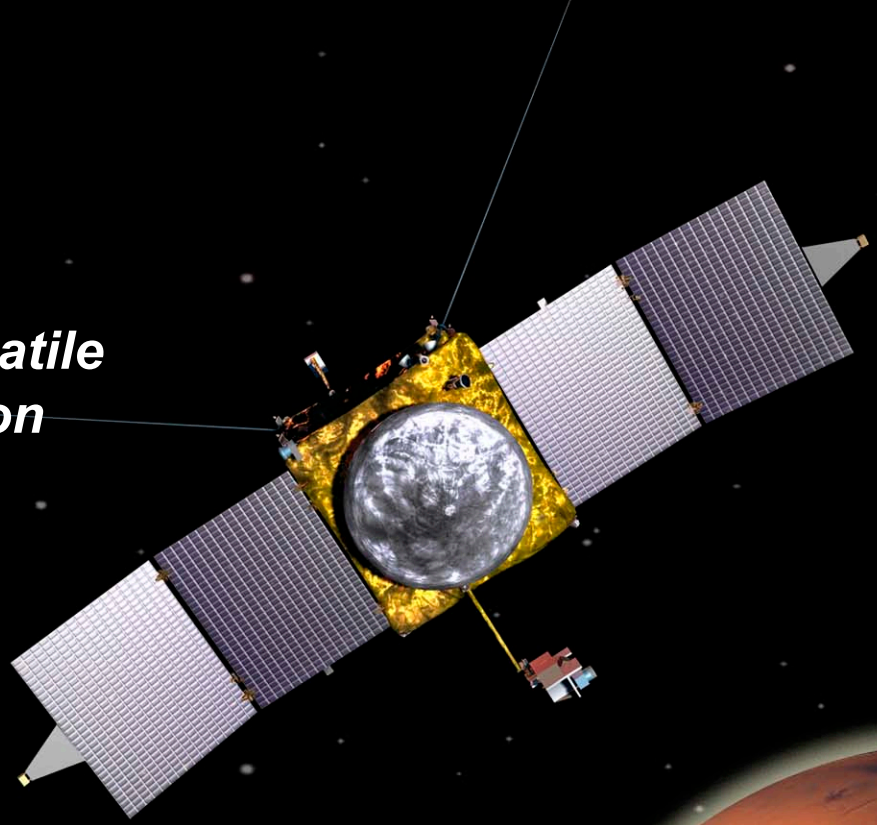
Mars Atmosphere and Volatile EvolutioN (MAVEN) Mission



Premiers résultats de la mission MAVEN autour de Mars

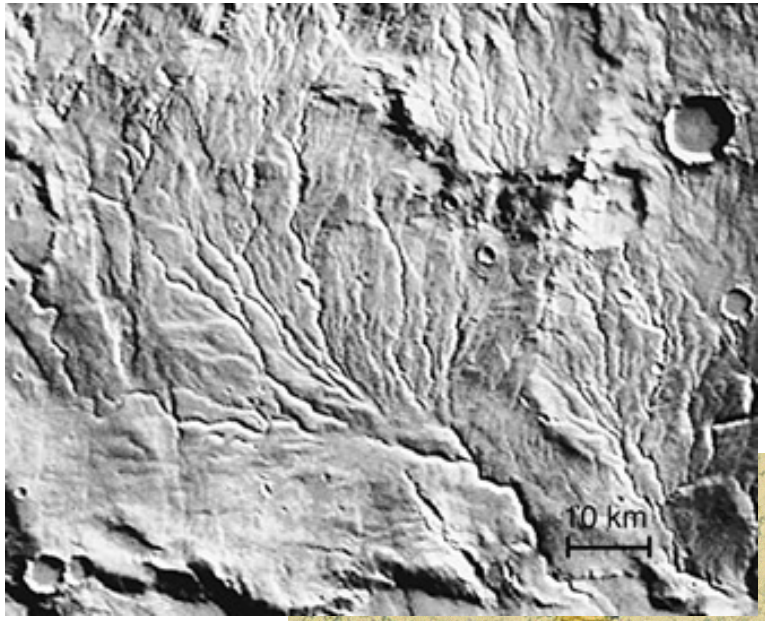
Christian Mazelle
IRAP

Colloque à mi-parcours du PNST, Hendaye, 14 mars 2016

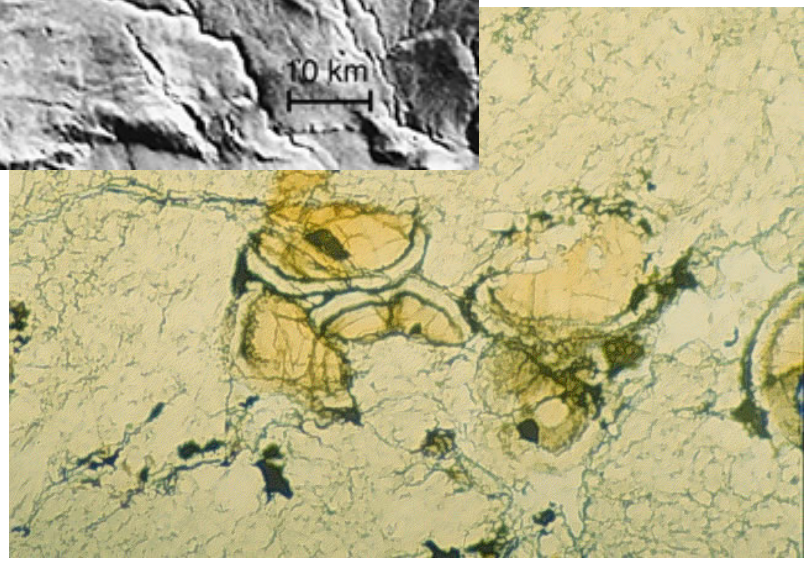
Evidence for Surface Water on Ancient Mars > 3 Gyears ago

Where Did the Water Go? Where Did the CO_2 Go?

Abundant evidence for ancient water

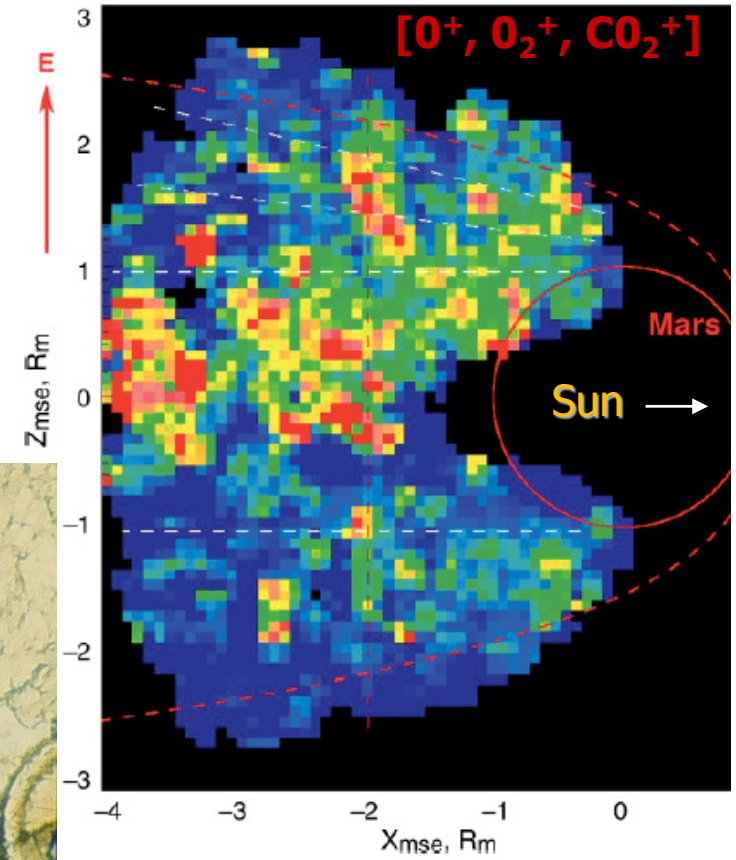


Volatiles can go into the crust



Carbonate deposits in a Martian meteorite

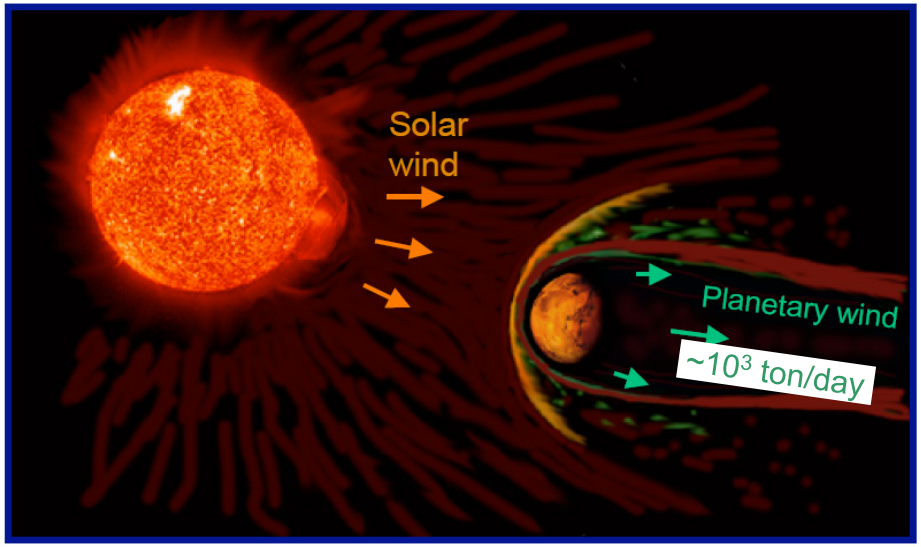
Volatiles can be lost to space



Escaping ions detected from Mars Express

Fedorov et al.,Icarus, 2006
Barabash et al., Science, 2007

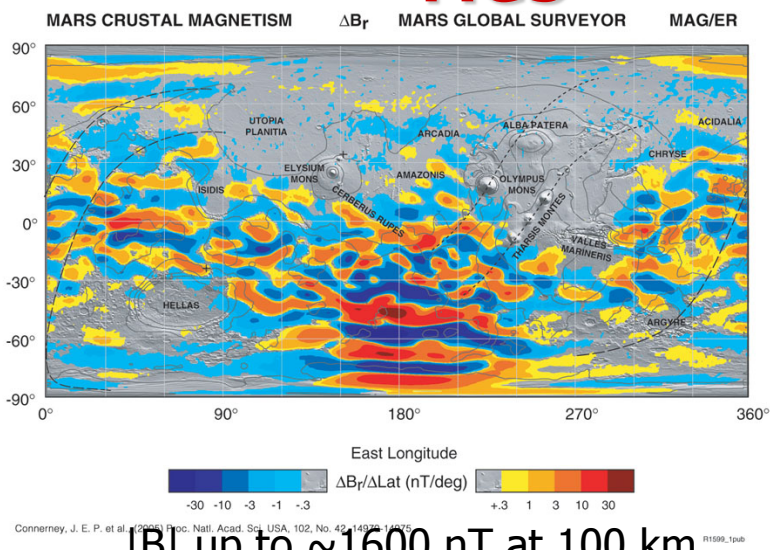
Erosion de l'atmosphère planétaire par le vent solaire



Mars comme Vénus n'est pas protégée par un champ magnétique planétaire interne à grande échelle

→ **Échappement non thermique**

MGS



L'érosion de l'atmosphère par le vent solaire est-elle responsable du dessèchement de Mars?

