MAVEN

Mars Atmosphere and Volatile Evolution Mission

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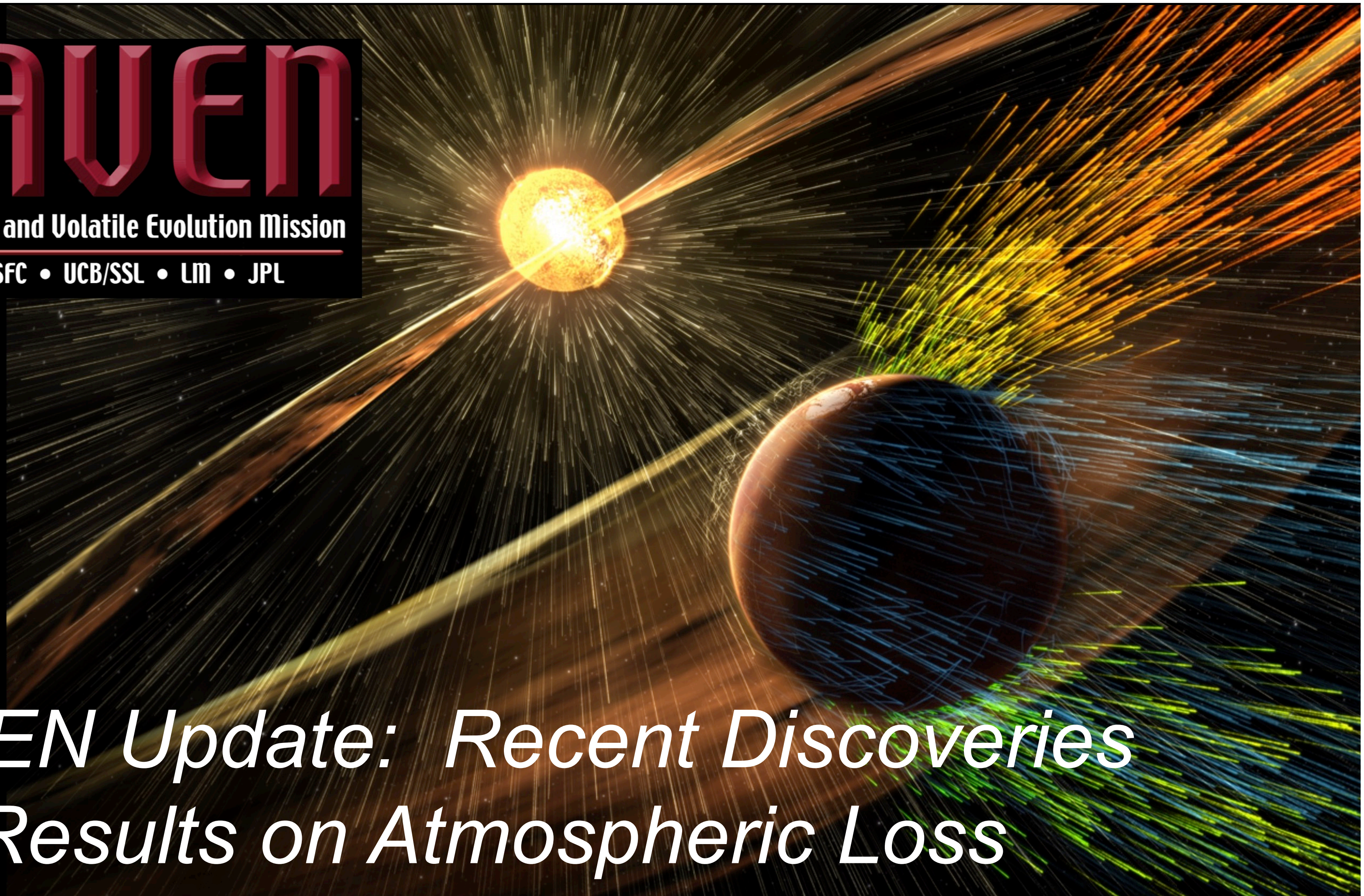


