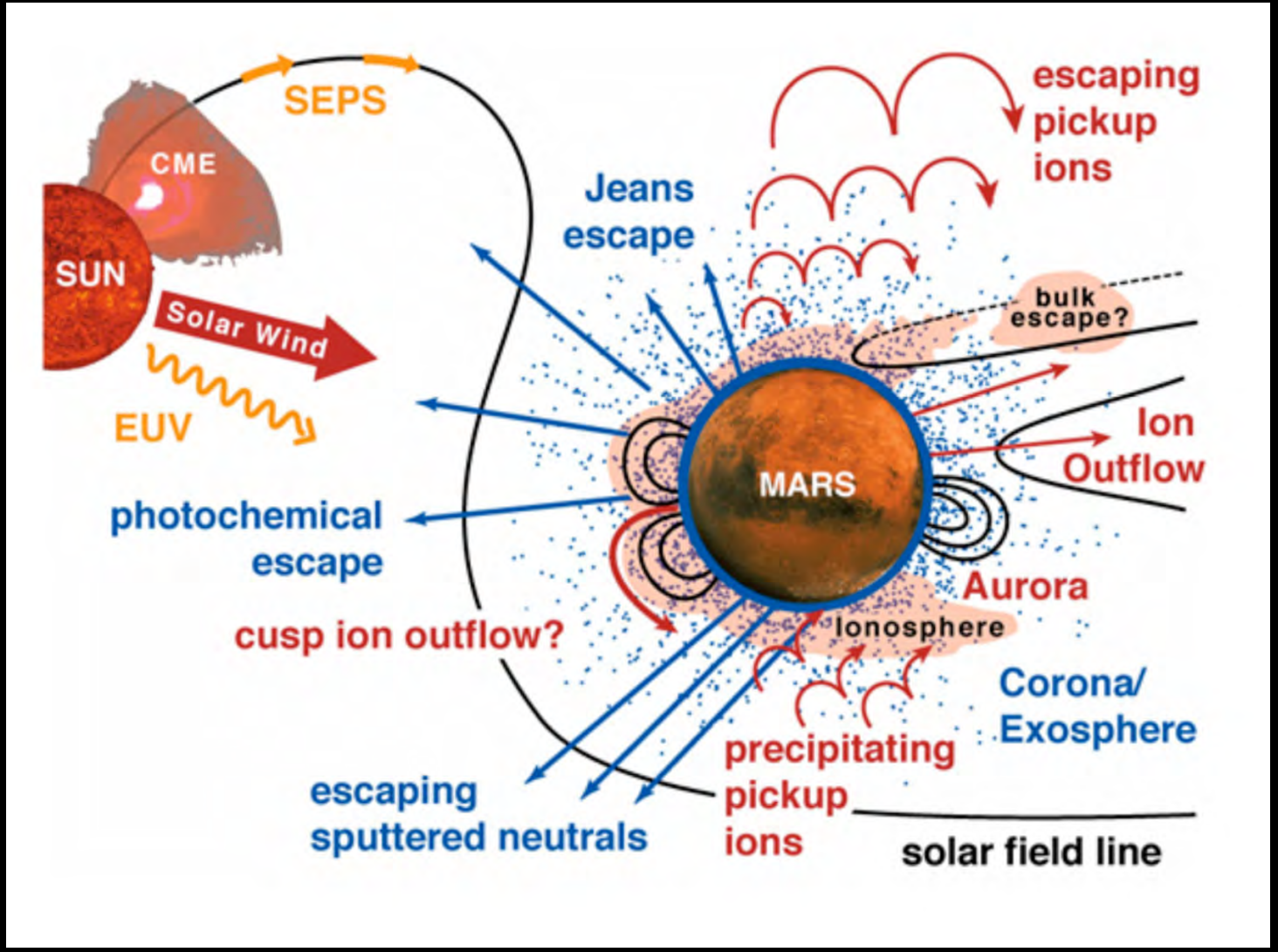
Mars have a thin atmosphere and does not have a global magnetic field to shield it.





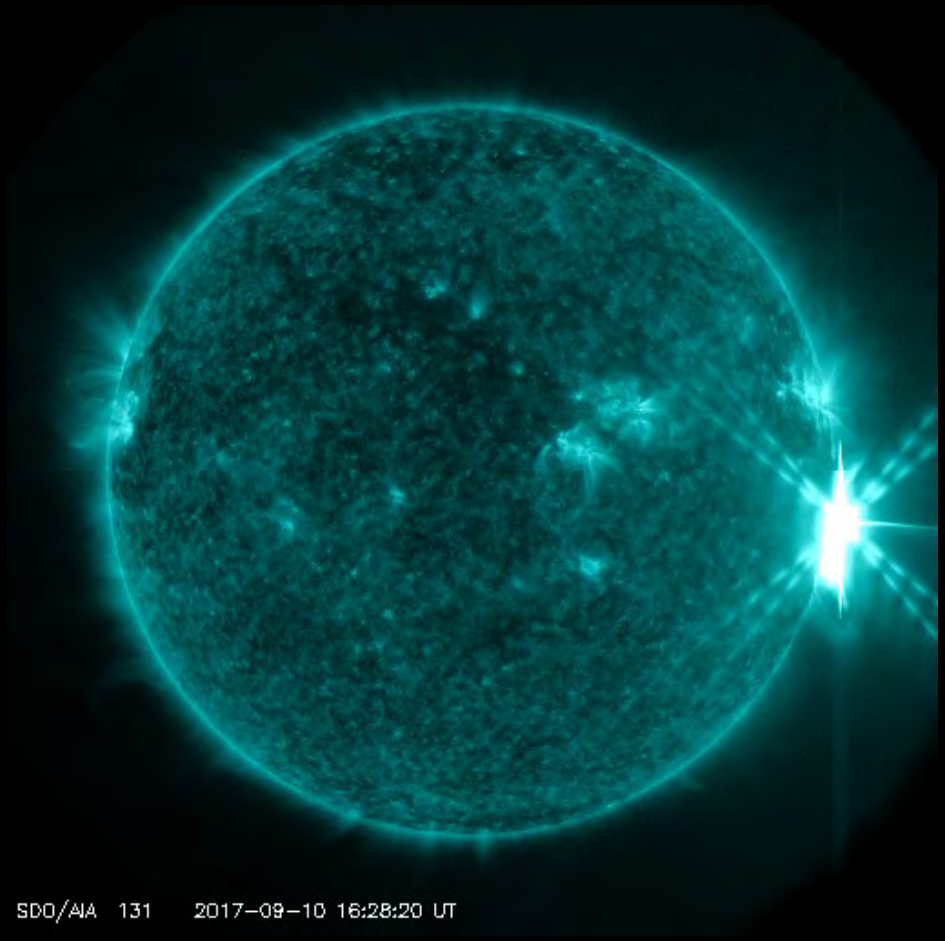


Why study solar storms at Mars? We want to understand the space weather effects on atmospheric loss over time to answer the question: Where did the water go?

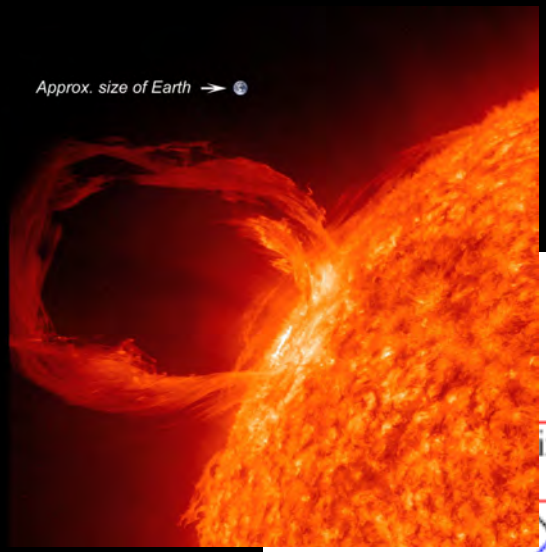


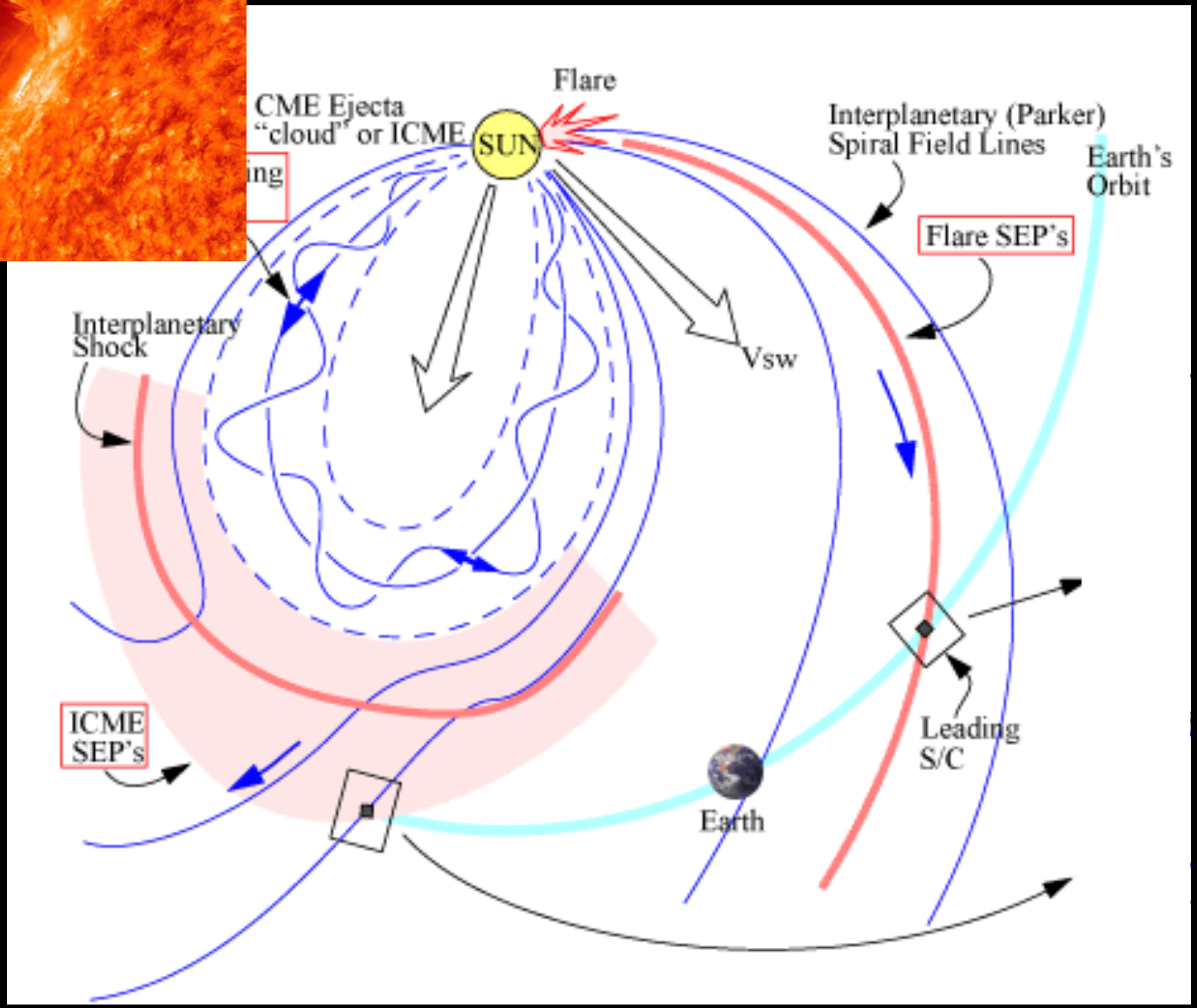
For future human exploration, we need to better understand space weather and related hazards at Mars.

Solar storm started on 10 September 2017: Eruption of an long-duration (~1hr) X8.2 class flare and a fast coronal mass ejection (CME)

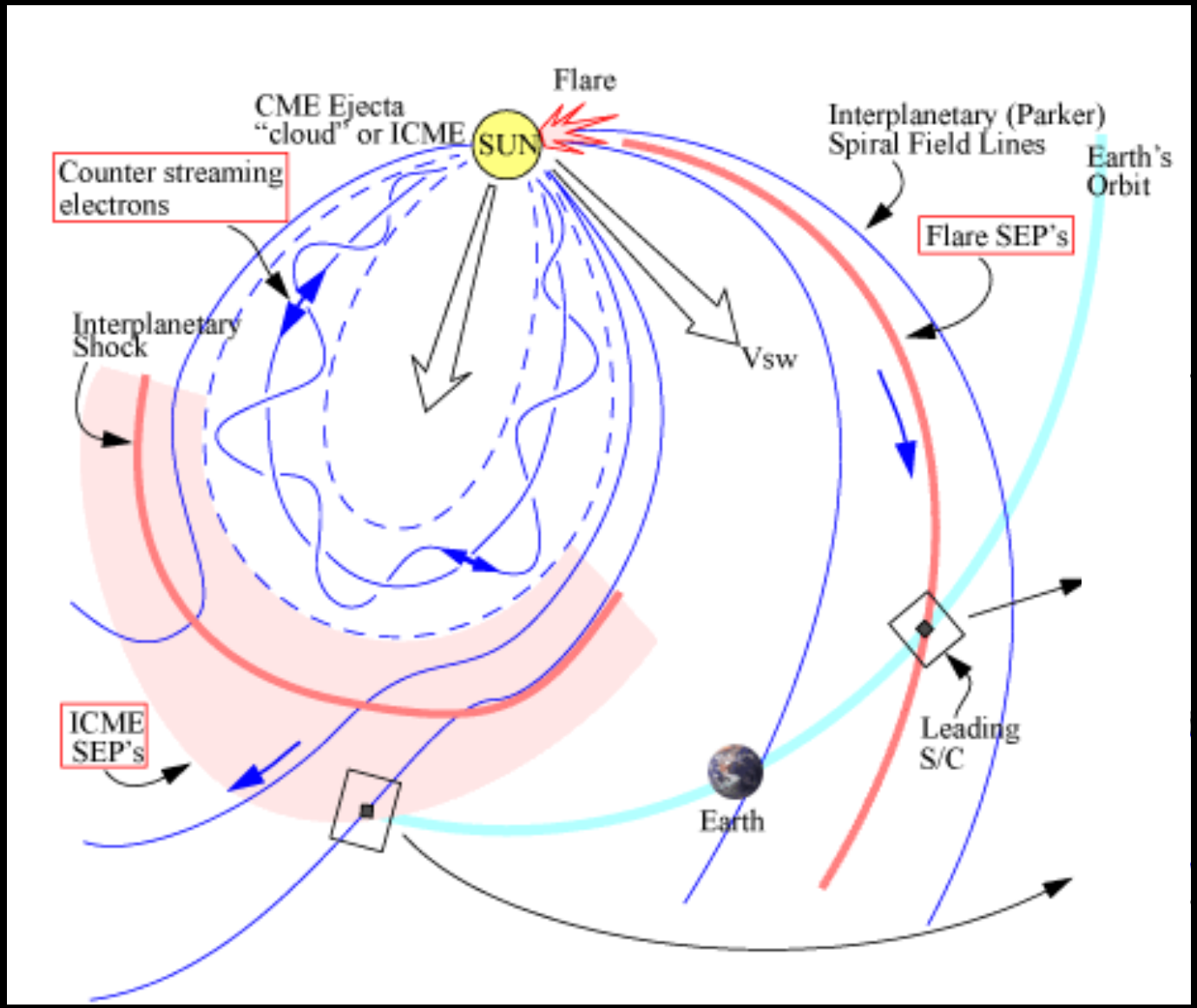


NASA/SDO/AIA

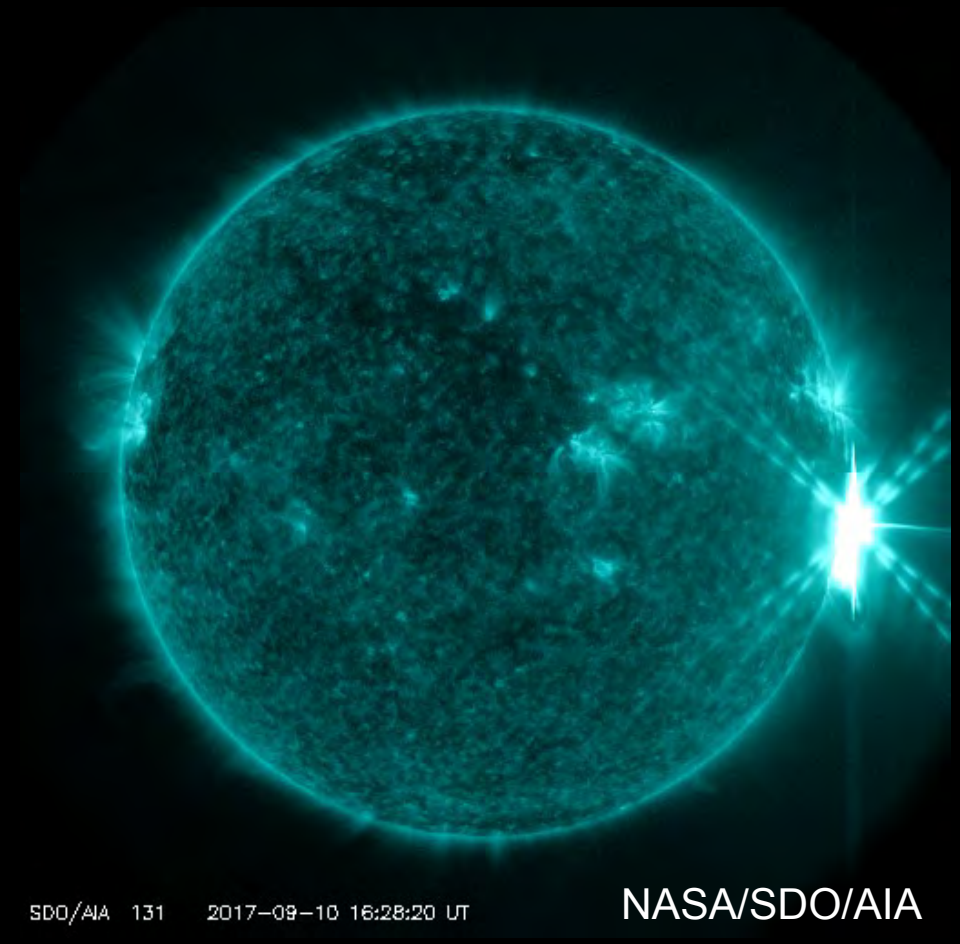

Approx. size of Earth


Flare
CME Ejecta
"cloud" or ICME
SUN
Interplanetary (Parker)
Spiral Field Lines
Earth's
Orbit
Flare SEP's
Interplanetary
Shock
Vsw
ICME
SEP's
Leading
S/C
Earth

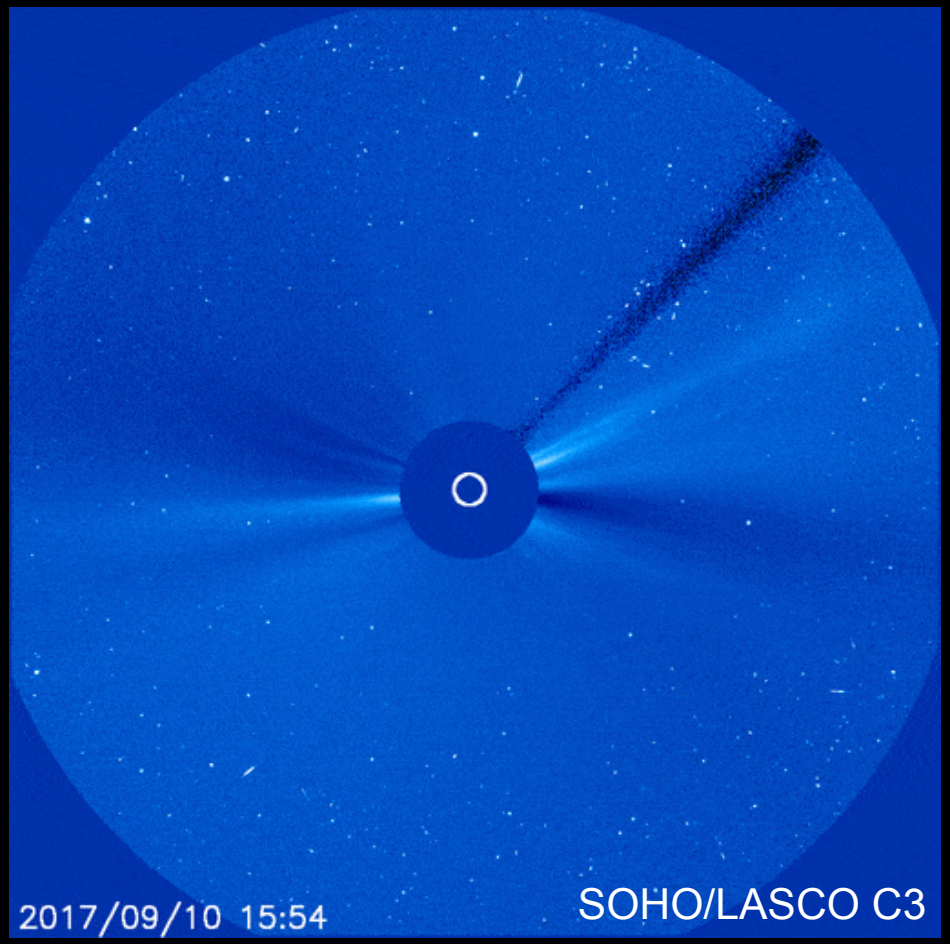
Because Earth was magnetically well-connected to the flare and CME activity region located near the west limb,



…the solar energetic particles (SEPs) streamed toward Earth and triggered a moderate radiation storm. The LASCO observations show SEPs striking the SOHO/LASCO camera near Earth.