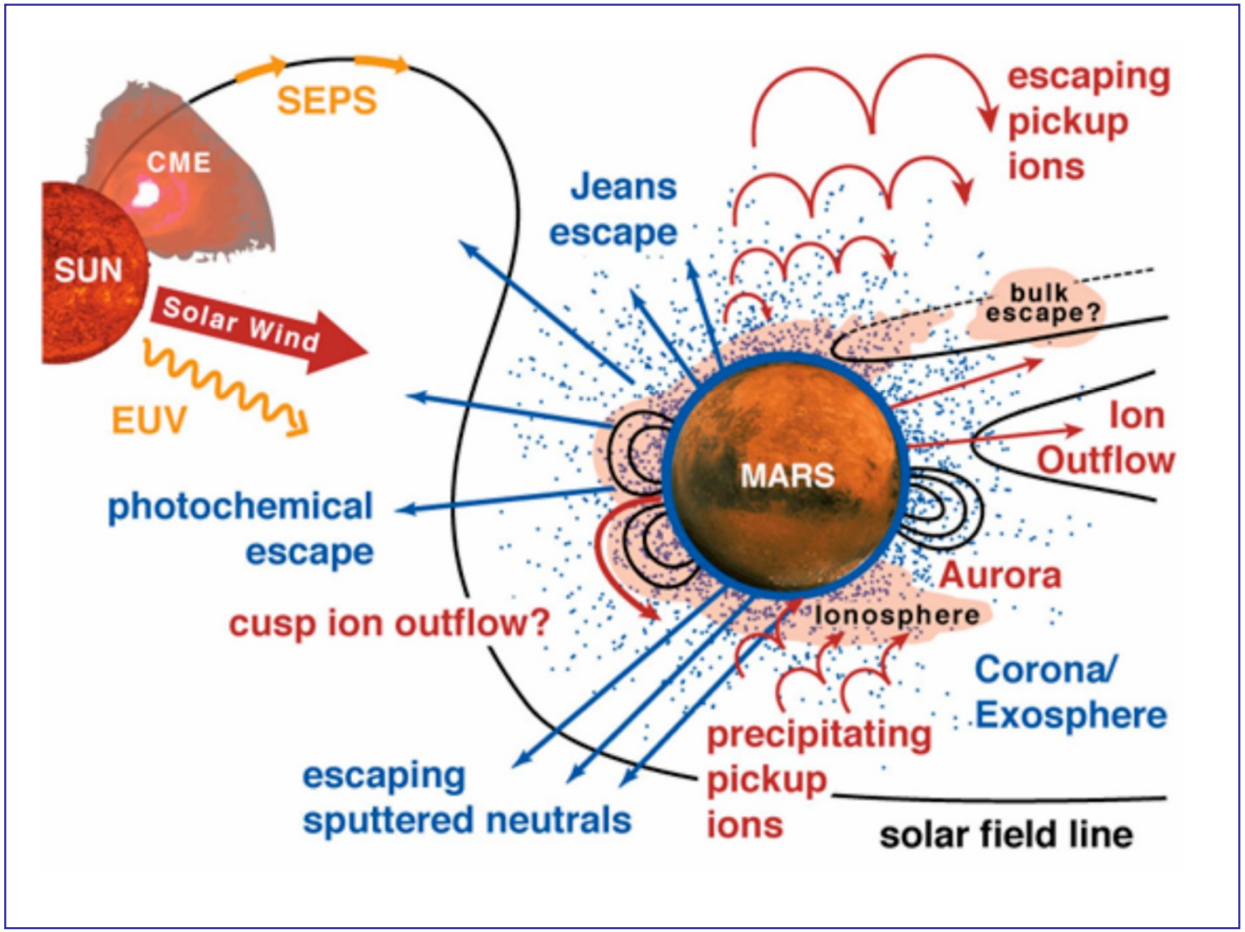
Mais Mars possède un champ magnétique crustal rémanant (ancienne dynamo éteinte)

→ Effets locaux mais potentiellement importants

|B| up to ~1600 nT at 100 km

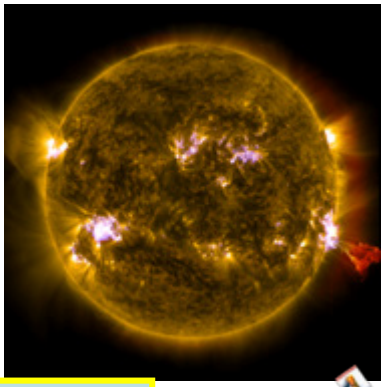
Science, 1998, 1999

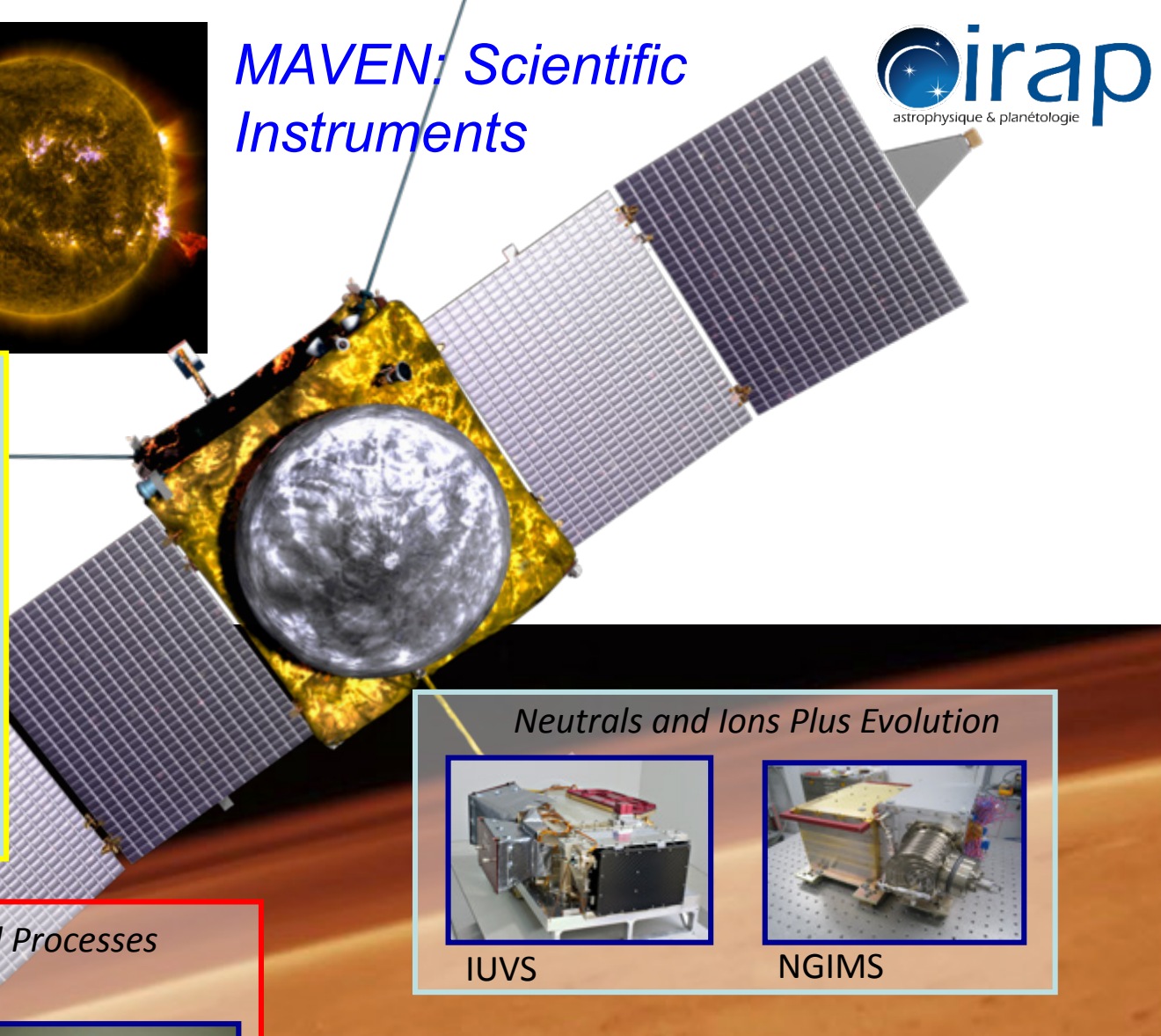
MAVEN Explores Escape of Atmospheric Gases to Space



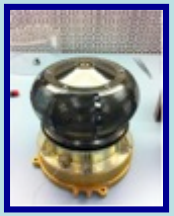
- Measure energetic drivers from the Sun, response of upper atmosphere and ionosphere, and resulting escape to space
- Understand the key processes involved, allowing extrapolation to loss over Mars history

MAVEN: Scientific Instruments





Sun, Solar Wind, Solar Storms



SWEA

SEP

EUV

SWIA

Neutrals and Ions Plus Evolution

IUVS

NGIMS

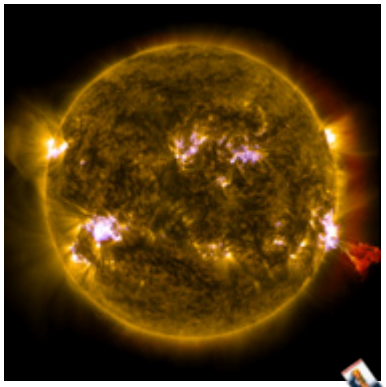
Ion-Related Properties and Processes

STATIC

MAG

LPW

MAVEN: Scientific Instruments



IRAP h/w

Sun, Solar Wind, Solar Storms

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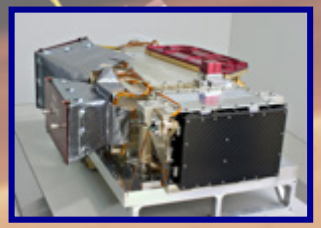
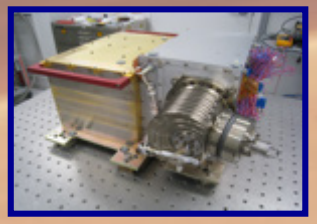
Neutrals and Ions Plus Evolution



