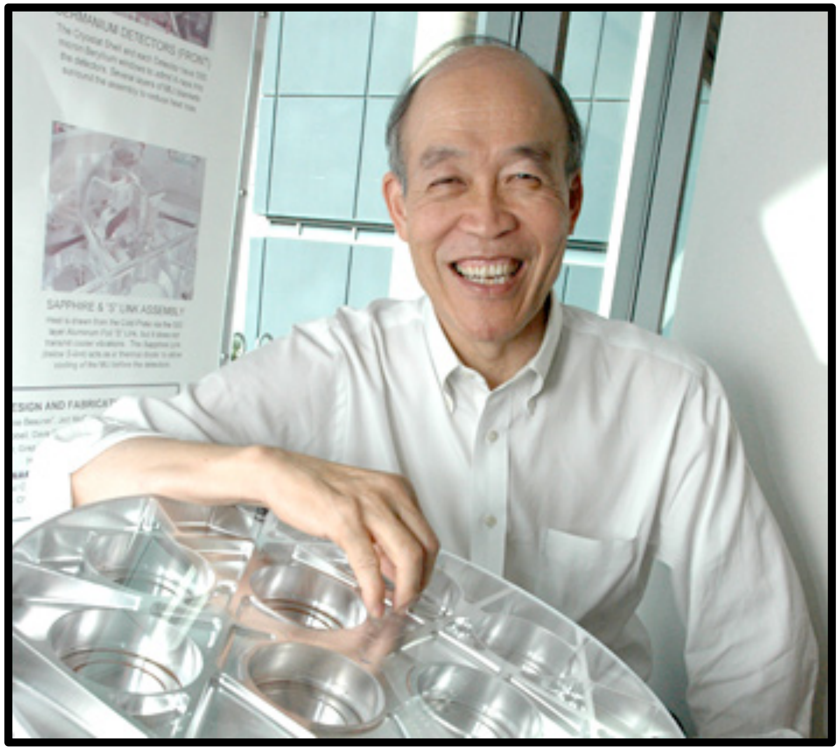
# MAVEN Status and Early Results

*Bruce Jakosky*
*LASP / University of Colorado*

*Presentation to CAPS and CSSP*
*31 March 2015*



Bob Lin

Mario Acuna

# MAVEN Status

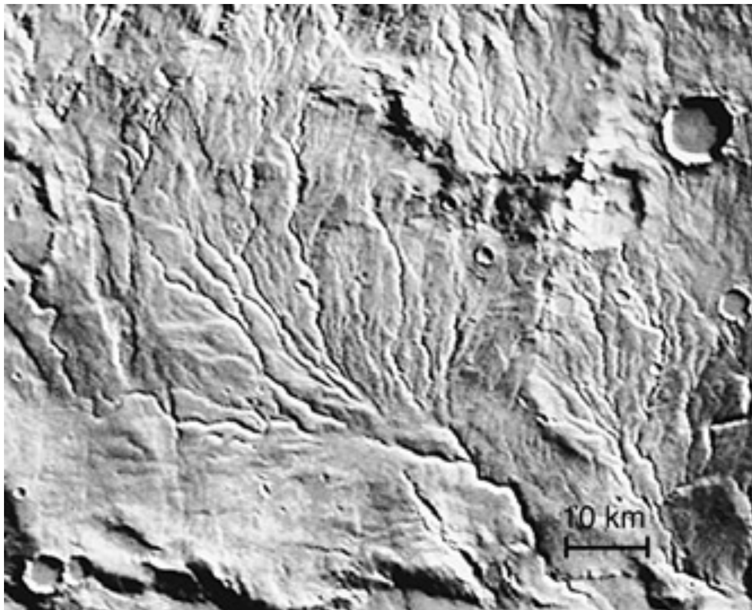
- MAVEN launched, 18 Nov. 2013
- Mars Orbit Insertion, 21 Sept. 2014
- Survived encounter with Comet Siding Spring, 19 October 2014
- Completed commissioning (transition phase) and began science phase on 16 Nov. 2014
- Currently 4.5 months into our one-Earth-year primary mission
- All instruments performing nominally, collecting data as planned
- Science team deep into understanding instrument behavior and calibrations; just now beginning multi-instrument analyses that are central to MAVEN science
- Extended-mission bridge-phase proposal for FY16 due May 4; covers period until next senior review

# Outline

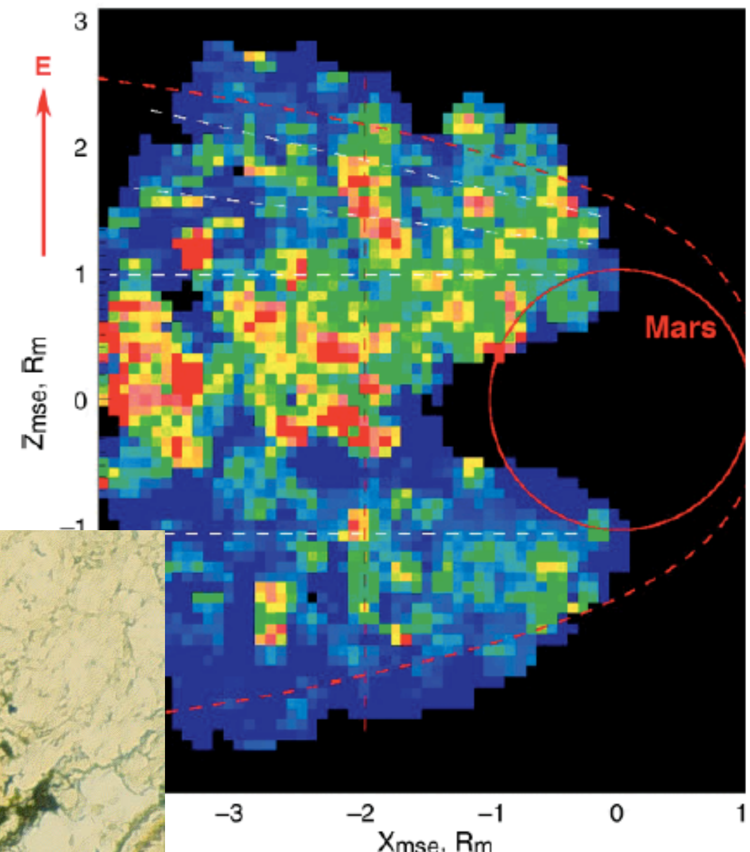
- Summary of science goals, development, and early science results
- Status of spacecraft and instruments
- Lessons learned
- Issues and concerns