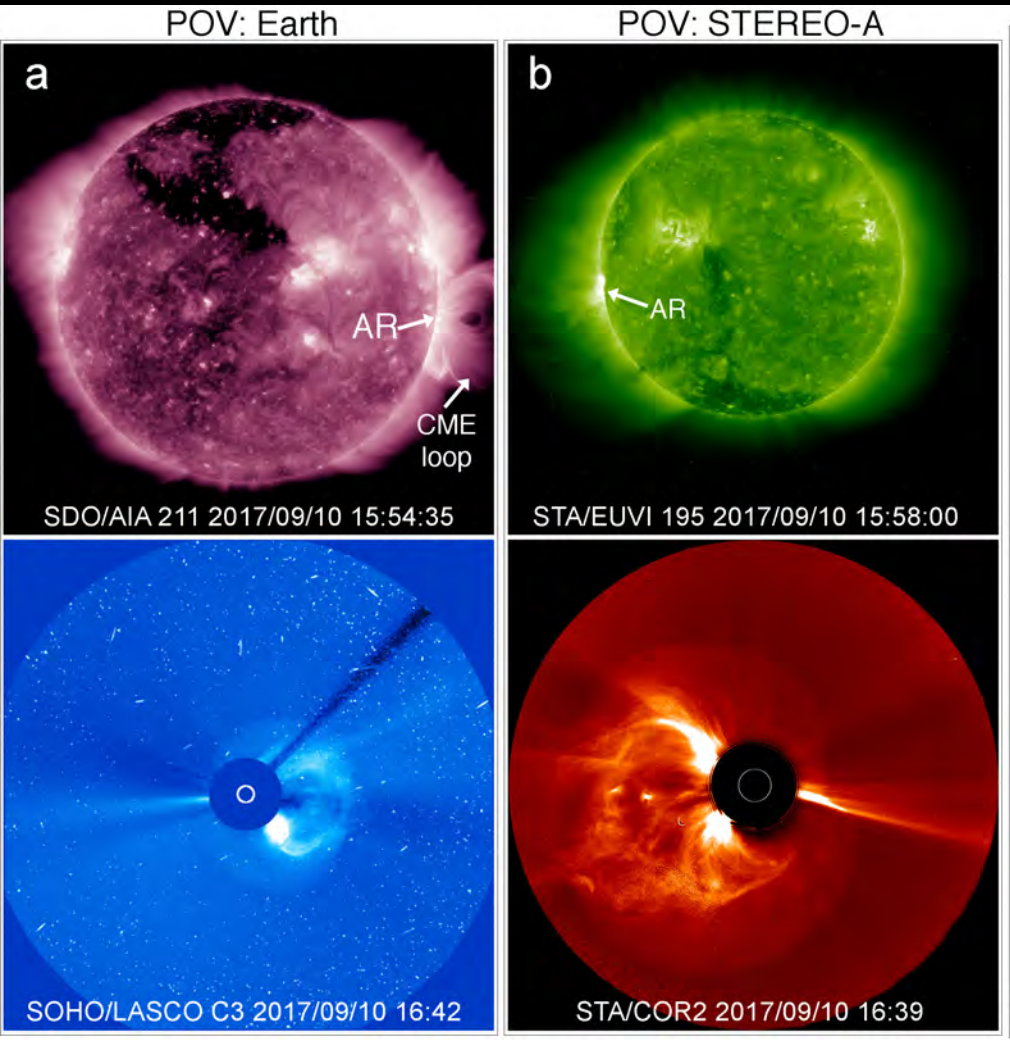


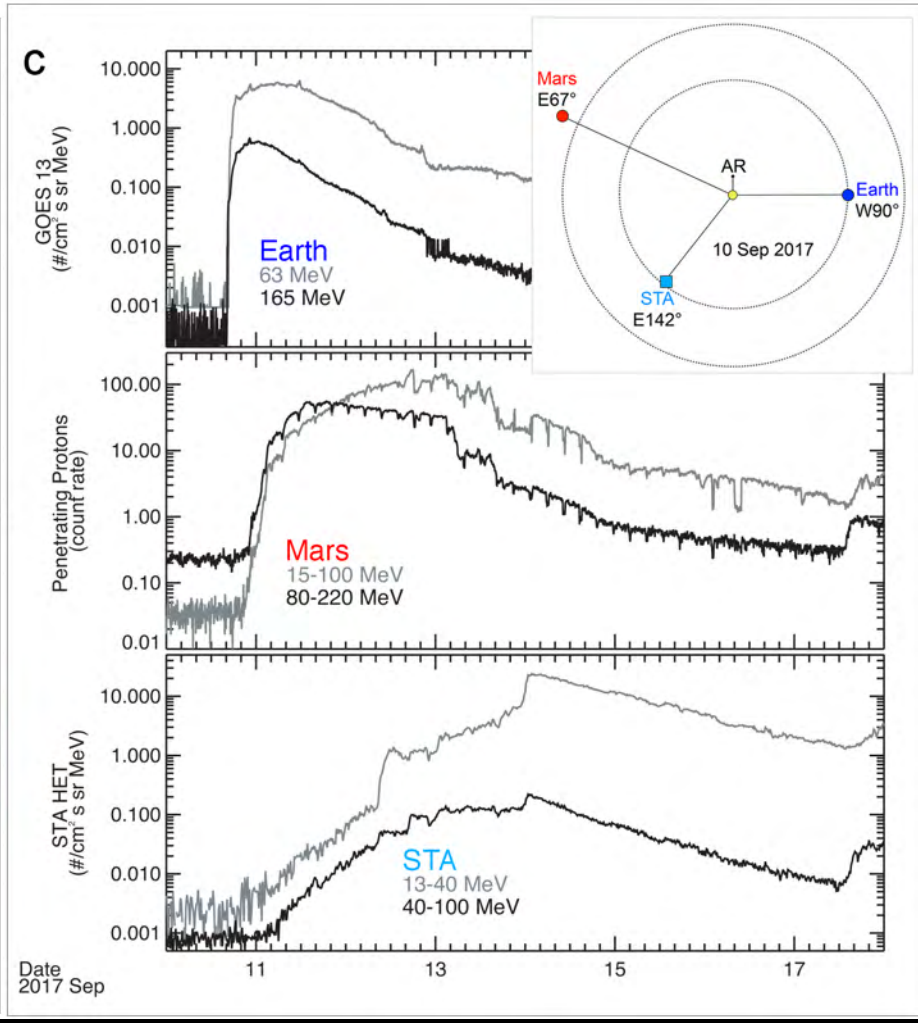
NASA/SDO/AIA



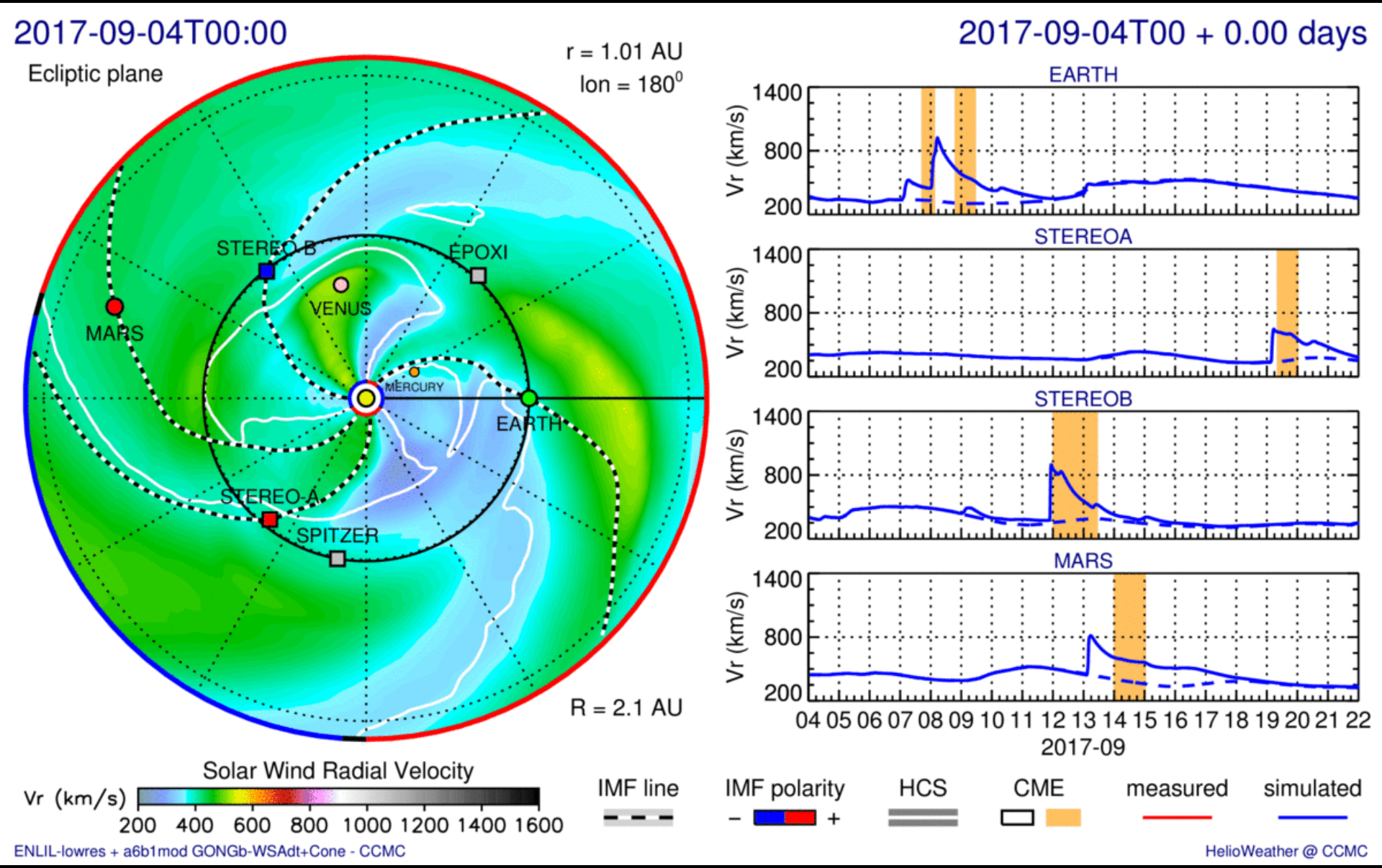
SOHO/LASCO C3

There was widespread observations of SEPs at Earth, Mars and STEREO-A triggered by the solar activity

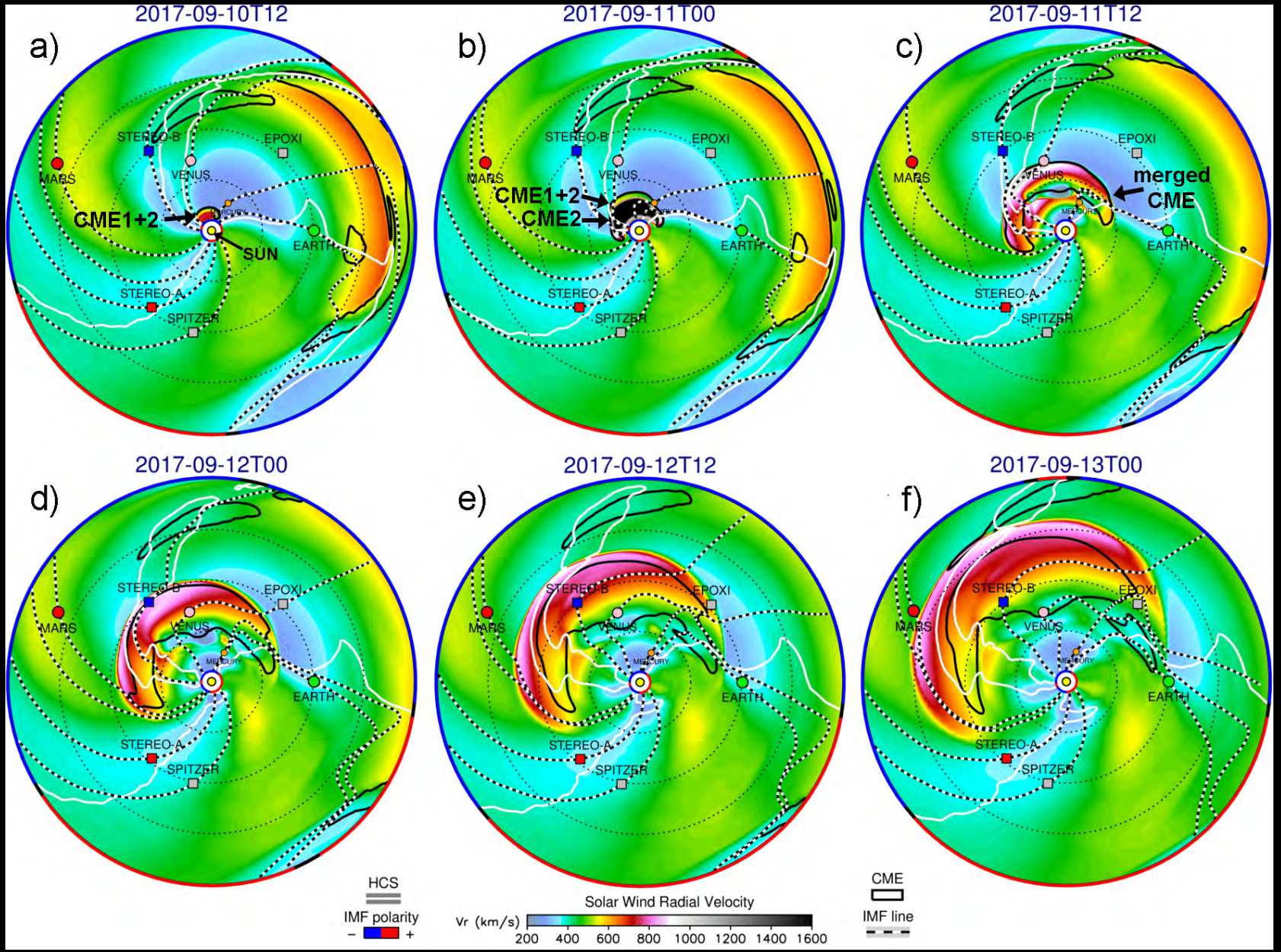




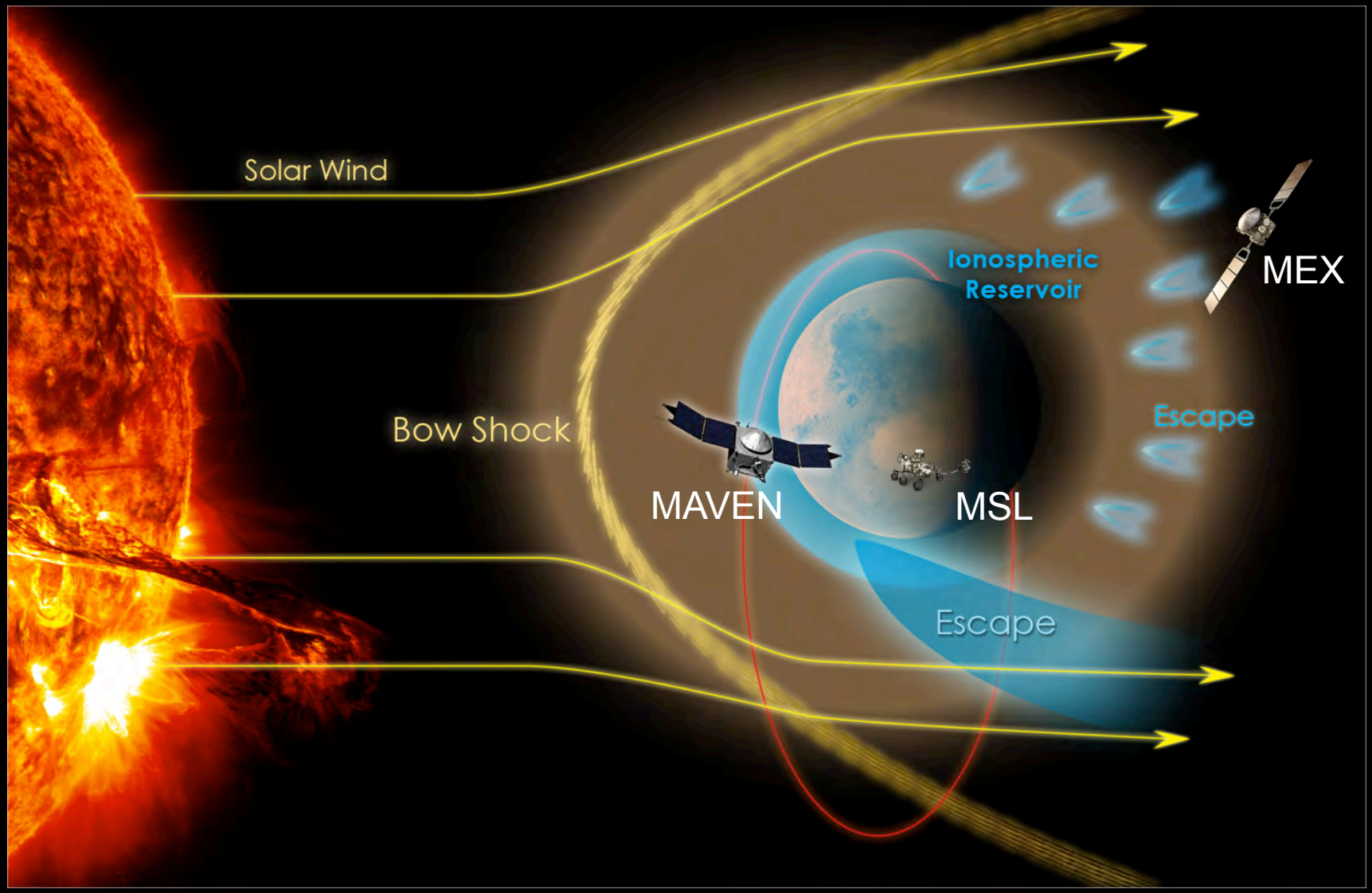
Space weather simulation for September 2017



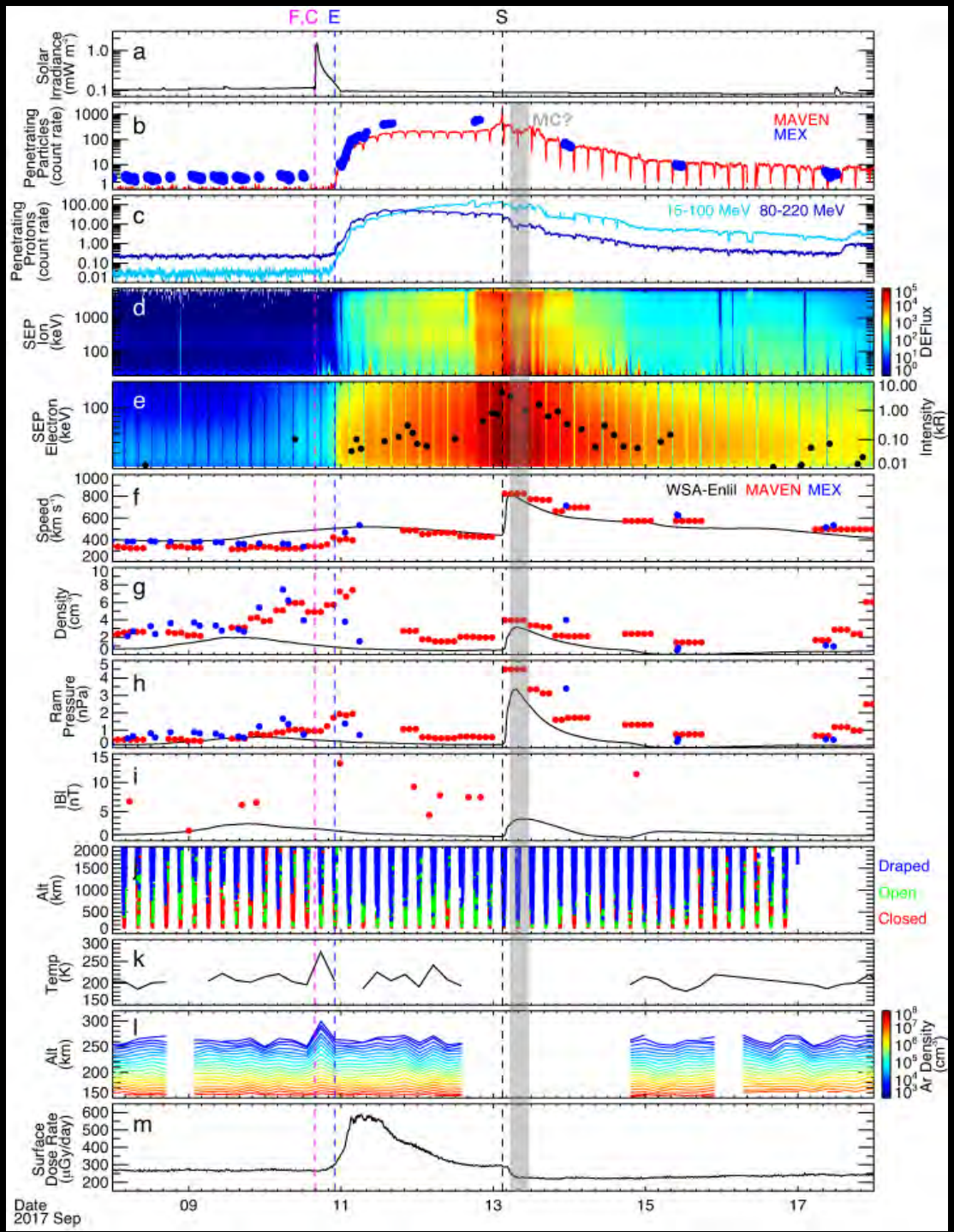
Model simulations provide global context to the local space weather conditions observed at Mars



The 10 September 2017 solar storm event provided an opportunity for instruments on board MAVEN (Mars Atmosphere and Volatile Evolution), MEX (Mars Express), and MSL (Mars Science Laboratory), to simultaneously observe the space weather impact at Mars.