IUVS



NGIMS

Ion-Related Properties and Processes

STATIC

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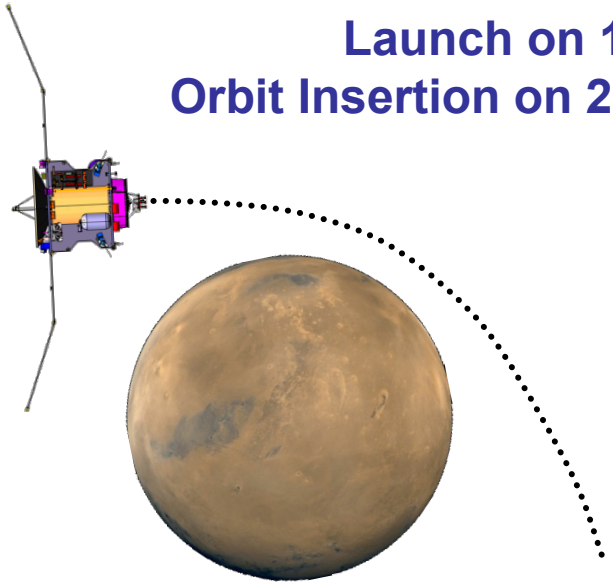
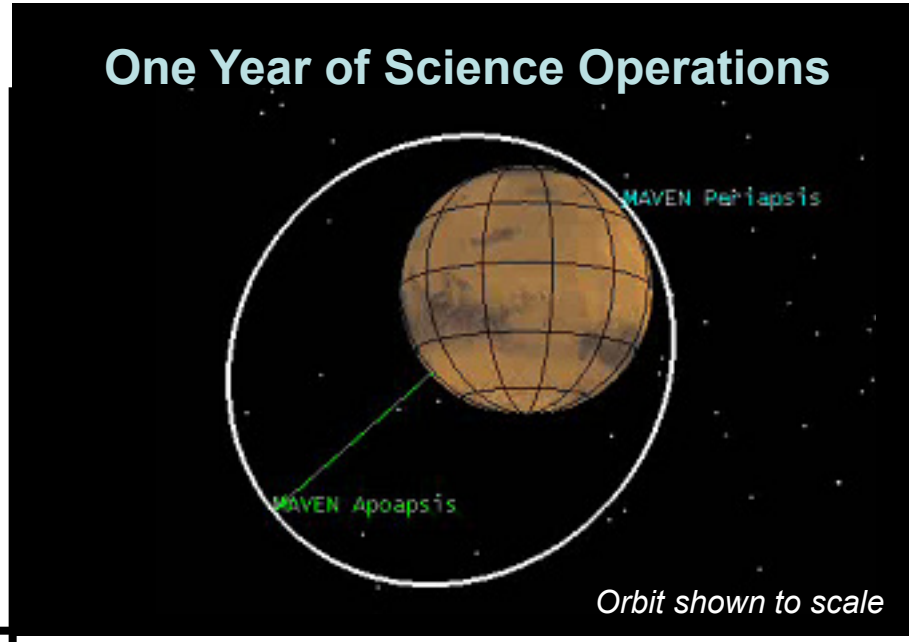
MAVEN Mission Architecture

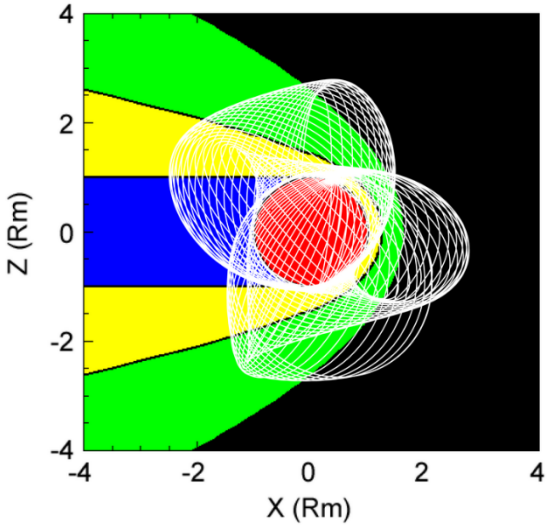
Launch on 18 Nov 2013
Orbit Insertion on 22 Sept 2014



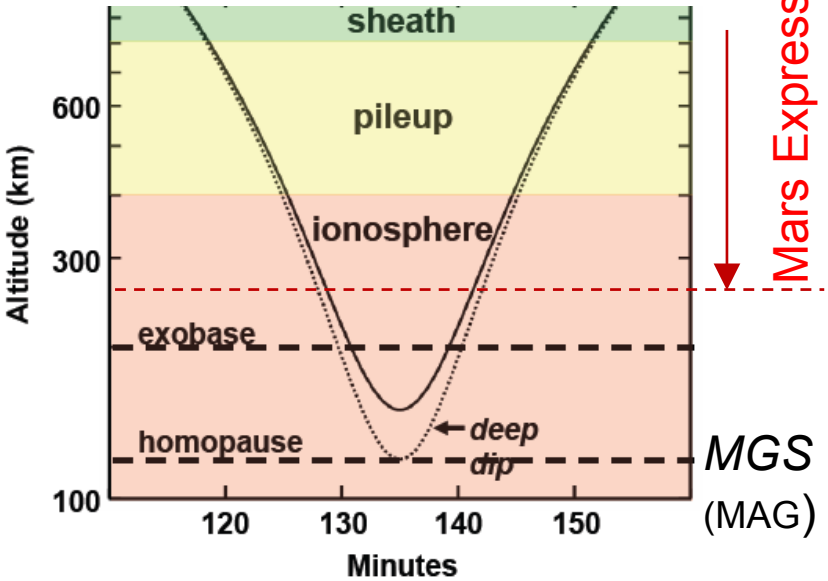
One Year of Science Operations



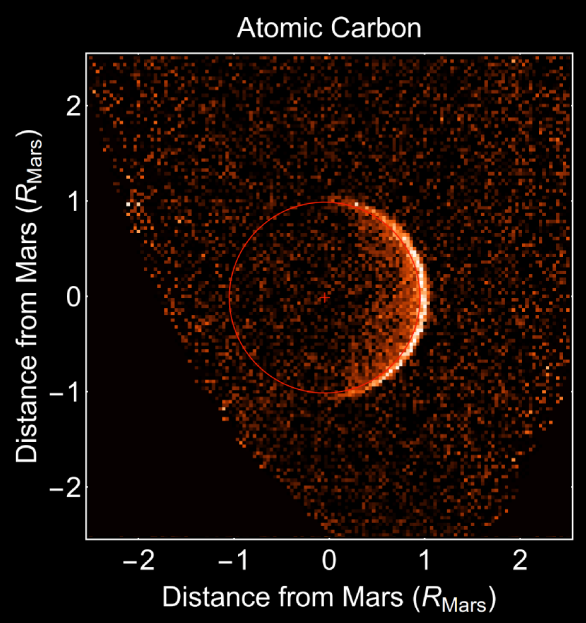
Orbit Precession Provides Coverage

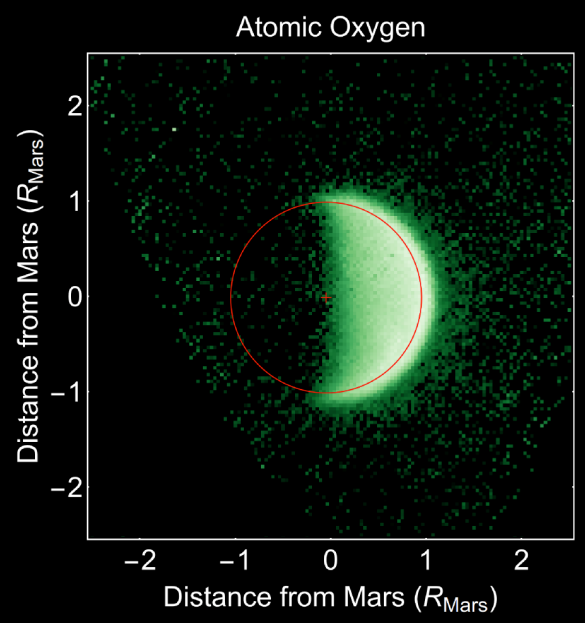


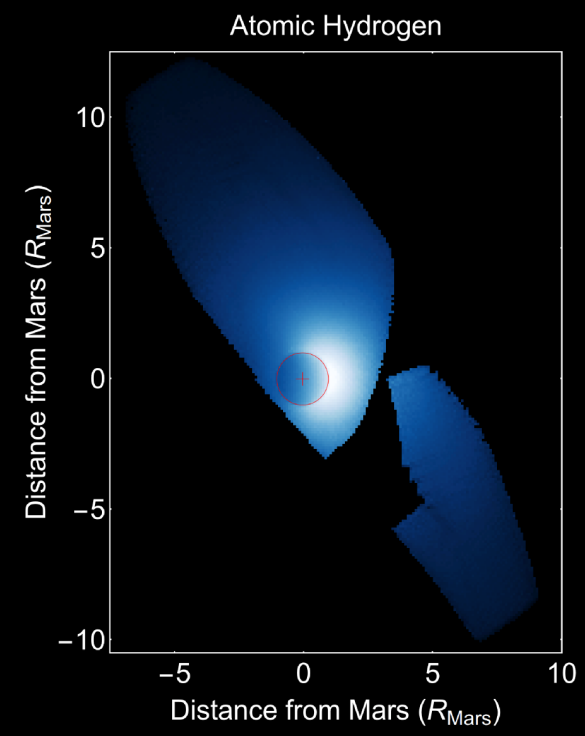
Deep Dips Cover All Altitudes



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







- Hydrogen distribution not modeled well by single-component, spherically symmetric model
- Analysis ongoing in order to derive unique density profile and infer escape rate

(Chaffin et al. 2015)

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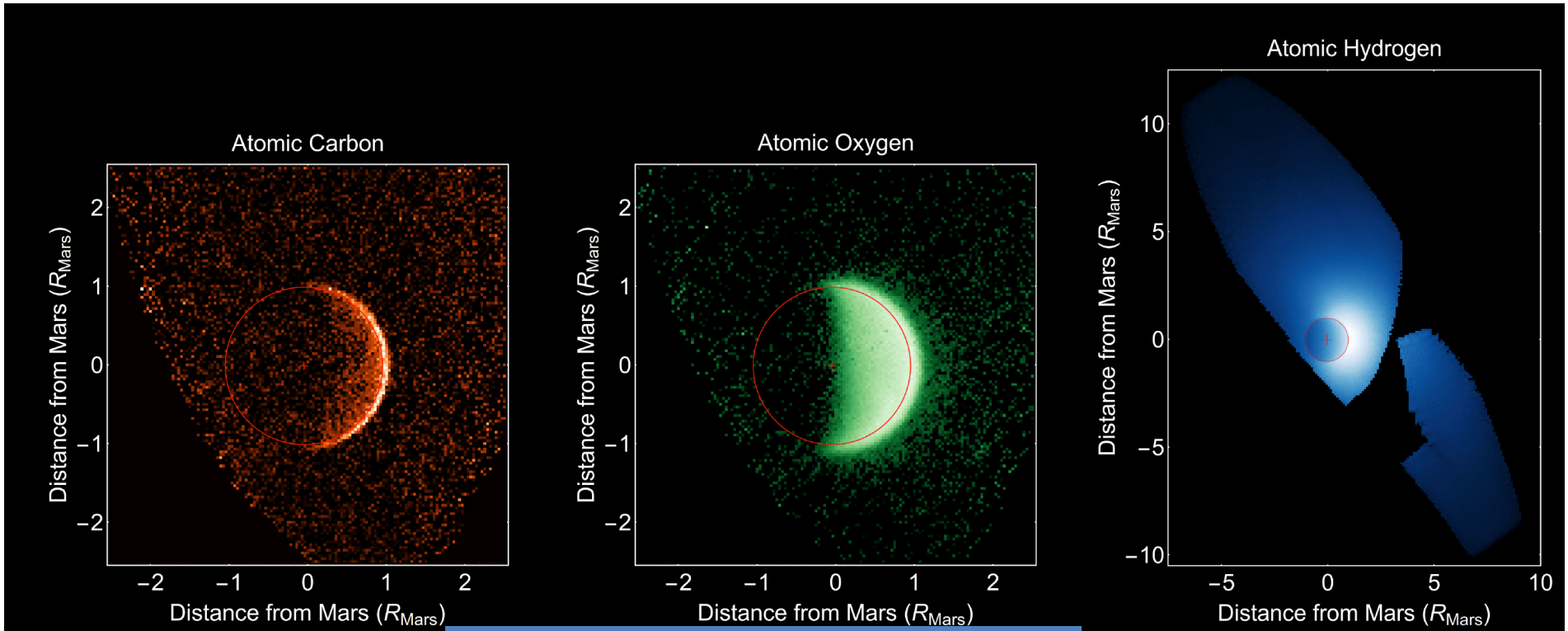