MAVEN Update: Recent Discoveries and Results on Atmospheric Loss

Bruce Jakosky and the MAVEN Science Team

MEPAG Meeting, 22-23 Feb. 2017

MAVEN Objectives And Status

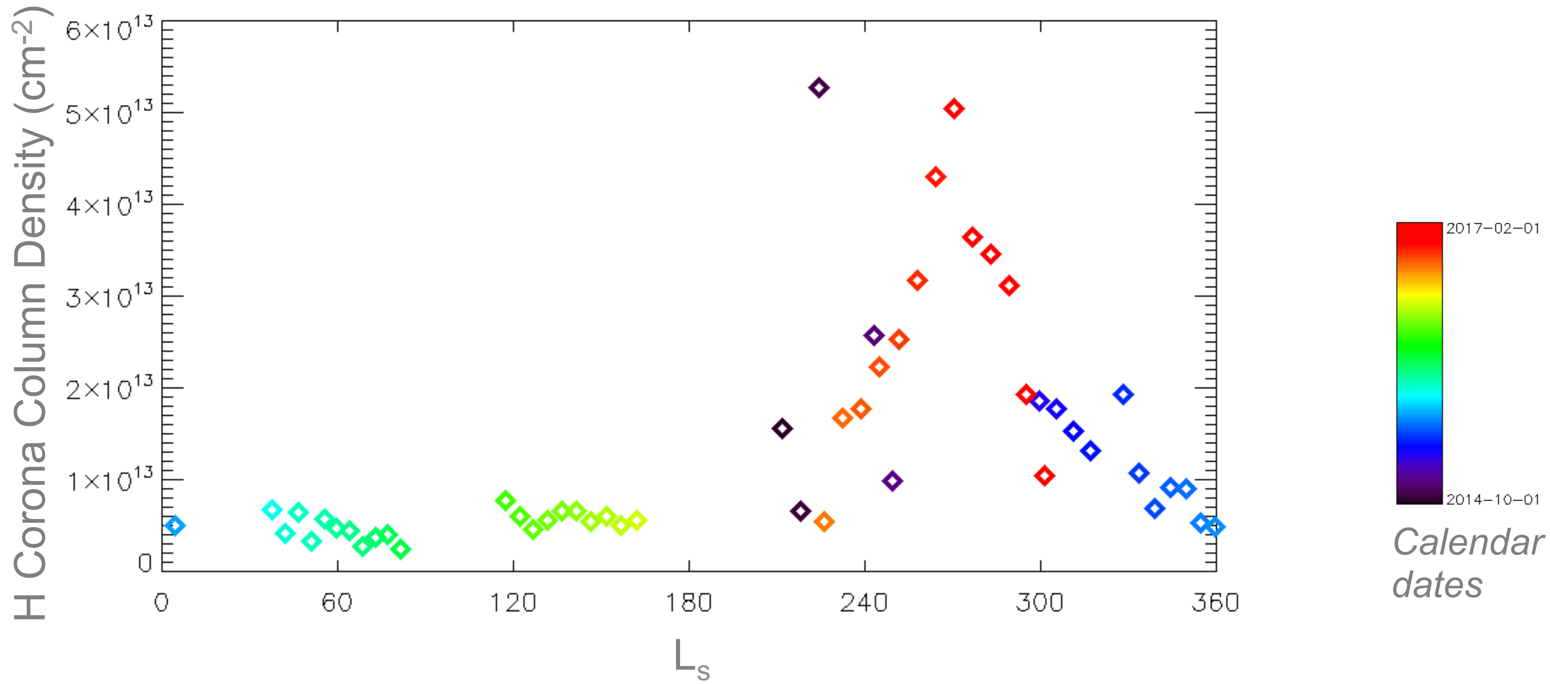
Science Objectives:

- Understand the behavior of the upper atmosphere at the present
- Determine today's rates of loss of atmospheric gas to space and processes controlling them
- Extrapolate to long-term behavior of loss to space

MAVEN Status:

- In orbit since September 2014
- Spacecraft and instruments all operating nominally
- New observations implemented for current Extended Mission
- Fuel to last possibly as long as a decade
- Long-term implementation for relay support under discussion

Characterization of H Corona and H Escape

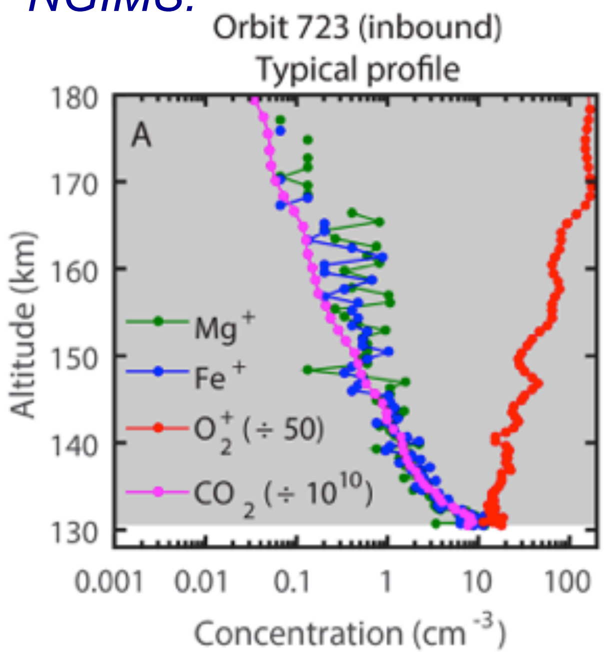


- Observed by SWIA based on incoming solar-wind protons that "charge exchange" with neutral corona; determination of integrated H column in corona; also observed by IUVS
- Corona density controls escape rate
- Order-of-magnitude seasonal variation seen; likely results from dust-driven temperature changes that allow water to rise higher into atmosphere and supply H corona more easily
- Better characterization than variations seen by *HST* and *Mars Express*

