MAVEN

Expanded Understanding of Thermosphere-Ionosphere-Magnetosphere Processes Using MAVEN's Mars Discoveries

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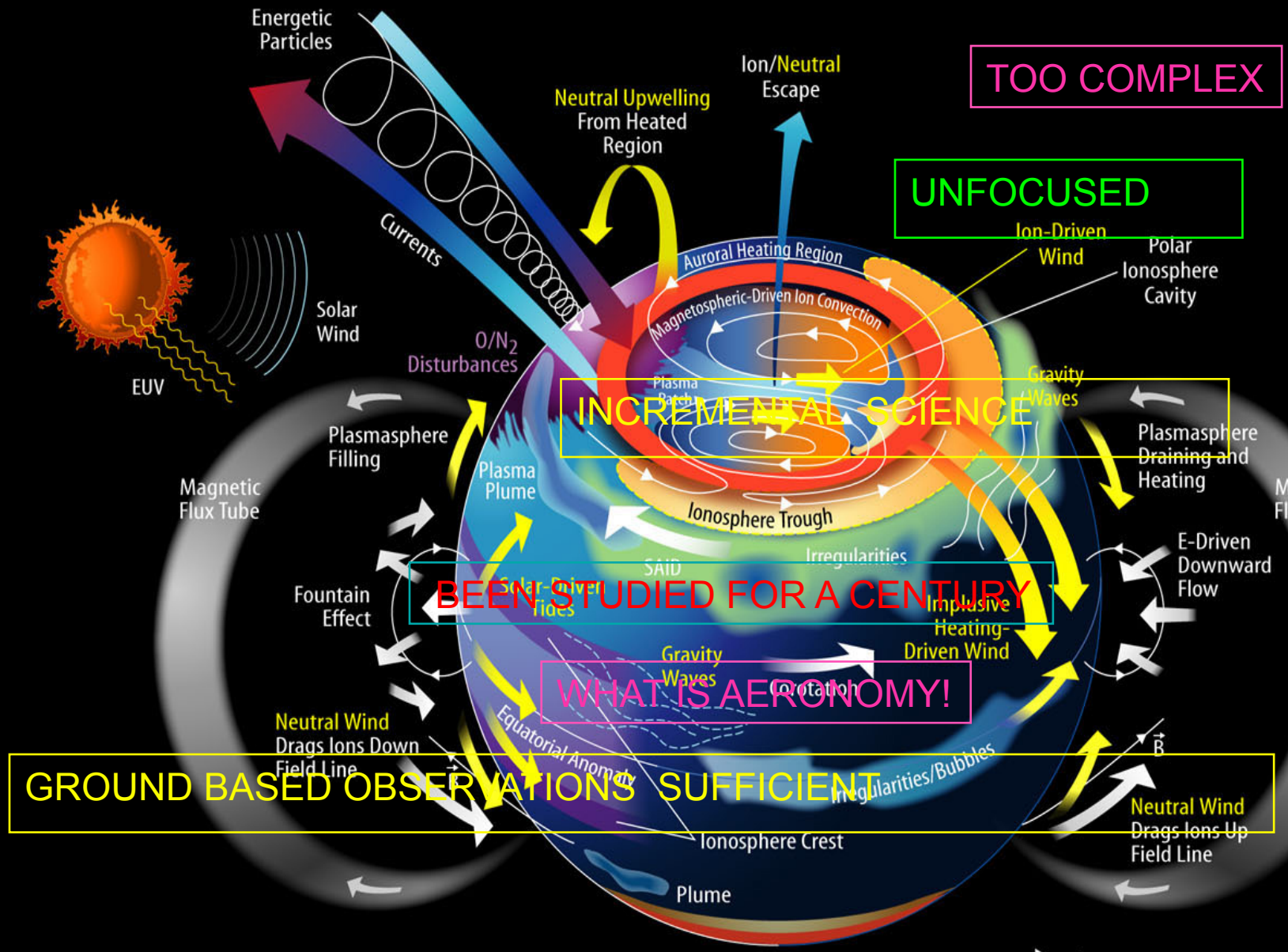
COMMENTS Heard ON ITM Mission PROPOSALS



TOO COMPLEX

UNFOCUSED

INCREMENTAL SCIENCE

BEEN STUDIED FOR A CENTURY

WHAT IS AERONOMY!

GROUND BASED OBSERVATIONS SUFFICIENT

IT COMMUNITY NEEDS TO GET ITS ACT TOGETHER

J. Grebowsky

MAVEN Proposal Strategy

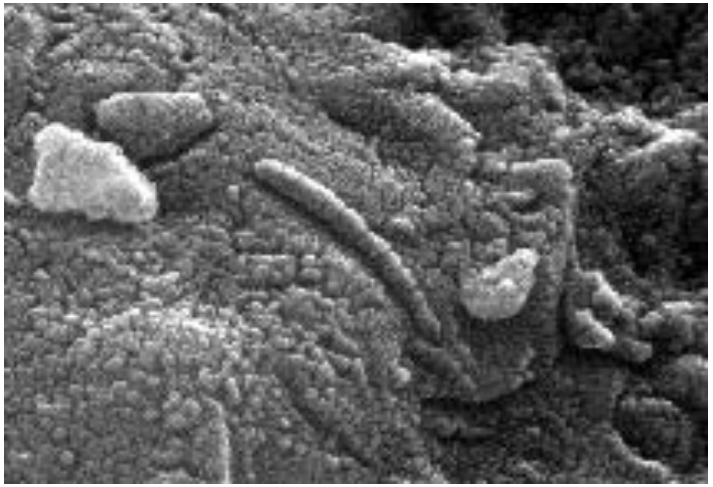
- Best ionosphere-thermosphere-magnetosphere coupling mission I've other been involved with (an aside: all others were not flown..)
- Was not selected because of ITM value alone
- When MAVEN proposal was written it was thoroughly scoured to make sure the word "Aeronomy" appeared nowhere.
- Why was it selected – it found a focus...

THE SELLING POINT FOR A MARS ITM EXPLORATION MISSION

Why the great interest in Mars: Did Mars Ever Have Life?

Mars appears to meet or have met all of the environmental requirements for the occurrence of life:

- Liquid water
- Access to the biogenic elements
- Source of energy to drive metabolism



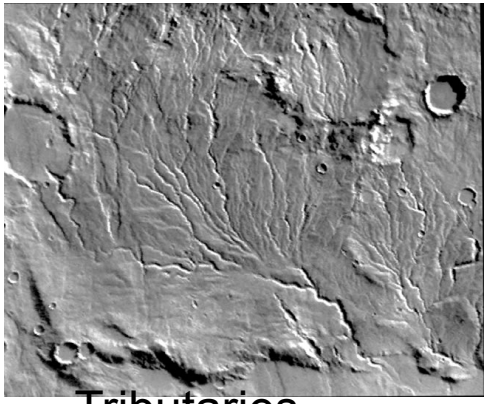
Did Mars ever have life?

How did any life interact with its planetary environment?

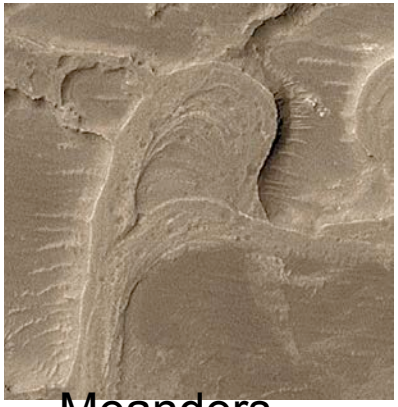
How has the habitability of Mars changed over time?