# *Evidence for Surface Water on Ancient Mars*
# *Where Did the Water Go? Where Did the $CO_2$ Go?*

*Abundant evidence for ancient water*

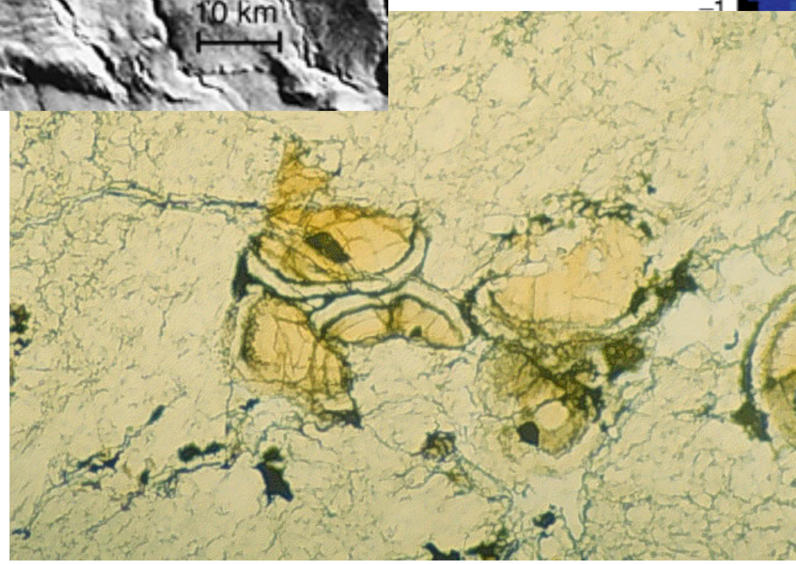



*Volatiles can be lost to space*



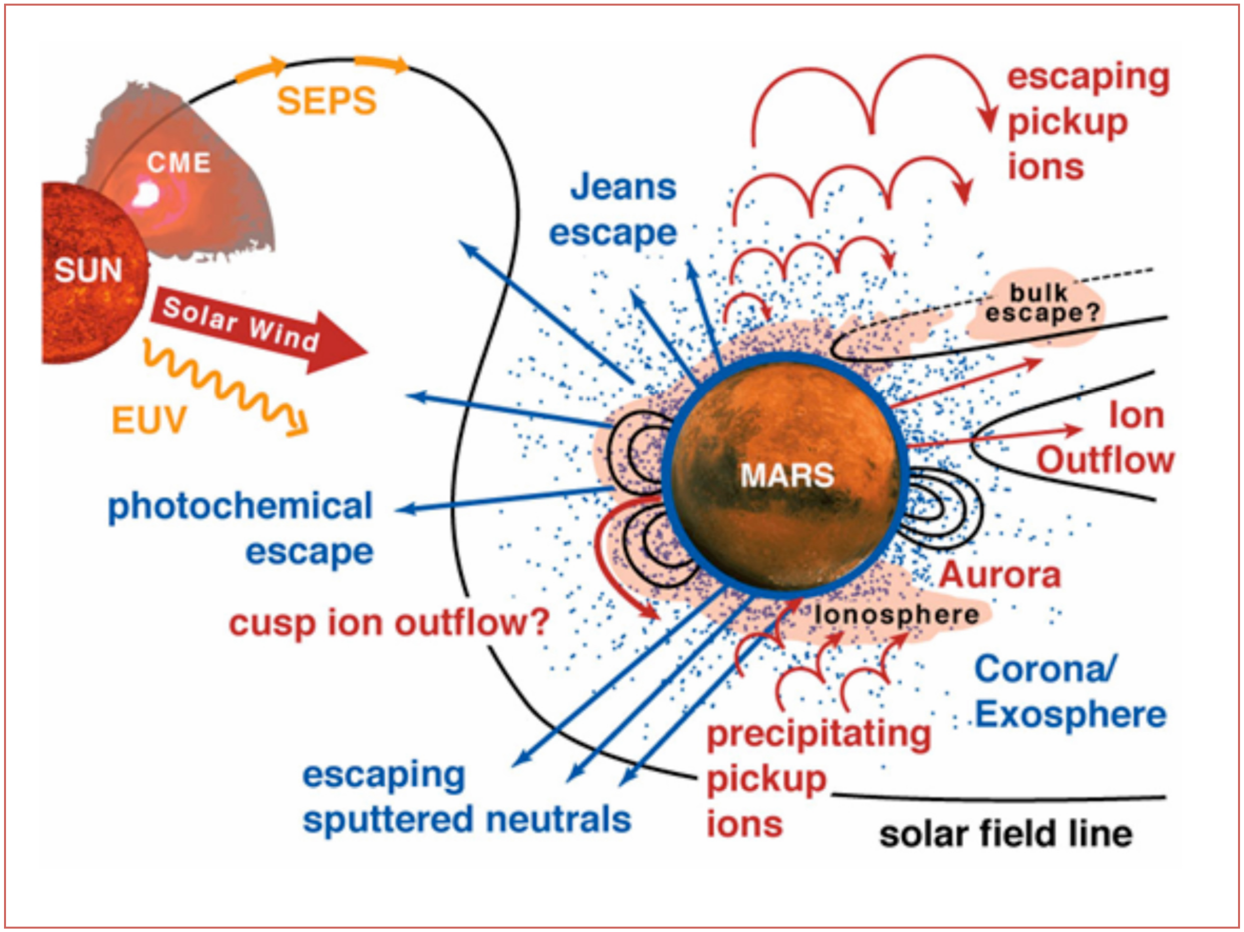

*Escaping ions detected from Mars Express*

*Volatiles can go into the crust*



*Carbonate deposits in a Martian meteorite*

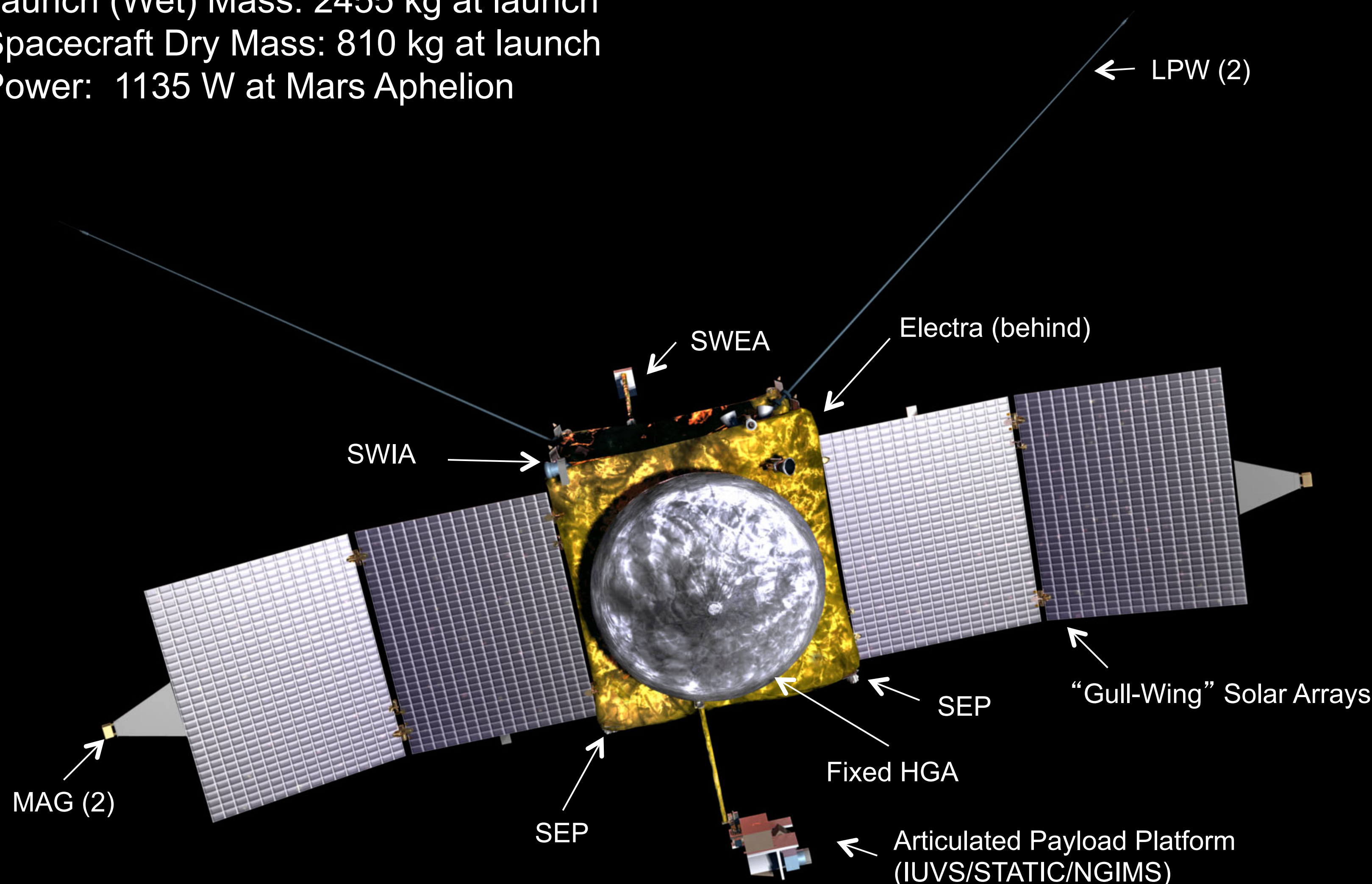
# MAVEN Will Allow Us to Understand Escape of Atmospheric Gases to Space

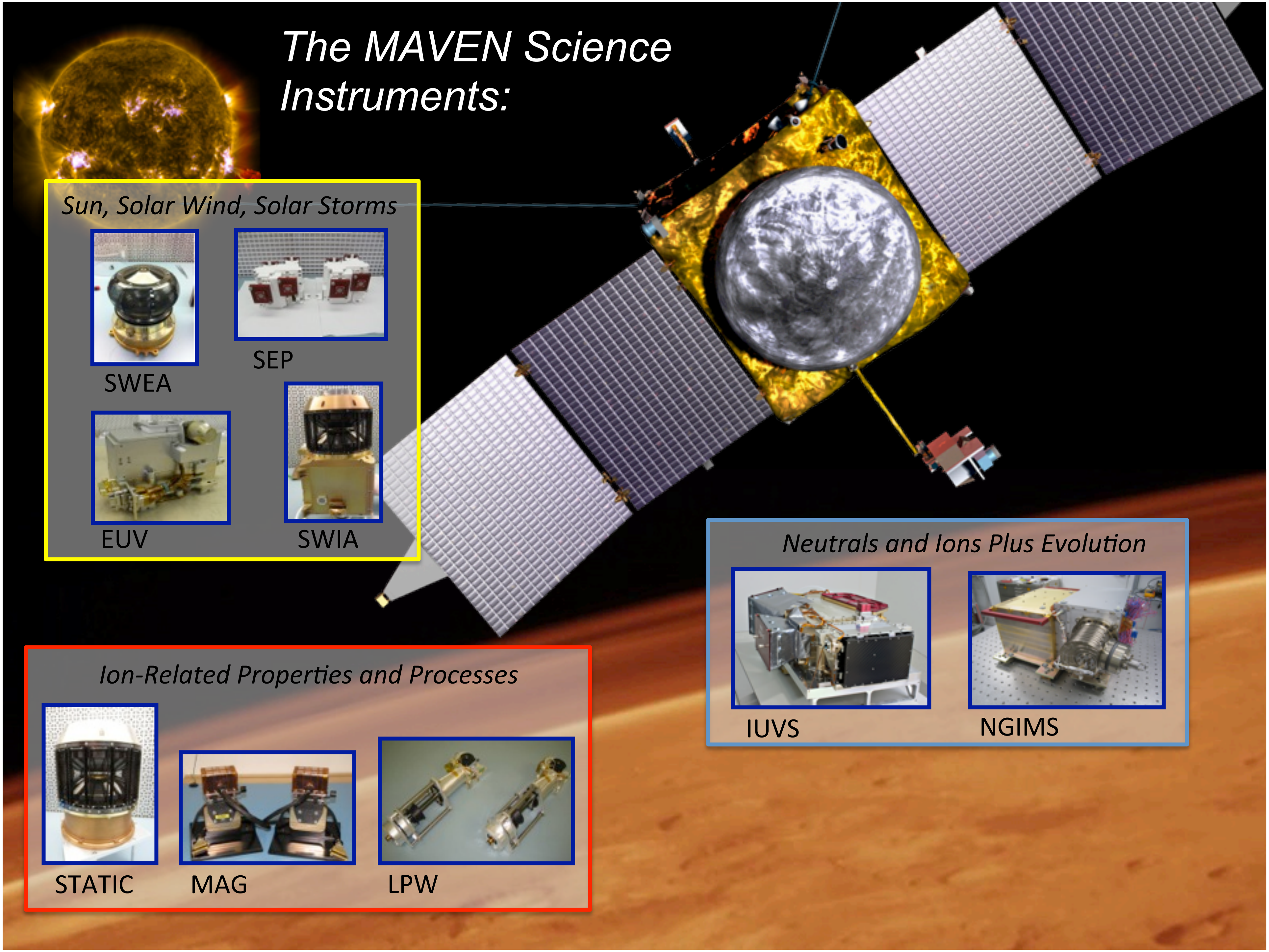



- Measure energetic drivers from the Sun, response of upper atmosphere and ionosphere, and resulting escape to space
- Understand the key processes involved, allowing extrapolation to loss over Mars history

# The MAVEN Spacecraft

- Launch (Wet) Mass: 2455 kg at launch
- Spacecraft Dry Mass: 810 kg at launch
- Power:  1135 W at Mars Aphelion

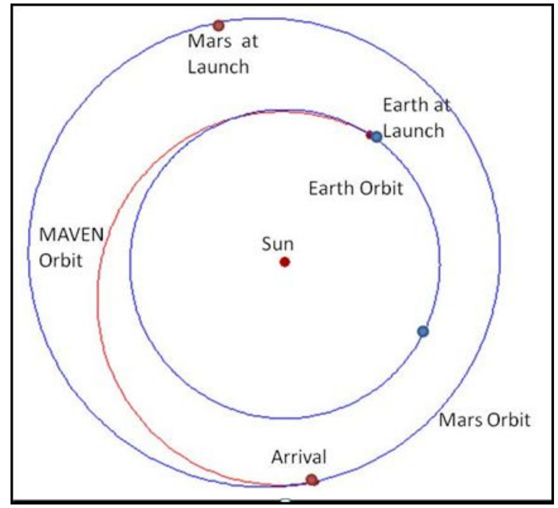


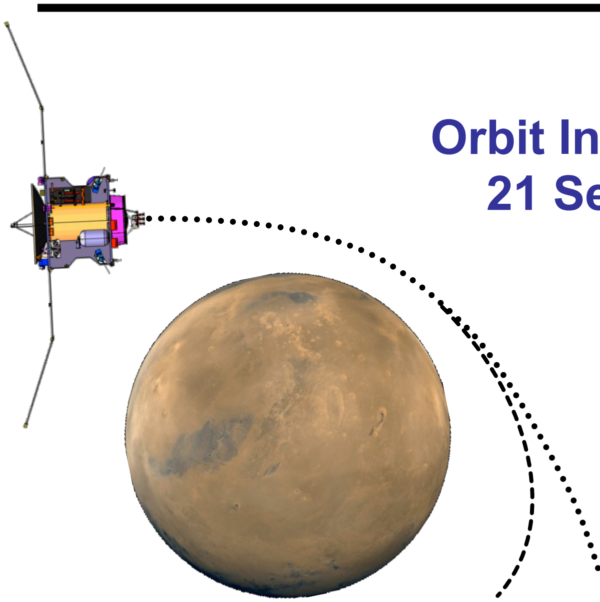

The MAVEN Science Instruments:
Sun, Solar Wind, Solar Storms
SWEA
SEP
EUV
SWIA
Neutrals and Ions Plus Evolution
IUVS
NGIMS
Ion-Related Properties and Processes
STATIC
MAG
LPW