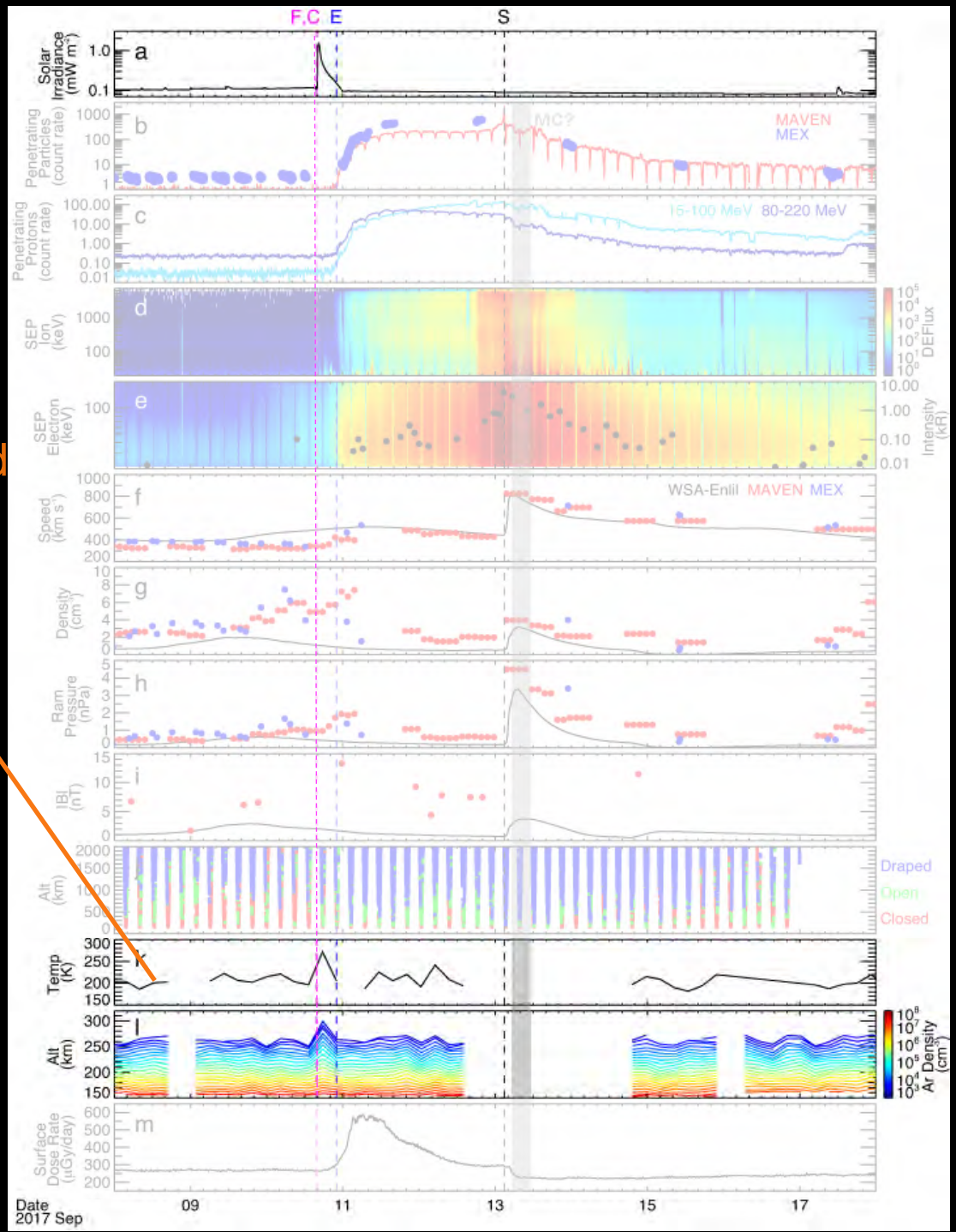


Stacking the MAVEN, MEX, and MSL observations together to get an overview of the impacts and response at Mars.



Solar flare photons impacted the Martian atmosphere

At ~170 km in the thermosphere, airglow measurements from the MAVEN/IUVS instrument showed that the temperature increased by ~70k during the flare event interval.



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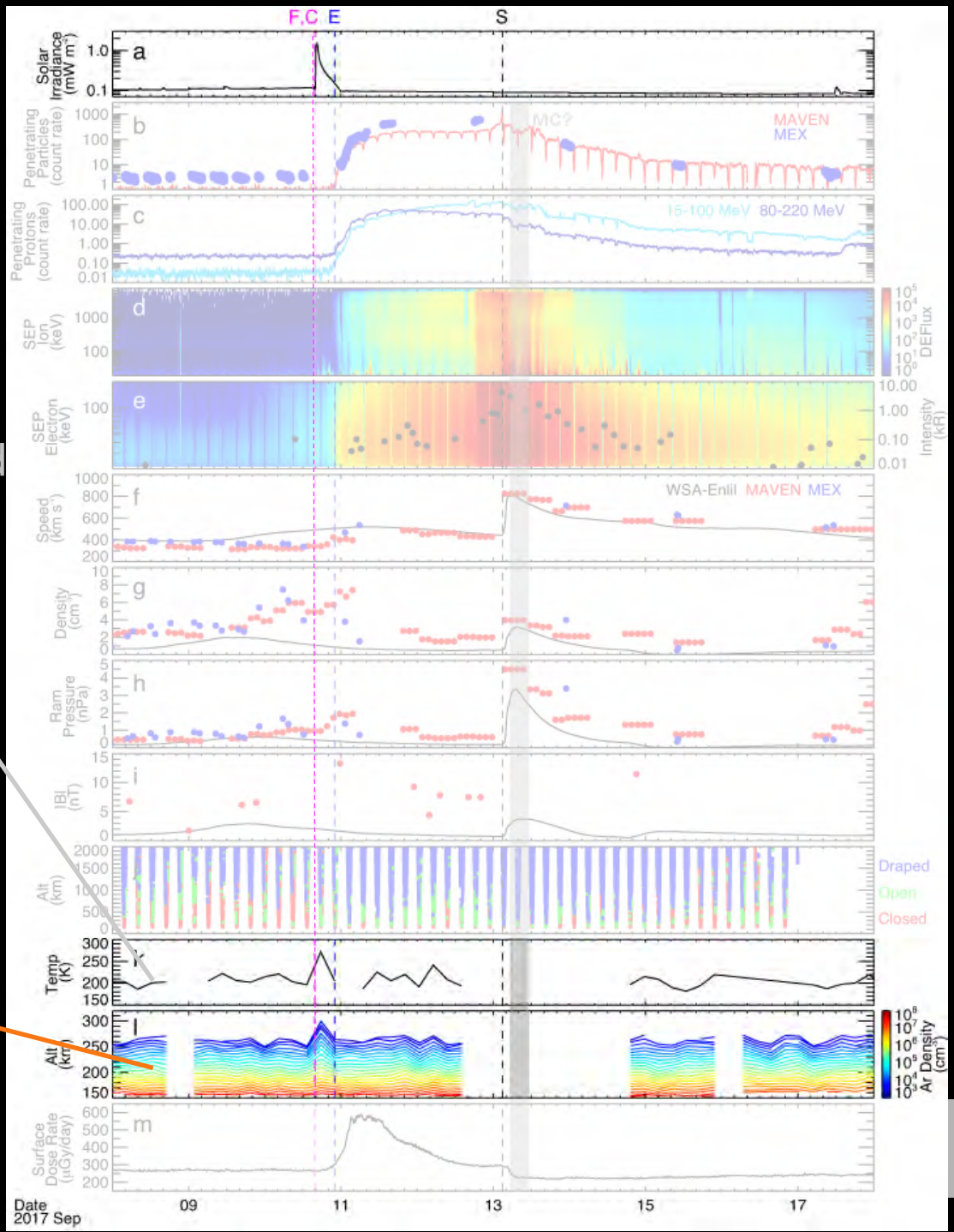
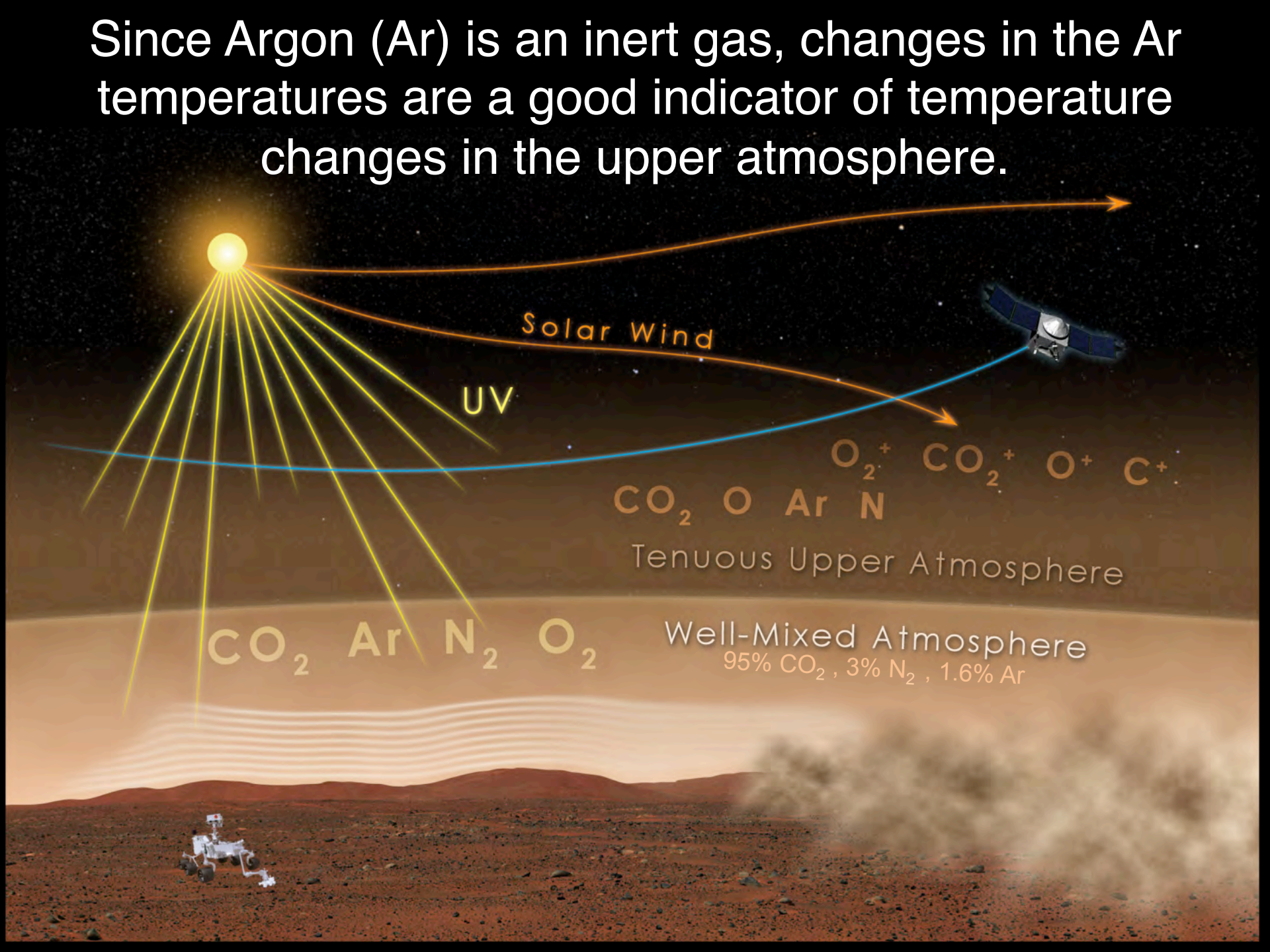
In the neutral exosphere above 195 km, MAVEN/NGIMS observations of neutral species showed significant density and temperature enhancements.



Since Argon (Ar) is an inert gas, changes in the Ar temperatures are a good indicator of temperature changes in the upper atmosphere.



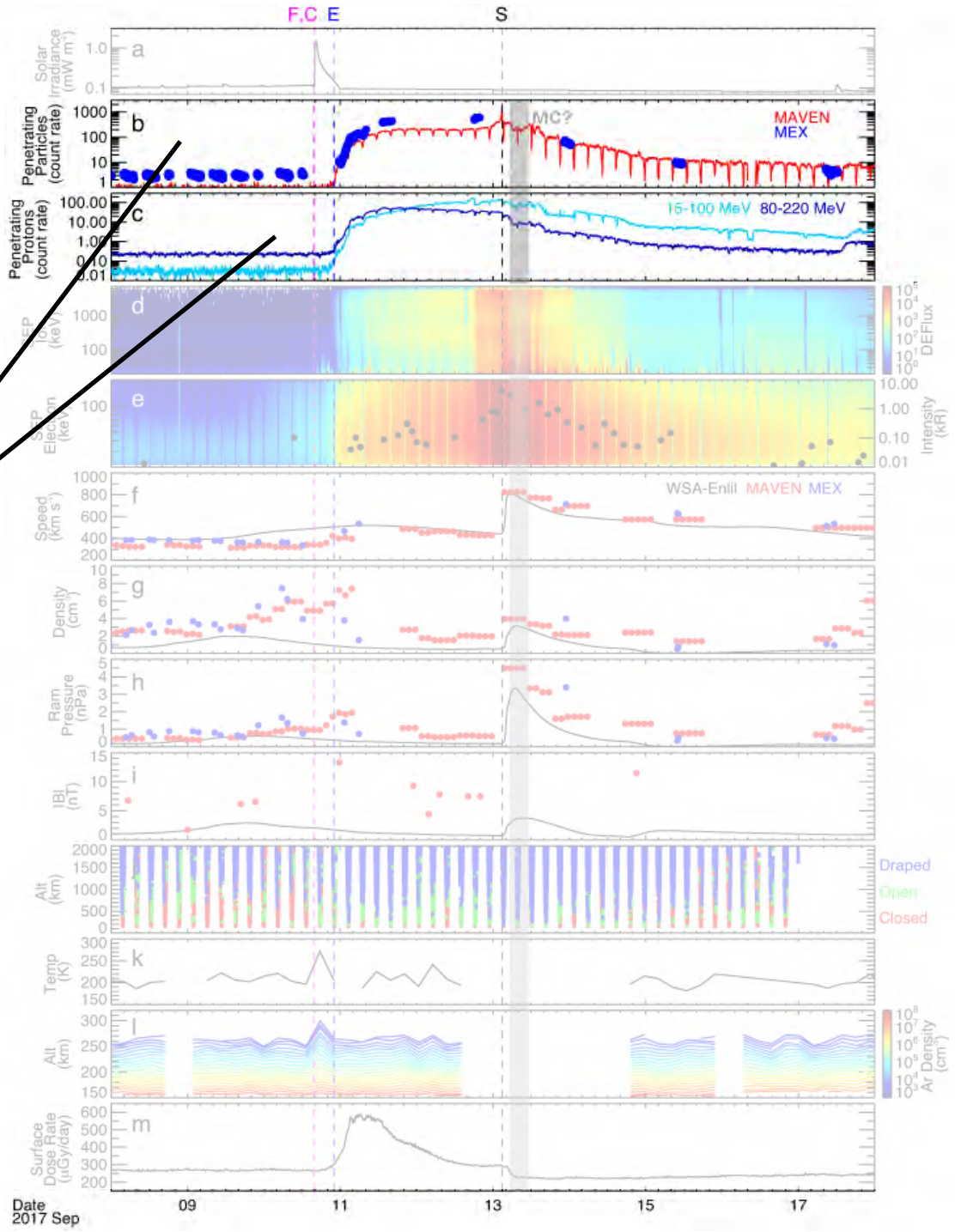
Higher energy SEPs penetrated through instrument housing to produce penetrating background counts

MAVEN/SWEA:

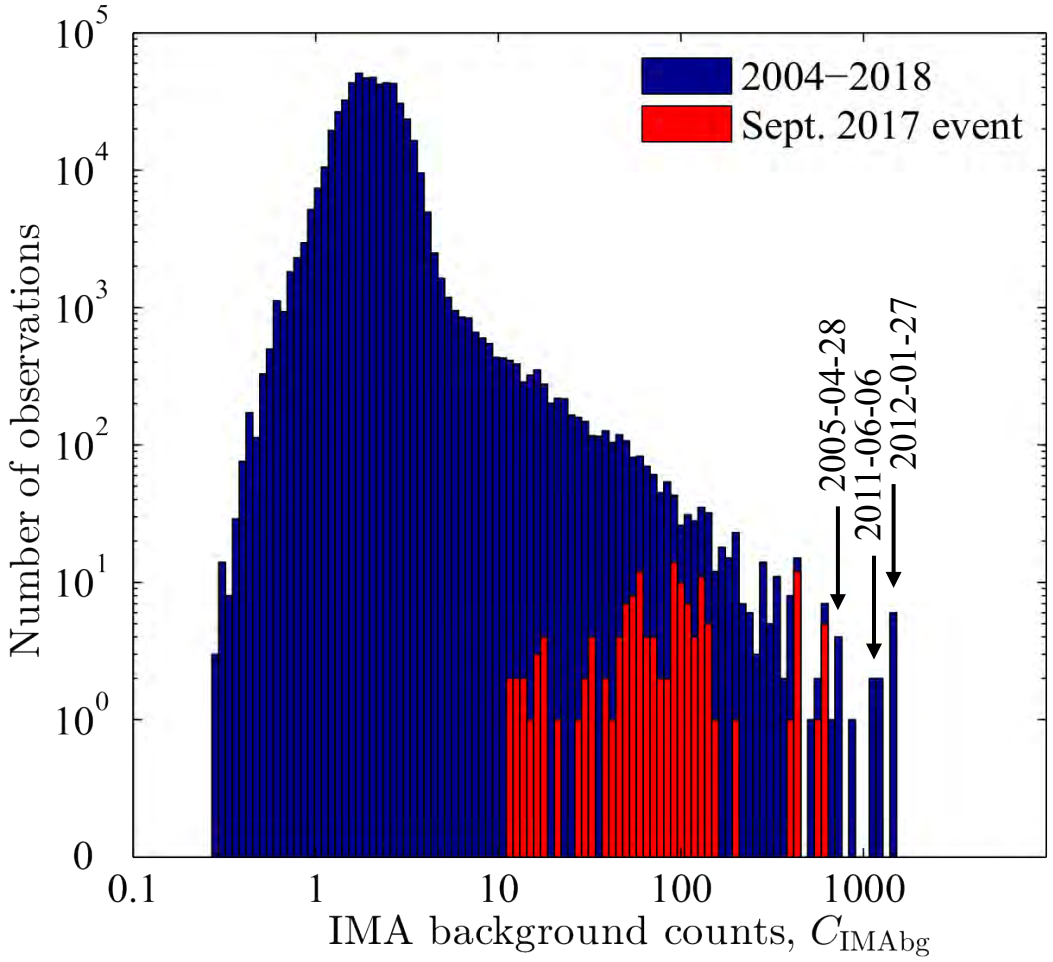
- few tens of MeV protons
- few MeV electrons

