Space Weather at Mars: 4.5 Years of MAVEN observations

CU/LASP • GSFC • UCB/SSL • LM • JPL

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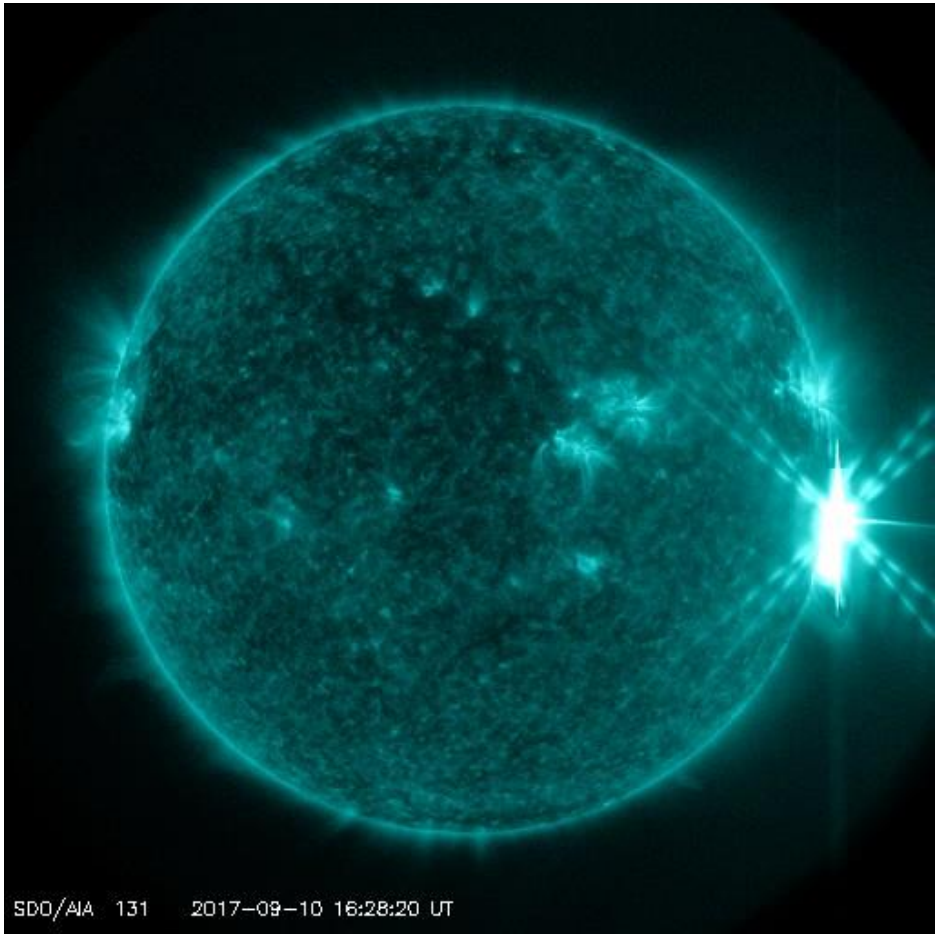
Space Weather 101

Solar flares are local bursts of radiation.

Coronal mass ejections (CMEs) are magnetized clouds of charged particles that spreads out into space.



Space Weather 101

Solar Energetic Particles (SEPS) are accelerated by the shock fronts created by these explosions.

An observer magnetically connected to the shock via the interplanetary magnetic field (IMF) can detect these particles.

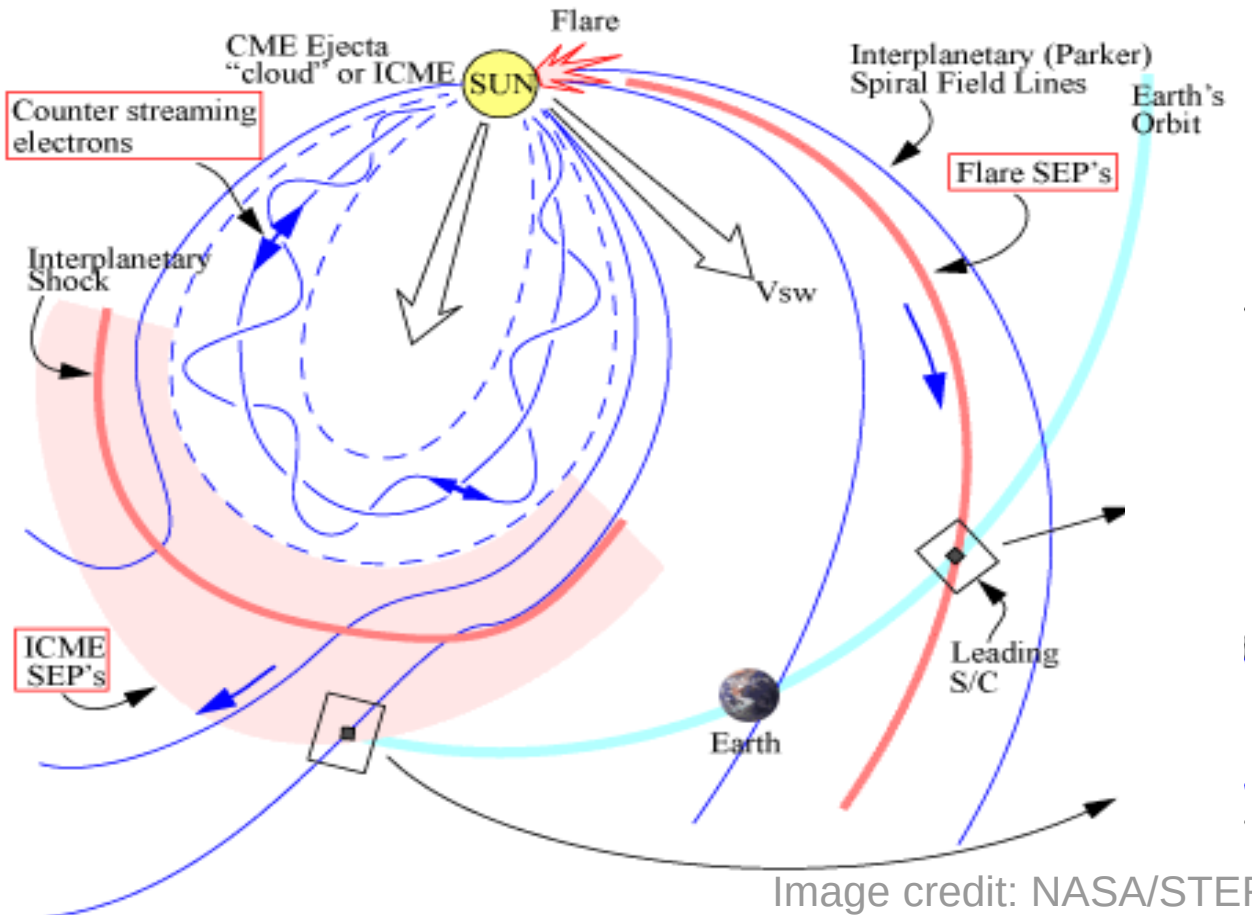


Image credit: NASA/STEREO mission

Without a strong planetary dipole magnetic field or thick atmosphere like Earth, exposure of equipment and explorers to the space environment is relatively direct at Mars.

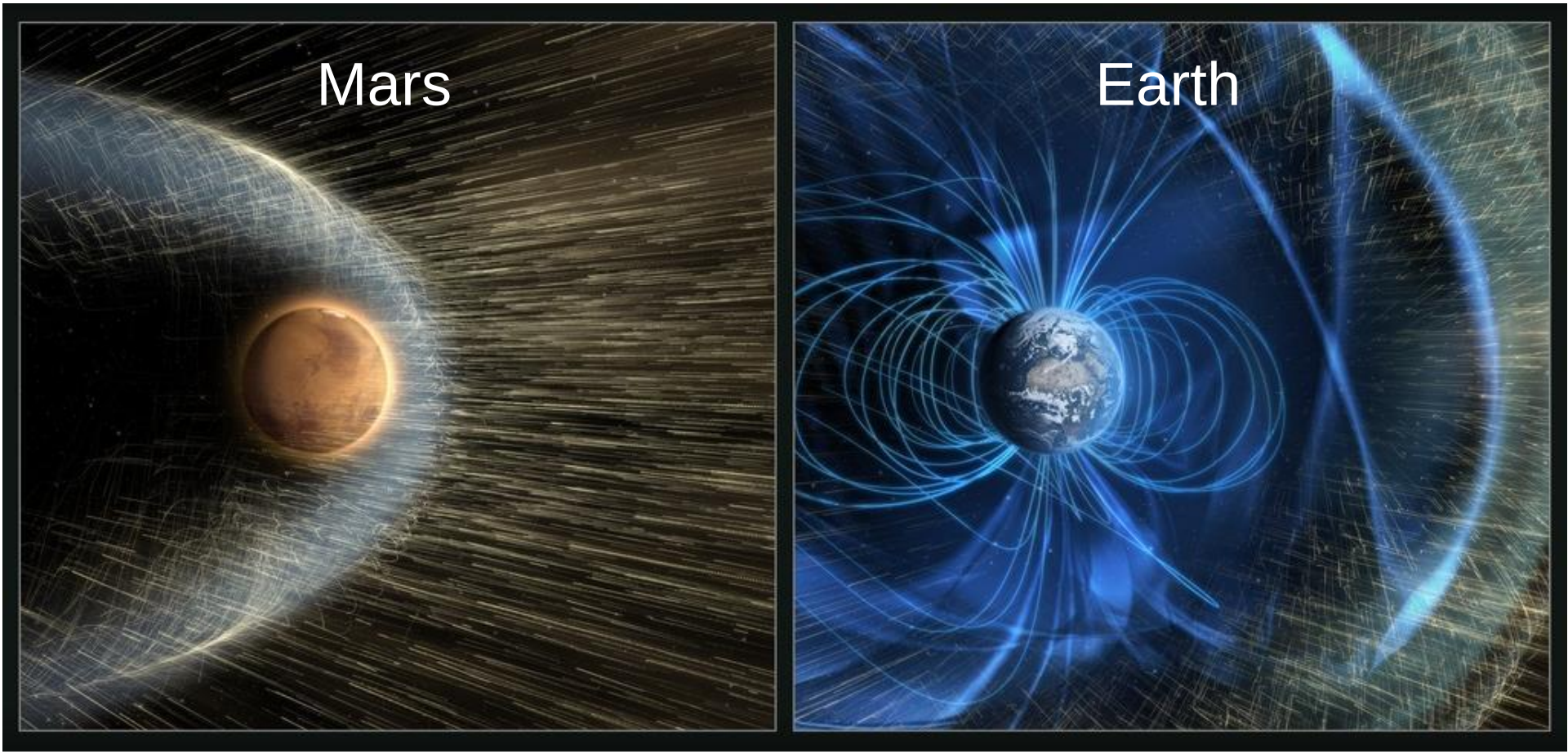
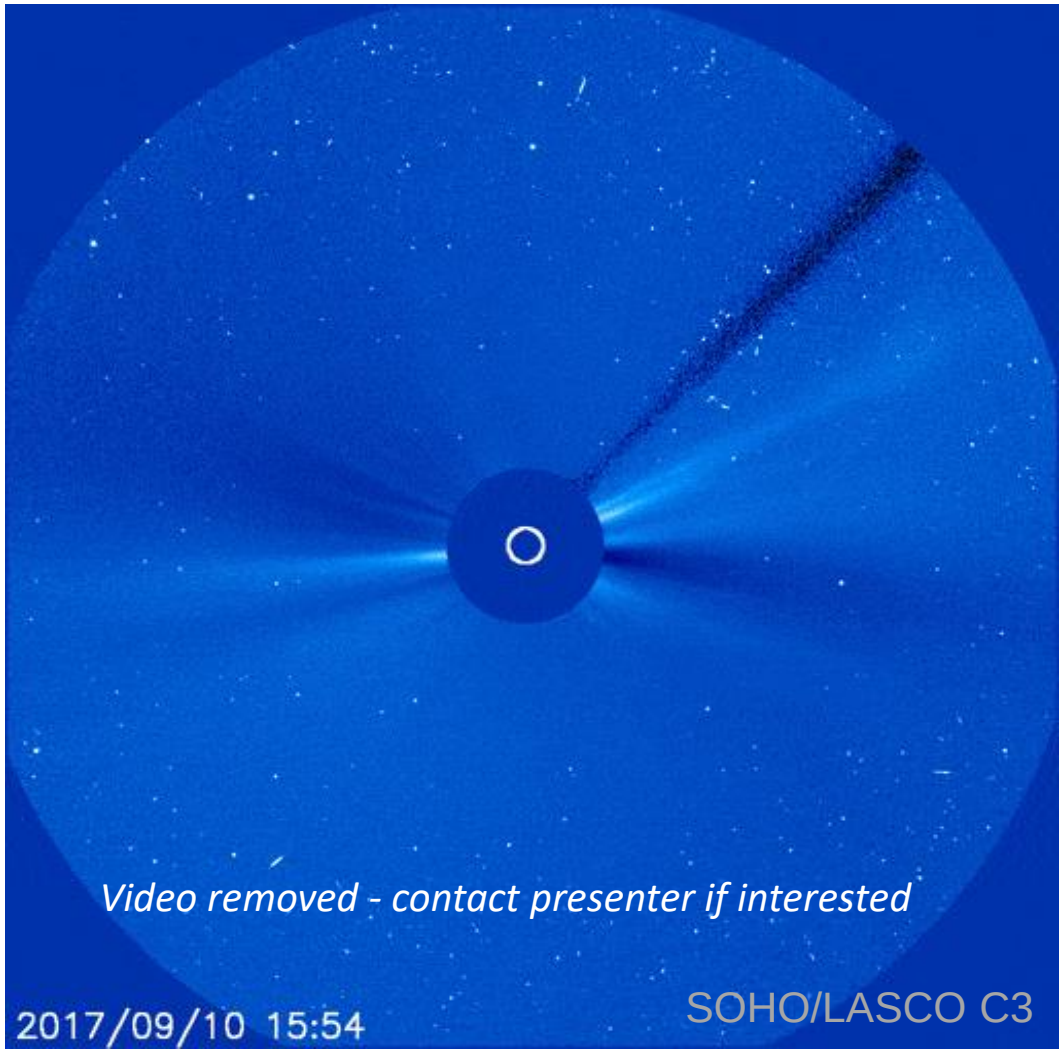