# MAVEN Mission Architecture

**Launched on 18 Nov. 2013; Atlas V-401, from CCAFS**

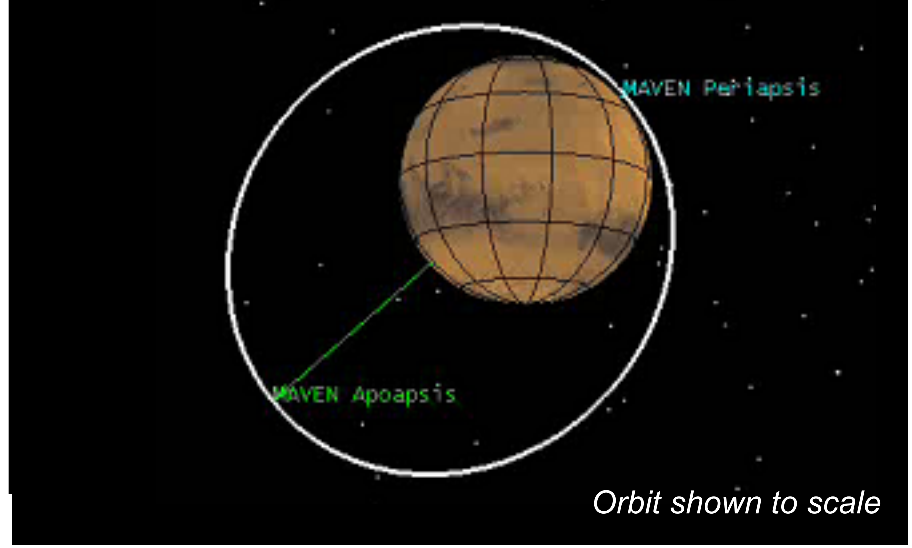
**Ten-Month Ballistic Cruise to Mars**



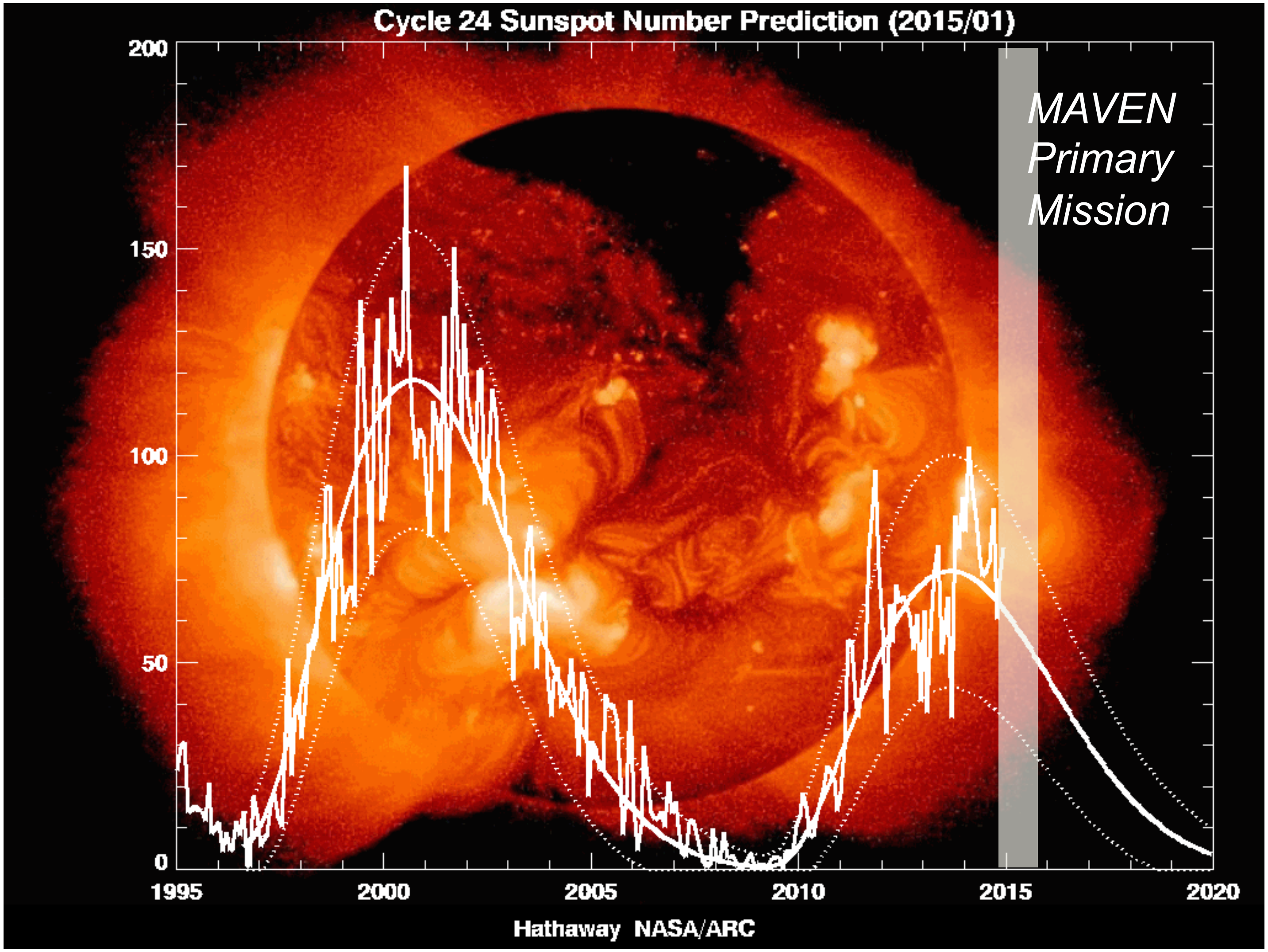



**Orbit Insertion on 21 Sept 2014**

**One Year of Science Operations**



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

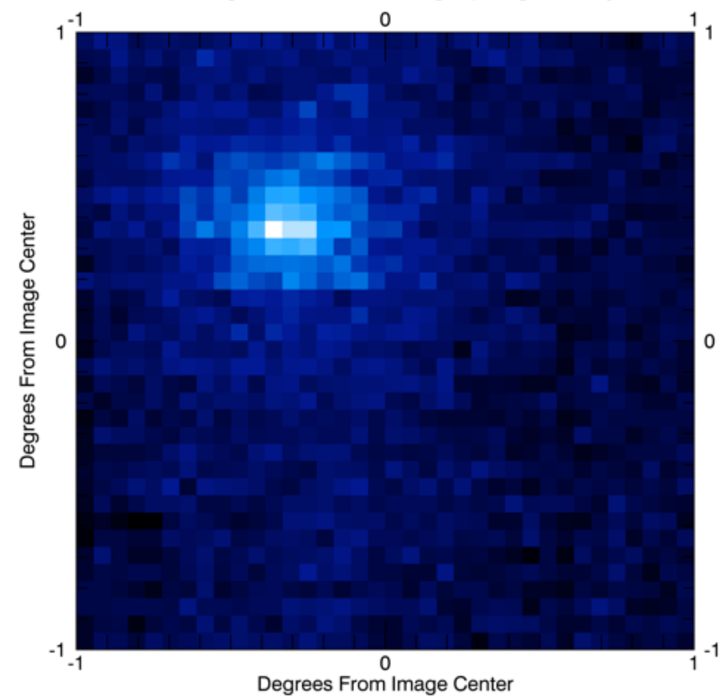


# Close Encounter With Comet Siding Spring

*Breckland Skies Observatory*

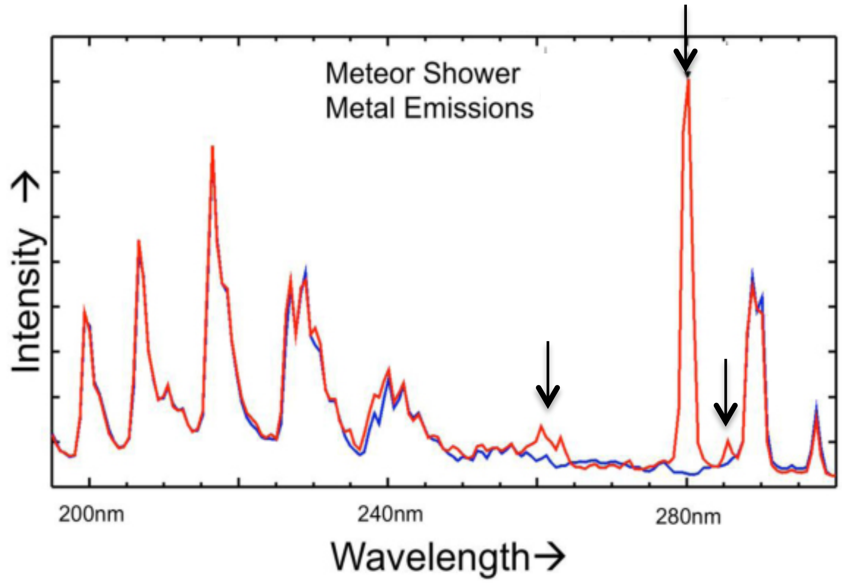
- Comet Siding Spring had close approach (~140,000 km) to Mars on 19 Oct. 2014
- Spacecraft and instruments took protective measures to ensure safety
- Strong desire to observe comet and its effects on Mars' atmosphere

MAVEN/IUVS Image of Comet Siding Spring in H-LyA, 10/17/14



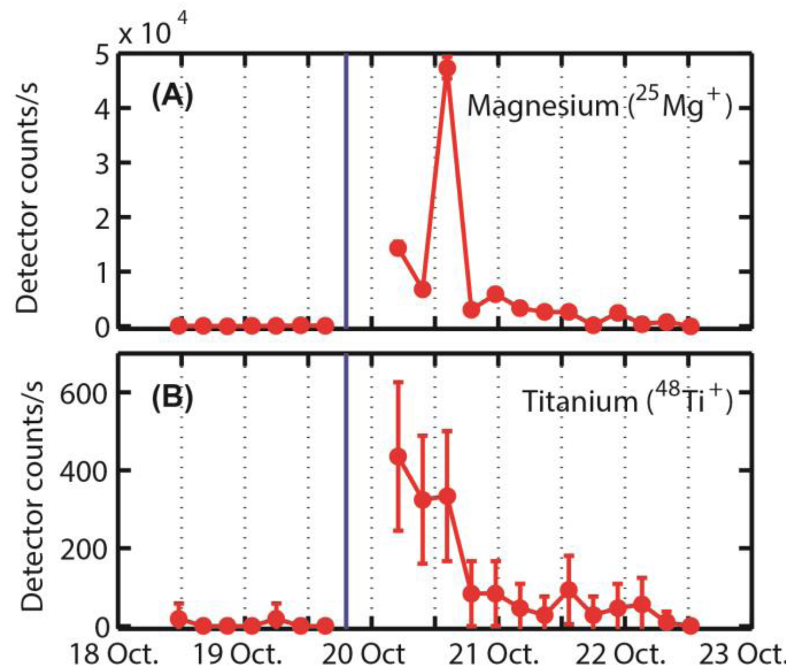

- MAVEN IUVS imaged CSS in scattered solar Lyman-alpha two days before closest approach to Mars
- H detected to distance of ~150,000 km (comparable to Mars miss distance of comet)
- Suggested significant potential risk to spacecraft

# Detection of Metal-Ion Layer Following Encounter With Comet Siding Spring

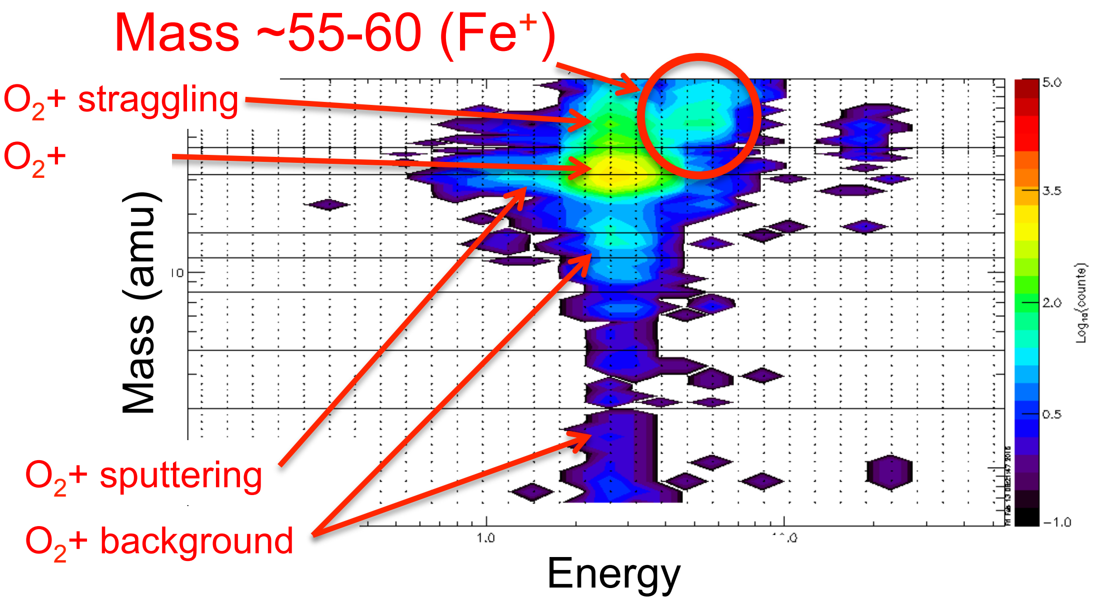



- Cometary dust entering Mars' atmosphere is vaporized and ionized
- IUVS saw very bright UV emissions due to metal ions (left)
- Emission observed at tangent altitude of ~120-150km

- NGIMS detected 11 different metal ions (right); detected *in situ* as low as periapsis altitude of ~185 km
- Metals not detected prior to CSS encounter
- Ions lasted hours to days, consistent with model predictions
- No previous detection of metal-ion layer at Mars; electron layers had been detected

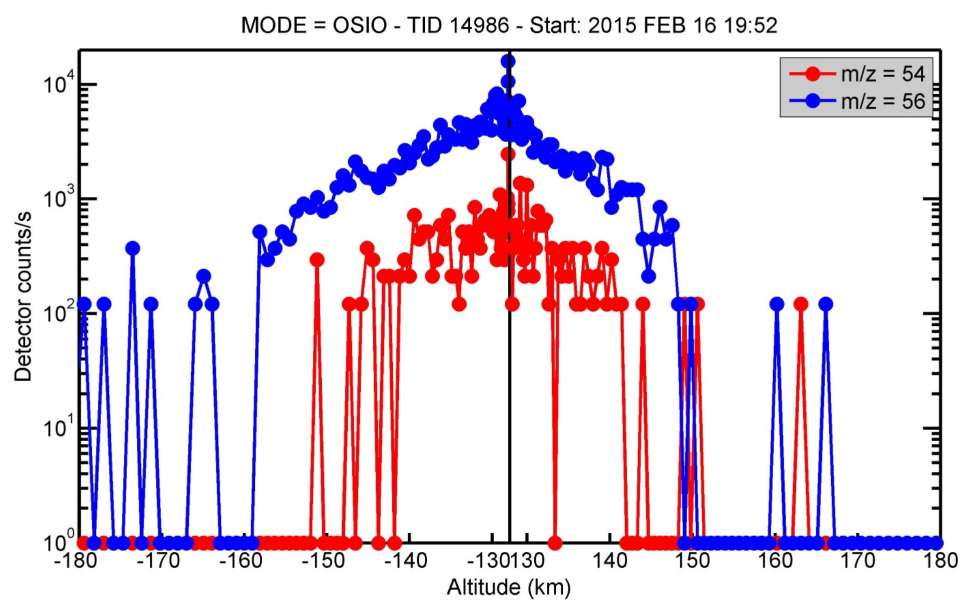


# Discovery of Long-Lived Metallic-Ion Layer




- Ions observed during deep dip at altitudes as low as 130 km
- STATIC (left) shows detection of ions at mass expected for $Fe^+$
- NGIMS (below) shows detection of two different isotopes of $Fe^+$; $Mg^+$ also seen

- Observed four months after Comet Siding Spring, likely no connection to it
- Previously, electron layers had been detected intermittently by *Mars Express*
- First detection of long-lived metallic-ion layer



# Dust Cloud Surrounding Mars Observed by LPW (1 of 2)

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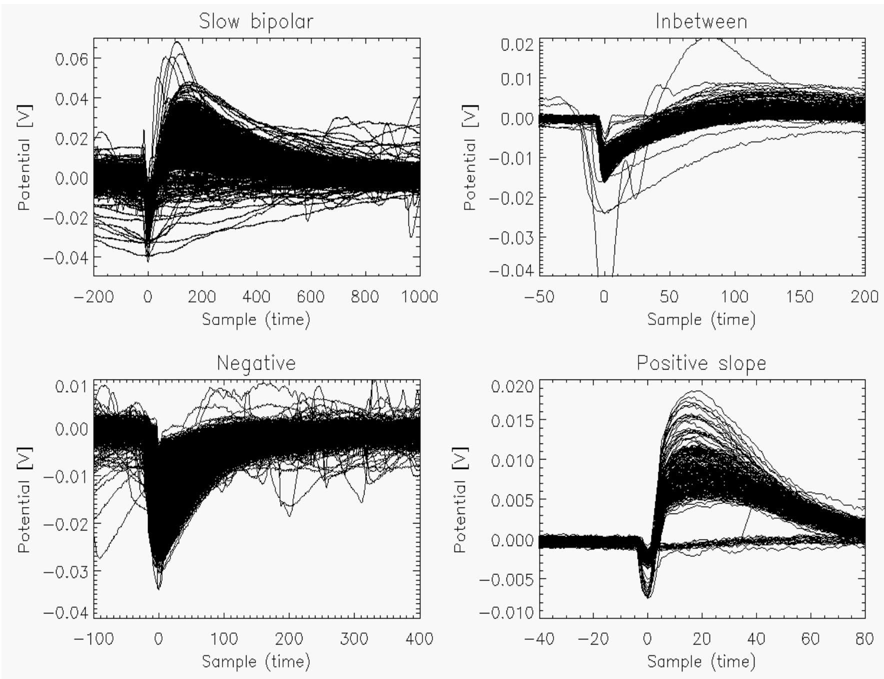
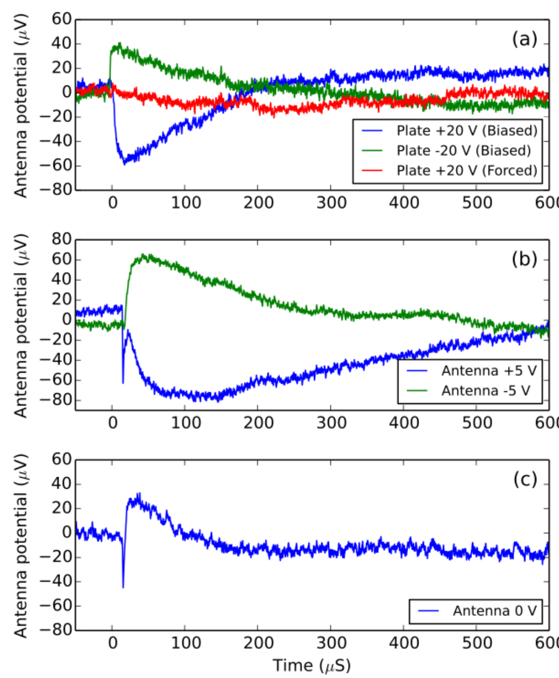
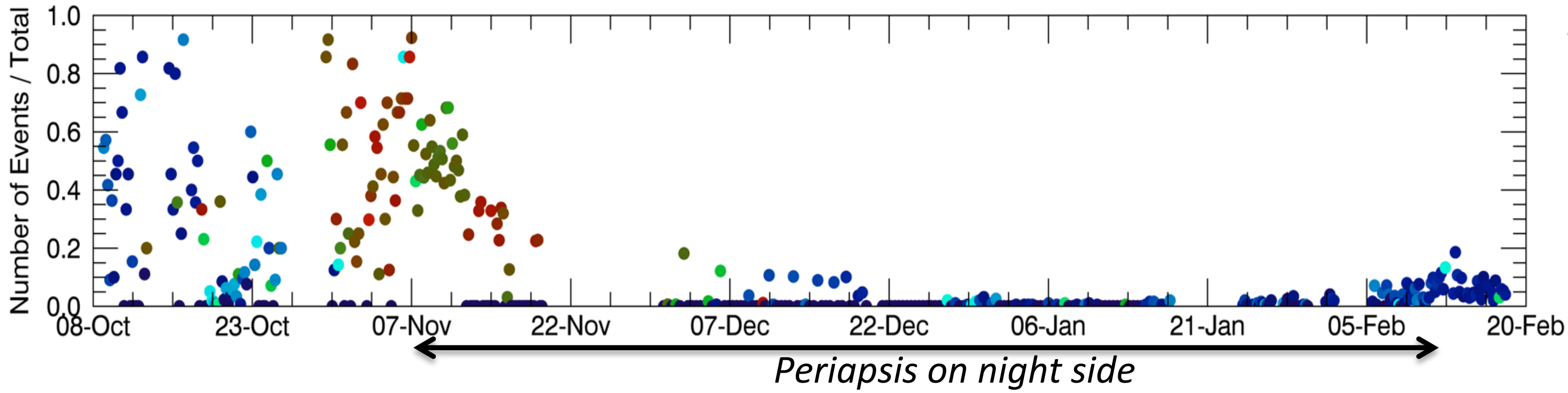