MEX/ASPERA-3 IMA

- >20 MeV protons
- >1 MeV electrons

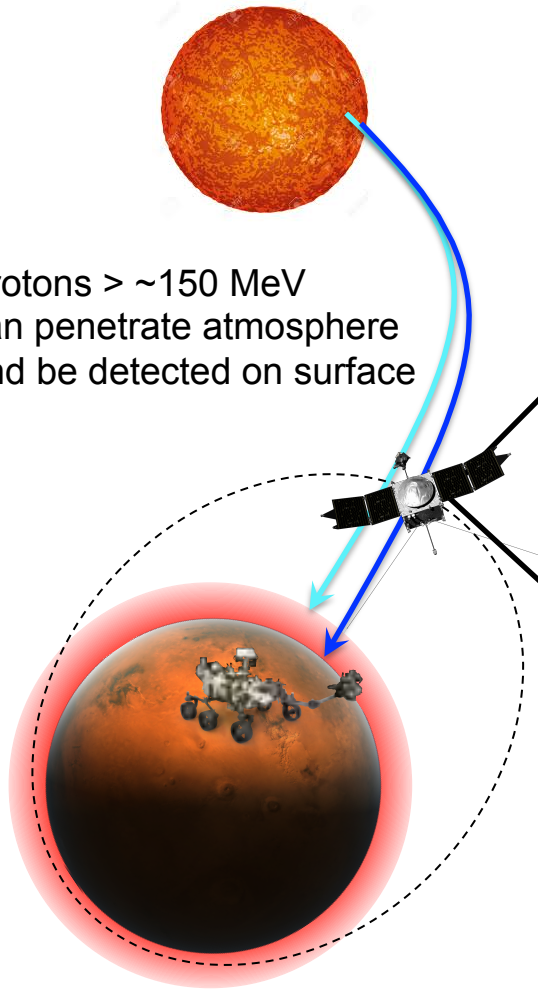


Comparing the background counts for the September 2017 event period to those over entire MEX mission (2004-2018), this event was the 4th strongest SEP event observed.

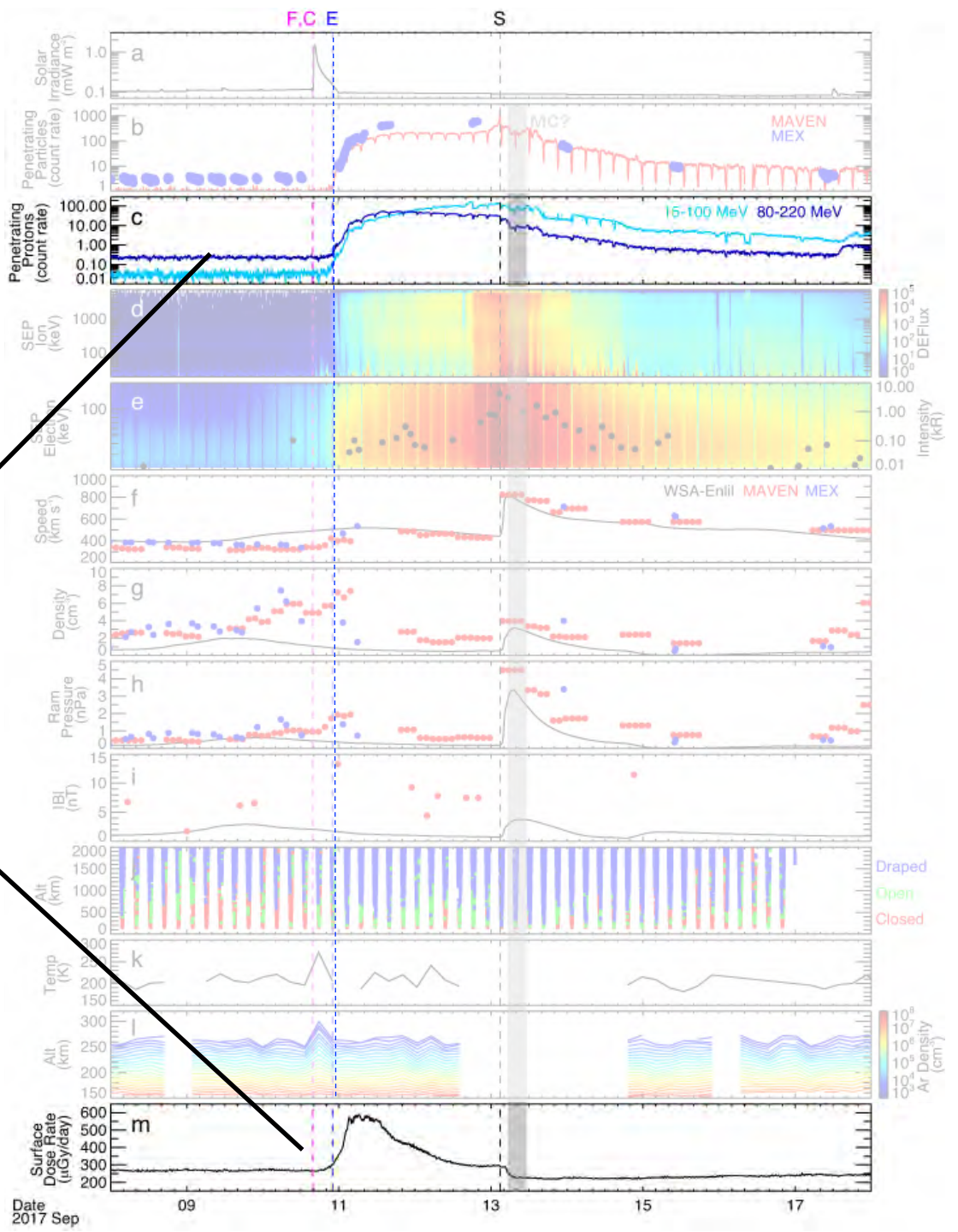


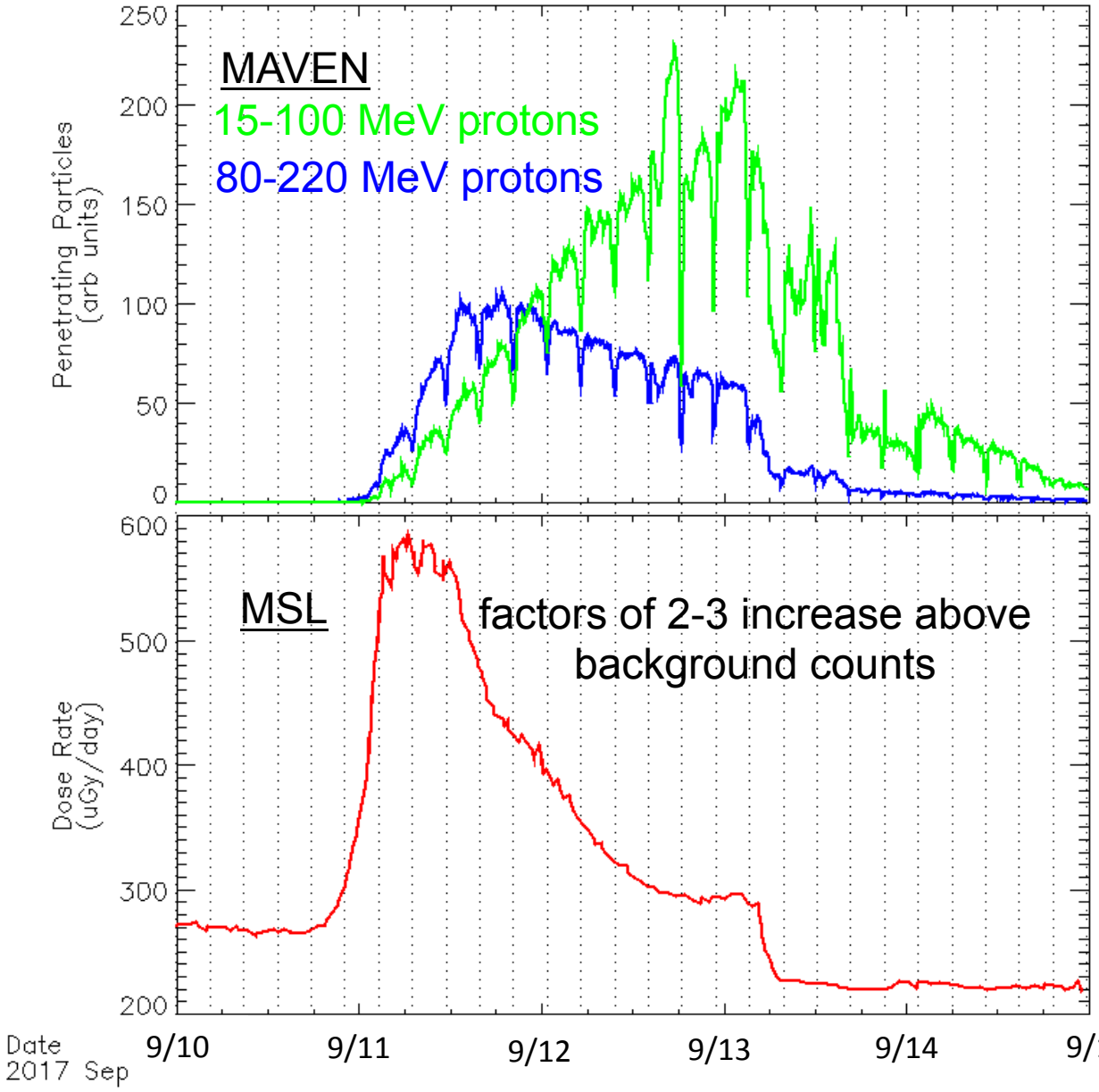
Ramstad et al. (GRL, 2018)

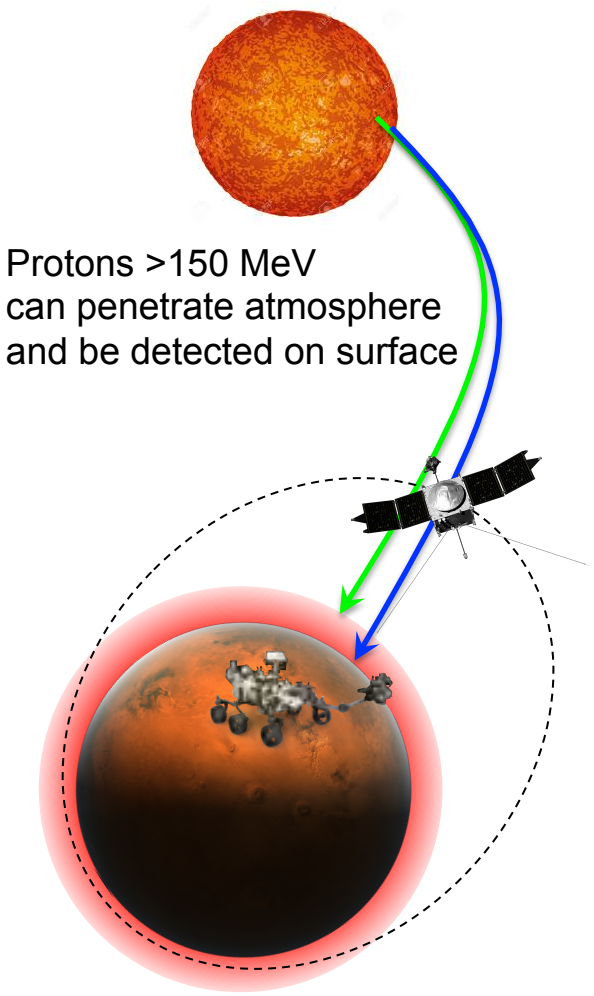
Higher energy SEP protons penetrated down to the surface



Protons > ~150 MeV
can penetrate atmosphere
and be detected on surface

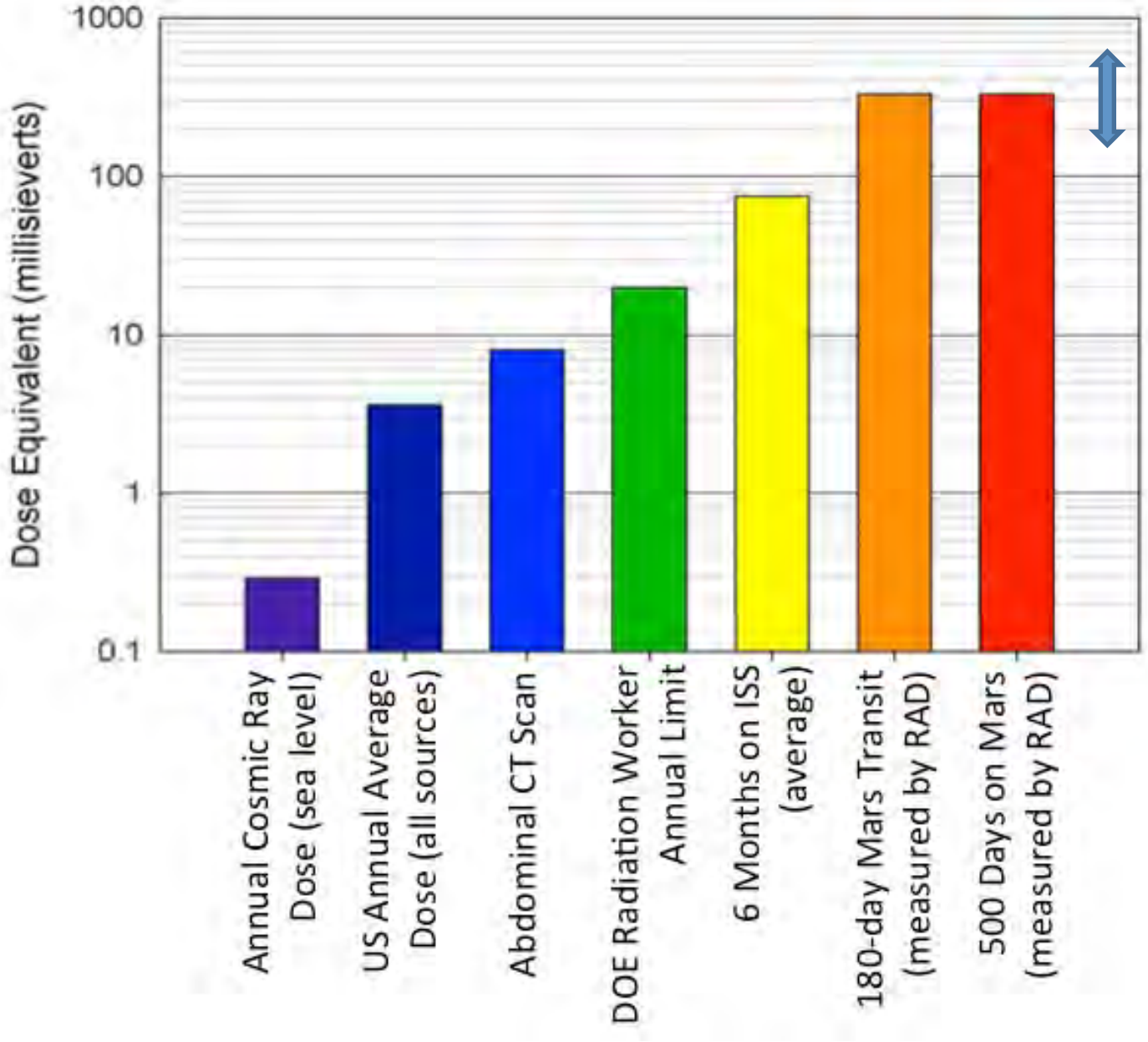






This is the largest surface enhancement observed by MSL/RAD since its arrival to Mars in 2012.