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

Abundant evidence for ancient water

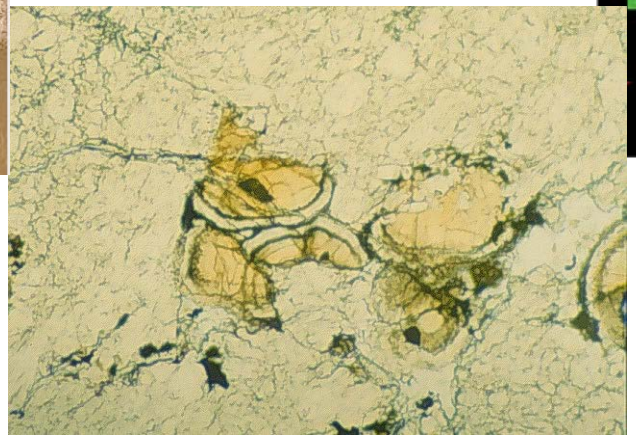


Tributaries



Meanders

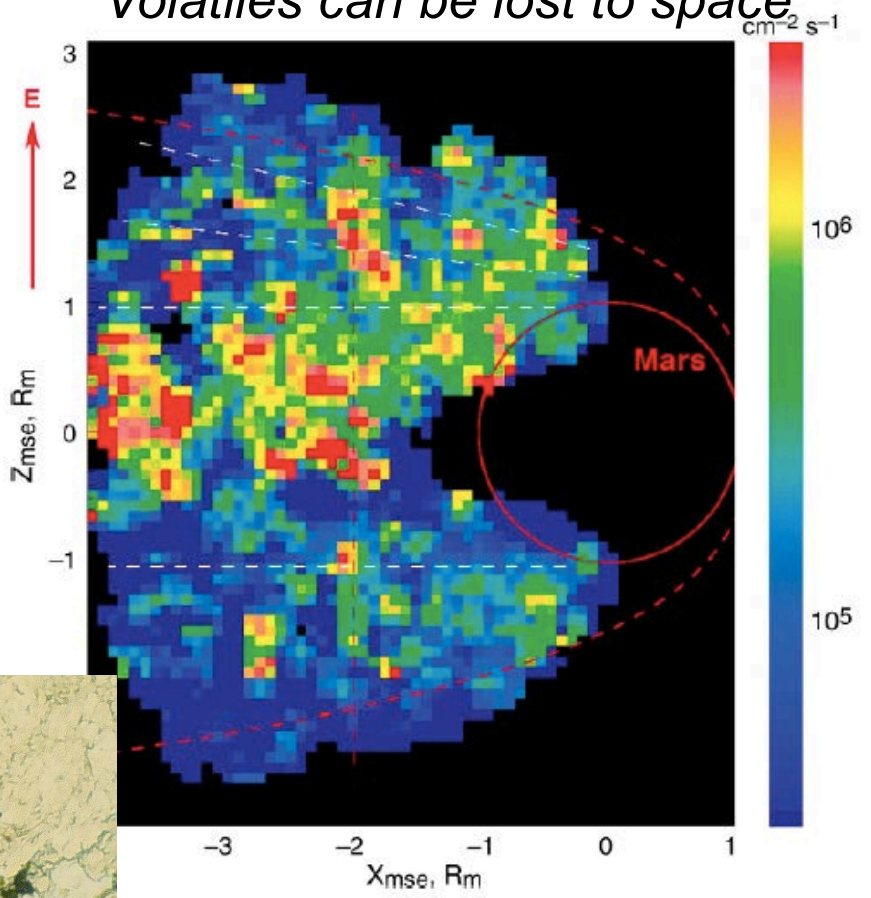
Sedimentary Layering



Carbonate deposits in a Martian meteorite

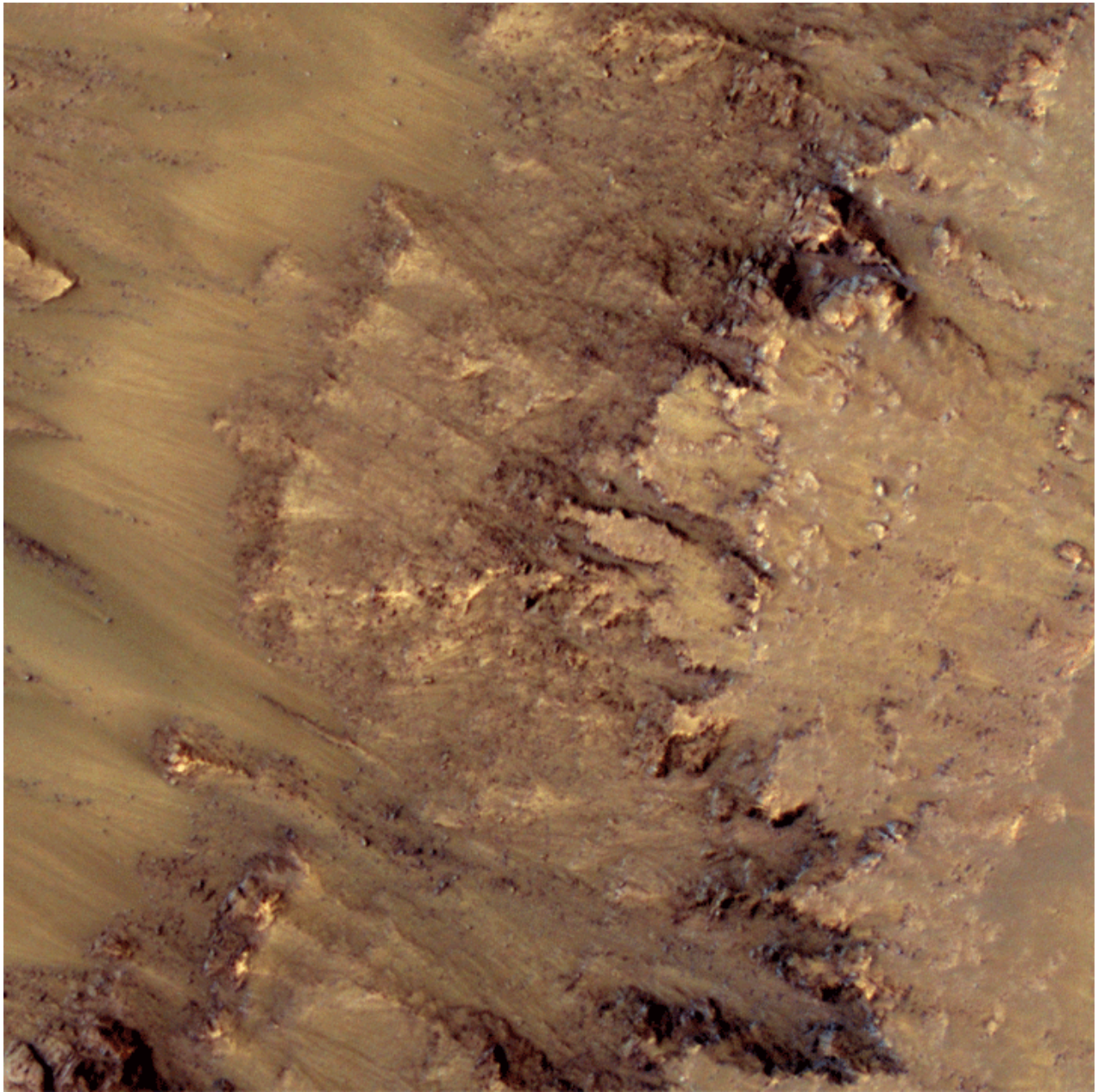
Volatiles can go into the crust

Volatiles can be lost to space

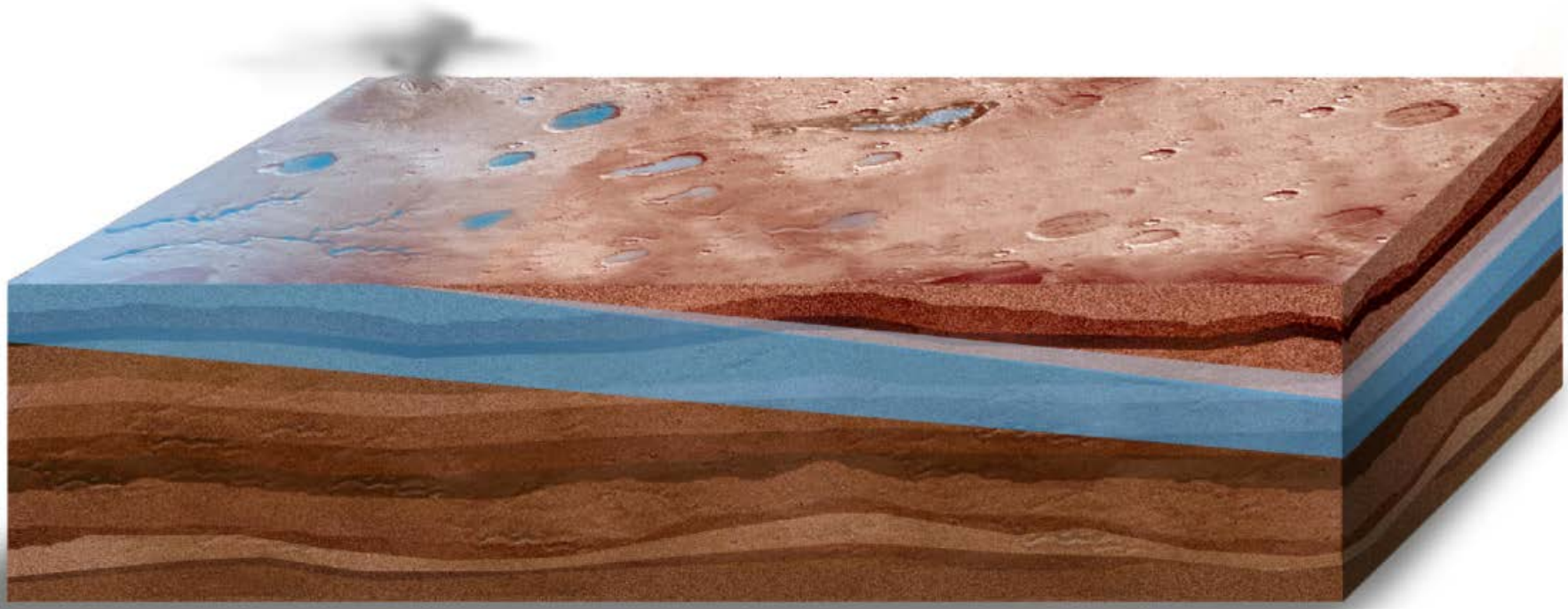


Escaping ions detected from Mars Express

Bursts of Liquid Water Occurs at the Surface Even Today



Conditions That Could Sustain Life on Mars: Changes Over the Eons

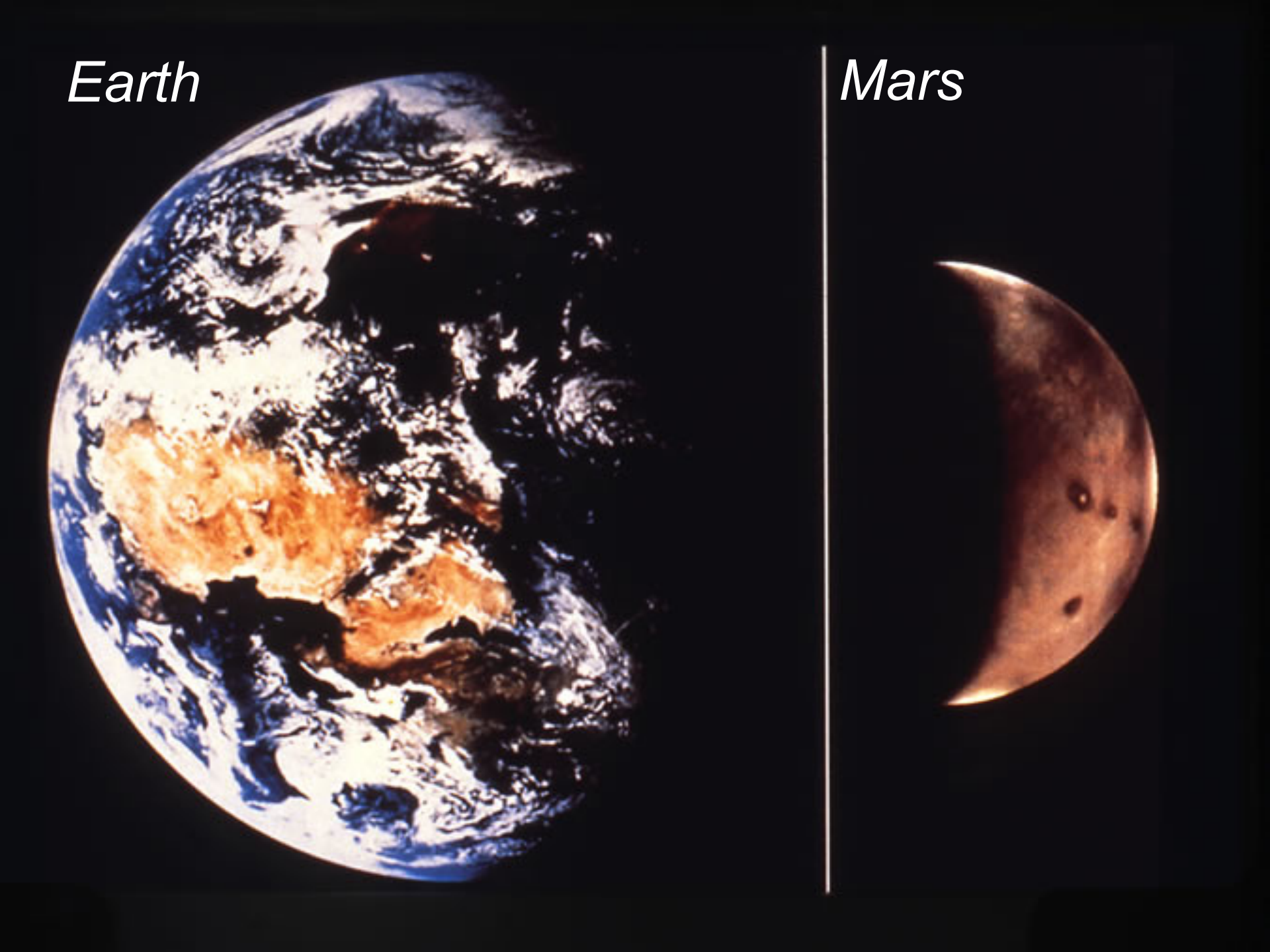


4.5 3.8? Today

Billions of Years Ago

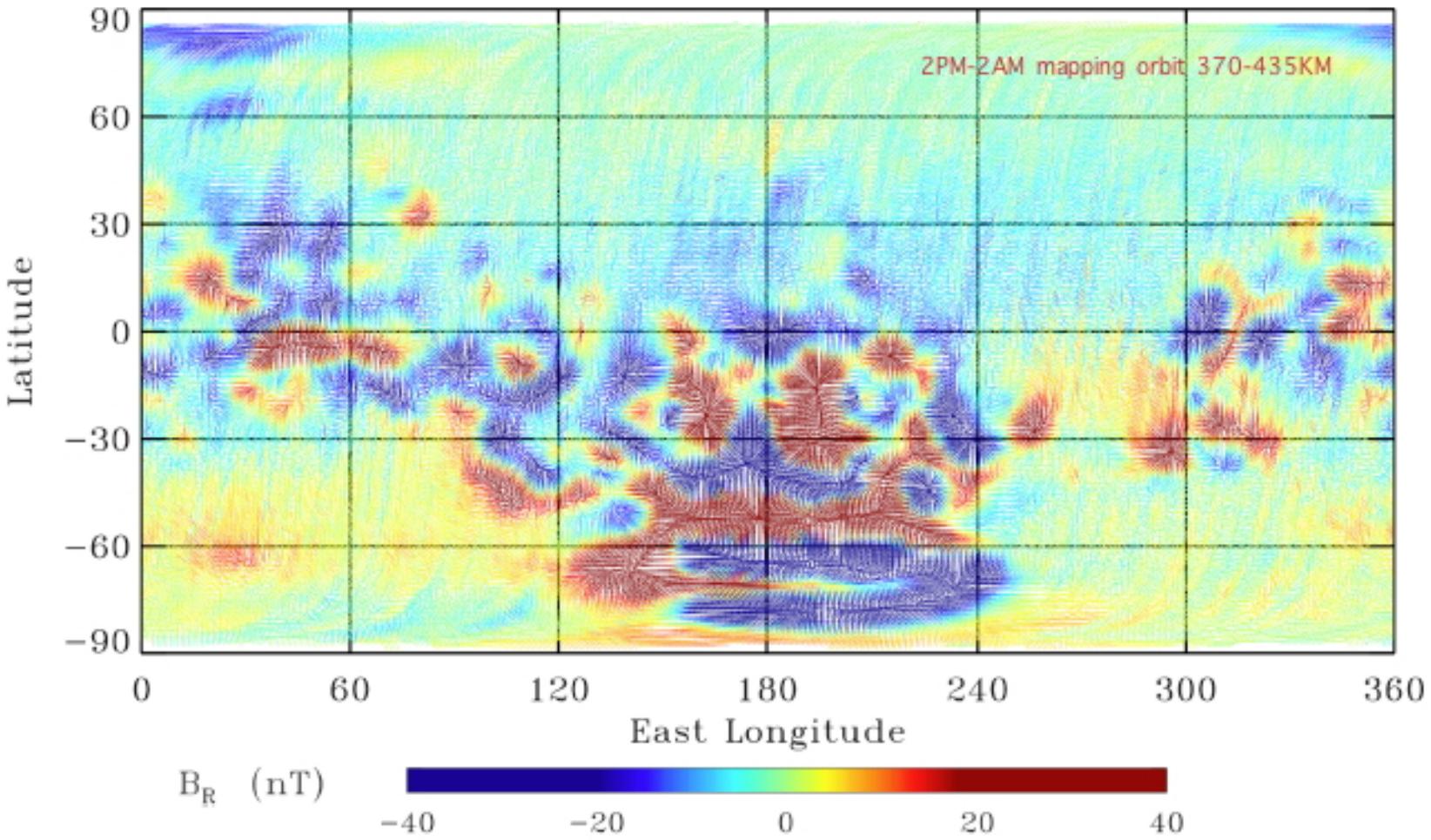
Des Marais, 8th Mars Conference

(Des Marais et al., 2008)


Earth
Mars

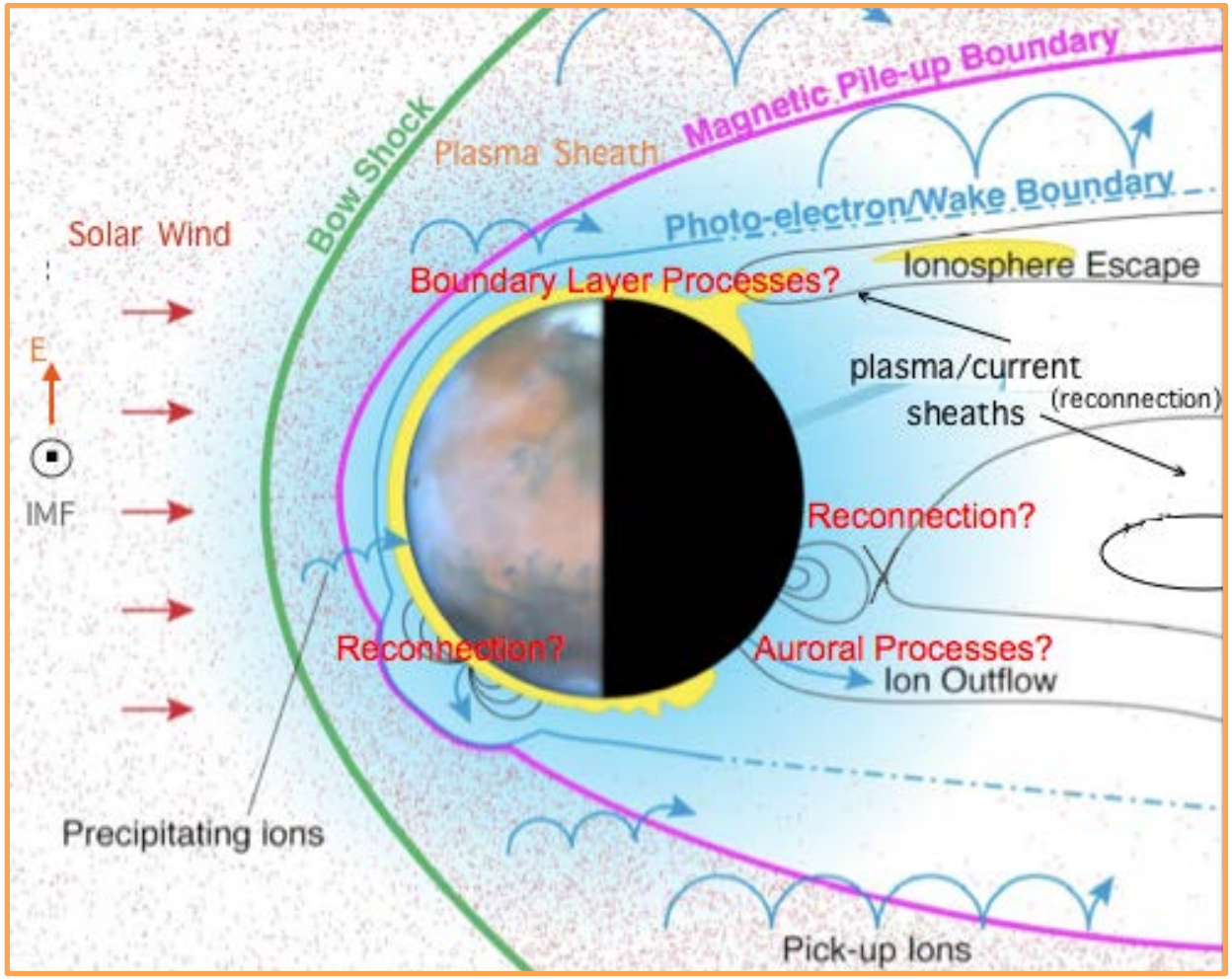
When Magnetic Field Vanished Solar Wind is Able to Strip Off Gas from the Top of the Atmosphere

But, A Plasma Complexity: Fossil Magnetic Fields Brings in Inner Magnetosphere Phenomena



- Radial B field from MGS binned 1°X1° (Connerney et al. 2001) –bipolar field regions are connected (dipoles)
- Highest measured B at 100 km exceeded 1500 nT
- Predominantly in **southern hemisphere**, in one longitude zone

Magnetosphere Processes



- Solar wind, IMF and Convection Electric Field Inputs to the Mars Conducting Ionosphere and its Imbedded B-Fields Drive Well-Studied Heliophysics Processes