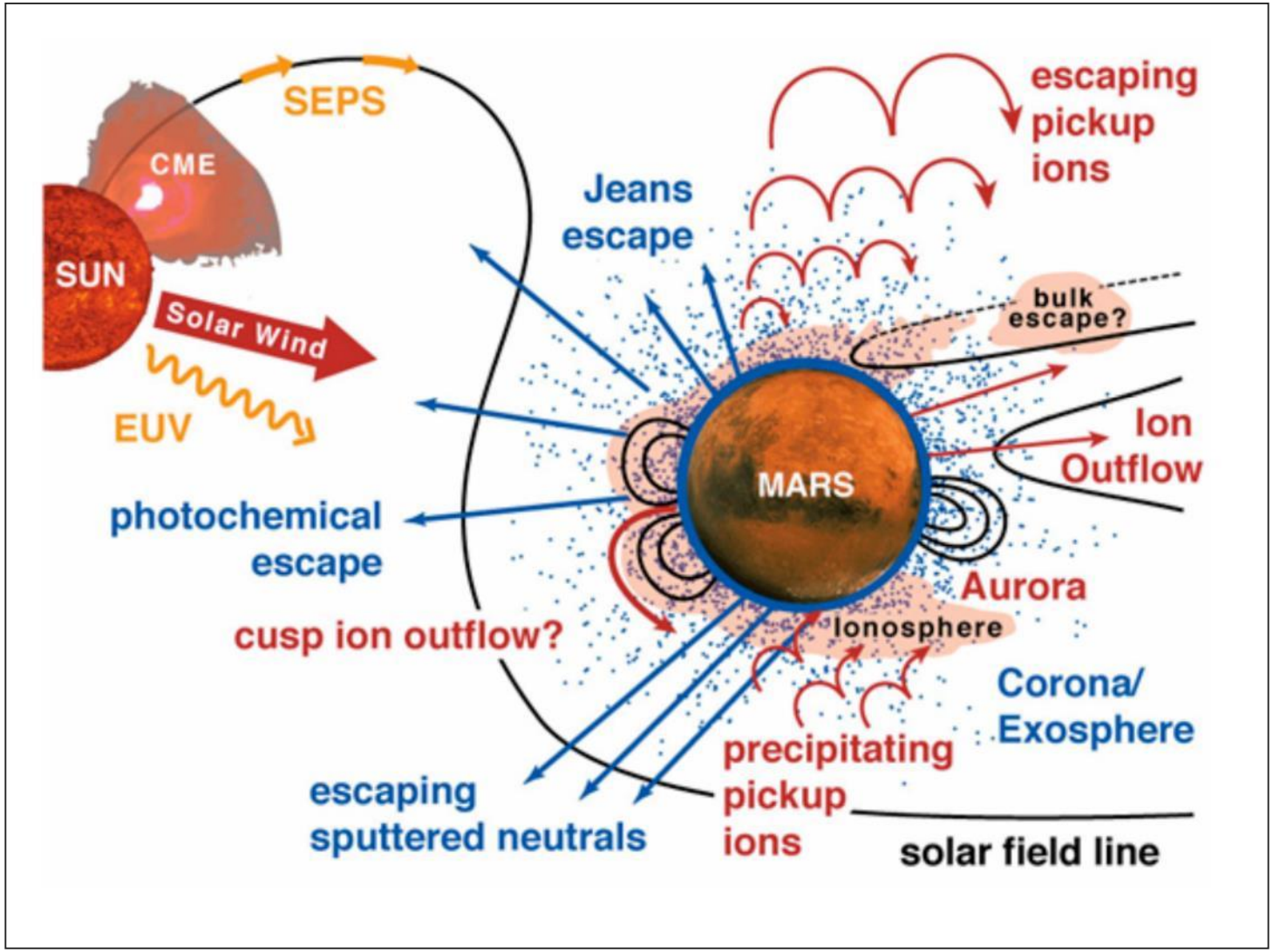
Image: NASA/GSFC

In particular, SEP protons of up to several hundred MeV or more can affect orbiting spacecraft, landed systems and human explorers.



Here, a solar coronagraph located at Earth's L1 point experiences a 'snowstorm' of SEPs.

MAVEN mission science goal: To understand the space weather effects on atmospheric loss over time and ultimately answer the question: “Where did the water go?”



Atmospheric escape rate at Mars can increase by an order of magnitude during extreme solar storm events.

Typical Conditions | Extreme Conditions

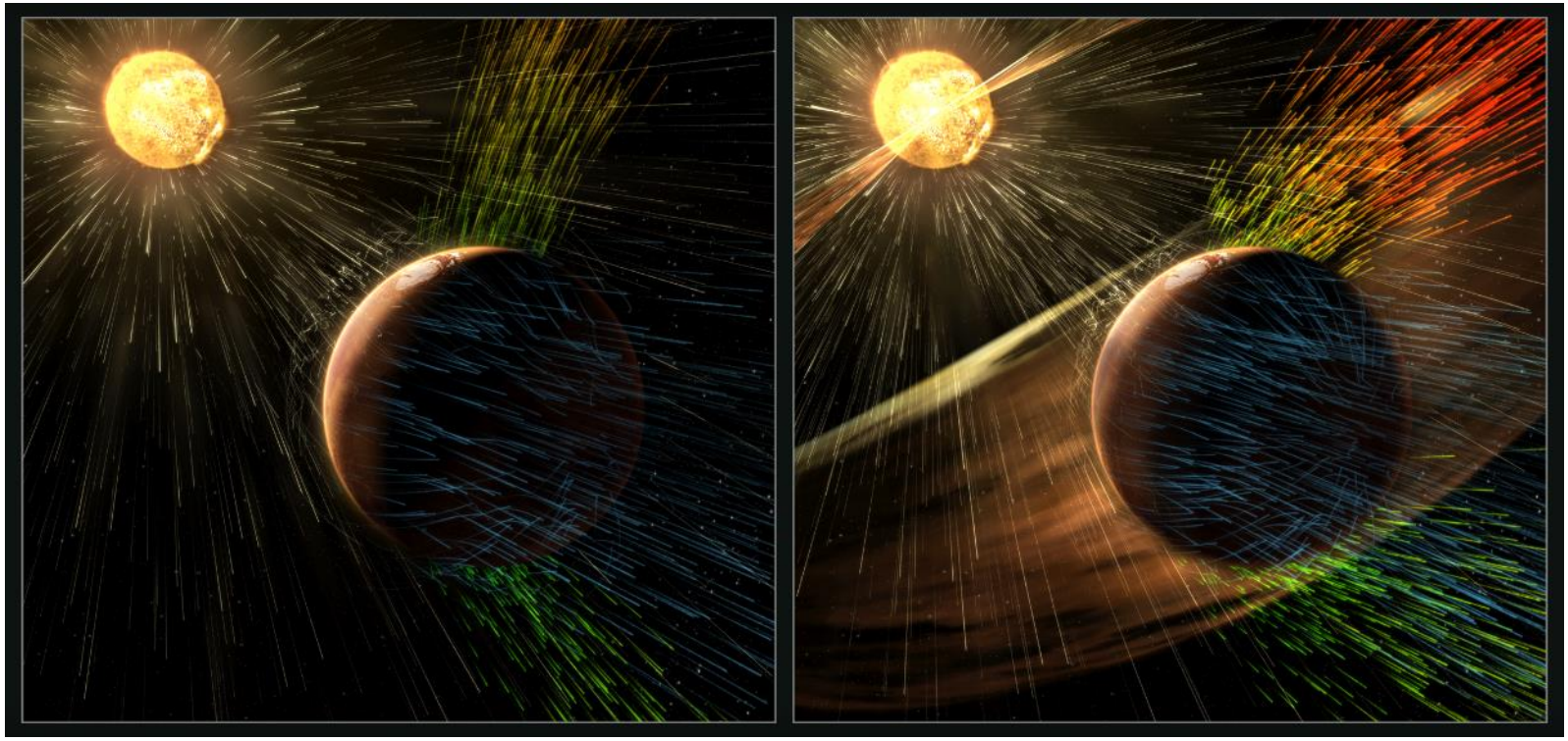
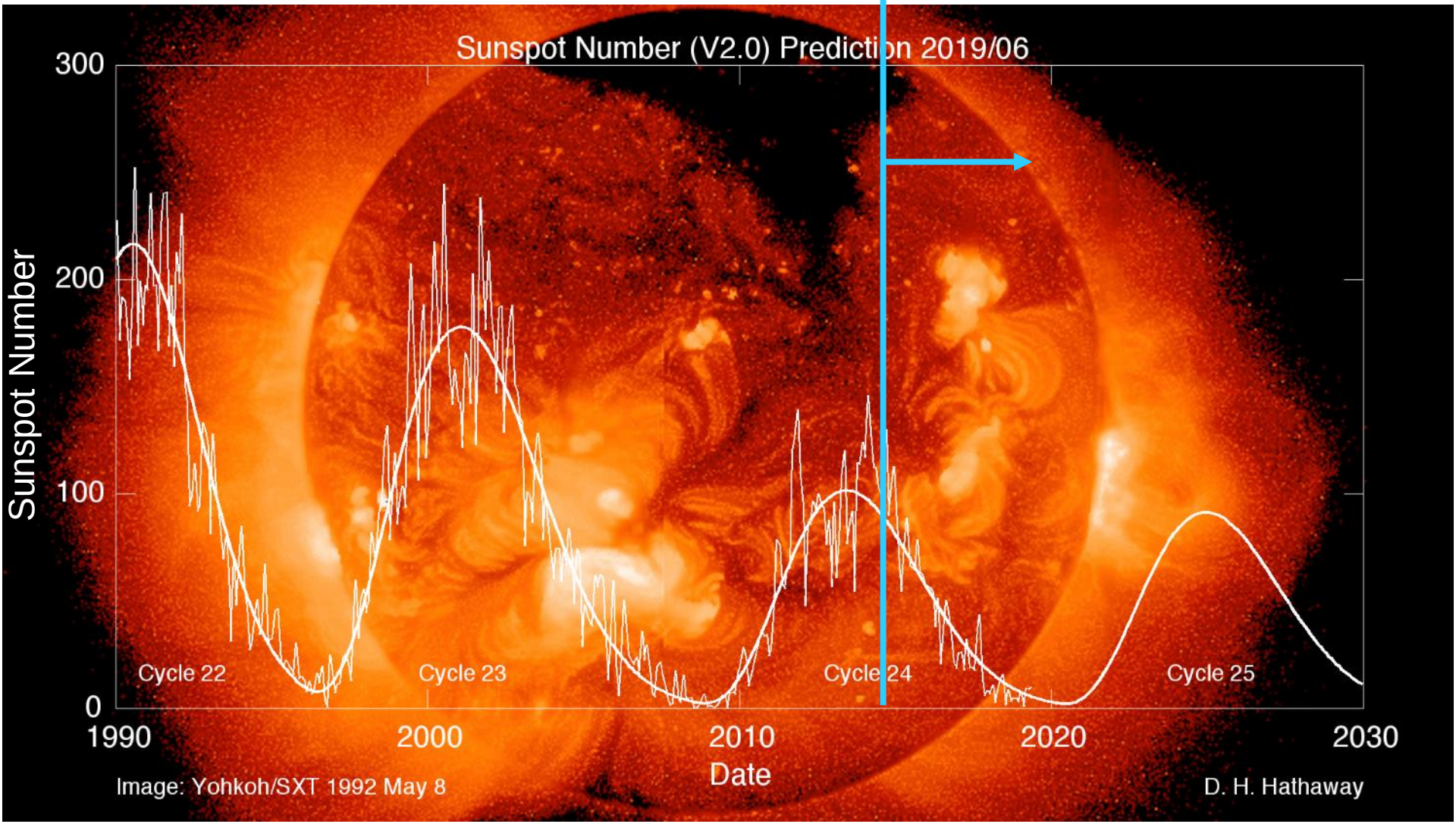


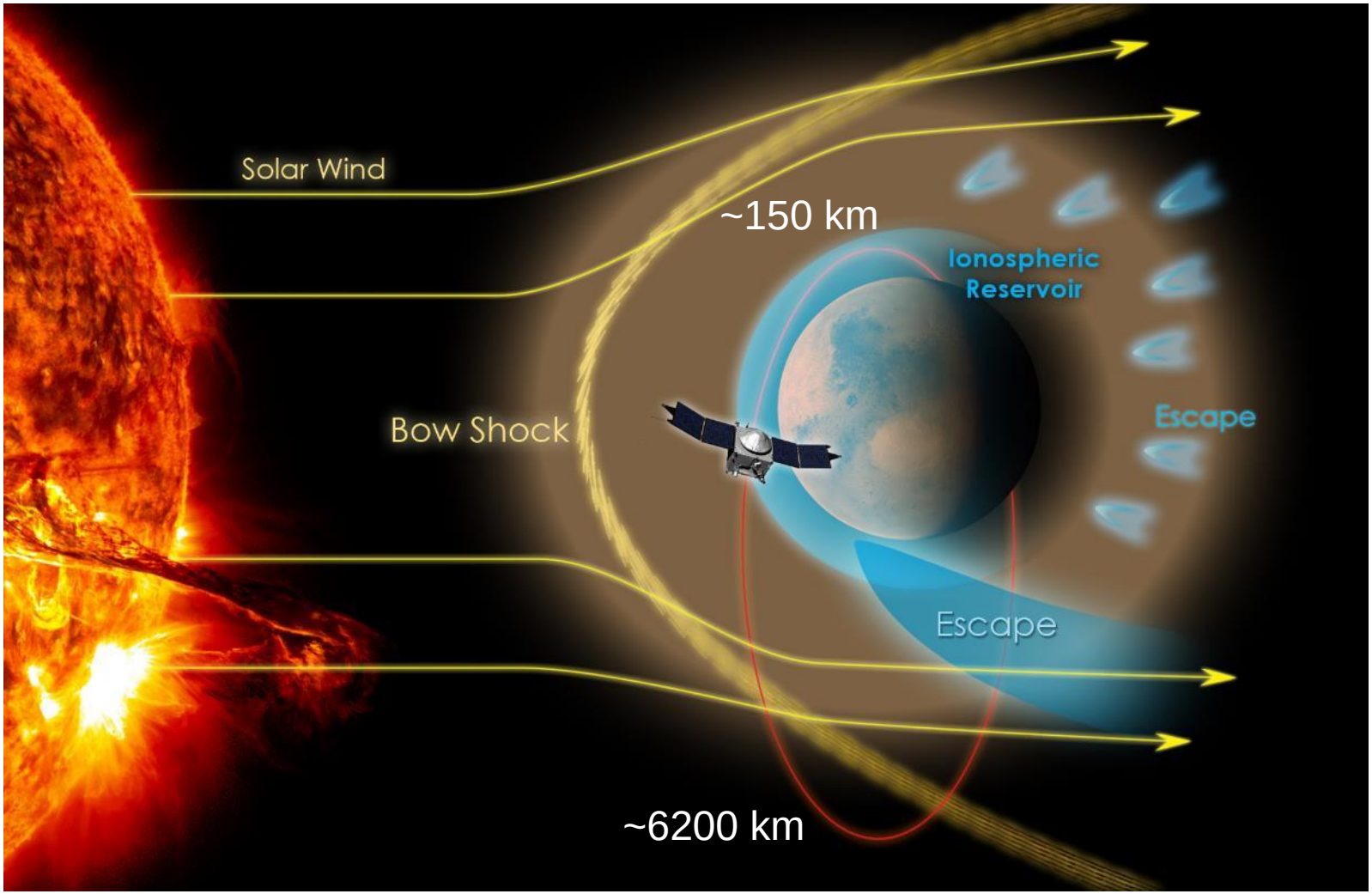
Image credit: (left) NASA and (right) Jakosky et al. (Science, 2015)

