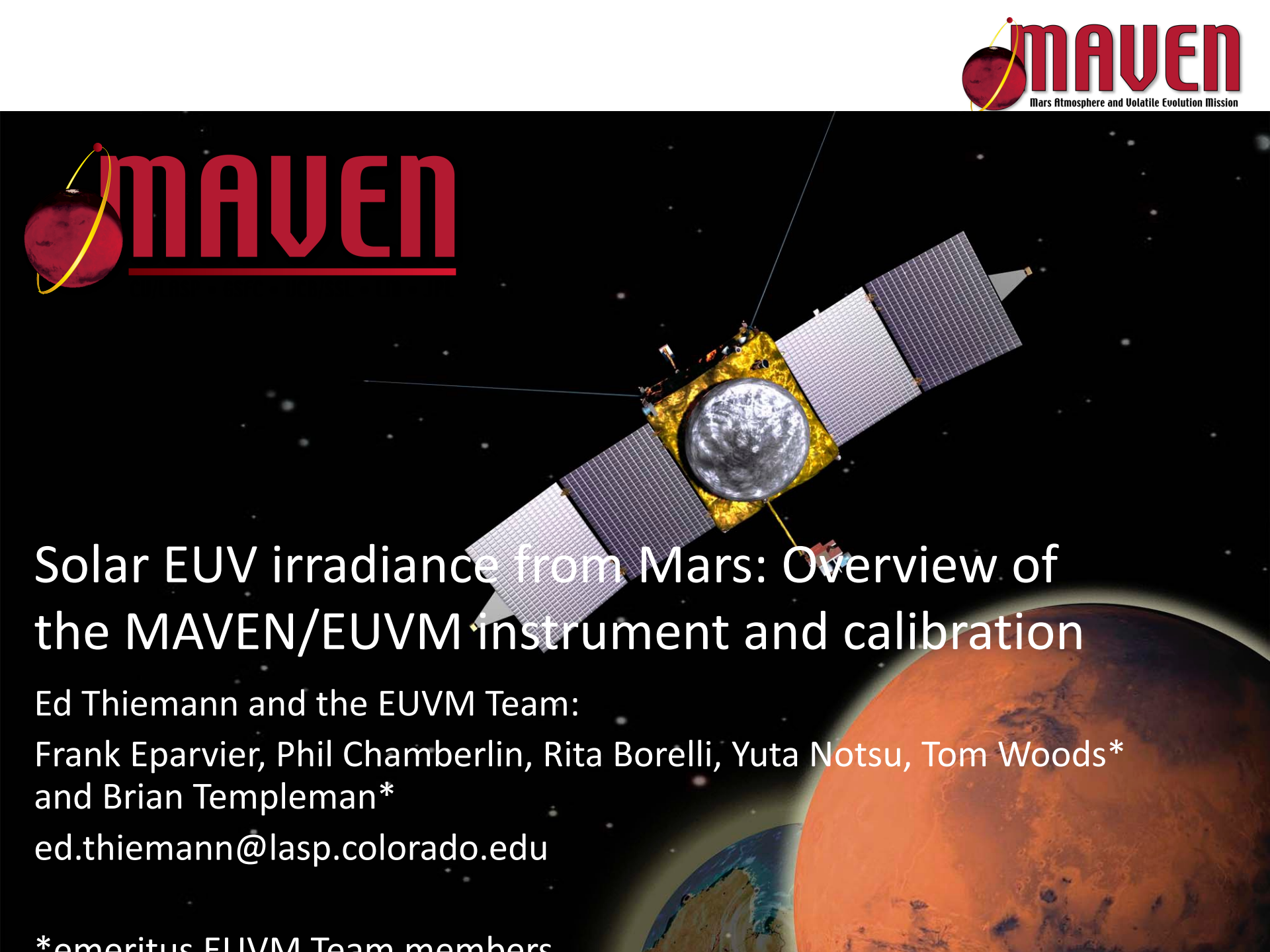


Solar EUV irradiance from Mars: Overview of the MAVEN/EUVM instrument and calibration

Ed Thiemann and the EUVM Team:

Frank Eparvier, Phil Chamberlin, Rita Borelli, Yuta Notsu, Tom Woods* and Brian Templeman*

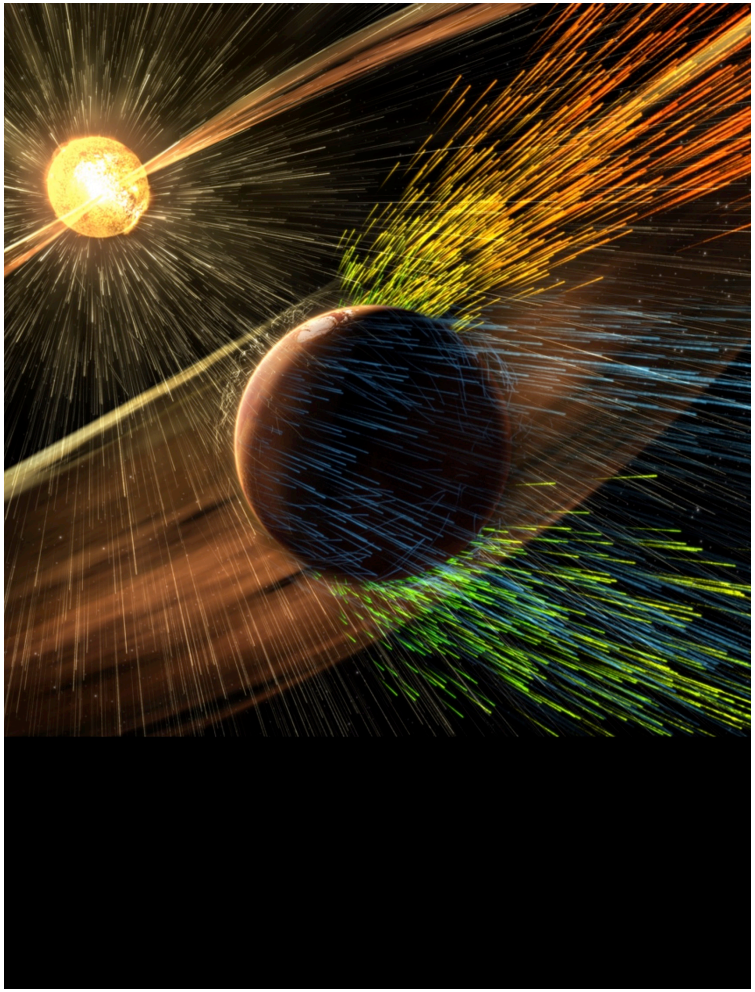
ed.thiemann@lasp.colorado.edu

*emeritus EUVM Team members

MAVEN Overview

MAVEN
Mars Atmosphere and Volatile Evolution Mission
CU/LASP • GSFC • UCB/SSL • LM • JPL

- The NASA Mars Atmosphere and Volatile EvolutioN Mission characterizes Mars atmospheric loss in the current epoch to quantify the loss to space over time.
  - Launched in November, 2013.
  - Arrived at Mars in September, 2014.
  - Instrumented to characterize the solar inputs into the Mars System and its response to solar forcing.
  - Currently operating and in its fifth extended mission.



MAVEN Instruments

- EUVM
  - Solar EUV Irradiance
- SEP
  - Solar Energetic Particles
- SWIA
  - Solar Wind Ions
- SWEA
  - Solar Wind Electrons
- MAG
  - Solar Wind and Martian Magnetic Field
- LPW
  - Mars Thermal Electrons
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- STATIC
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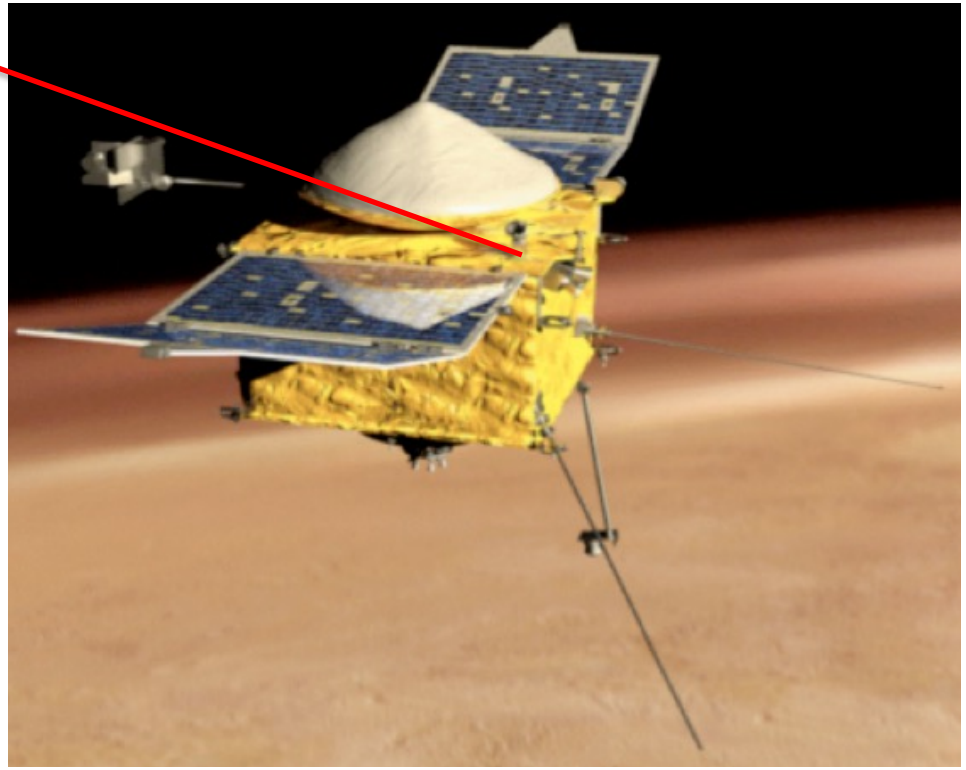
- IUVS
  - Mars Airglow Imaging Spectrograph



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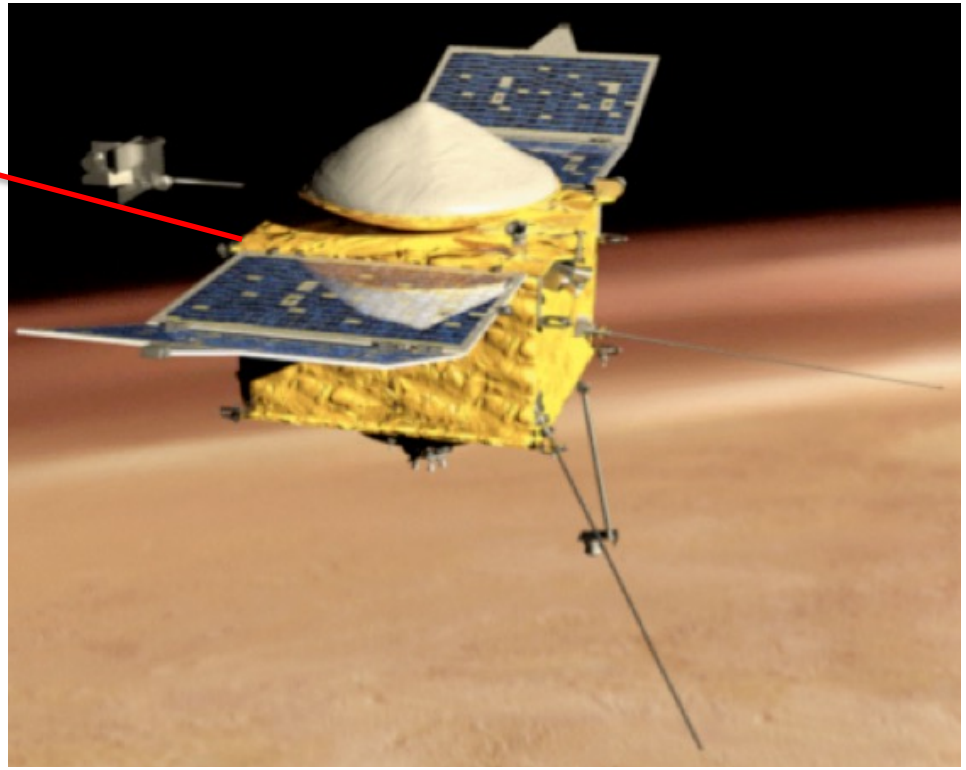