MAVEN Goal: Understand Escape of Atmospheric Gases to Space

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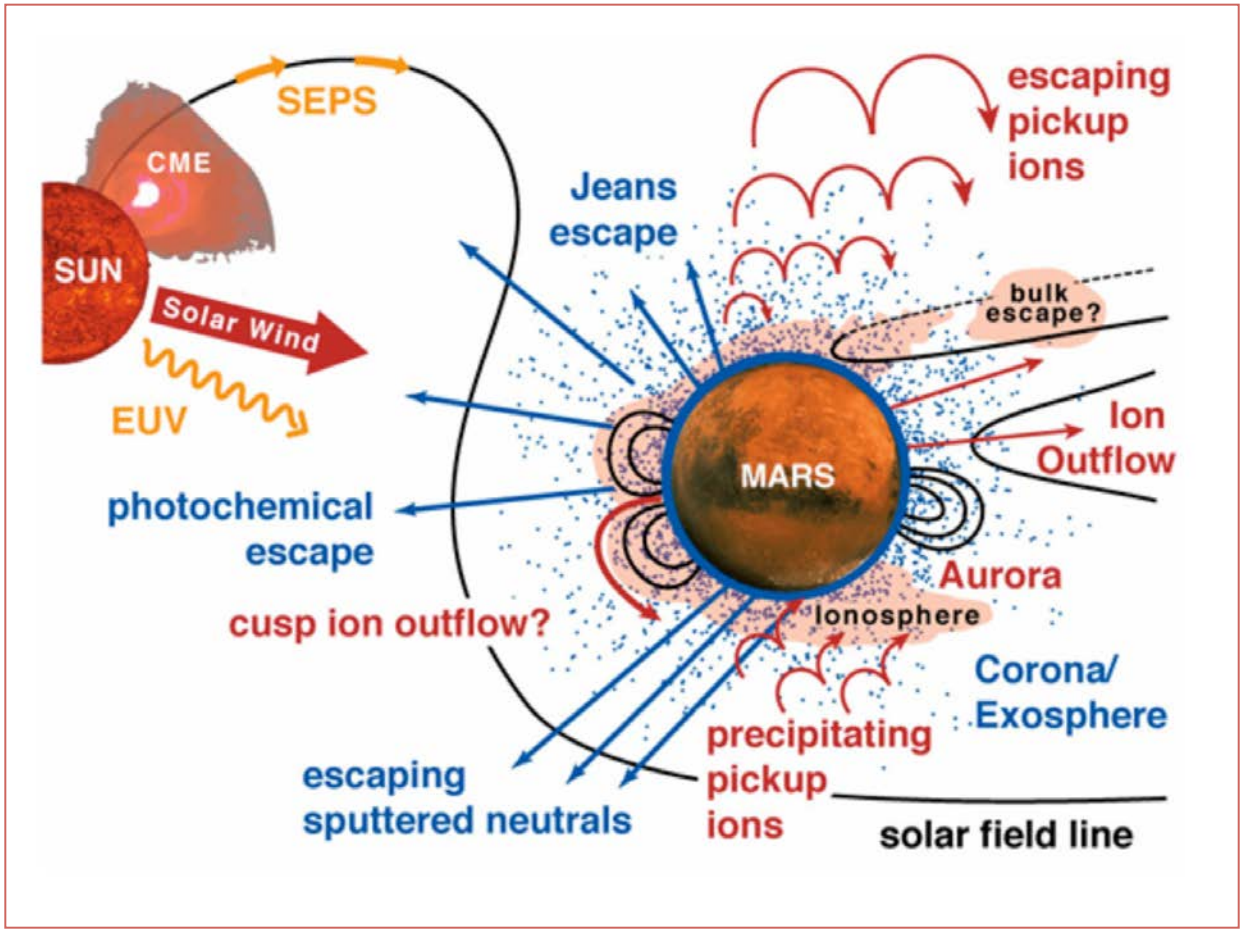
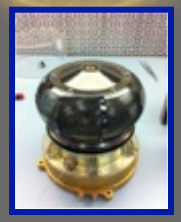


- Measure energetic drivers from the Sun, response of upper atmosphere and ionosphere, and resulting escape to space
- Understand the key processes involved, allowing extrapolation to loss over Mars history

The MAVEN Science Instruments:

Sun, Solar Wind, Solar Storms



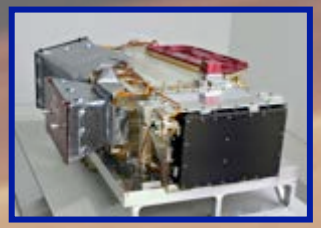
SWEA

SEP

EUV

SWIA

Neutrals and Ions Plus Evolution



IUVS

NGIMS

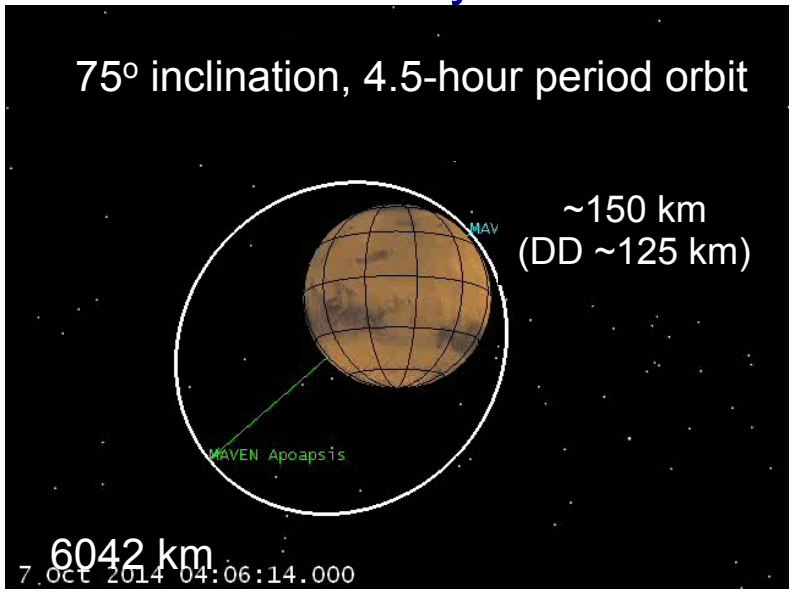
Ion-Related Properties and Processes

STATIC

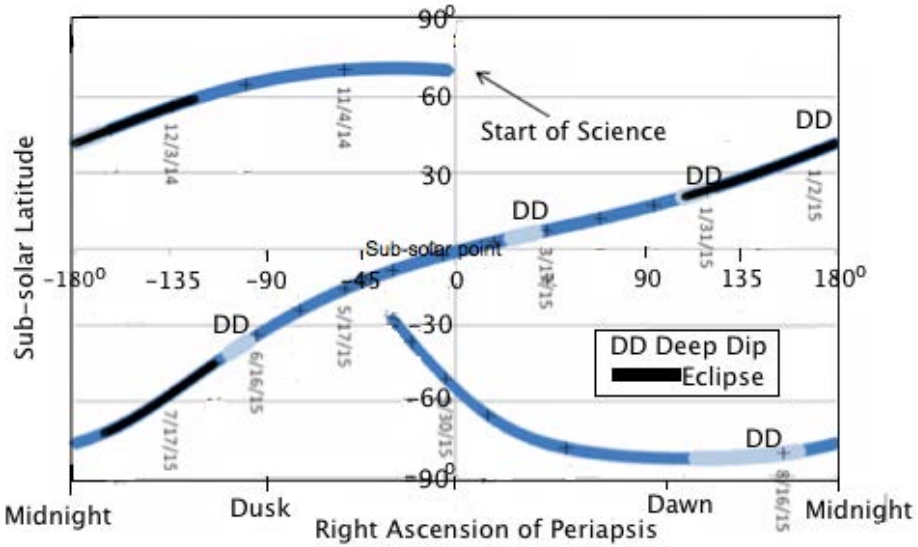
MAG

LPW

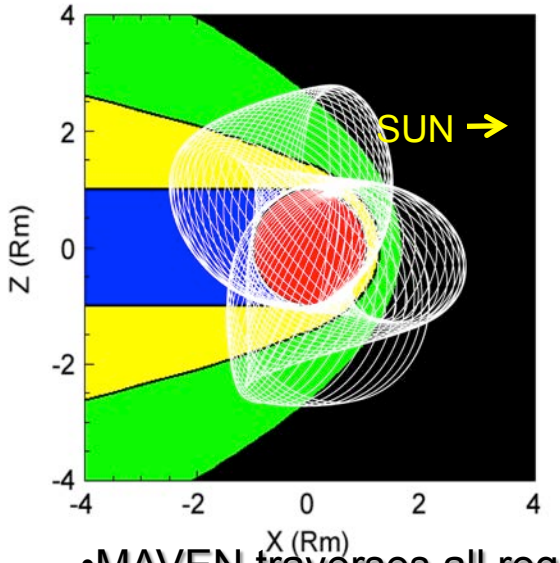
Judiciously Selected orbit (21 September 2014 Insertion)

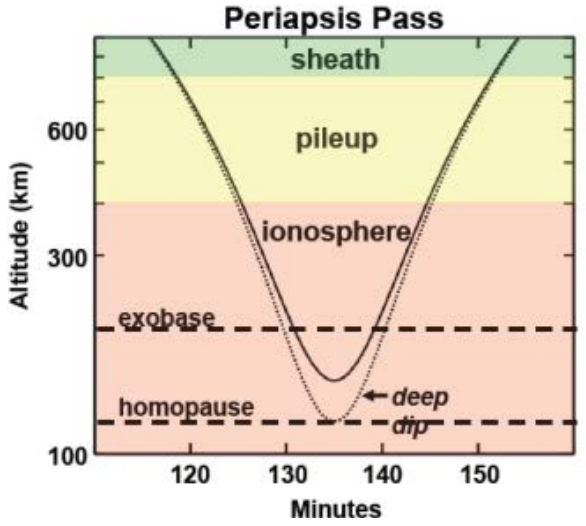


Periapsis Coverage of Latitude-Local Time



Looking Down on Polar Cap





Five 5-day "deep dip" campaigns

- MAVEN traverses all regimes

(solar wind; sheath, tail, below exobase)

MAVEN's Mission Samples Different Solar Conditions and Mars Orbit's Obliquity Varies EUV at Mars by ~40%

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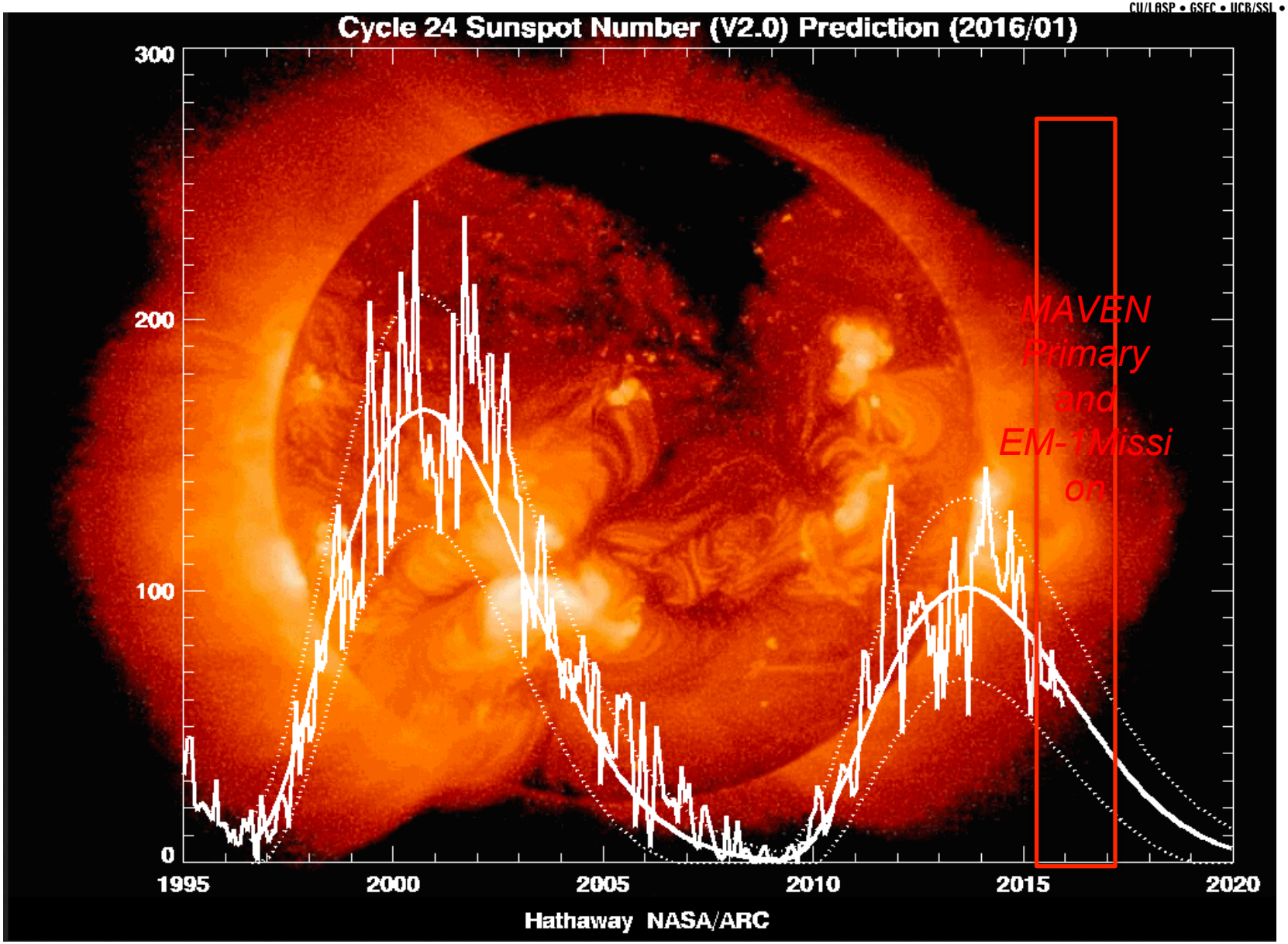
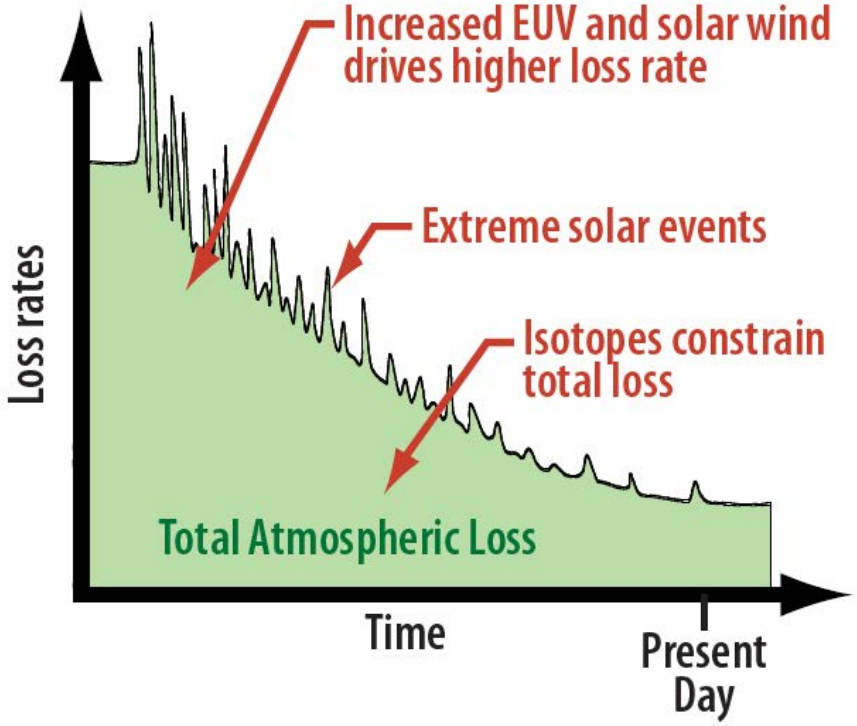


