MAVEN Science Results

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MEPAG meeting, 3 March 2016

Evidence for Surface Water on Ancient Mars: Where Did the Water Go? Where Did the CO_2 Go?

MAVEN
Mars Atmosphere and Volatile Evolution Mission
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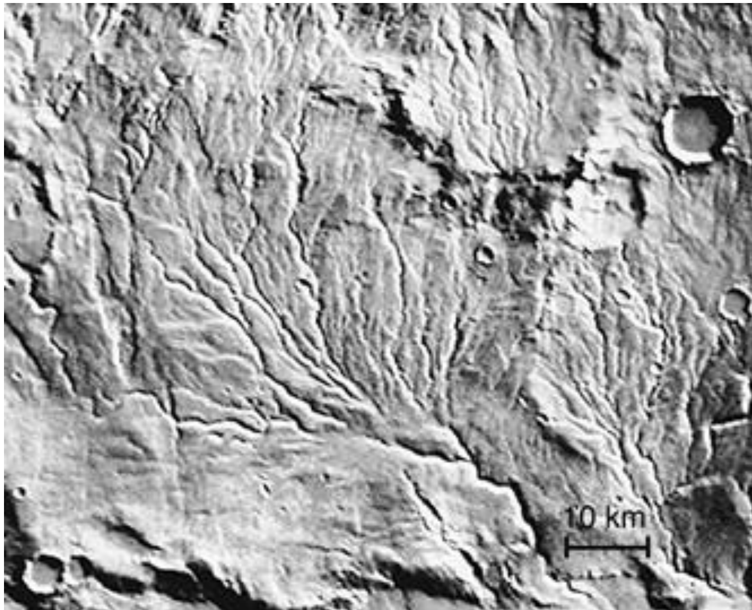
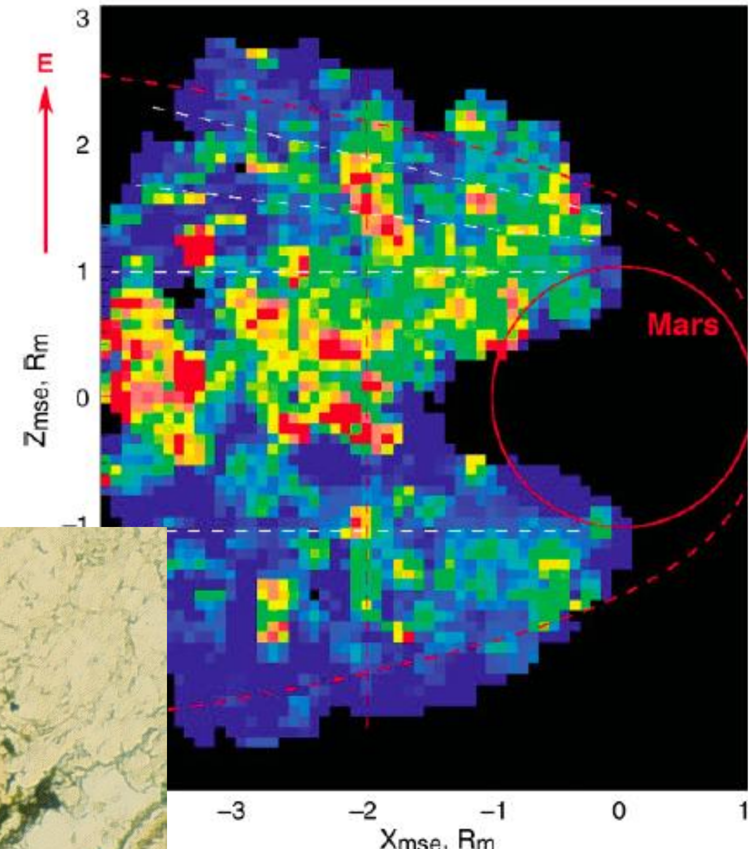
Abundant evidence for ancient water

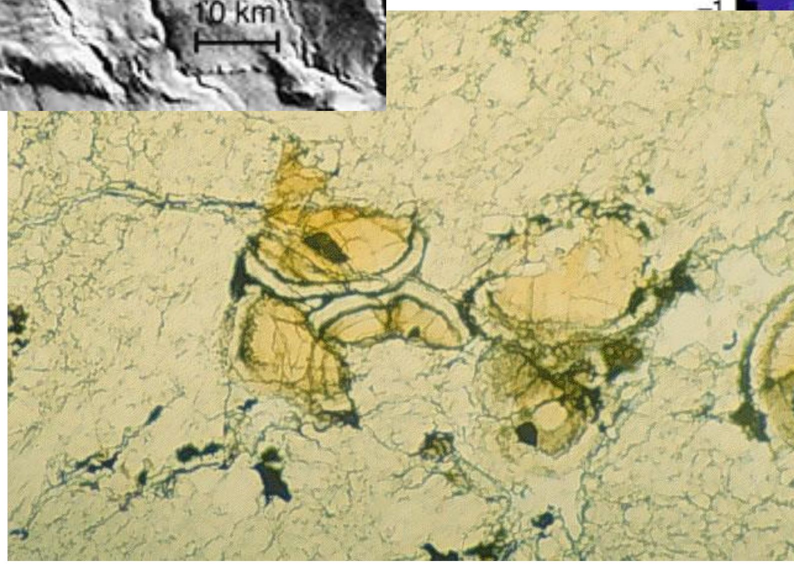


Volatiles can be lost to space



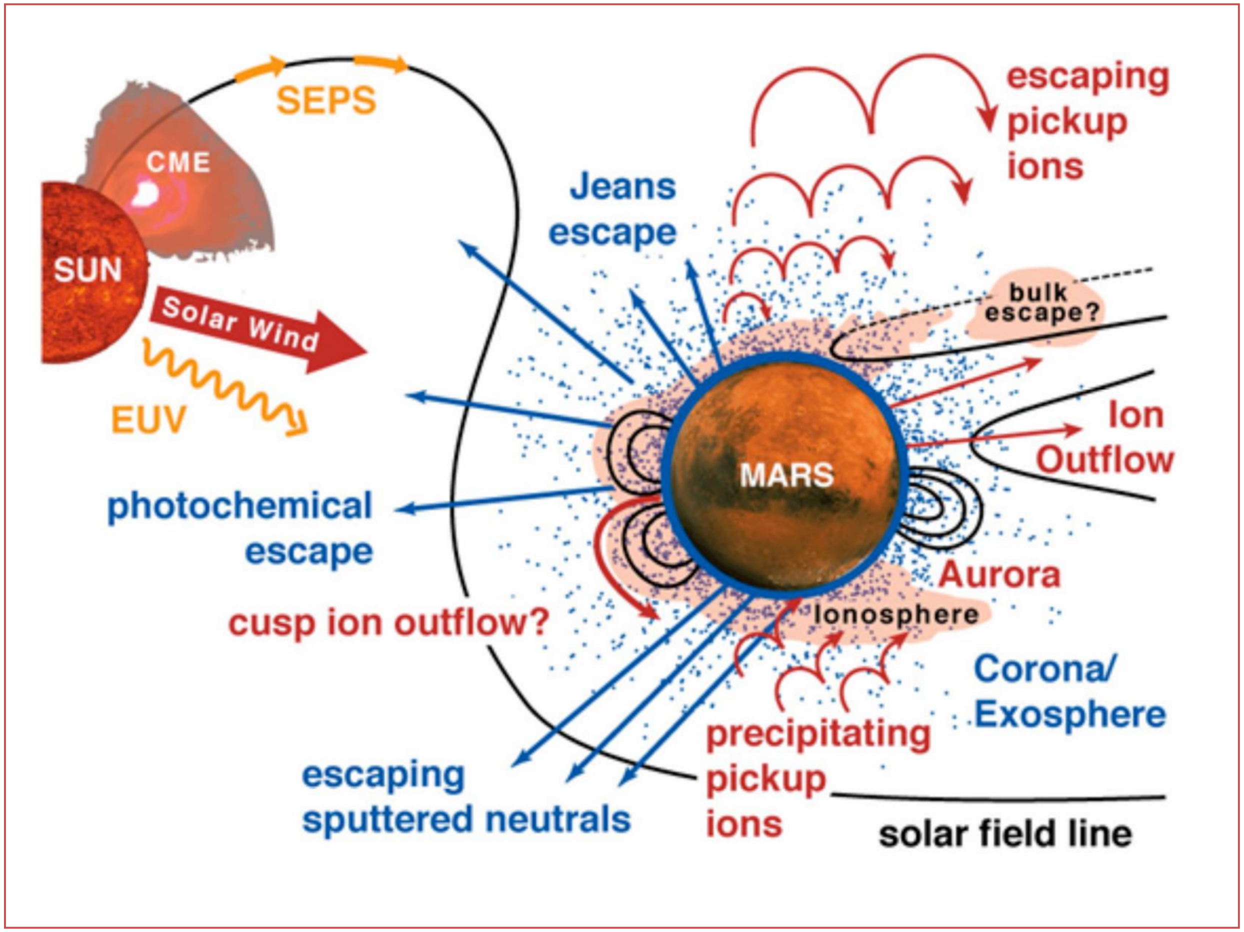
Escaping ions detected from Mars Express

Volatiles can go into the crust



Carbonate deposits in a Martian meteorite

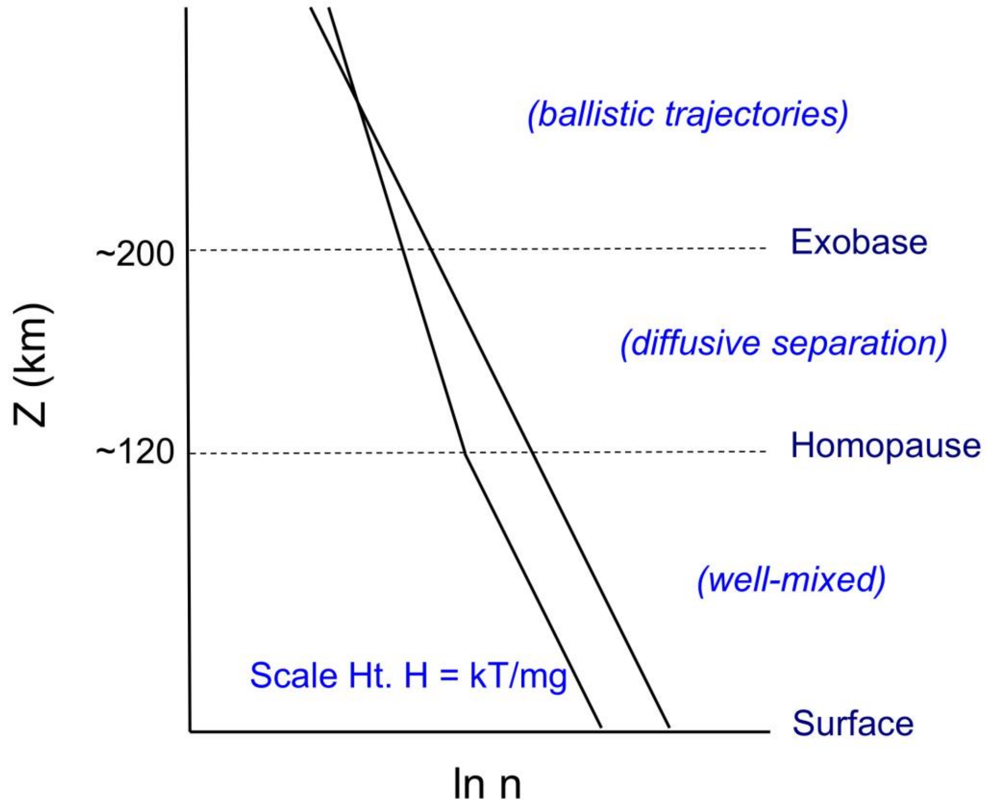
MAVEN Explores Escape of Atmospheric Gases to Space



- Measure energetic drivers from the Sun, response of upper atmosphere and ionosphere, and resulting escape to space
- Understand the key processes involved, allowing extrapolation to loss over Mars history

Basic Structure of the Mars Atmosphere

- The Mars upper atmosphere is an extension of the lower atmosphere
- Dynamical mixing between the two allows each to affect the other



