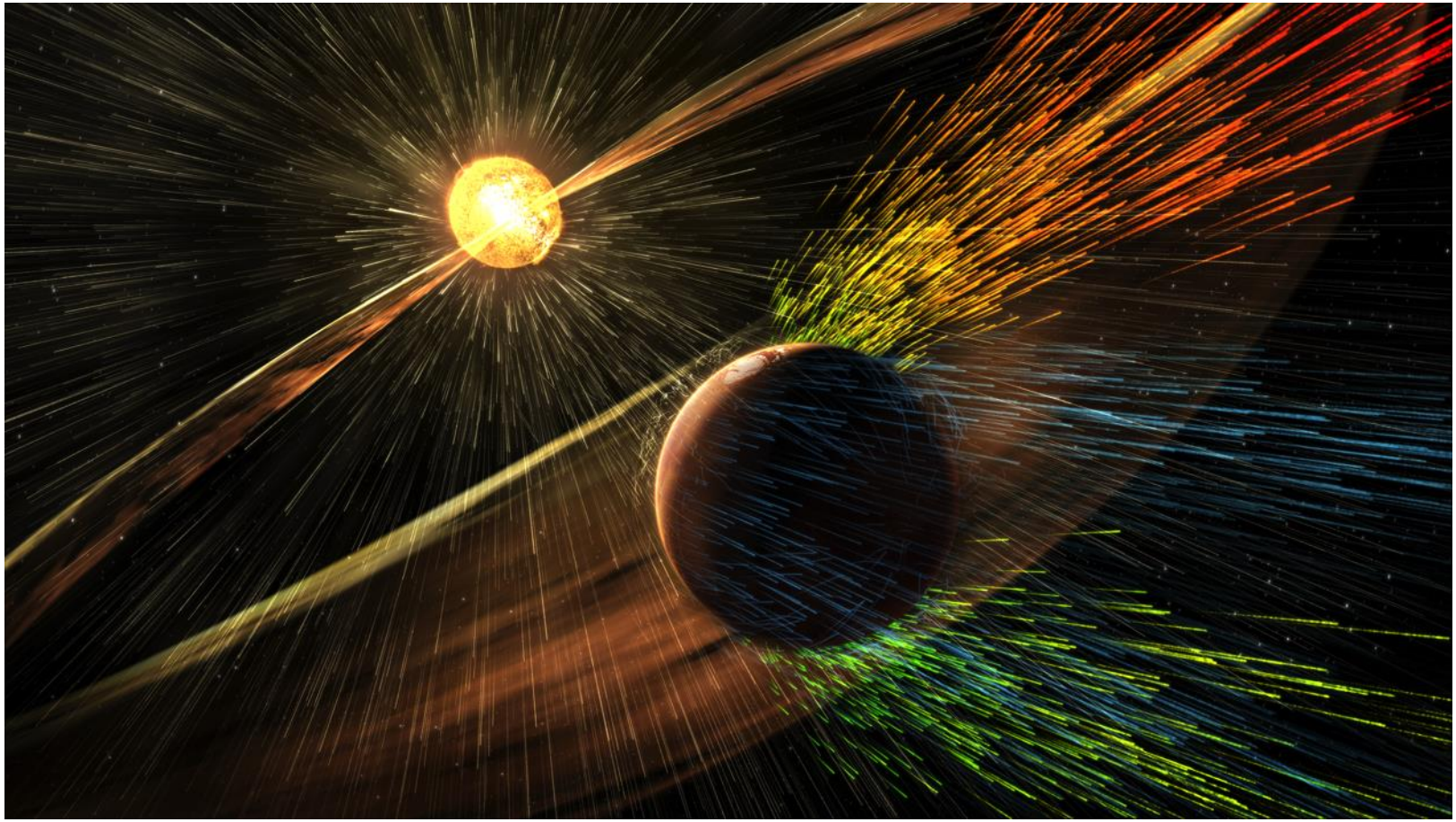
Mars Atmosphere and Volatile Evolution Mission (MAVEN)

Project Status And Recent Science Results

Bruce Jakosky and the MAVEN Science Team

MEPAG Meeting, Crystal City, 4 April 2018



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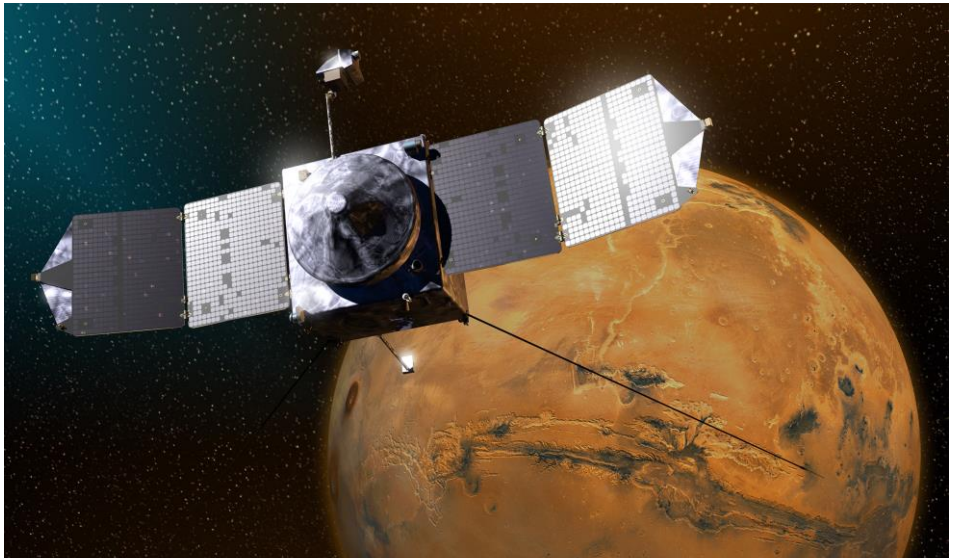
MAVEN Project Status