Constraining Atmospheric Loss Through Time



- From history of solar activity (from similar stars) and MAVEN's understanding of the physics of "all" escape processes and dependence on solar wind and EUV, can extrapolate losses back in time
- MAVEN **targeted the declining phase of solar cycle** to provide maximum variation in solar wind drivers

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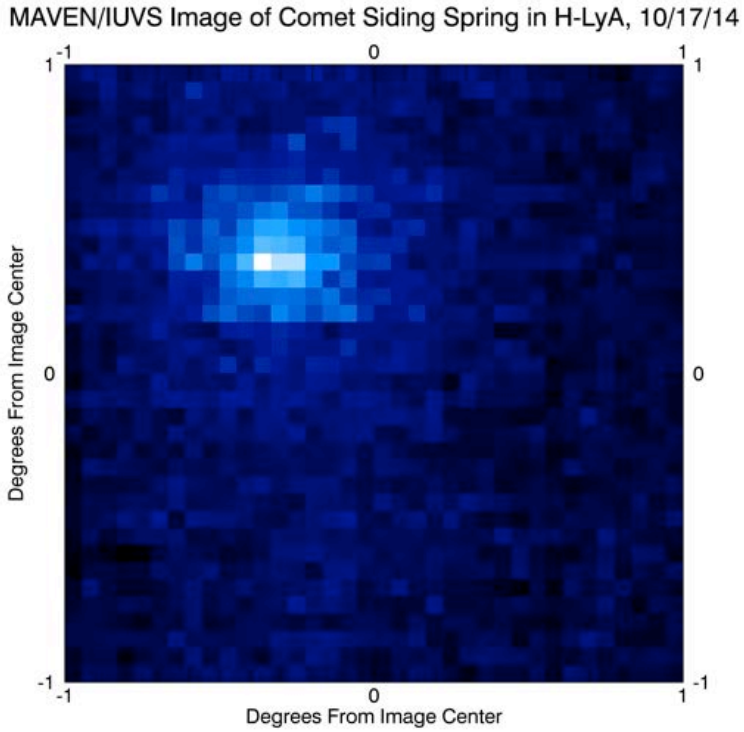
A Few of MAVEN's Many Mars Discoveries Follows

First science: Close Encounter With Comet

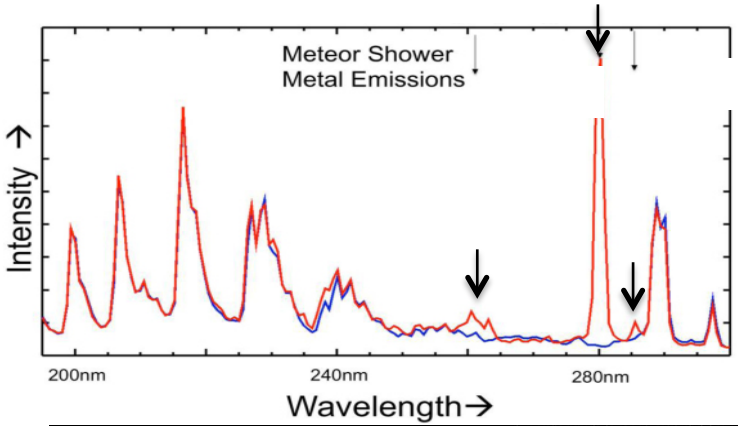
Breckland Skies Observatory

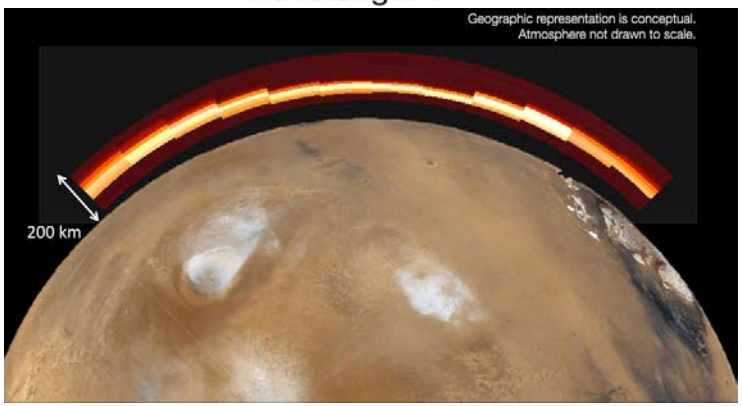
- Comet Siding Spring had close approach (~140,000 km) to Mars on 19 Oct. 2014
- Spacecraft took protective measures to ensure safety

- MAVEN IUVS imaged CSS in solar Lyman-alpha two days before closest H detected to
- If flown past Earth it would have been a spectacular event passing between the Earth and Moon

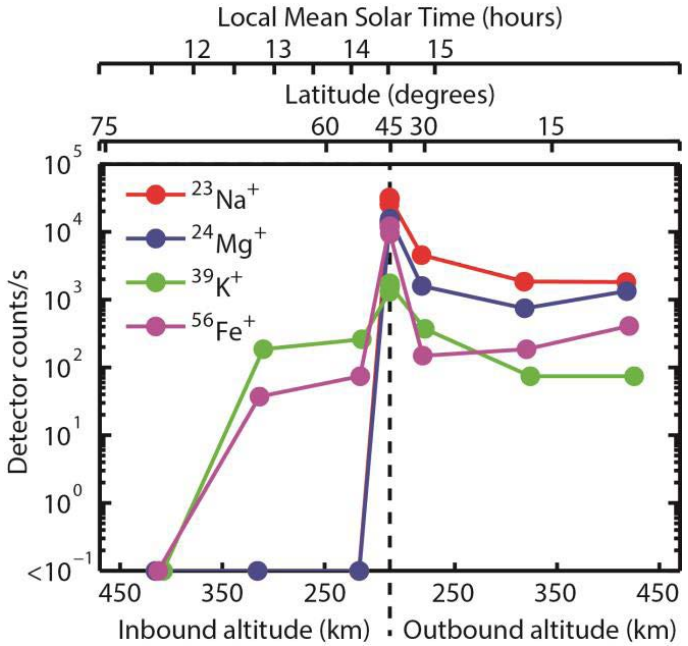


Consequences of the Comet





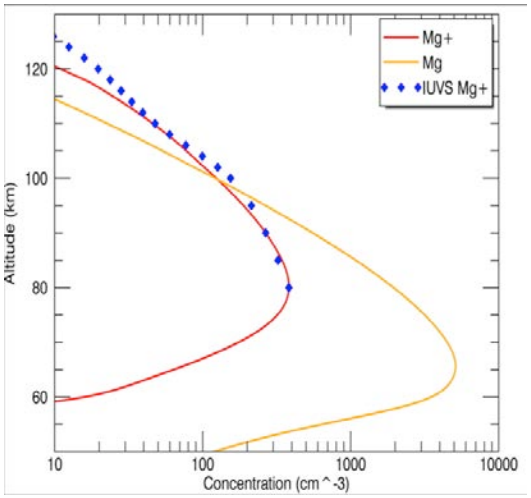
- Cometary dust impacting Mars' atmosphere at high speed (56 km/s) was vaporized and ionized
- IUVS saw very bright emissions due to metal ions (left) – 120-150 tangent altitude over a broad latitude range
- NGIMS detected 11 different metal ions (bottom) *in situ* from periapsis altitude of ~185 km to above 300 km

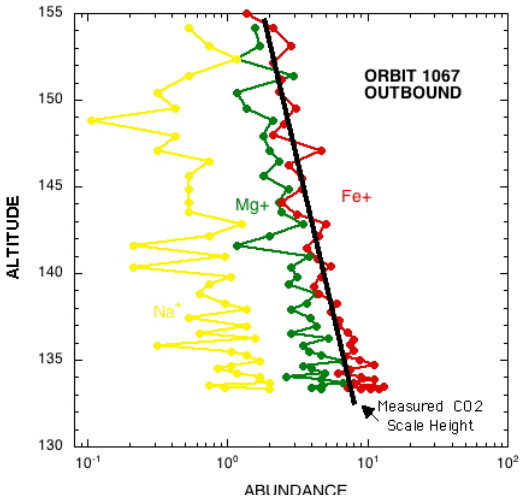


- Following the ~1 hour localized deposition of 3000 to 16000 kg, metal ion detections lasted for days
- Magnetosphere perturbations were lalso seen consistent with a storm produces by the impact of the comet's ion coma

Permanent Metallic-Ion Layer Exists Unrelated to Comet

Main Ion DepositonLayer



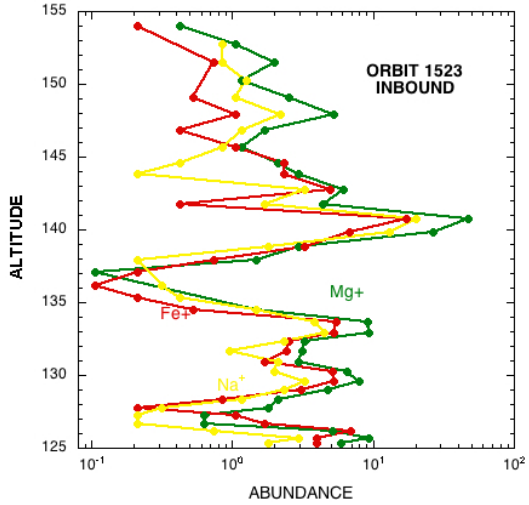


NH NGIMS – 3 metals
Topside of Later

Vertical eddy diffusion from ablation zone below 100 km – well mixed

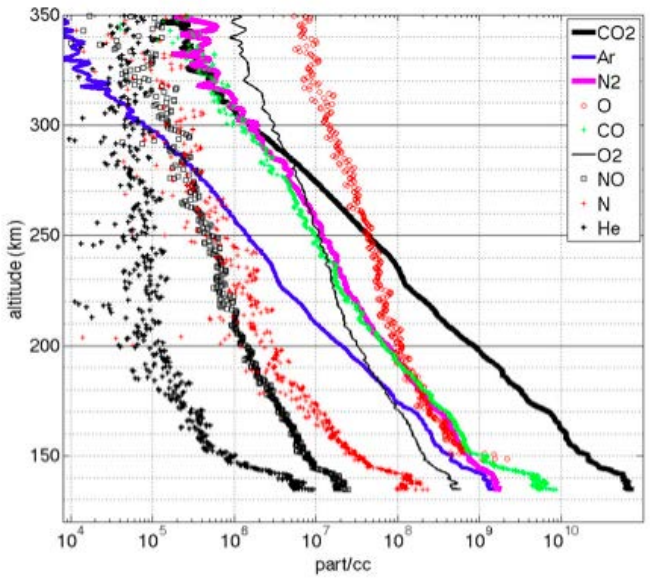
- Low altitude electron layers from metals had previous been inferred from *Mars Express* Radio occultations
- IUVS detects Mg+, Fe+ in ablation zone on every limb scan in daylight
- NGIMS (right) always detects Mg+, Fe+, Na+ below 160 km

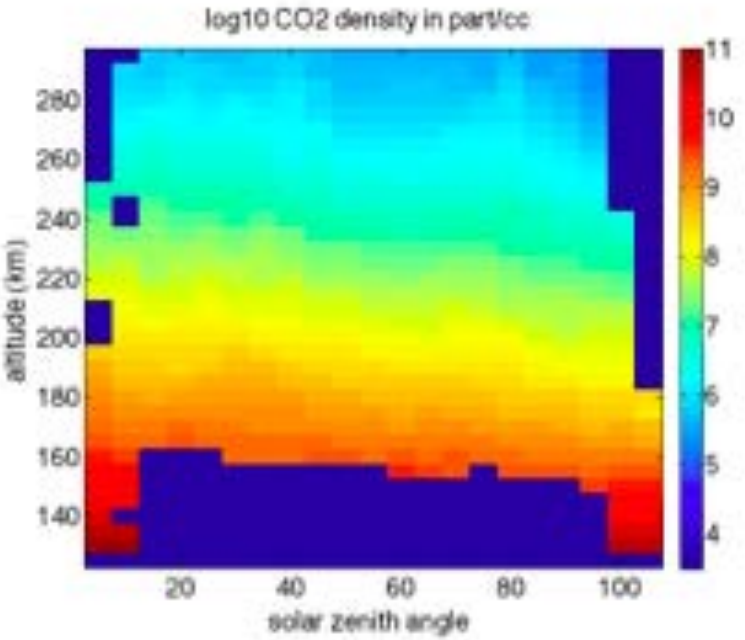
In SH Region with Remanent B-field
(Sporadic-E analogy)

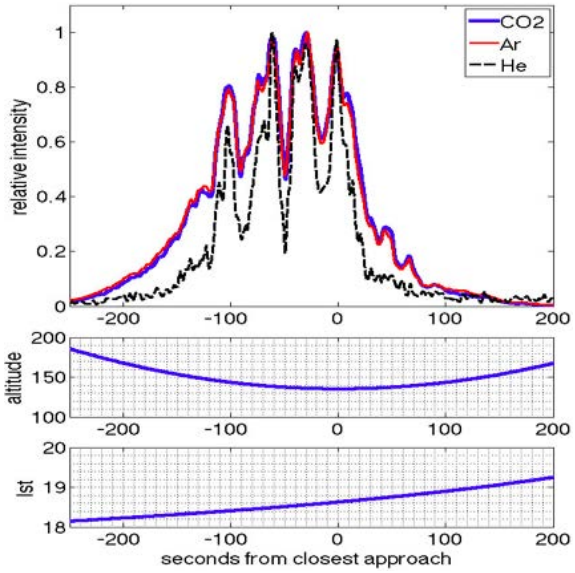


Wind Shears drag ions across and along B-fields

Mars atmosphere - predominantly CO_2







- First measurements of composition since Viking
- Temperatures from scale height measurements
- Planet-wide, gravity waves more prevalent than at Earth
- Cooling and drop of density going into darkness
- Very large wave structures at terminators

Extended IUVS Neutral Atmosphere Corona Measurements of Atomic Components of H_2O and CO_2 on Their Way to Escaping