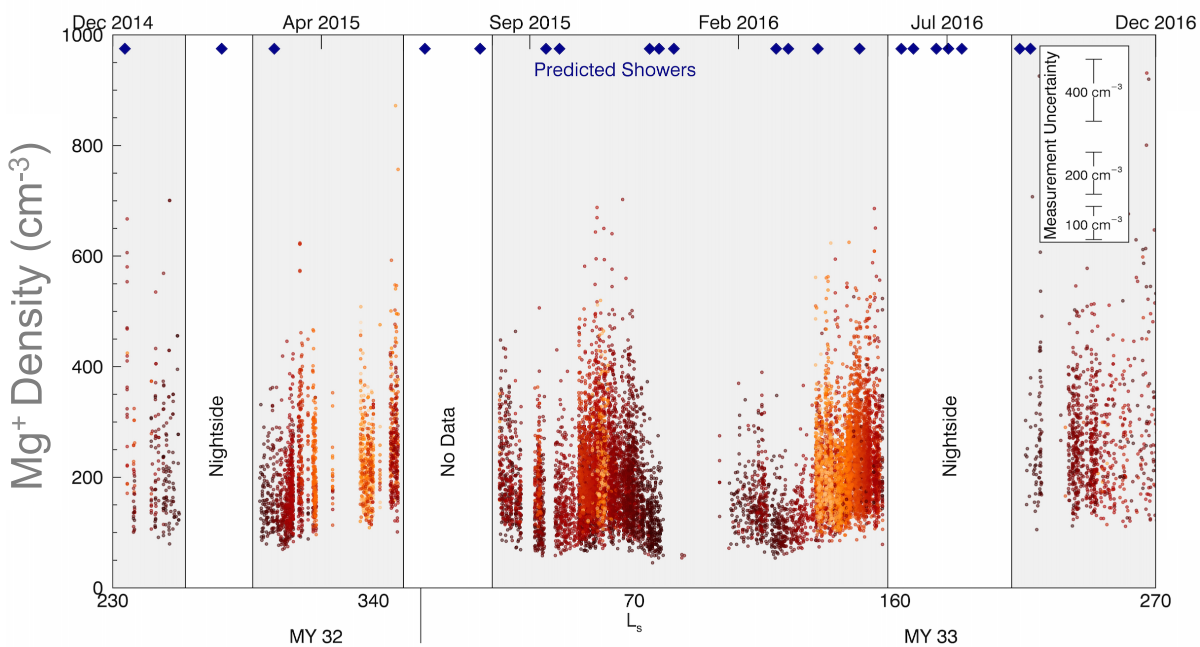
(J. Halekas, M. Chaffin)

Discovery Of Long-Lived Metal-Ion Layer In The Ionosphere

NGIMS:



IUVS:

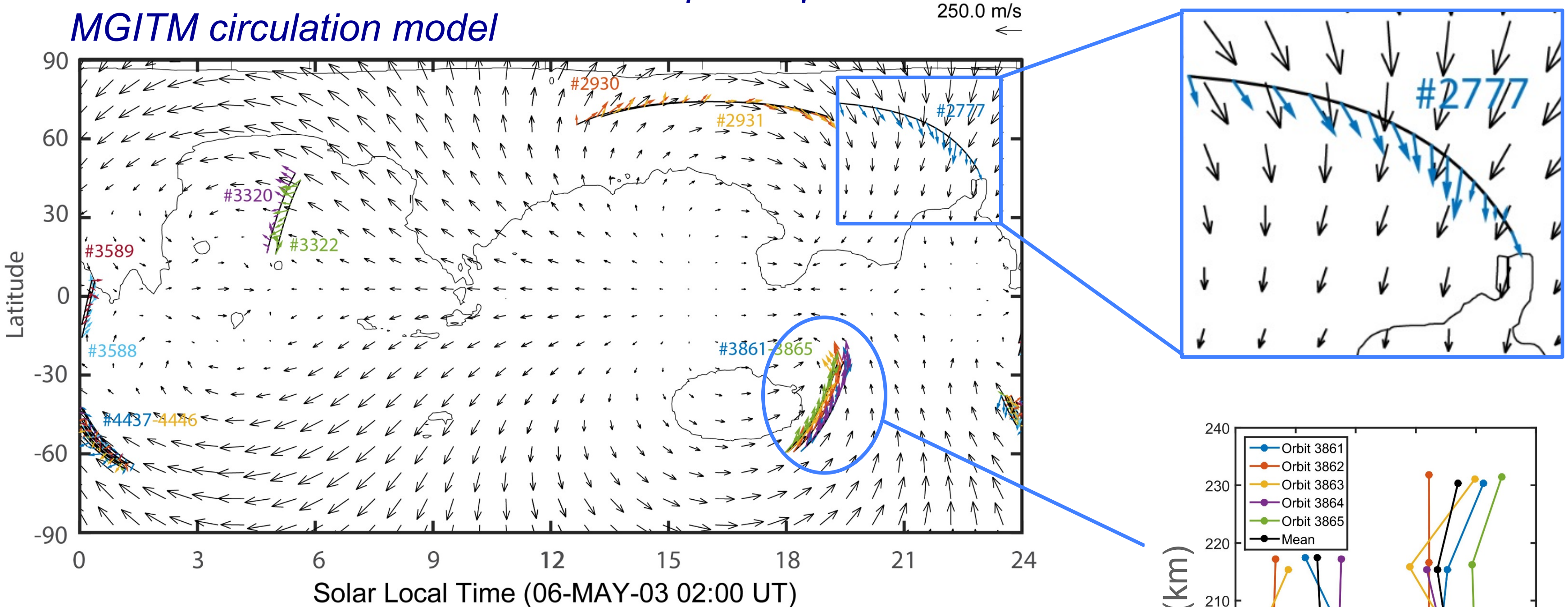


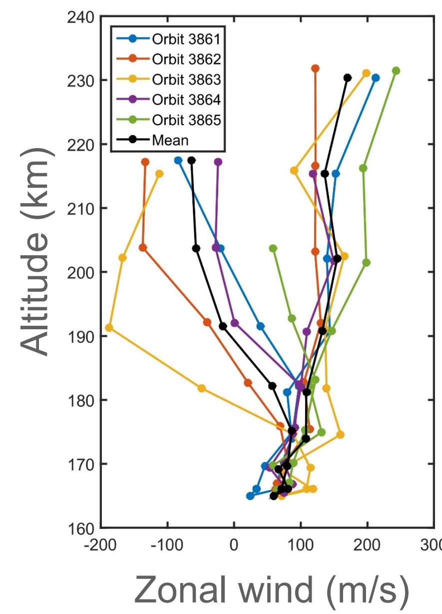
- Metal ions detected in ionosphere – originally discovered associated with Comet Siding Spring, but now detected continually throughout mission
- Observed *in situ* with NGIMS, remotely via scattered sunlight by IUVS
- Source is interplanetary dust from comets/asteroids
- May be important in driving chemical reactions and in dust providing cloud condensation nuclei, similar to on Earth