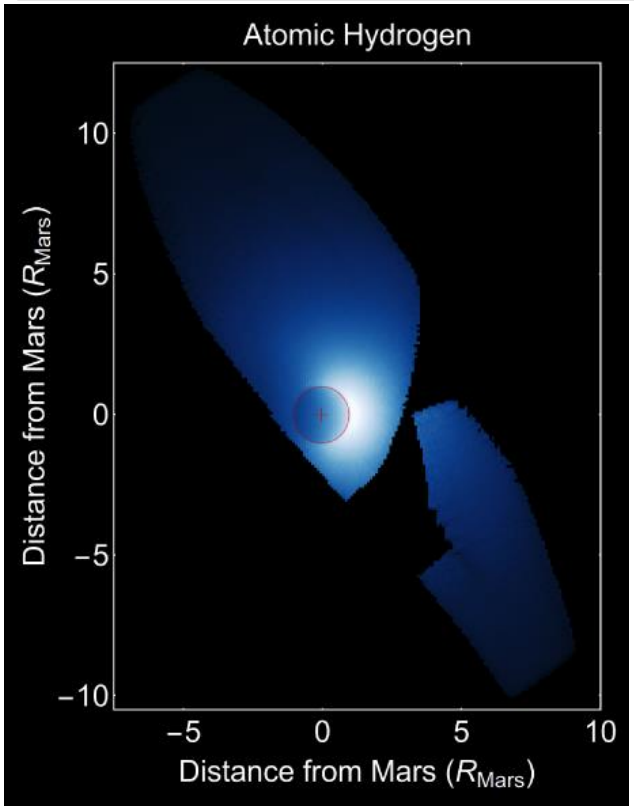
- Entered orbit 21 Sep 2014, completed commissioning on 15 Nov 2014
- Will complete 2 Mars years of science observations in Aug 2018
- Spacecraft and science instruments are performing nominally
- Planning for enhanced communications relay operations
  - Currently supporting ~1 relay pass per week (split between MSL and MER-B)
  - Relay support during InSight commissioning, ~1 pass per day
  - Aerobrake into a lower-apoapsis orbit (~March – June, 2019)
  - Raise periapsis to 200+ km to minimize drag and fuel use
  - Anticipate doing 2-3 relay passes/day in the 2020 era
  - Current fuel exhaustion date ~2030
- MAVEN can continue to operate as a combined science/relay orbiter

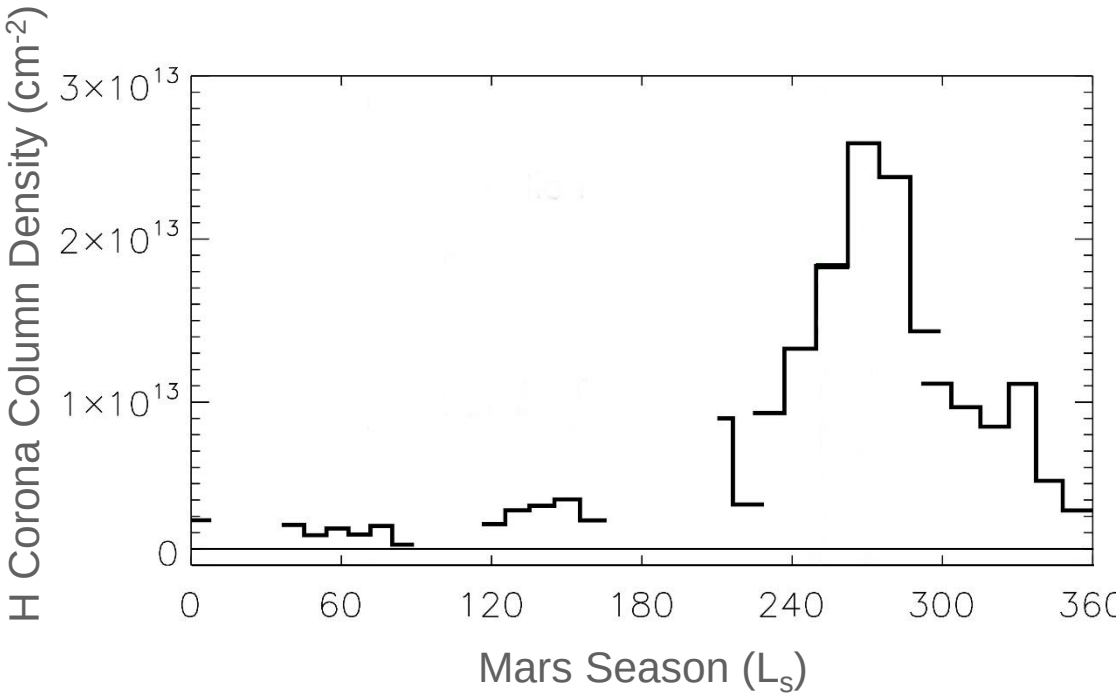


Outline

- Loss of atmosphere to space during the “MAVEN Mars year”
- Effects of the largest solar event observed to date by MAVEN, on 10 Sept 2017
- Implications of MAVEN results for evolution of habitability of exoplanets
- Upcoming observations/plans for EM-3 (through 30 Sep 2019)