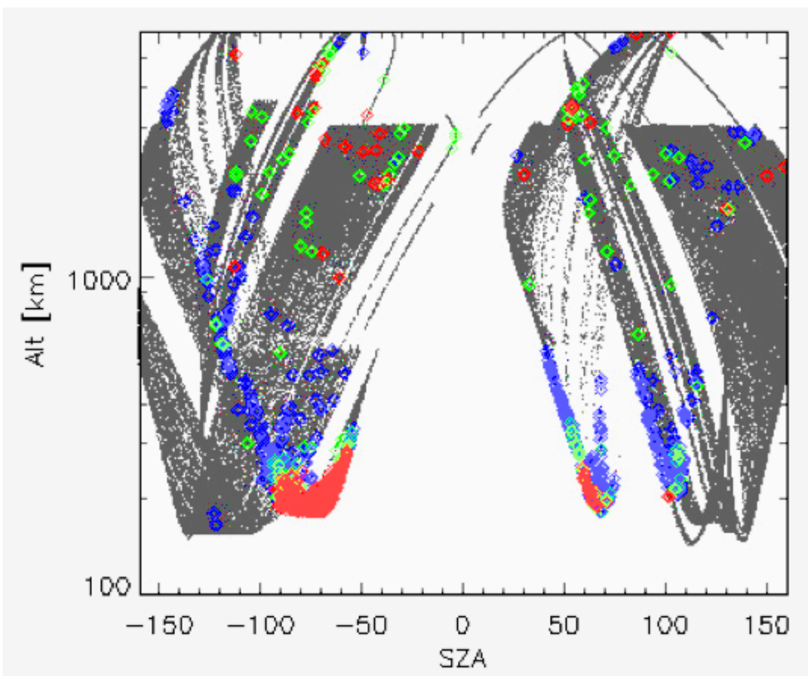

- Dust impact anywhere on spacecraft produces plasma cloud, affects spacecraft potential in a way that can be detected by LPW
- Characteristic signatures measured on MAVEN (left) similar to those seen on other spacecraft (Voyager, Cassini, STEREO, DS1, Wind)




- Similar signatures measured in lab (right)
- Events predate Comet Siding Spring, so not uniquely related to that
- Four days of observations shown at right

# Dust Cloud Surrounding Mars Observed by LPW (2 of 2)




*(Black = observations; color is dust-signature amplitude – blue = weakest, red = strongest)*

- Dust appears to concentrate on day side, near dawn/dusk terminators, and between 150-500 km altitude
- Spatial coverage very incomplete so far
- Dust source not known – could be lofted from atmosphere, come from Phobos and Deimos, or come from outside of Mars system
- Charge-particle effects likely redistribute dust

# IUVS Detection of Diffuse Aurora (1 of 2)

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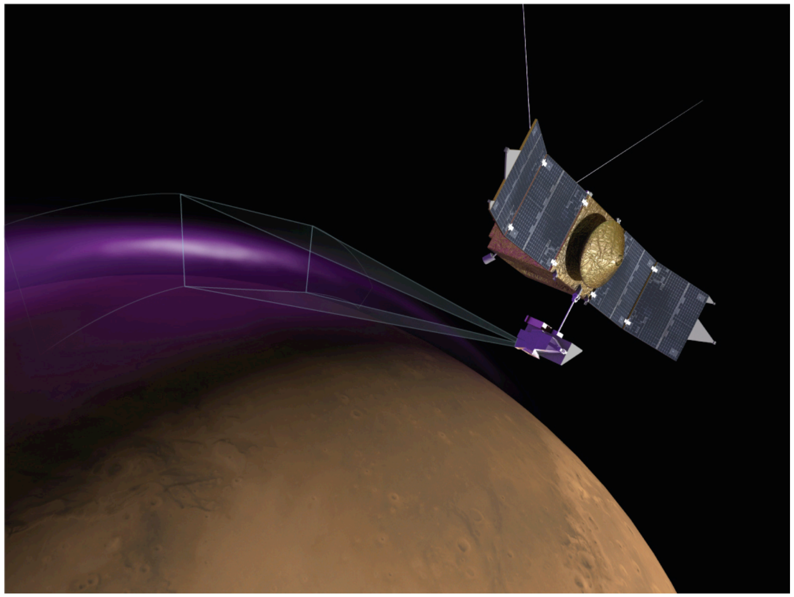
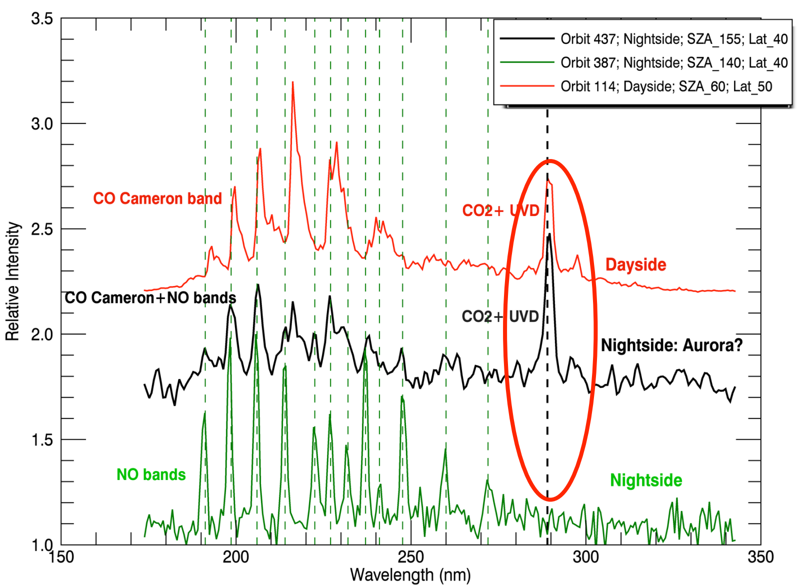
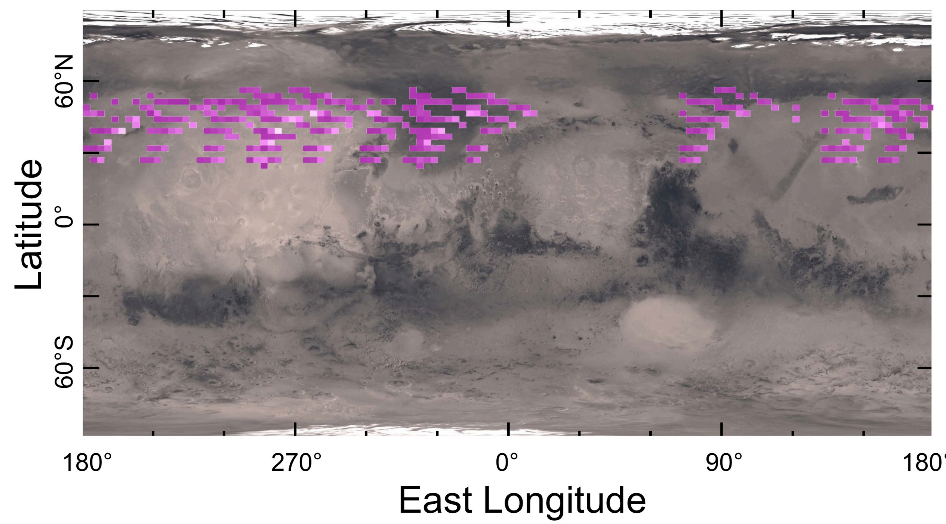
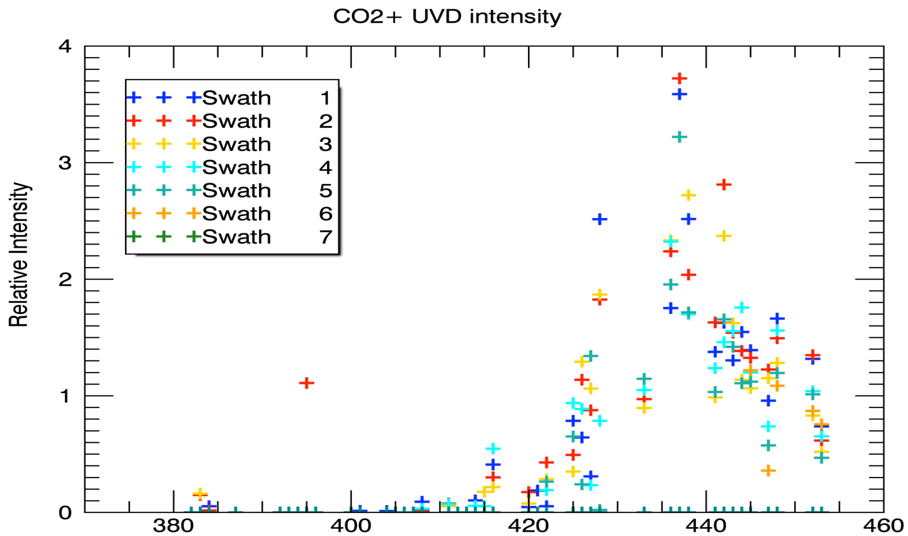


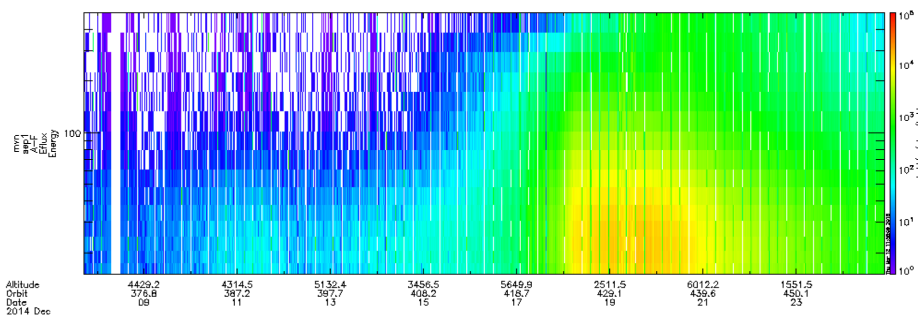
- "Christmas lights" aurora observed for five days on 18-23 December 2014
- Nightside emission at same wavelengths as dayglow; characteristic of aurora in general and of those observed by *Mars Express*
- Diffuse distribution throughout northern hemisphere; no connection to magnetic anomalies