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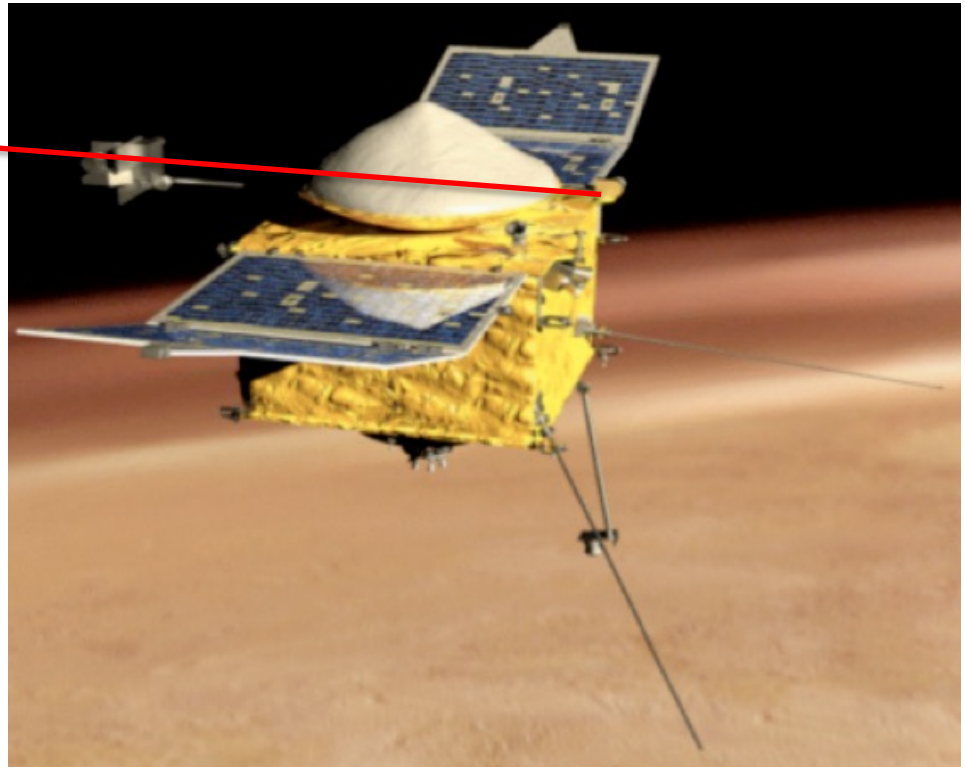

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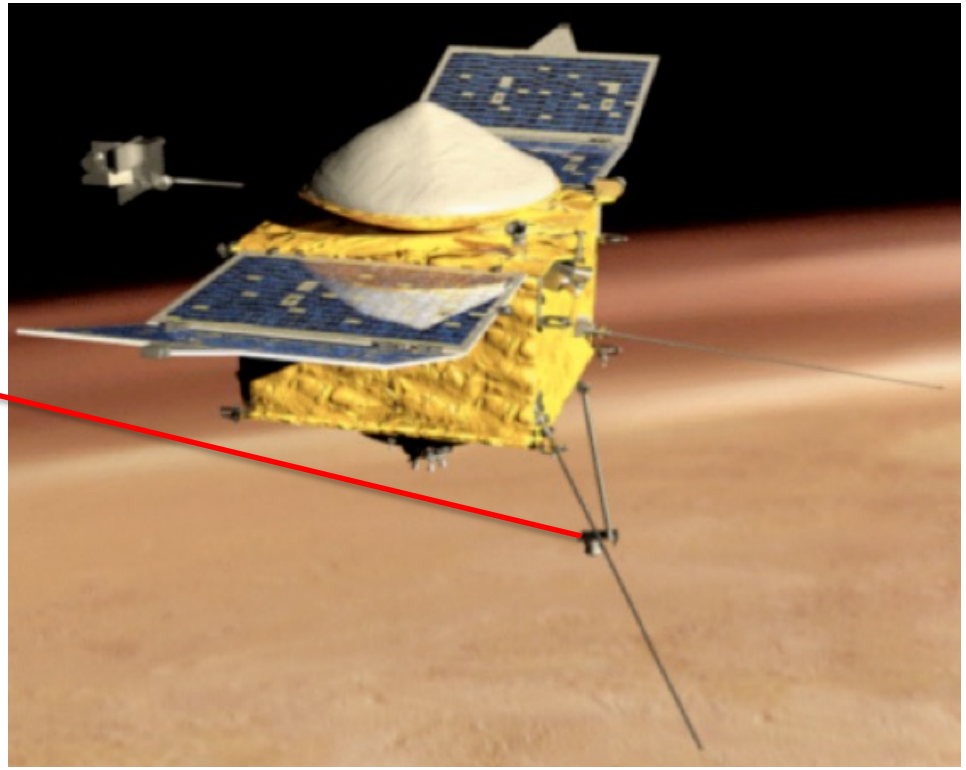

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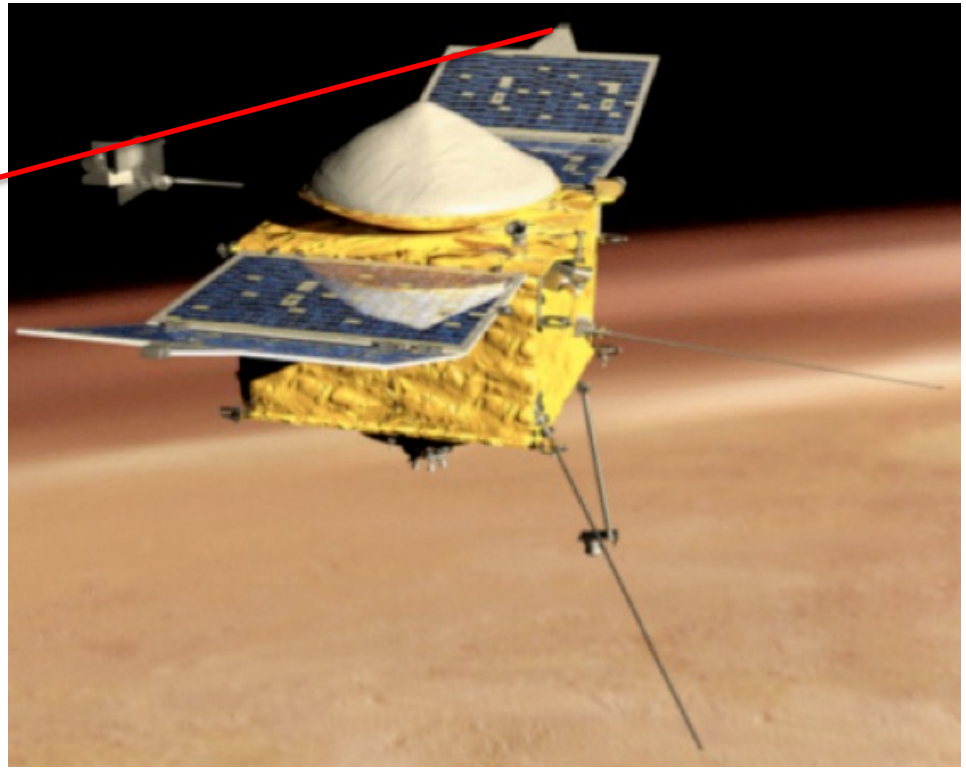

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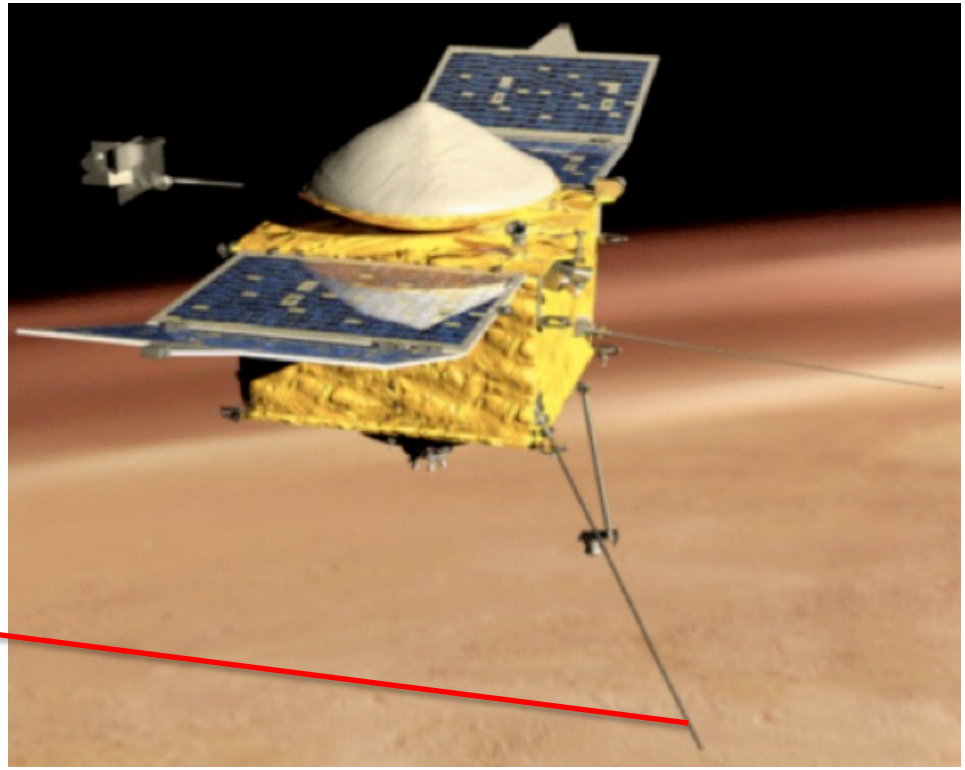