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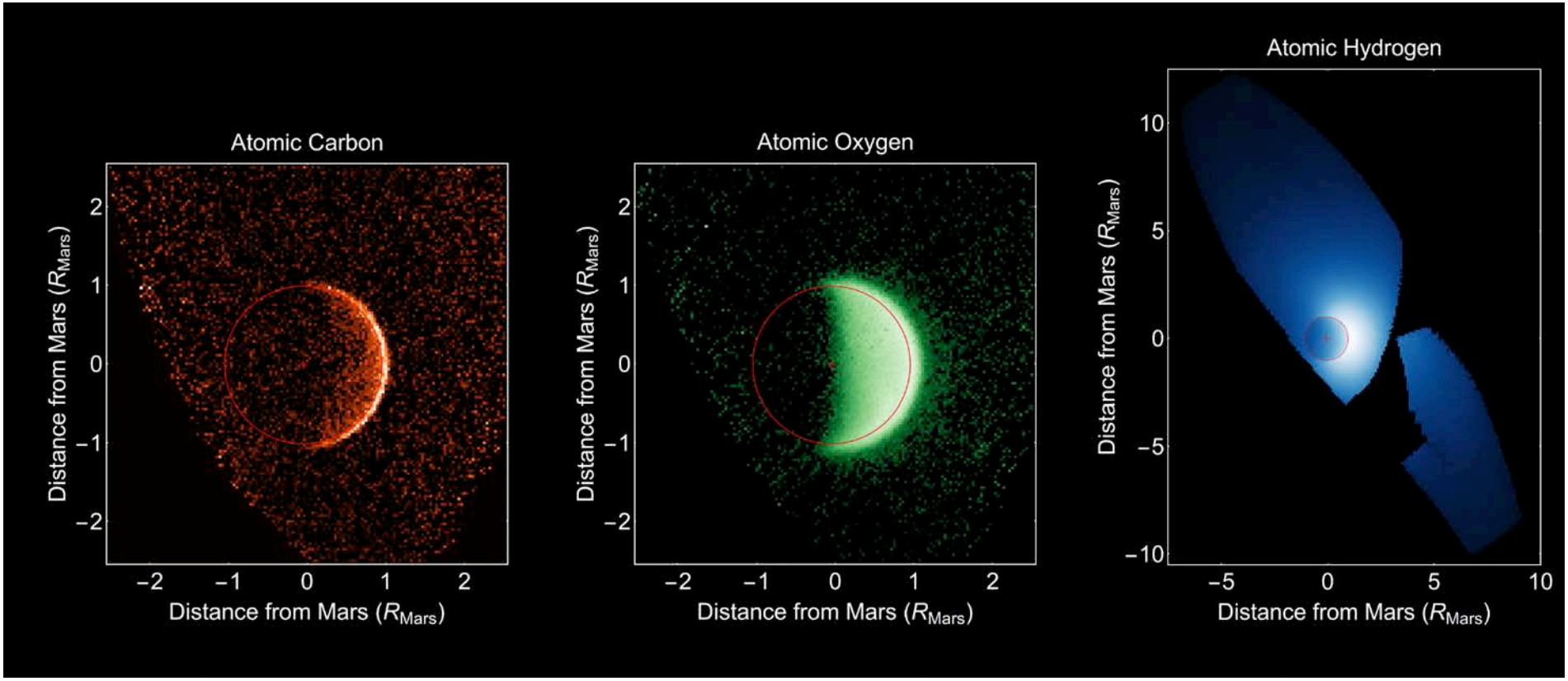
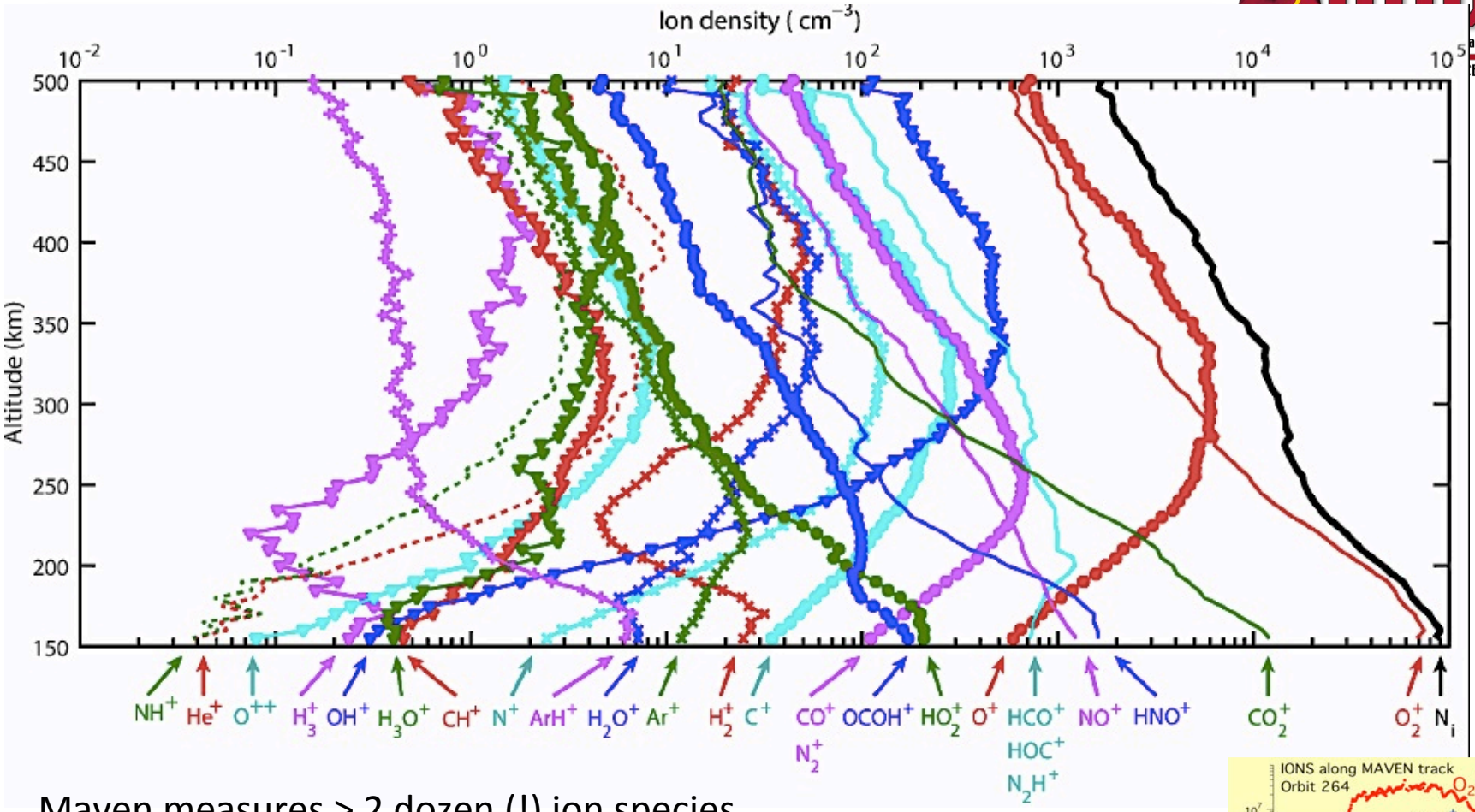


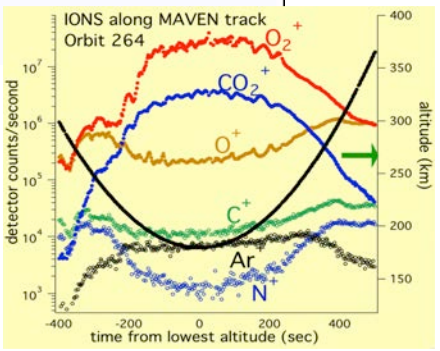
- Complex temporal and spatial variations seen in the coronas of these species – lack of spherical symmetry as modeled
- The measured H/D ratio, an important indicator of loss over time surprisingly shows unexpected seasonal or shorter temporal variations

Comprehensive Samplings of Ionosphere Composition

MAVEN
atile Evolution Mission
B/SSL • LIM • JPL



- Maven measures > 2 dozen (!) ion species,
- O_2^+ is major ion with peak below 160 km
- Dayside produced photochemical peak, $^+$ like the terrestrial E-region
- Note: the presence of water associated O-H containing molecules. Water transported from lower atmosphere? (Fox et al.,2015)



Note Waves

First Global Mapping of Ionosphere

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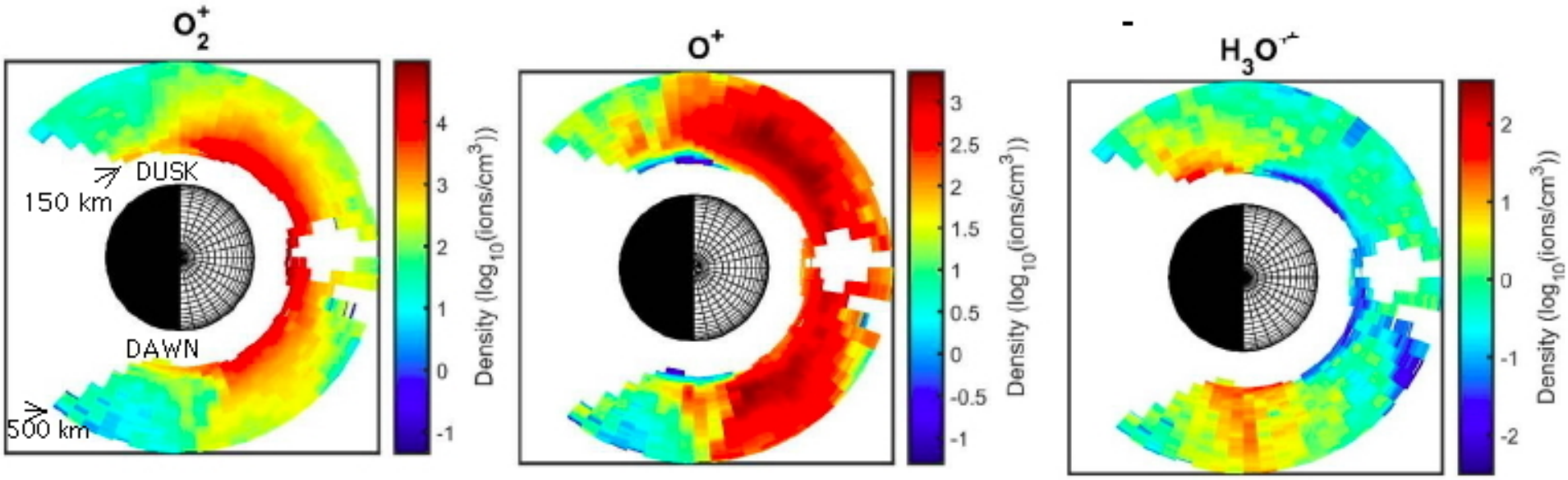
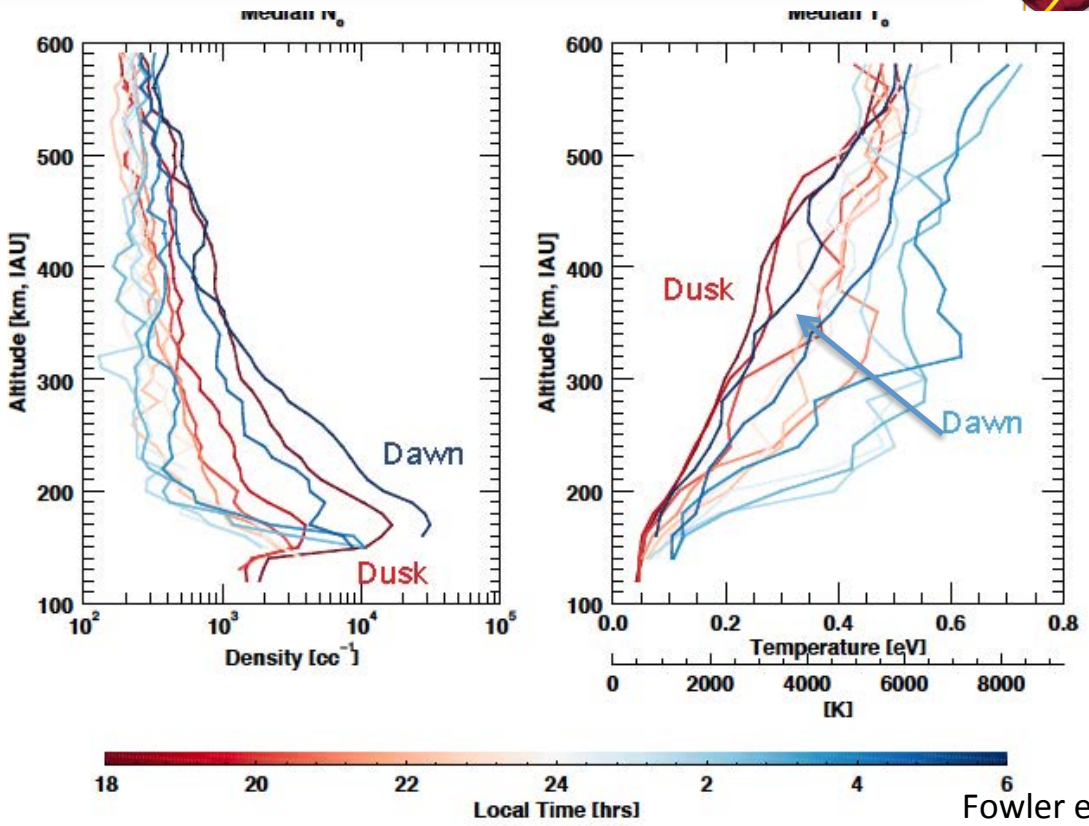


- O_2^+ transitions to O^+ at high altitude but no F-Region peak as on Earth.
- Prominent dawn-dusk asymmetries in major ions and water related species
- No such asymmetry at Earth (due to a nighttime scattered and stellar radiation sources)
- Source of Mars nightside ionosphere is transport from day and/or energetic particle precipitation.