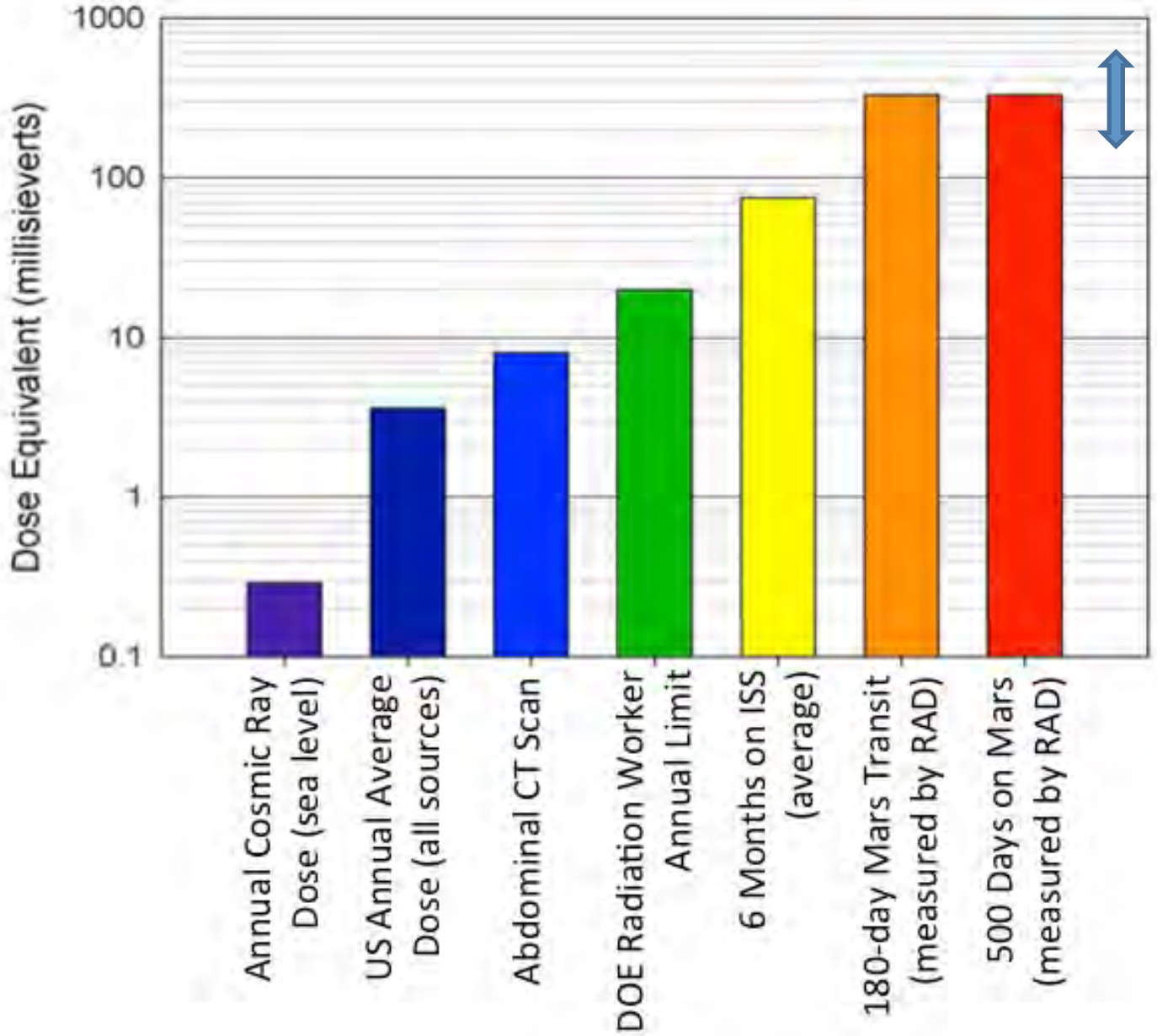
Radiation Exposure Comparison



Doses from a single GLE

One strong GLE can produce a dose equivalent to several quiet years, all at once

Radiation Exposure Comparison

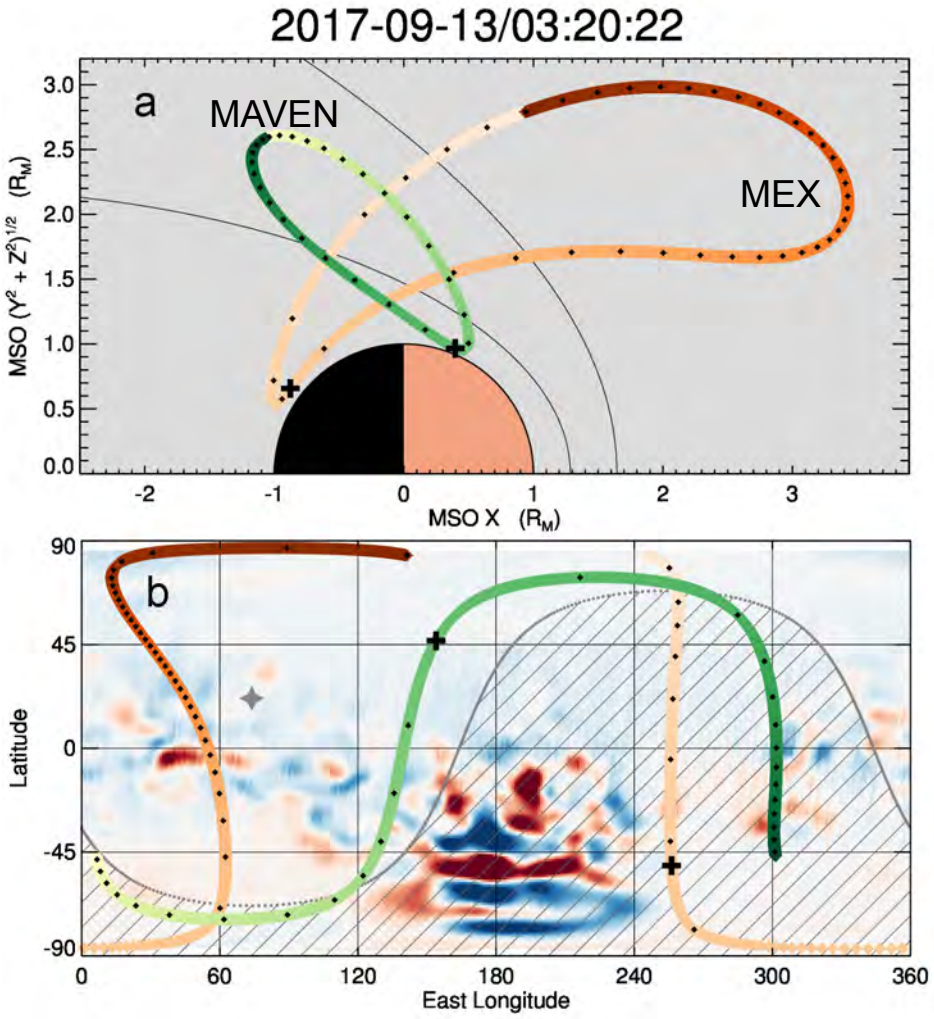


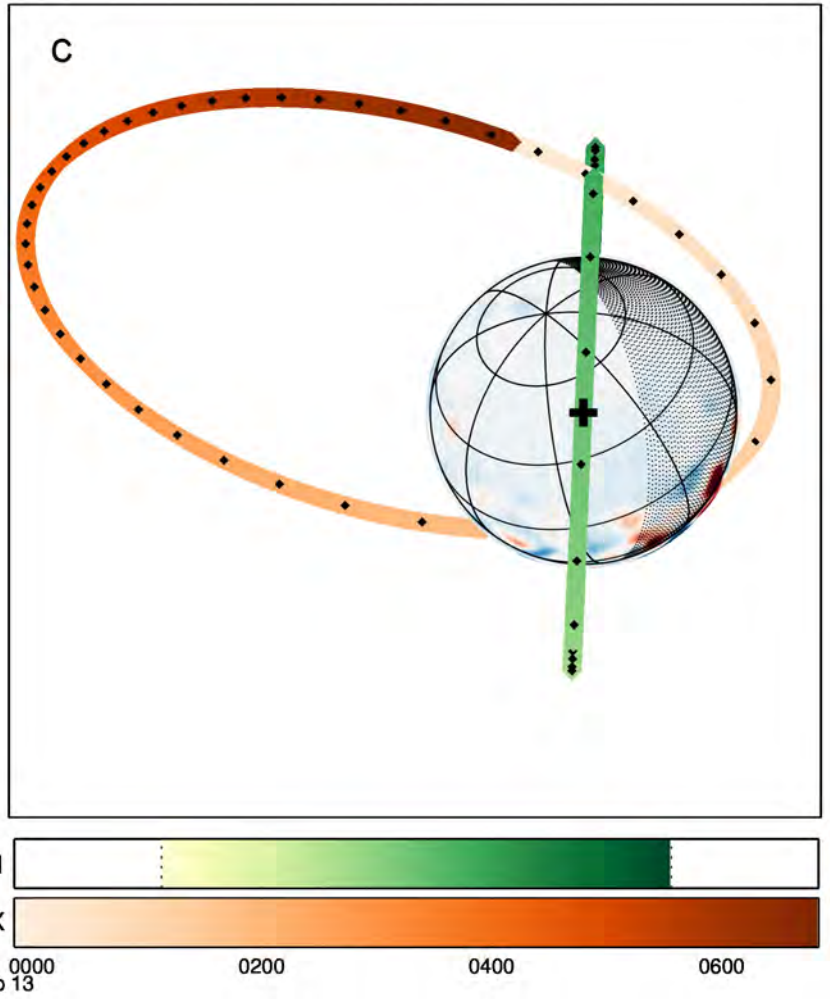
Doses from a single GLE

Where does the September 2017 event fall on this scale?

Stay tuned…

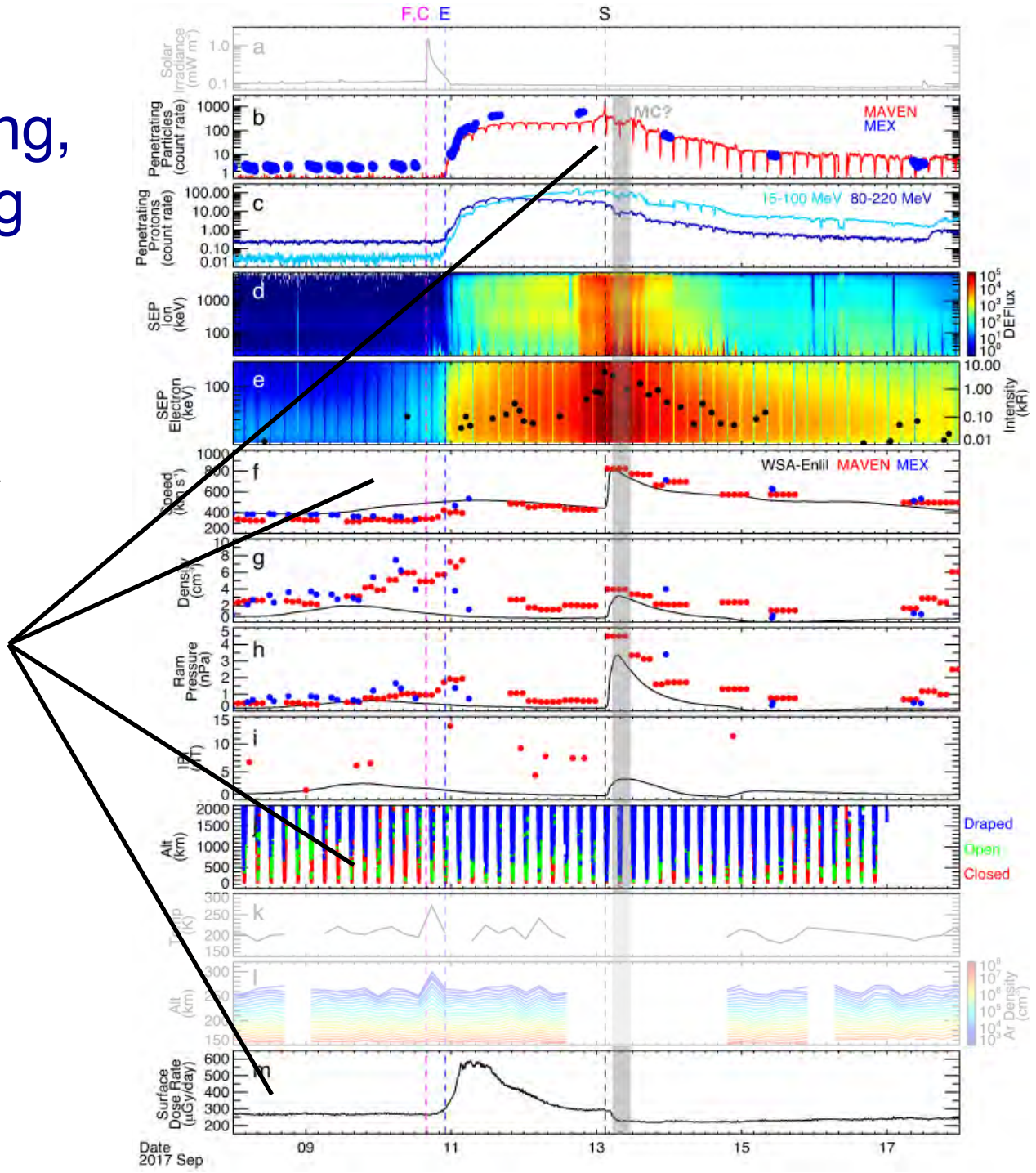
Limited space weather observations in orbit during the solar storm: MAVEN was not well positioned while MEX was in a power-conservation mode.





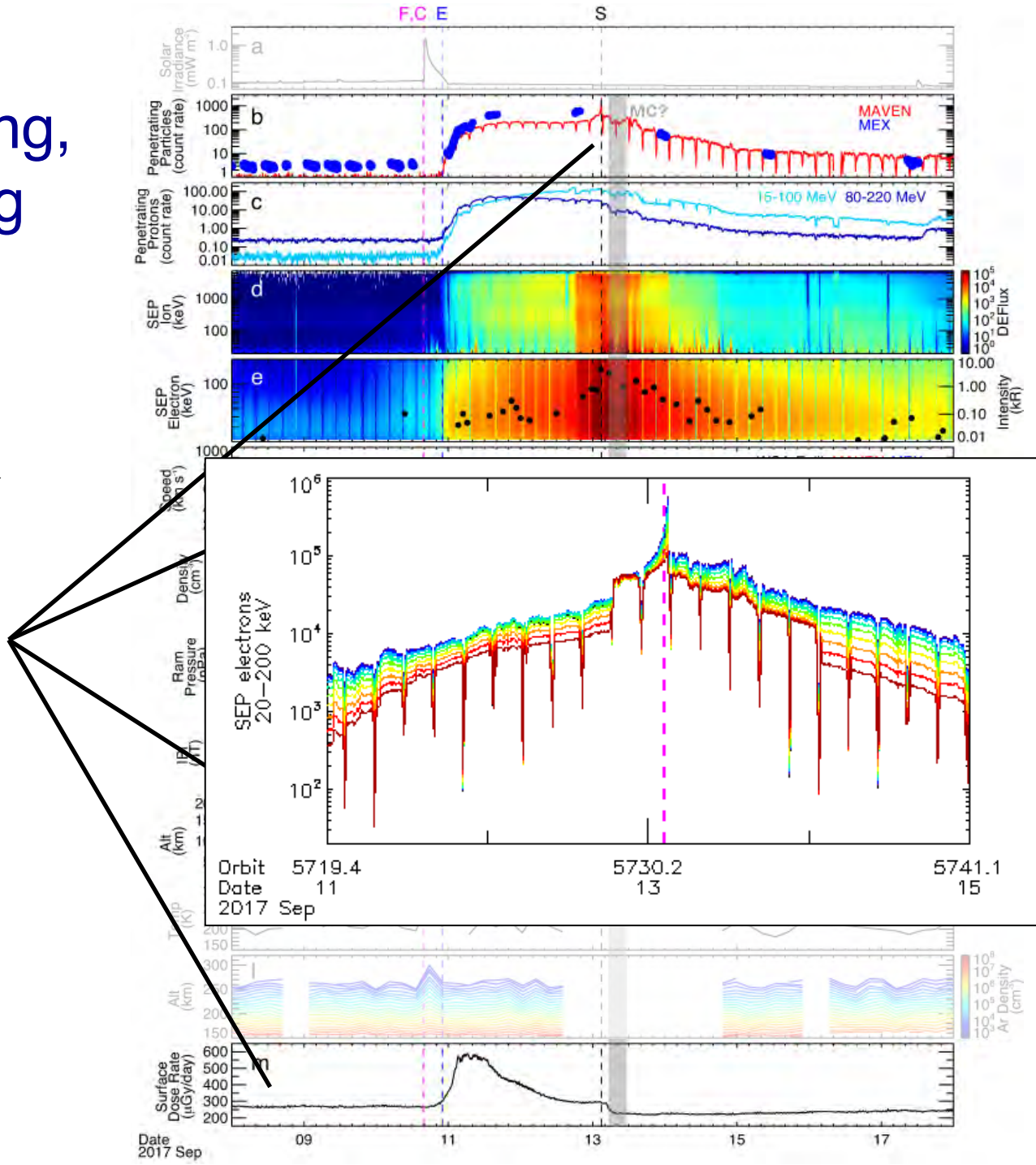
Understanding the ICME interval (timing, duration, etc.) using observations and modeling results

- small ‘bite out’ in SEPs → encounter with magnetic structure?



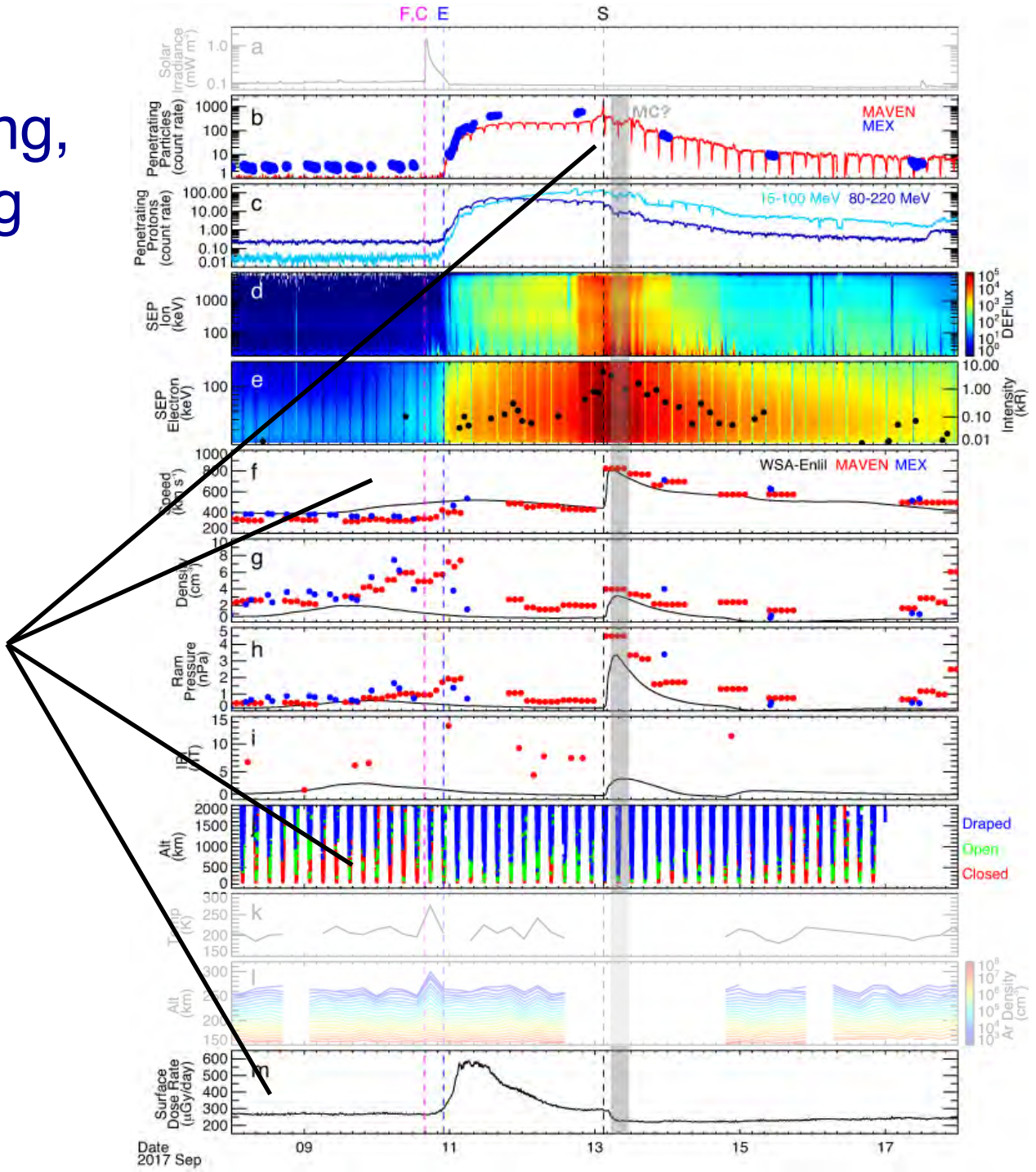
Understanding the ICME interval (timing, duration, etc.) using observations and modeling results

- small ‘bite out’ in SEPs → encounter with magnetic structure?
- timing of shock arrival inferred from SEPs



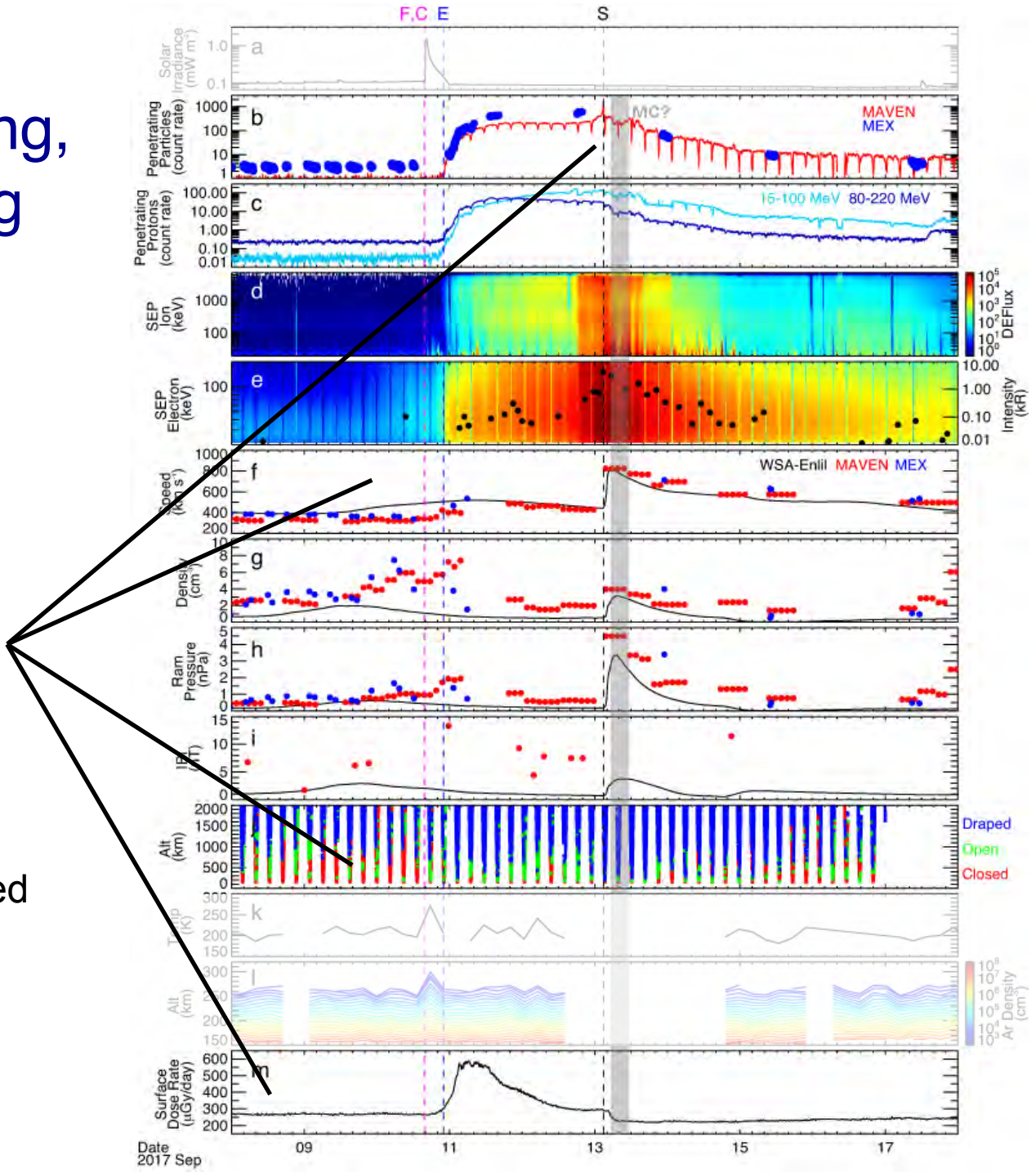
Understanding the ICME interval (timing, duration, etc.) using observations and modeling results