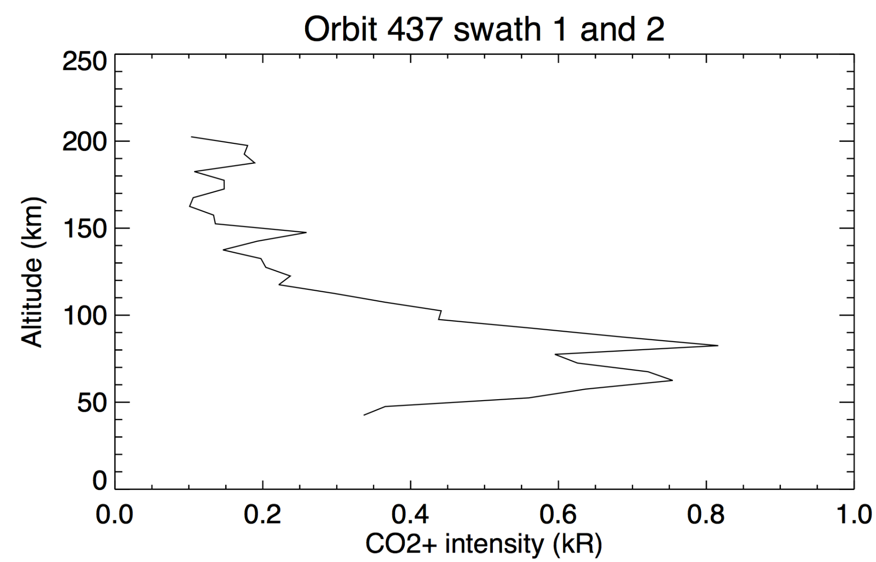



# IUVS Detection of Diffuse Aurora (2 of 2)



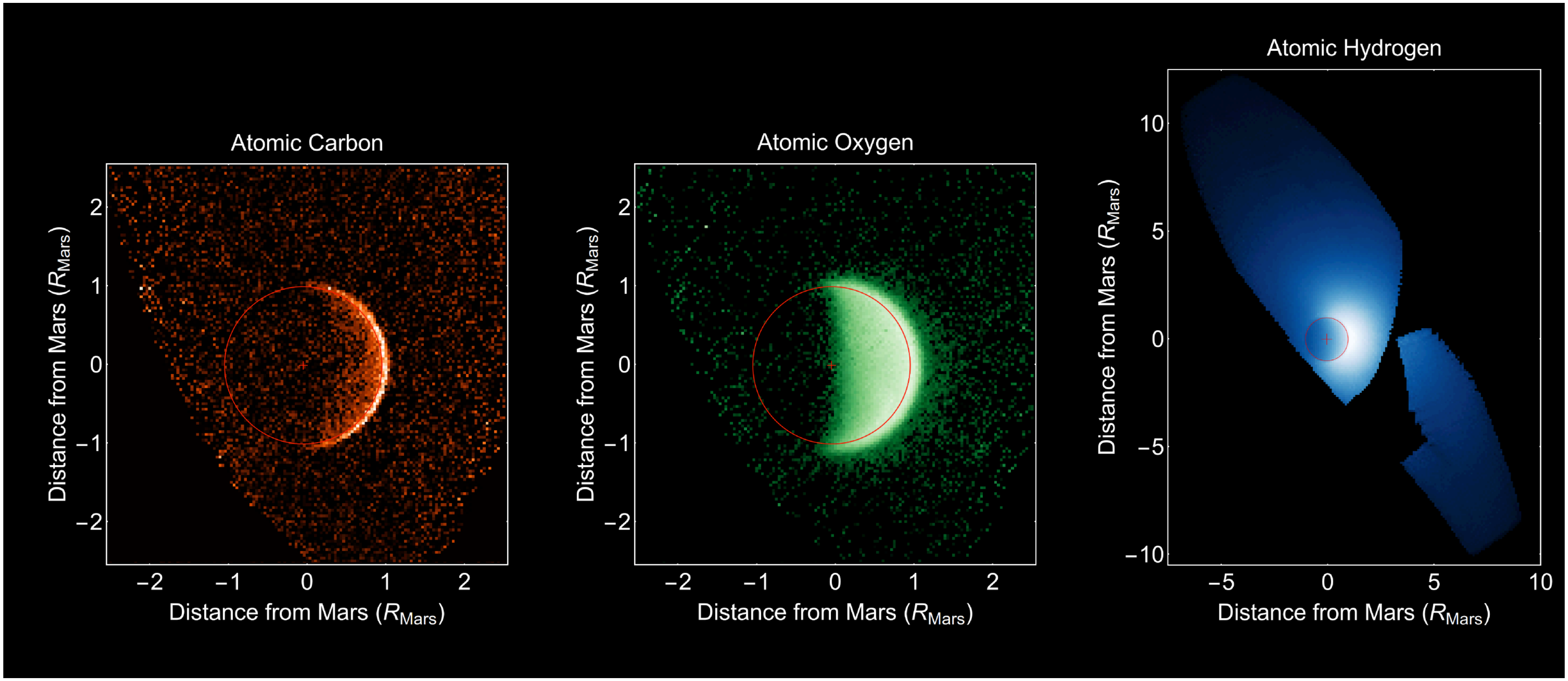

- To date, seen only on those five days
- Diffuse aurora, no apparent connection to magnetic fields as on Earth
- Occurs deep in upper atmosphere; requires extremely energetic electron flux
- Solar energetic-electron storm is the likely driver – arrived at Mars at the same time, has energies that penetrate to these altitudes



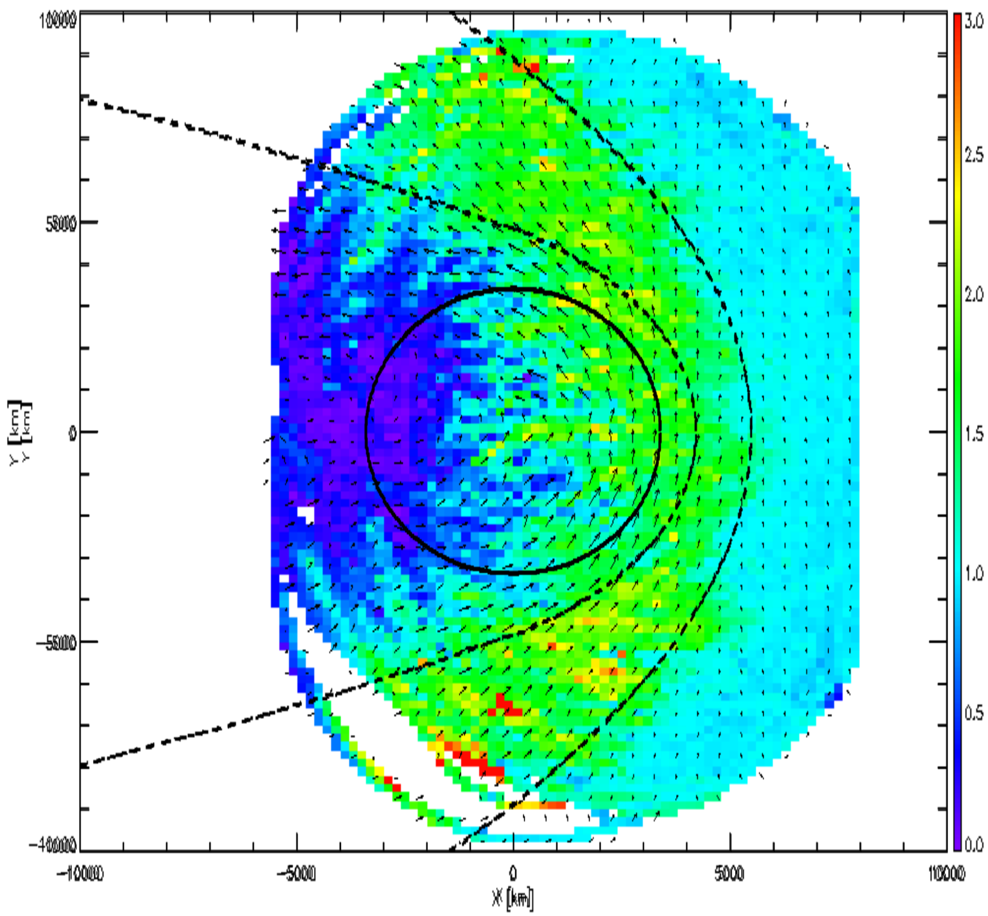

*(Radiance profile, not yet inverted to emission profile)*

- Distinct from localized aurora seen by *Mars Express* in vicinity of crustal cusps
- MAVEN has not yet observed in regions with crustal remnant magnetization

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

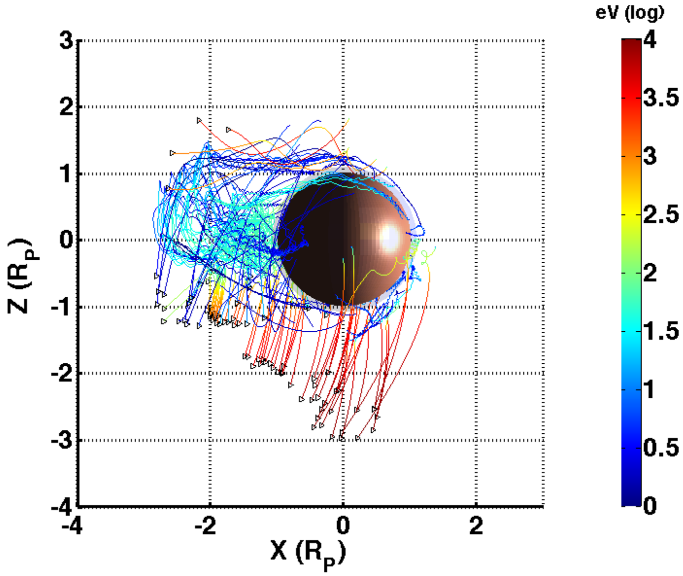


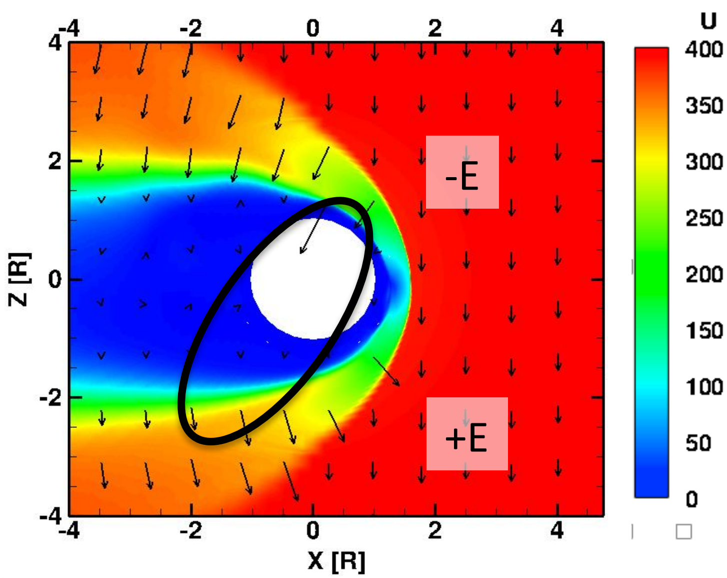
# Regions of Near-Mars Space Defined by SWIA and MAG Measurements




- Shows average behavior of interaction regions
- MSE coordinates defined so that:
  - Solar wind velocity in –X direction
  - IMF is in the X-Y plane w/ +Y component
  - Convection electric field points in +Z
  - Sun at right, solar wind moves right to left
- Colors represent ion density, vector B field superimposed
- Clearly shows average bow shock, magnetic pile-up boundary, and wake behind planet

# MAVEN Observes Escaping Polar Plume (1 of 2)

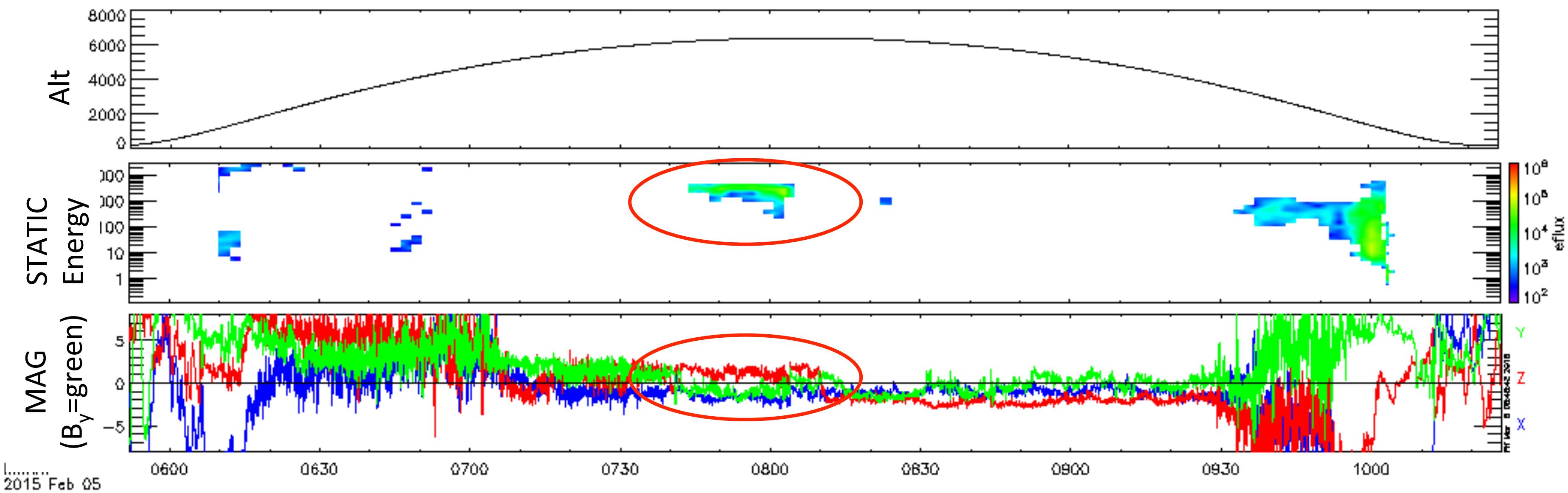


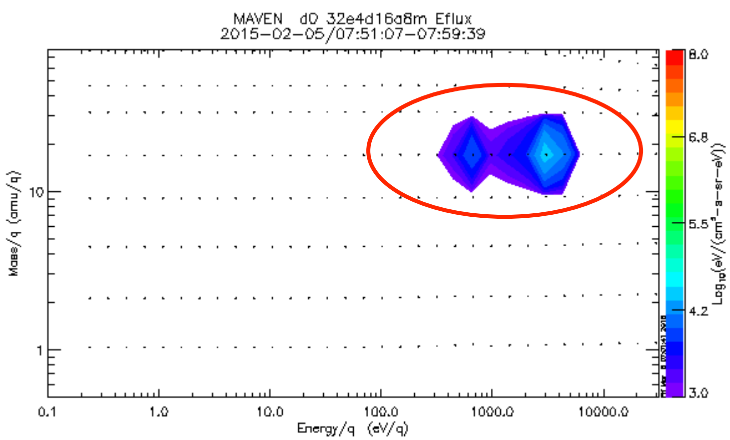




- Models show that ion loss occurs down the tail and in a "polar plume" (top left)
- Plume goes in only one direction, controlled by solar-wind-driven electric field
- Models predict that the polar plume might account for as much as half of the loss
- Requires simultaneous measurements of ion motions and magnetic field
- We are looking for orbits where the $B_y$ component is <u>negative</u> so that MAVEN can measure escaping ions at apoapsis, which was in the southern hemisphere early in the mission (bottom left)