+ Voir POSTER 4.8
Chaufray *et al.*

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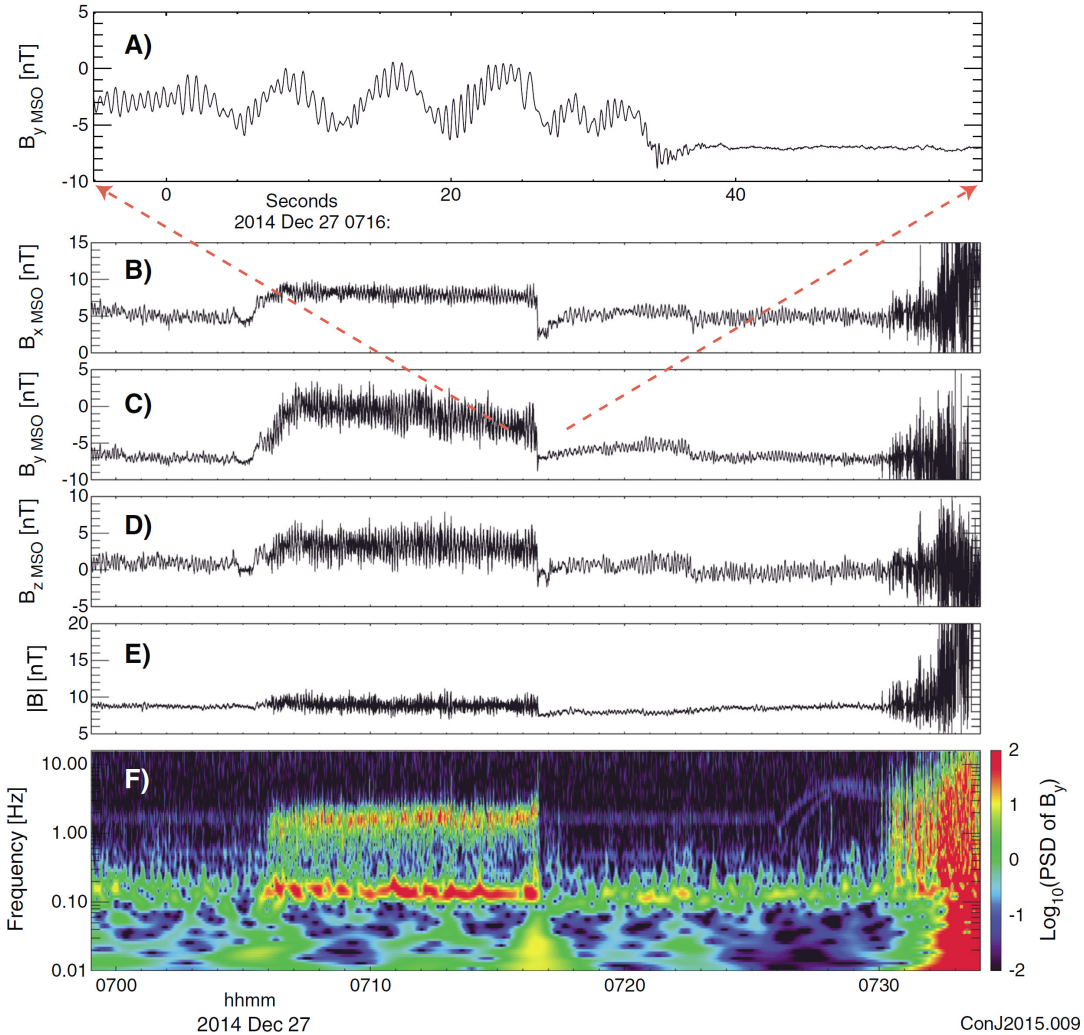
Waves at the proton cyclotron frequency: variability of the exosphere



(Connerney et al., GRL, 2015)

- Origin of the waves: proton pickup after ionization of exospheric H (plasma microinstabilities)
- The temporal variability in the occurrence of waves at the proton cyclotron frequency Ω_p is linked to the expansion of the of the H exosphere due to orbital and seasonal effects
- Thus, it can be used to study the coupling of the thermosphere with the exosphere of Mars where direct observations are unavailable.

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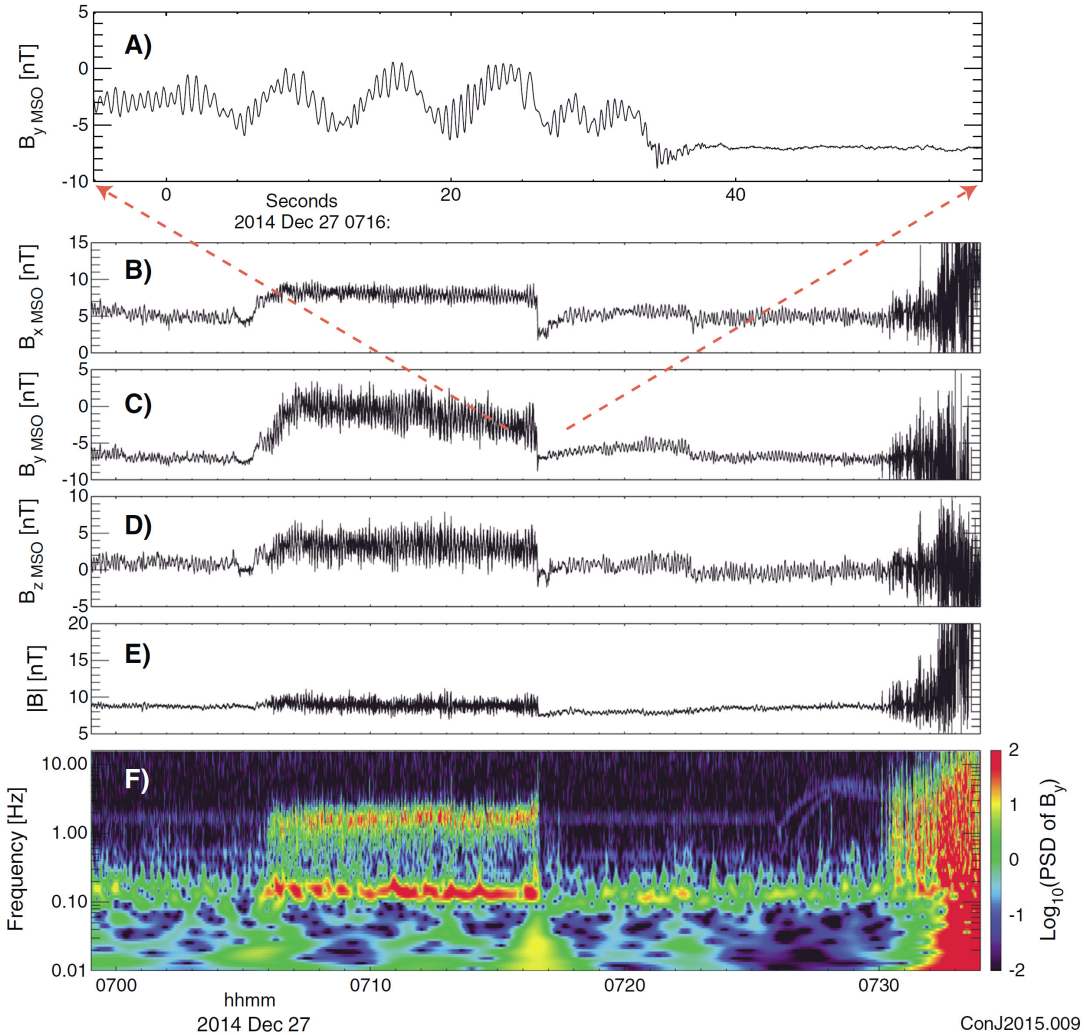

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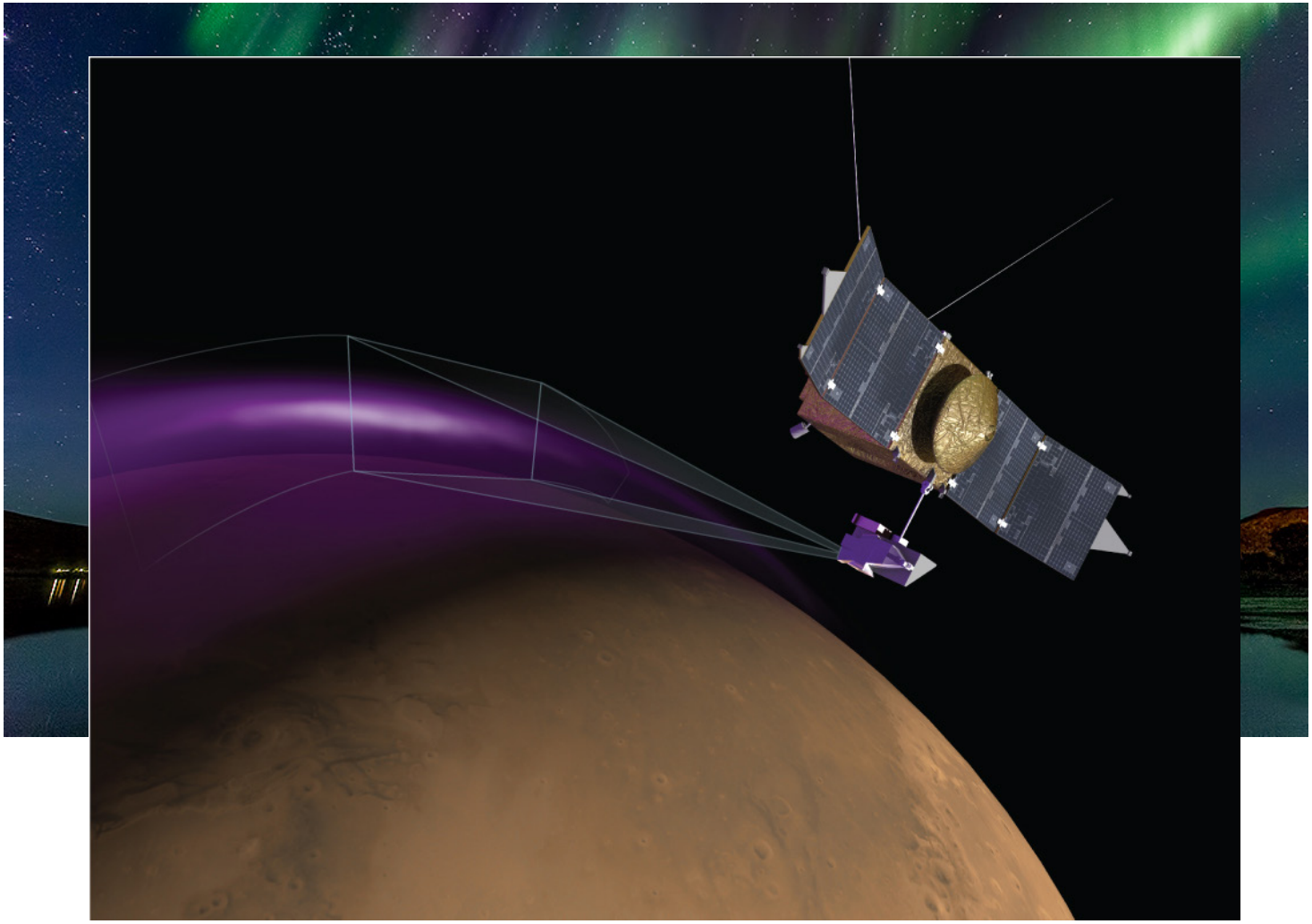
- Thus, it can be used to study the coupling of the thermosphere with the exosphere of Mars where direct observations are unavailable.
- But also ULF Foreshock waves (backstreaming ions from the shock).