(J. Grebowsky, M. Crismani, N. Schneider)

NGIMS Measurement of Neutral and Ion Winds

Neutral wind measurements to date plus representative MGITM circulation model

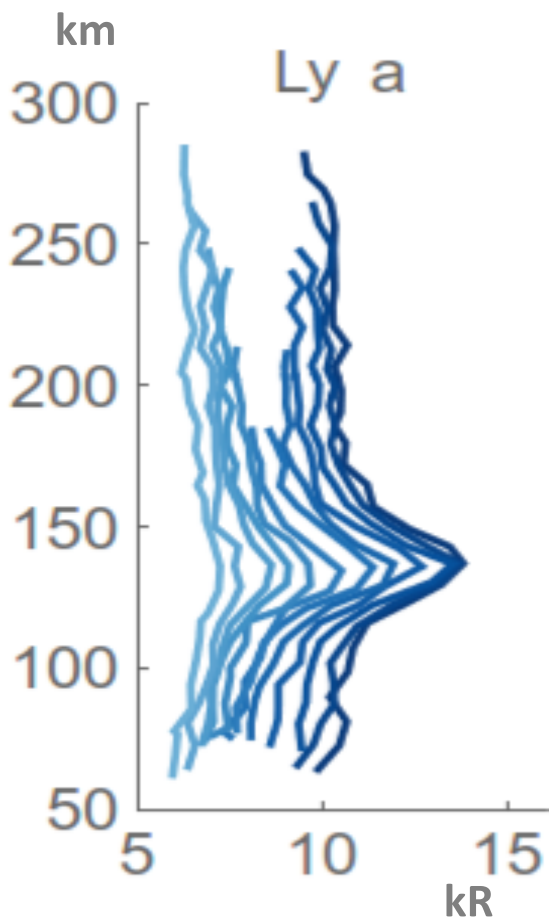


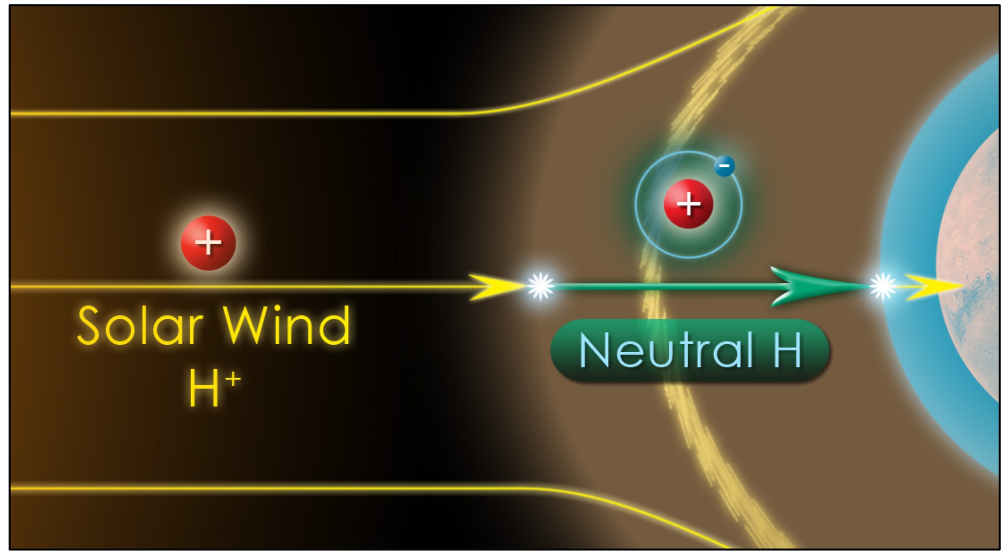


- NGIMS yaws left/right during periapsis pass to derive winds, implemented on all orbits one day/month
- Measure both neutrals and ions, on consecutive days
- Results show both similarities to model circulation and differences, plus significant longitudinal variability
- First synoptic measurements of upper-atmospheric winds

(M. Benna et al.)