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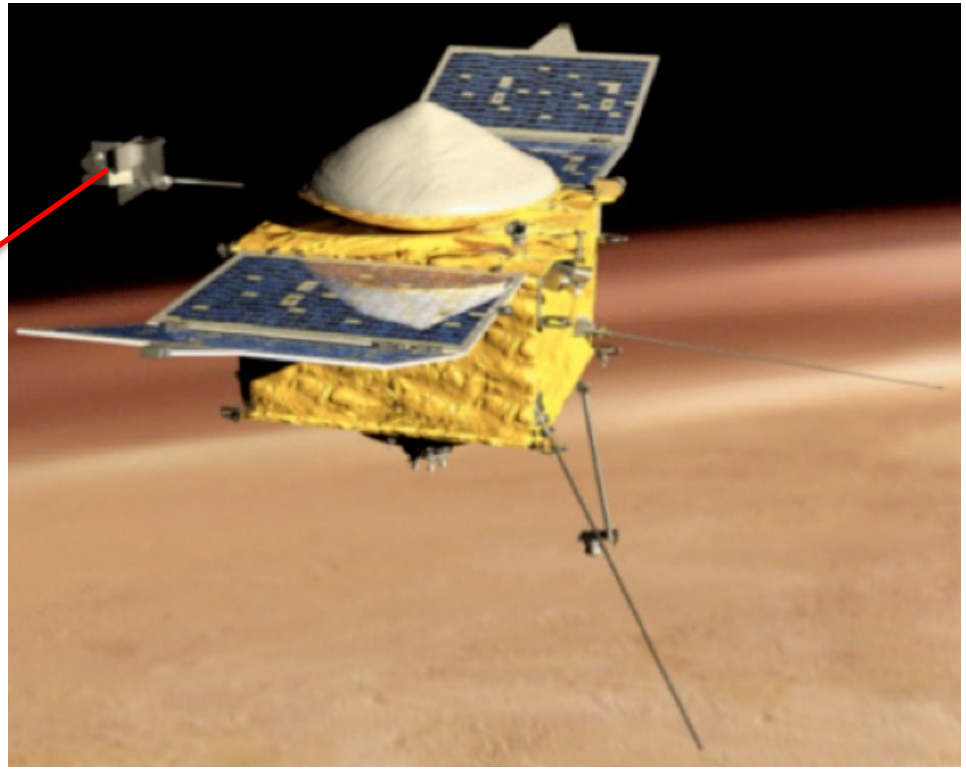

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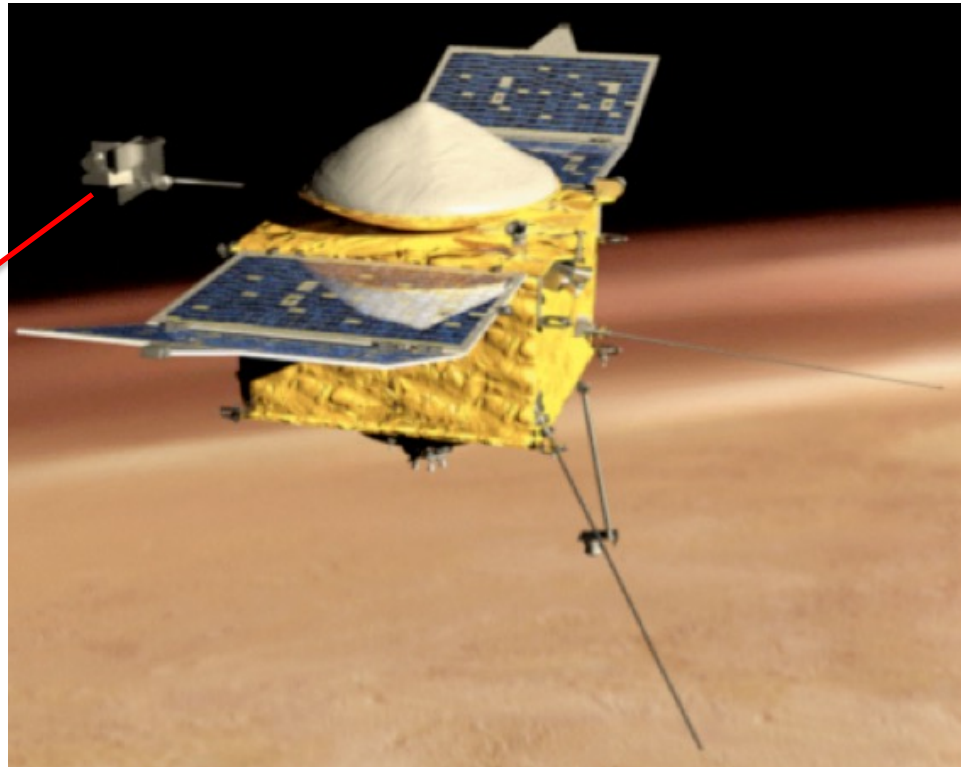

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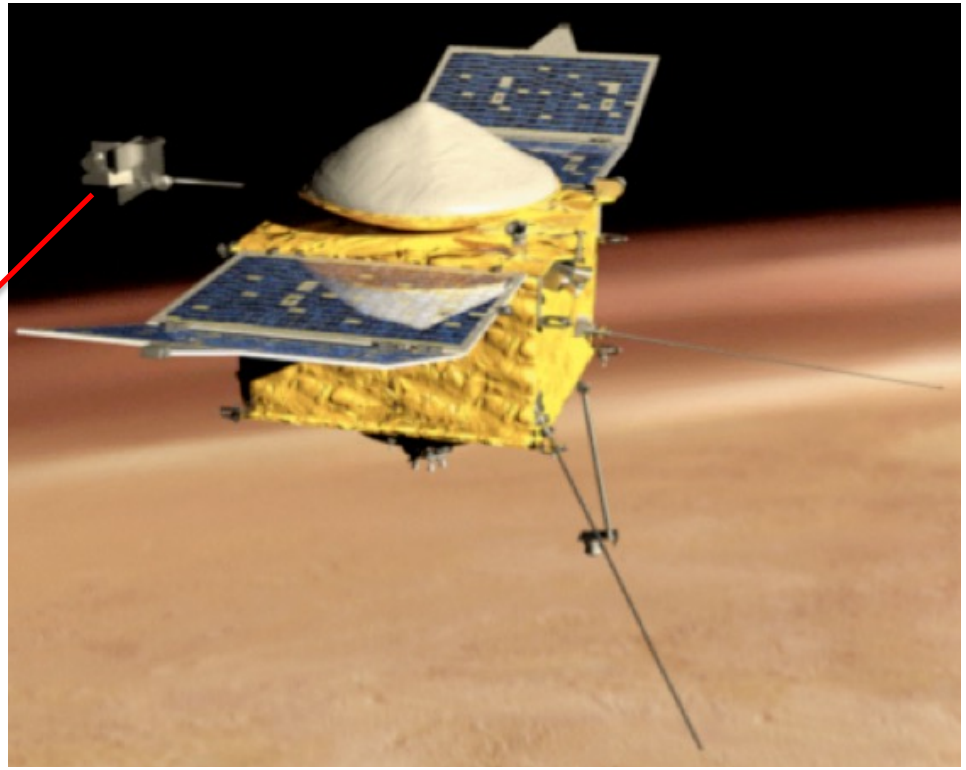
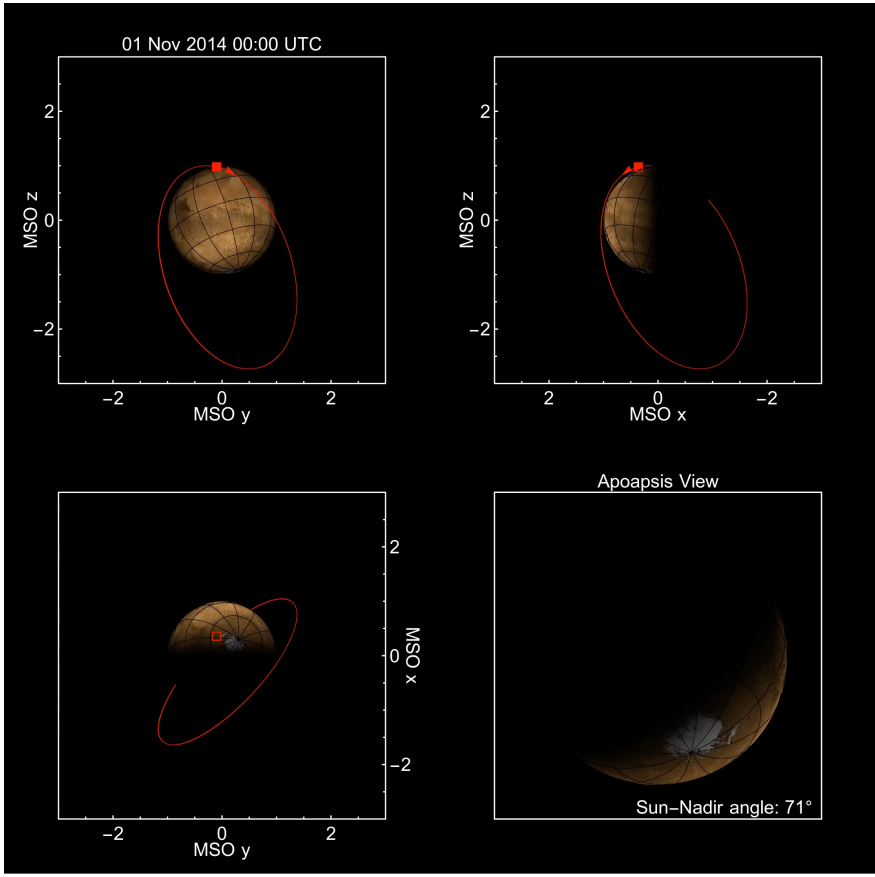


MAVEN Orbit

- Highly elliptical orbit.
  - 150 km → 200 km periapsis
  - 6000 km →4500 km apoapsis
- Allows for in-situ sampling of both near-space and upper atmosphere in same orbit.
- Orbit precesses.
  - Low orbit segments sample many latitudes and local times.
  - High orbit segments sample solar wind, magneto-tail and sheath.