*(Analysis by S. Curry)*

# MAVEN Observes Escaping Polar Plume (2 of 2)

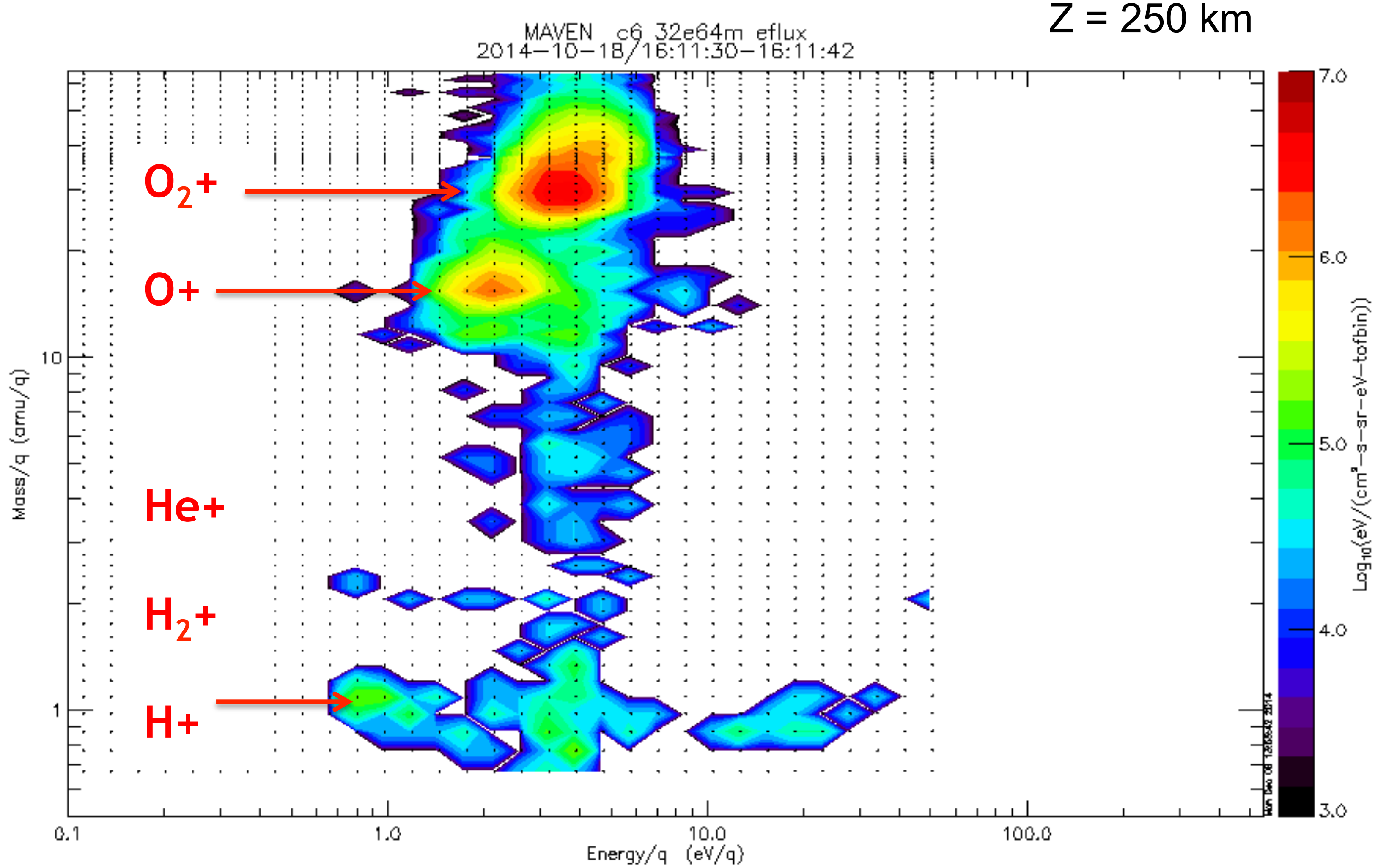


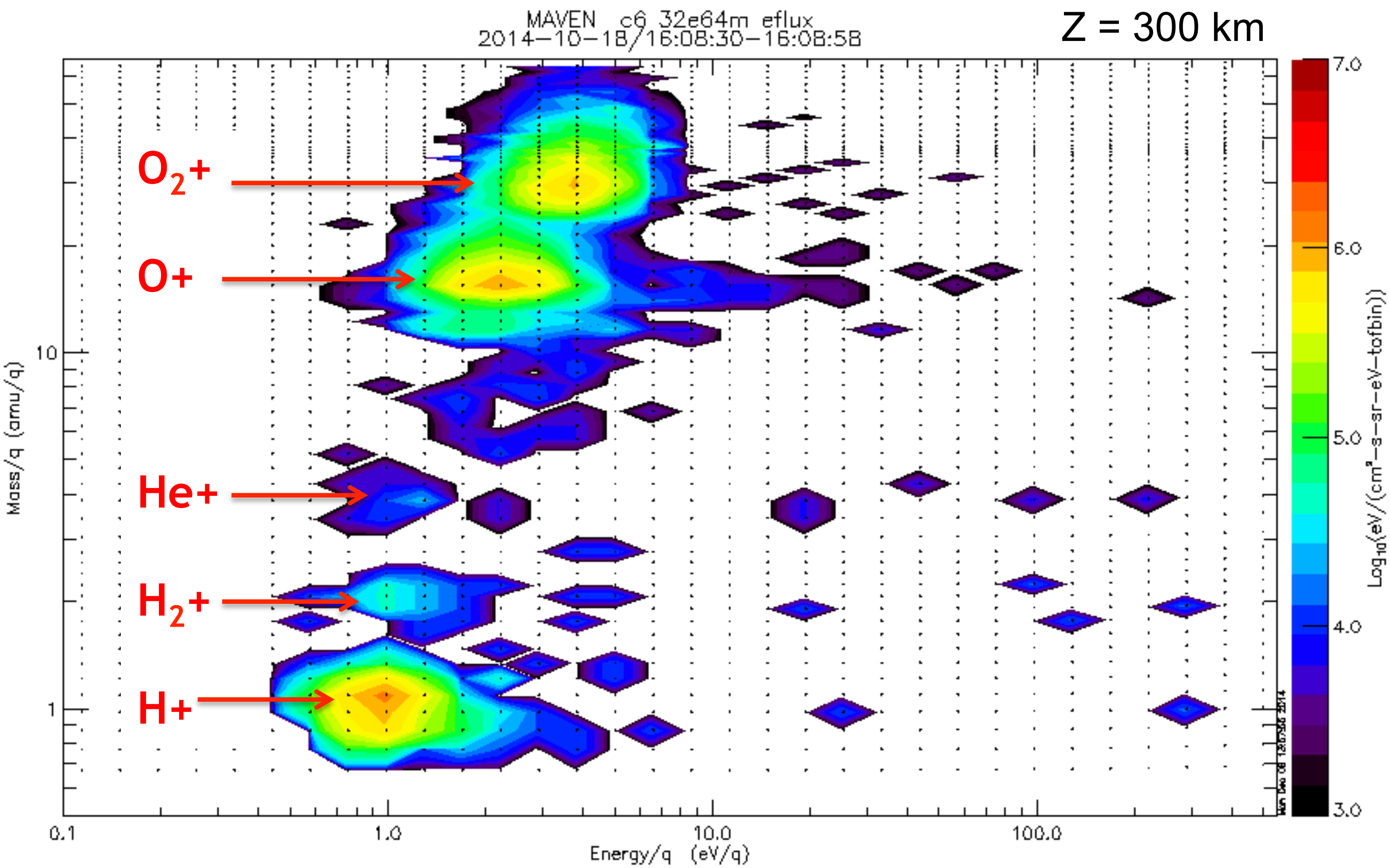

- Negative $B_y$ field at apoapsis (green in lower panel, above)
- High-energy ions detected by STATIC (middle panel, above; left)
- Mass 16 = $0^+$, escape energy (left)
- Will allow estimates of loss via plume