MAVEN science observations began at the end of Solar Cycle 24 maximum phase

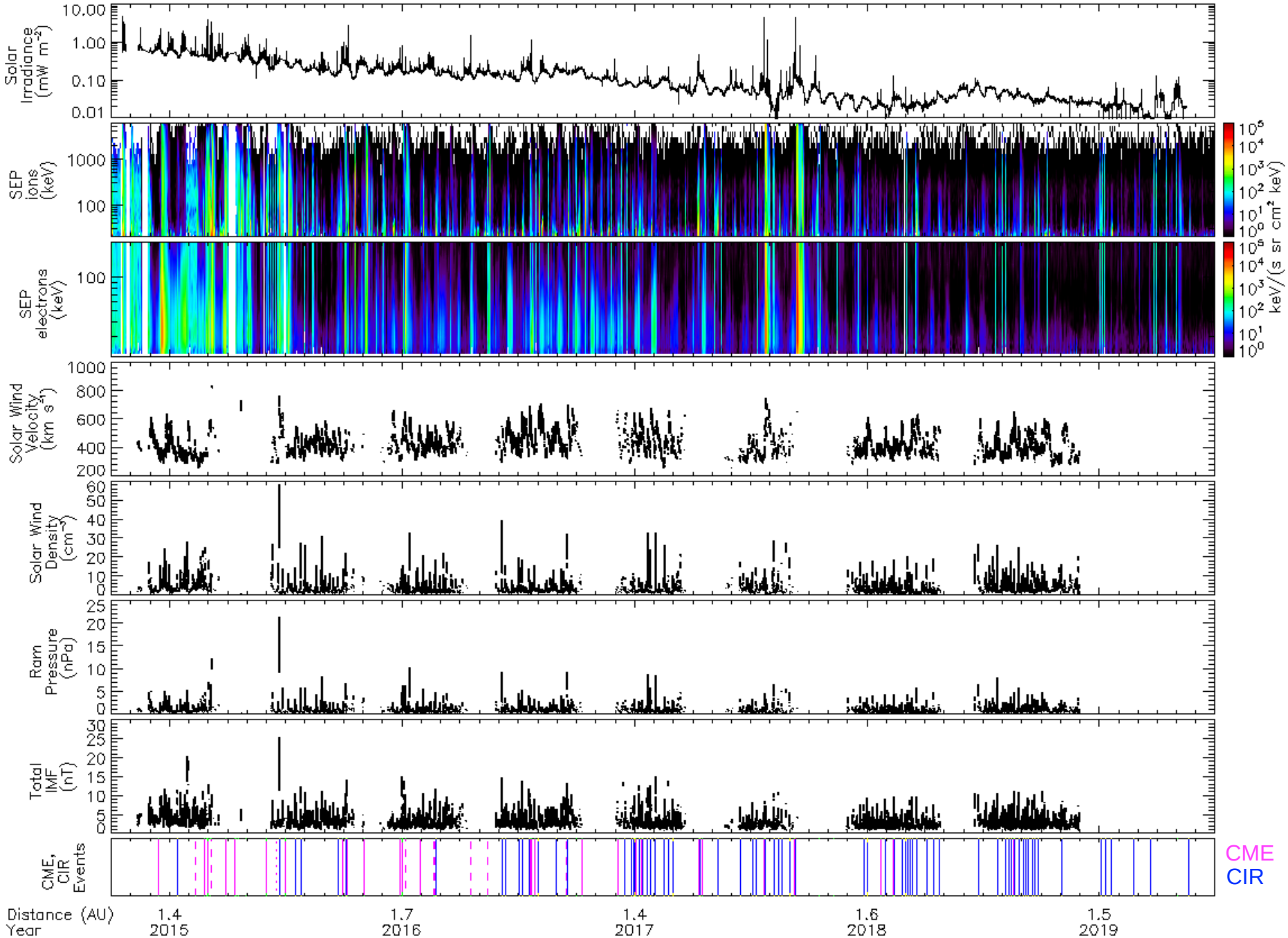
primary science mission plus extended missions



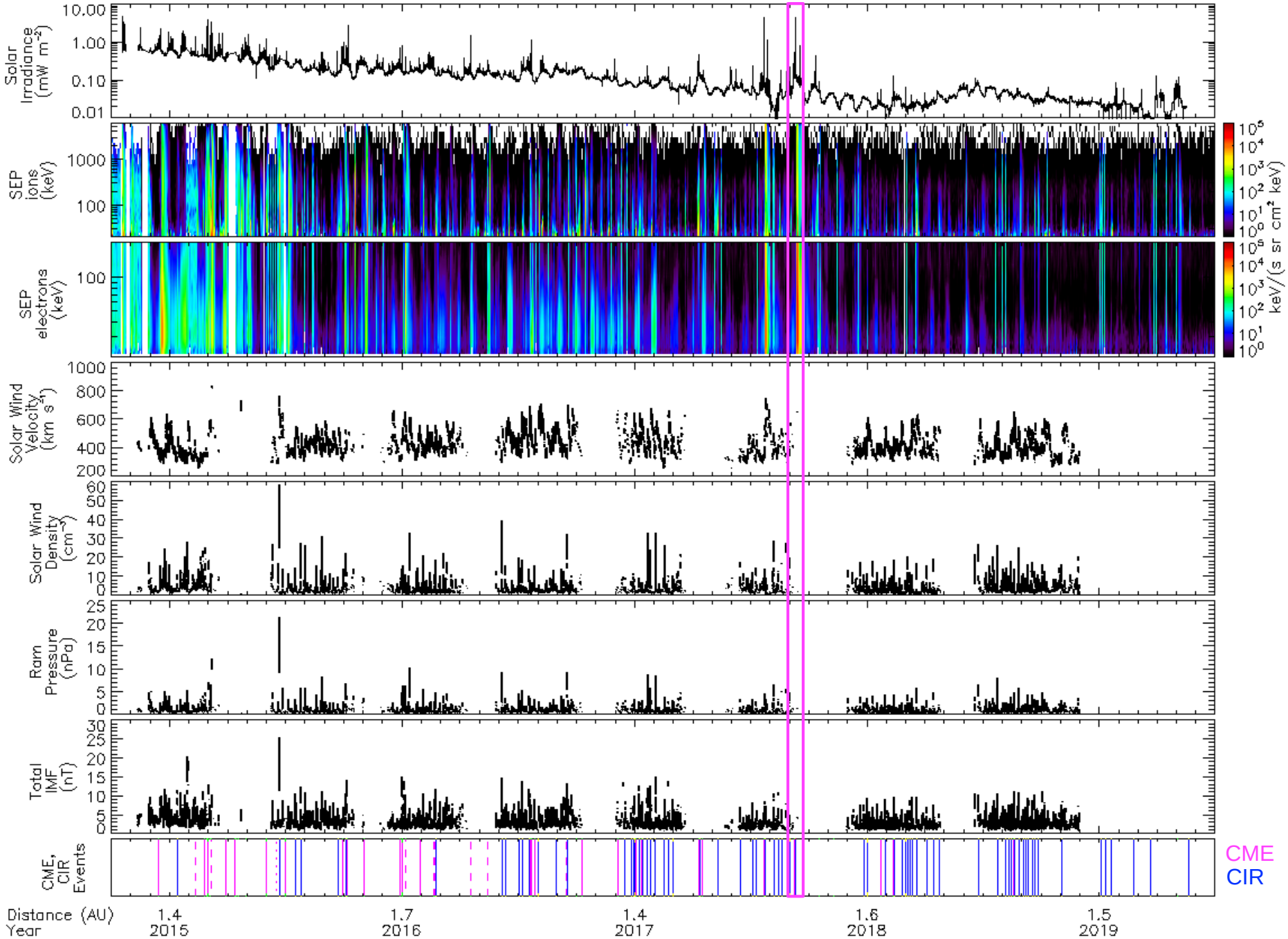
MAVEN's highly elliptical and precessing orbit allows the instruments to observe different plasma environments



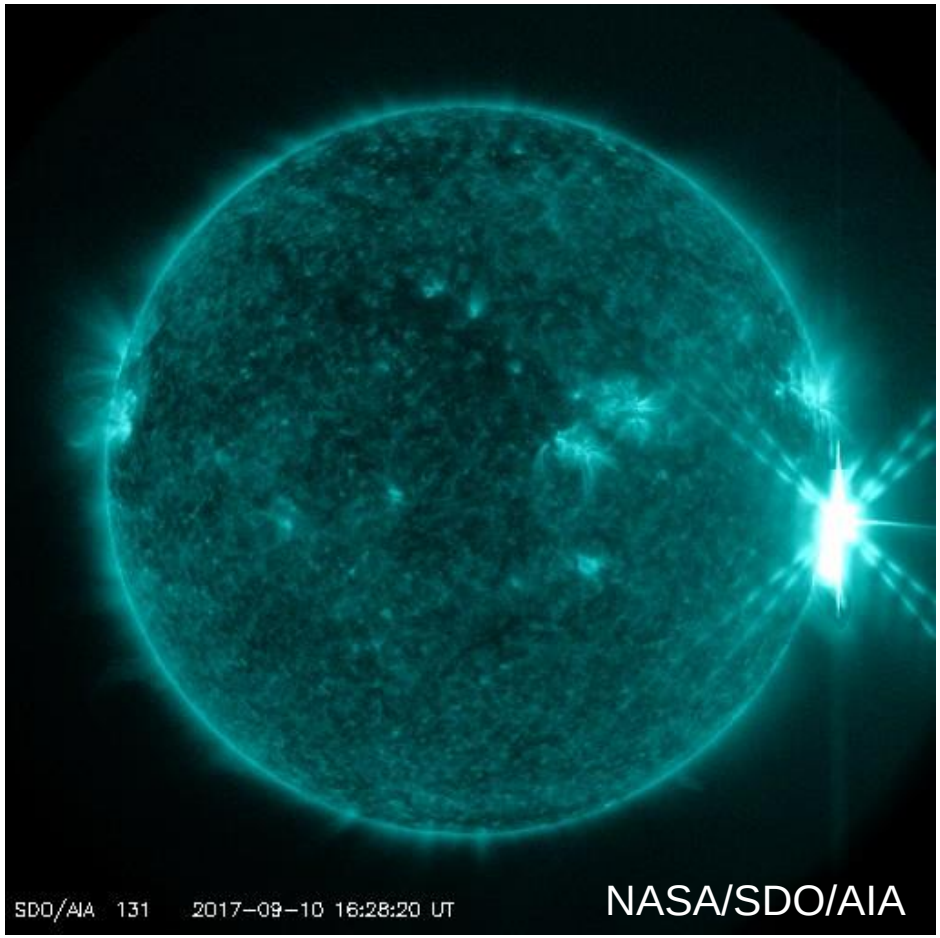
MAVEN upstream measurements (Nov 2014 to date)