MAVEN Space Weather Science

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- MAVEN Measurements of the space environment.
- Mars Response to ICMEs.
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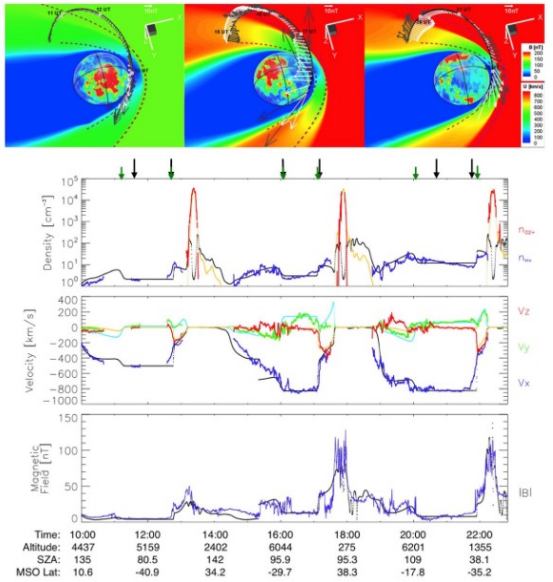

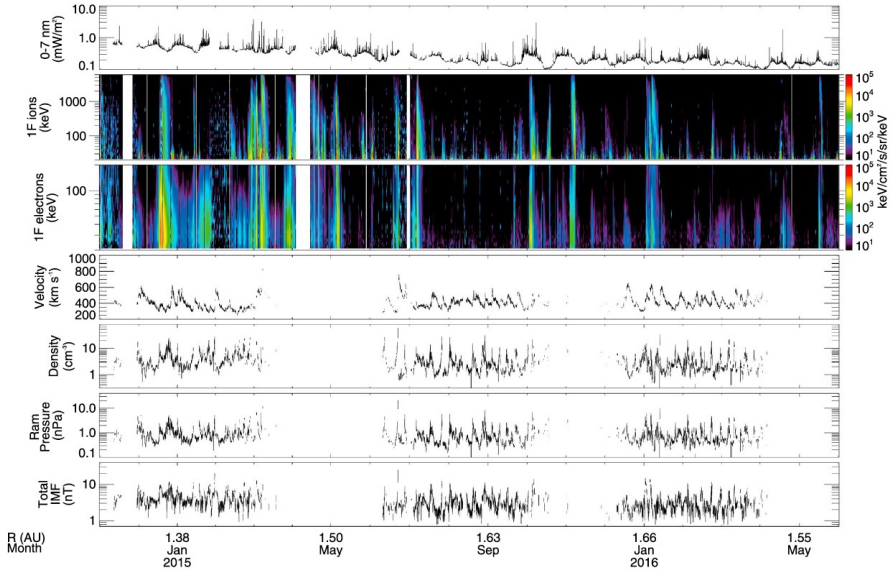

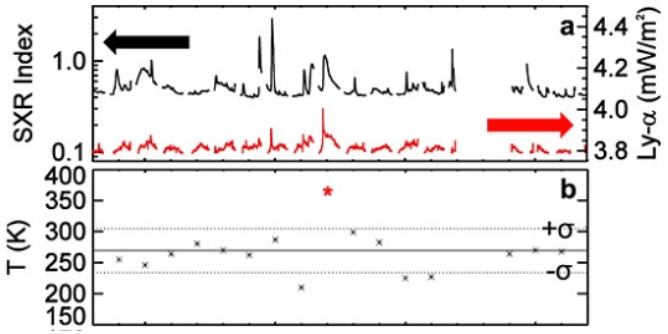

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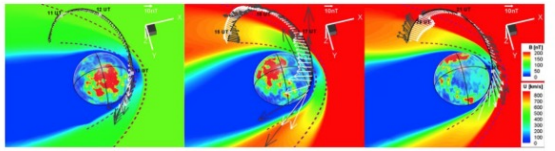

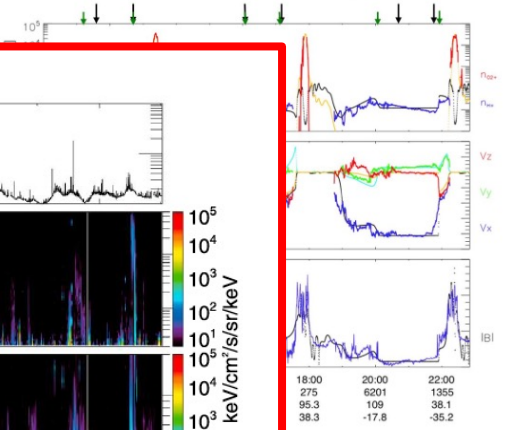

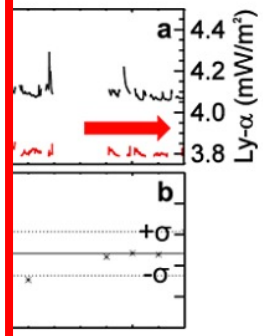

Lee et al. *JGR-Space* **122** 2017

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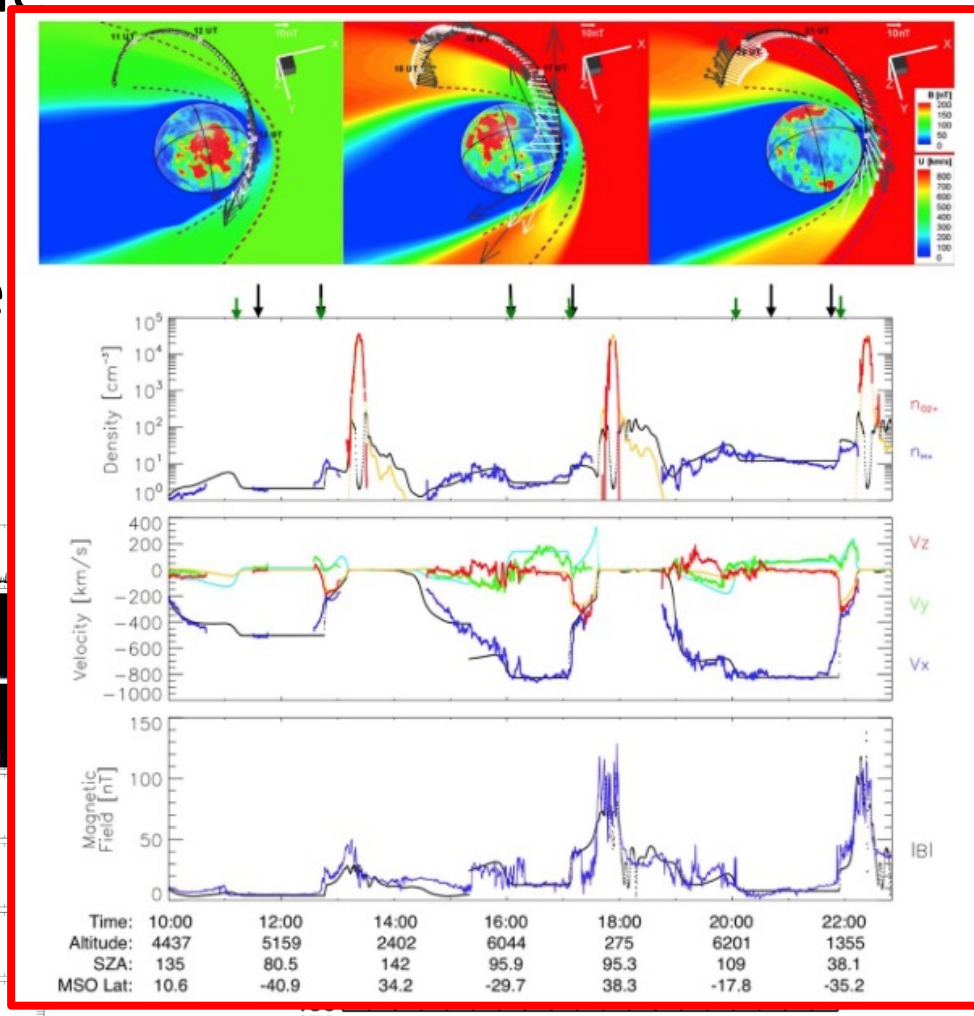