Processes Leading to Escape in the Mars Upper Atmosphere*

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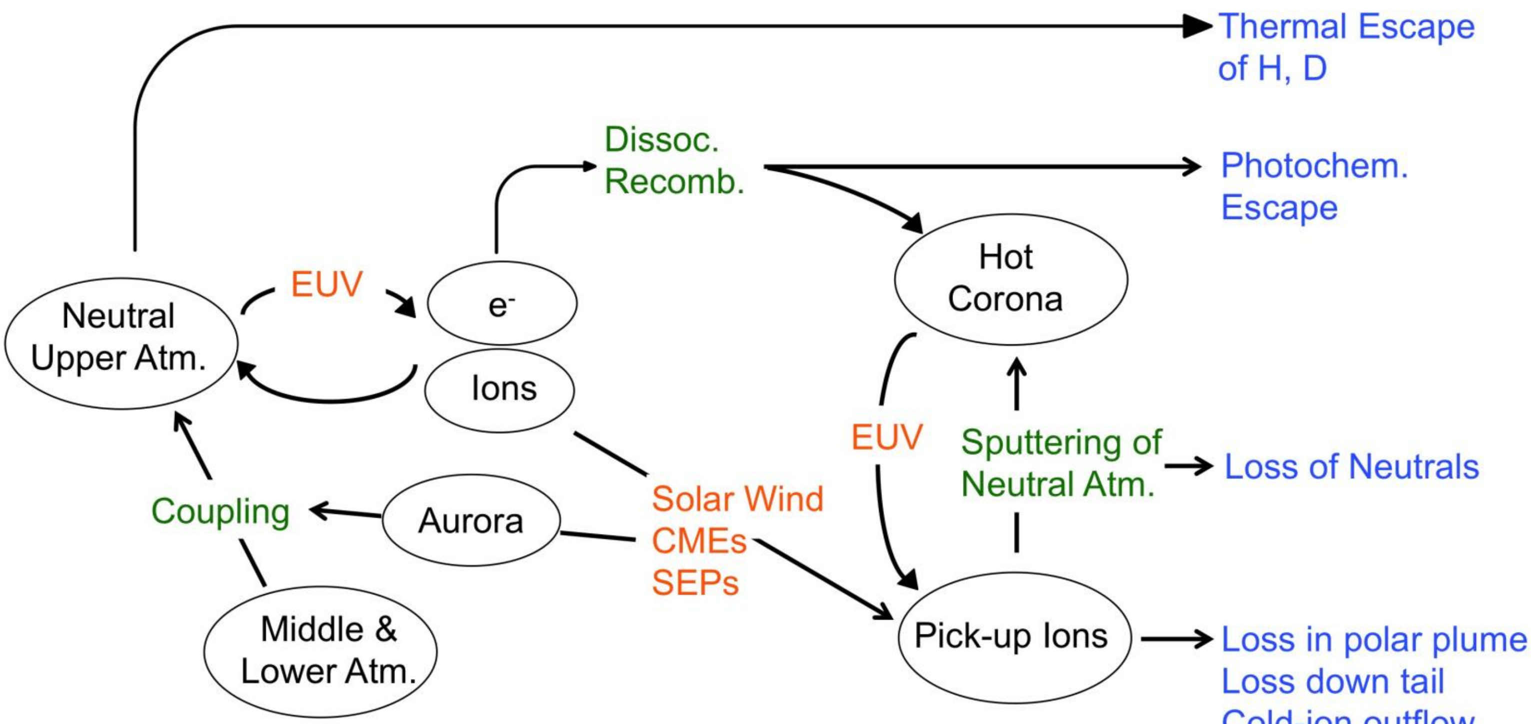
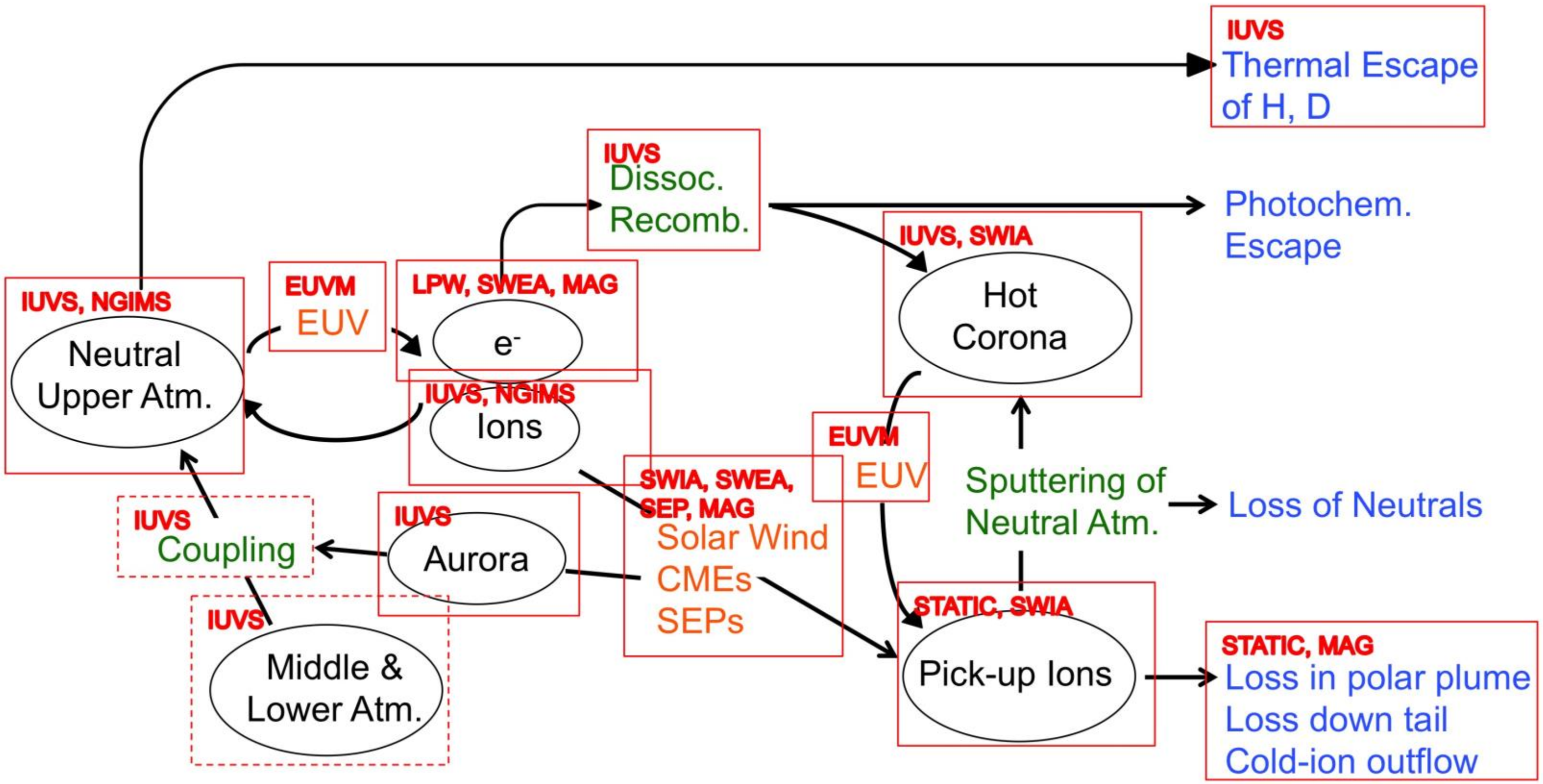
What controls the behavior of the Mars upper atmosphere, and how do processes there lead to loss of gas to space?



** Shorthand for Mars upper atmosphere, ionosphere, solar-wind interactions, and the consequent loss of gas to space*

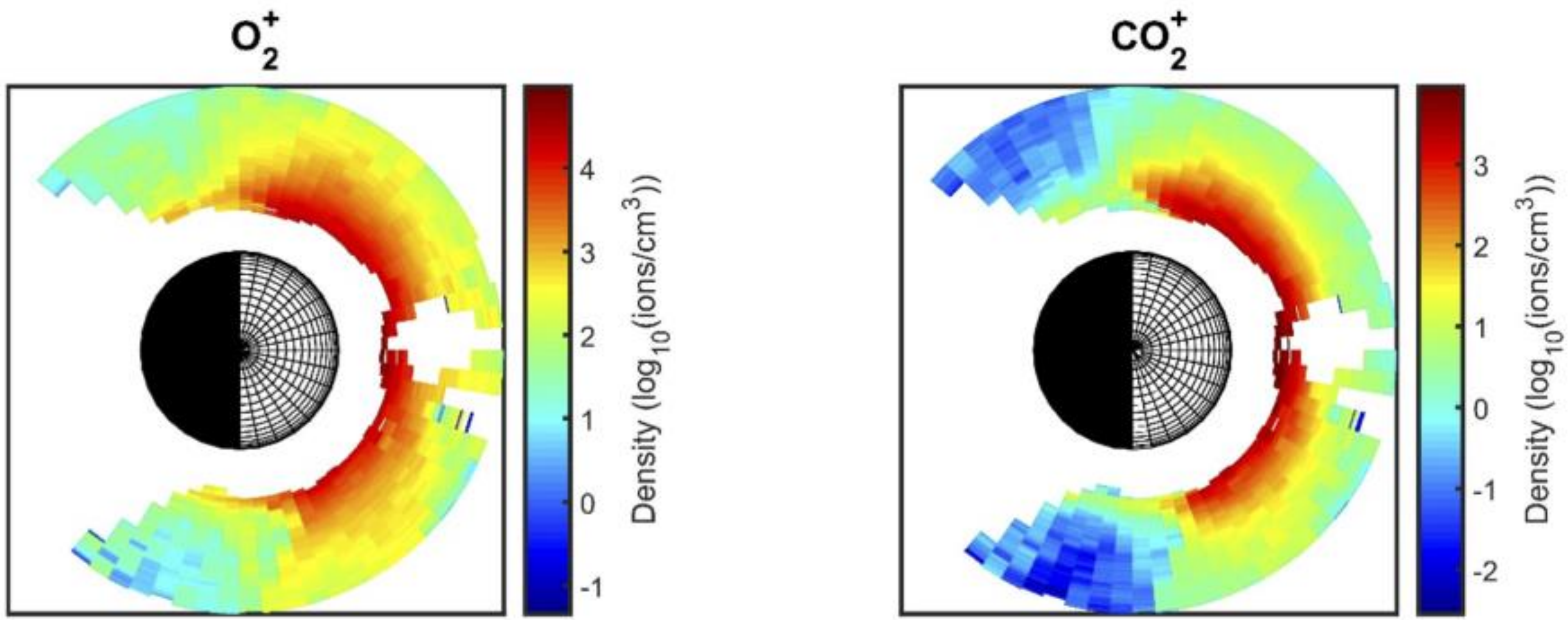
MAVEN Coverage of Processes in the Mars Upper Atmosphere

What controls the behavior of the Mars upper atmosphere, and how do processes there lead to loss of gas to space?



* *Shorthand for Mars upper atmosphere, ionosphere, solar-wind interactions, and the consequent loss of gas to space*

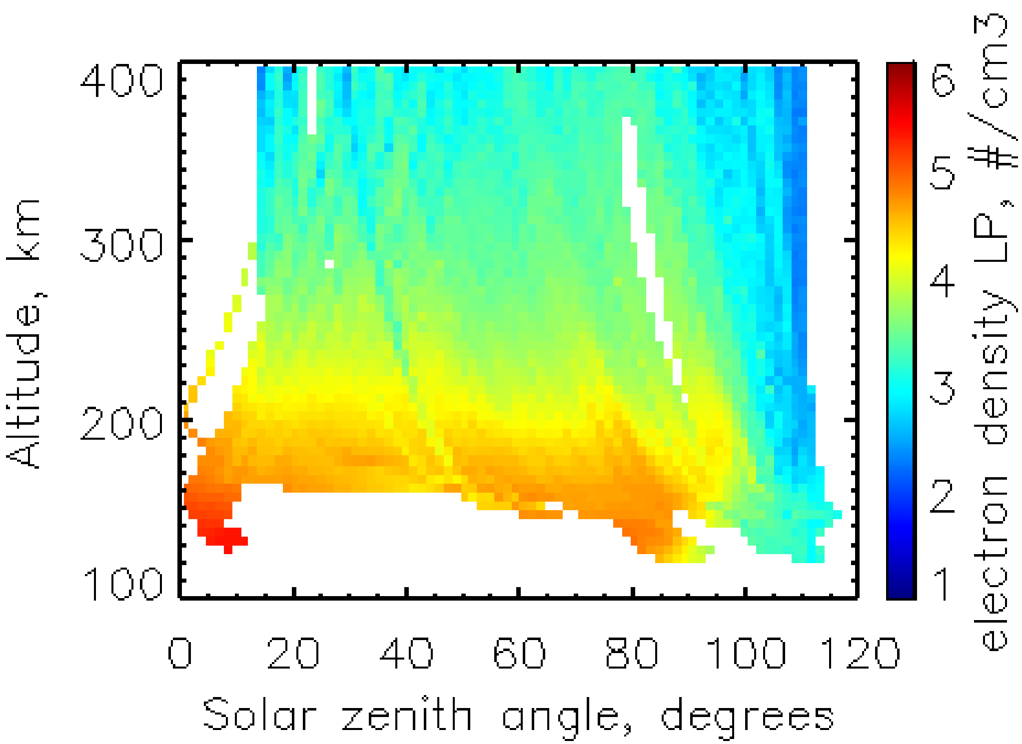
Composition and Structure of the Ionosphere

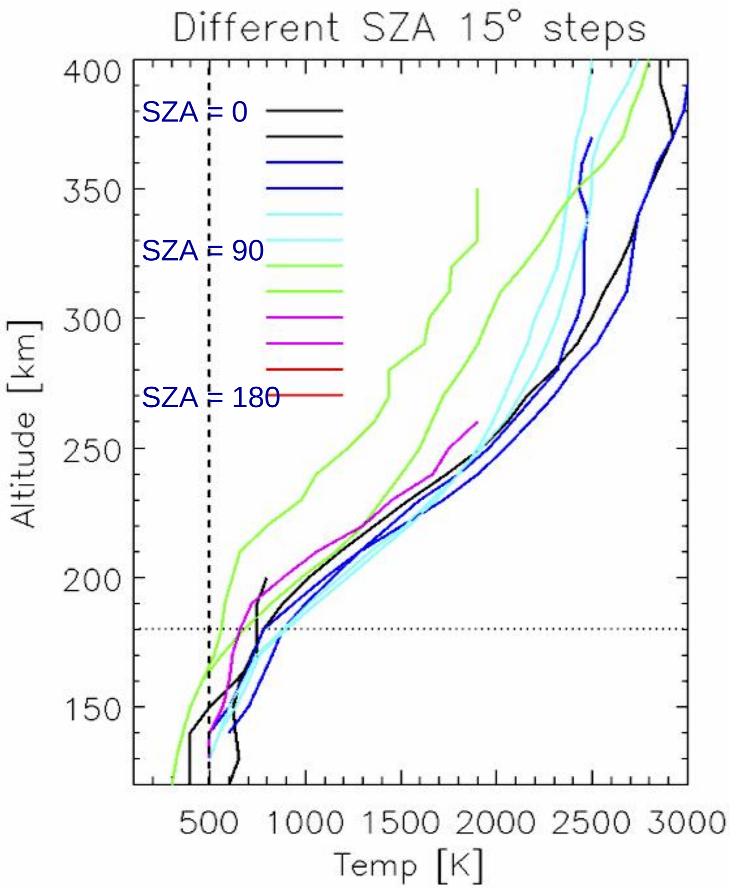


Ion densities mapped out by NGIMS, between 150-500 km altitude, shown as a function of solar zenith angle (but divided into dawn and dusk sides). Sun is to the right.