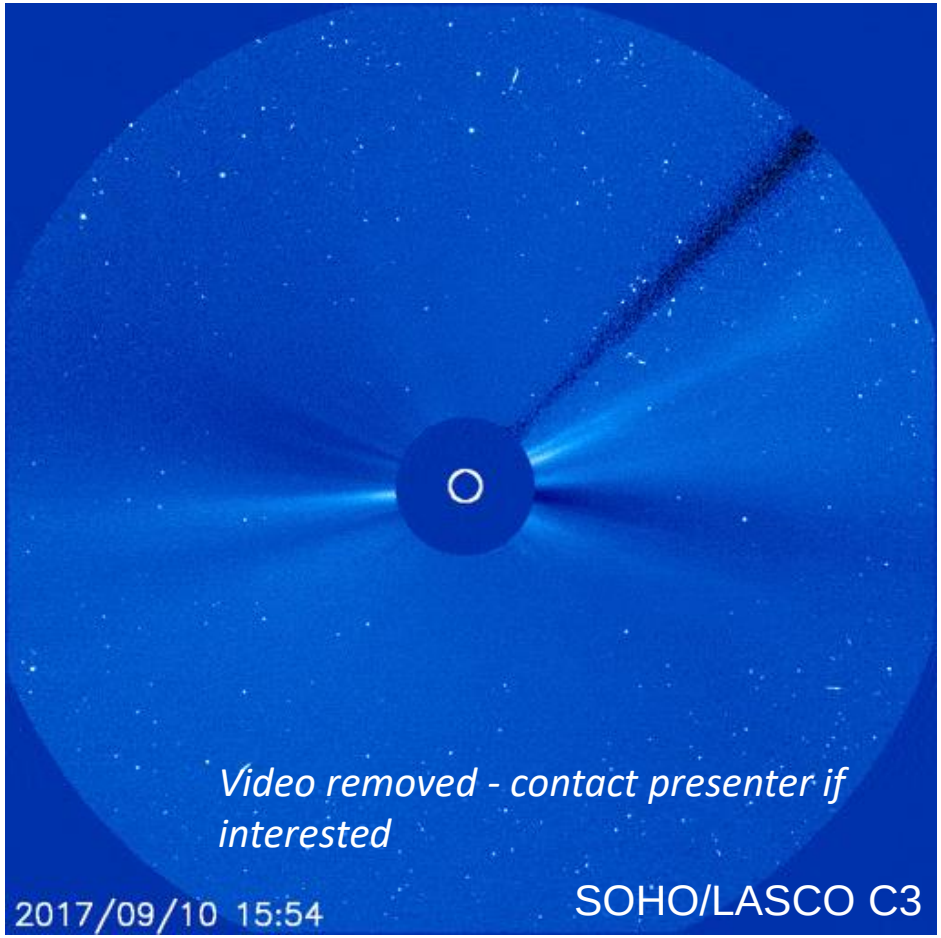


MAVEN observed one of largest space weather event in 2017



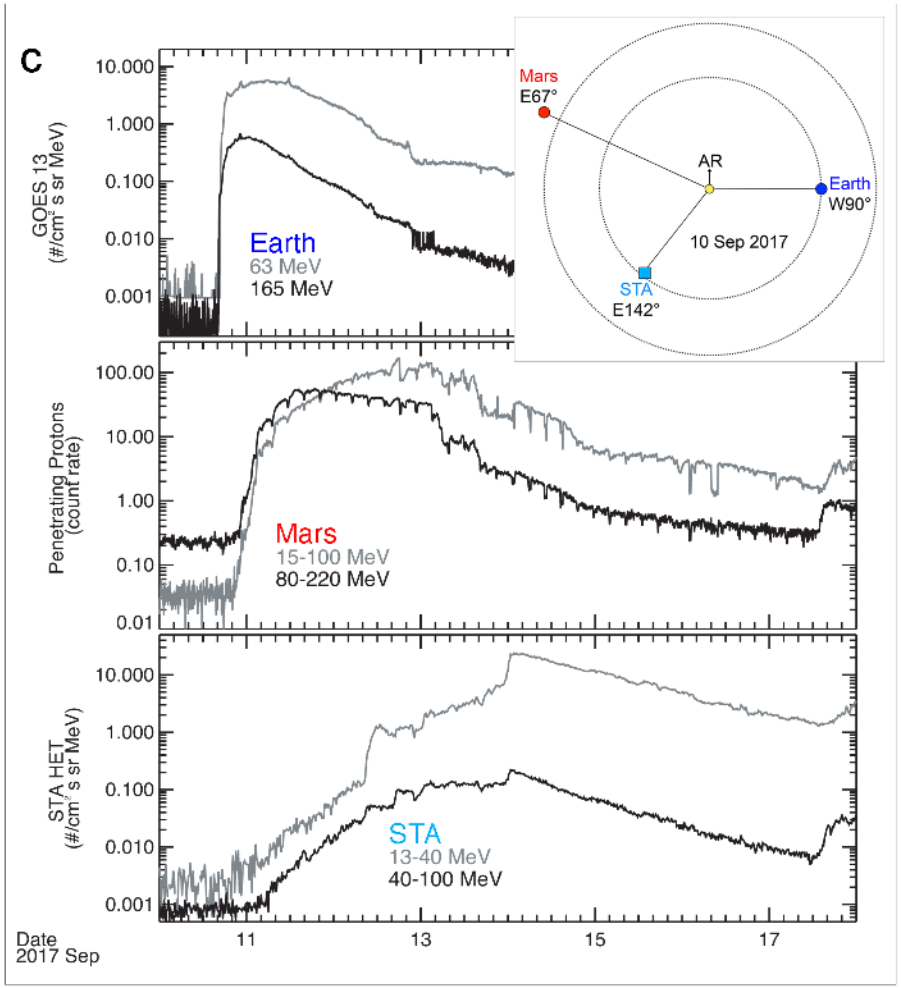
Solar eruptions on 10 September 2017: (left) an intense solar flare and (right) a fast CME

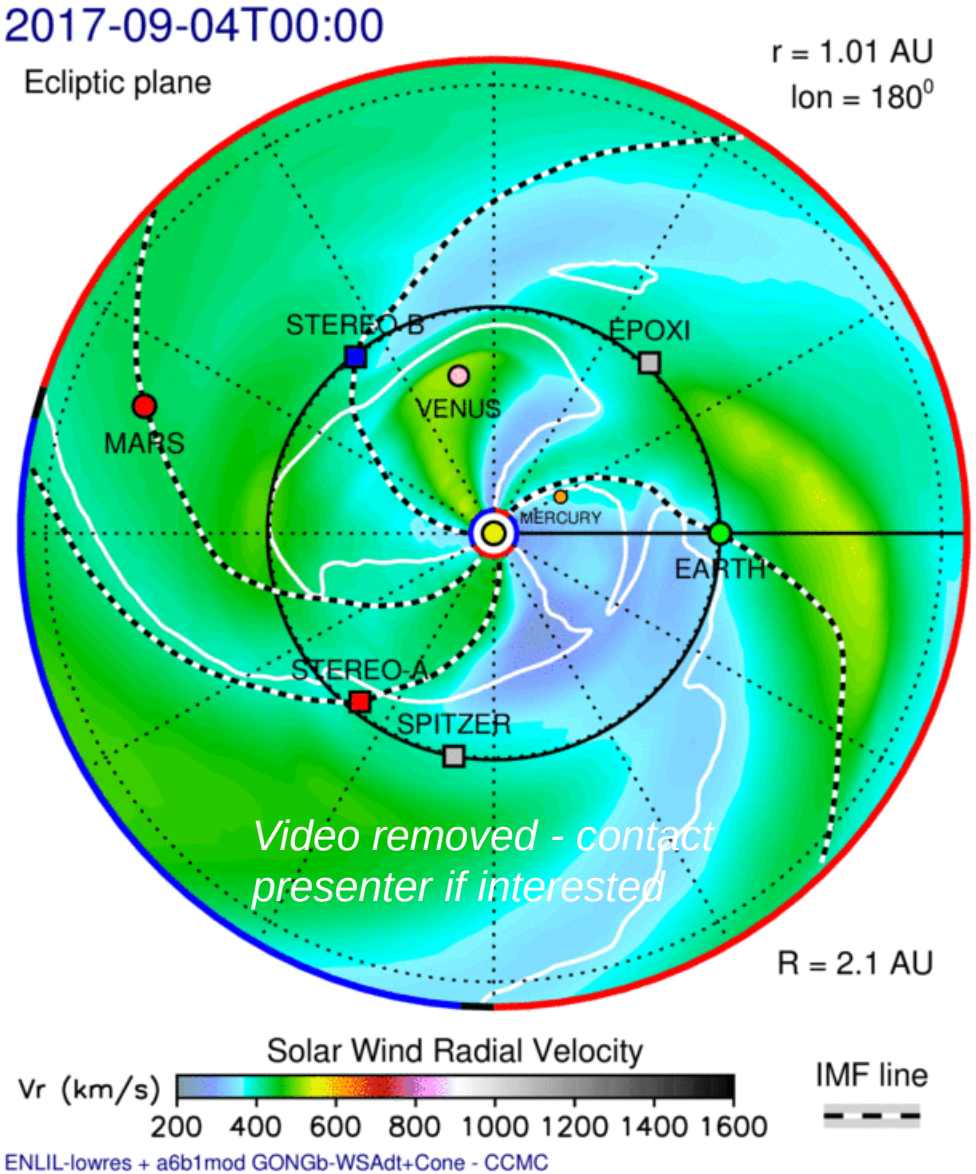




SEPs produced the ‘snow storm’ seen in the Earth/L1 solar coronagraph

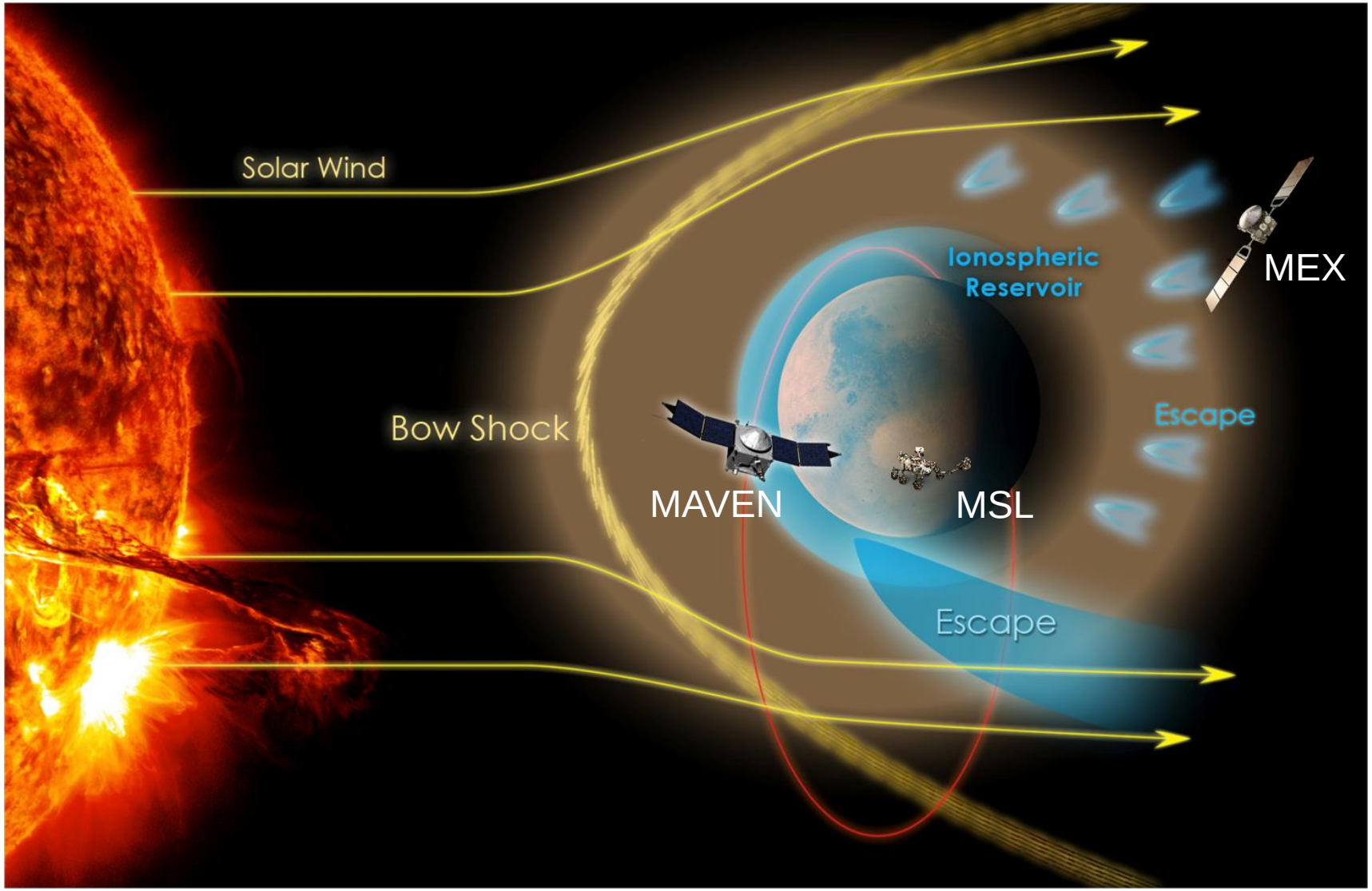
Detection of SEPs was widespread and observed at different interplanetary locations, including Mars



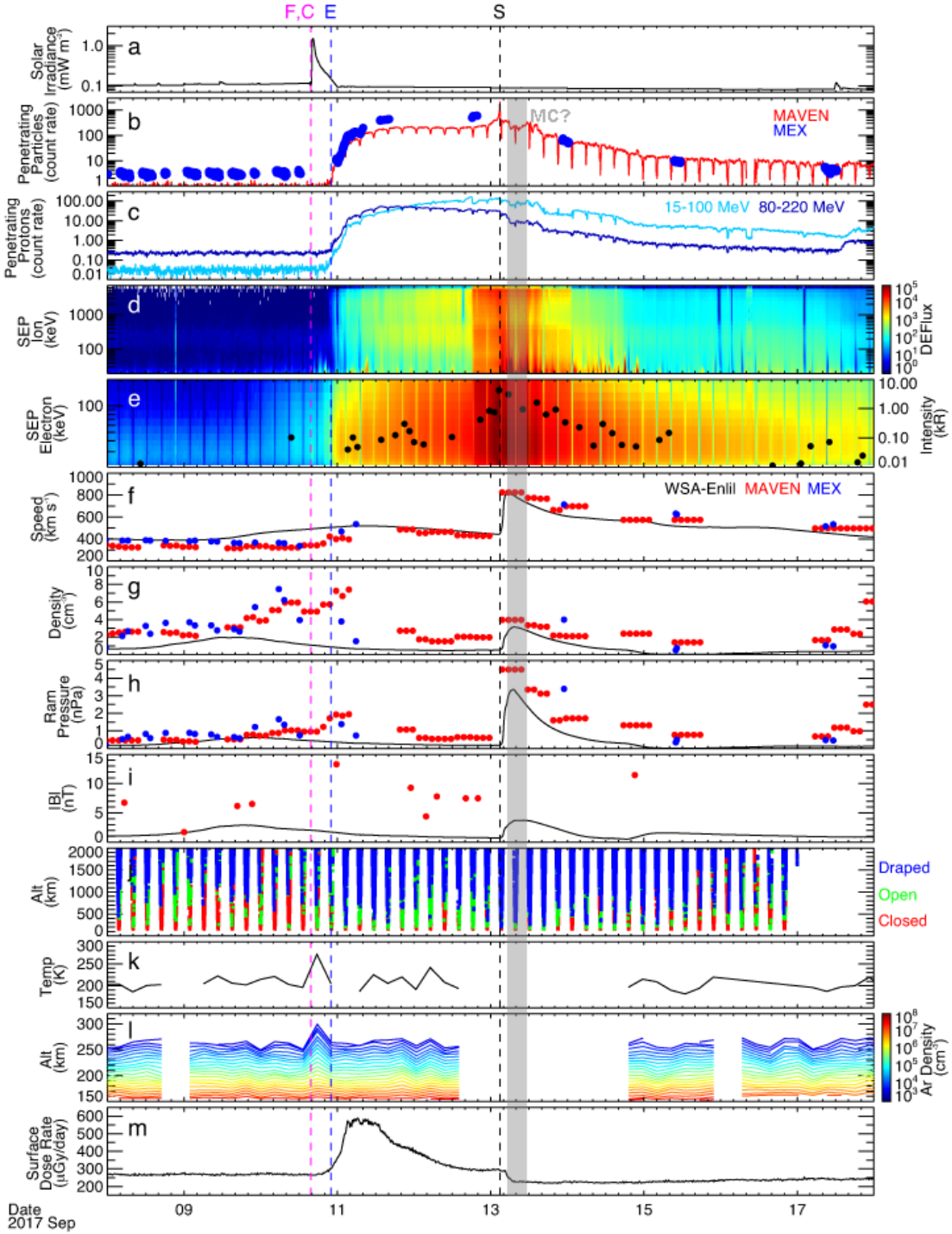


Lee et al. (GRL, 2018)
Simulations by M. L. Mays (NASA/CCMC)

The 10 September 2017 solar storm event provided an opportunity for instruments on board MAVEN, MEX, and MSL to simultaneously observe the space weather impact at Mars.



Combined observations from MAVEN, MEX, and MSL together with solar wind modeling results provides context for understanding the impact and response at Mars.