# Pre-Escape Energization in Polar Plume (1 of 4)

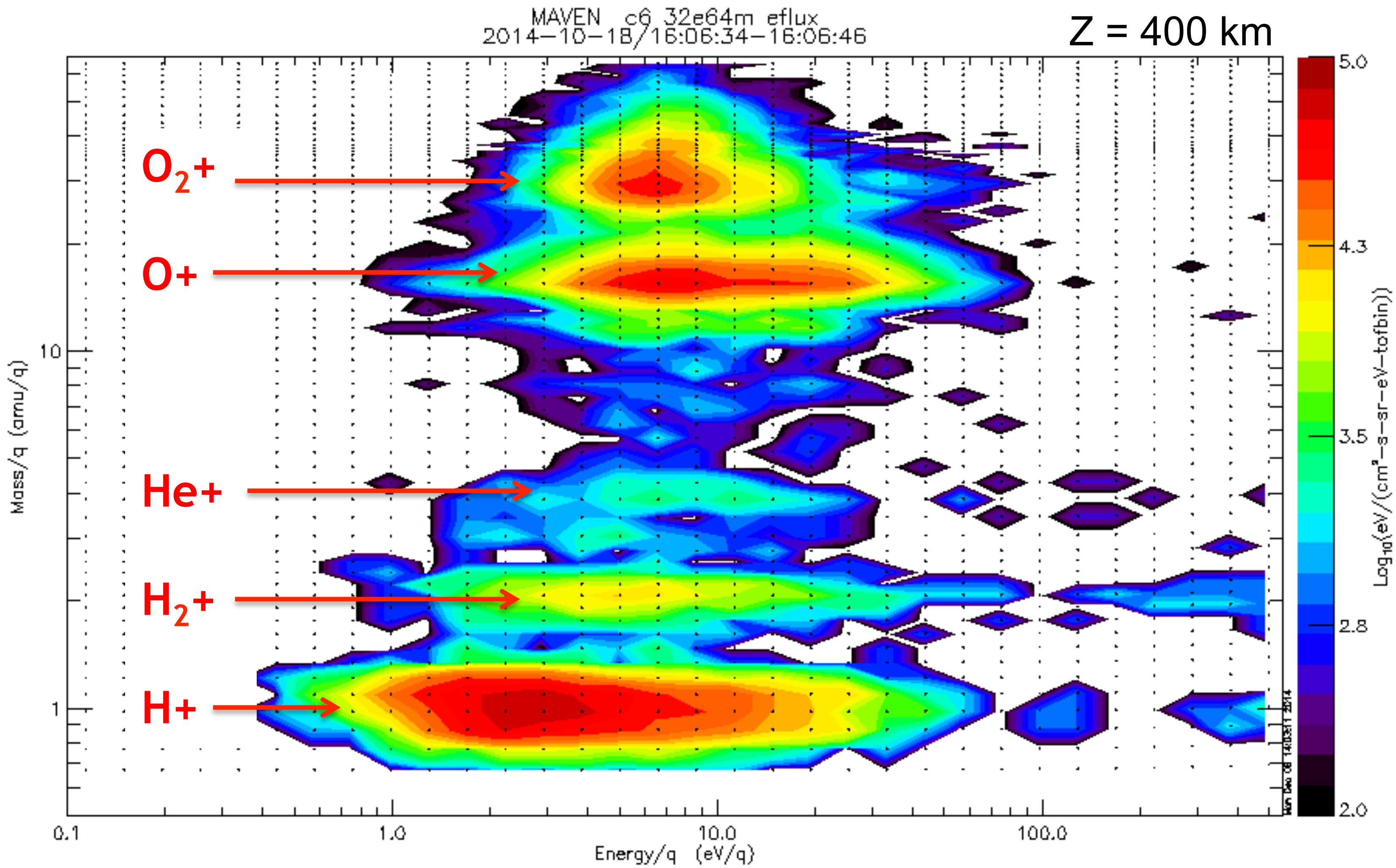
Z = 250 km



# Pre-Escape Energization in Polar Plume (2 of 4)

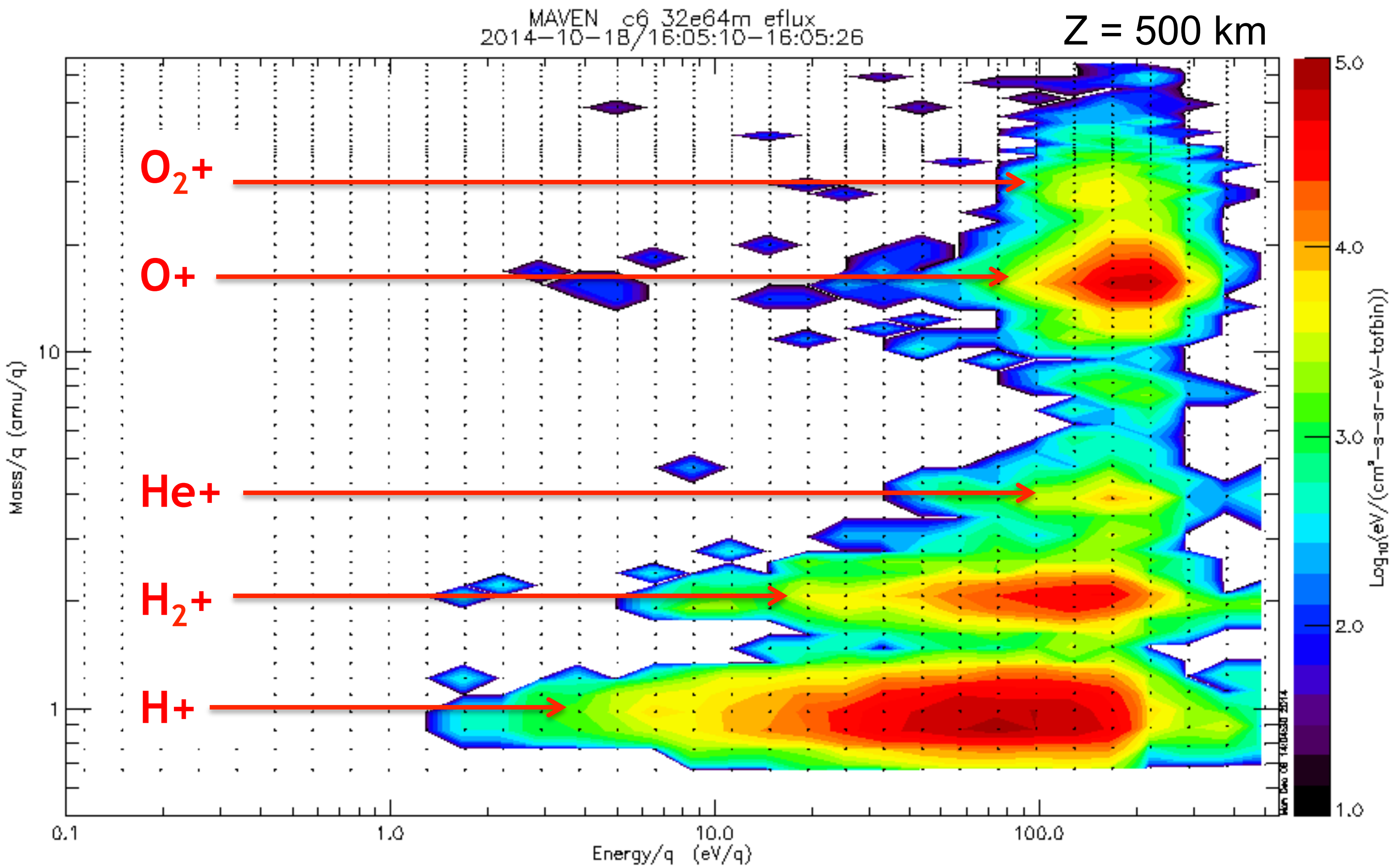


# Pre-Escape Energization in Polar Plume (3 of 4)

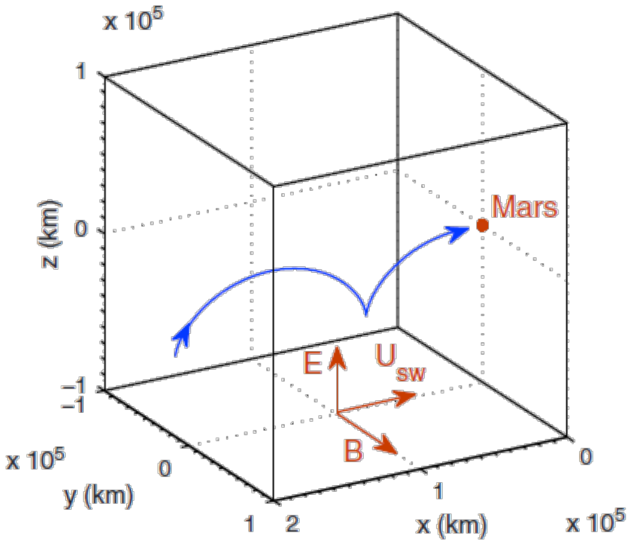


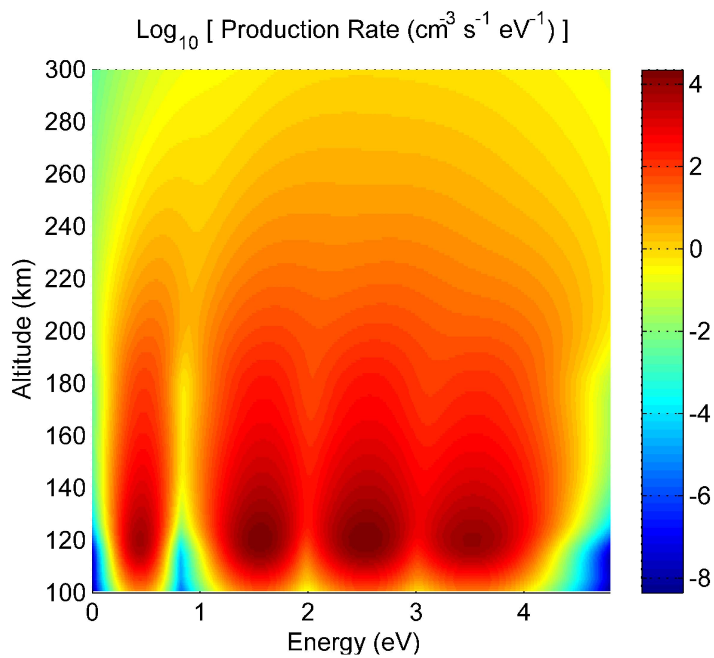
# Pre-Escape Energization in Polar Plume (4 of 4)

Z = 500 km



# Detection of Oxygen Pickup Ions (1 of 2)

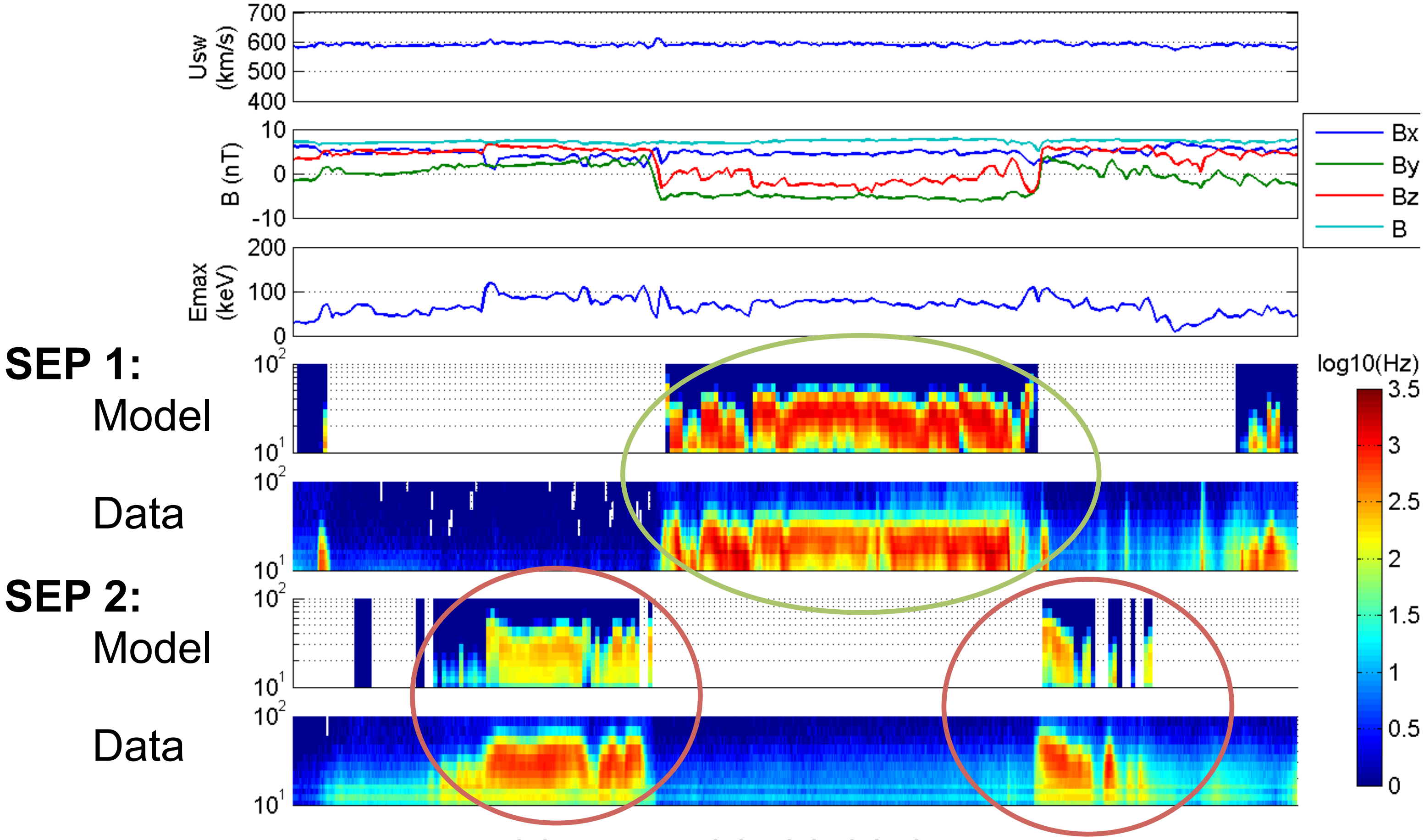



- Pickup ions are $O^+$ swept up by **v x B** force from solar wind sweeping by (top left)
- SEP should be able to detect them when energies are great enough and direction is in FOV
- Flux can be modeled from solar wind velocity, magnetic field orientation, $O^+$ production rates
- "Hot O" production rate modeled from dissociative recombination of $O_2^+ + e^-$ (bottom left)

*(Model and data analysis by Rahmati and Cravens)*

# Detection of Oxygen Pickup Ions (2 of 2)




2014 Dec 28, 00:00-01:55

Comparisons between data and model will allow constraints to be developed on pickup $O^+$ escape rates.

# Escaping Pickup Ions (1 of 2)

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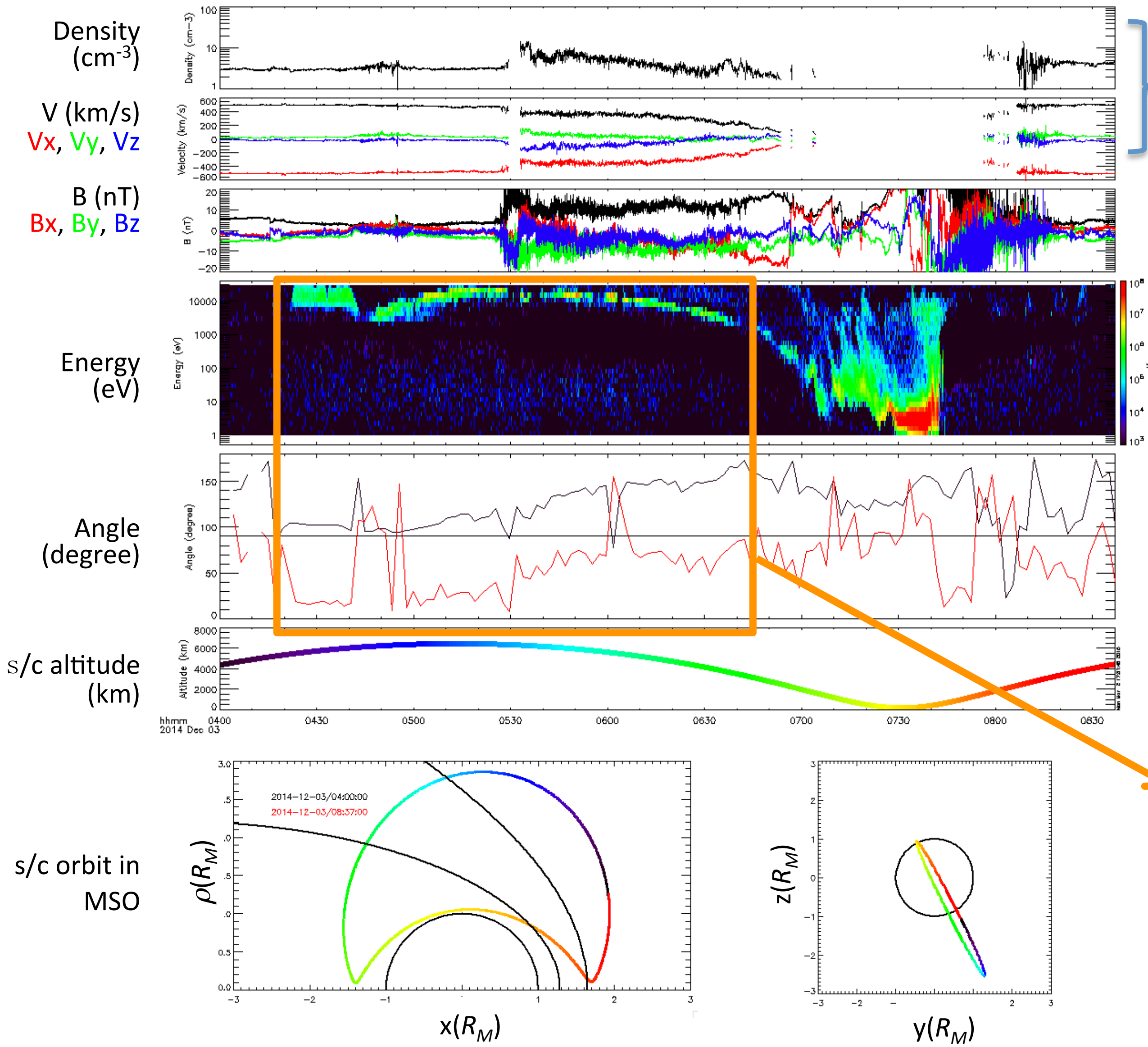
## Pick-up ion velocity directions