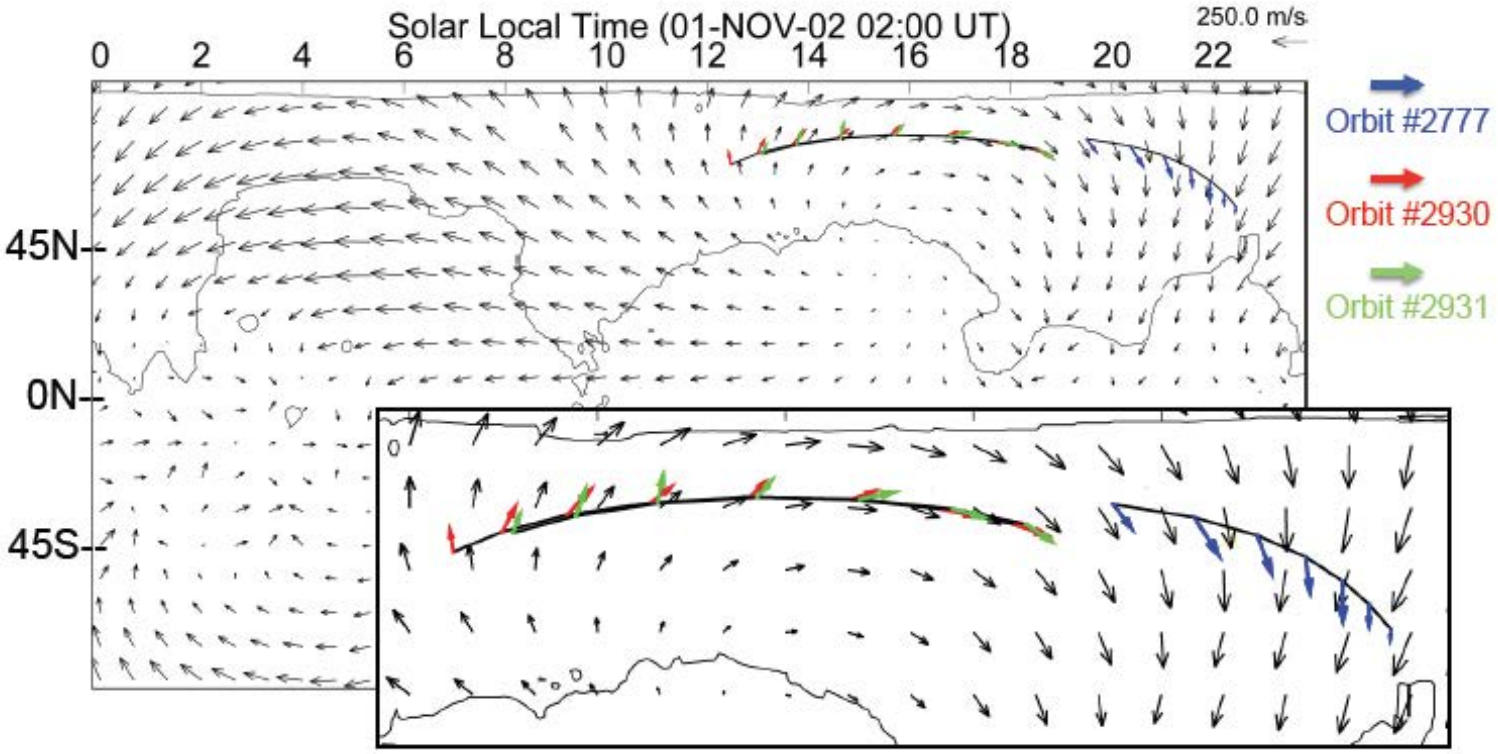
Ionosphere Transition into Night



Fowler et al, 2015 LPW data

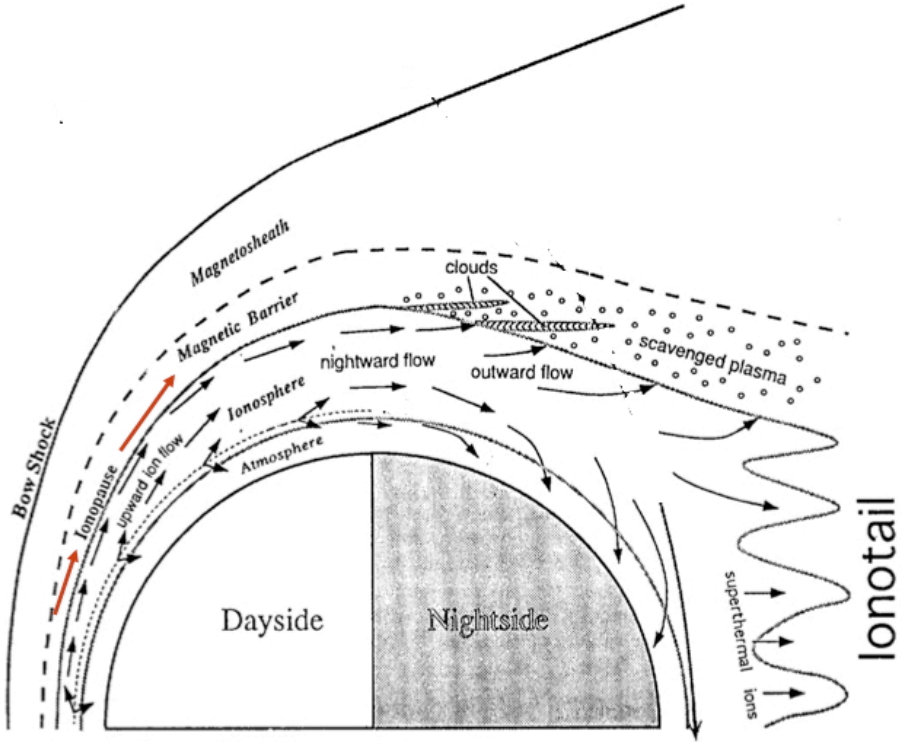
- Edensity, temperature profiles show striking terminator transition differences
- Typical conception: ionosphere rotates with planet, chemically decaying at dusk and photo-produced in dawn transition to sunlight. Maybe not true?
- On Earth it does due to dynamo electric field from high speed planetary co-rotation of atmosphere across B
- Solar heating produced day-to-night Mars wind speeds comparable to planetary surface rotation speed and no B in NH

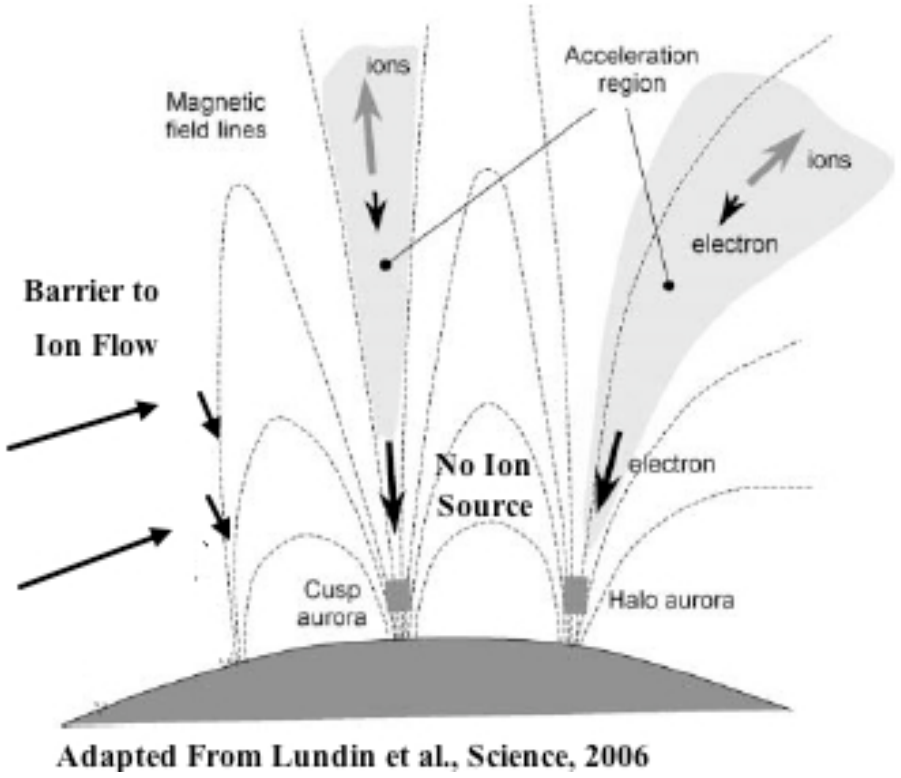
Mars Horizontal Neutral Winds and New Measurement Capability



- **Exciting** new MAVEN capability of NGIMS – measurement of neutral and ion winds
- Comparison of measured winds and geographical pattern from MGITM, with inset showing close-up of region containing measurements
- Winds of order of 250 km with definite dawn-dusk asymmetry

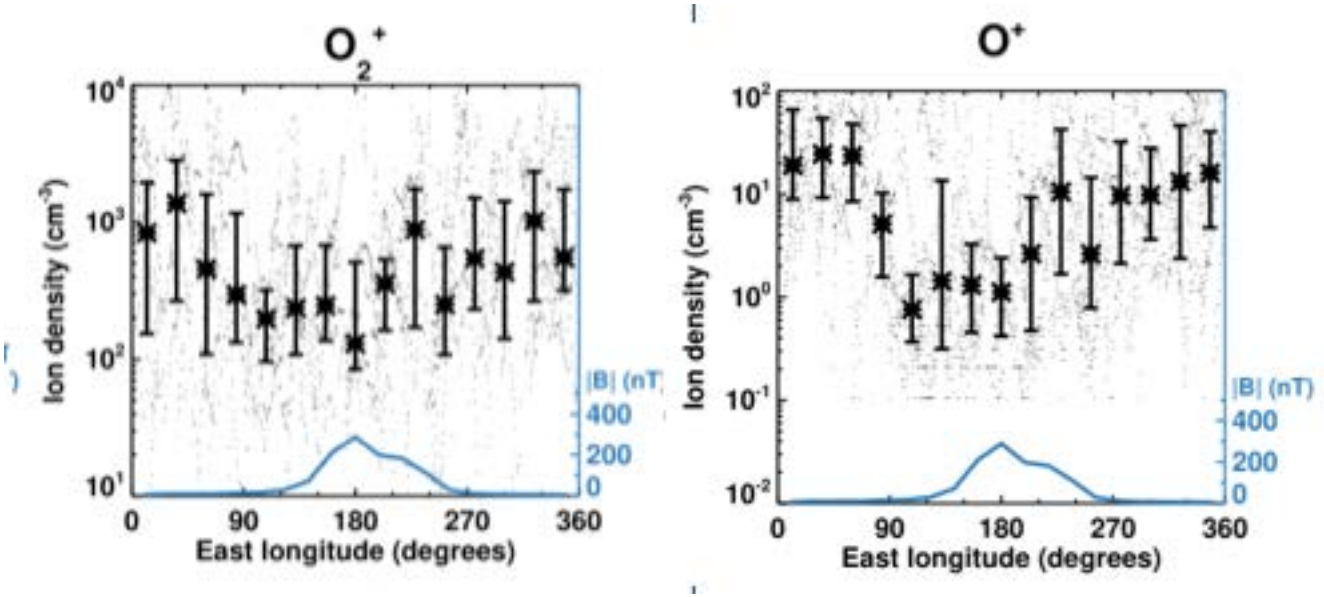
Source of Mars Nightside Ionosphere?





- Sources: 0_2^+, O^+ flow from day (from photo ionized source to chemical sink at night and Energetic particle precipitation

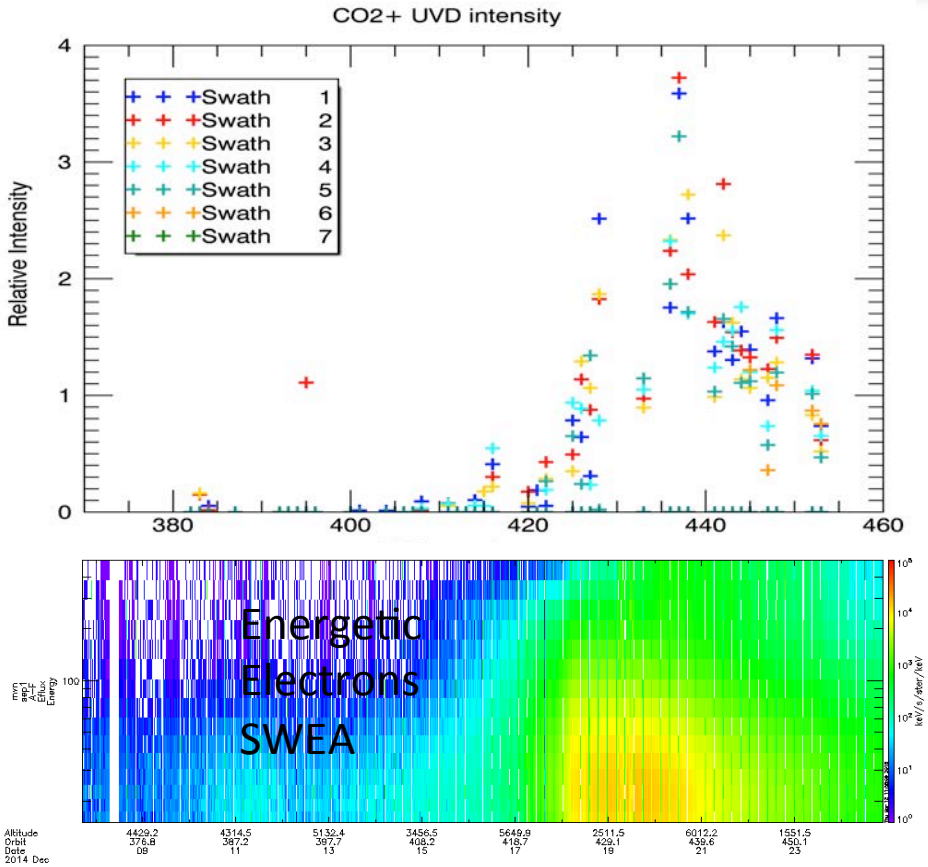
Effects of Magnetic Fields



Study by Girazian, 2016

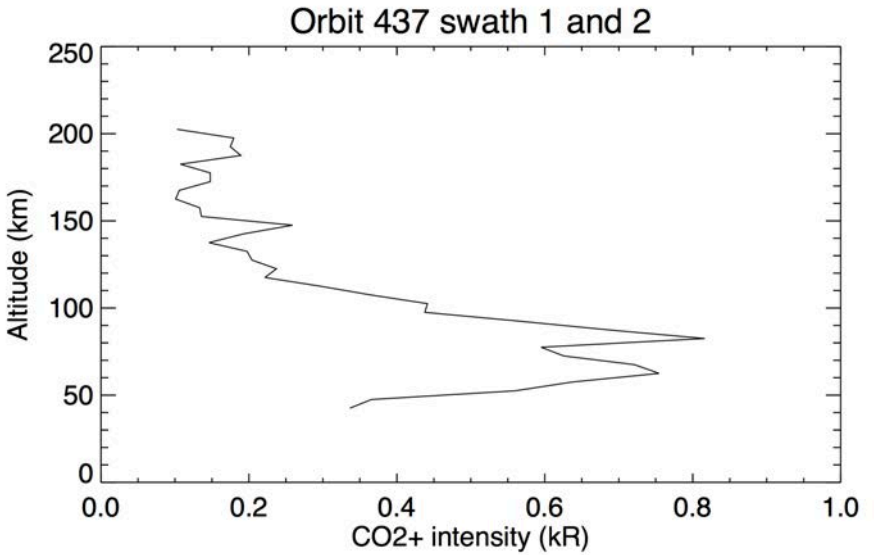
- Nightside altitude band concentrations of 2 ions in magnetic anomaly latitude zone
- Consistent with magnetic barrier to ions flowing from daylight and
- absence of energetic particles on closed field line
- Question being looked at –
  does main ionosphere layer rotate with planet into night