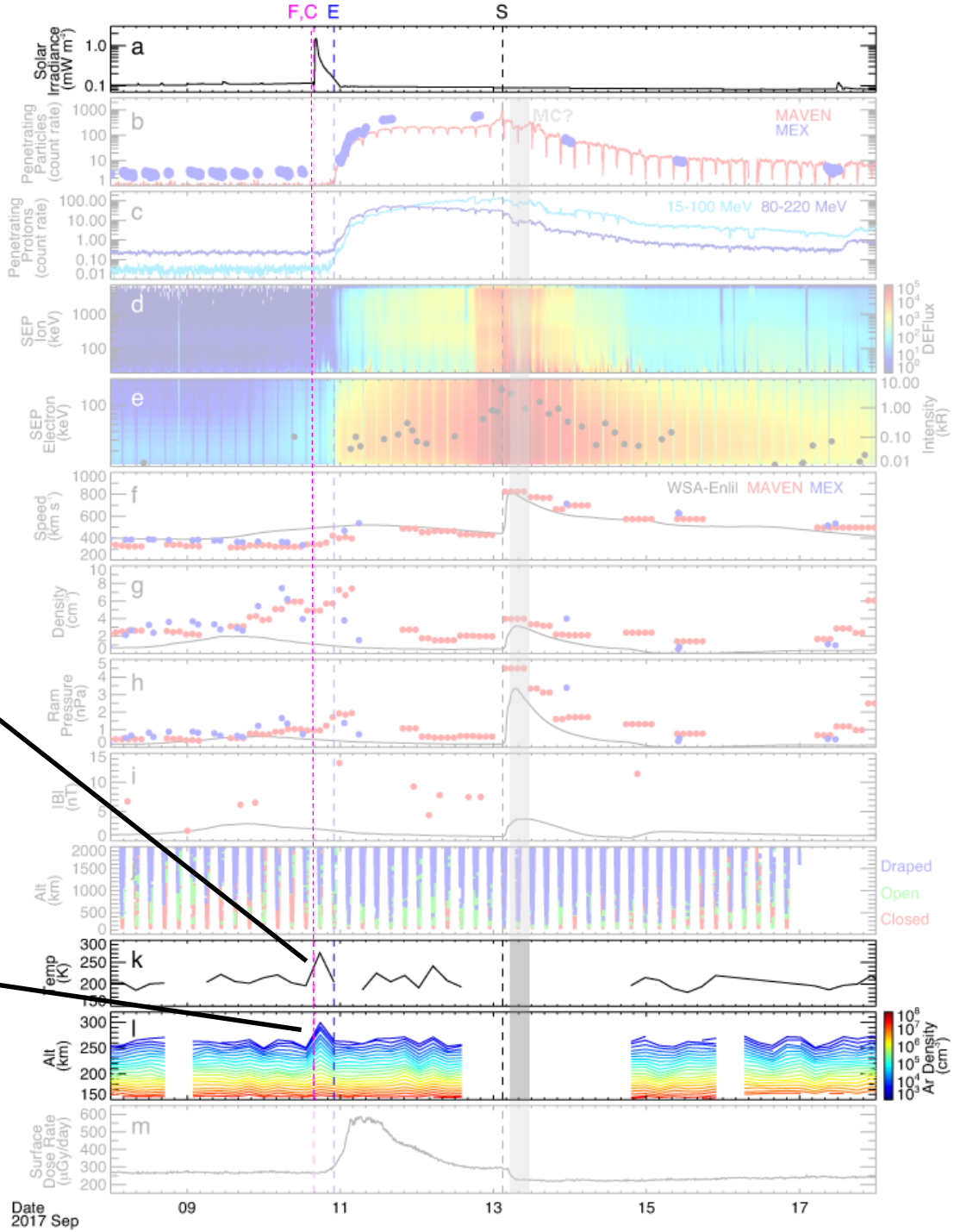


Lee et al. (GRL, 2018)

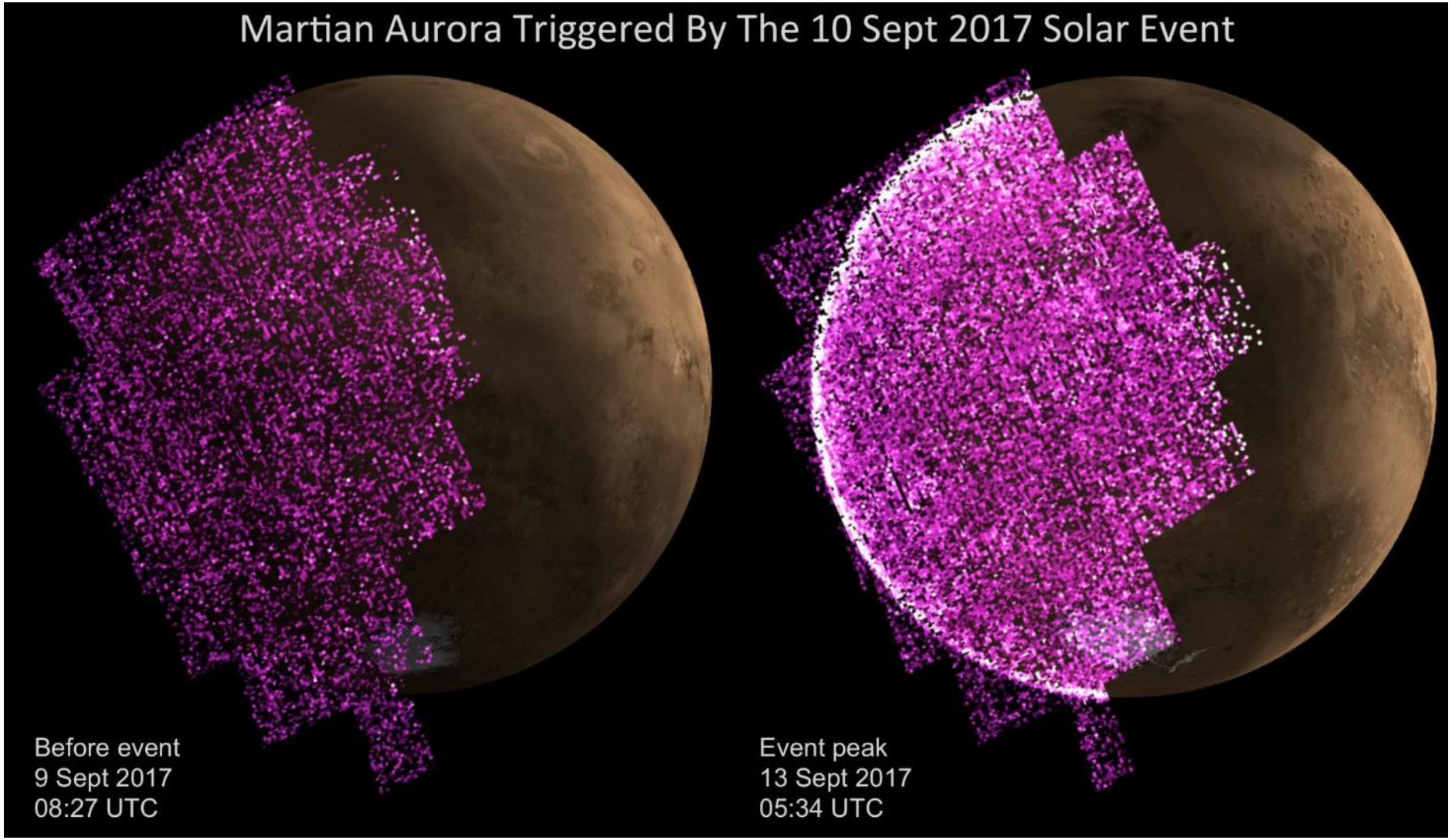
Solar flare photons impacted the Martian atmosphere

<u>Thermosphere at ~170 km:</u>
MAVEN/IUVS airglow measurements showed temperature increase of ~70 K during the flare event interval (Jain et al., GRL, 2018).

<u>Neutral exosphere, >195 km:</u>
MAVEN/NGIMS detected significant temperature and density enhancements of neutral species (Elrod et al., GRL, 2018).

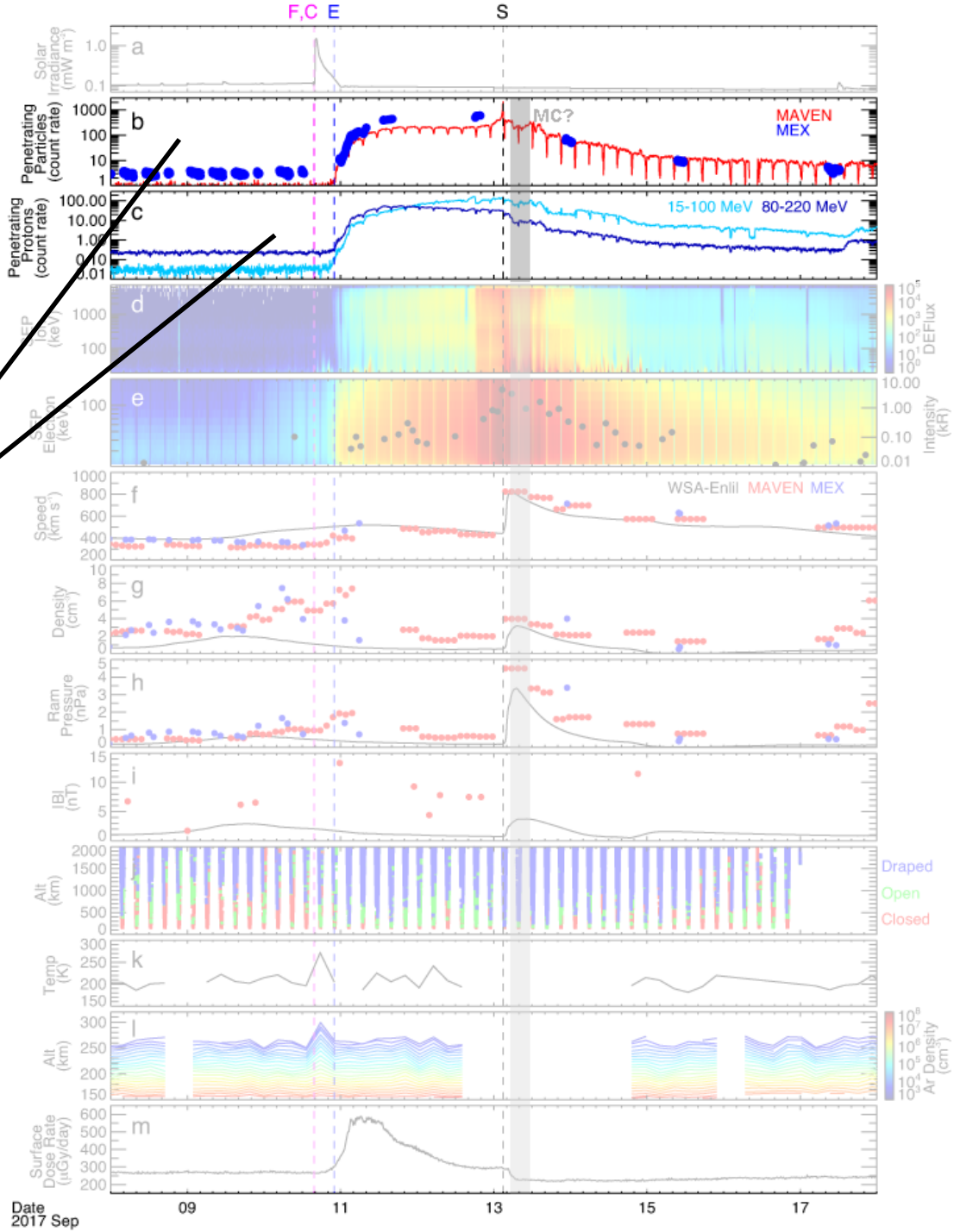


Lower energy (100s keV) SEPs penetrated deep into the atmosphere to produce a bright diffuse aurora that is visible around the limb and across the disk.



Schneider et al. (GRL, 2018)

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



MAVEN/SWEA:

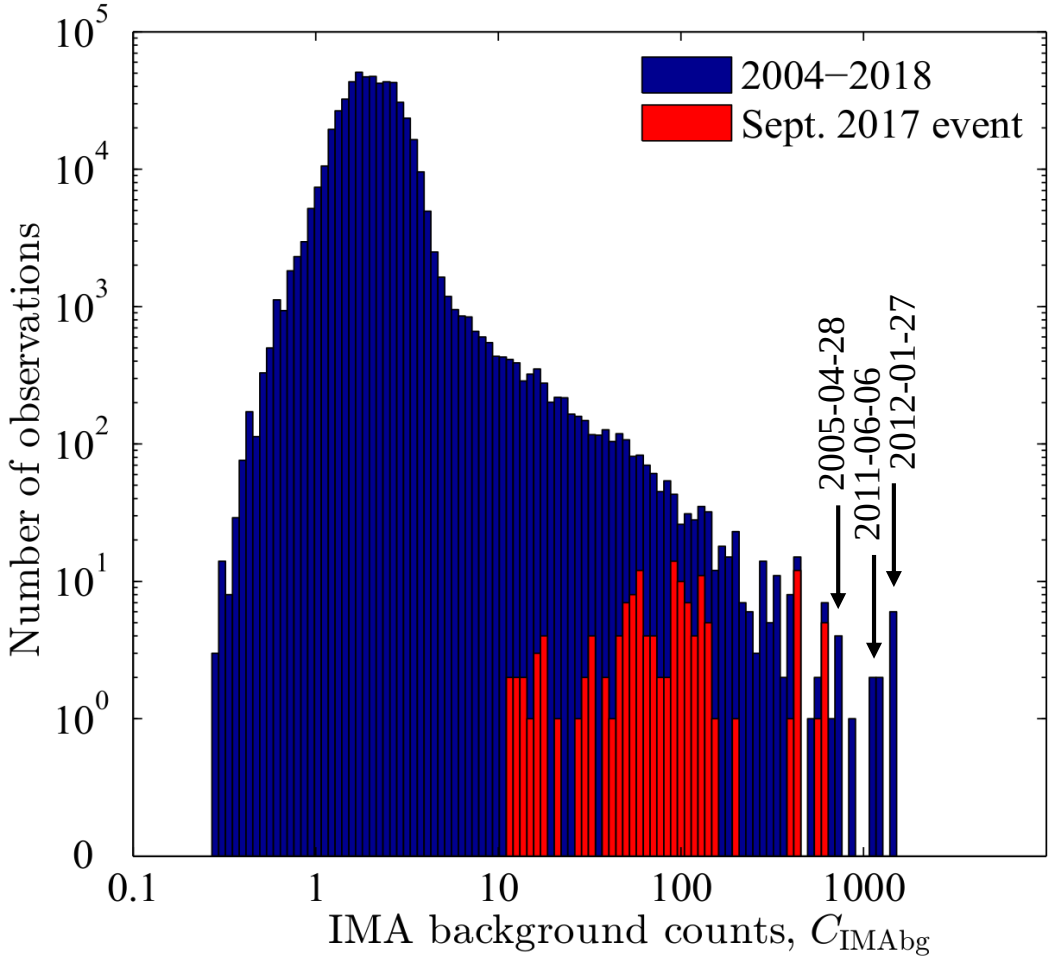
- few tens of MeV protons
- few MeV electrons