(Benna et al. 2016)

Electron Density And Temperature

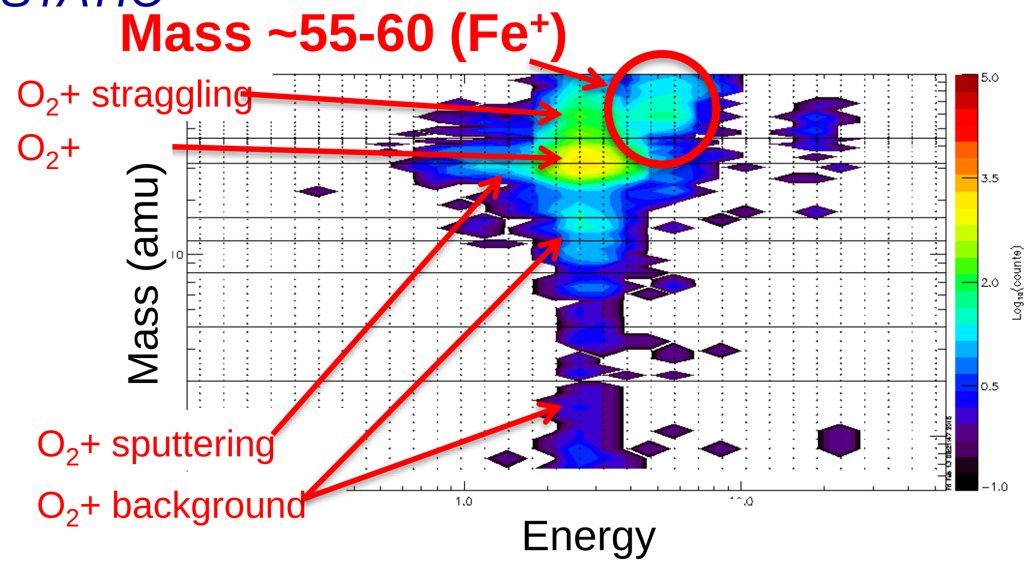




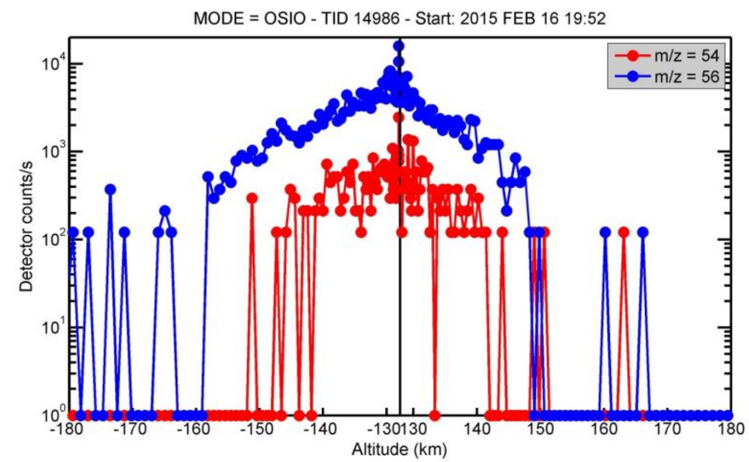
(Andersson et al.,

Discovery of Metal-Ion Layer in Ionosphere

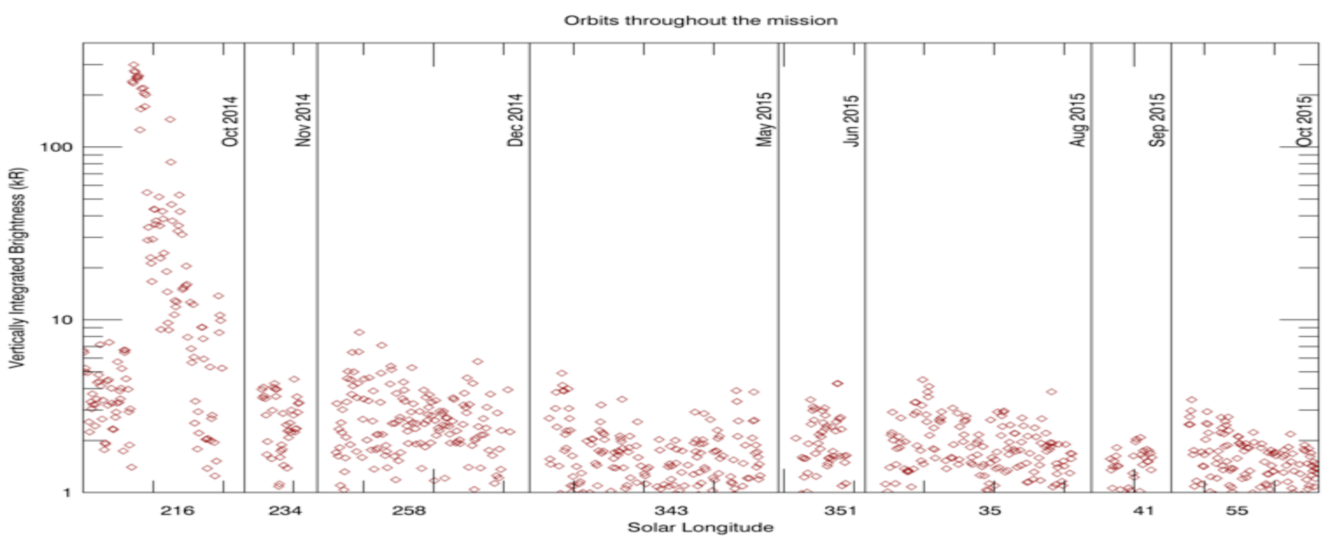
STATIC



NGIMS



IUVS

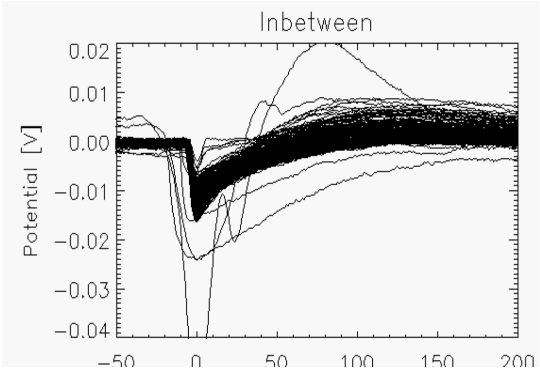


(McFadden et al., Benna et al., Schneider et al.)

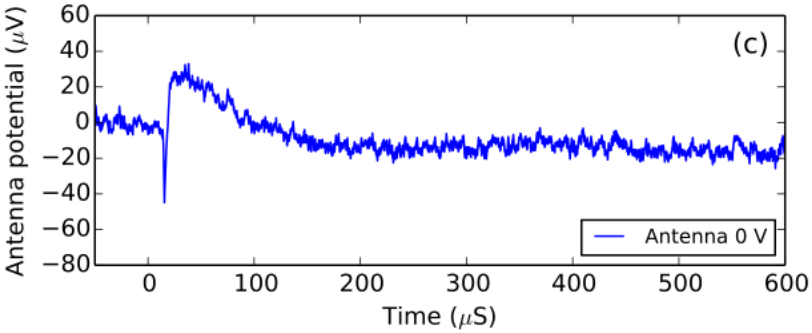
Discovery of Dust Cloud Surrounding Mars, Observed by LPW

Dust-impact signature

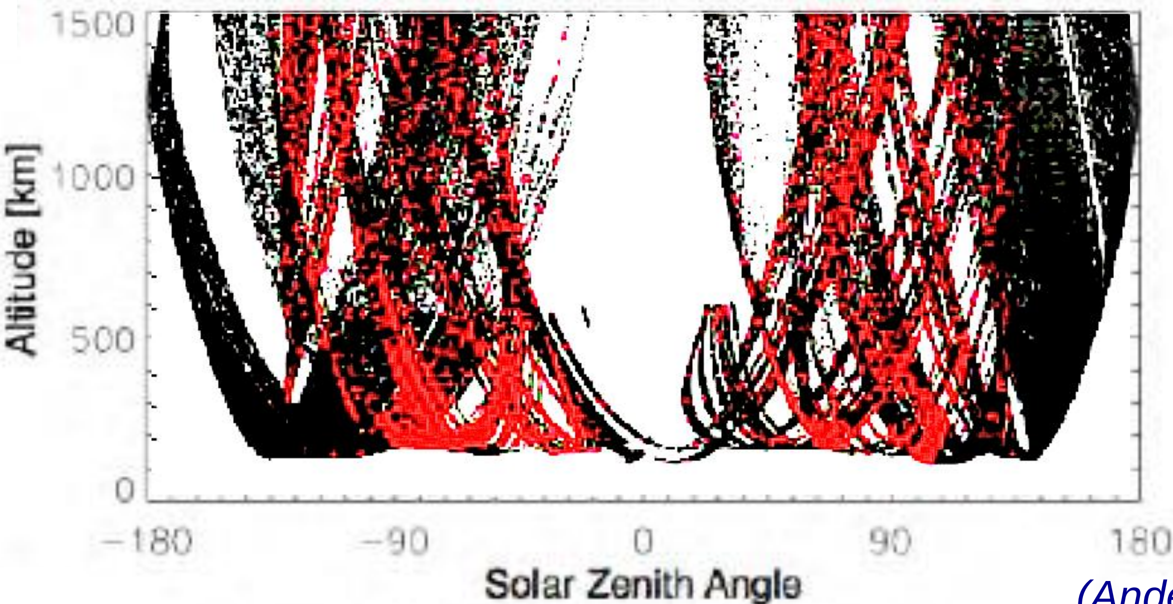
At Mars:



And in the lab:

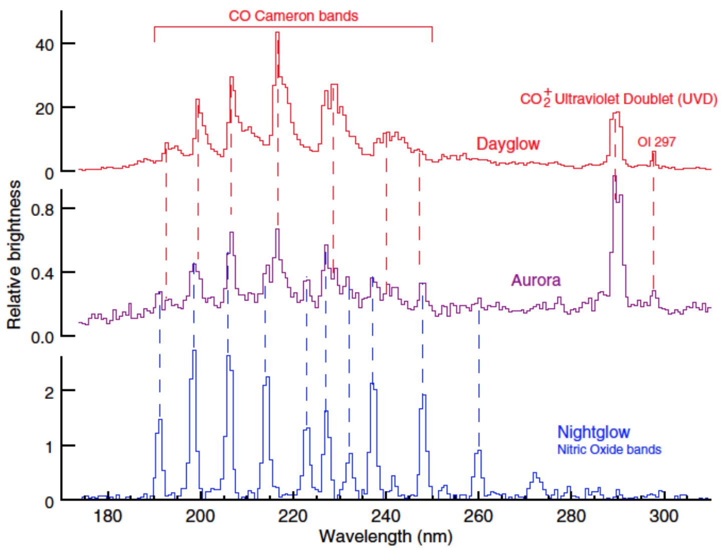


Observed distribution of dust impacts:

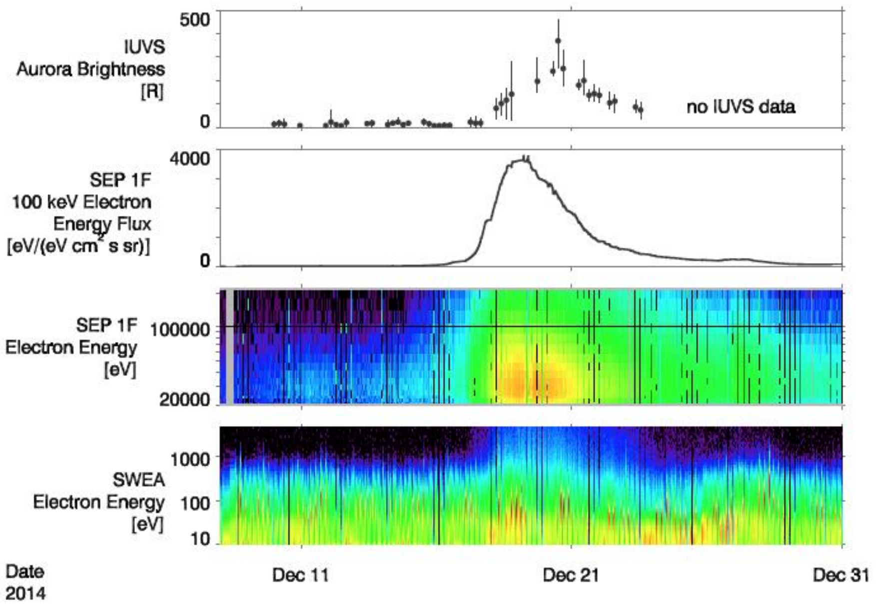


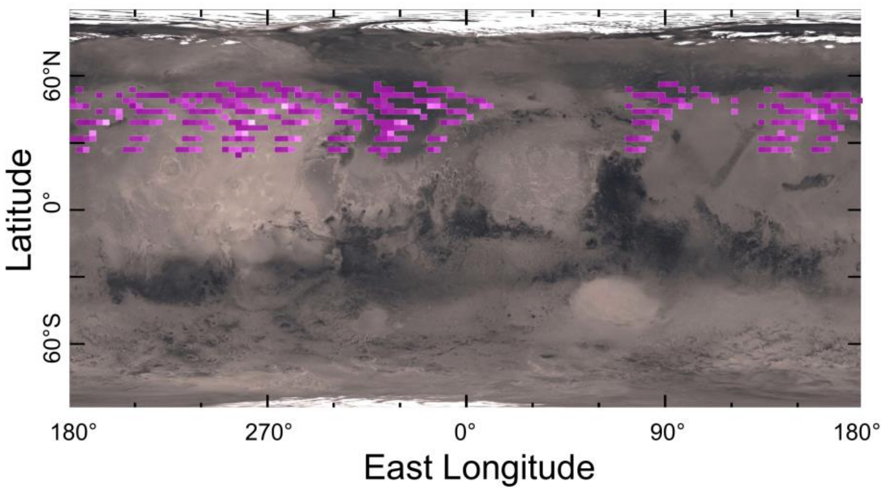
(Andersson et al. 2015)

IUVS Detection of Diffuse Aurora



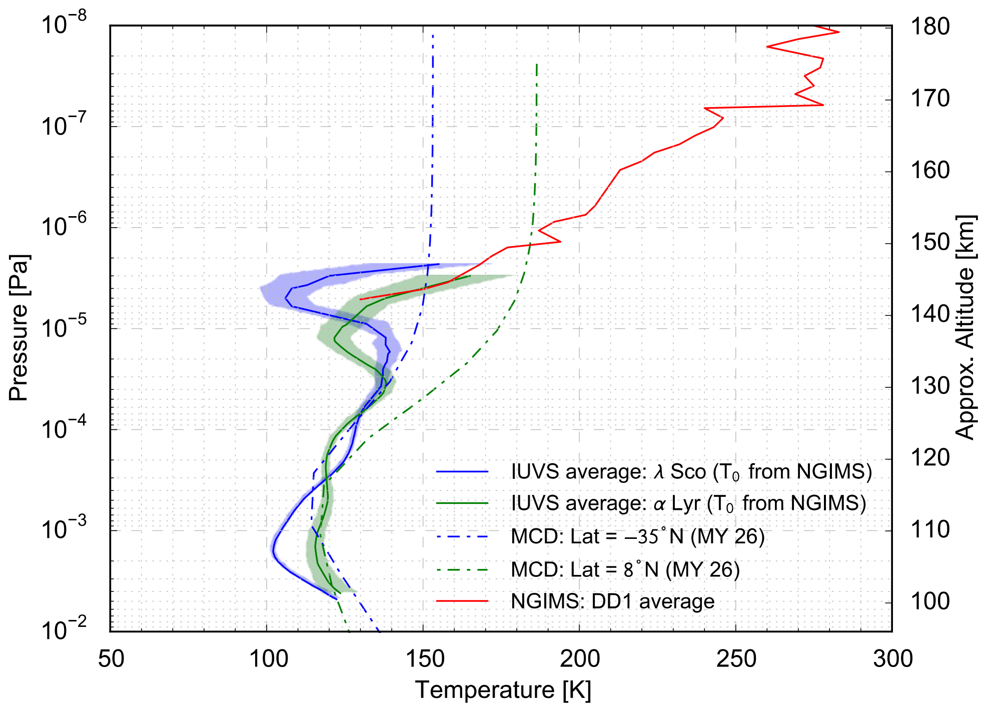
- "Christmas lights" aurora observed for five days on 18-23 December 2014
- Nightside emission at same wavelengths as dayglow; characteristic of aurora in general and of those observed by *Mars Express*
- Diffuse distribution throughout northern hemisphere; no connection to magnetic anomalies

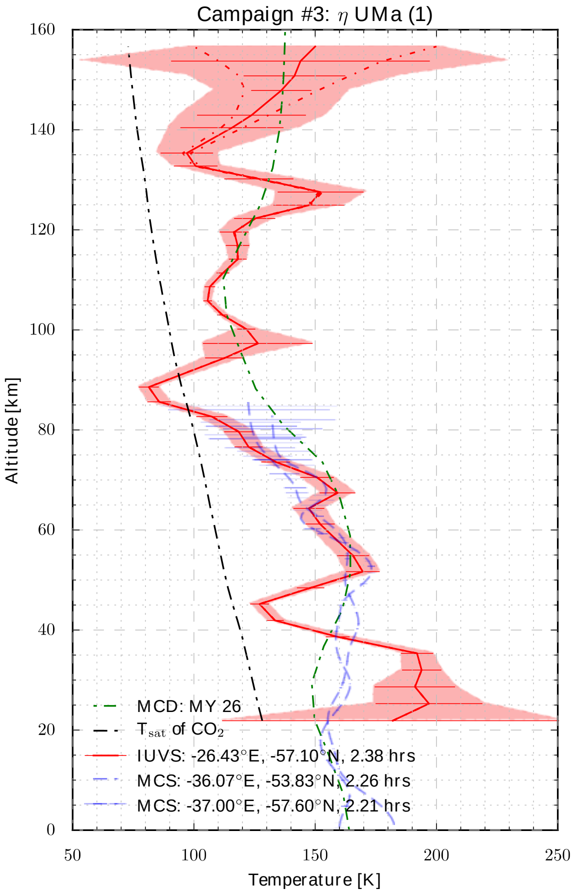




(Schneider et al. 2015)

Temperature Profiles – Surface To 180 km



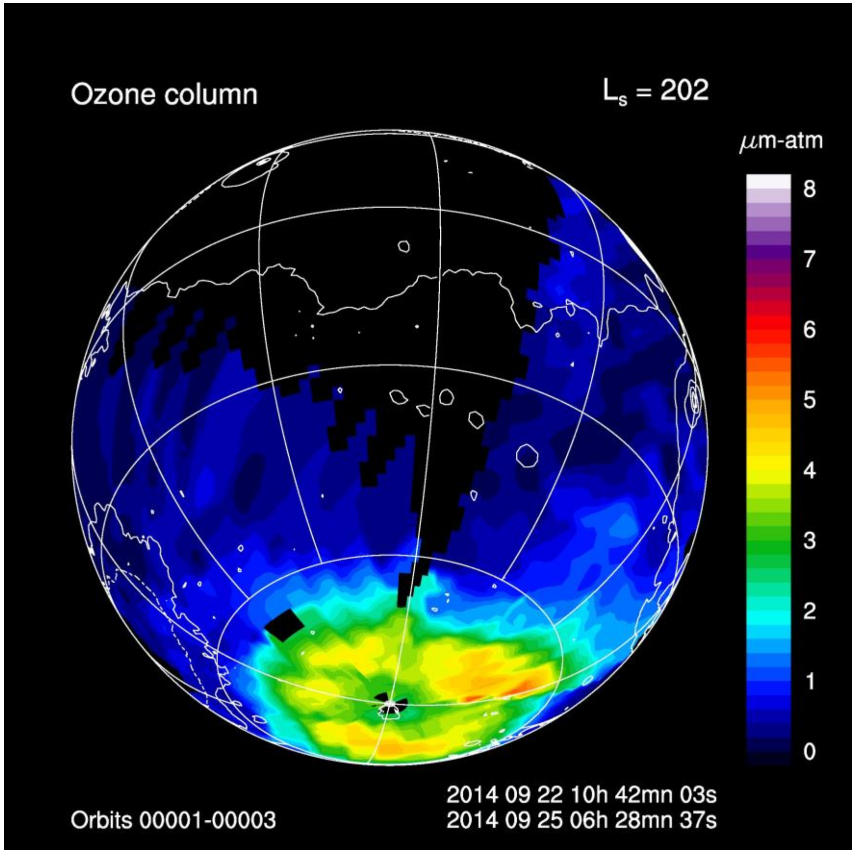


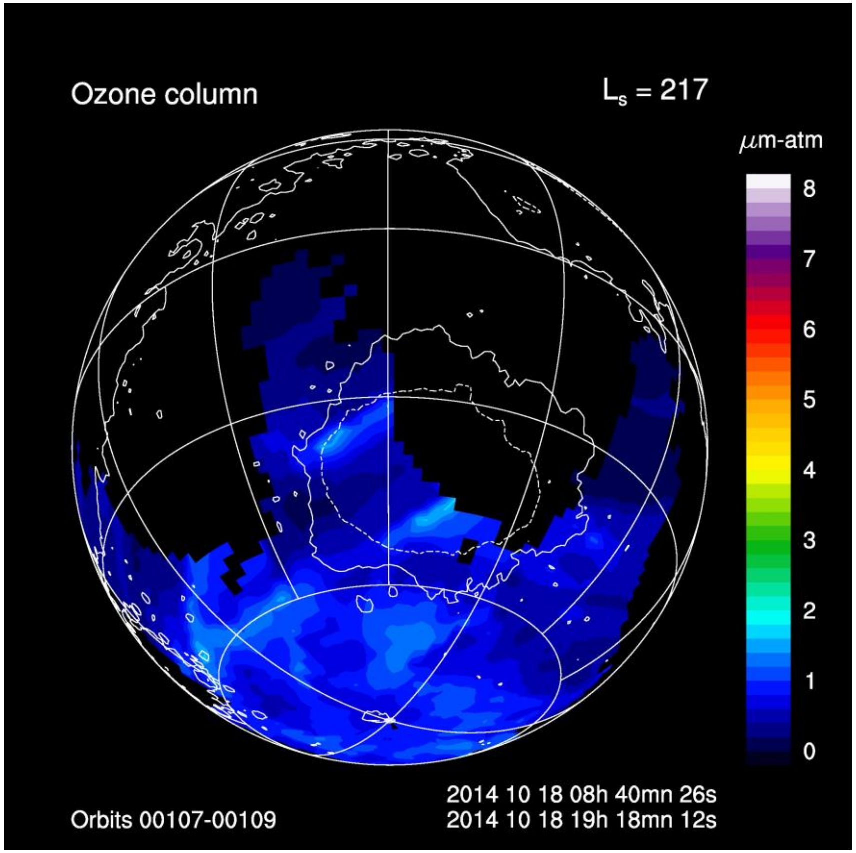
Temperatures derived from density profiles from MAVEN NGIMS and IUVS data

MAVEN temperatures combined with MRO MCS temperature profiles

(Gröller et al. 2016)