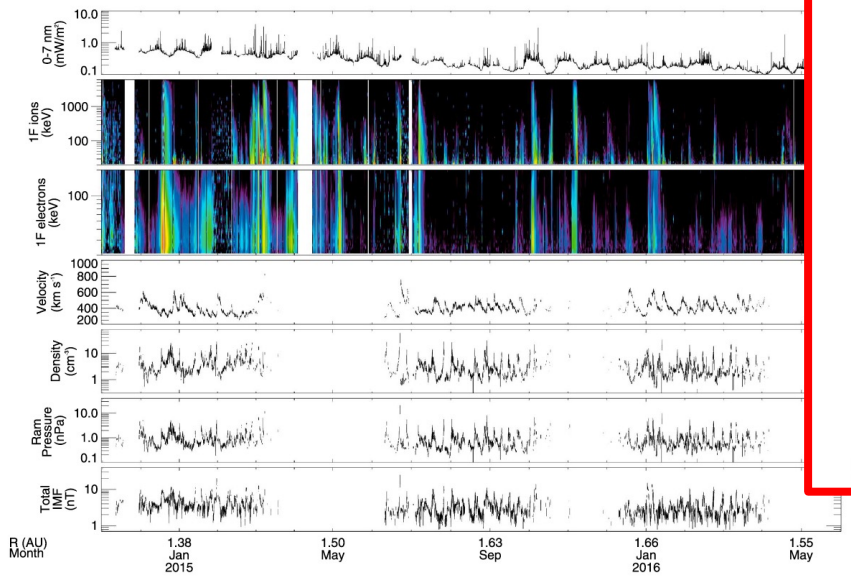

Jakosky et al. *Science* **350** 2015

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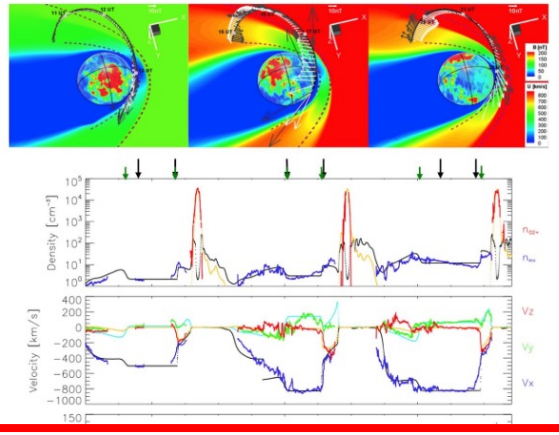
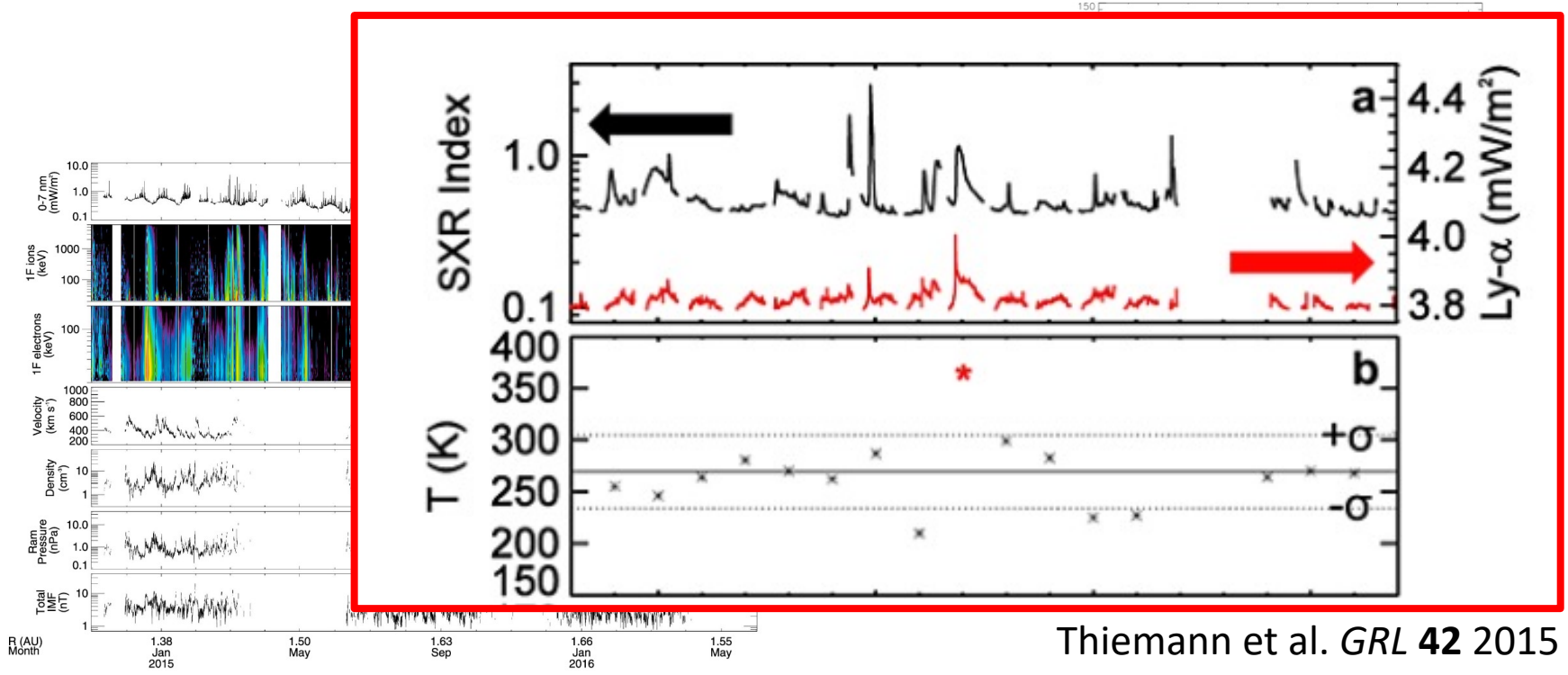
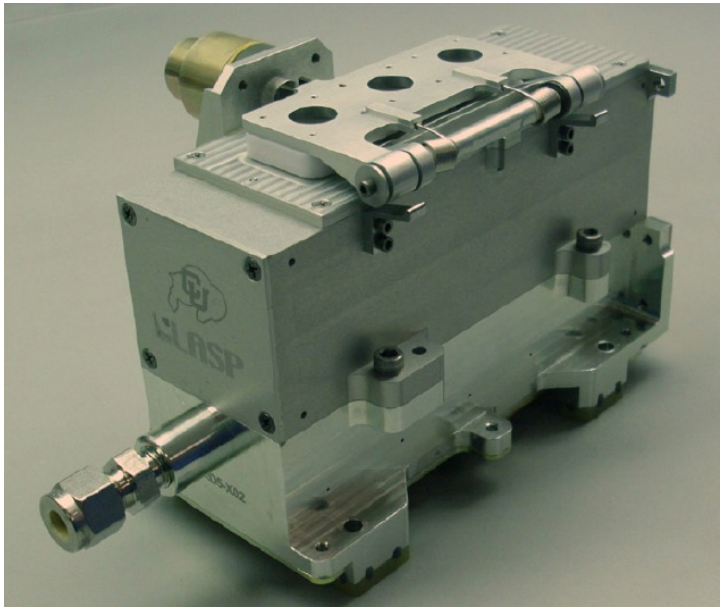
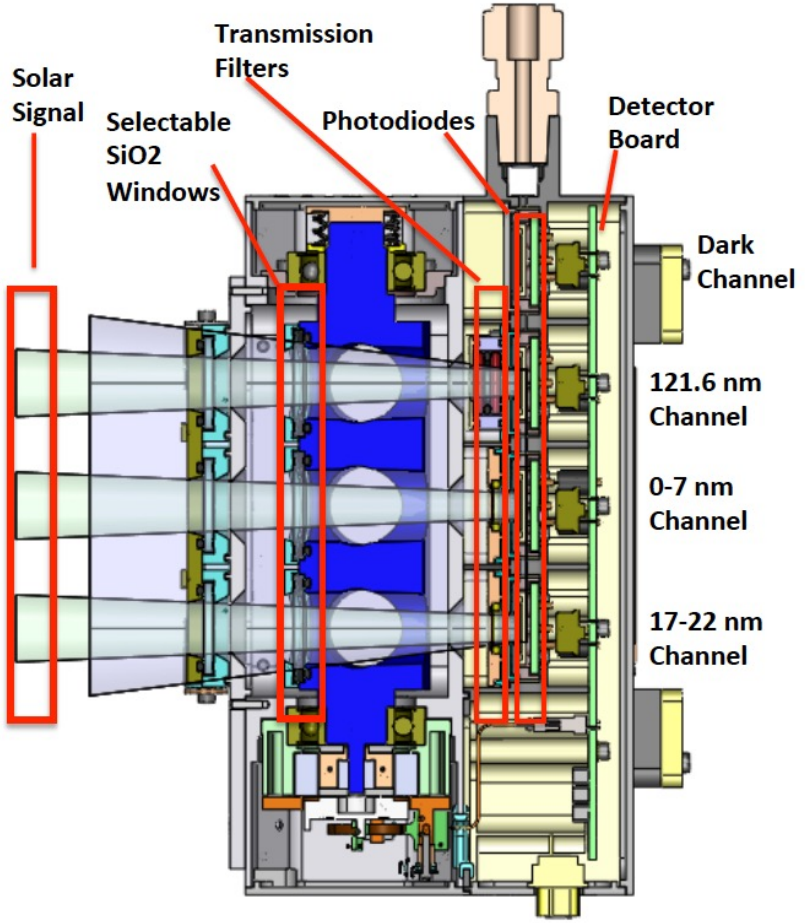




Thiemann et al. *GRL* **42** 2015

MAVEN EUV Monitor (EUVM)



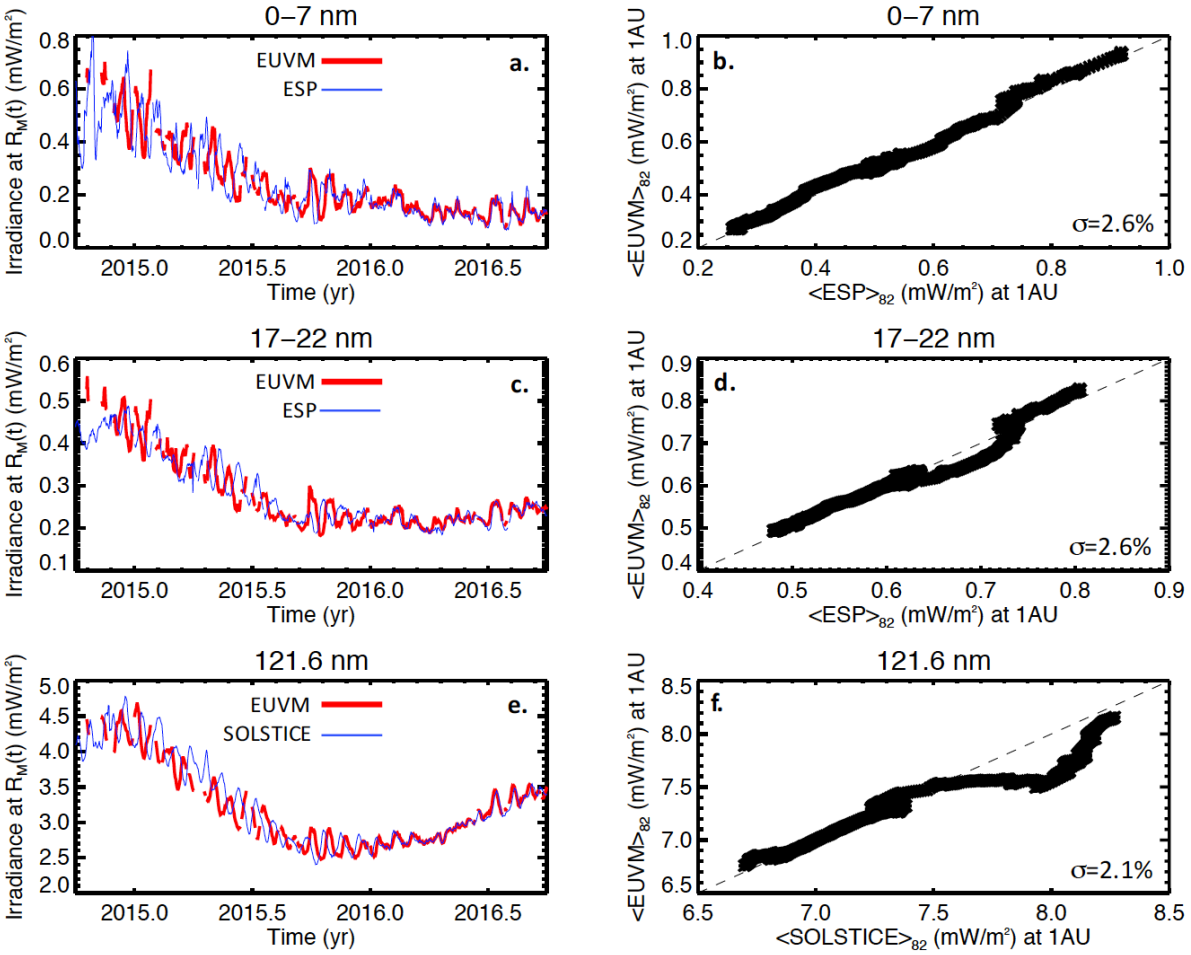


Data Products Include:

- Calibrated Irradiances (Level 2) for
  - 0-7 nm
  - 17-22 nm
  - 121.6 nm
- Modeled Spectral Irradiance
  - Reference Spectra Model (Internal), 0-106 nm @ 0.2 A res.
  - Flare Irradiance Spectral Model-Mars (Level 3), 0.5-195 nm @ 1 A res.[17]

EUVM Level 2 Calibrated Irradiances

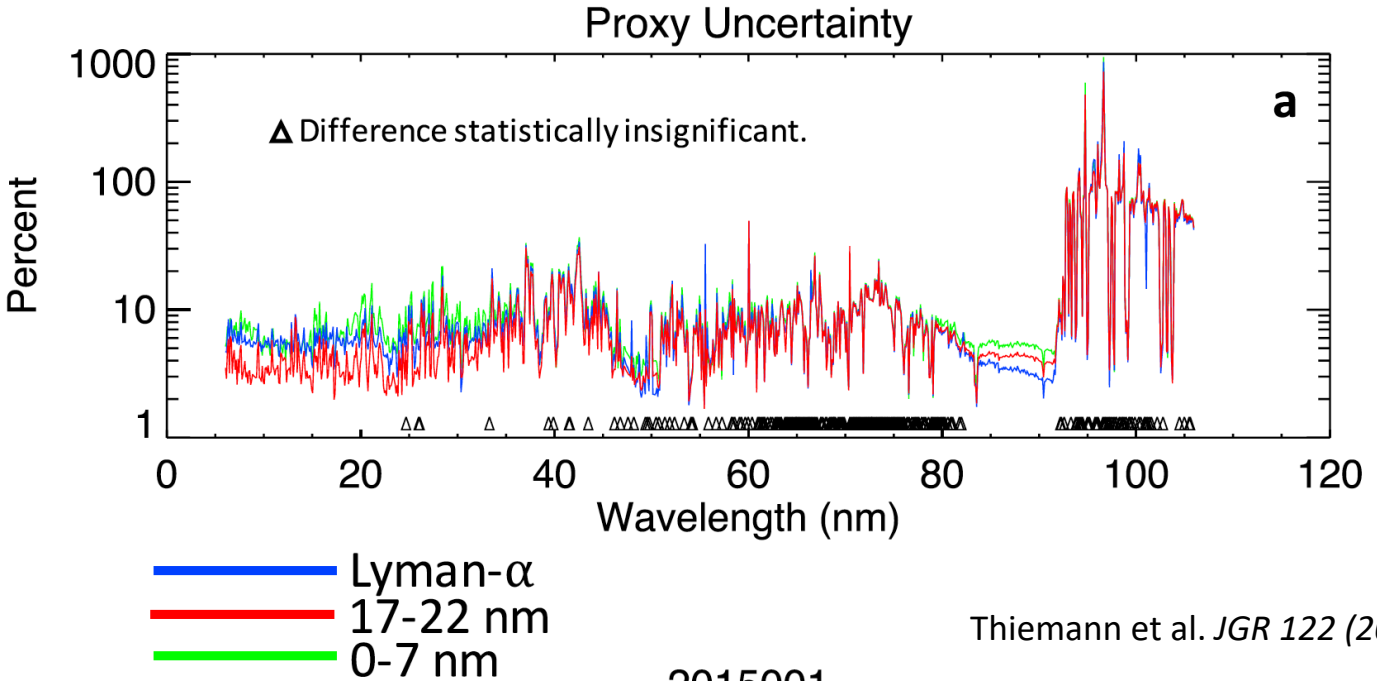
- EUVM measurement cross-calibrated with Earth measurements.
  - SDO/ESP 0-7 nm
  - SDO/ESP 17-22 nm
  - SOLSTICE 121.6 nm
- Cross-calibration linearity < 2.6%.
- These measurements serve as inputs to the FISM-M spectral irradiance model.