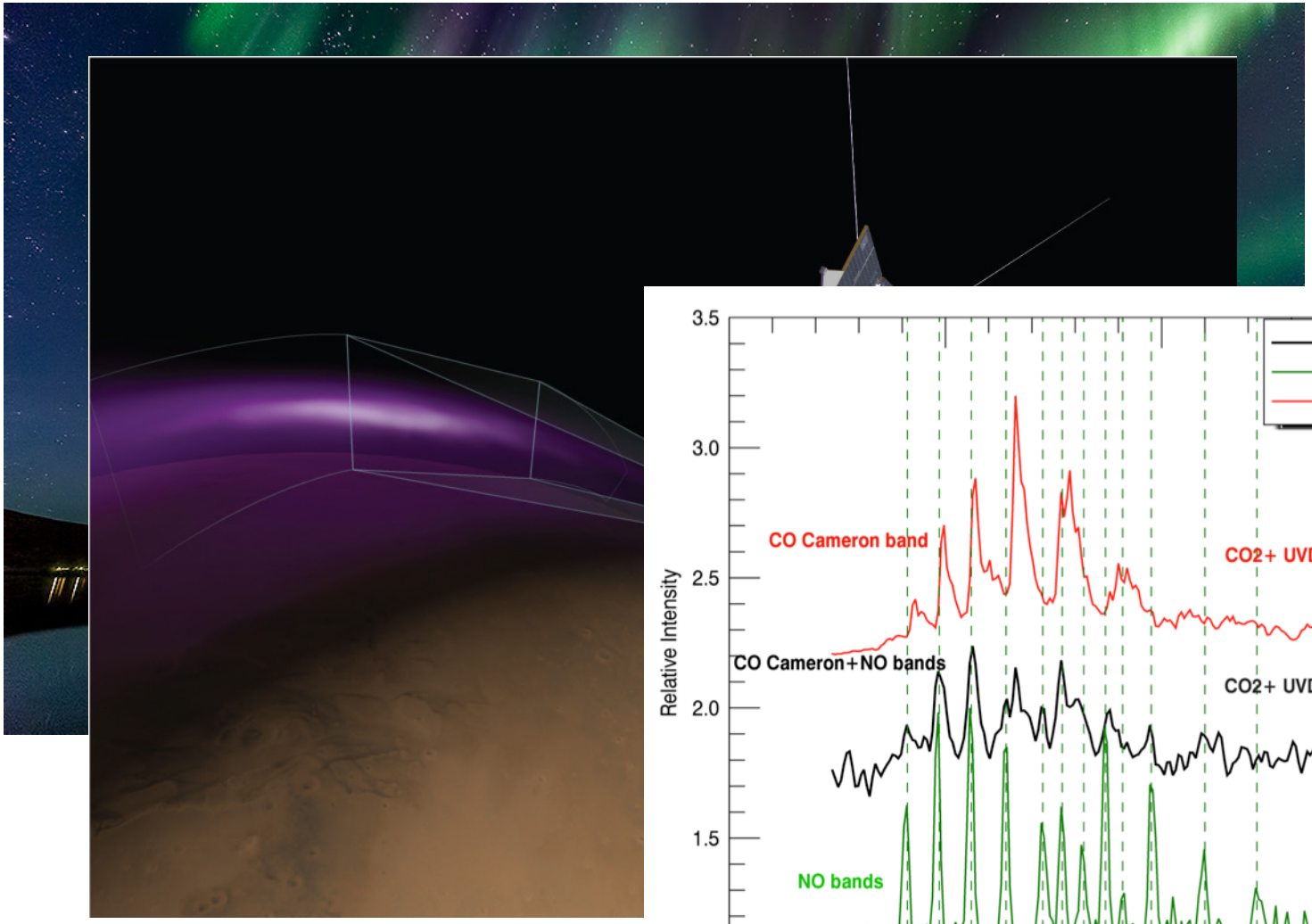
Voir POSTER 4.8

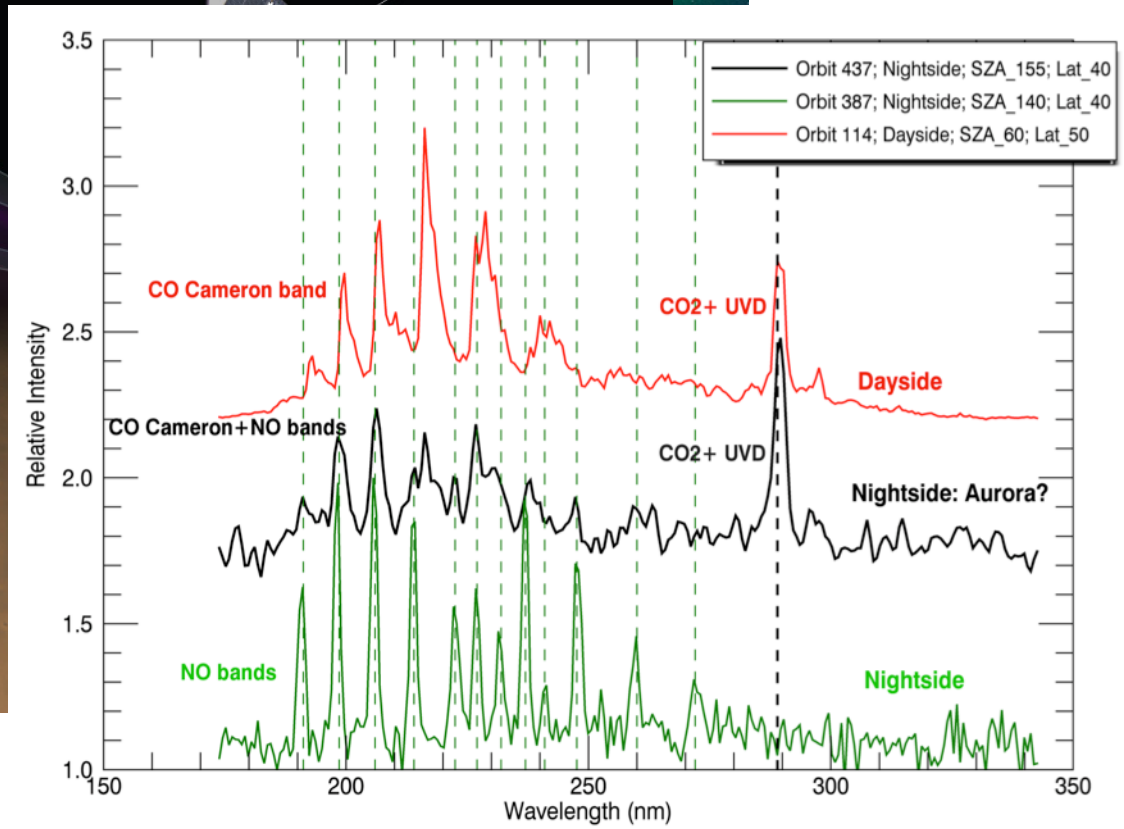
Aurora at Mars

Aurora at Mars

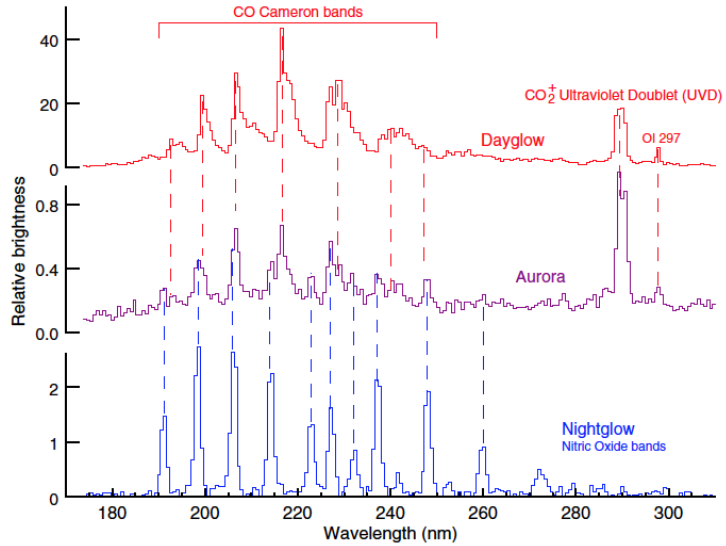


Aurora at Mars

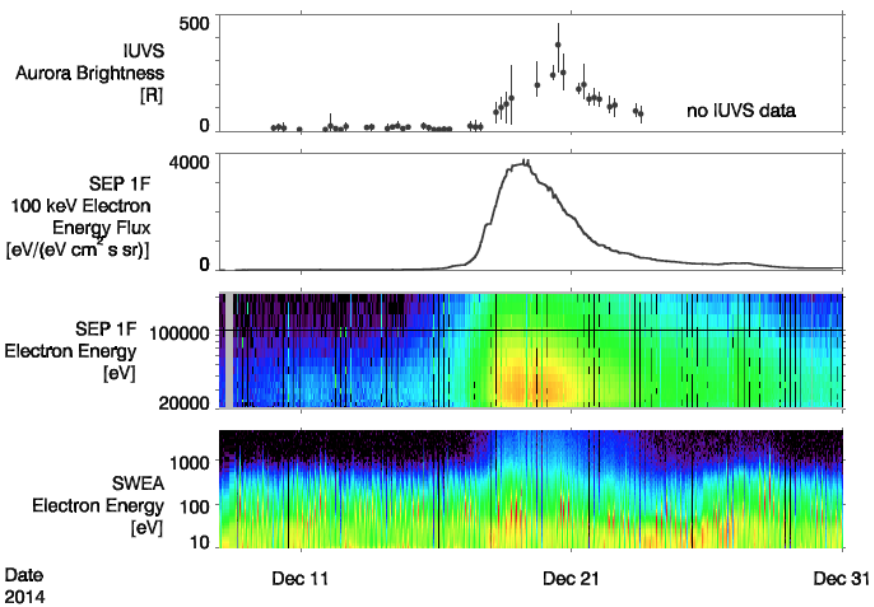


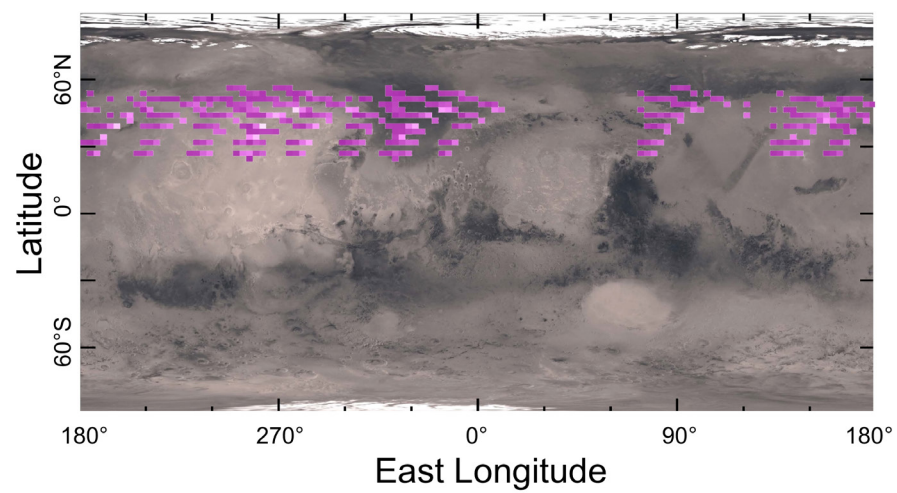


IUVS Detection of Diffuse Aurora



- "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 crustal sources





[*Schneider et al.*, Science, 2015]