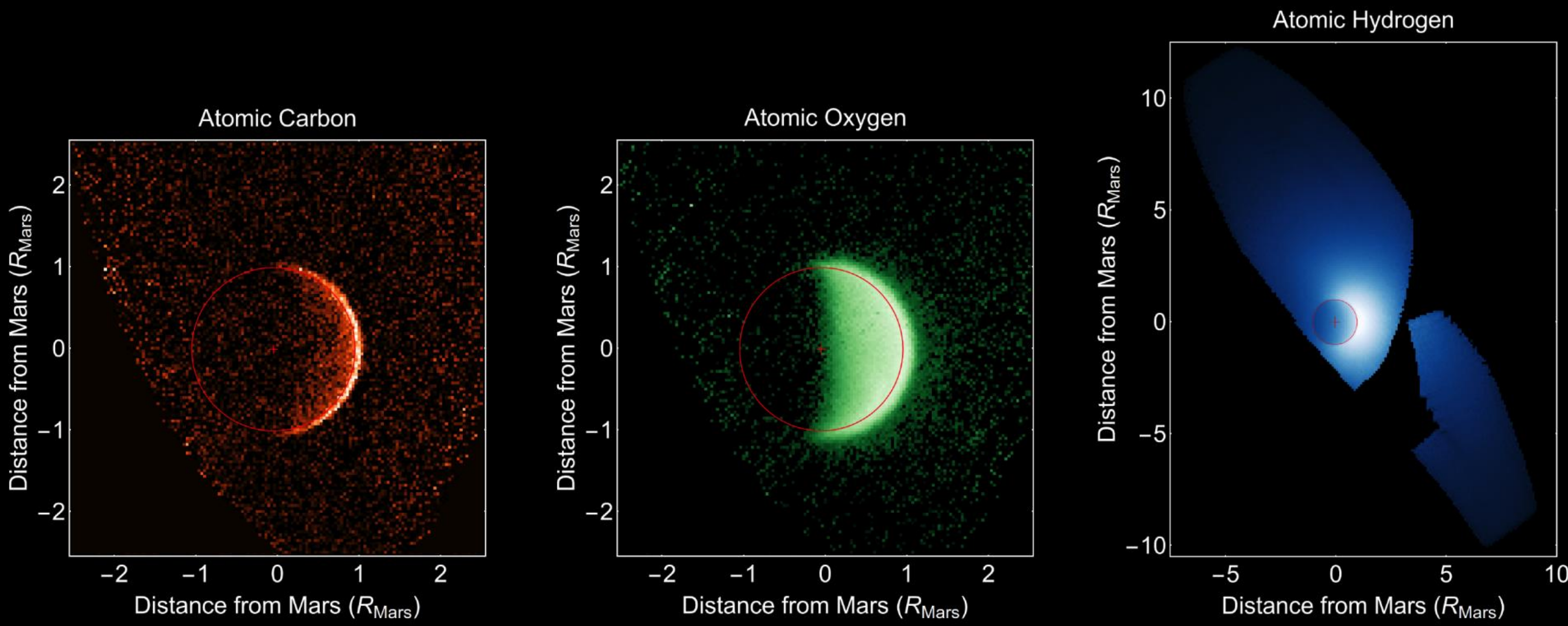
Mars Ozone Observed By IUVS



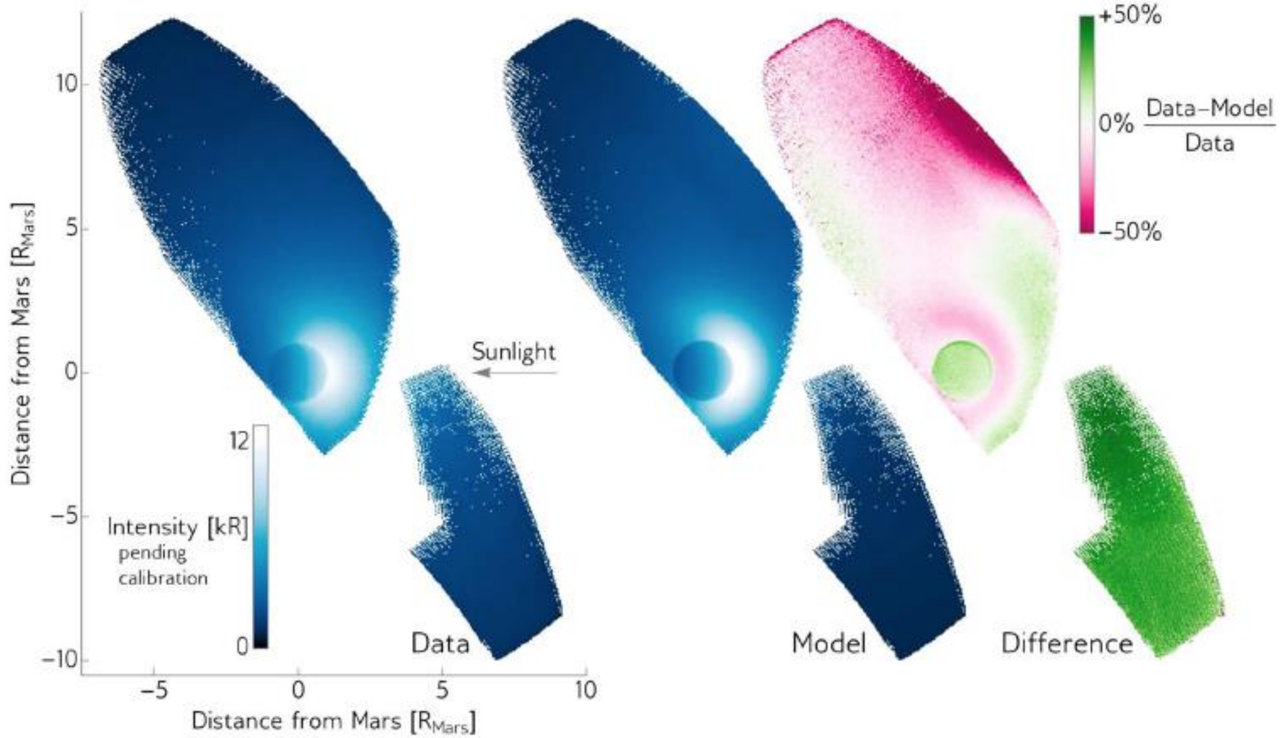


(Lefevre et al. 2016)

IUVS Observations of Atomic Components of H_2O and CO_2 on Their Way to Escaping



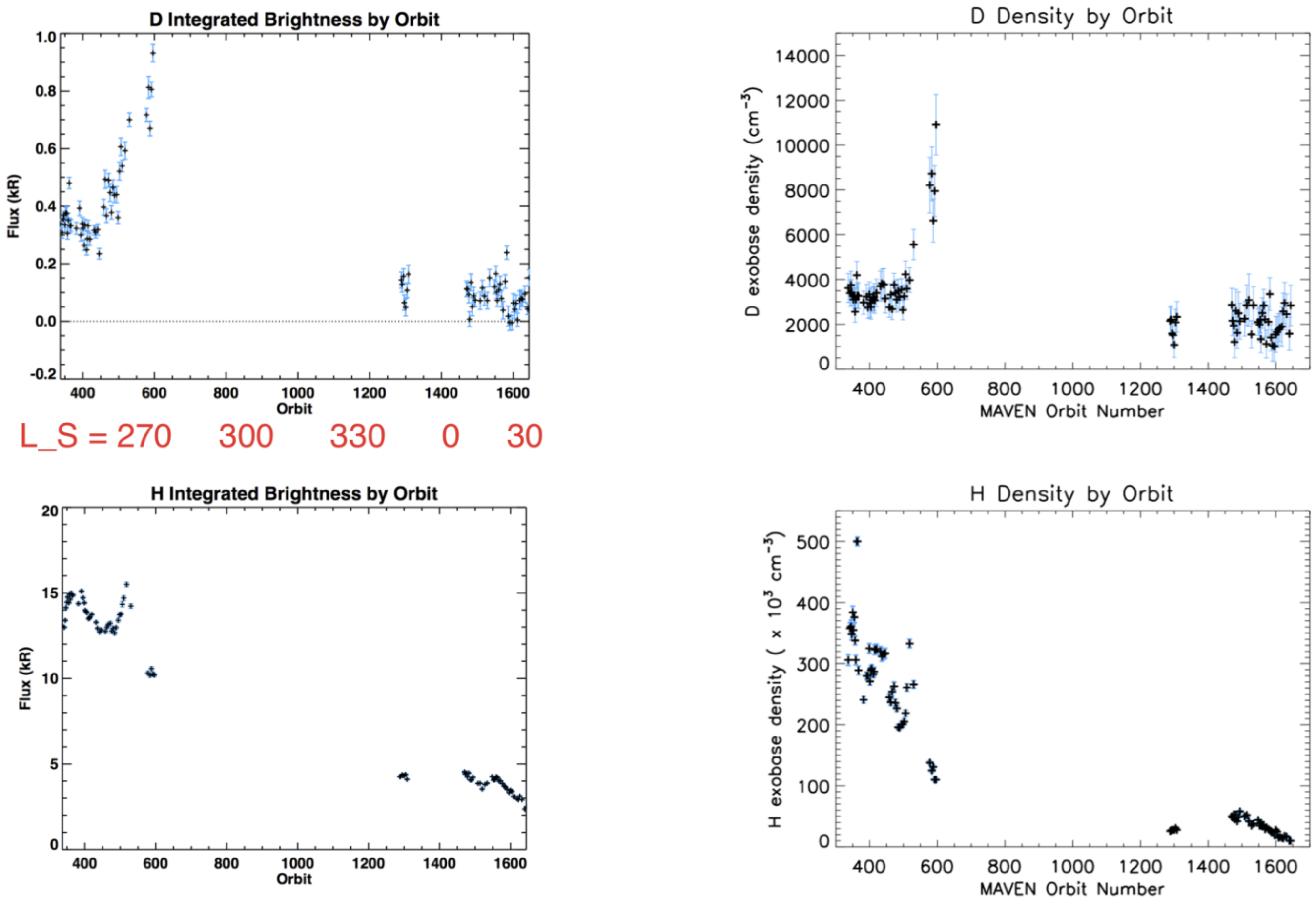
Hydrogen Distribution and Escape



- Hydrogen distribution not modeled well by single-component, spherically symmetric model
- Radiative-transfer degeneracy in terms of number density and temperature
- Analysis ongoing in order to derive unique density profile and infer escape rate

(Chaffin et al. 2015)

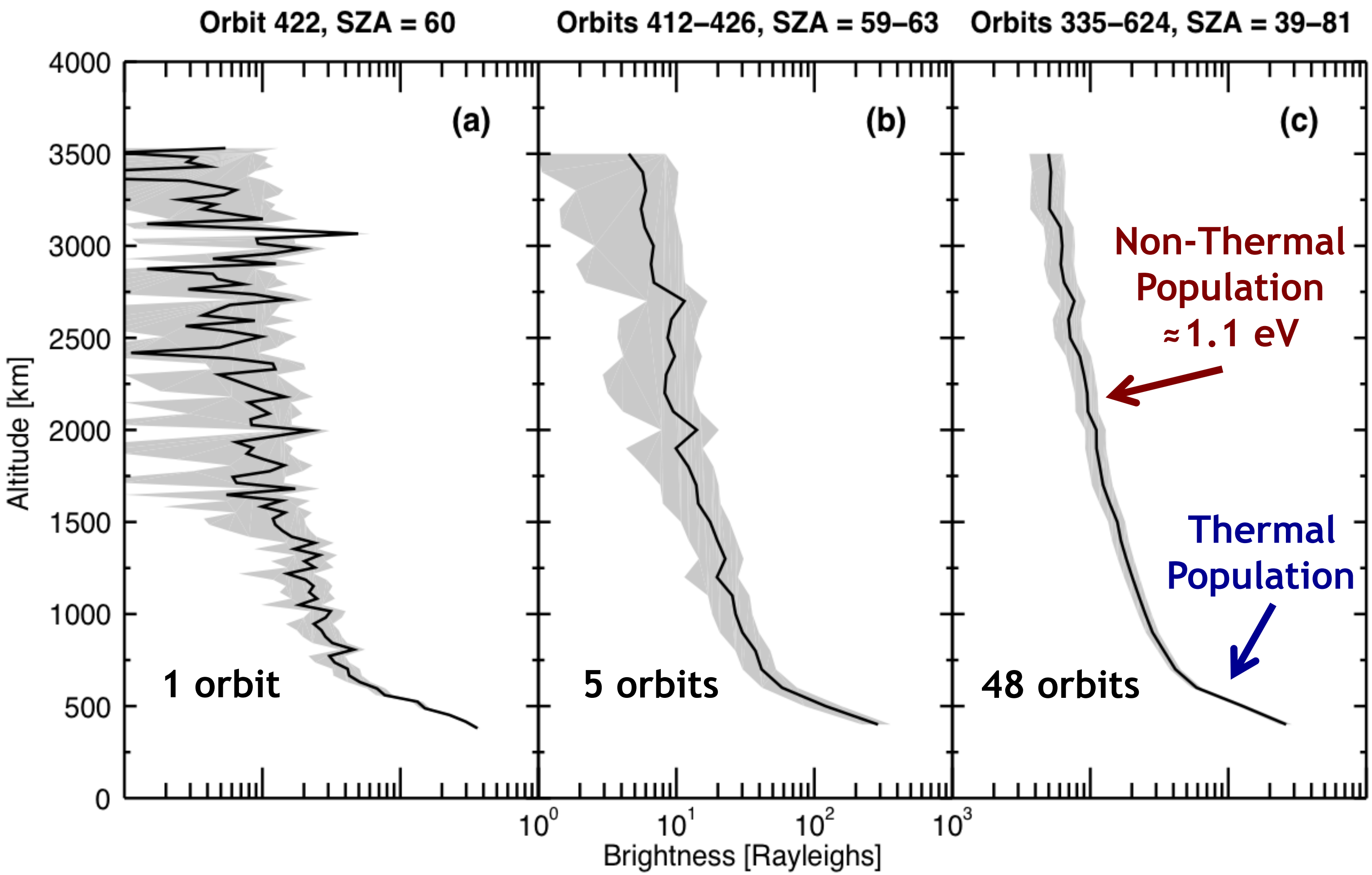
Observed Variations in Coronal D and H



- H and D appear to vary by an order of magnitude throughout mission to date
- Not predicted by any model, not understood at present
- Translates directly into variation of H and D escape rates