- One orbit in Dec 3., 2014




SWIA solar wind data

MAG data

STATIC data for mass >10 amu

Ion (~16amu) velocity direction angles with

- x axis in mso
- Local motional electric field ($E = -U_{sw} \times B$)

- Pick-up ion velocity changing from local electric field direction to solar wind direction
- Polar plume → tail region escaping ions

*(Analysis by Y. Dong)*

# Escaping Pickup Ions (2 of 2)

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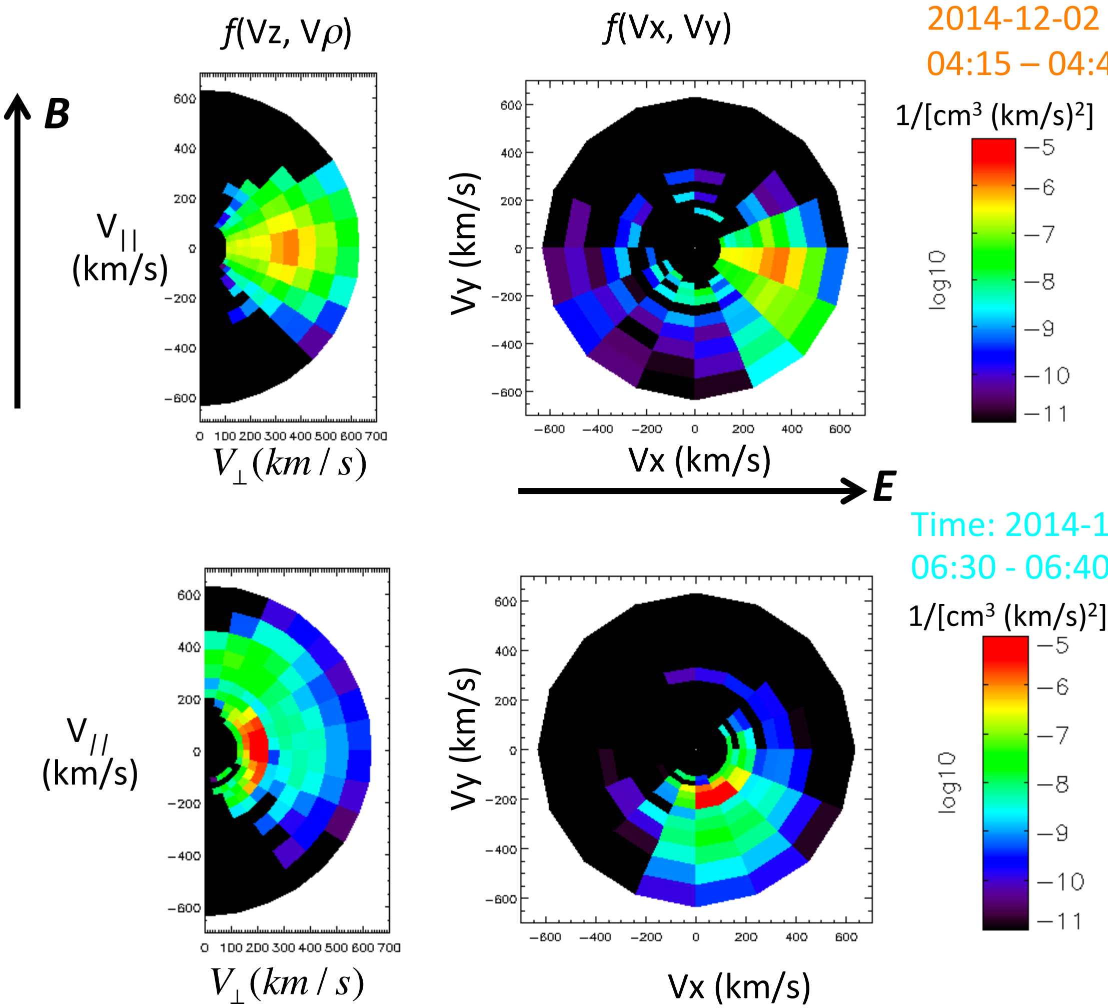
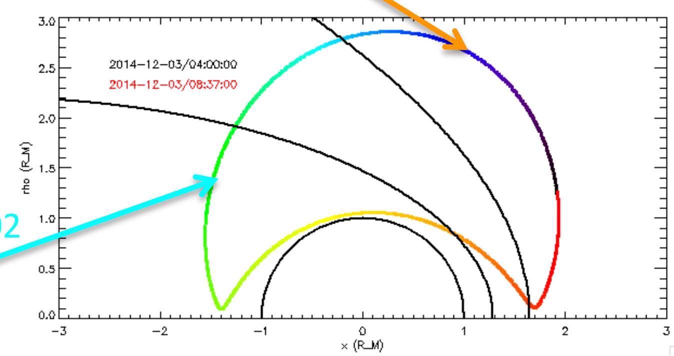
**Pickup ion velocity space distributions with respect to the local magnetic field:**

**polar plume vs. tail region escaping ions**

- X: ***E*** = - ***U***$_{sw}$ x ***B***
- Y: - (***E*** x ***B***)
- Z: ***B***
- Mass ~ 16 amu
- energy > 1000 eV

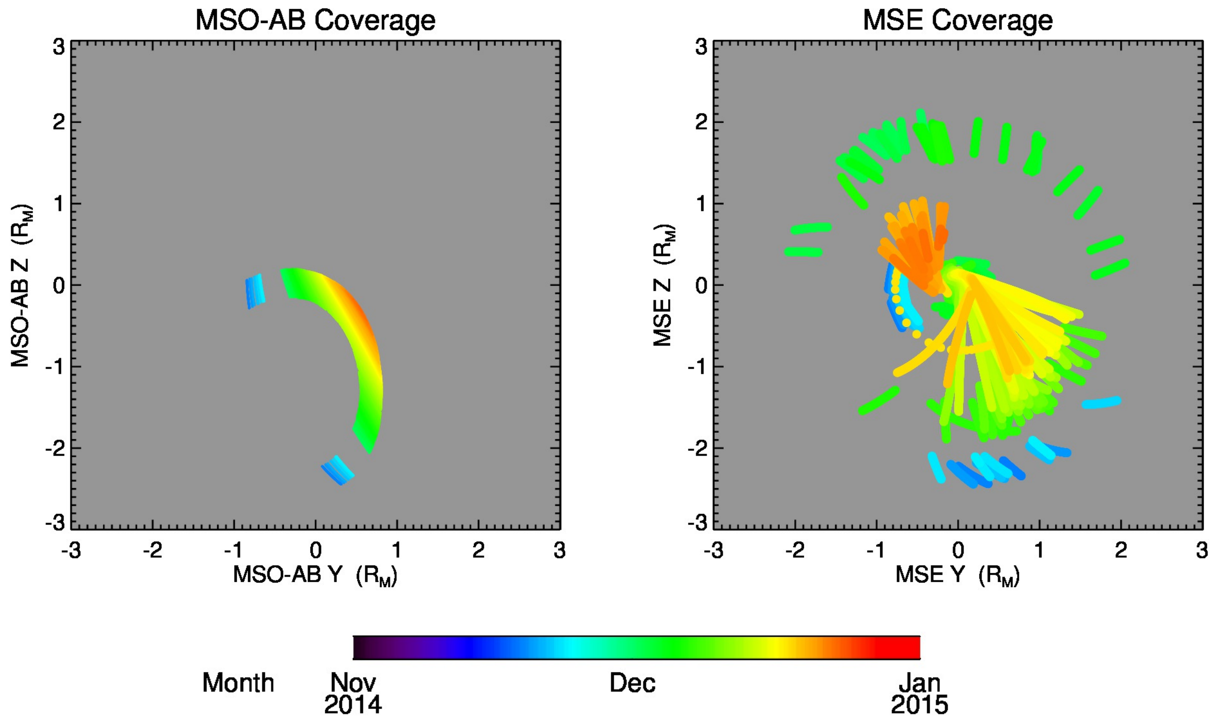



Difference:

- Position
- Velocity distributions

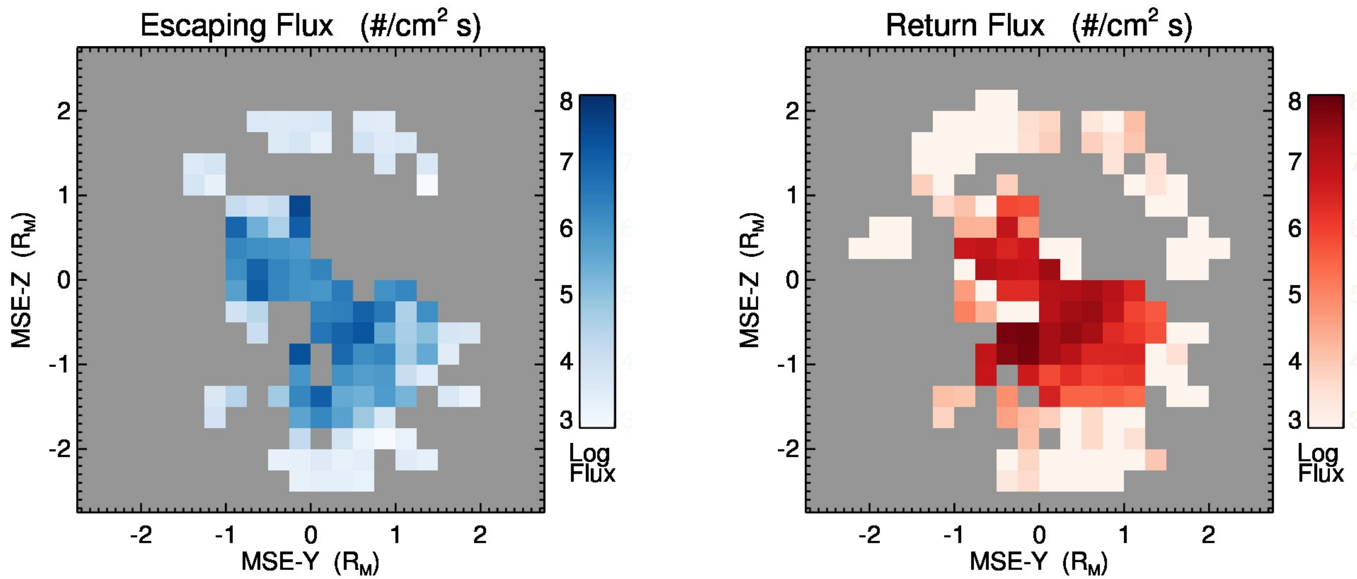
# Flux Escaping Down the Tail (1 of 2)




- Count up the ions passing through a plane downstream of planet to determine overall escape rate
- Geometric coverage limited (left)
- Processes controlled by solar-wind electric field direction; including its variations gives much better coverage (right)

*(Analysis by D. Brain)*

# Flux Escaping Down the Tail (2 of 2)




- Boxes show flux of all ions (E < 25 eV; 9 amu < M < 50 amu)
- Flux is measured separately for ions moving downstream and returning upstream
- Net escape is difference between these two
- Premature to give a number due to coverage, calibration issues, etc., but this demonstrates that conclusions will be robust

# Status of Spacecraft and Instruments

- Spacecraft and instruments fully operational
- Meeting Level 1 science requirements
- Fuel usage nominal so far
  - Lack of an MOI upset freed up the fuel allocated for recovery to be used instead for an extended mission
  - Fuel usage during primary mission to date is at (or modestly below) the predicted nominal levels
  - Potential for sufficient fuel for 10-year mission lifetime (includes nominal mission, extended mission in full-science mode for ~32 mo., raise periapsis, continue long-duration extended science/relay mission for six yrs.)
- No evidence of degradation in limited-lifetime items
- Have fully tested Electra relay; prepared to carry out relay contact if necessary

# Science and Instrument Status

- Science primary mission
  - Spacecraft and instrument ops going smoothly in general
  - Science instruments are returning high-quality data
- Successful first deep-dip campaign, 10-18 Feb. 2015
  - Intense planning and testing effort
  - Daily cadence of NAV tracking/analysis, maneuver decisions
  - Second deep-dip walk-in scheduled to begin 14 April
- Instrument watch items (mitigable, not expected to affect ability to meet Level 1s)
  - IUVS calibration
  - NGIMS contamination and/or defocusing
  - Solar-array magnetic field
  - STATIC anomalous ion measurements
  - Spacecraft charging effects
- MAVEN publications status
  - Space Science Reviews manuscripts
  - Comet Siding Spring manuscripts submitted
  - First-results manuscripts coming up

# Lessons Learned

- MAVEN launched on schedule, with full technical capability
- Budget at confirmation was $671.2M, life-cycle cost adjusted to $606.7M after MOI to reflect cost savings during development; allowed funding of science team at robust levels
- Key identifiable drivers allowing success
  - Flew the mission essentially as proposed; no major changes (exc. descopes necessitated by cost increases in Phase A)
  - Minimal changes to requirements; no science or engineering creep
  - Adequate cost reserves built in from the beginning
  - Contractual mechanism with spacecraft contractor that facilitated cost control
  - Real heritage in spacecraft and instruments, both institutionally and with the key individuals involved
  - No technology development required
  - Strong project management; pushed decisions to appropriate level; minimal revisiting of decisions
  - Appropriate degree of support from GSFC

# Issues and Concerns

- Conference-travel approval process
- Potential use of MAVEN as a relay during extended mission
- Potential that budget cuts in extended mission will impact mission ops and science; detailed analysis in progress
- Potential that aerobraking into a more-favorable relay orbit will be required; major impact to MAVEN science, but not yet formally taken off of the table
- MAVEN is observing during a weak solar cycle; declining solar cycle during extended mission

# Summary

MAVEN
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- MAVEN launched on schedule, under budget, and with full technical capability.
- MAVEN is operating well, has already made significant discoveries about the Mars system, and is on track to achieve its science goals for the primary mission.
- There are significant additional, high-priority science goals that can be addressed during an extended mission.