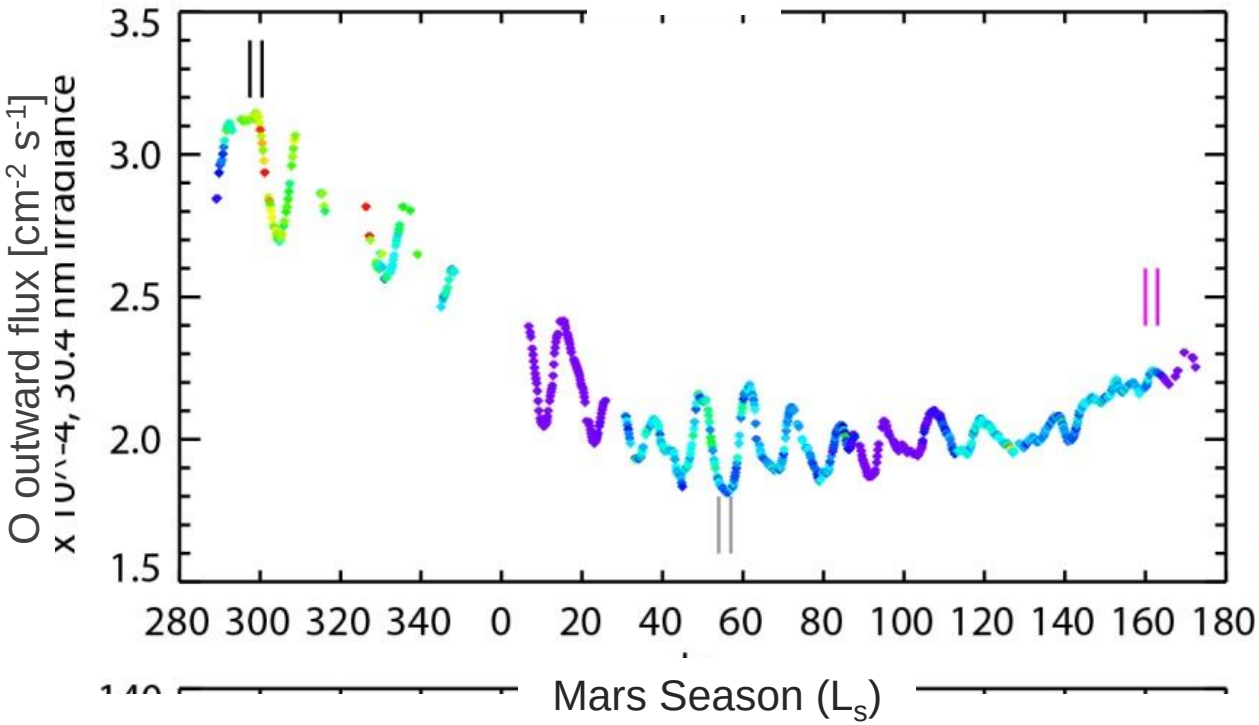
Loss To Space: H Corona and H Escape





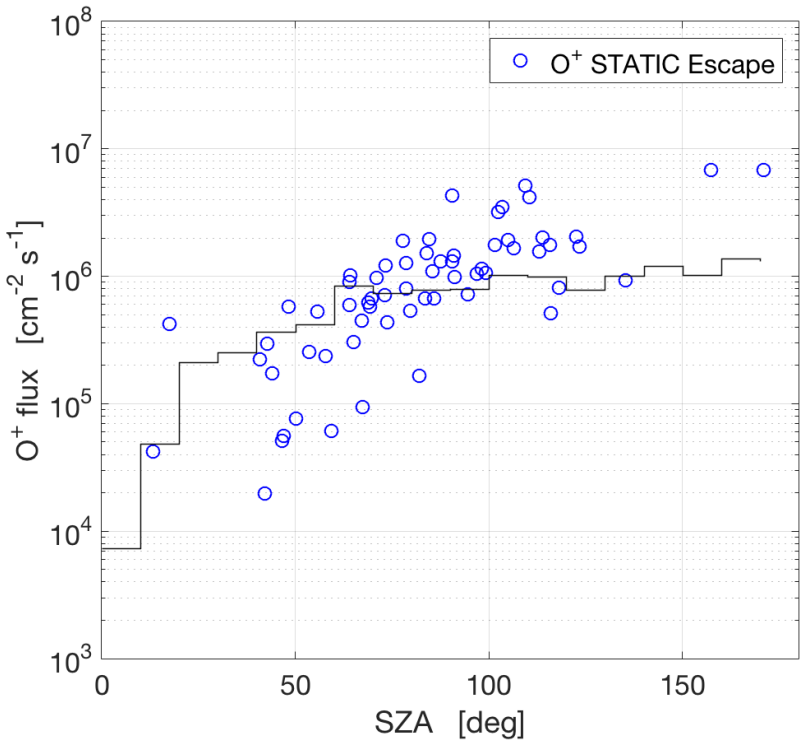
- H in extended corona is produced from photodissociation of H_2O in lower atmosphere, diffusion to corona; H in corona can escape
- Large seasonal variation due to atmospheric dust effects on temperature and vertical distribution of H_2O in lower atmosphere
- Strong dependence of loss rate on dust and water content implies potential for significant interannual variability and dependence on obliquity

Loss To Space: Photochemical Loss Of O



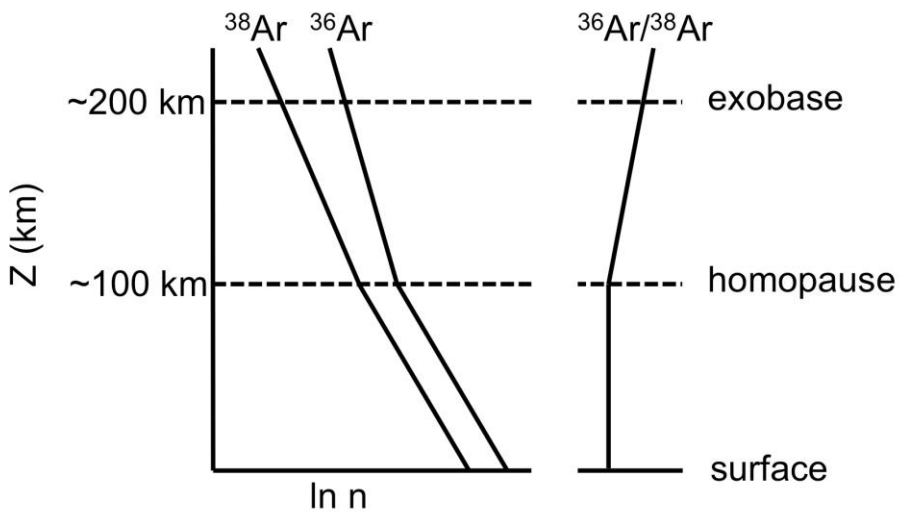
- Derived average loss rate ~ 1300 g O/sec, largest present-day loss process
- Loss is by dissociative recombination of O_2^+ ions and electrons
- Derived loss shows strong geometry dependence (e.g., no O escape when ionosphere is minimal as observed at night)
- Mean loss rate would remove all of the present-day atmospheric O (mainly from CO_2) in ~ 300 m.y.