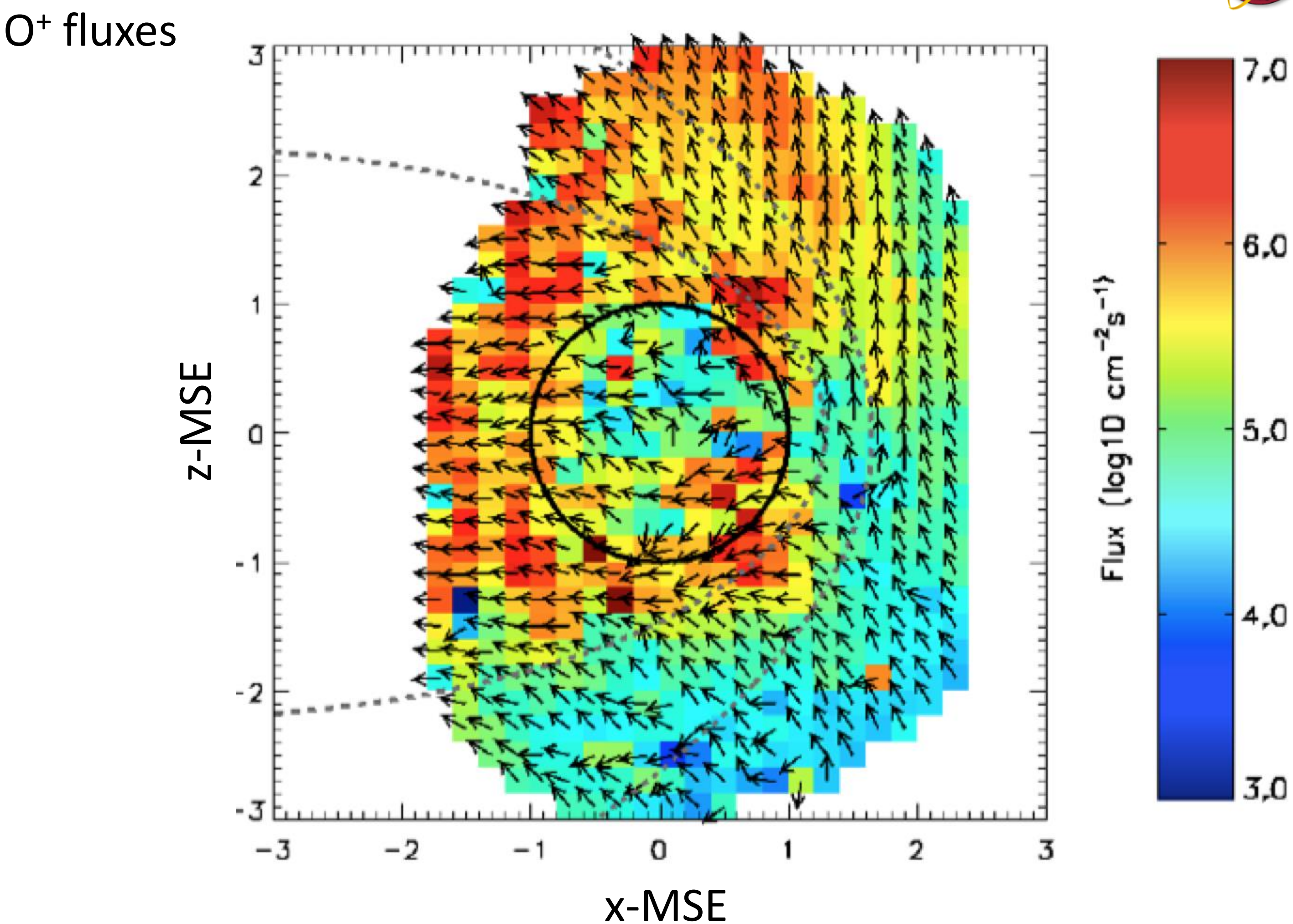
(Clarke et al. 2016)

O 130.4 nm Brightness Profiles



(Deighan et al. 2016)

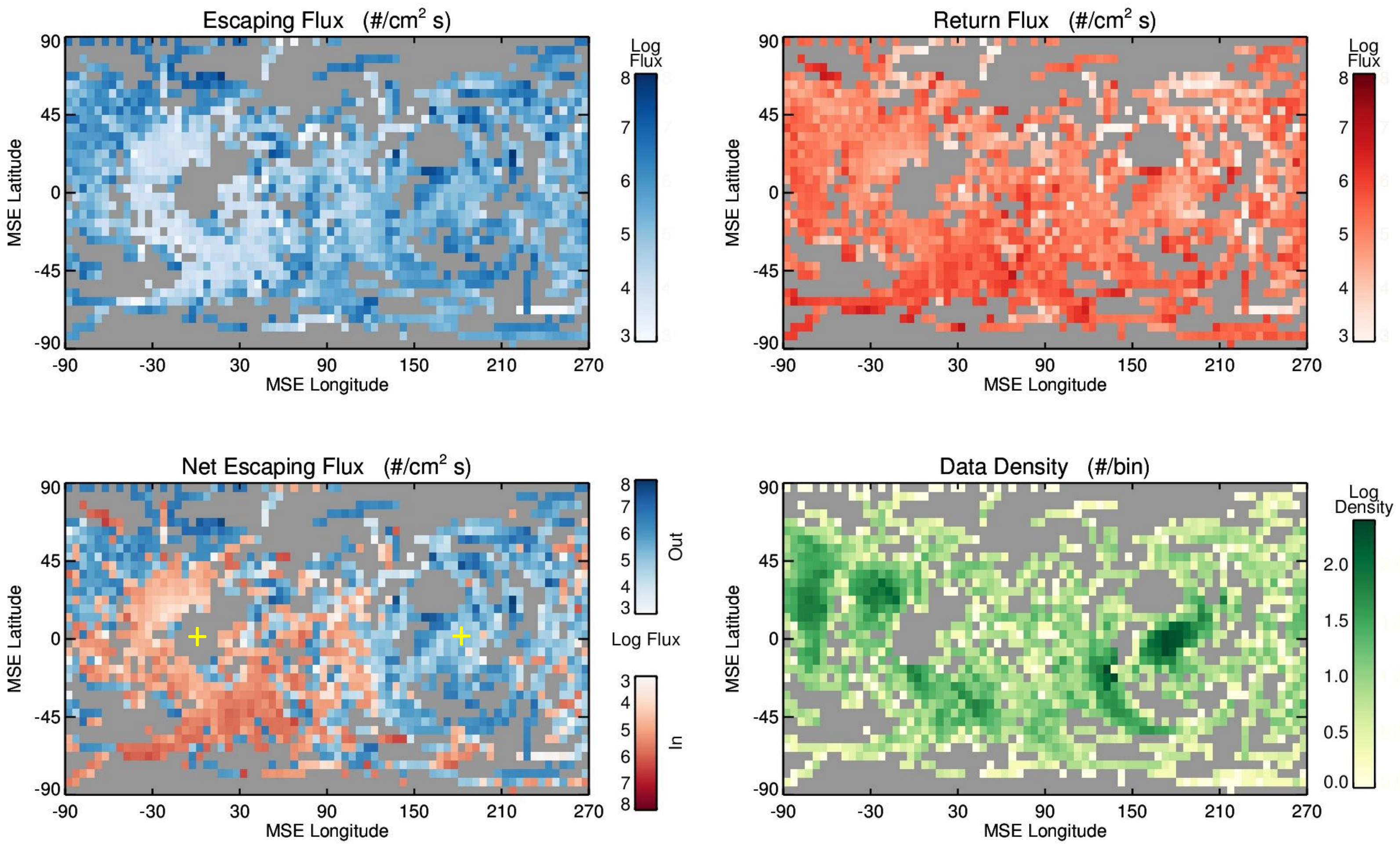
Ion Escape Driven by the Solar Wind



- Accumulation of all data shows that polar plume is a substantial and stable feature
- Accounts for significant fraction of total escape

(Dong et al. 2015)

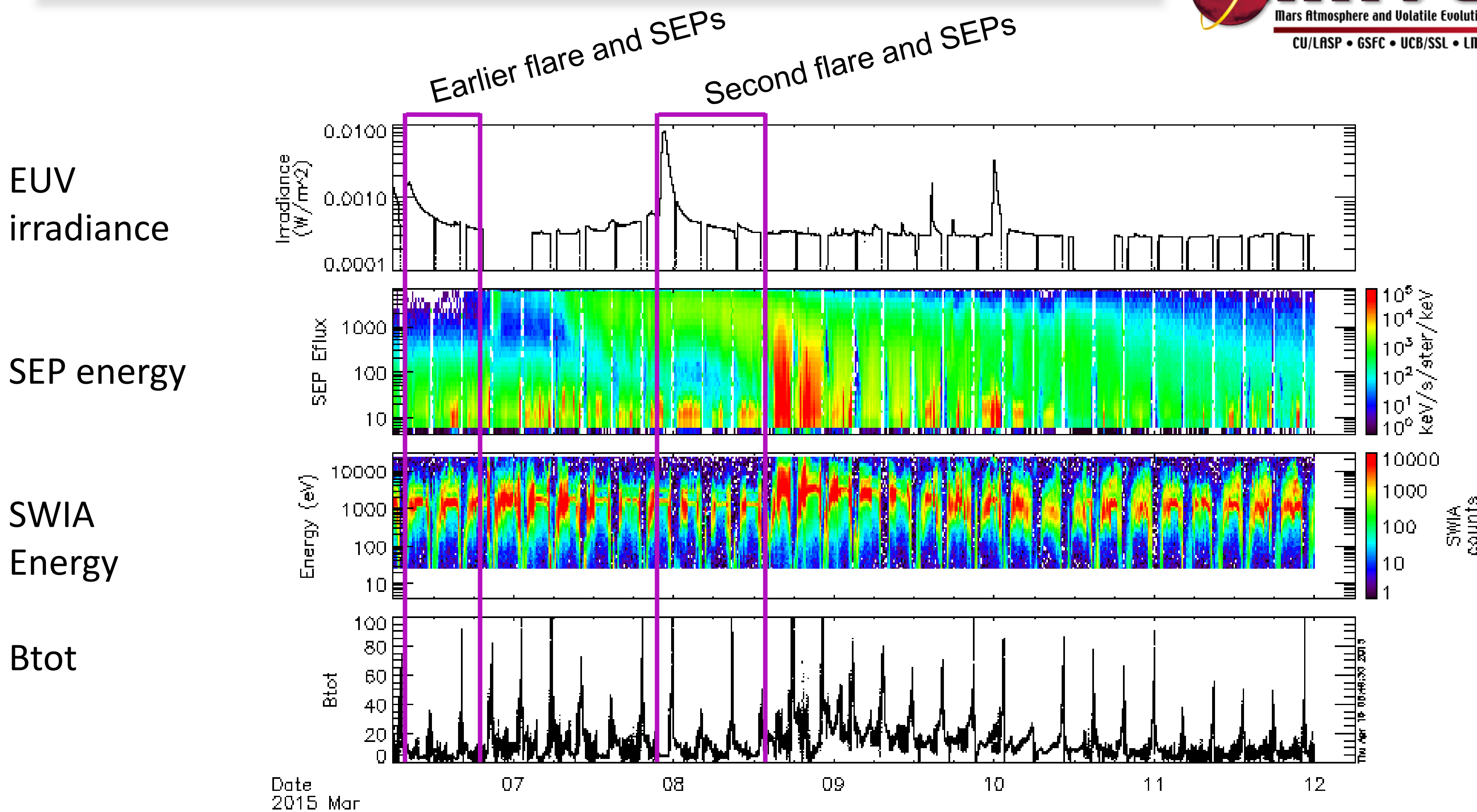
Total Escaping Flux



- Ion escape rate ~ 3 x 10^{24} s^{-1}, or ~100 g/s
- Not expected to be constant through time

(Brain et al. 2015)

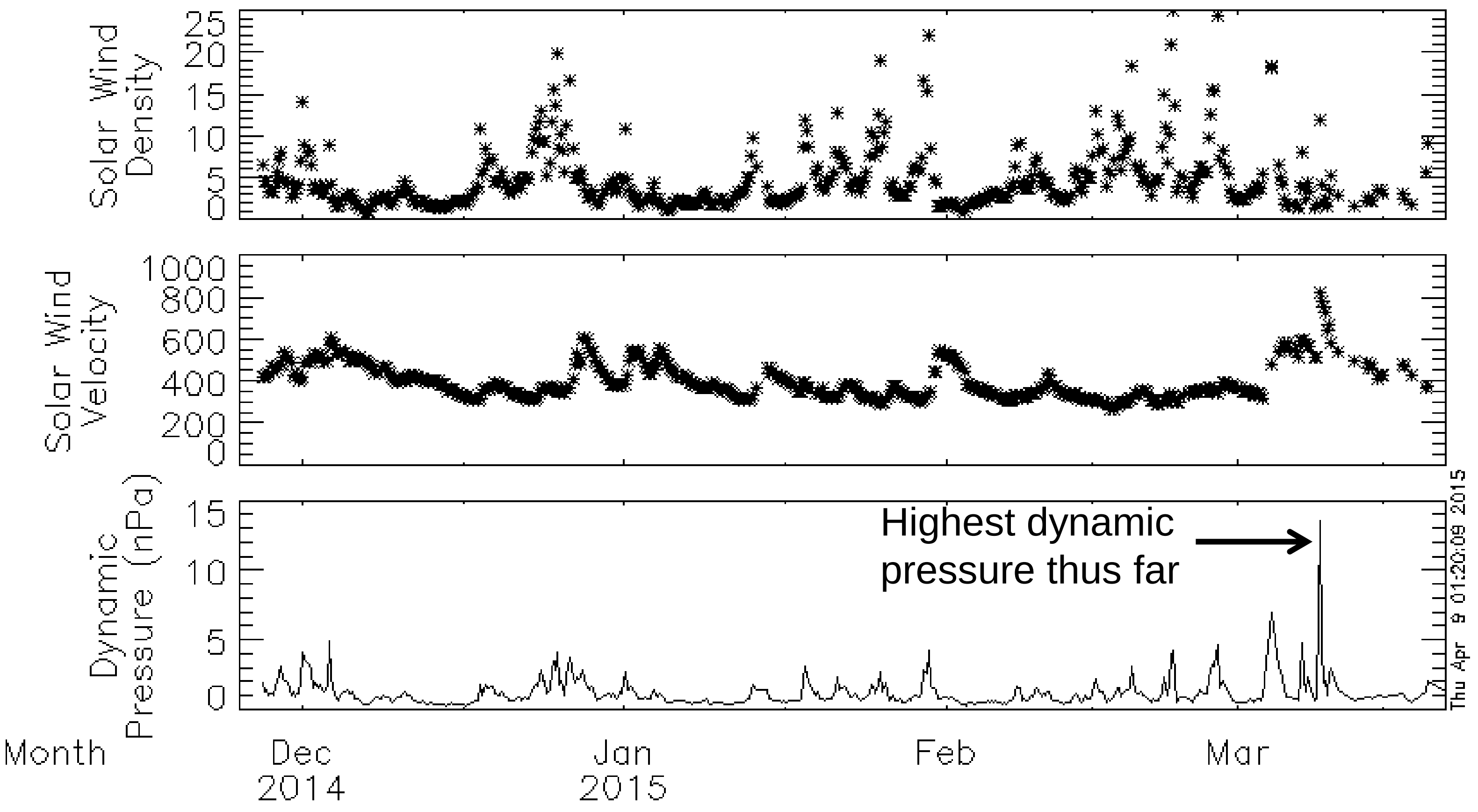
Determining the Effects of Solar Storms



- Three solar events occurred, on March 1st, 6th, then 8th
- March 8 event was largest, but complicated by preceding events
- Flare and CME also observed by SOHO
- Examine energy input, atmospheric response