- small ‘bite out’ in SEPs → encounter with magnetic structure?
- timing of shock arrival inferred from SEPs
- timing of observed and modeled ICME arrival

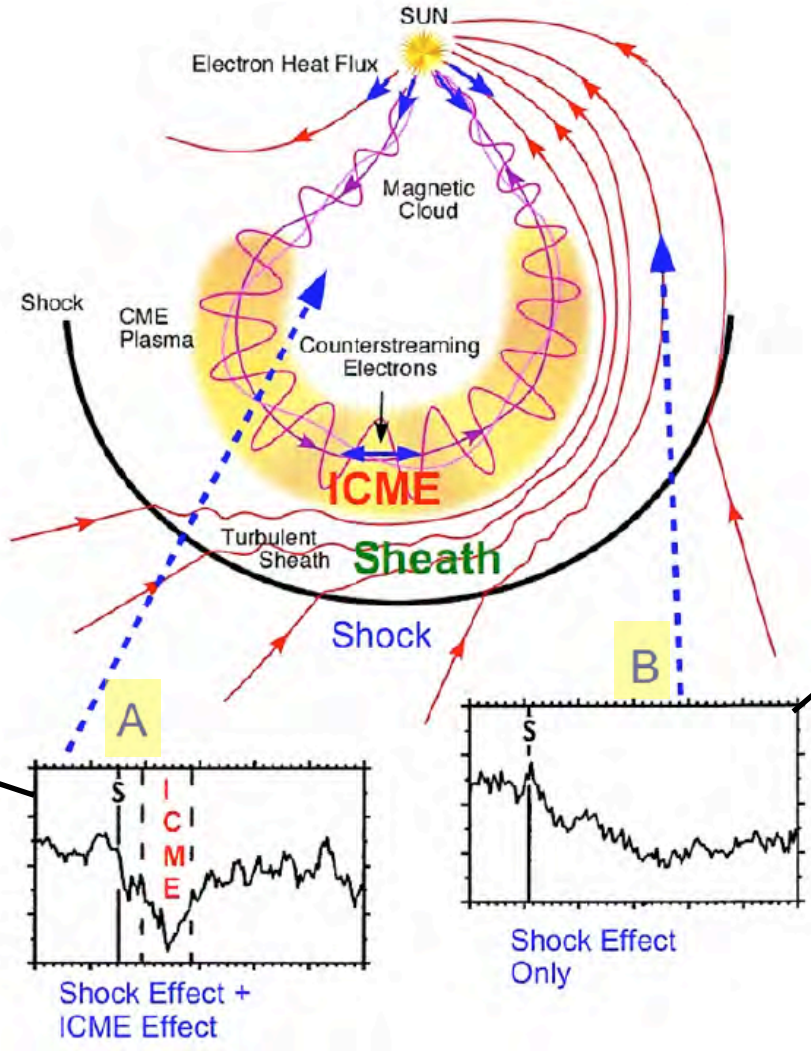


Understanding the ICME interval (timing, duration, etc.) using observations and modeling results

- small ‘bite out’ in SEPs → encounter with magnetic structure?
- timing of shock arrival inferred from SEPs
- timing of observed and modeled ICME arrival
- timing/duration of observed Forbush Decrease

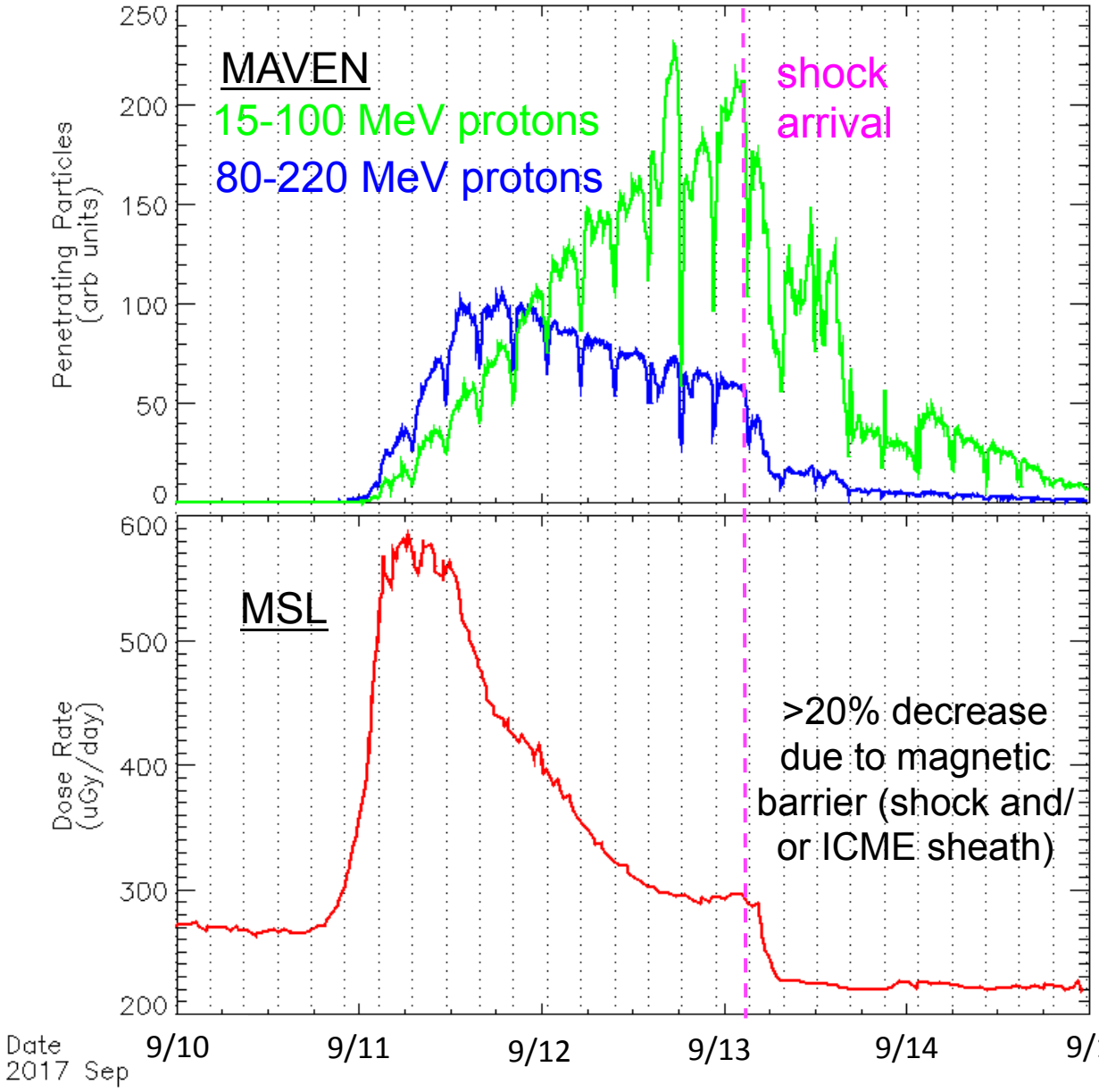


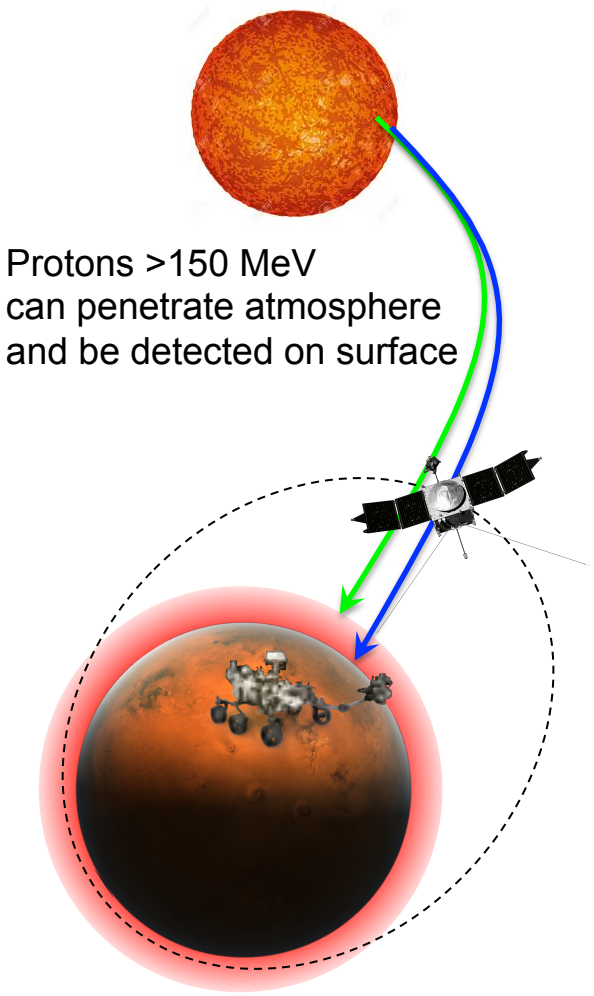
CMEs can act as magnetic barriers!
Below is a cartoon showing the idealized features of a CME and its shock front. 'Forbush decreases' are observed in galactic cosmic ray (GCR) measurements made at the surface and depends on the trajectory of the CME.



Decline in GCR due to the passage of the ICME shock/ sheath region followed by the passage of ICME cloud

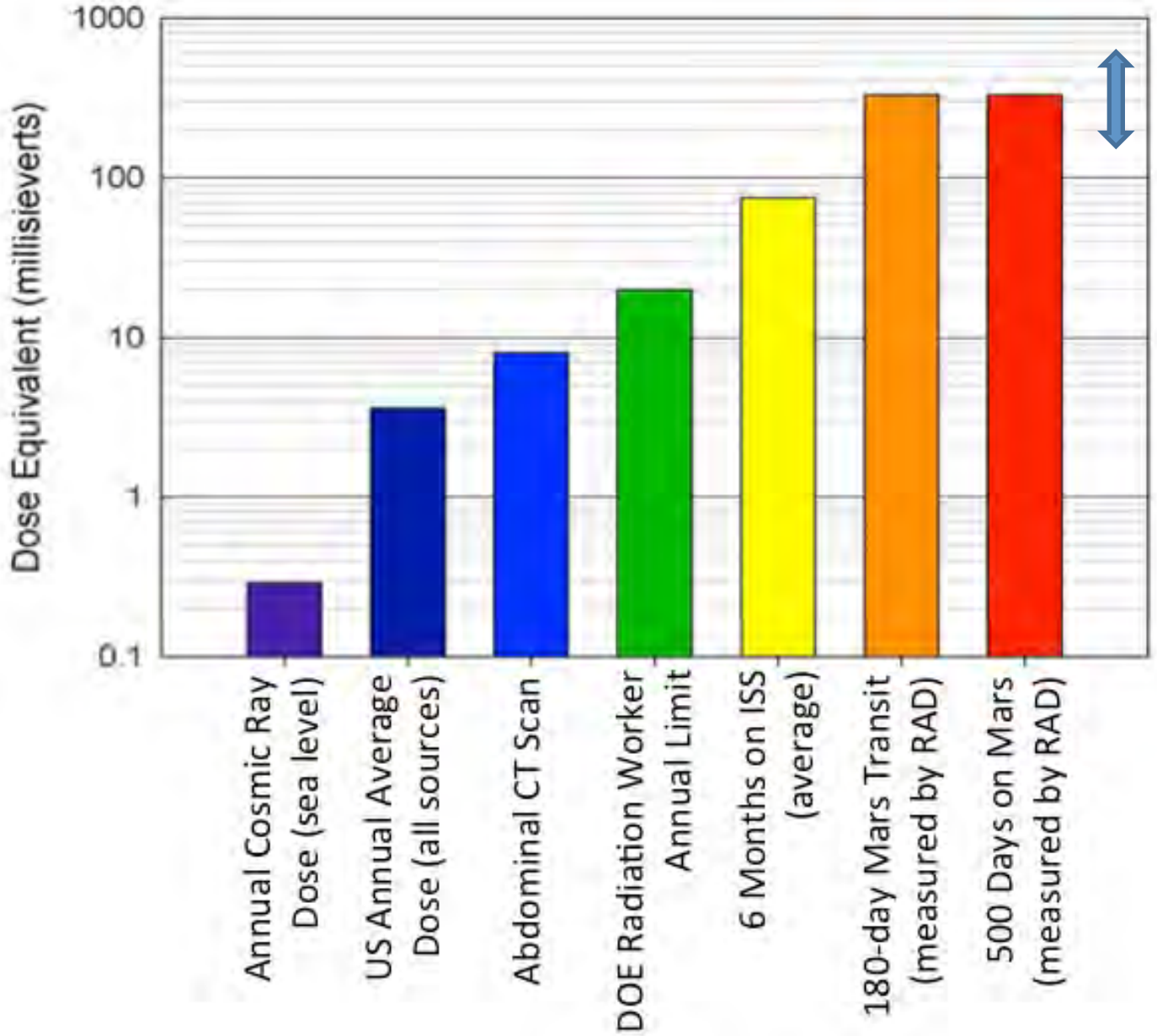
Decline in GCR due to the passage of only the ICME shock/sheath region





This is the deepest decrease in observed dose rate by MSL/RAD.

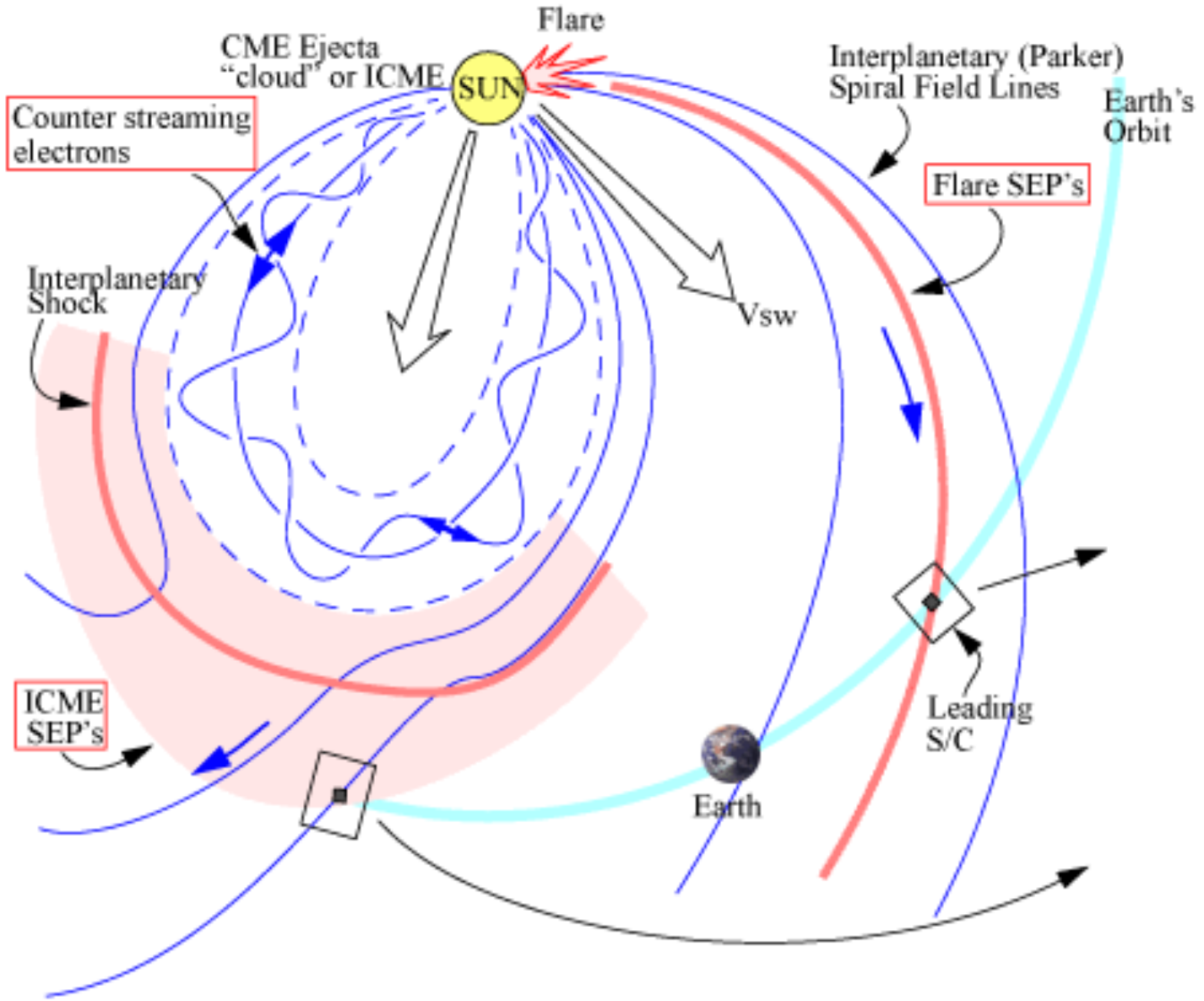
Radiation Exposure Comparison



Doses from a single GLE

Where does the September 2017 event fall on this scale?