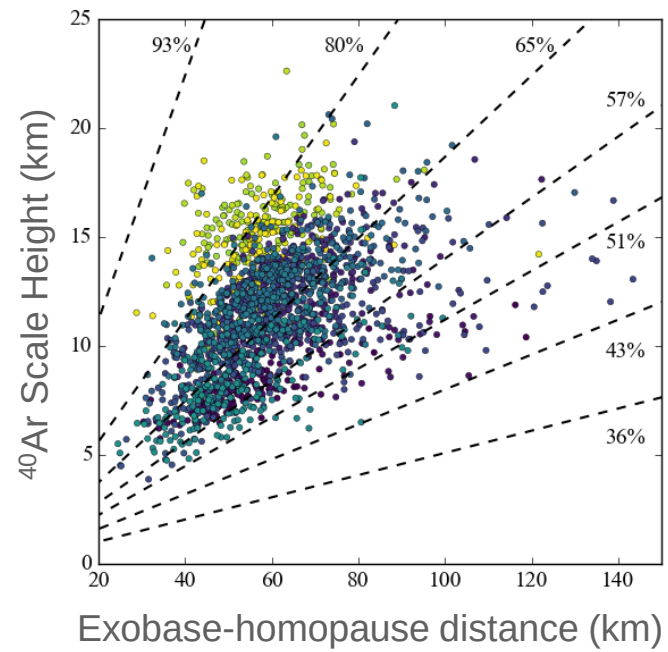
Loss To Space: Enhanced Ion Loss Rates From Series Of Solar Events Observed By MAVEN



- Loss rate into all 4π directions cannot be determined for a single event from a single spacecraft
- Using multiple events, we can get a statistical indication of effects on total loss
- Figure compares loss rate at specific solar zenith angles from multiple solar events (circles) with average loss rate through year (histogram)
- Net effect is significant enhancement of loss due to solar events

Loss To Space: Using Argon Isotopes To Derive Integrated Loss Through Time



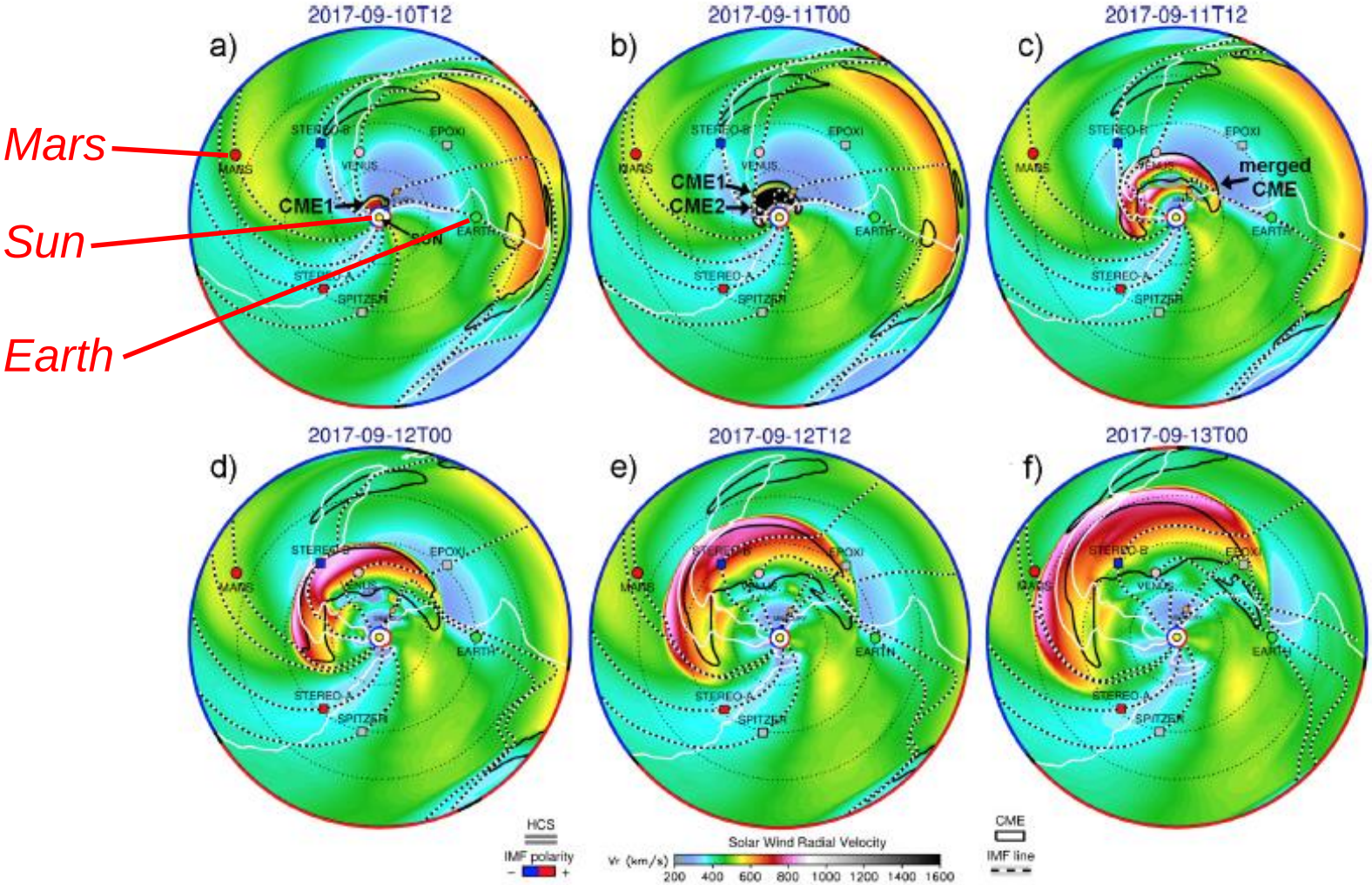


- Diffusive separation by mass occurs above homopause, loss from exobase preferentially removes lighter isotope; loss mechanism for Ar is sputtering
- $^{38}Ar/^{36}Ar$ ratio used because no process fractionates Ar isotopes other than sputtering loss to space
- Average fraction lost is 66 ± 4.5 %
- CO_2 loss also occurs by sputtering, but also through additional loss processes