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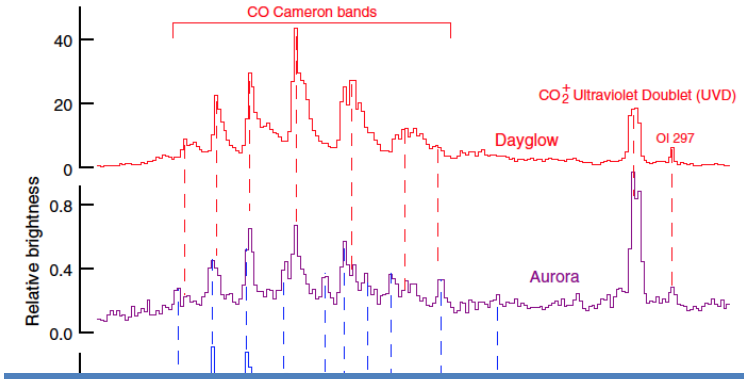

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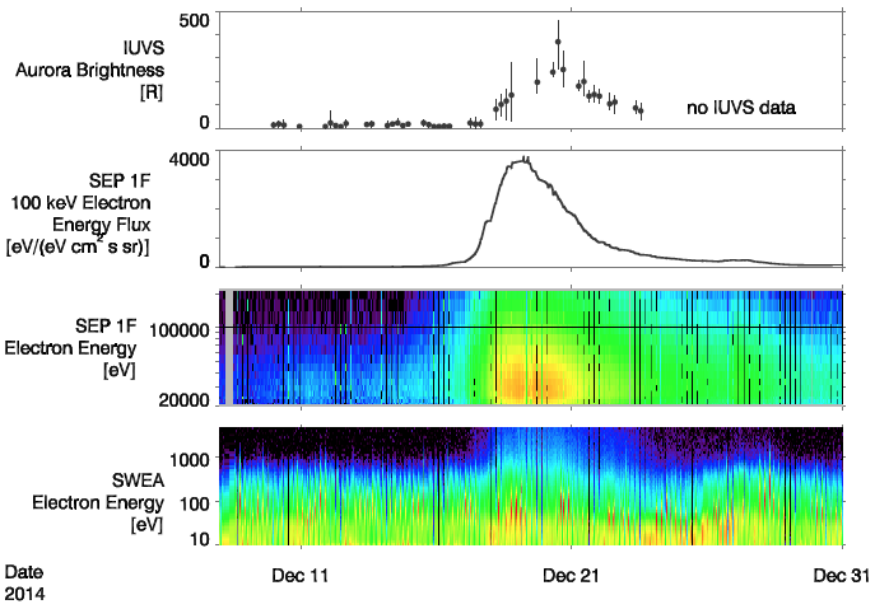
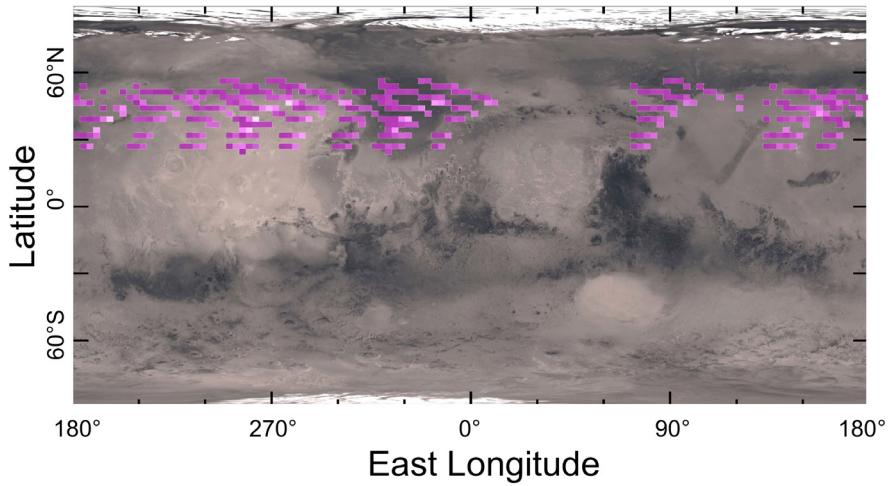
- Nightside emission at same wavelengths as dayglow; characteristic of aurora in general and of those observed by *Mars Express*

throughout northern
nnection to magnetic

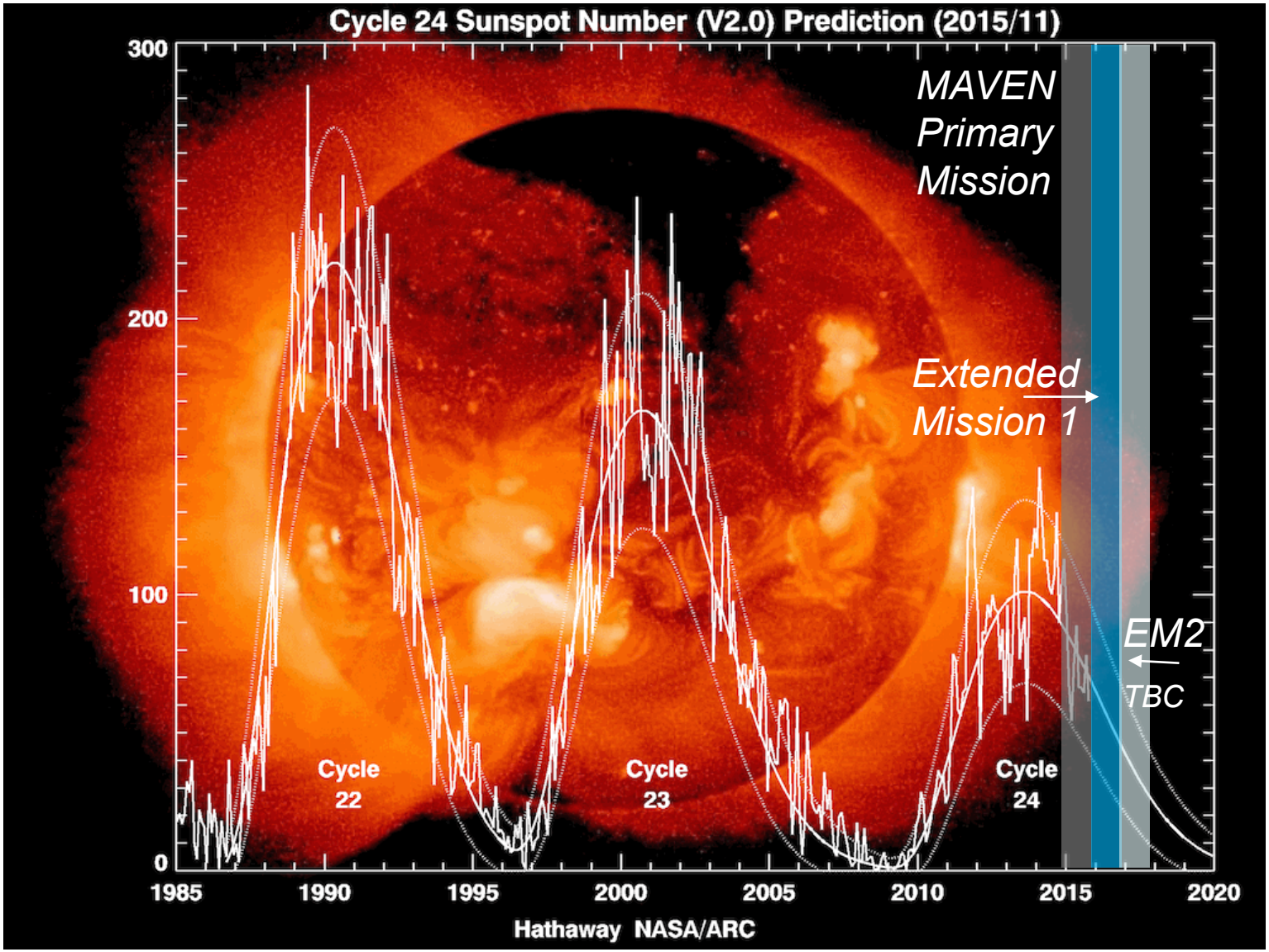
+ Possibilité d'aurores dans le visible?
Voir POSTER 3.7 par Lilensten *et al*.



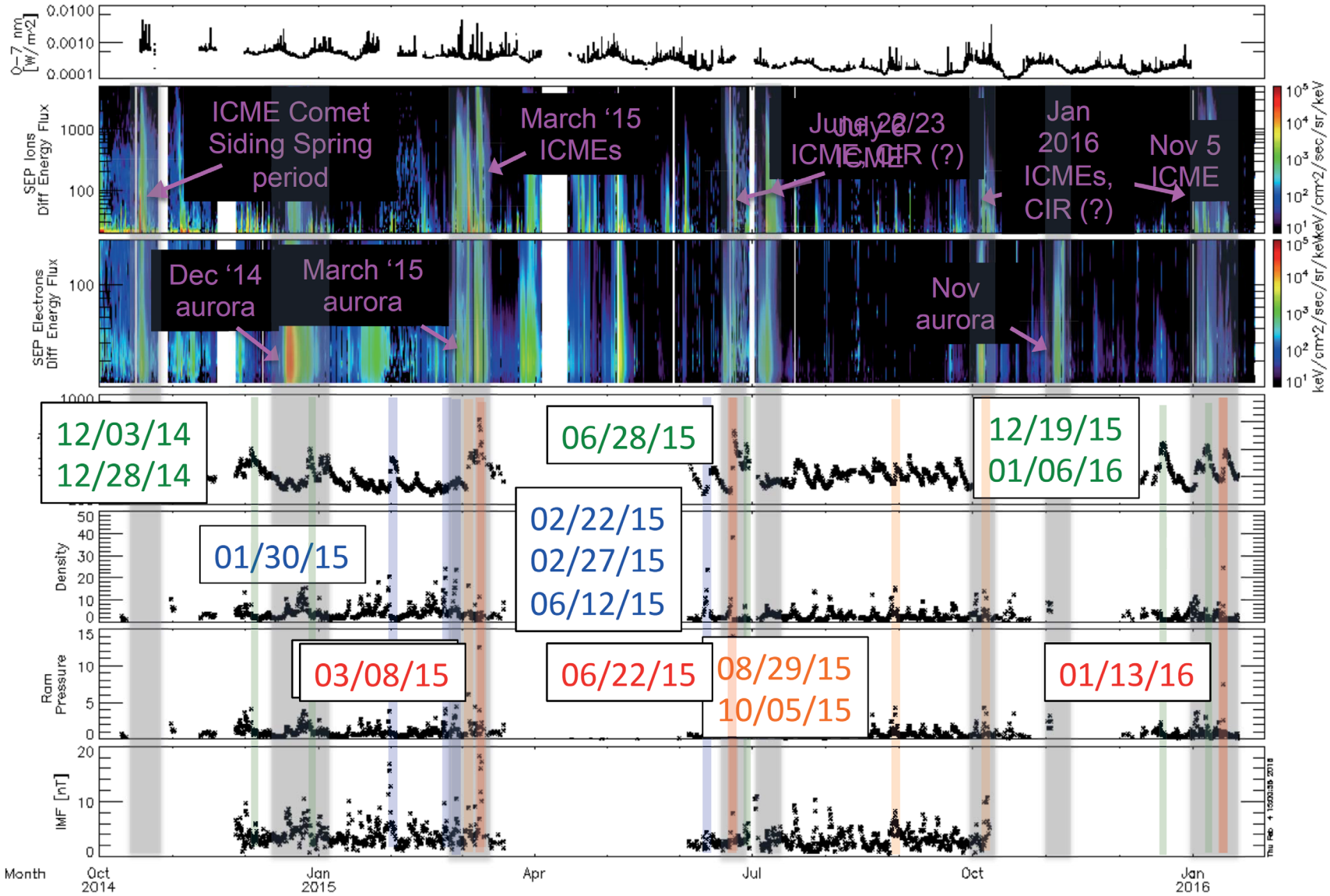


[*Schneider et al.*, Science, 2015]