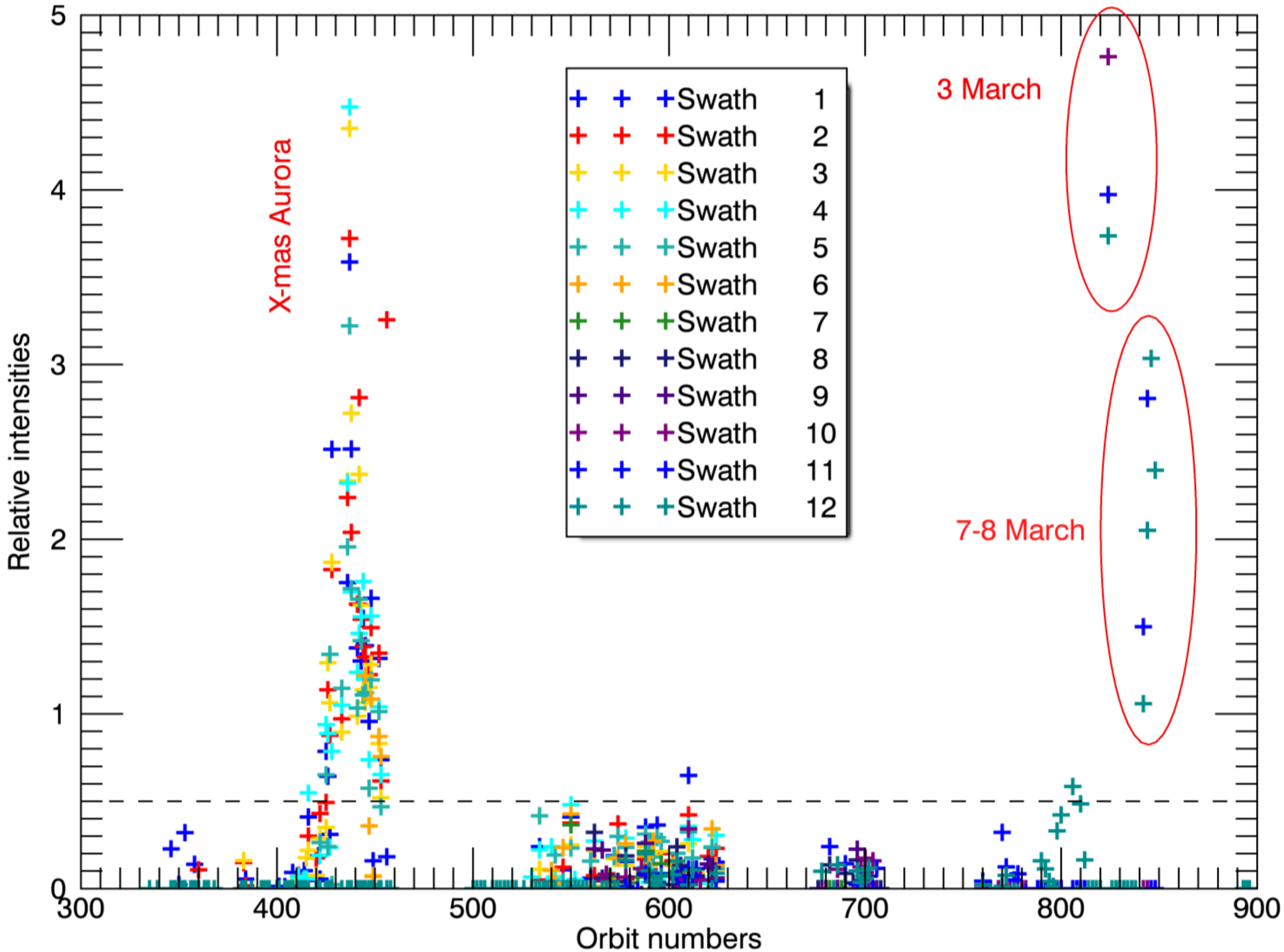
(Jakosky et al. 2015)

Increased Dynamic Pressure of Solar Wind

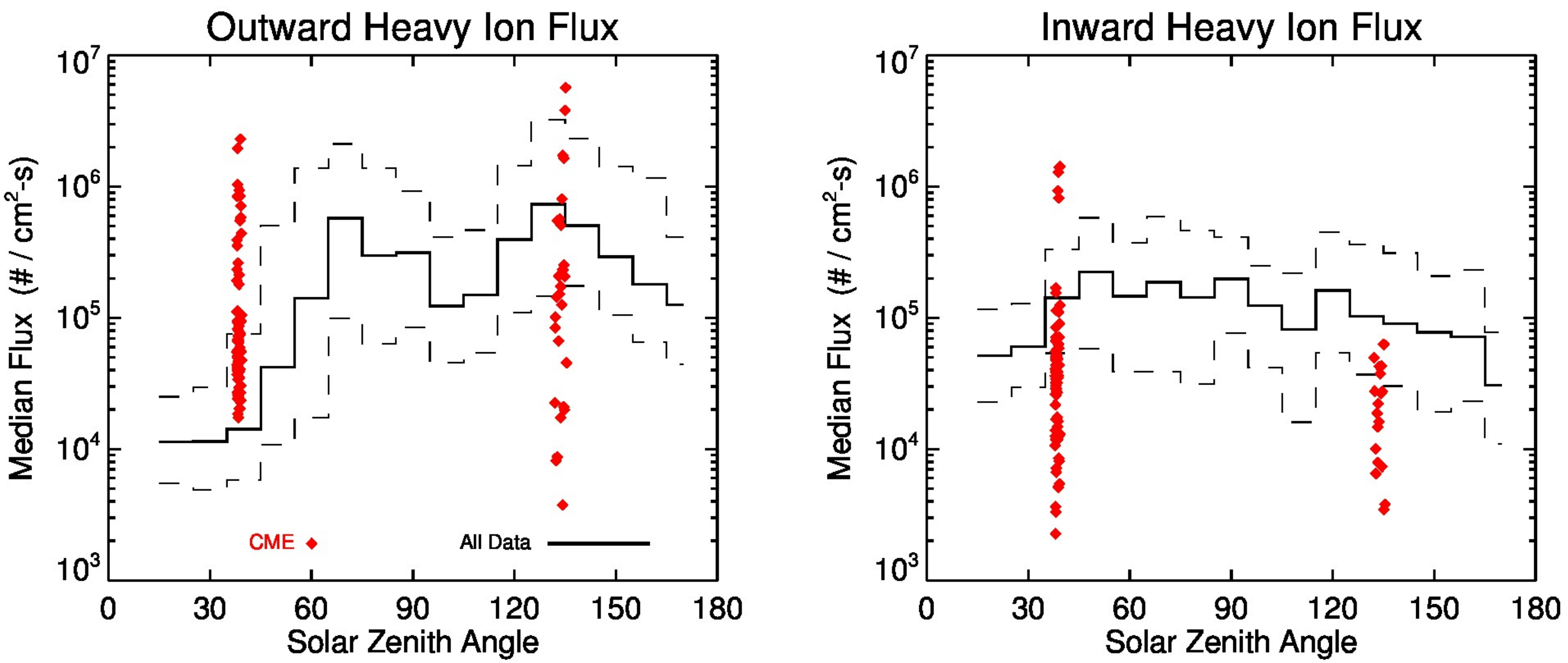


Aurora Triggered by Both Events

…and compared to the earlier "Christmas lights" aurora

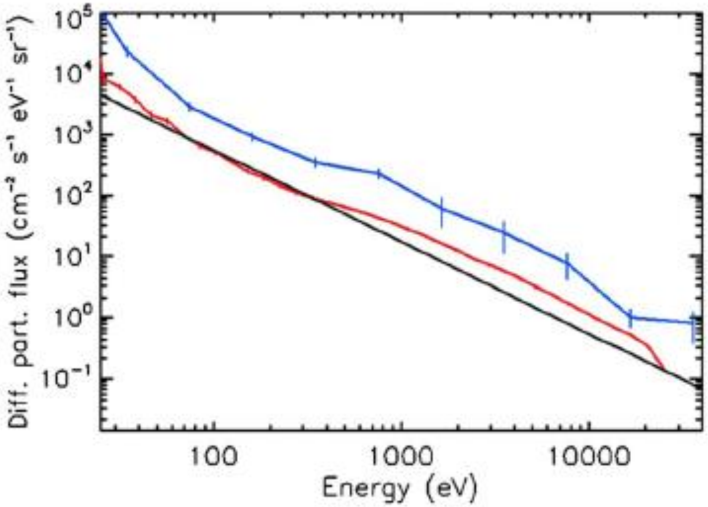


Enhanced Loss Resulting From ICME

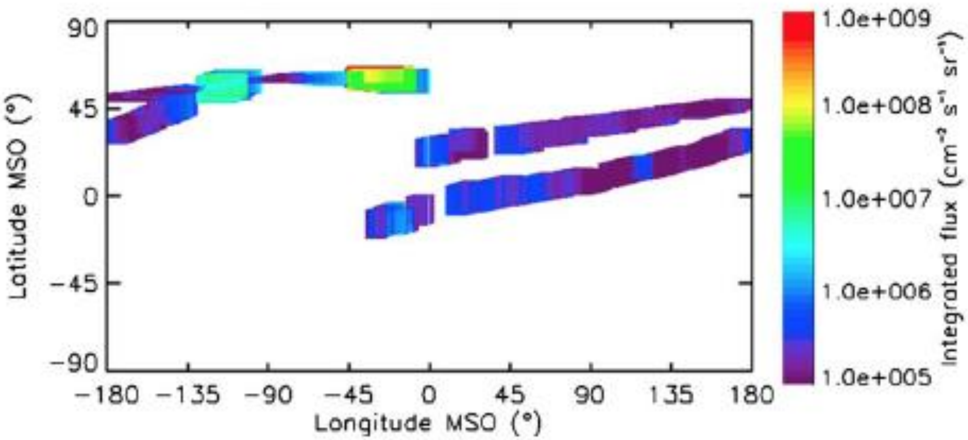


- Limited geographic coverage during ICME precludes unique determination of total escape, integrated over all angles
- Measurements indicate minimal change to tailward flux, and significant enhancement of flux on sunward side

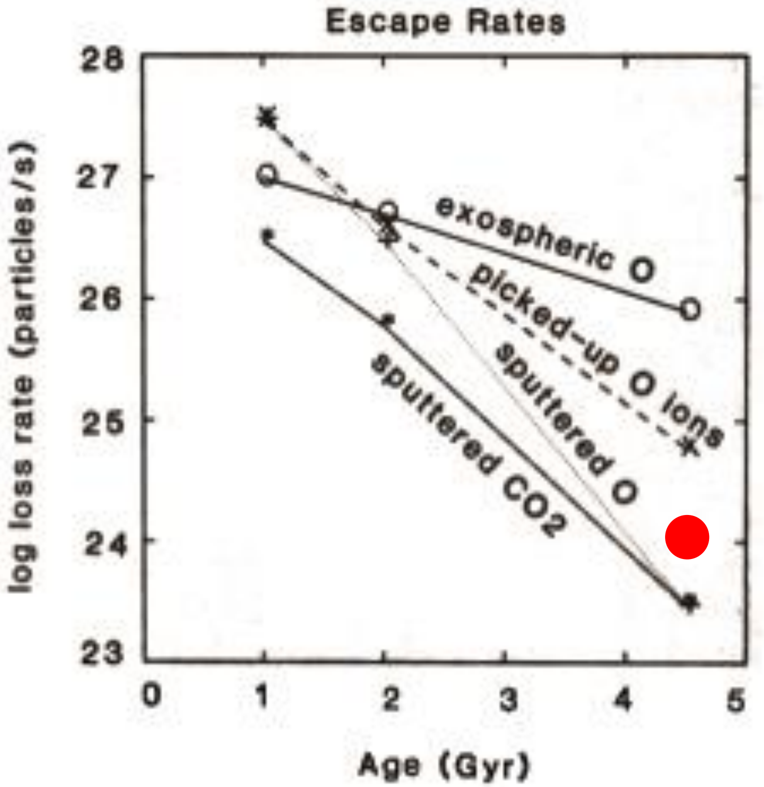
Loss Resulting From Sputtering



Energy spectrum of precipitating ions from STATIC (blue) and SWIA (red)