Loss To Space: Adding Up Loss Rates Over A Mars Year

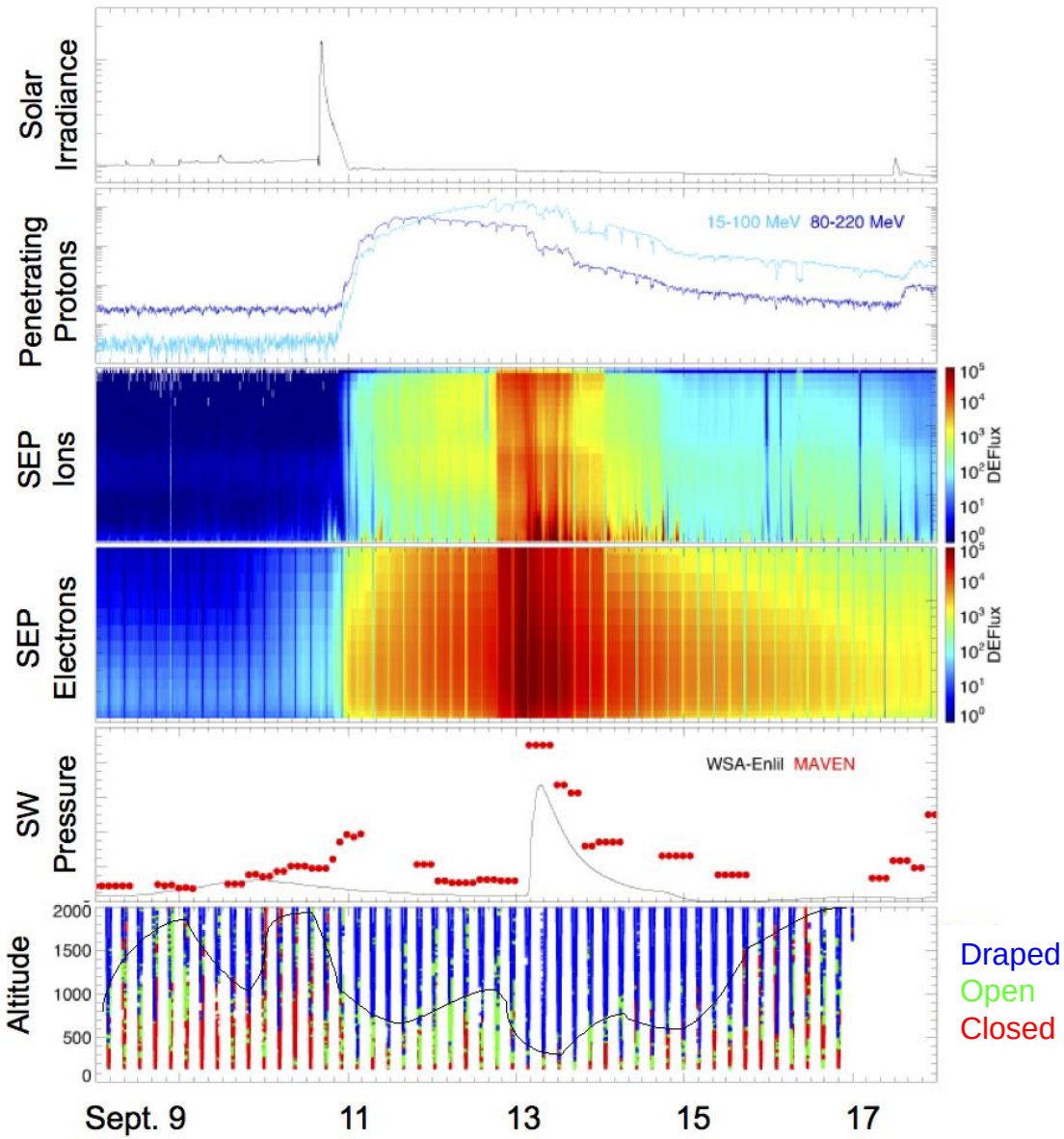
- **Total loss rate from Mars today:**
  - Total measured loss rate of ~ 2-3 kg/s
- **At *current* loss rates:**
  - Mars would have lost H equivalent to a global equivalent layer of water between ~ 3.4 – 24 m thick in 4 billion years
  - Mars would have lost O equivalent to either ~75 mbar of CO_2 or ~ 2.3 m of H_2O in 4 billion years
- **Loss rates have not been constant through time**
  - Loss rate greater early in history due to greater solar EUV flux, stronger solar wind, and more-abundant and more-intense solar storms
  - Integrated loss of O through early Hesperian greater than 0.8 bar CO_2 or 23 m H_2O

Solar Event of 10 Sept 2017: Largest-To-Date Solar Event Observed By MAVEN



WSA-ENLIL model output showing event, based on observations from multiple spacecraft

Solar Event of 10 Sept 2017: MAVEN Observations Of The Event

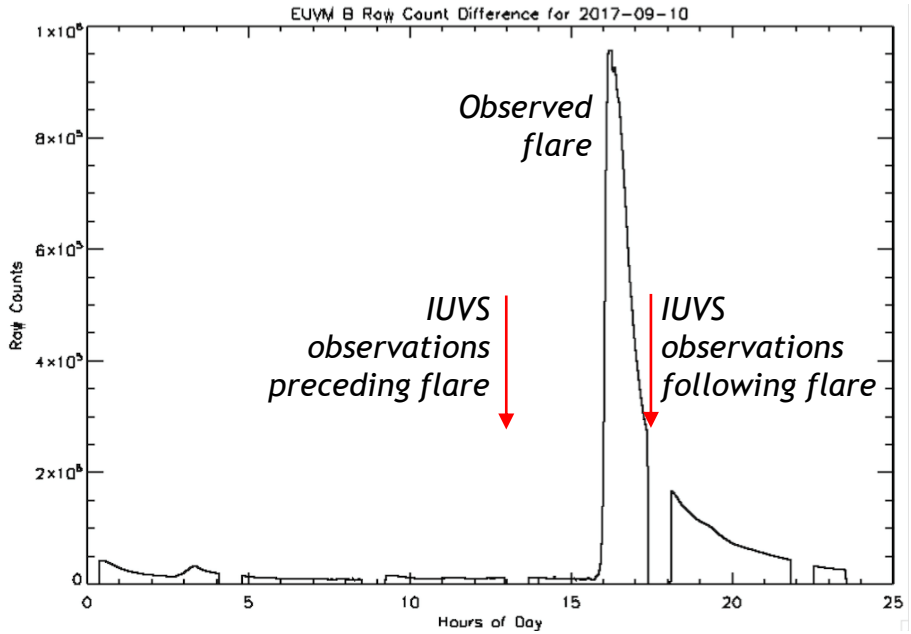


Key observations of the event (shown top to bottom):