MEX/ASPERA-3 IMA

- >20 MeV protons
- >1 MeV electrons

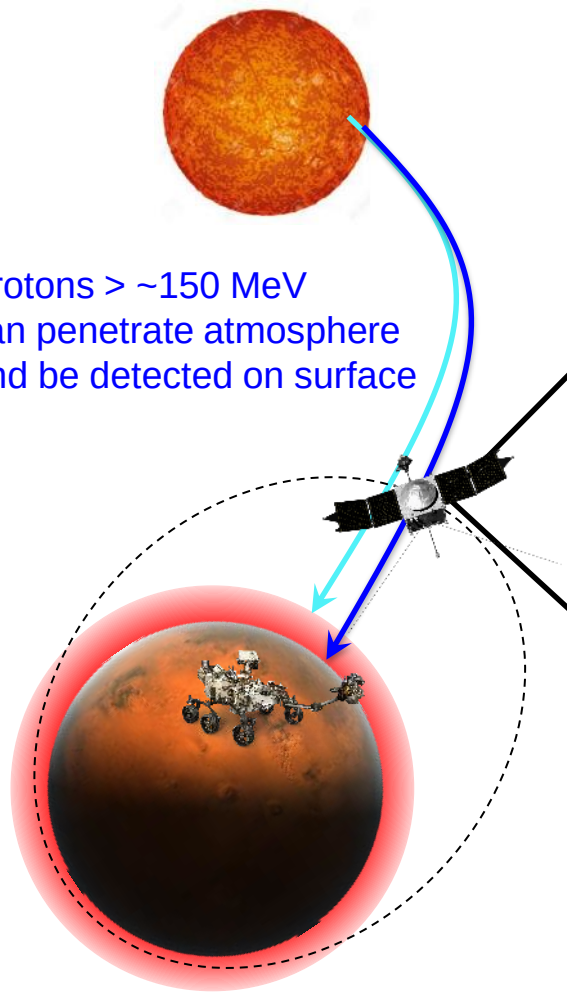
(Ramstad et al., GRL, 2018)

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.

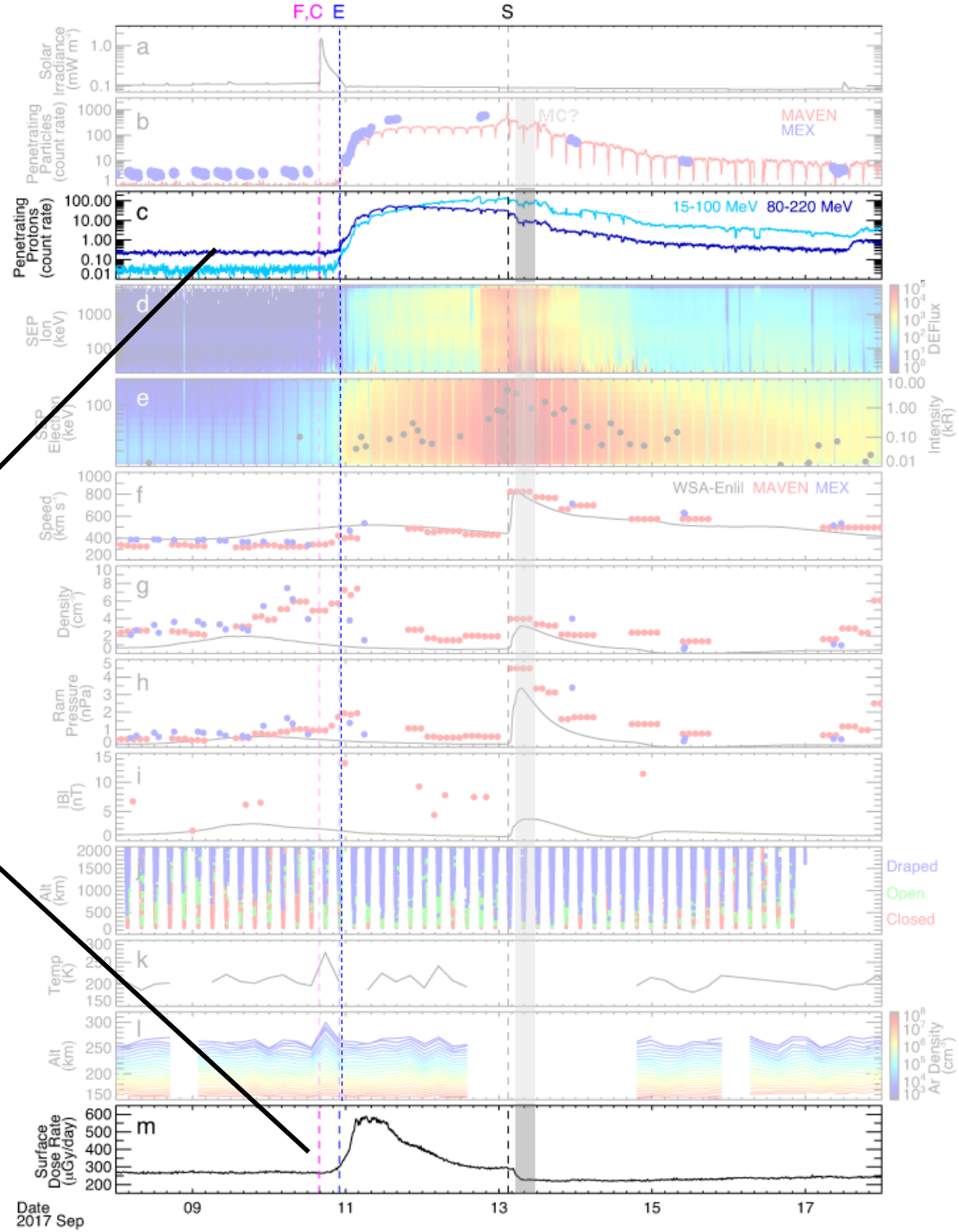


Ramstad et al. (GRL, 2018)

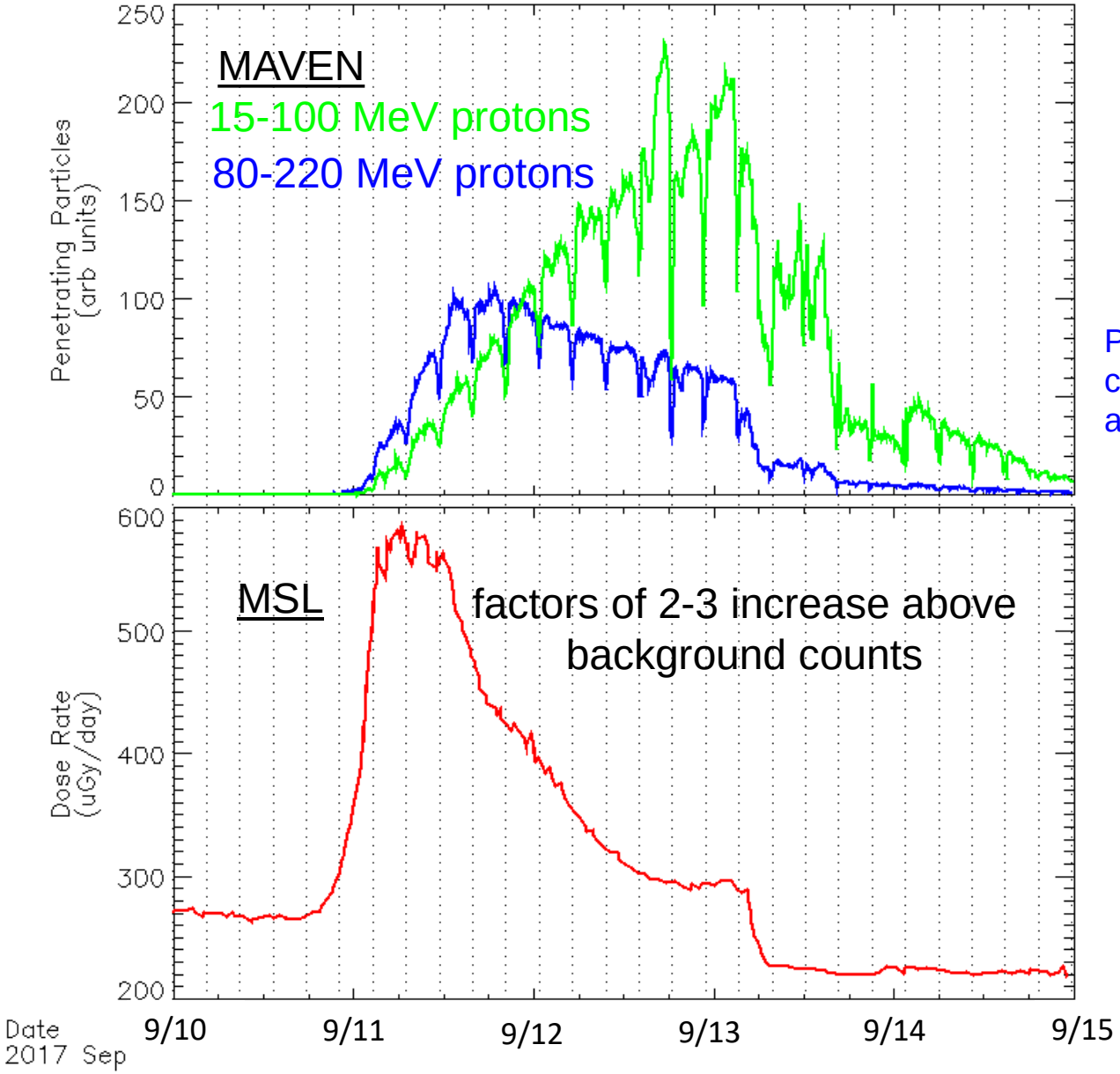
Higher energy SEP protons penetrated down to the surface

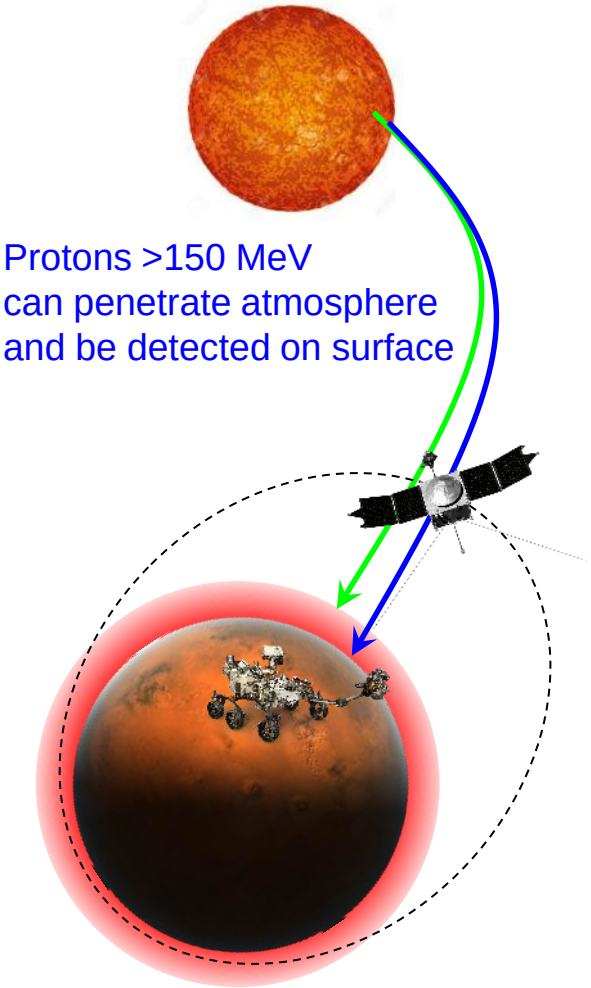


Protons > ~150 MeV
can penetrate atmosphere
and be detected on surface



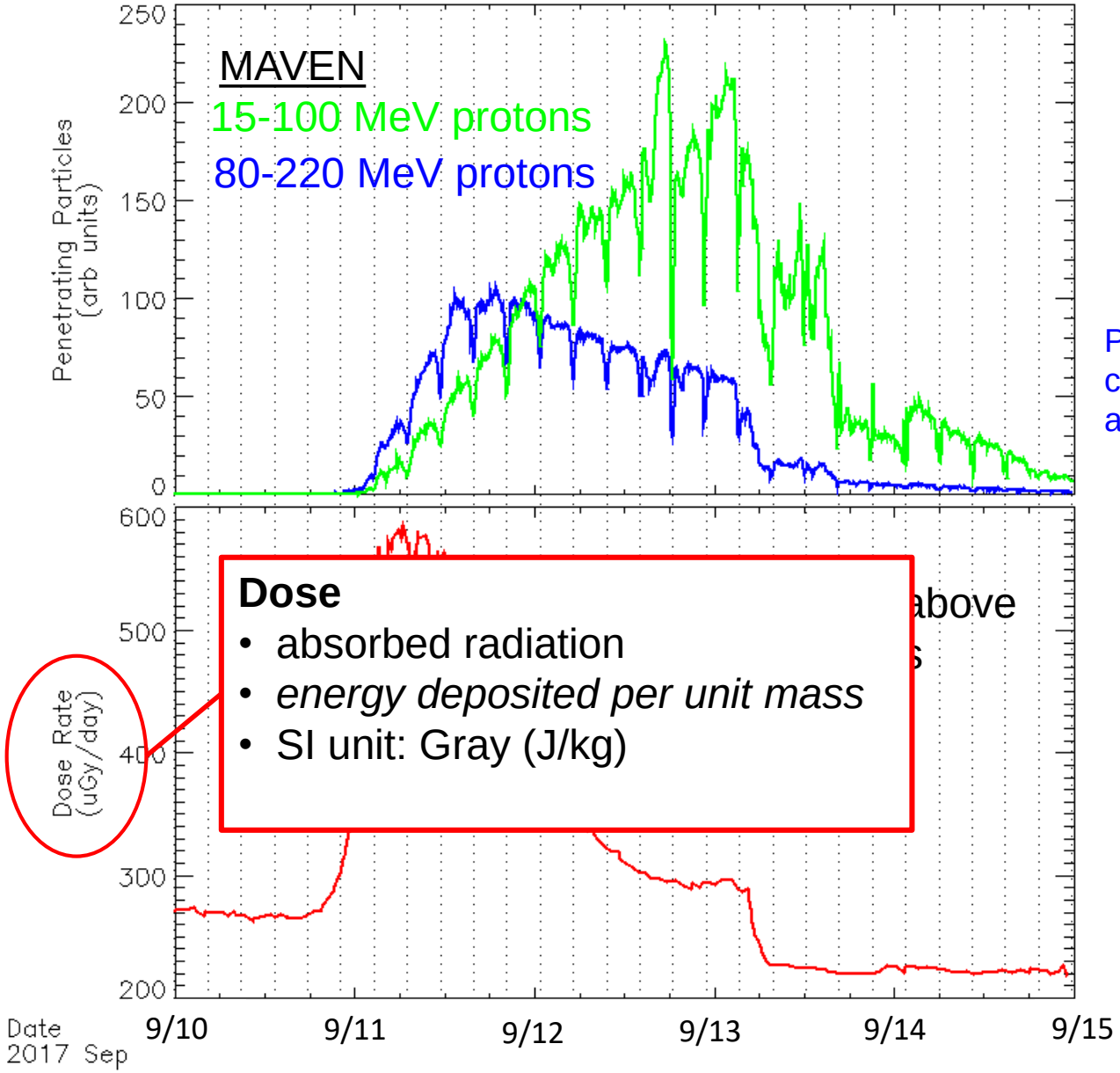
(above) D. Larson (SSL/UC Berkeley)
(right) Lee et al. (GRL, 2018)