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



Full mission flares, SEPs, upstream solar wind & IMF observations



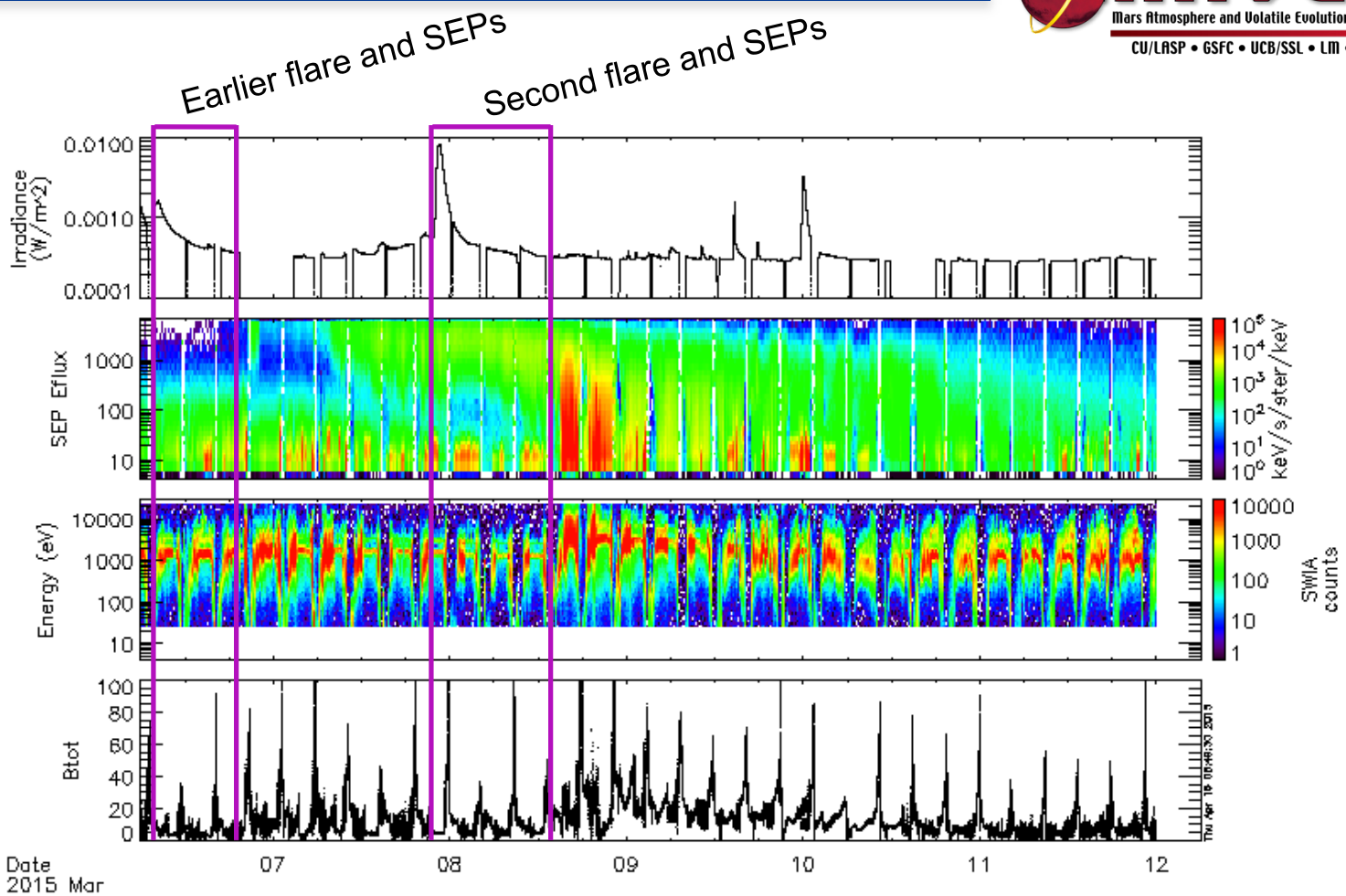
Determining the Effects of Solar Storms

EUV irradiance

SEP energy

SWIA Energy

Btot

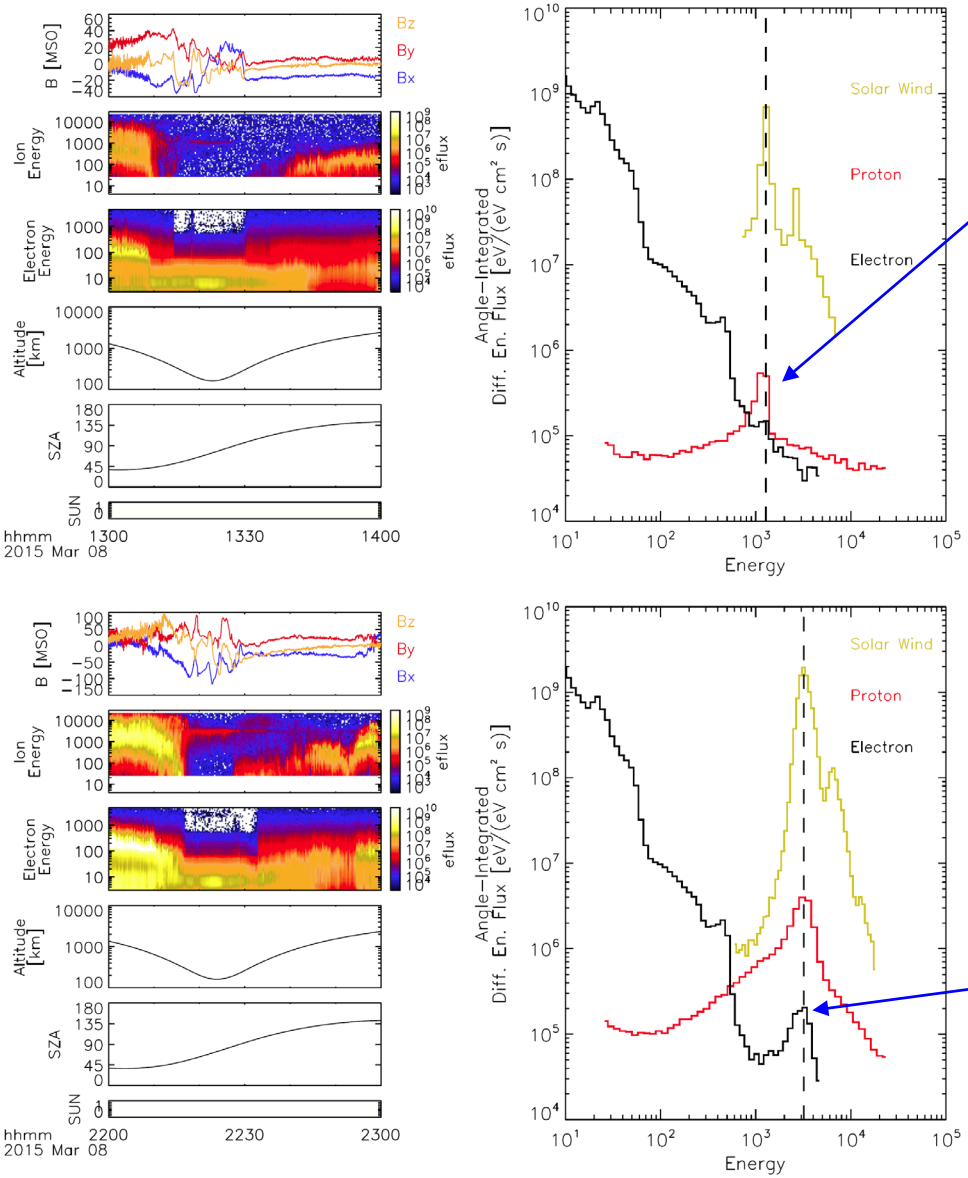


- Three solar events occurred, on March 1st, 6th, then 8th
- March 8 event was largest, but complicated by preceding events
- Flare and CME also observed by SOHO
- Examine energy input, atmospheric response

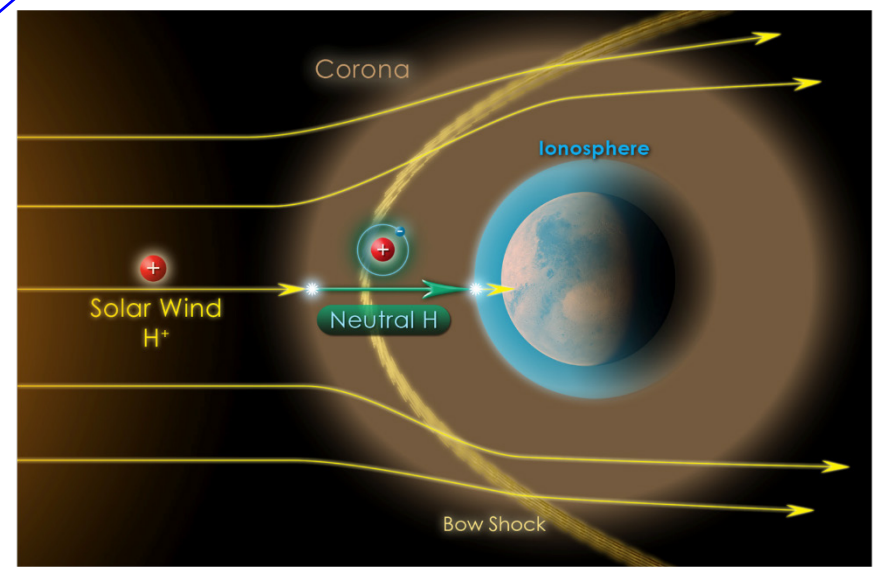
Escape fluxes x10 at least

(Jakosky et al. Science 2015)

Solar Wind hydrogen deposition in the atmosphere of Mars



Penetrating protons of solar wind origin observed at low altitude at the same energy after double charge-exchange