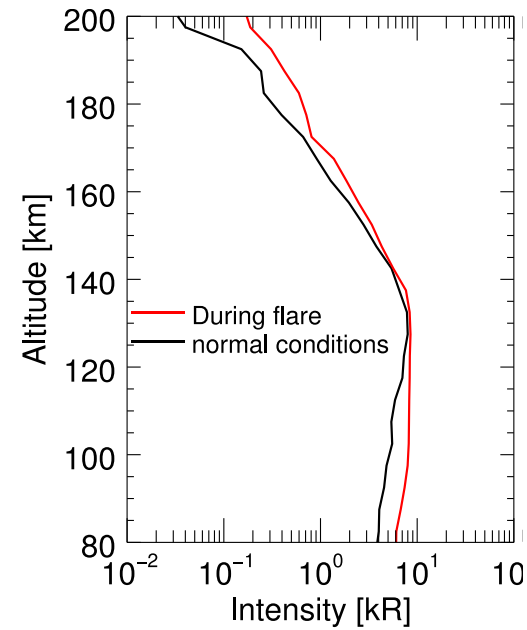
- Flare
- Arrival of high-energy protons
- Arrival of energetic ions and electrons
- Increase in solar-wind dynamic ram pressure
- Compression of solar-wind magnetic-field lines

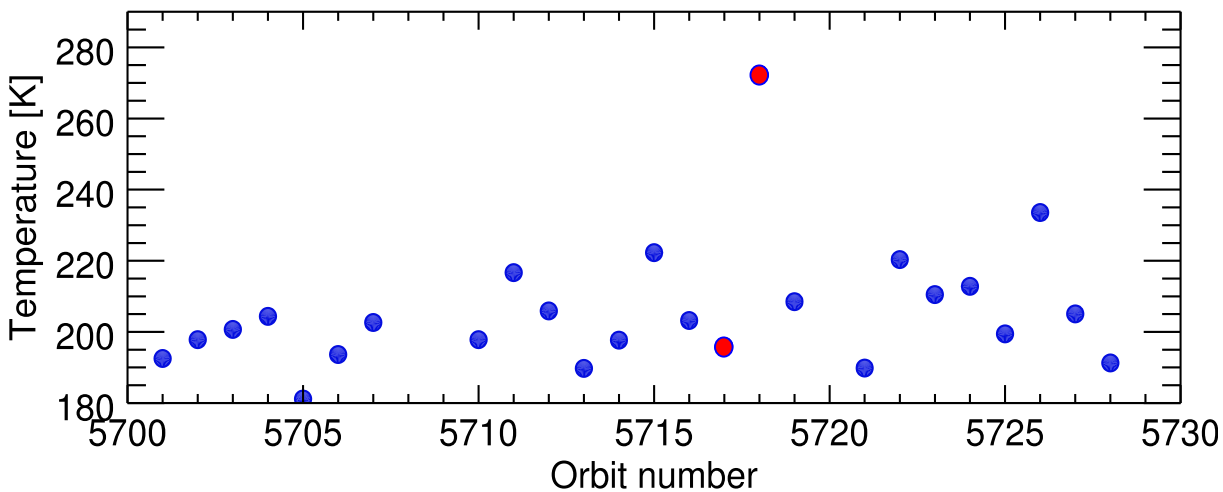
Solar Event of 10 Sept 2017: Solar Flare Effects On Thermospheric Temperature