Discovery of Proton Aurora at Mars

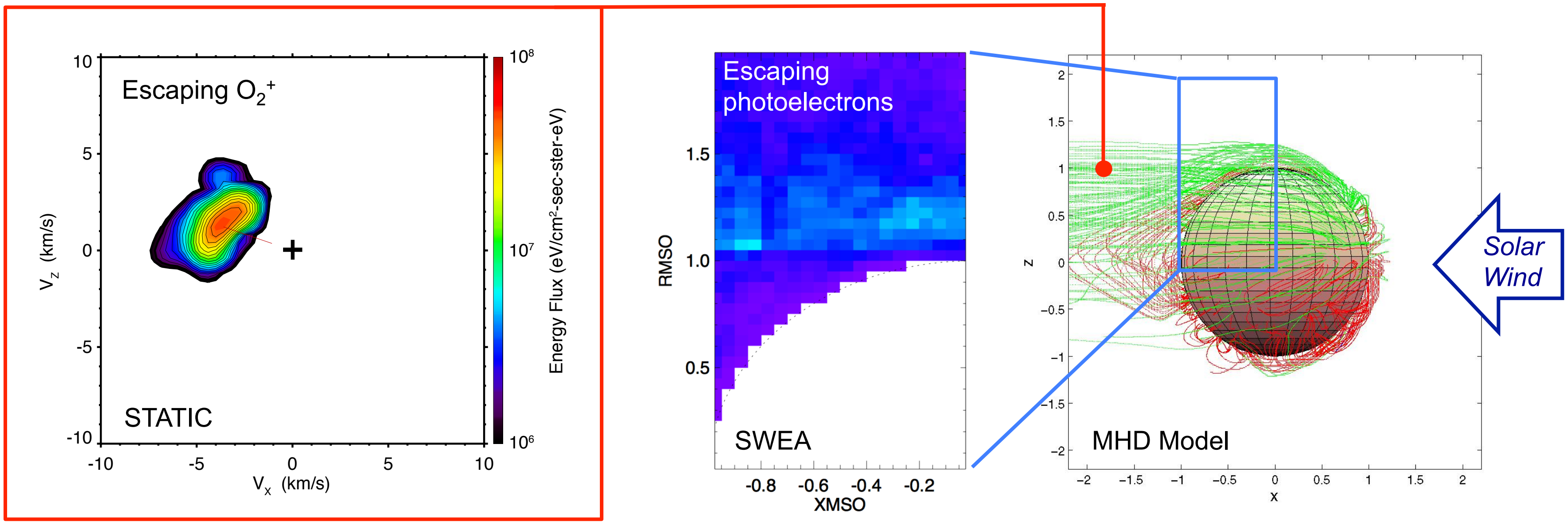




- Solar-wind protons can “charge exchange” with H in corona to become neutral, and penetrate at solar-wind speeds
- Collision with molecules in upper atmosphere induces auroral emission from incoming H atoms
- Scattering seen in H Lyman alpha profiles occurred simultaneously with penetrating high-energy solar wind protons.

(J. Deighan, N. Schneider)

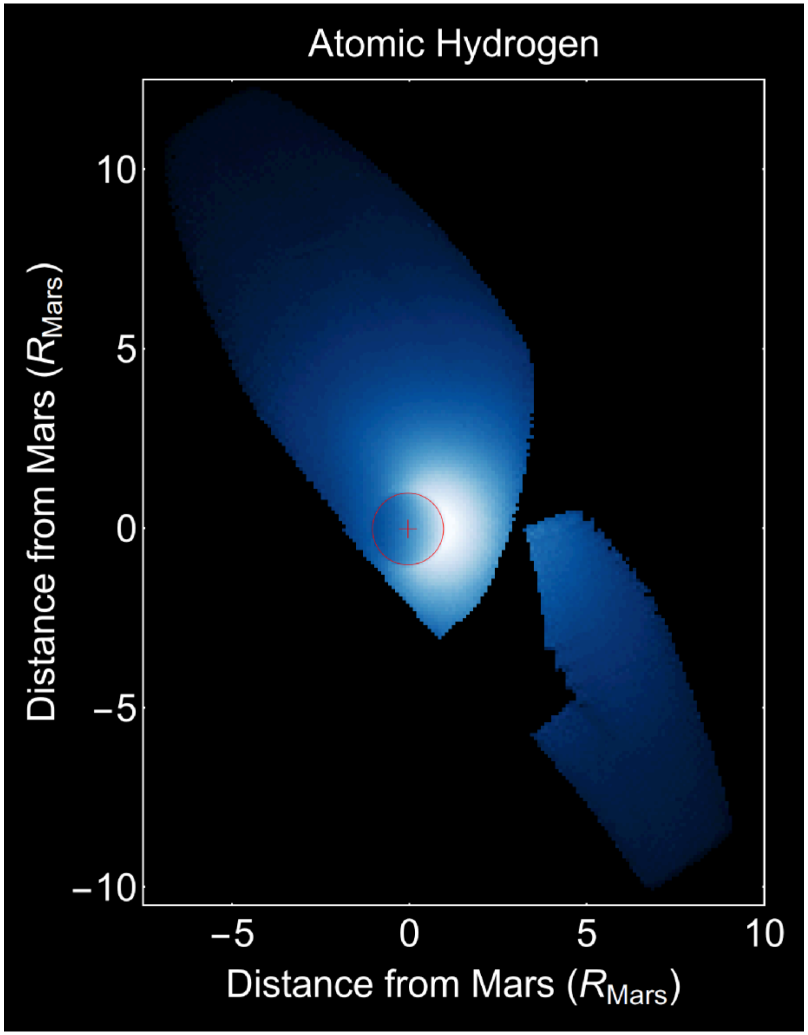
Characterizing Low-Energy (Cold) Ion Outflow



- MHD simulation (right) shows magnetic-field lines that connect to planet at both ends (red) and that are open to space at one end (green)
- Electron measurements (center) uniquely identify open field lines connected to the day-side ionosphere
- Acceleration of ions up open field lines drives low-energy outflow loss to space
- New STATIC measurements of ion velocities in this cold-ion outflow (left) show substantial loss at velocities just above Mars escape velocity
- Previously uncharacterized, this loss could dominate O_2^+ ion loss at present epoch