Mars was *not* magnetically well-connected to the flare and CME activity region at the Sun



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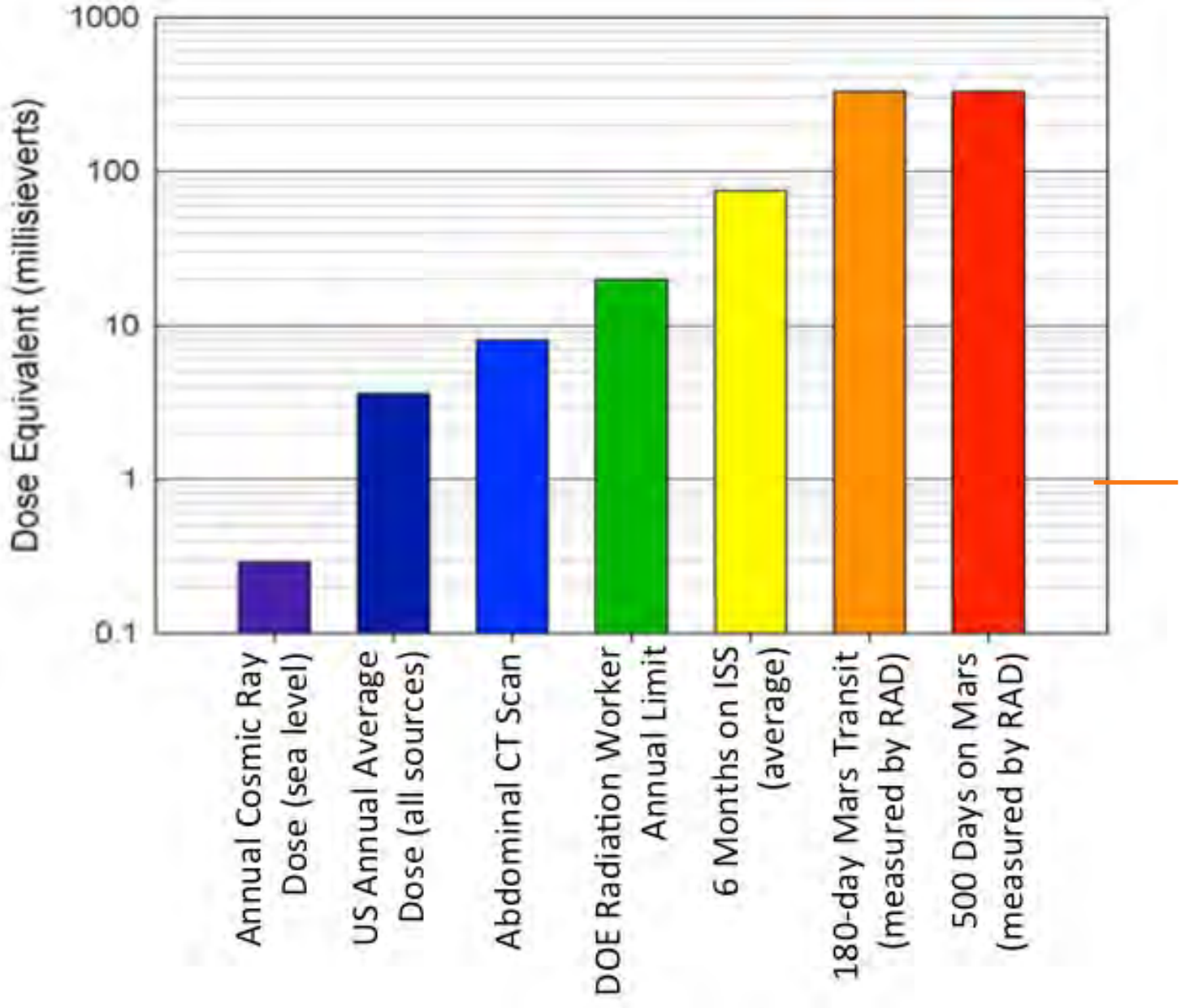
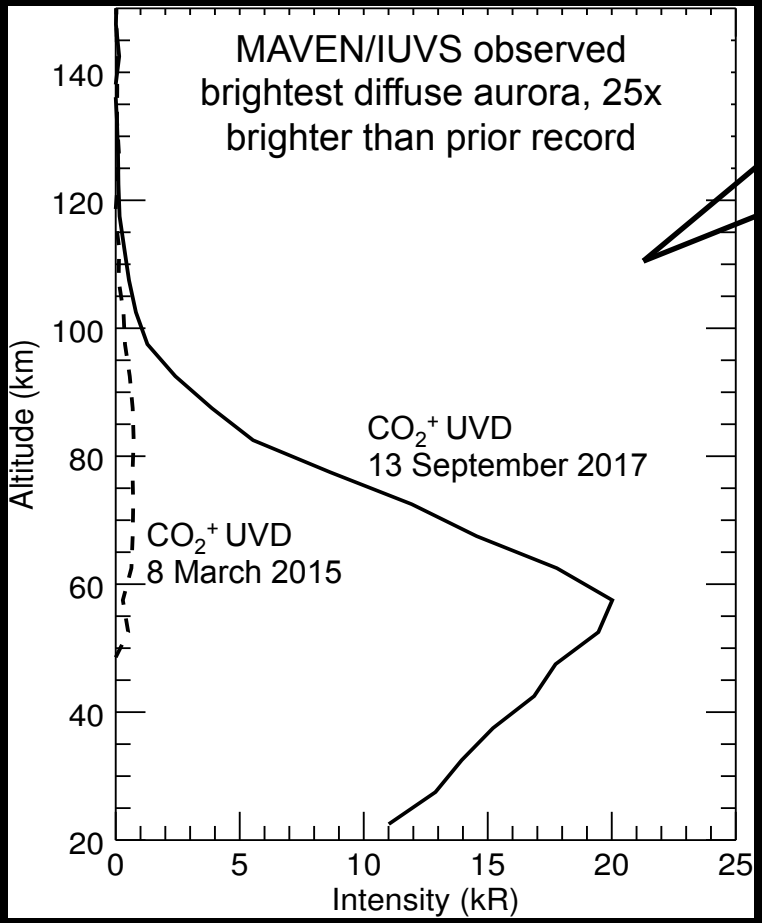
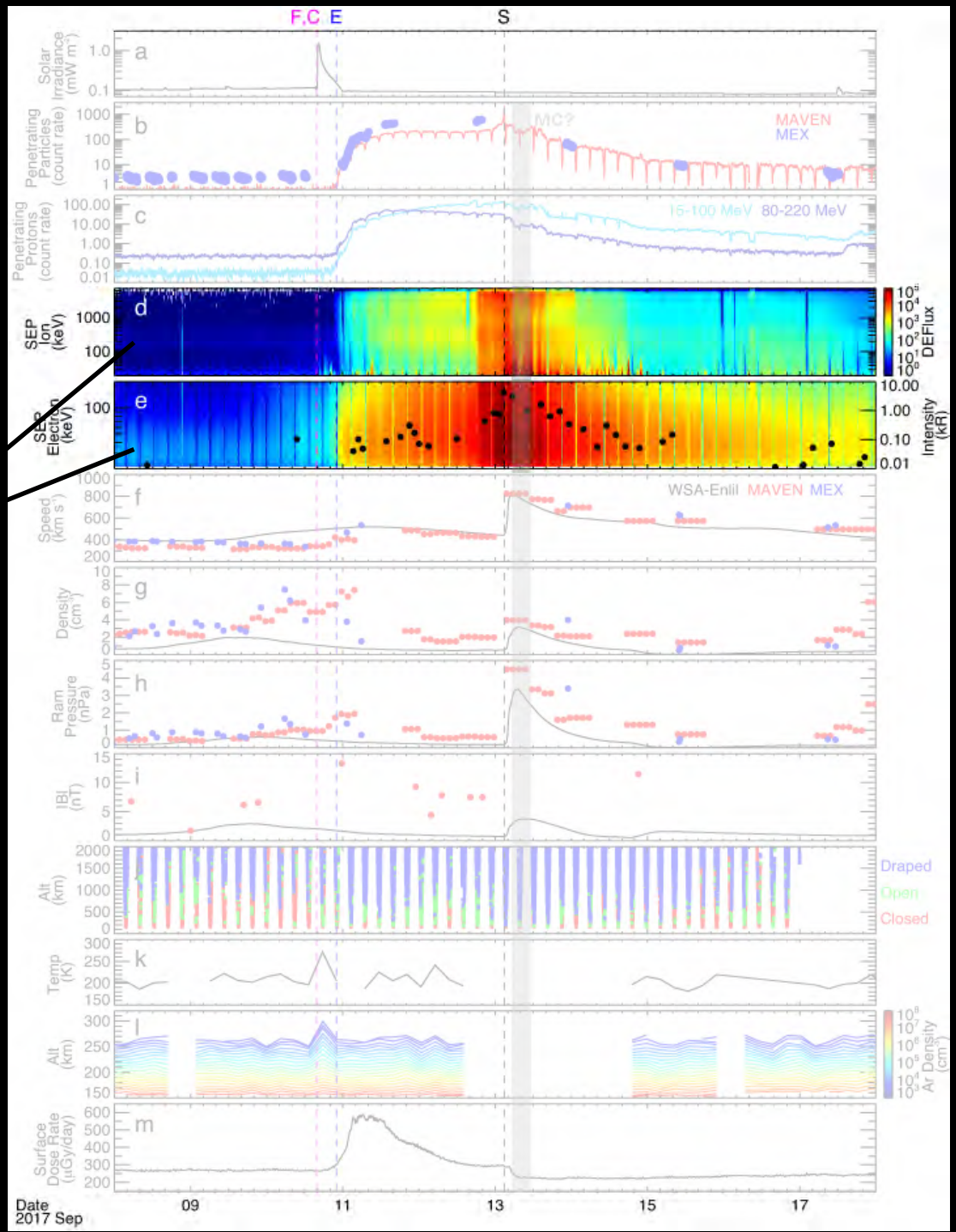
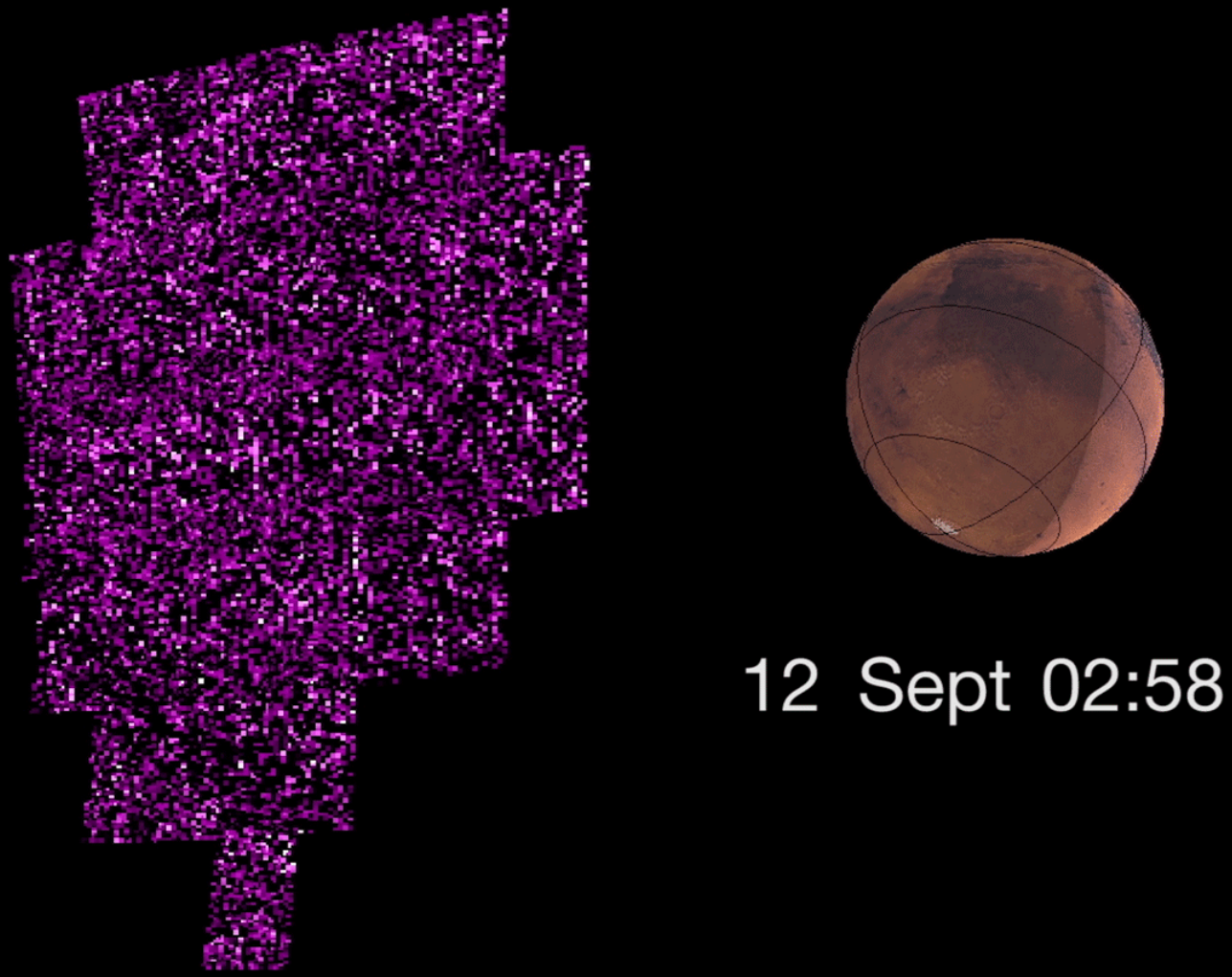


From D. Hassler SWW presentation

Lower energy SEPs penetrated deep into the atmosphere to produce a bright diffuse aurora

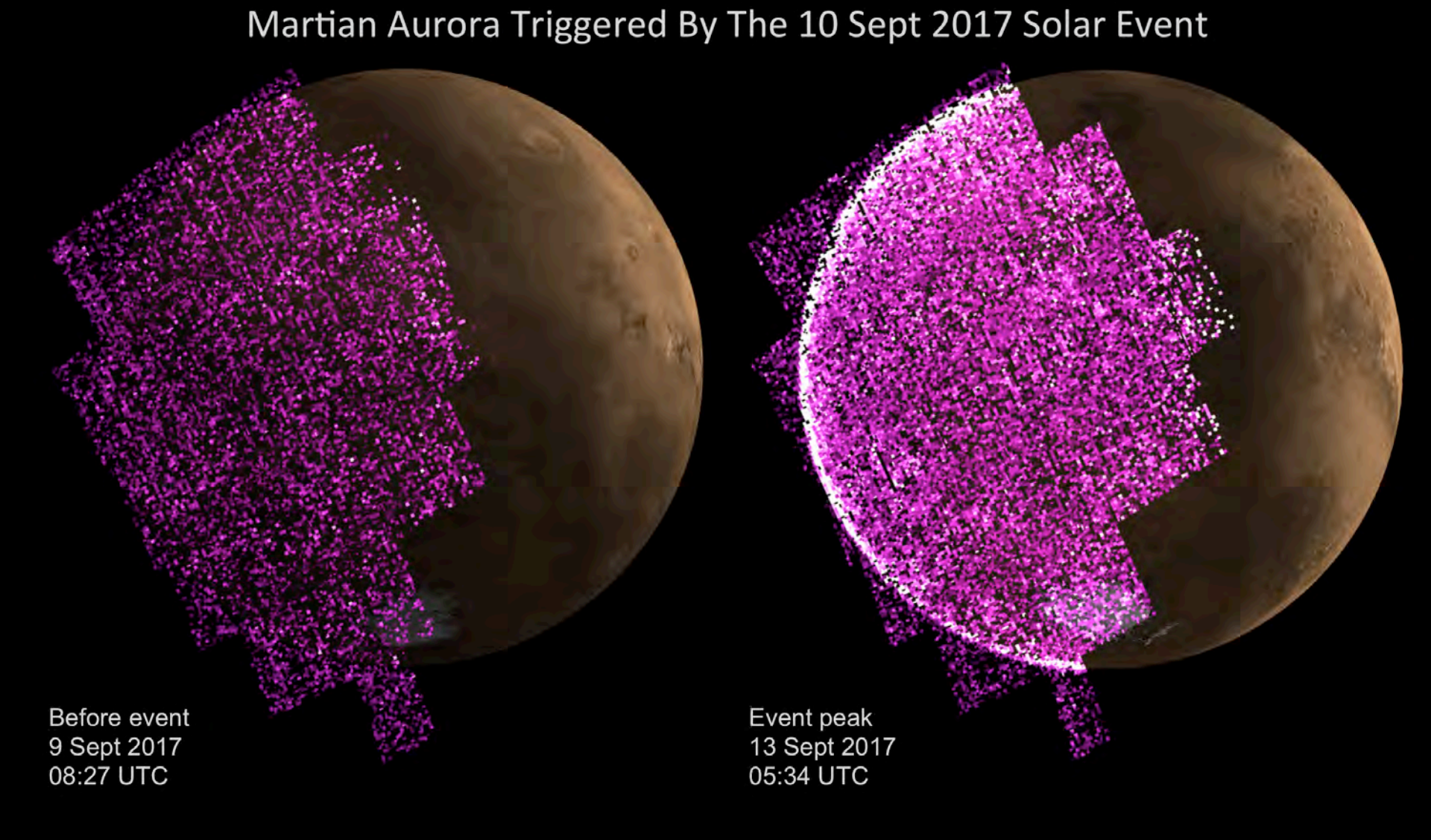




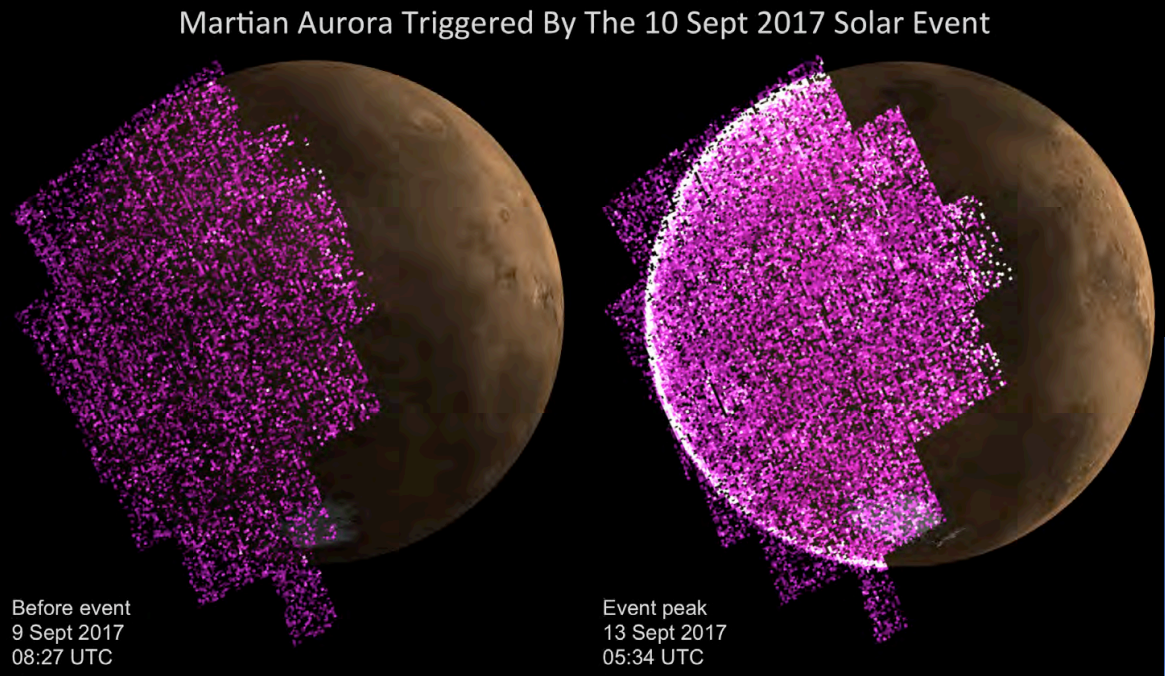


Sonal Jain (CU/LASP): “If a human had been present, with eyes sensitive to visible light, they would have probably seen Mars lit up in green light (557.7nm) much like auroras on Earth.”

The aurora is global, visible around the limb and across the disk.



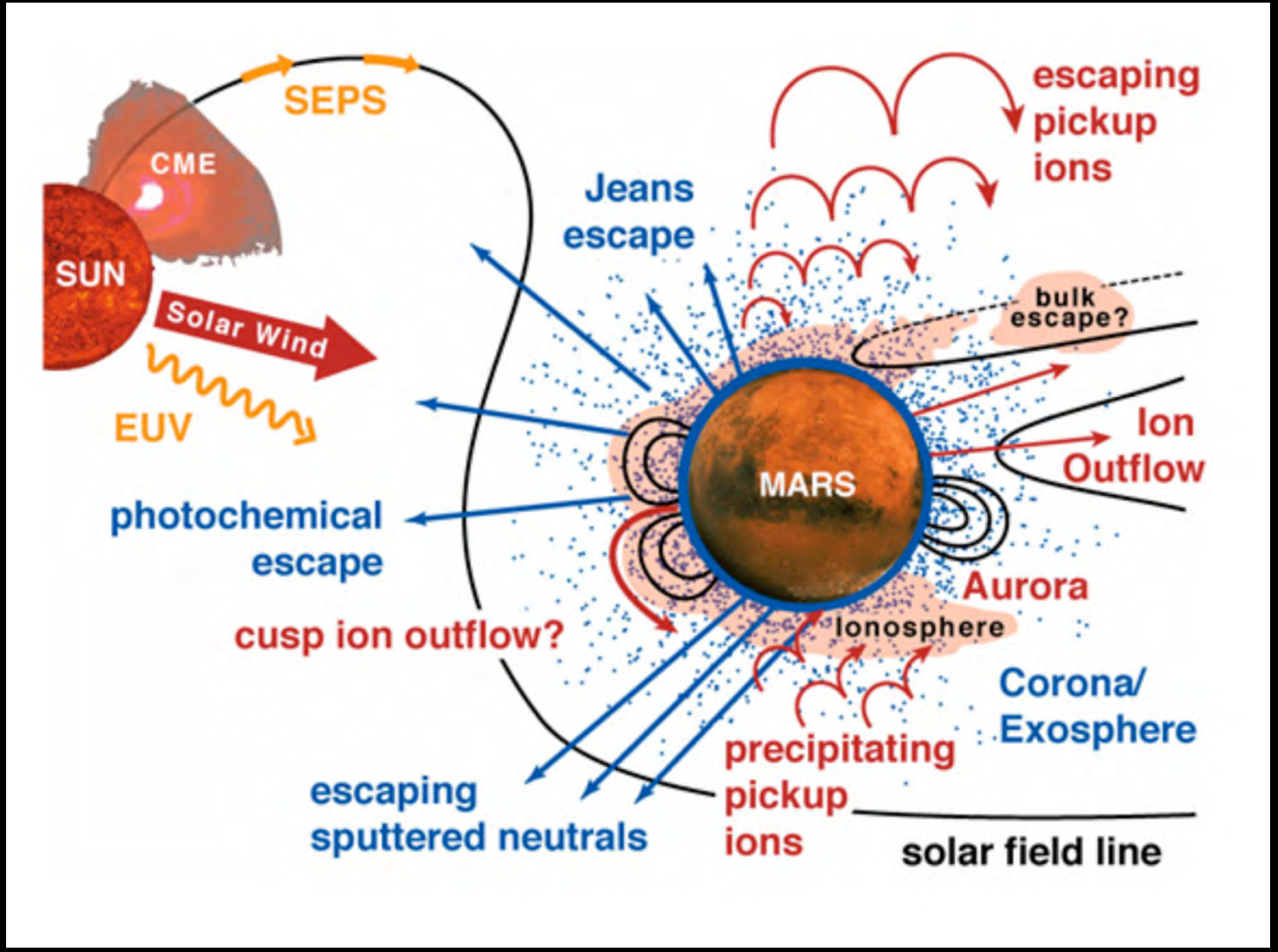
The solar storm of September 2017 caused simultaneous auroras on both Earth and Mars!