EUVM B L0: 0-7 nm irradiance



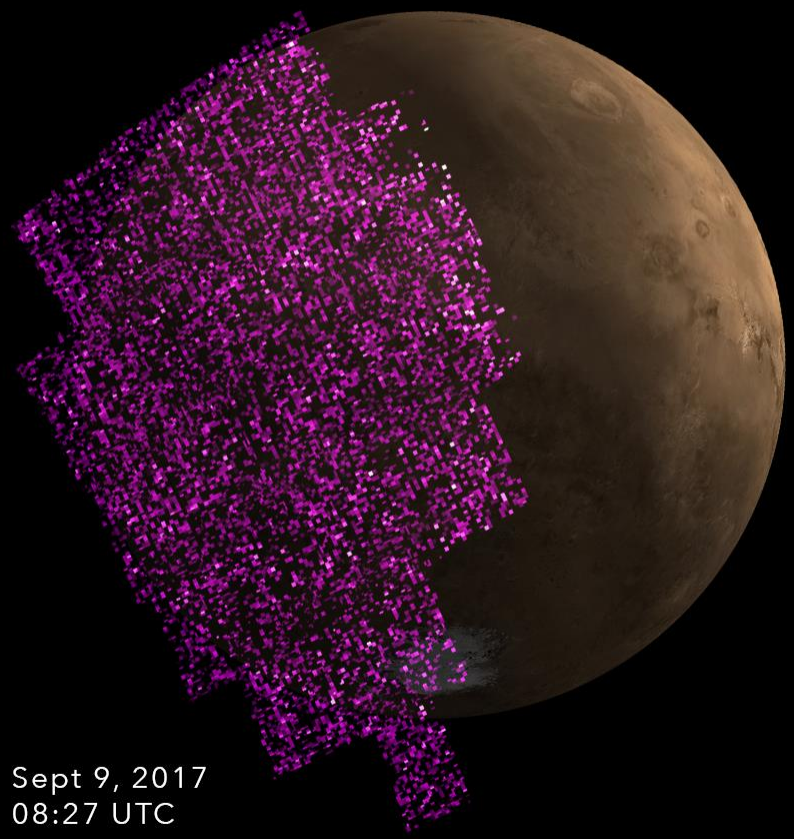
CO_2^+ Ultraviolet doublet





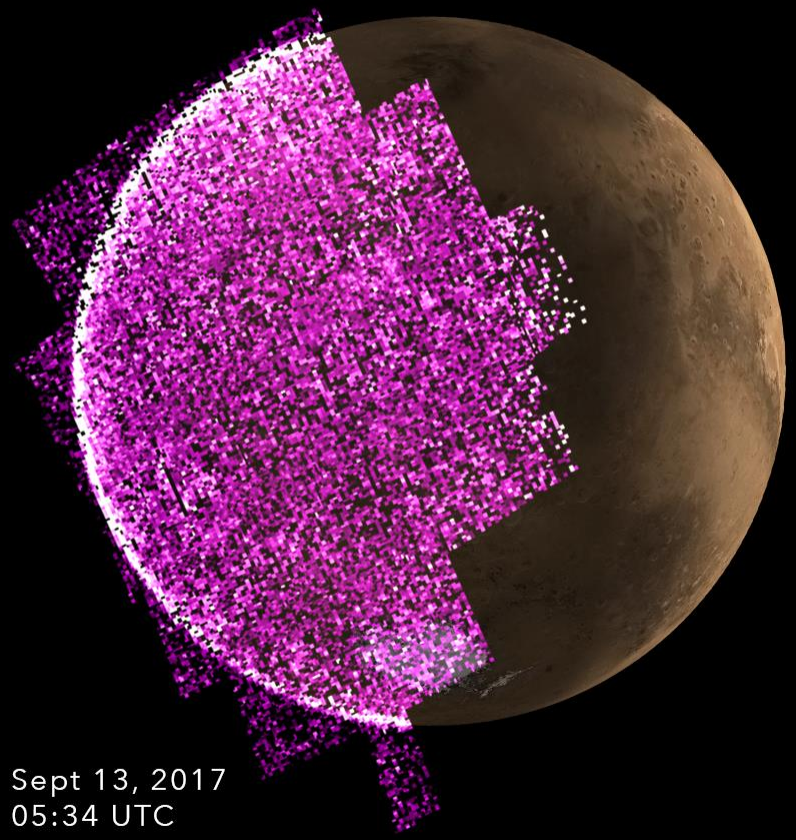
Solar Event of 10 Sept 2017: Solar Energetic Particles Produced Global Aurora

Before:



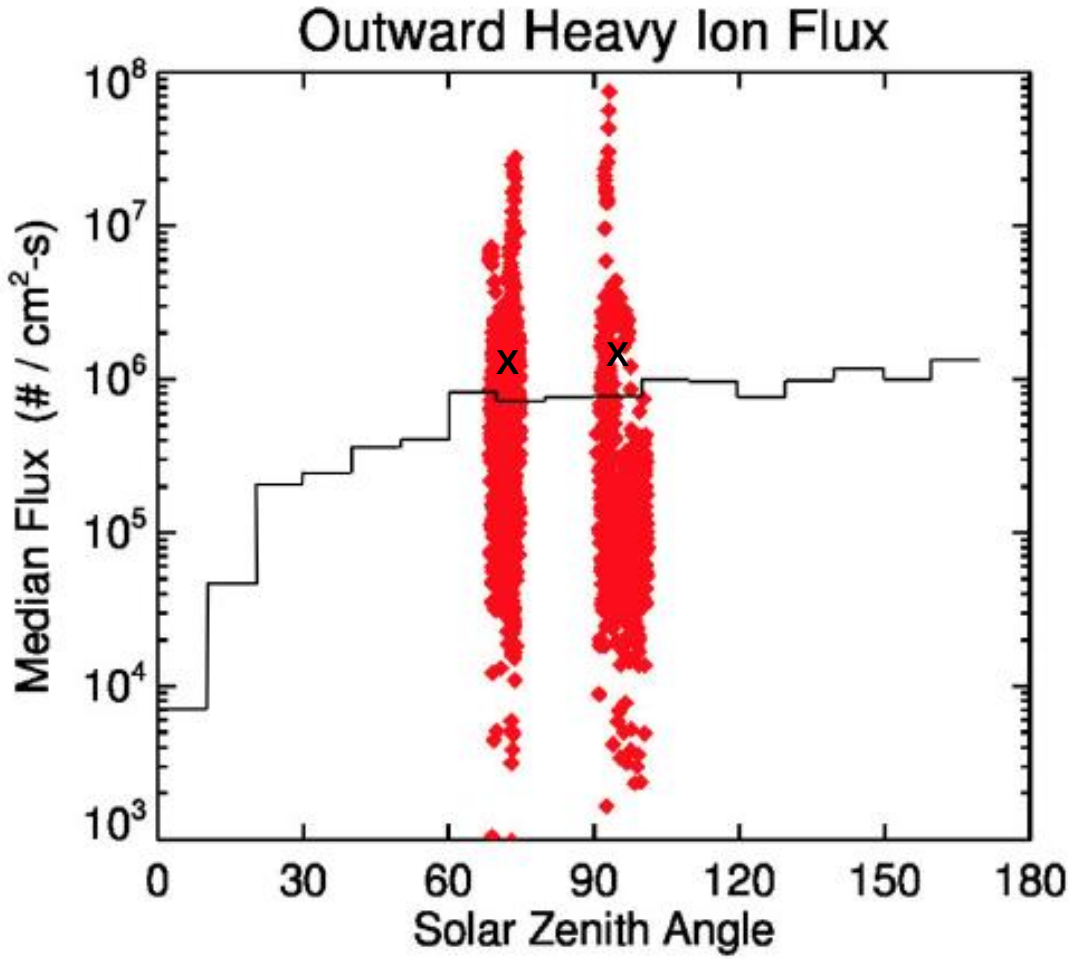
Sept 9, 2017
08:27 UTC

During:



Sept 13, 2017
05:34 UTC

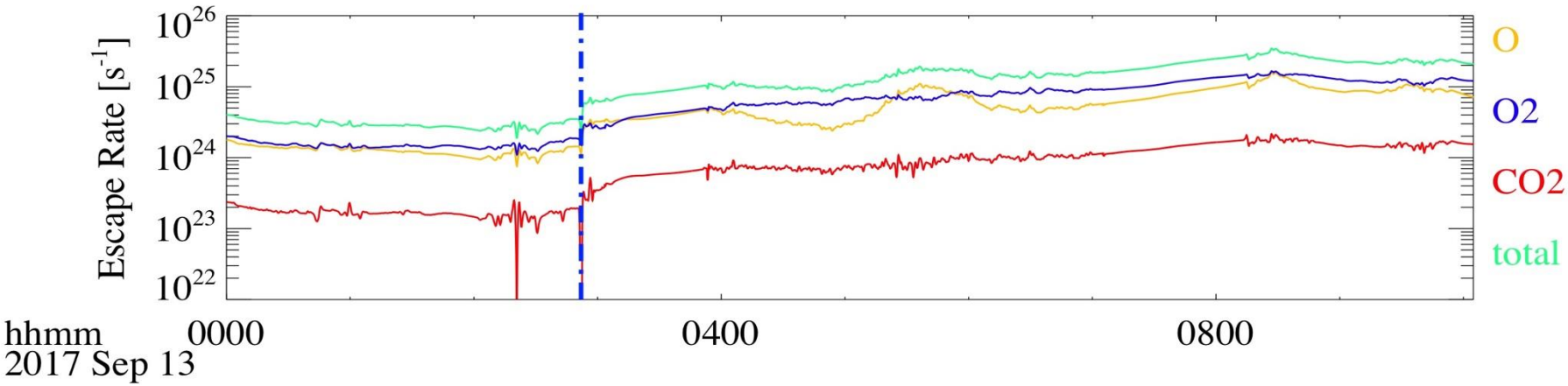
Solar Event of 10 Sept 2017: Enhanced Heavy-Ion Loss (1 of 2)



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.

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

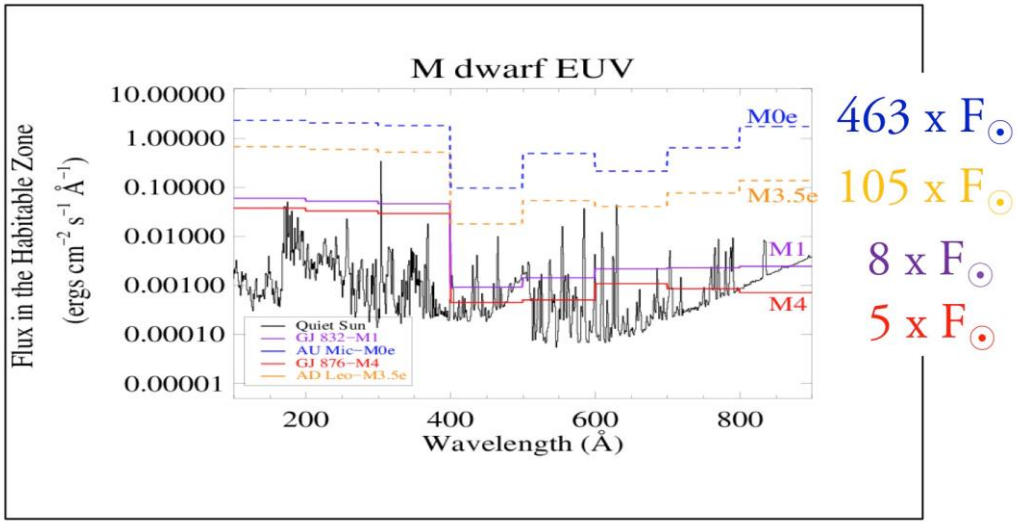


Heavy-ion loss into 4π derived from model that matches MAVEN observations: 20x increase in loss rate

- Measurements are at a limited range of SZA and do not capture full loss
- Use models that are validated against full range of MAVEN measurements to derive loss into all 4π directions
- Models show 3-20x increase in loss rate during this event
- *May represent the major loss mechanism early in Mars history, when solar events were stronger and occurred much more often*

Exoplanet Habitability: Mars Around An M-Dwarf Star

- M Dwarfs are the most abundant stars in the galaxy and appear to have abundant terrestrial planets in their Habitable Zones
- How long would a ~1/2 bar atmosphere persist if a Mars-like planet occupied the Habitable Zone of a range of M Dwarf stars?
- Use Mars because of its history of climate change



Early EUV flux is greater on M Dwarfs, and stellar events can be much more common (courtesy K. France/CU LASP)

Luminosity:

10-1000x fainter than Sun

EUV flux:

5-10x greater than Sun

Stellar wind:

~100x greater dynamic pressure than Sun

Stellar activity:

Active (young) M dwarfs have EUV flux 20-60x higher than inactive dwarfs, more-abundant solar storm events

Exoplanet Habitability: Synthesis Of Loss From An M-Dwarf Mars

- Hydrodynamic blow-off: *Requires T_{exo} > ~50 T_{eff}, only very early in history*
- Ion loss: *Rates increase by roughly 3x*
- Photochemical O loss: *Increases by 5-10x*
- Thermal H escape: *Unchanged or increases*
- Sputtering loss: *Increases 5-10x*
- Loss during extreme events: *Increases 10^3-10^4x*

- *Escape rates from each process should increase or remain unchanged relative to Mars in our solar system*
- *Timescale for habitability likely to be most-strongly influenced by extreme events*
- *Mars orbiting an M Dwarf is likely to be habitable for significantly shorter time than in our solar system – 0.01 - 0.1 b.y. versus 0.5 - 1.0 b.y.*
- *Significant implications for habitability and life in the galaxy*

Science Focus Through EM-3

In EM-3, we'll focus on observations to address specific questions about the behavior of the Mars upper atmosphere:

- How does coupling between the lower atmosphere, the upper atmosphere, and the ionosphere affect escape to space?
- How do interactions between the solar wind and the crustal magnetic fields affect the upper atmosphere and escape to space?
- How does the approaching solar minimum affect interactions between the Sun and Mars, upper-atmospheric processes, and escape to space?
- *Overarching question: What are the implications for H escape, evolution of D/H, and the history of water?*

Observations to Address These Science Questions

- Observe behavior of upper atmosphere and driving processes during the important time period encompassed by EM-3 (L_s ~ 260 - 86°, dusty + wet season)
- Observe the entire upper atmosphere and crustal magnetic fields during a three-month-long deep-dip campaign (a.k.a. aerobraking)
- Couple *MAVEN* observations to *Trace Gas Orbiter*, *InSight*, and ongoing *Mars Reconnaissance Orbiter*, *Mars Express* and *MSL* observations for more-complete characterization of atmosphere, magnetic field, and radiation environment

Observational goal is to observe Mars under as wide a range of driving conditions as possible, in order to:

- *Determine the range of atmospheric responses at this epoch*
- *Understand processes controlling upper atmosphere and escape*
- *Constrain extrapolation to other epochs*