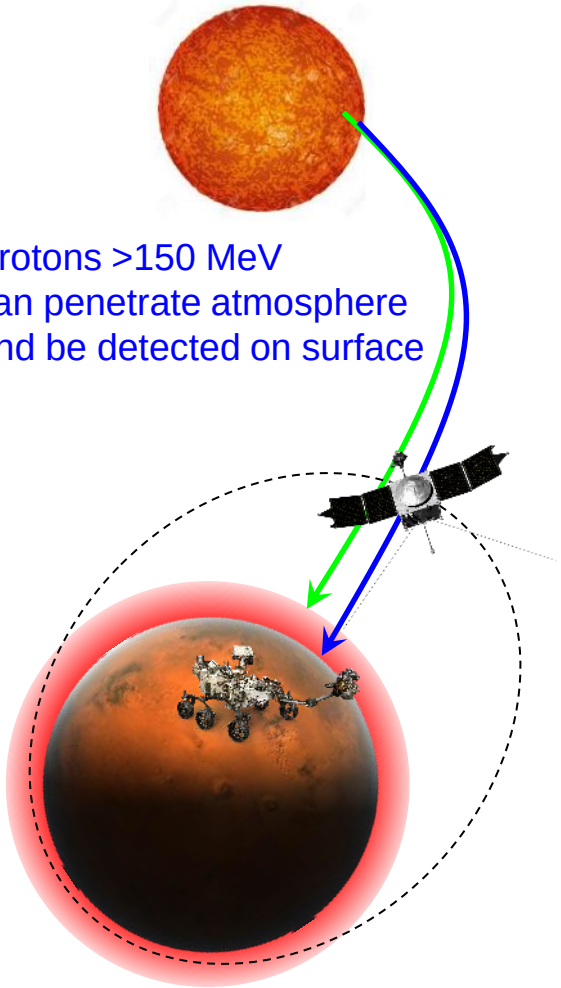
D. Larson (SSL/UC Berkeley)

This is the largest surface enhancement observed by MSL/RAD since its arrival to Mars in 2012 (Zeitlin et al.; Ehresmann et al. GRL, 2018).



Dose

- absorbed radiation
- *energy deposited per unit mass*
- SI unit: Gray (J/kg)



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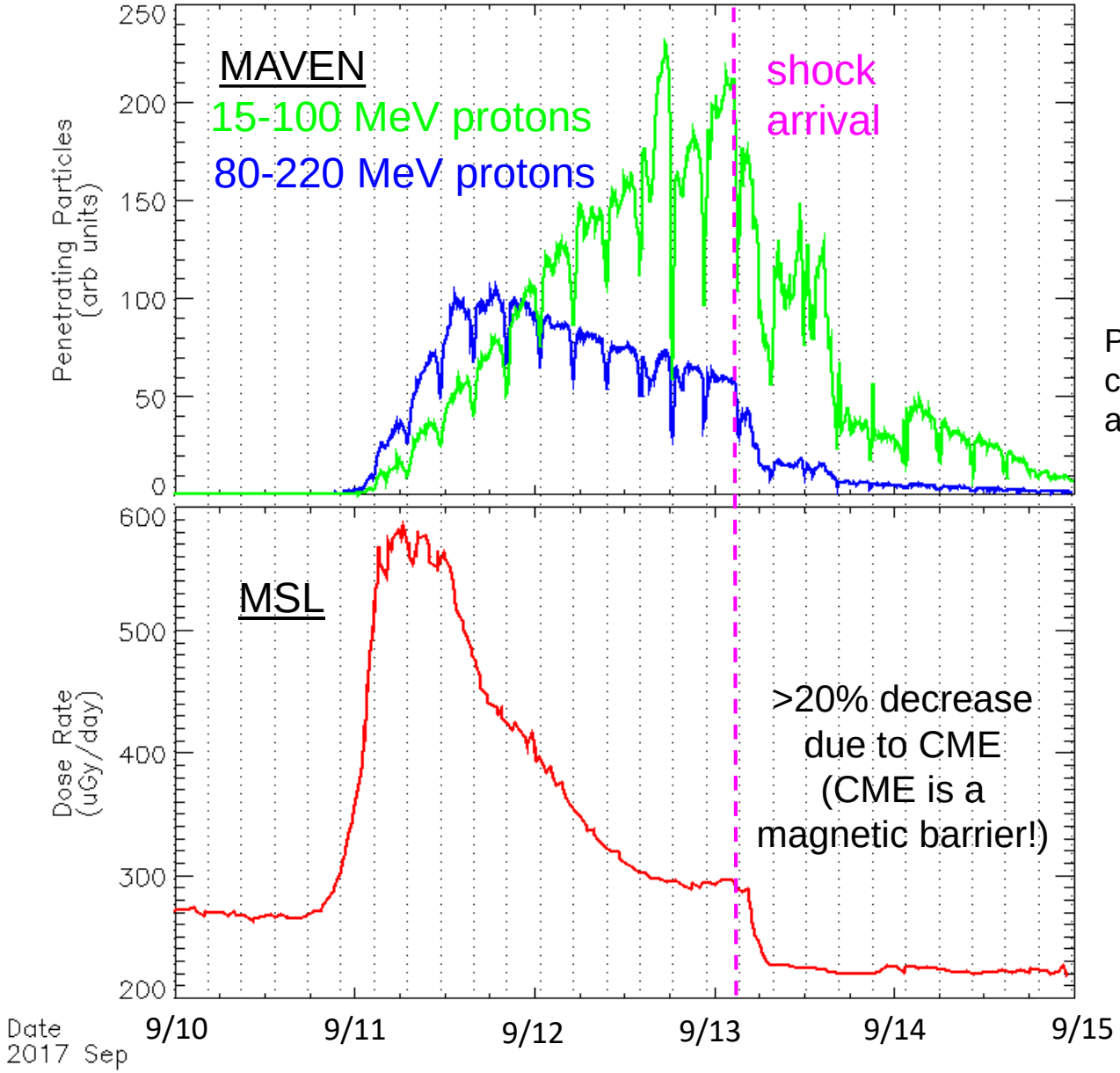
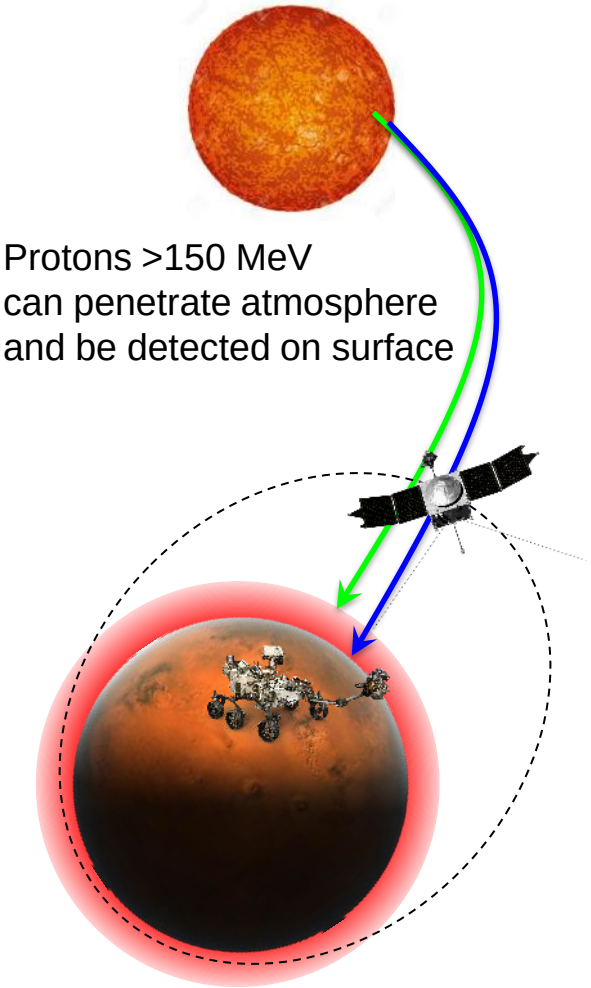




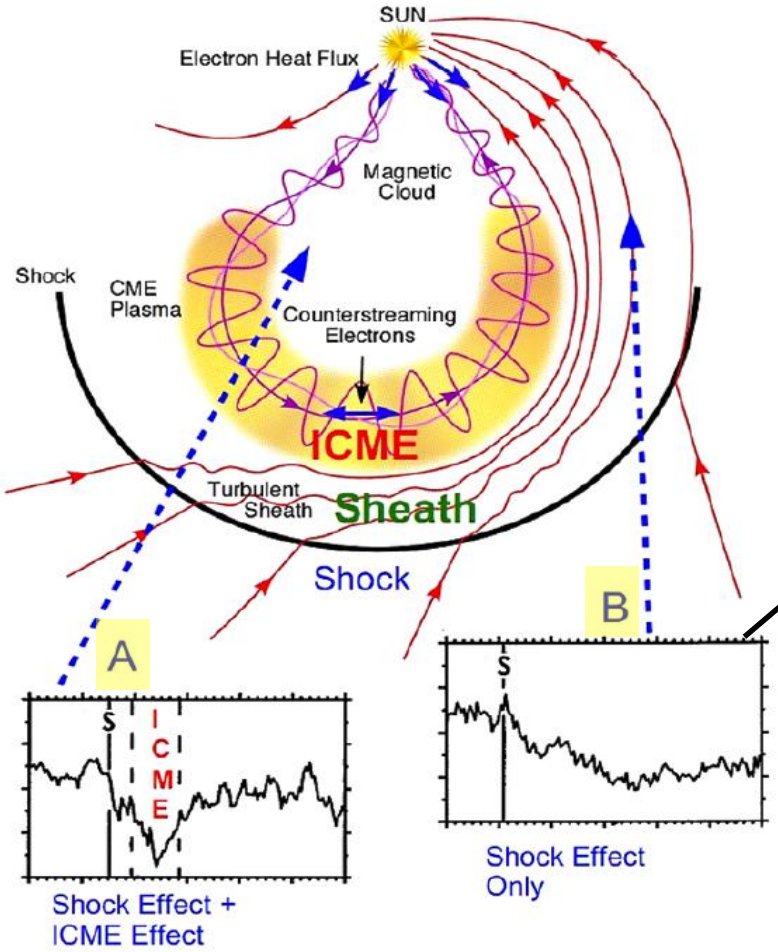
D. Larson (SSL/UC Berkeley)

This is the deepest FD decrease observed in the dose rate observations by MSL/RAD (Guo et al., Space Weather, 2018).

Space Weather 101

A **CME** can act as a **magnetic barrier** to scatter Galactic Cosmic Ray (GCR) particles away from the local observer, reducing the observed intensity.

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

Richardson and Cane (2011)

Dose Impact: September 2017 solar event

	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 9/11/17
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

- Increased dose from SEP event almost exactly compensated by decreased rates after event.
- Radiation exposure limit from this event: < 1 mGy-Eq*.
- Compared to 30-day limit for the heart and blood-forming organs: 250 mGy-Eq.

* Gray-Equivalent: biological effective of protons compared to photons to cause non-cancer radiation effects

Zeitlin et al. (GRL, 2018)

Dose Impact: September 2017 solar event

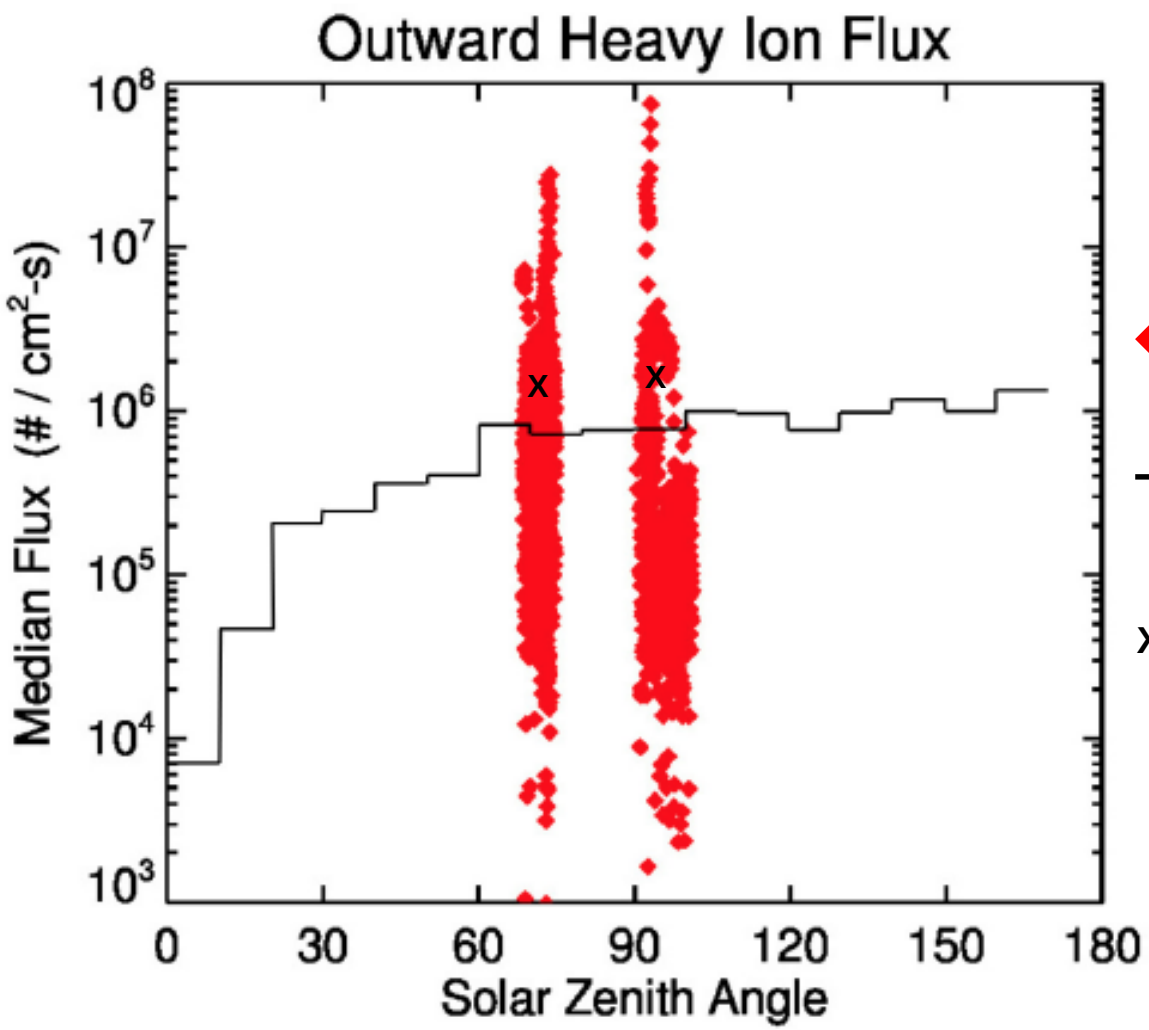
	Totals, 30 days starting 9/11/17
B, omnidirectional	7.7 mGy
E, omnidirectional	8.2 mGy
Dose equivalent using B	16.6 mSv

The Martian (2015; 20th Century Fox)

- Increas
  compen
- Radiati q*.
- Compa rming
  organs:

TL;DR: The radiation risk at the surface from this event was negligible (Zeitlin et al., GRL, 2018).