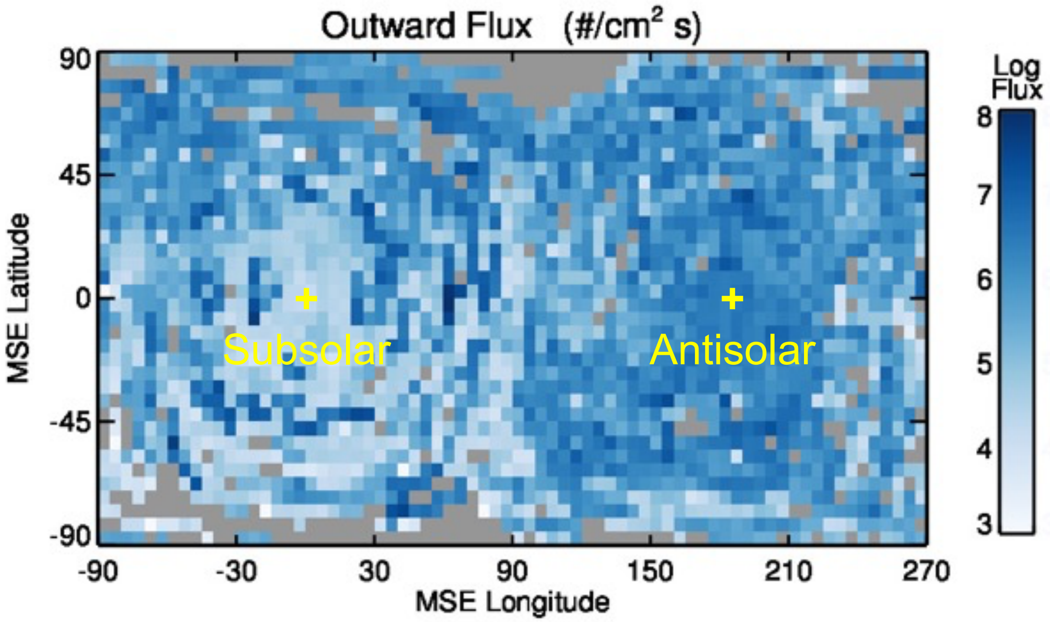
(D.L. Mitchell, J. McFadden, C. Dong)

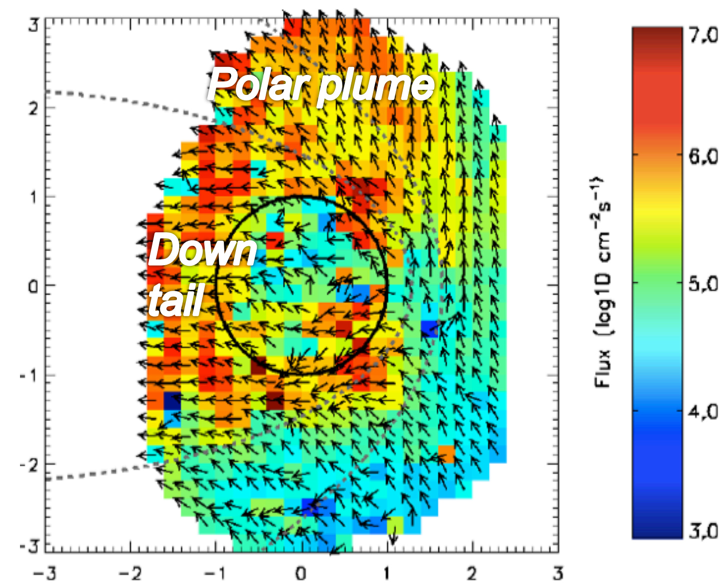
Integrated Hydrogen Loss



- H is lost by thermal (Jeans) escape from an extended corona surrounding Mars; H is derived from atmospheric H_2O
- Loss of H equivalent to atmospheric column of H_2O in $4 \times 10^3 – 4.1 \times 10^4$ years (using the extreme seasonal values of loss rates)
- At current rate, loss over 4 b.y. of ~2 - 15 m H_2O global equivalent layer
- Extrapolation difficult due to uncertain cause of present-day variability; there are reasons that loss could be greater or less than the 2-15 m estimate