IUVS Detections of Diffuse (and discrete and proton) Aurora



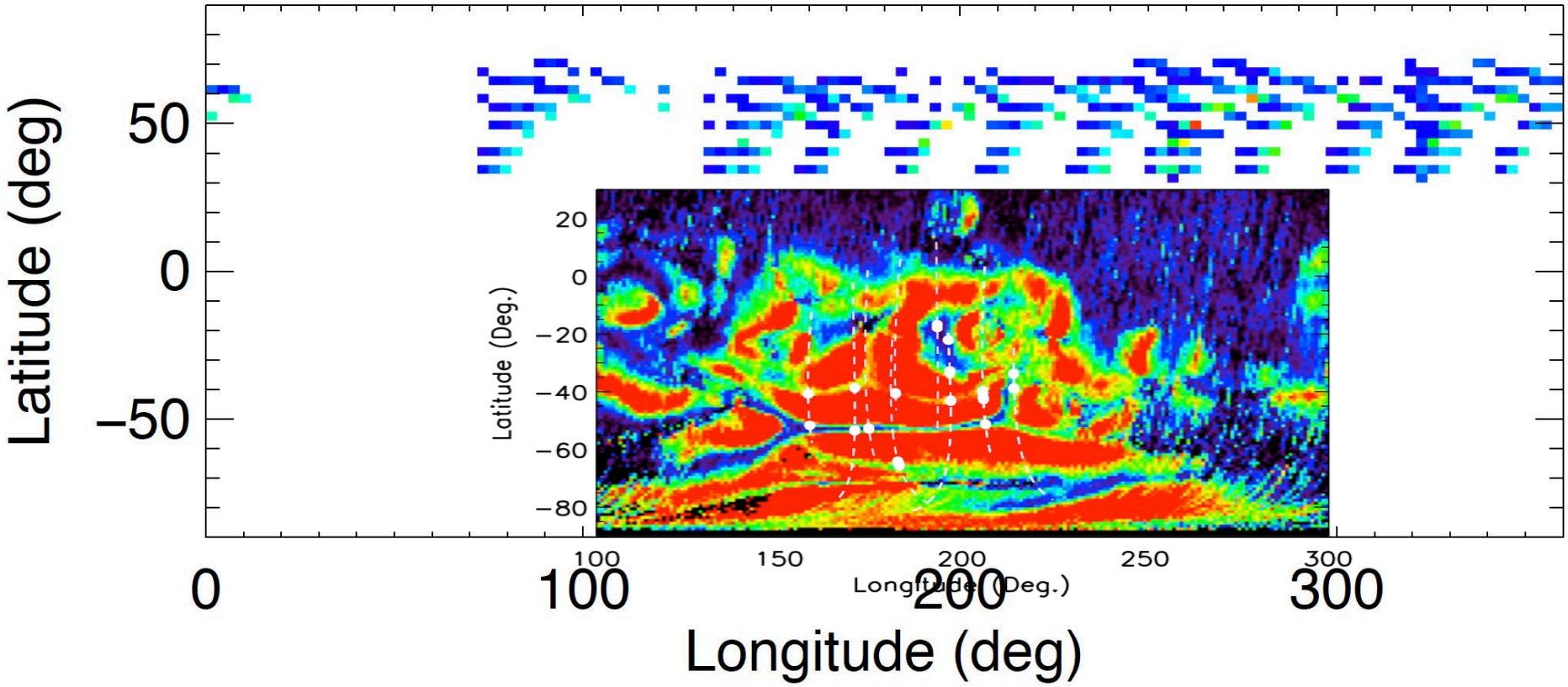
- Diffuse aurora, no apparent connection to magnetic fields as on Earth
- Occurs deep in upper atmosphere; requires extremely energetic electron flux
- Solar energetic-electron storm is the driver – arrived at Mars at the same time, has energies that penetrate to these altitudes
- Seen in NH every time an SEP event occurred

- *NOTE: MAVEN is now also observing discrete aurora in magnetic cusps – like MEx, and has recently identified proton aurora signatures*



(Radiance profile, not yet inverted to emission profile)

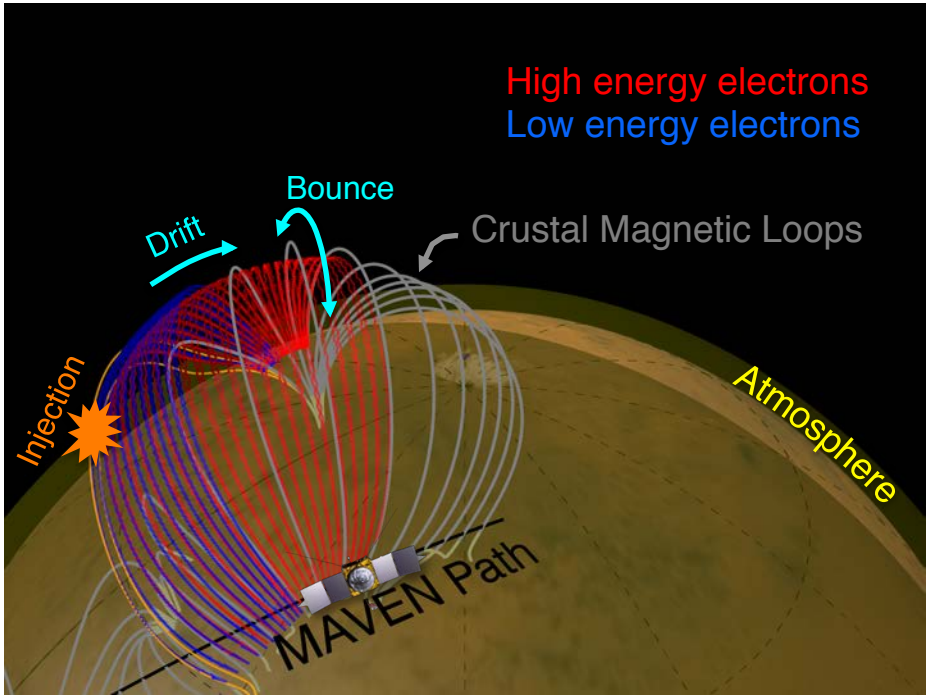
IUVS Diffuse Auroral Detections Span Much Of Northern Hemisphere

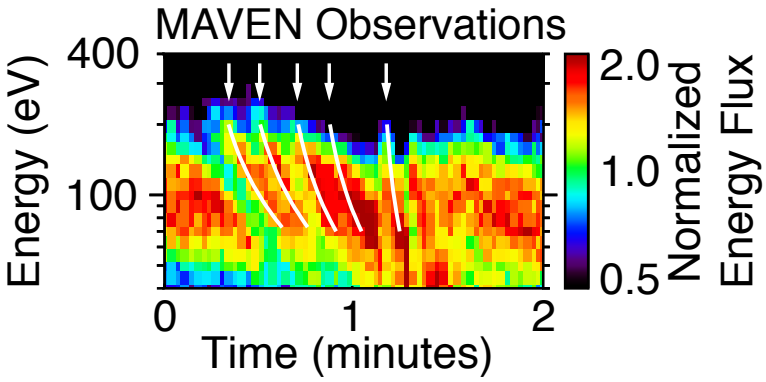


- Unlike discrete auroral detections by MEx SPICAM detections (white dots) at crustal field magnetic cusps, (now being measured by MAVEN)

Earthlike Inner Magnetosphere Trapped - Drifting Electrons

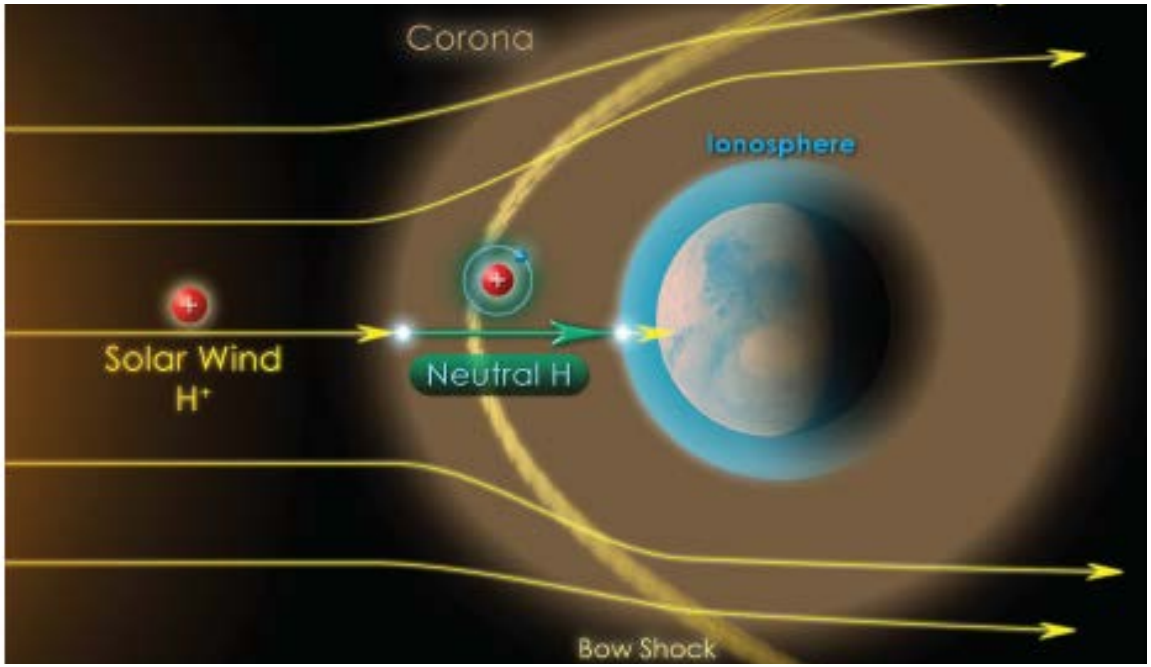
- Trapped electrons bouncing along the SH dipole loops drift pass MAVEN as they bounce.
- Dispersion: High energy electrons observed before low energy electrons (bottom figure).
- Many electron injection events observed over a short period (bottom figure) –source?
- Analogous to electron drifts in Earth's global dipole

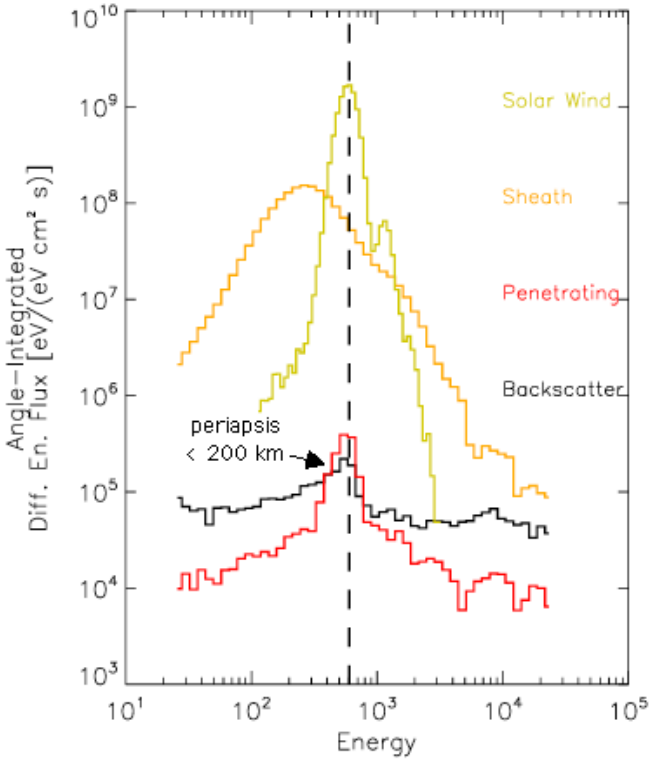




Harada, Y., et al. (2016),

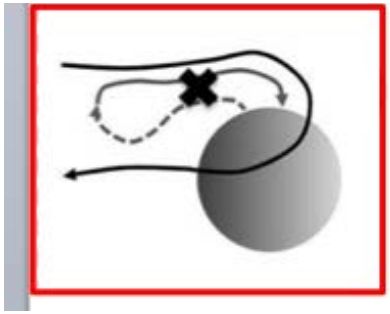
Penetrating Solar Wind Protons

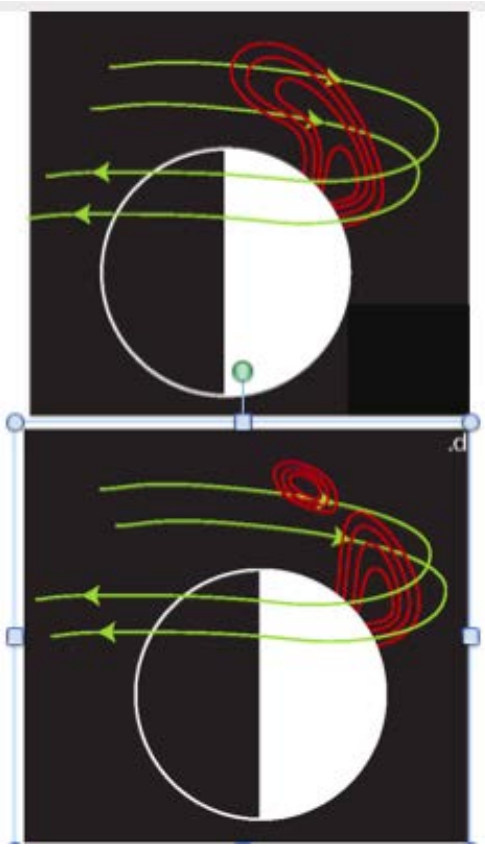


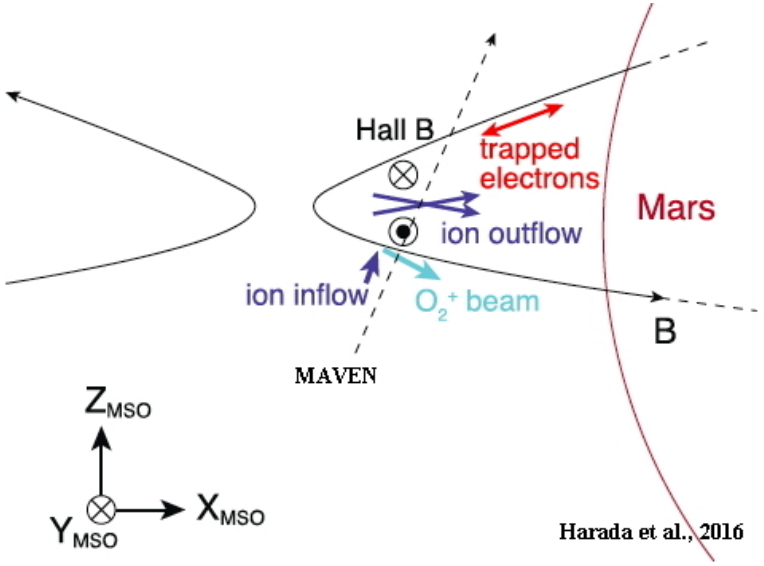


- Solar wind protons neutralized by charge exchange (ENAs) with extended Mars H corona
- ENA's penetrates to the lower atmosphere at solar wind speed
- Reionized in lower atmosphere by electron stripping in atmosphere CO_2 impacts and ionosphere charge transfer
- Penetrating proton energy can be used as a proxy for solar wind activity