Spatial distribution of sputtered ion flux



MAVEN sputtering estimate (red dot) superimposed on Luhmann et al. model of escape history

(Leblanc et al. 2015)

Ratio of $^{38}Ar/^{36}Ar$ Provides Integrated Sputtering Loss to Space (1 of 2)

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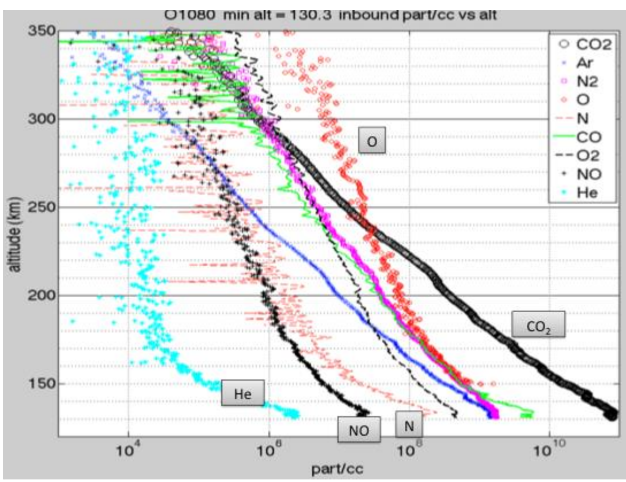
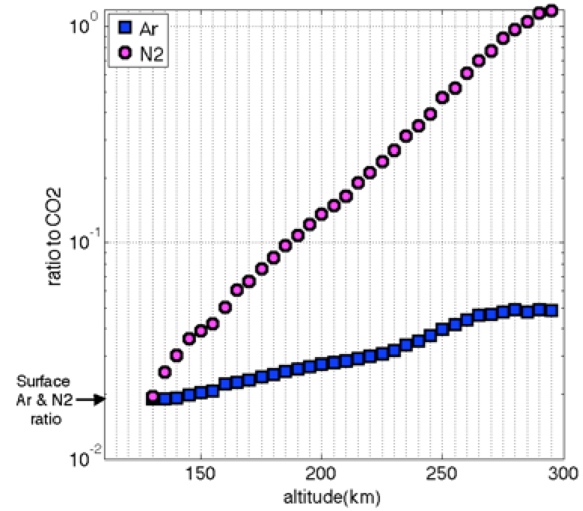
Diffusive separation above homopause enriches ^{36}Ar relative to ^{38}Ar at exobase, such that sputtering loss preferentially removes the lighter isotope.

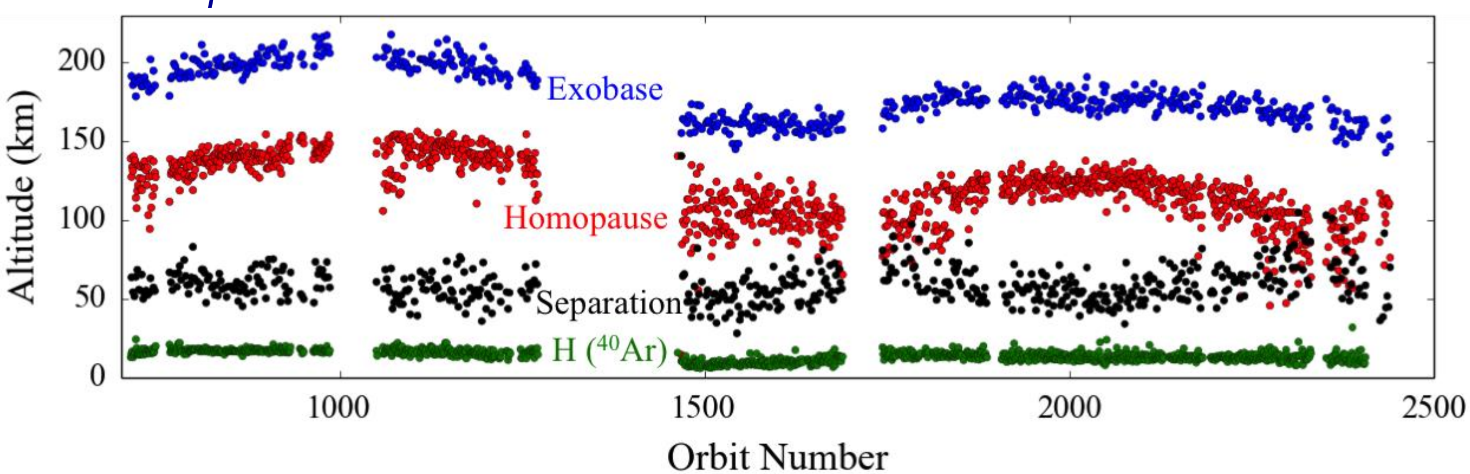
Representative Orbit:



Homopause Altitude:

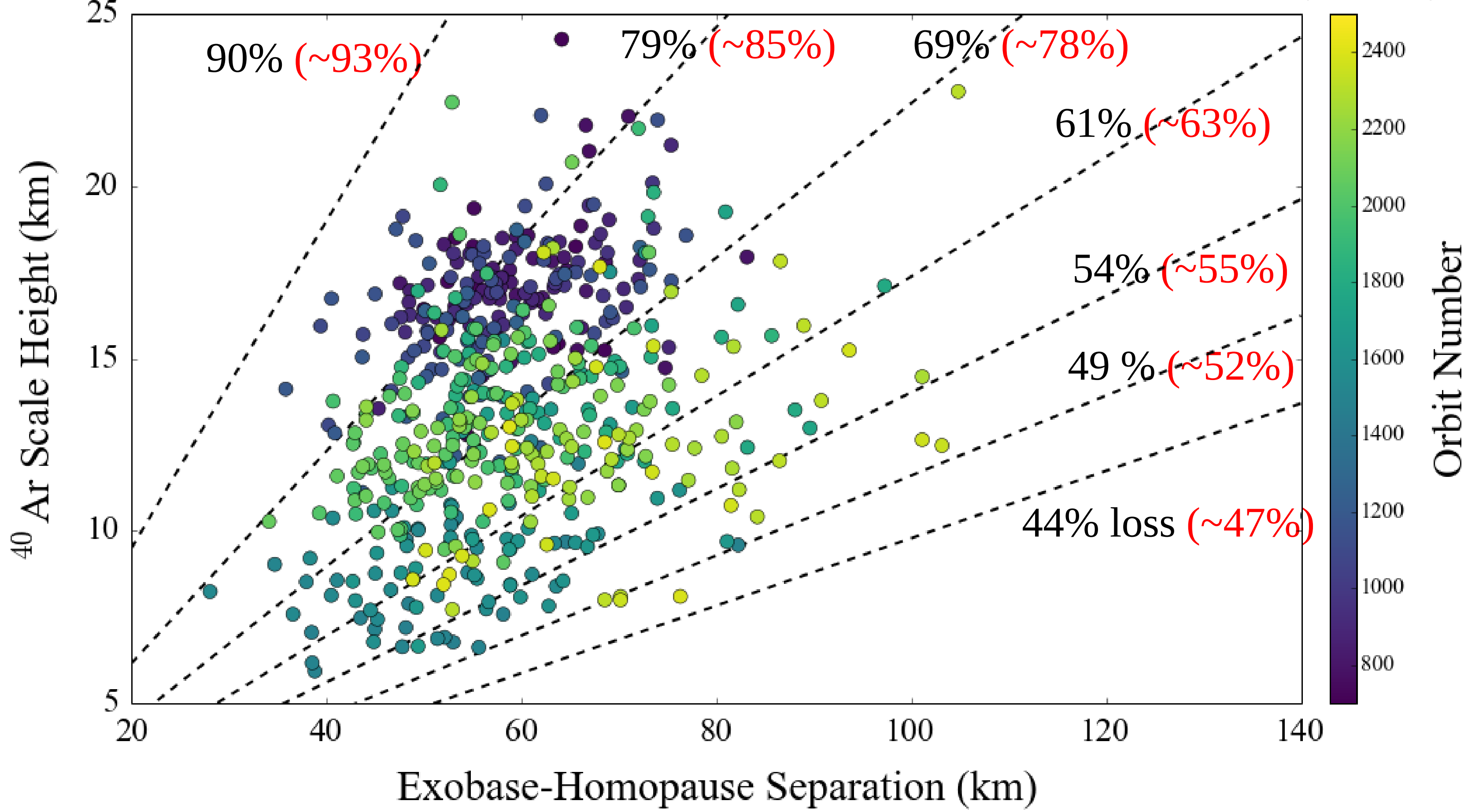


Exobase and Homopause Altitudes:



(Mahaffy et al. 2015; Jakosky, Slipski, Alsaeed 2016)

Ratio of $^{38}Ar/^{36}Ar$ Provides Integrated Sputtering Loss to Space (2 of 2)

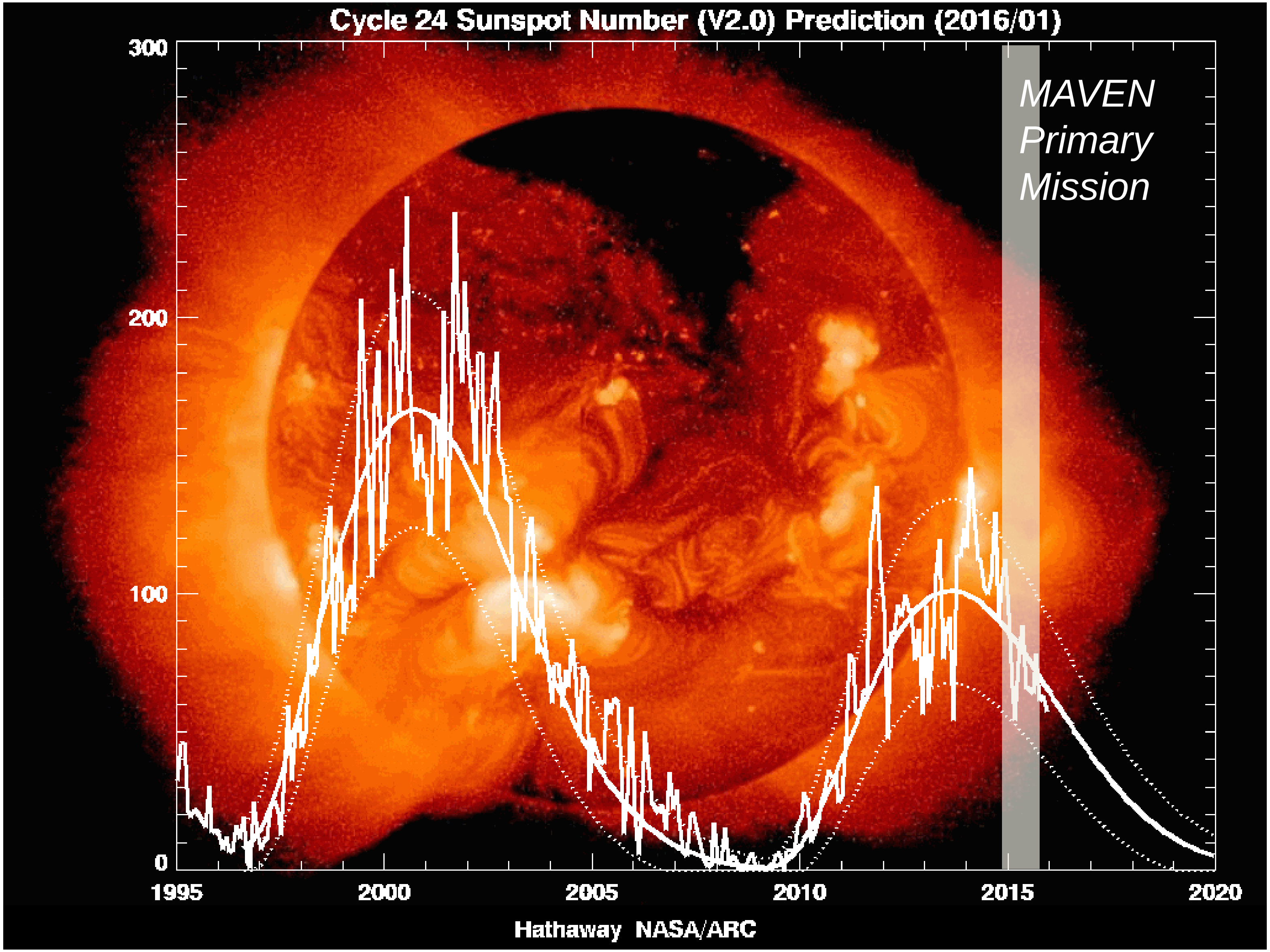


Fractional ^{36}Ar loss derived from measurements:

Black, calculated assuming simple Rayleigh distillation

Red, incorporating supply/loss from impacts, outgassing, and crustal erosion.

MAVEN's Primary Mission Occurs on the Declining Phase of the Solar Cycle



MAVEN Status Summary

- The MAVEN spacecraft and instruments are operating nominally and are providing high-quality data.
- MAVEN is defining the basic characteristics of the Mars upper-atmosphere / ionosphere / magnetosphere system, escape rates at the present epoch, and the processes controlling them.
- Results tell us that loss to space was a major mechanism for the changes in the Mars atmosphere and climate through time.
- Primary mission was completed mid-November, 2015; initial results were published in November in *Science* and *GRL*.
- Continuing observations are allowing us to understand behavior through a Mars year and with variations in the solar-cycle drivers.