Thiemann et al. *JGR 122 (2017)*

FISM-M Spectral Model

- FISM-M is an empirical model for daily and flare irradiances that uses a set of regression coefficients with the EUVM bands to estimate solar irradiance.
- FISM-M is an improvement of the FISM model developed by Chamberlin et al *Space Weather* [2007; 2008].
- Calibrated to SDO/EVE data from 6-106 nm (0.1 nm resolution), SEE and SOLSTICE data (1 nm resolution), otherwise.

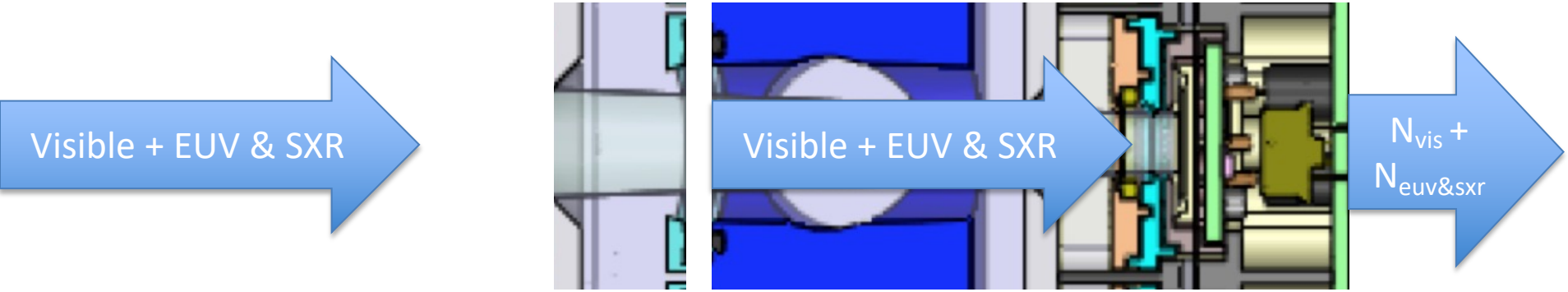


Thiemann et al. *JGR 122 (2017)*

EUVM Calibration Notables

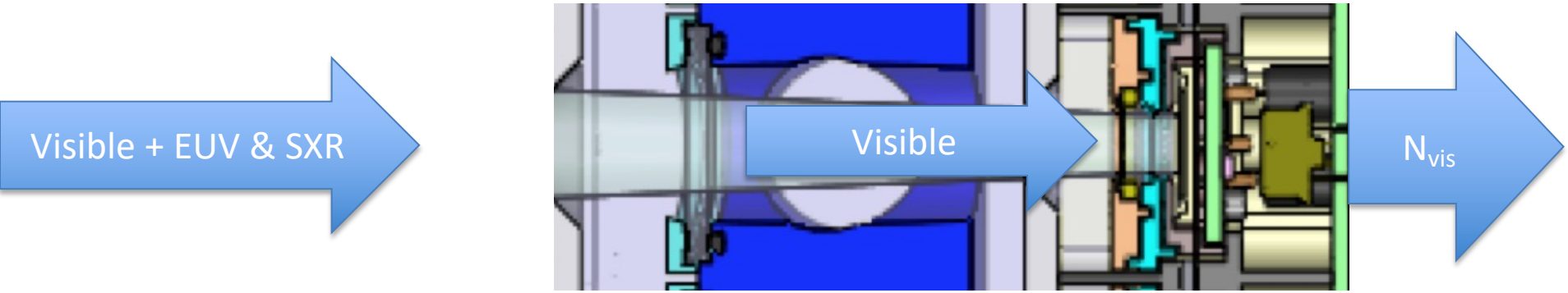
- A visible light leak was incorporated into the instrument response function resulting in more consistency between manufactured and estimated foil filter parameters.
- The independent instrument calibration is within 10% of EVE MEGS A.
- Calibration is scaled to EVE ESP and Ly-α composite (pre ~2022).

Light Leak Calculation



- “Pin-holes” in filter result in a measurable visible signal contribution.

Light Leak Calculation



- "Pin-holes" in filter result in a measurable visible signal contribution.
- Can isolate visible signal for removal by shuttering SiO_2 window.
- Visible transmission due to pin-holes:
  - EUVM A : $T = 8 \times 10^{-8}$
  - EUVM B : $T = 8 \times 10^{-10}$
- Pin-holes will transmit short wavelengths too….and more efficiently! (Bethe(1944), Meyer(2007))

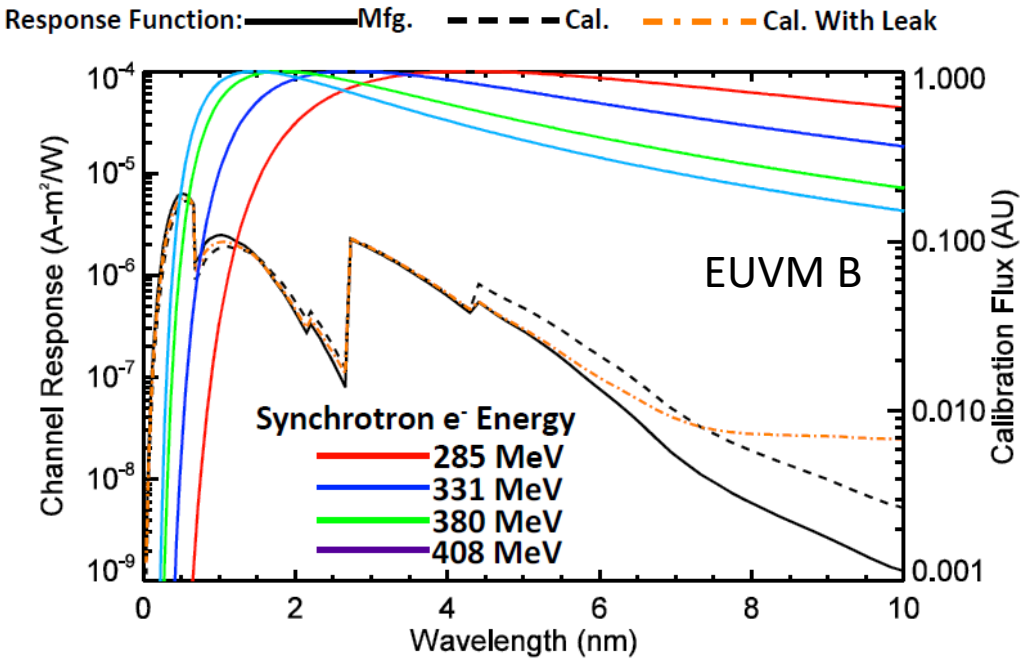
$$T_{pin-hole} \propto \left(\frac{d}{\lambda}\right)^4$$

Multi-Energy Calibration

$$G_{i,j} = \frac{N_{meas}}{I_{predicted,i,j}} = \frac{N_{meas}}{\int R_i(\lambda) E_{SURF,j}(\lambda) d\lambda}$$

1. Gain calculated for each calibration spectrum (j energies) with filter thicknesses s(i permutations).
2. Bethe(1945), Meyer(2007) used to estimate light leak pin-hole size based on visible contribution.
3. Step 1 repeated but using pin-hole transmission function based on size found in step 2.

* Case that includes light leak is in much better agreement with manufacturer reported filter parameters.



EUVM A

	C	Al	Nb	Si	Leak (<30 nm)
Design	504 A	2515 A	503 A	50,000 A	NA
Calibrated, No Leak	354 A	2365 A	353 A	29,500 A	NA
Calibrated, With Leak	554 A	2565 A	513 A	38,000 A	0.812%

EUVM B

	C	Al	Ti	Si	Leak (<10 nm)
Design	392 A	1467 A	2937 A	50,000 A	NA
Calibrated, No Leak	742 A	1117 A	2587 A	35,500 A	NA
Calibrated, With Leak	342 A	1517 A	2907 A	38,000 A	0.447%

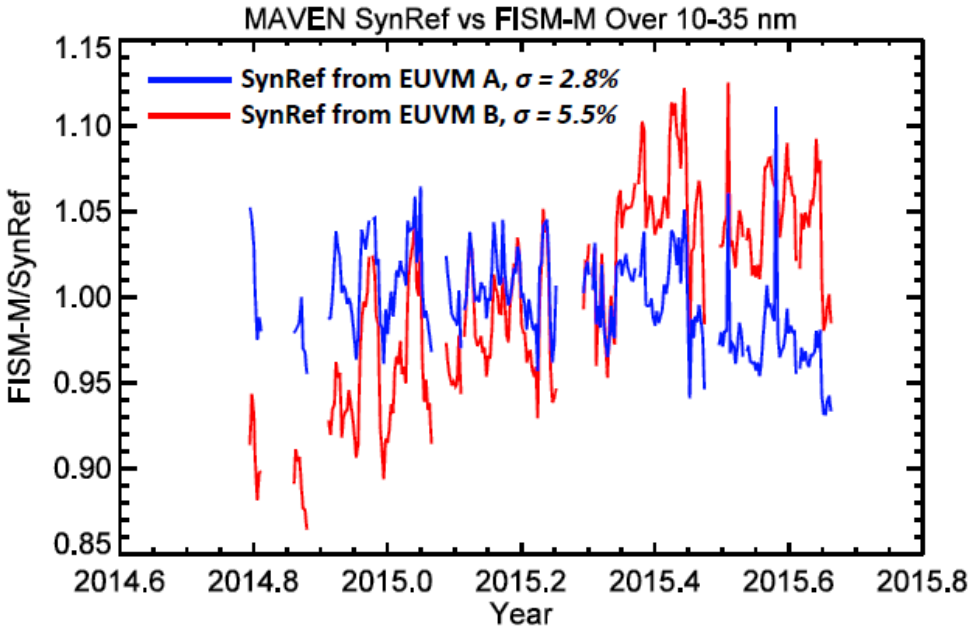
Absolute Calibration Comparison with SDO/EVE