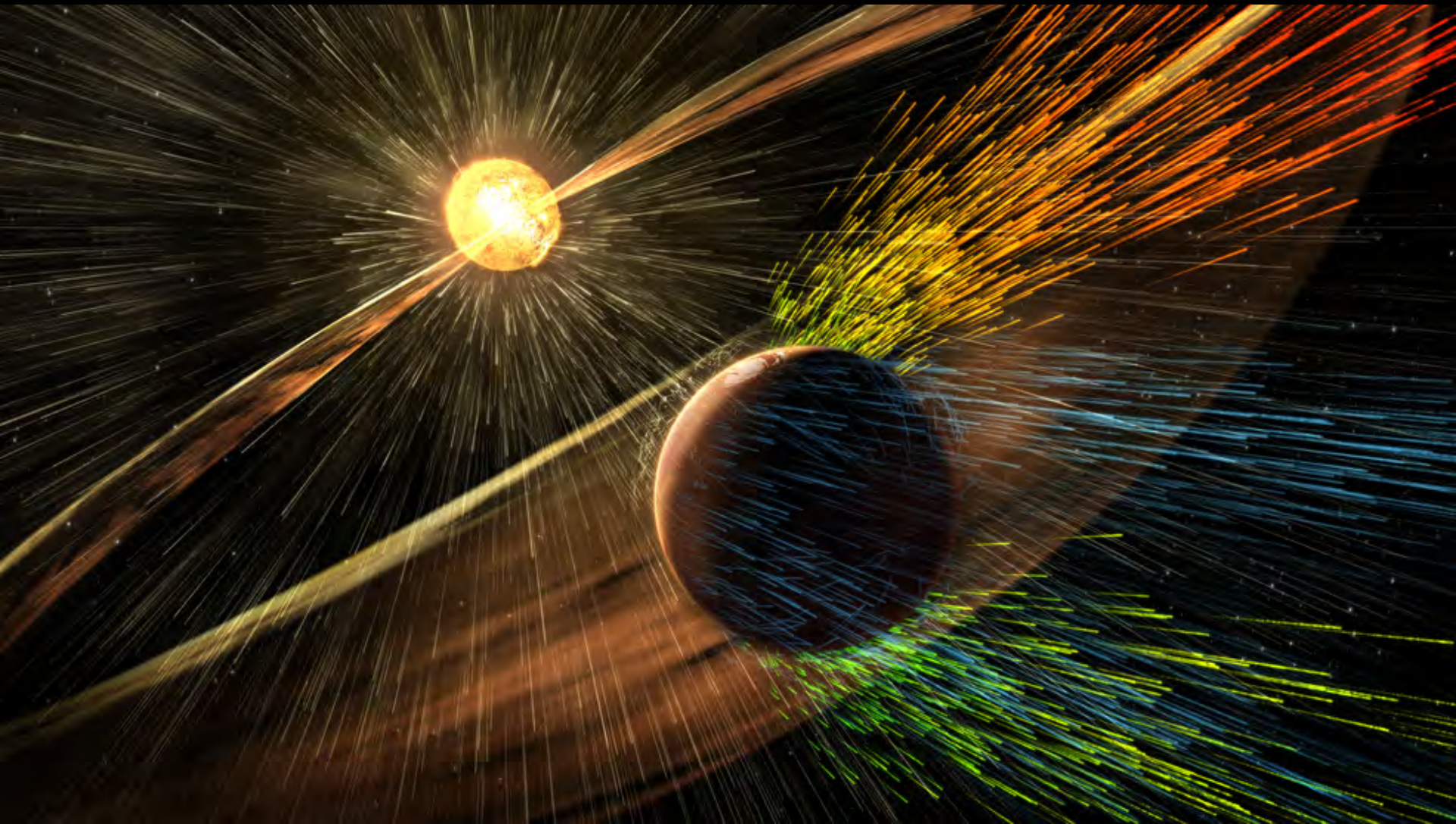
Aurora seen on Earth from Alaska

Image courtesy Lindsay Ohlert

Why study solar storms at Mars? We want to understand the space weather effects on atmospheric loss over time to answer the question: Where did the water go?



Prior to this event, the previous calculation for the atmospheric ion loss rate at Mars, based on MAVEN observations, was ~100 grams (quarter pound) per second.



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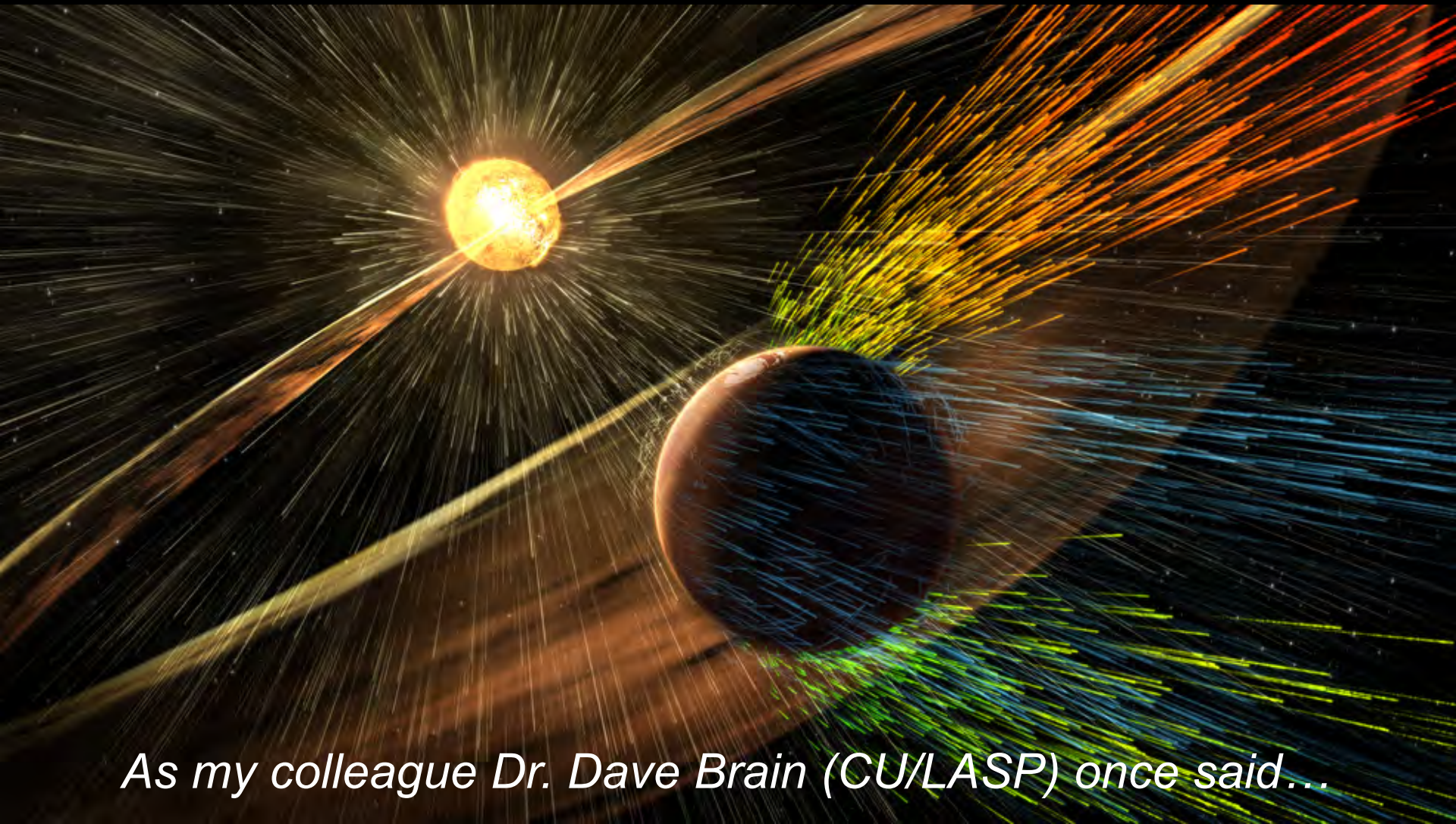
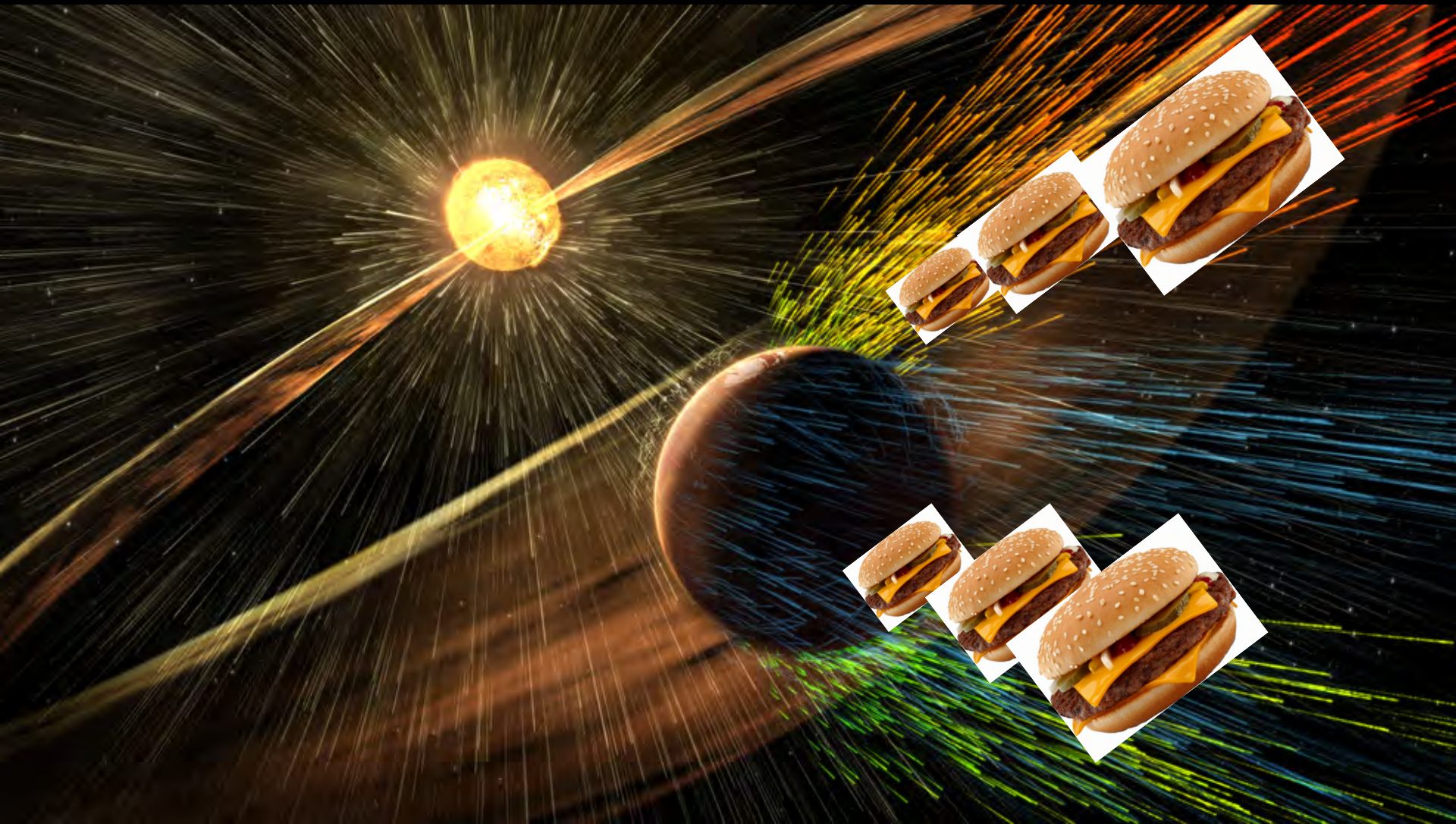


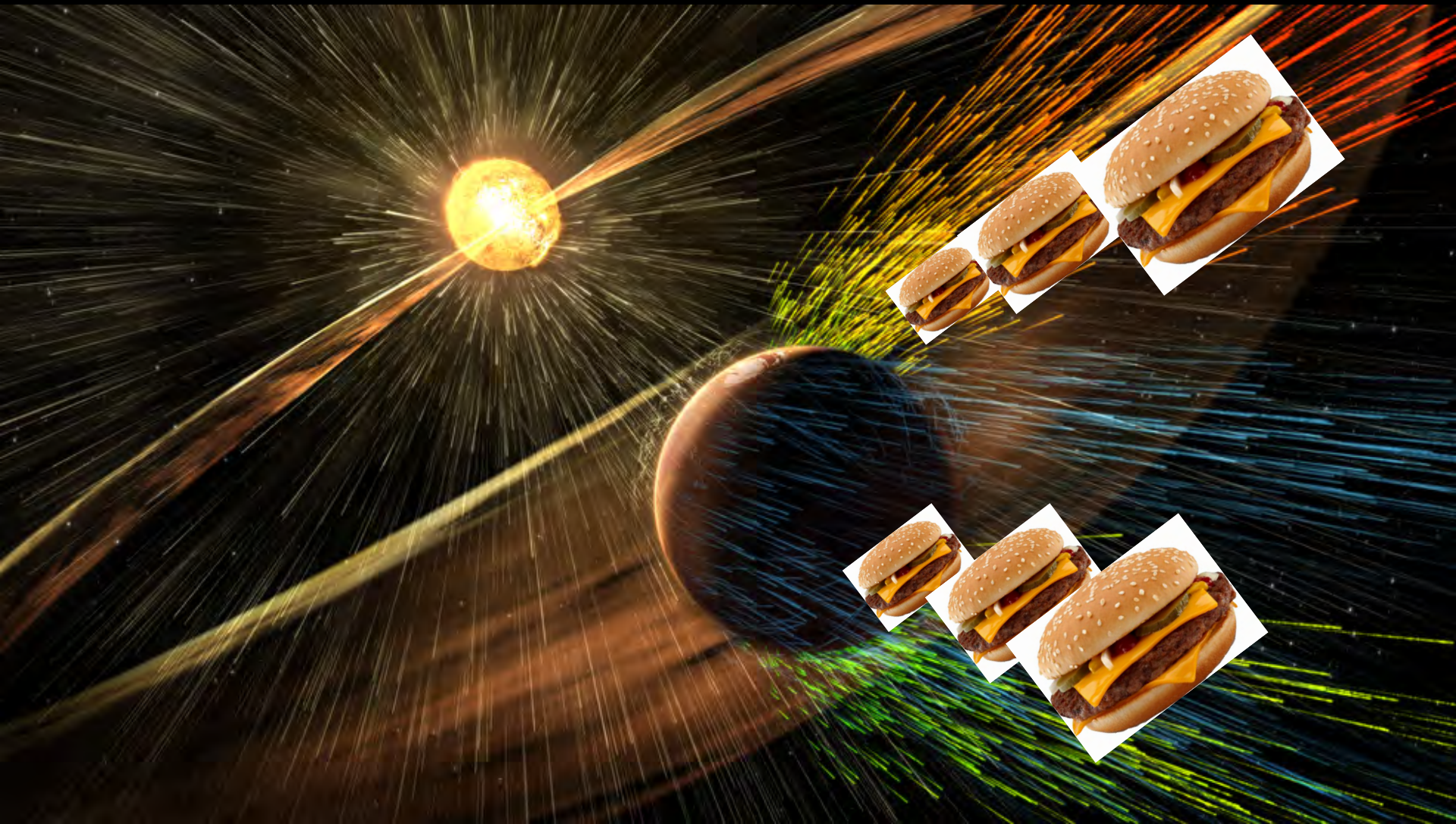
As my colleague Dr. Dave Brain (CU/LASP) once said…

“I can’t help but imagine hamburgers shooting out of the Martian atmosphere.”

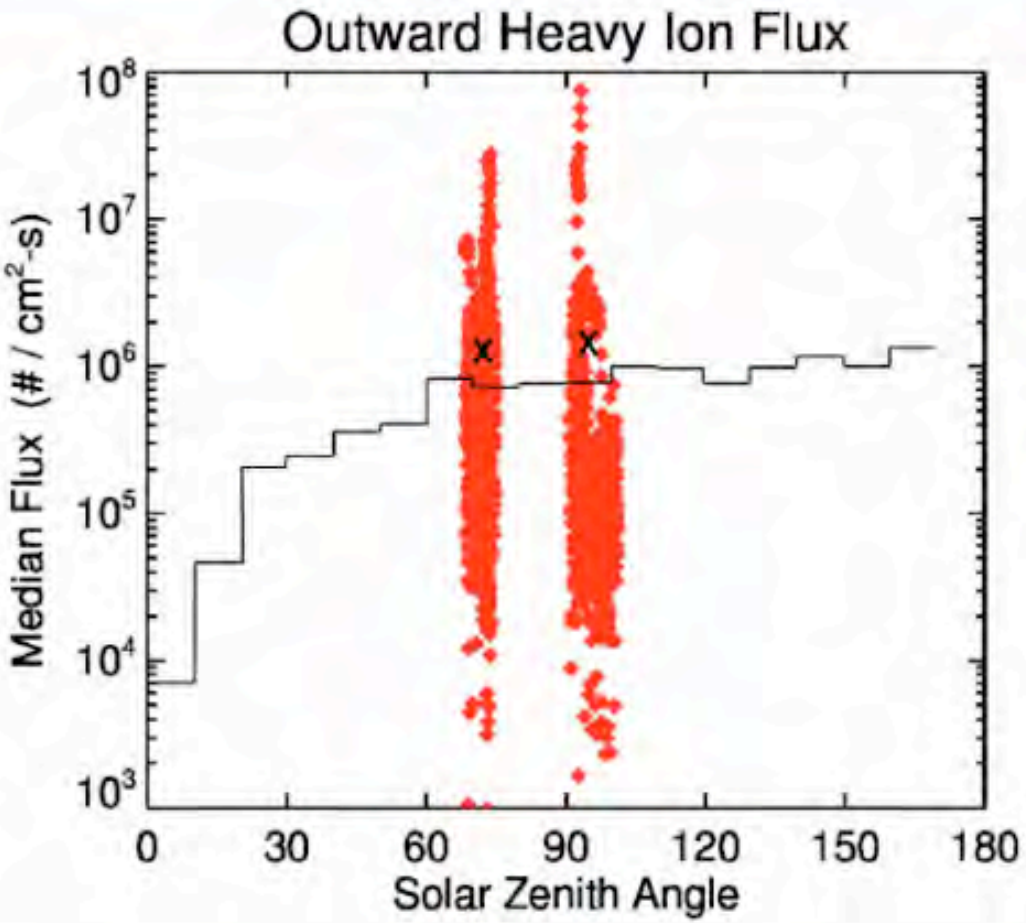


“I can’t help but imagine hamburgers shooting out of the Martian atmosphere.”

For the September 2017 solar event, did Big Macs shoot out instead of quarter pounders?



Solar Event of 10 Sept 2017: Enhanced Heavy-Ion Loss (1 of 2)



X *shows average outward flux during event*

Observations show an increase in loss, but are at a limited range of SZA, are at angles at which enhancement is small, and are not unambiguous.

Will there be more solar storms at Mars? We hope so! We need more statistics on measurements related to current atmospheric loss and the impacts on the radiation environment during space weather events. But right now the solar activity levels are low (we are in solar minimum!)

Thank you!