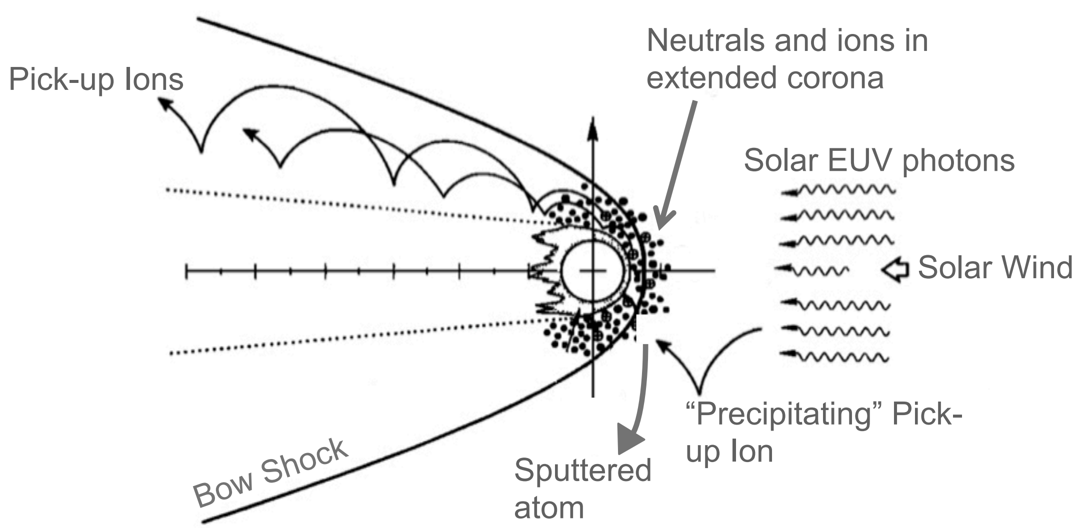
Oxygen Ion Loss

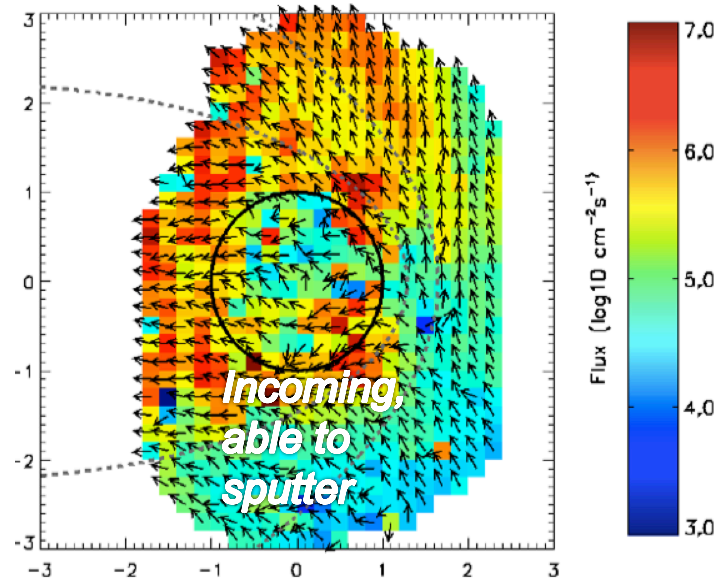




- Ions are stripped away from the upper atmosphere by the solar wind
- Loss over mission shown here in two views – mapped and projected onto plane (with Sun at the right), both sorted by solar-wind magnetic field
- Mean loss rate would remove atmospheric O (mainly from CO_2) in ~2 b.y.
- Modeled extrapolation into past based on greater EUV flux early in history that drives much greater loss
- Estimated loss as high as ~0.4 bar CO_2 equivalent

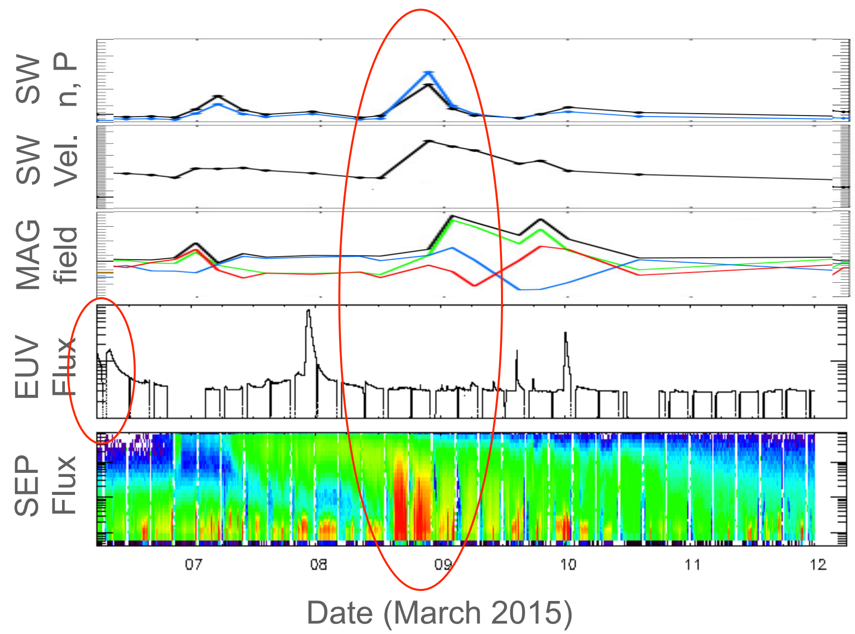
Sputtering Loss of O





- Oxygen ions get picked up and accelerated by solar wind
- Those picked up upstream of Mars get accelerated into Mars' upper atmosphere, and can physically knock other atoms and molecules out
- Loss at present epoch ~10x less than for O ion loss; not significant today
- Loss rate early in history as much as 10^4x greater
- Integrated loss of >0.6 bar CO_2 equivalent

Loss During Solar Storm (Space Weather) Events



- Example solar event hitting Mars, with MAVEN measuring all pertinent parameters
- Escape enhanced by ~20x for this moderate event, shown both in data and in MHD models of loss
- Solar events likely to have been stronger and more abundant early in history, and storm-induced loss could dominated total loss