- A reference spectrum used with response function to derive spectral irradiance from photocurrent.
  - Uses Woods et al. (2008) XPS model approach with updated reference spectra.
  - We call this model "SynRef" on EUVM

- **10-35 nm irradiance estimate from EUVM SURF calibrated photocurrent with 10% of SDO/EVE.**
  - FISM-M used as proxy for SDO/EVE

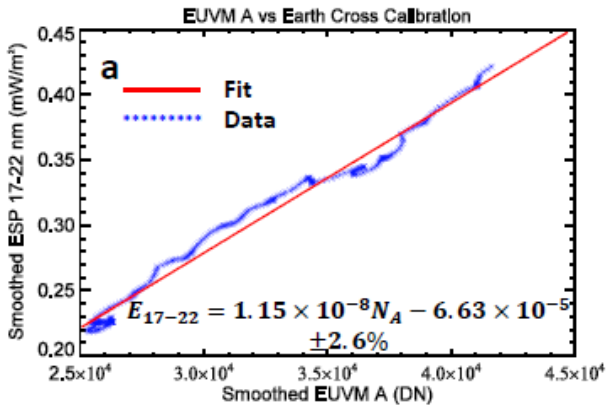
EUVM Channel	Gain Correction Factor
A	0.9146
B	1.0542

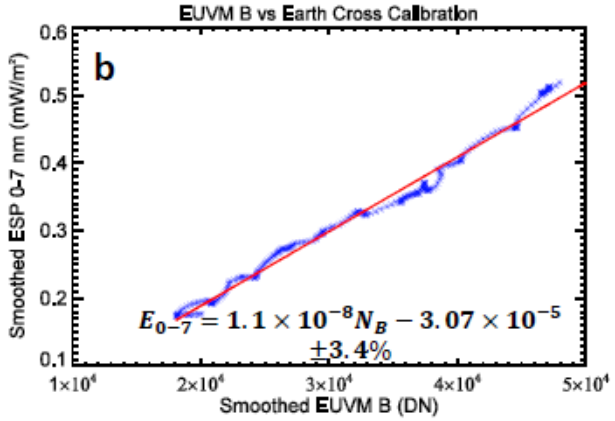
- **Well within the 20-40% absolute uncertainty estimated from the response functions.**

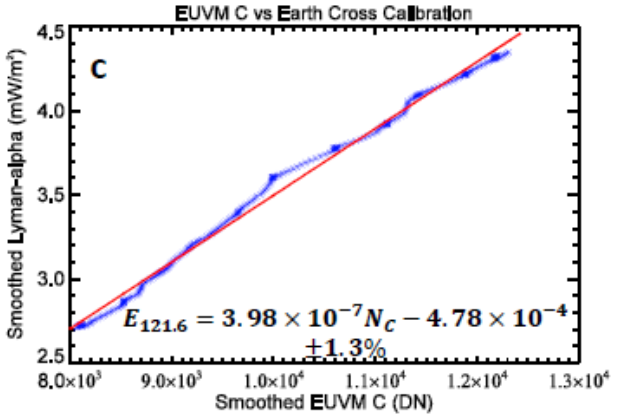


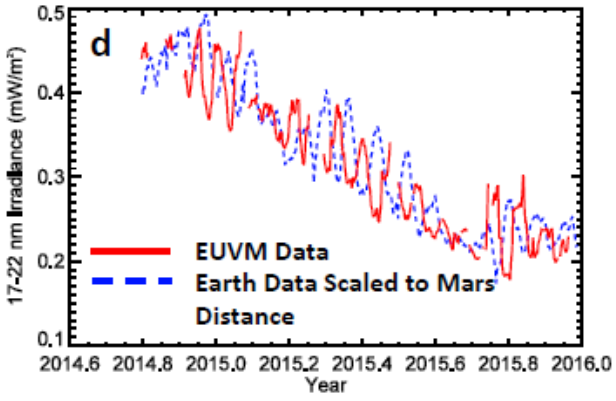
EUVM Cross-Calibration with Earth-Assets

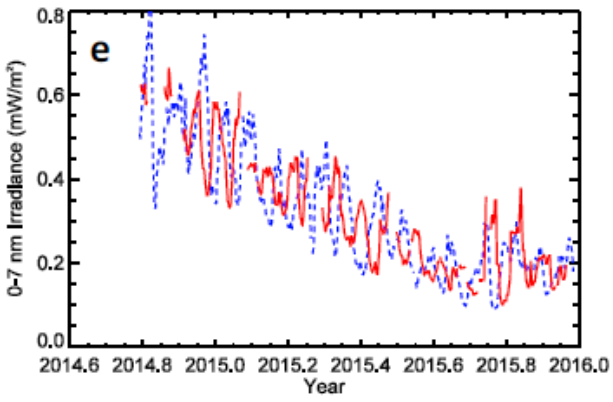
- EUVM channel counts are calibrated against assets at Earth:
  - EUVM A –ESP 17-22 nm channel
  - EUVM B –ESP 0-7 nm channel
  - EUVM C –LASP Lyman-α composite
- Need matched calibration to drive FISM-M

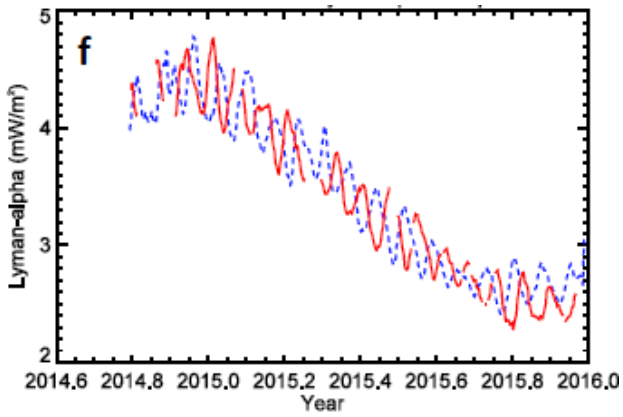






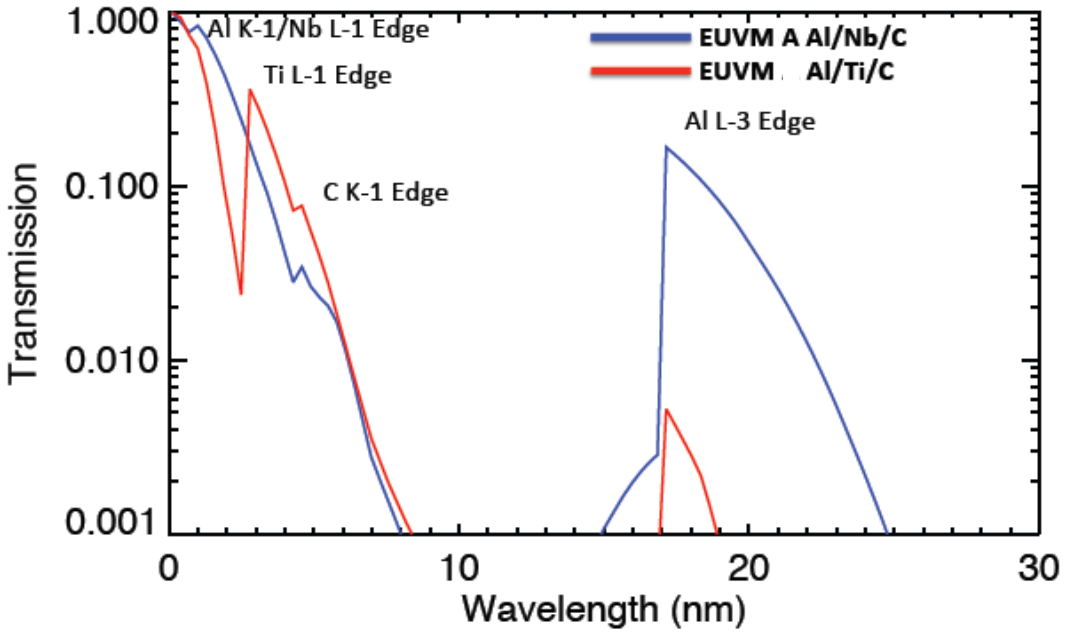






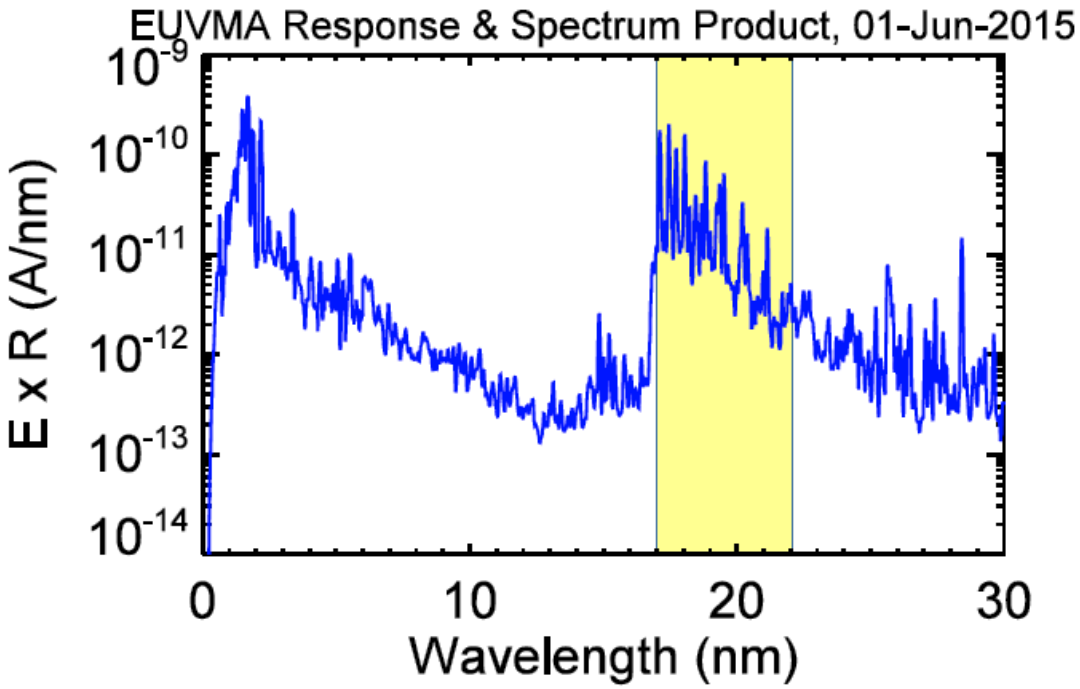
EUVM A Soft X-Ray Removal

- EUVM A intended as 17-22 nm coronal EUV channel but has significant SXR contribution which must be removed prior to earth-asset calibration.



EUVM A Soft X-Ray Removal

- Synthetic spectra from SynRef used to estimate fraction of counts in 17-22 nm band.