Atmospheric loss: the average outward flux from the September 2017 space weather event is greater than the mission average*



* Loss rates may be higher in regions not sampled by MAVEN during this event

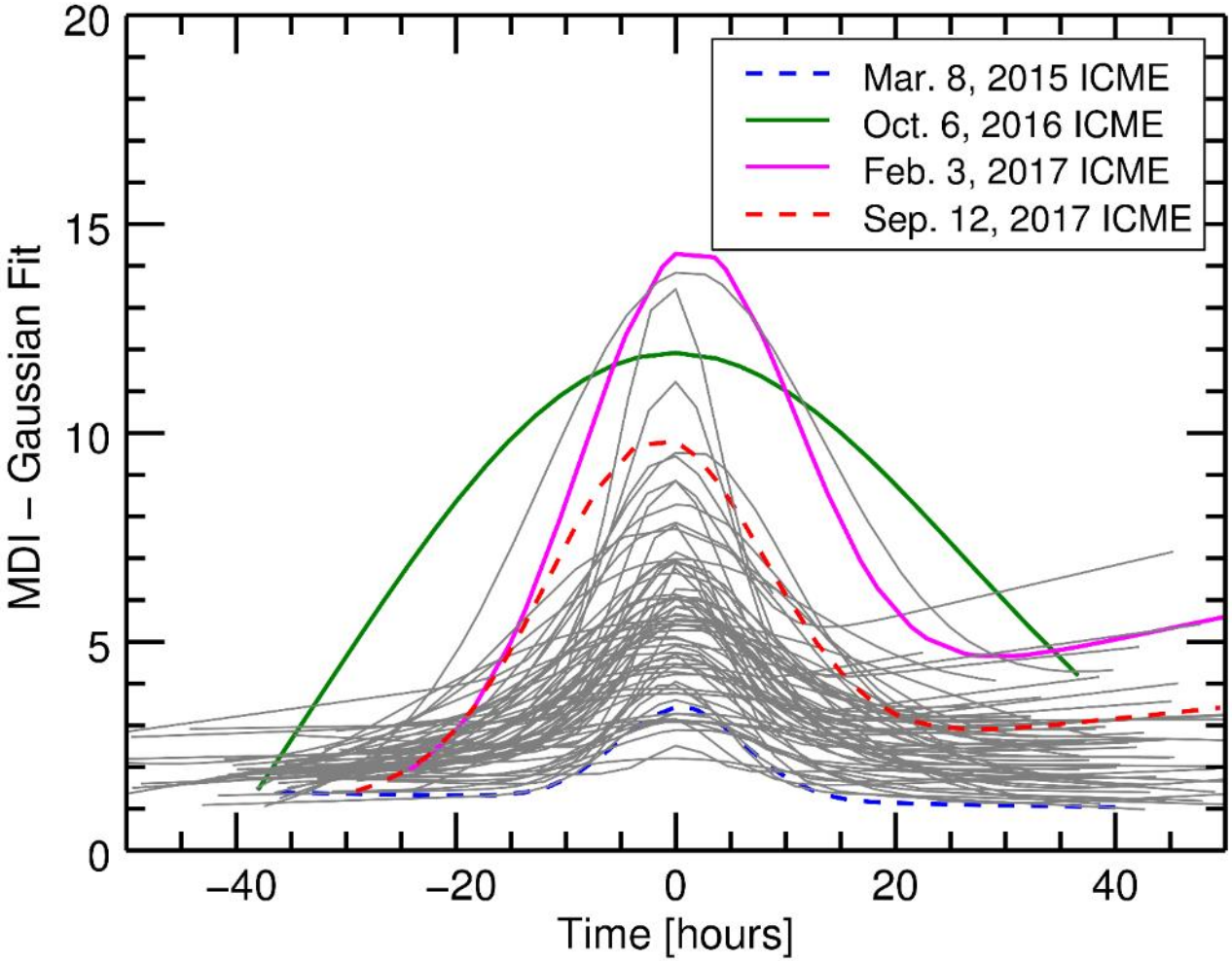
◆ Inferred loss rates from September event

– Average loss rate over MAVEN mission

x Average outward flux during September event

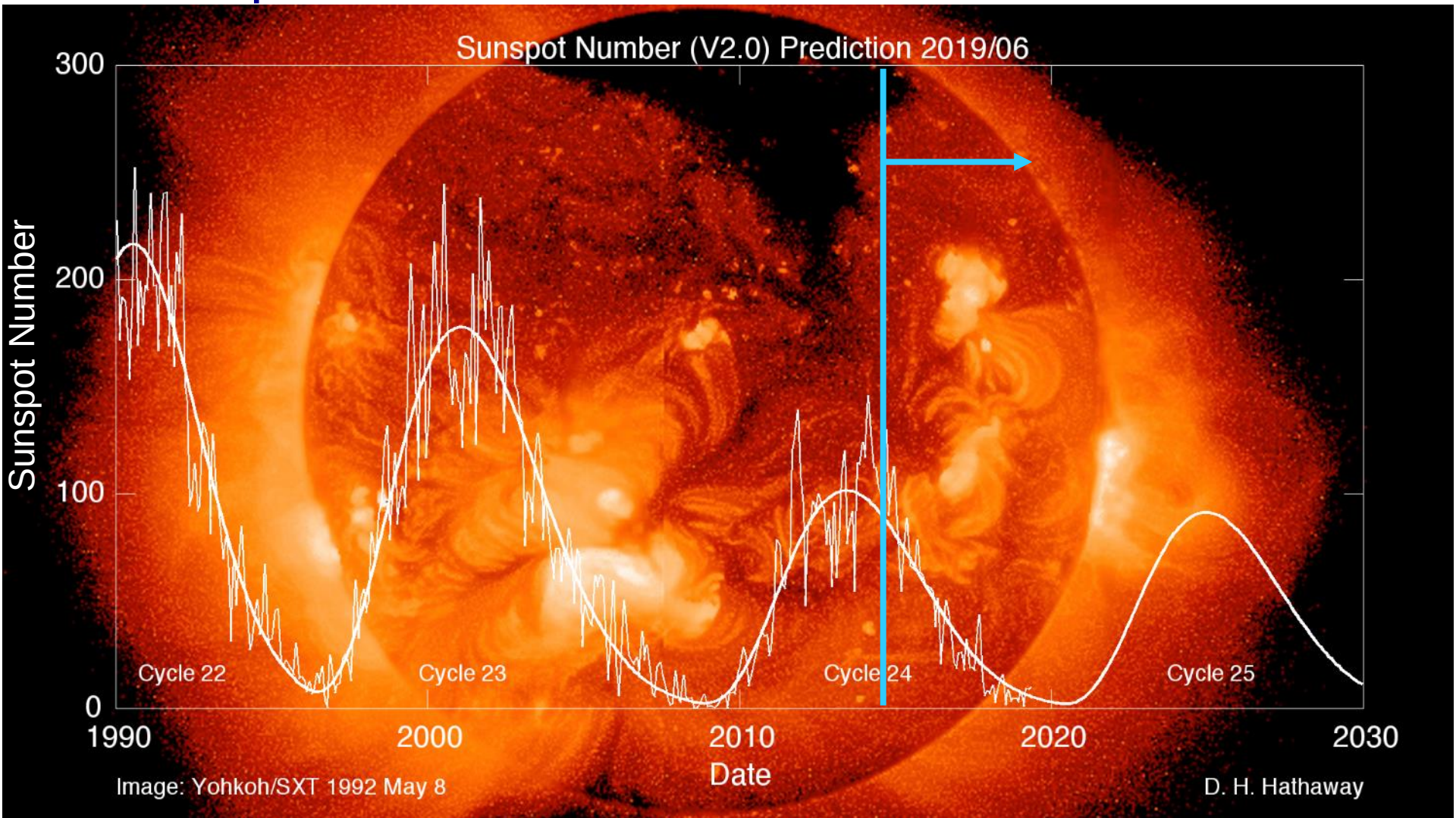
D. Brain (CU/LASP)
in Lee et al. (GRL, 2018)

Based on the Magnetospheric Disturbance Index (MDI) computed from MAVEN/MAG measurements, the September 2017 CME triggered the 4th largest magnetospheric disturbance



From Espley & Gruesbeck Poster #6113: How to Measure Space Weather at Mars: A disturbance index

MAVEN continues to observe the space weather conditions at Mars. Currently we are observing the response of Mars to quieter conditions, which are important baseline measurements to have.



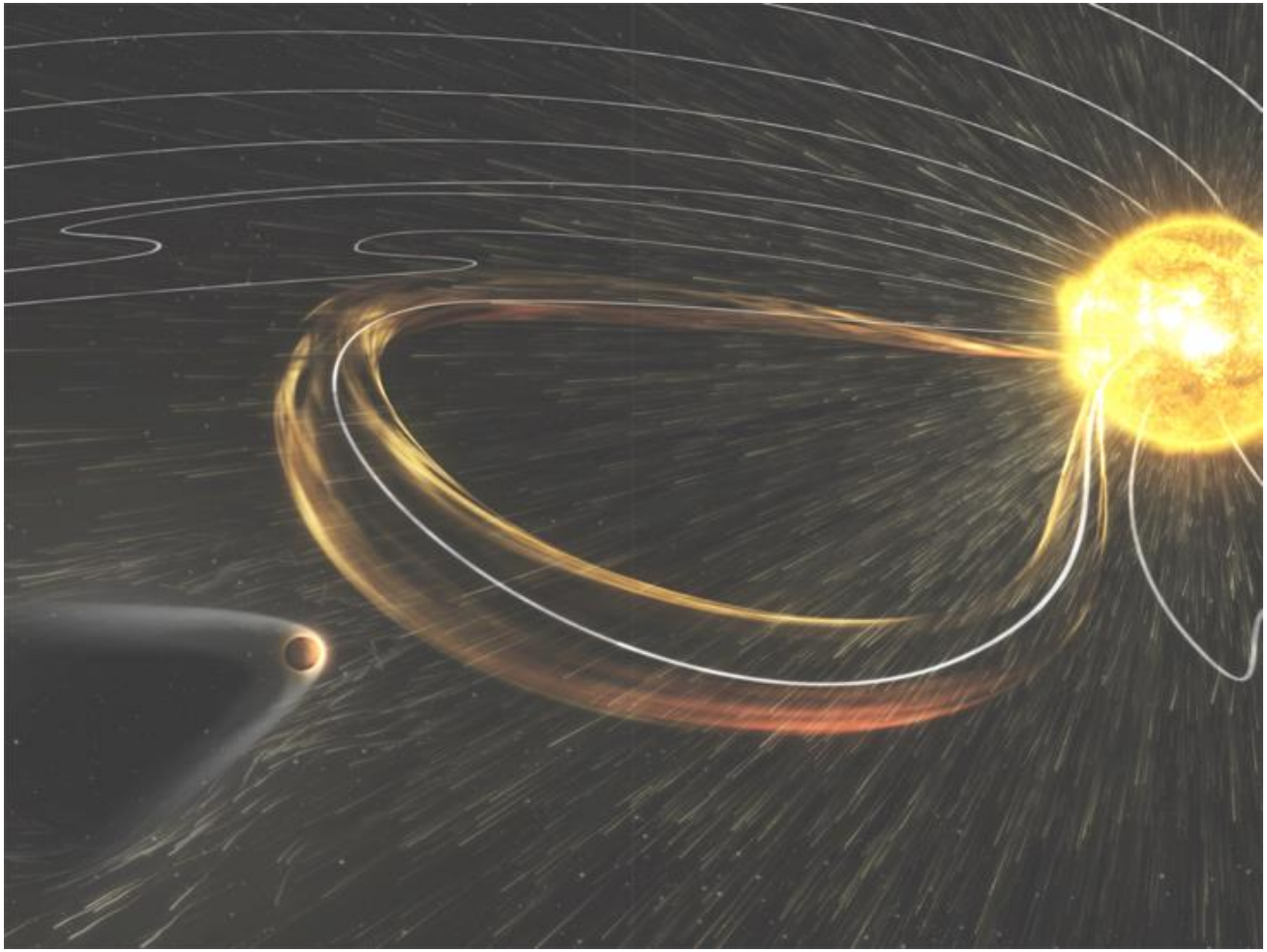
Space Weather 101 - Pop quiz!

Solar flares and CMEs are the same solar phenomena.

A) True

B) False

C) What does this have to do with Mars??



Thank you for your attention!

Space weather event questions, comments:
clee@ssl.berkeley.edu

MAVEN L2 data available at
NASA Planetary Data System
http://ppi.pds.nasa.gov/mission/MAVEN