Reconnection Observations Isolated by Maven Observations



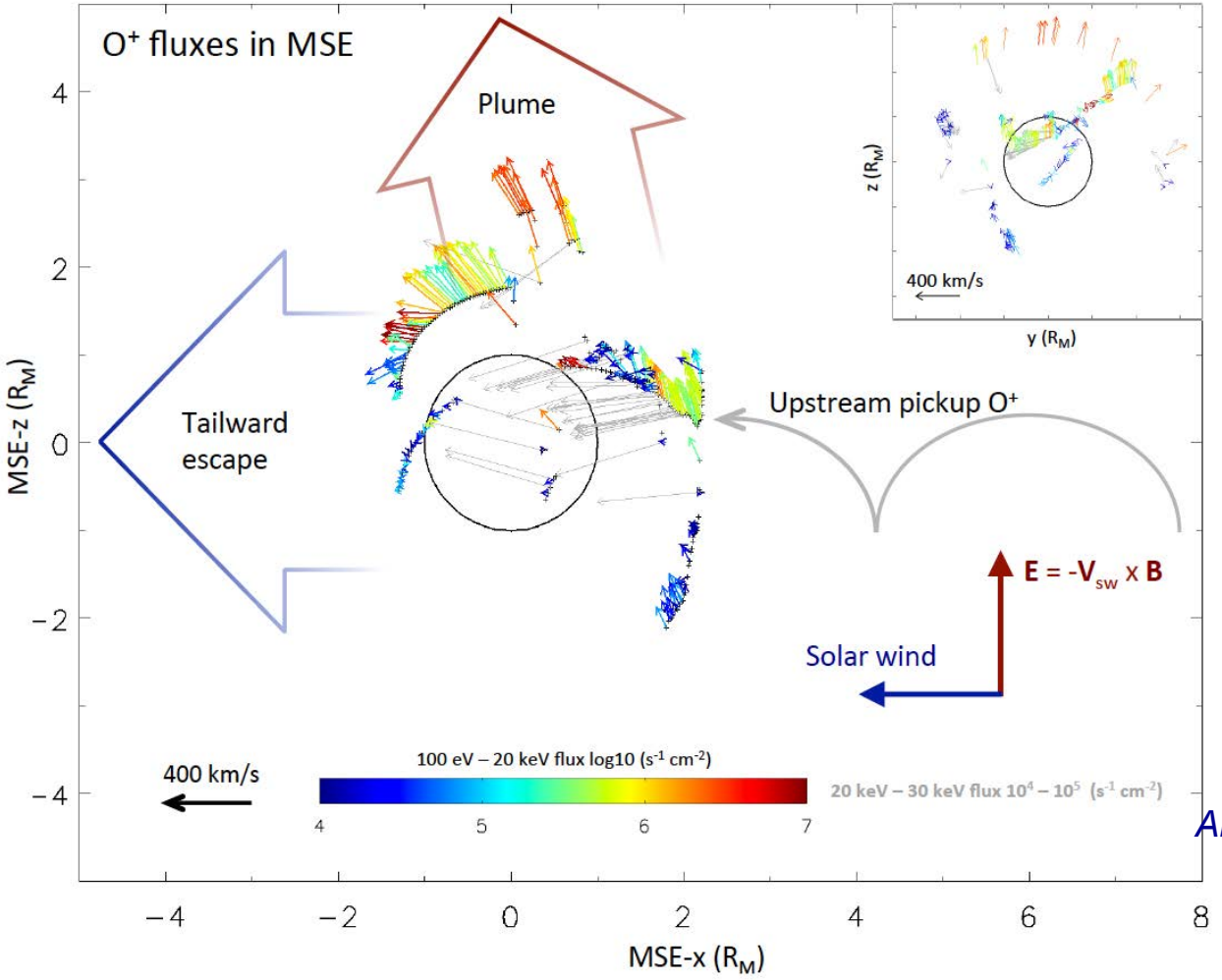




- Remanent Flux tubes stretched by Solar wind to merge opposite directed field lines (Dibraccio et al.)

- Classical reconnection event observed in magnetic tail of Mars (Harada et al. 2016)

Observation of Escape Channels –Identification of Polar Plume

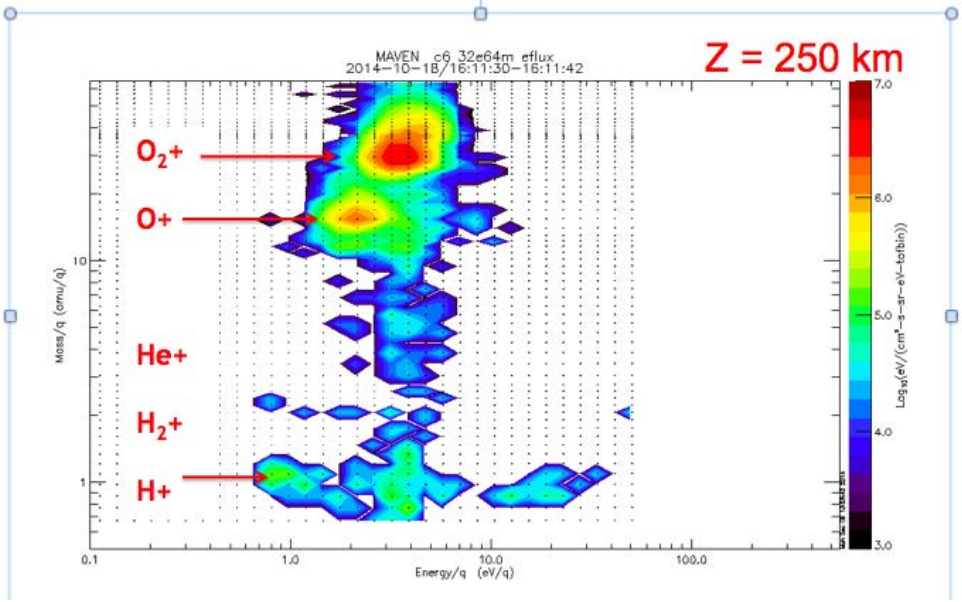


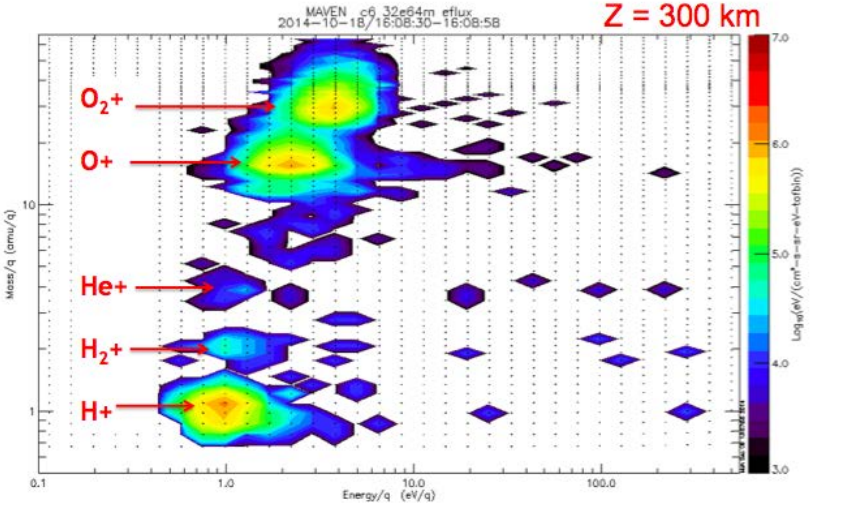
Analysis by Dong et al.

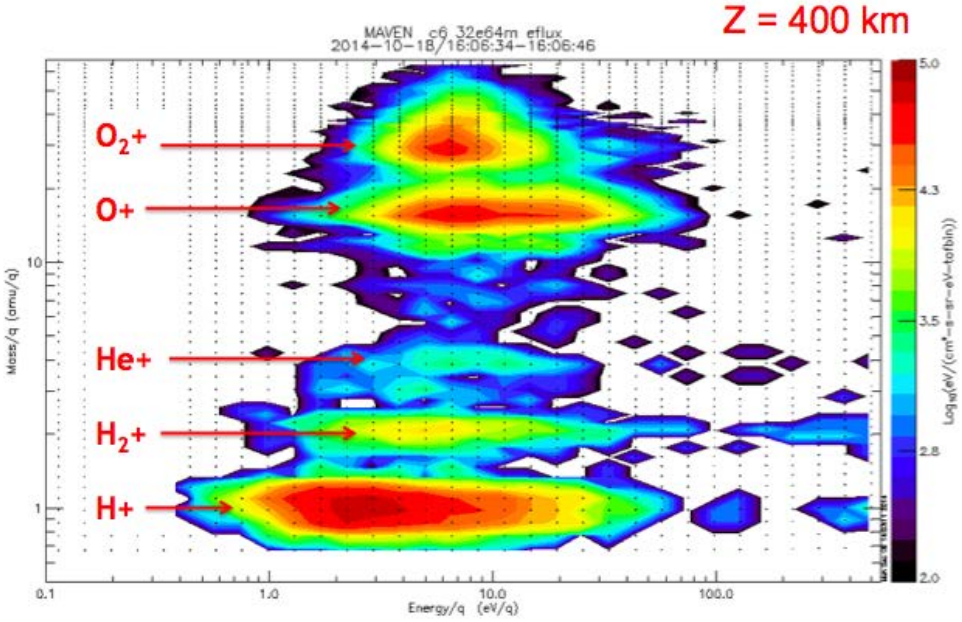
- Single MAVEN orbit detects upstream pickup ions, tailward escape, and polar plume in STATIC observations
- Plume (red) goes in only one direction - (E) solar-wind-driven electric field

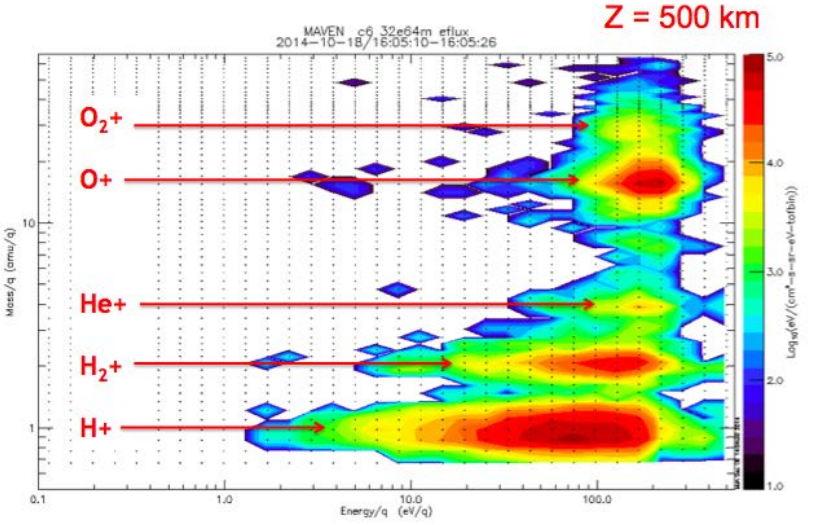
Polar Plume Evolution from Ionosphere to Space

MAVEN
Mars Atmosphere and Volatile Evolution Mission

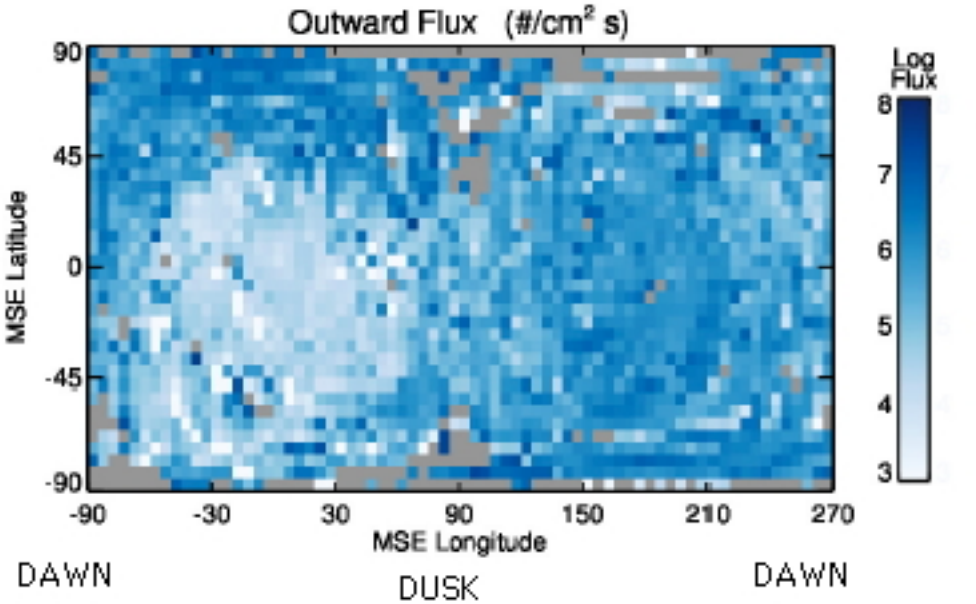


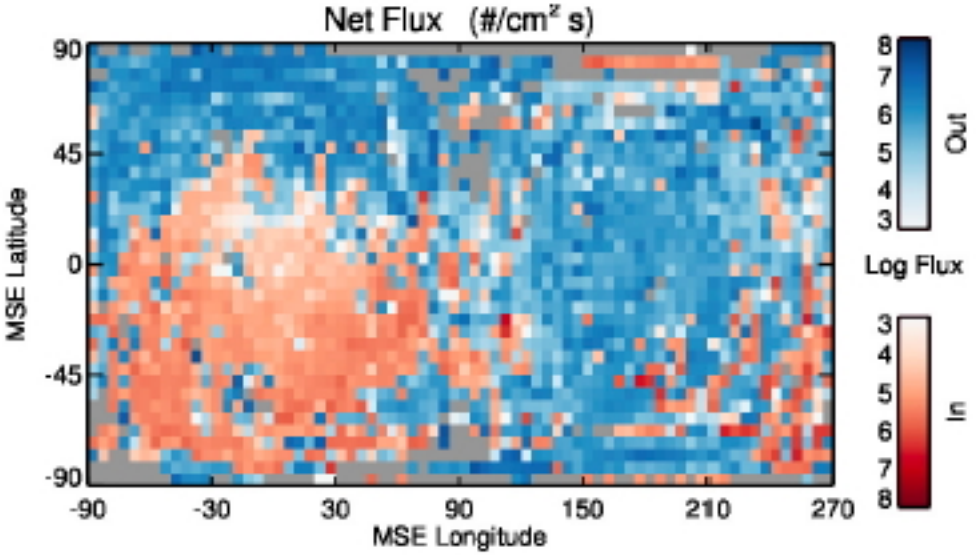






Current Estimate of "Ion" Loss from MAVEN

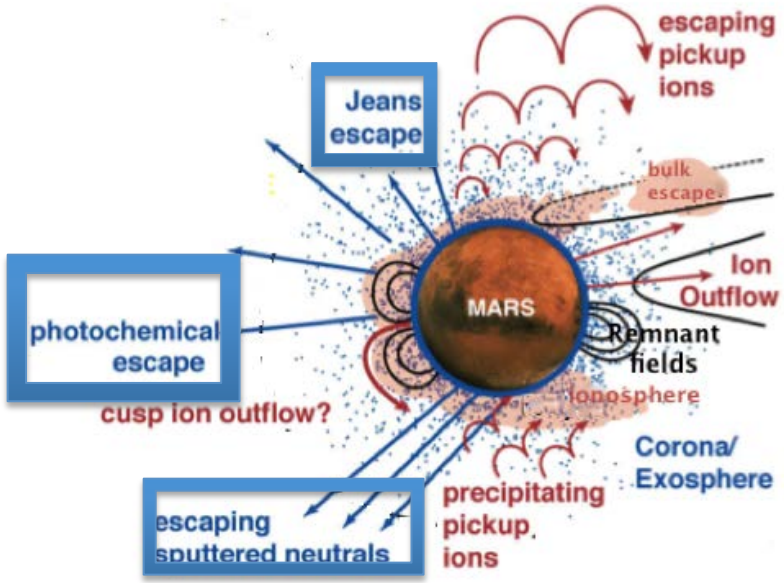




Fluxes of ions through a spherical shell around Mars
E>10 eV, M>9 amu
15 months of data

Median Ion Loss ~2X10^{24} s^{-1}

Neutral escape processes may exceed the ion losses –require intensive modeling



Ongoing study by Brain 21016

Scientists are not alone in fascination with Mars