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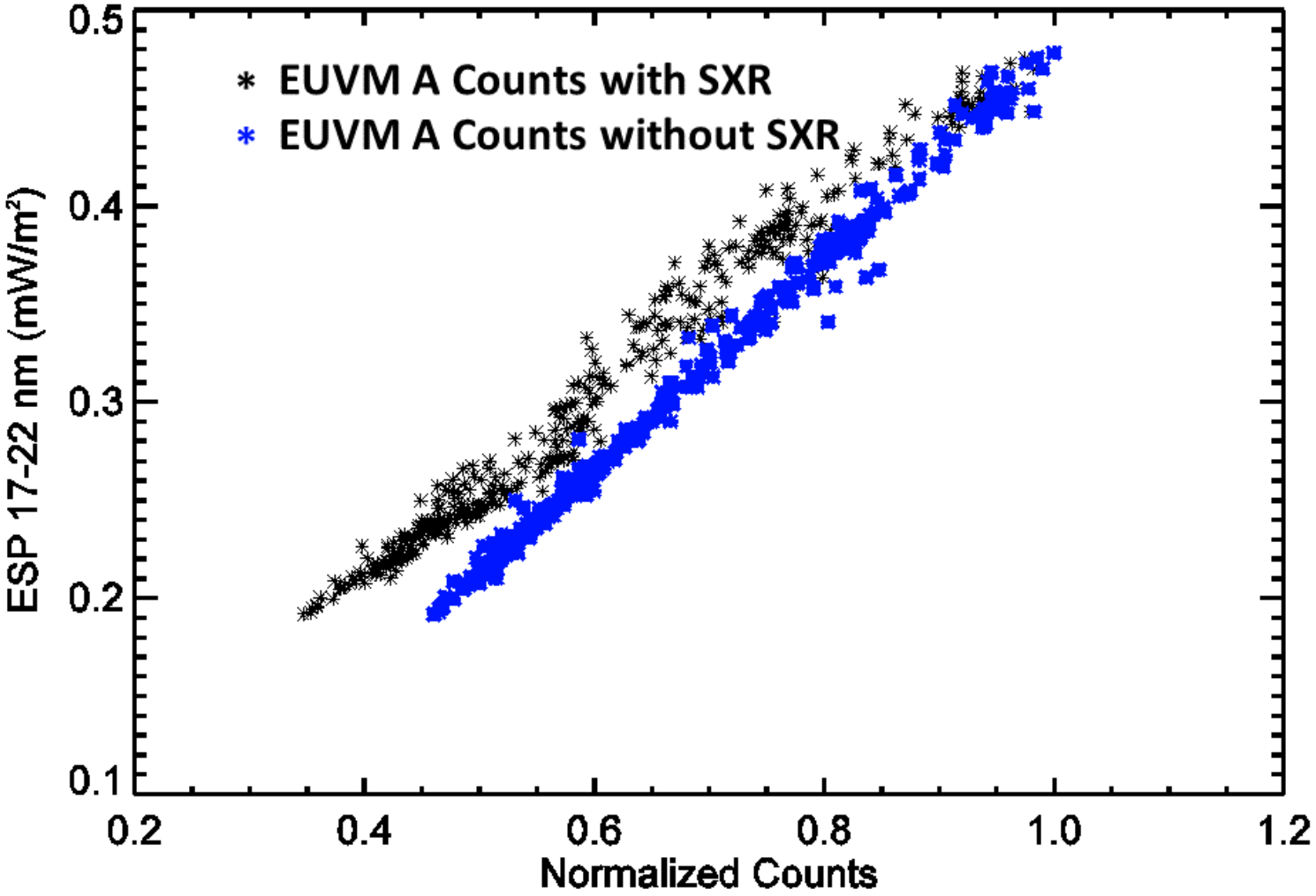
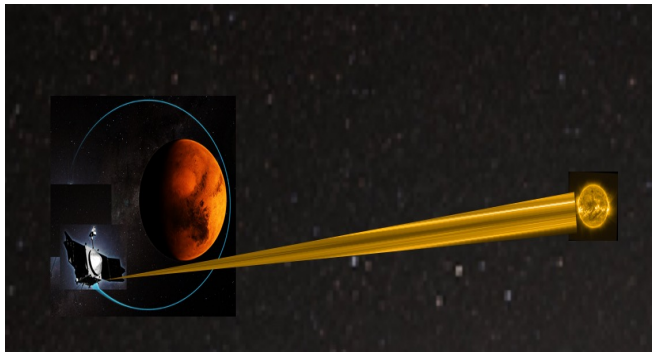
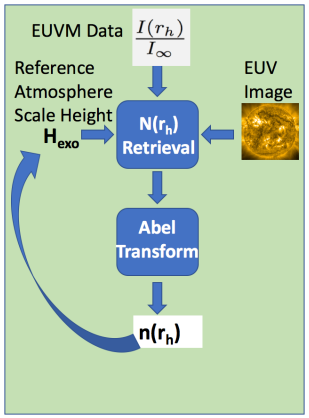


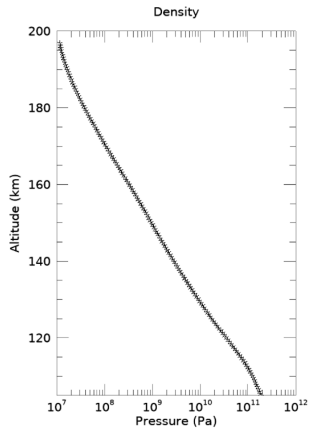
Time Left for Occultations?

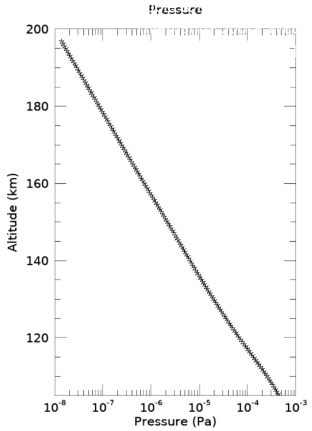
Serendipitous EUV Occultations of Mars' Thermosphere

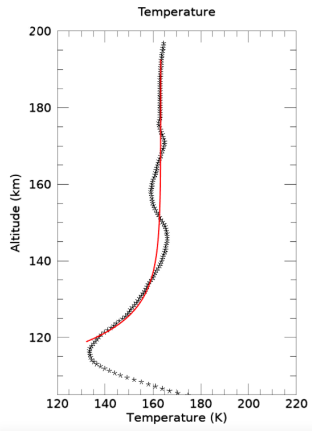
- EUV signal is absorbed between ~110-200 km.
- Retrieval integrates the solar disk over reference atmosphere to find number density.
- Vertically integrate to find pressure. → T=p/nk
- Fit Bates Temperature Profile → T_{exo} from Bates Coefficients







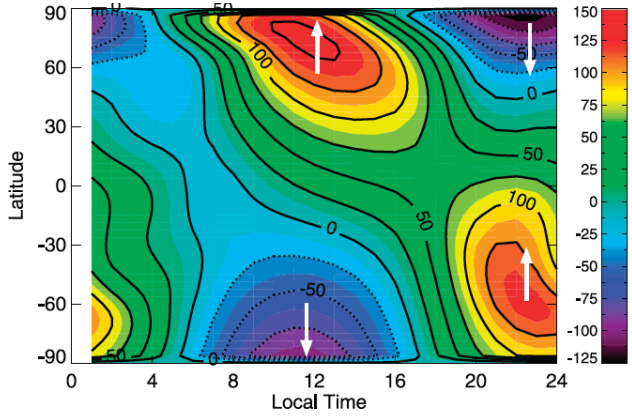




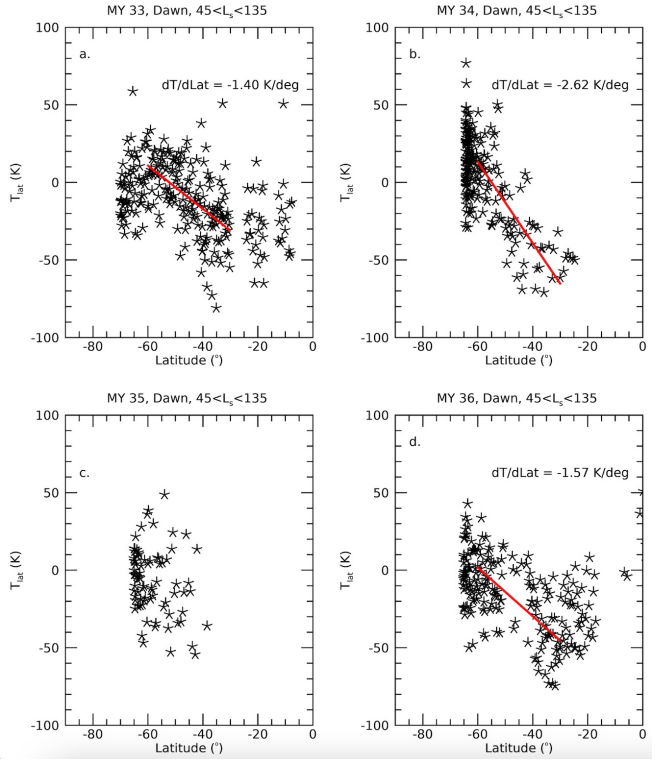
MAVEN EUVM Observes Aphelion Thermospheric Polar Warming

- Circulation cell occurs at solstices with upwelling at summer hemisphere and downwelling in winter hemisphere.
- EUVM has made first conclusive measurements of aphelion TPW and its climatology.

Meridional Winds (m/s) at Perihelion



Gonzalez-Galindo+ 2009

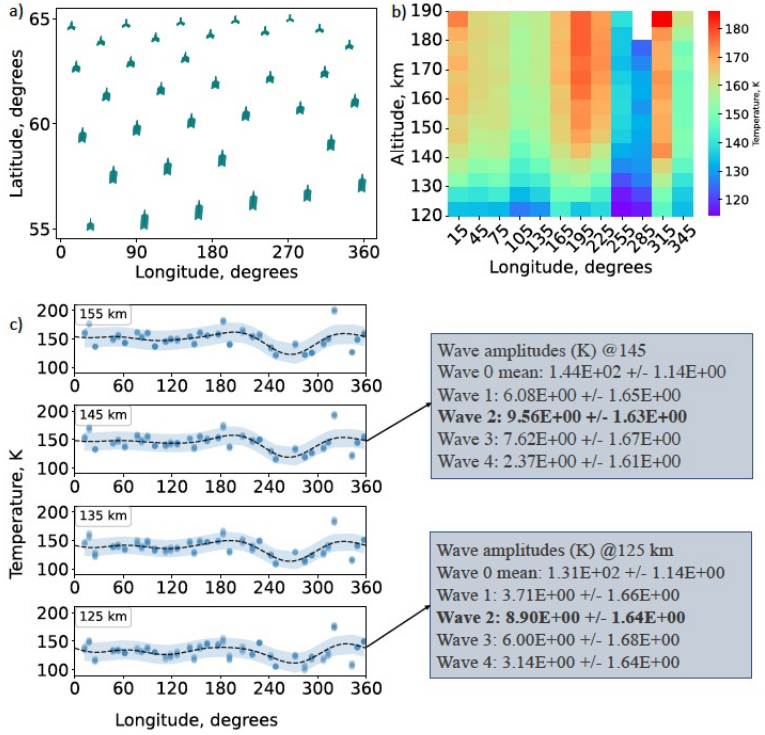


Thiemann+ In Prep, 2023

MAVEN EUVM Observes Tides in Mars Thermosphere

- Kumar et al. (in prep) are studying propagation of tides into Mars thermosphere using MAVEN EUVM AND MRO MCS.
- Identified different dominant modes in middle (wave 3) and upper (wave 2) atmosphere.

EUVM Observation of Thermosphere



MCS Observations of Middle Atmosphere