Summary Of Atmospheric Loss To Space

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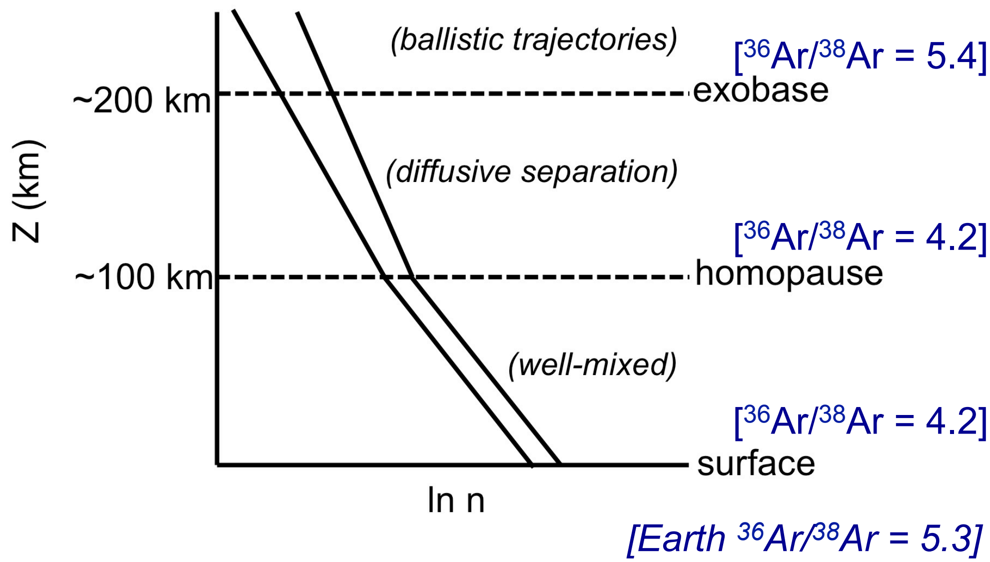
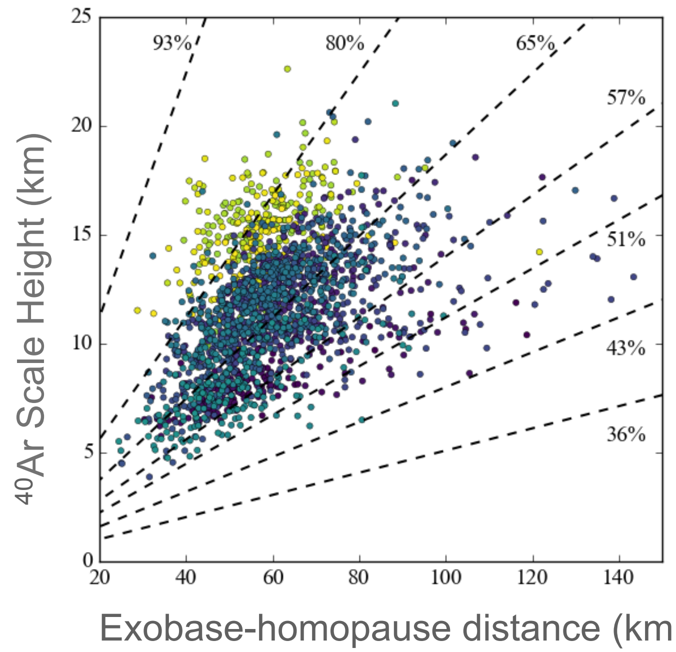
- *Jeans escape loss of H*
  - Loss of Global Equivalent Layer (GEL) of ~ 2 - 15 m H_2O
  - Could be substantially larger
- *Solar-wind stripping of O*
  - Loss of O from multiple processes, equivalent to
    - Up to a couple of bars of CO_2, or
    - 2 - 40 m H_2O, or
    - A mix of these end-members
- *Loss from solar storms*
  - Enhanced loss observed during solar events
  - Storms early in history were stronger and much more abundant, and resulting loss could dominate total loss

Preliminary Results!

$^{38}Ar/^{36}Ar$ Requires Substantial Loss



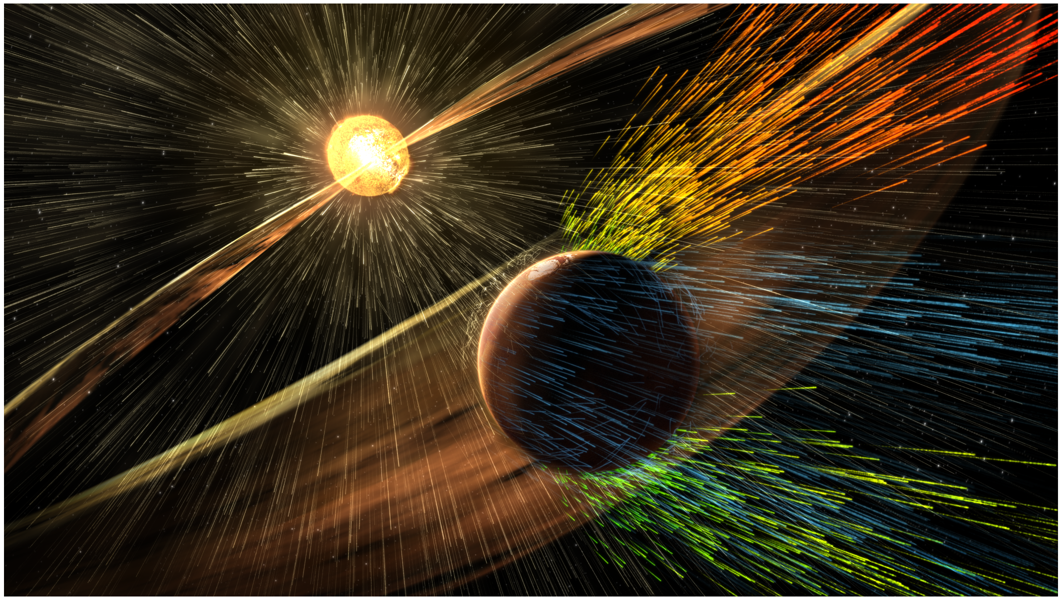


- Above homopause (~100 km), each gas has a scale height determined by its own mass; shown in upper left as profile of two gases having different masses
- Causes $^{36}Ar/^{38}Ar$ ratio to increase with altitude; loss from top of atmosphere preferentially removes ^{36}Ar and leaves remaining gas enriched in ^{38}Ar.
- We use this enrichment to quantitatively determine fraction of gas lost by sputtering alone
- Indicates directly that majority of atmosphere has been removed to space

Integrated Results on Atmospheric Loss

- Loss to space would have been able to remove the largest part of a thick, early atmosphere
- O that is lost can have come from either CO_2 or H_2O
- Argon-isotope enrichment requires loss of the bulk of the atmosphere by sputtering but applies to all constituents; O loss has to include loss of CO_2

Bottom line: Loss to space likely was a (if not the) major process for changing Mars from having an early warm, wet climate to the cold, dry climate we see today.



Ongoing and Upcoming Measurements

- Observations through a second Mars year (interannual variations)
- Different time in the 11-year solar cycle (effects of different solar drivers)
- Comprehensive measurements not previously made
- Coordinated observations with *Trace Gas Orbiter*