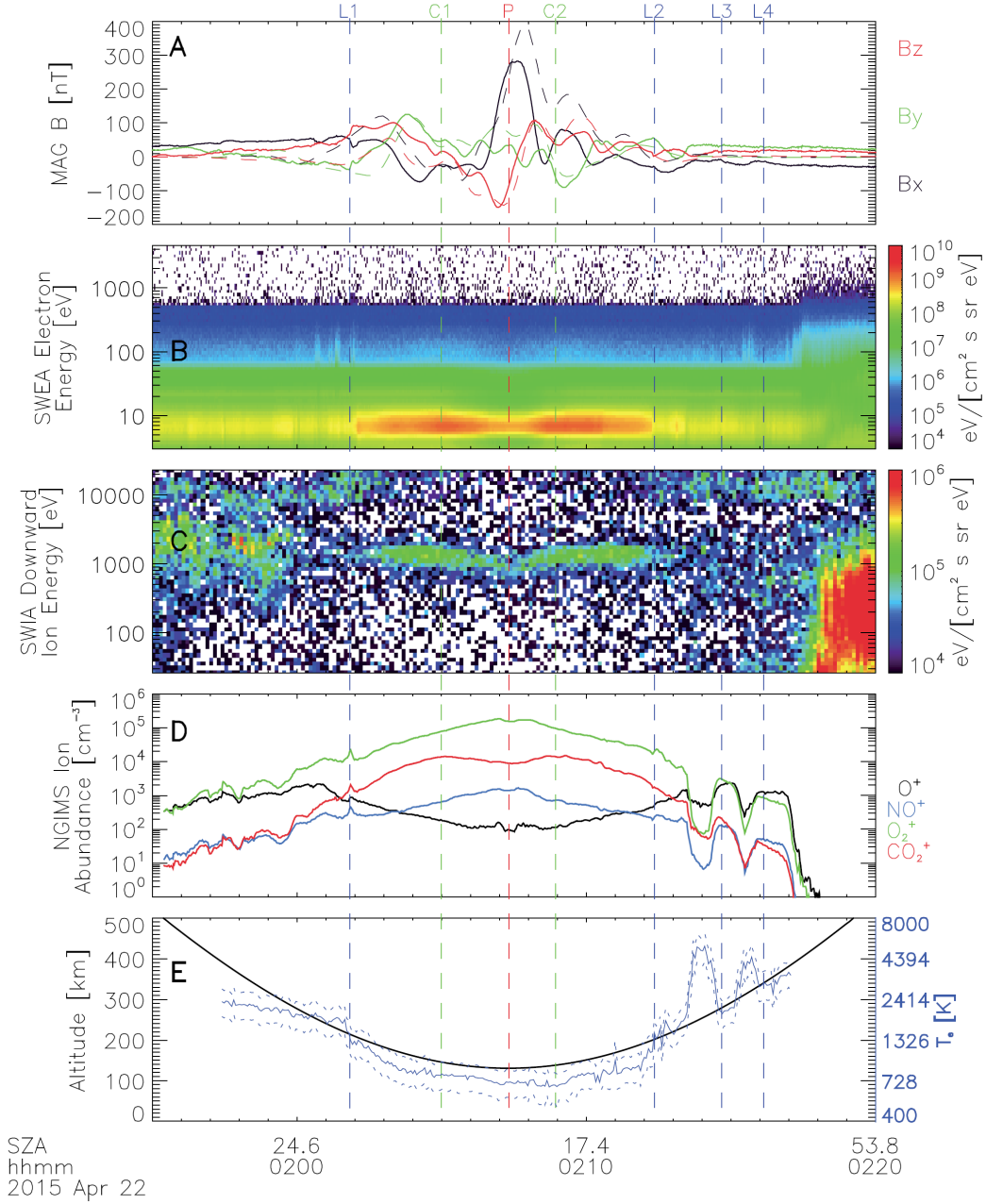


Strong enhancement of hydrogen deposition in the atmosphere after ICME + observations of negative ions H^- likely produced by electron attachement (ratio 1 to 10 with penetrating H^+)

(Halekas et al., GRL, 2015)

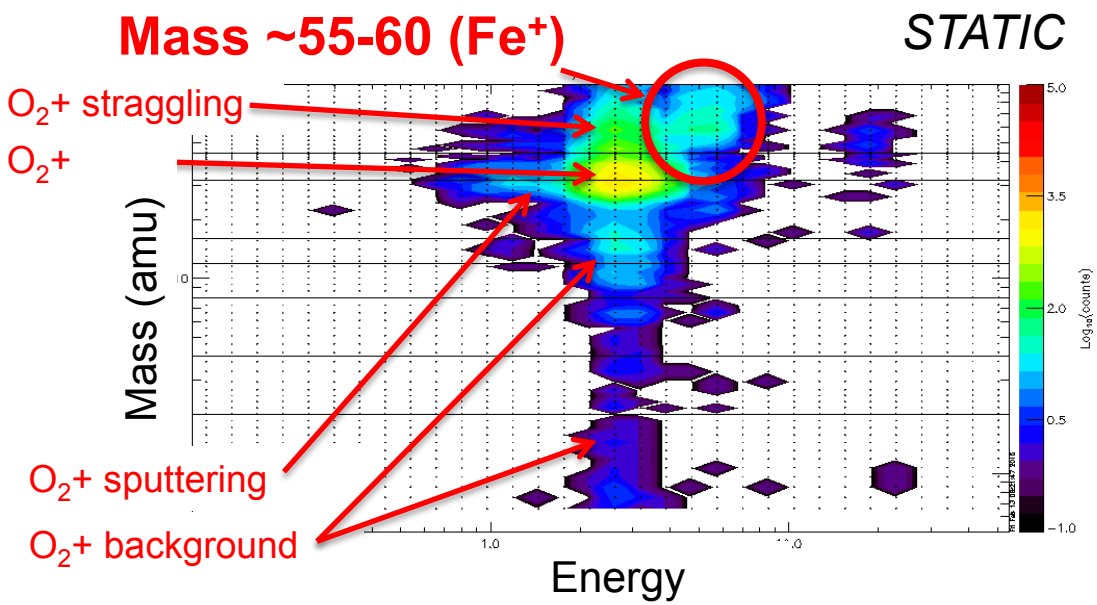
‘Deep Dip’

First in situ observations of Martian Ionosphere down to 130 km altitude



(Bougher et al. Science 2015)

Discovery of Long-Lived Metallic-Ion Layer During Deep-Dip Campaign

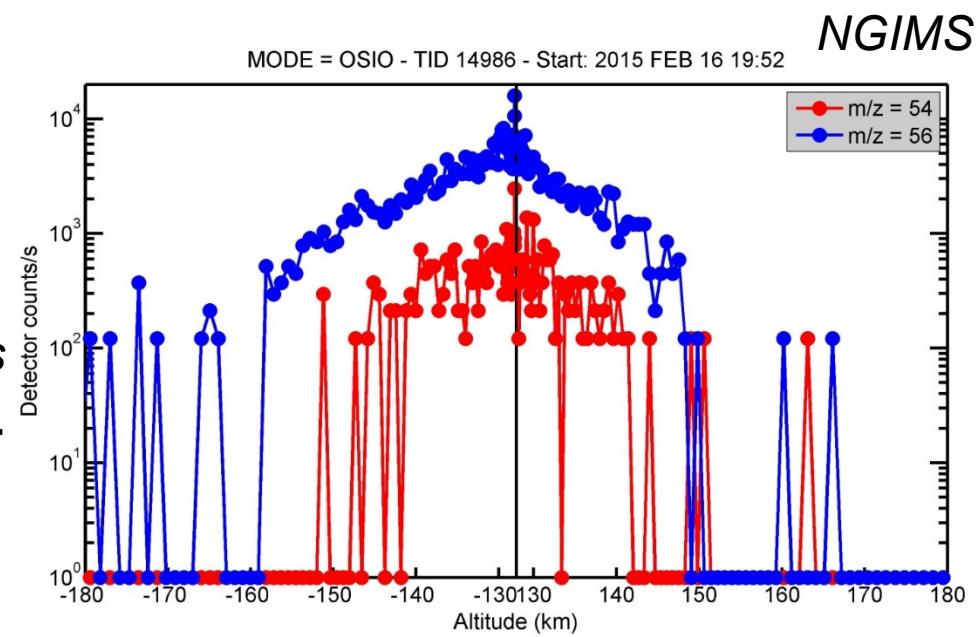


(Mc Fadden et al. 2015)

- 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

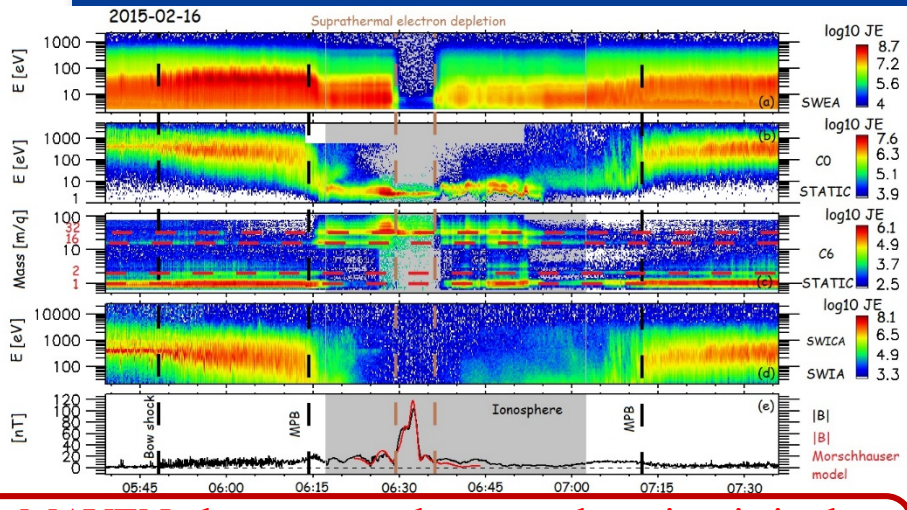
- Observed four months after Comet Siding Spring, likely no connection to it
- Previously, electron layers had been detected intermittently by *Mars Express*
- **First detection of long-lived metallic-ion layer**

(Benna et al. 2015)

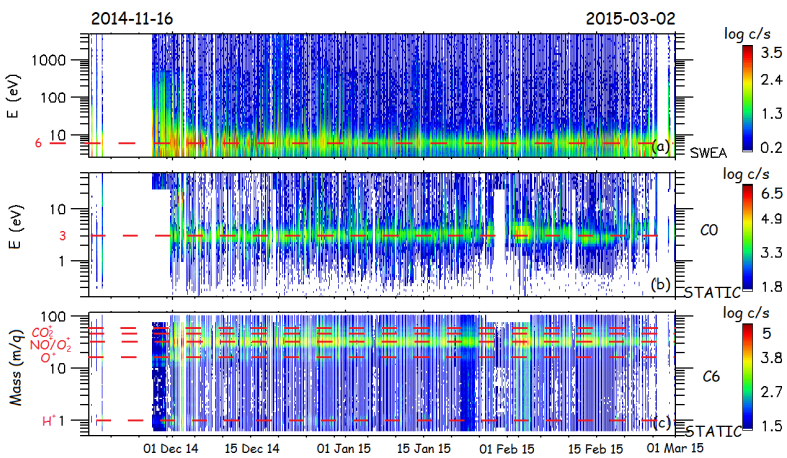


Altitude dependence of nightside Martian suprathermal electron depletions

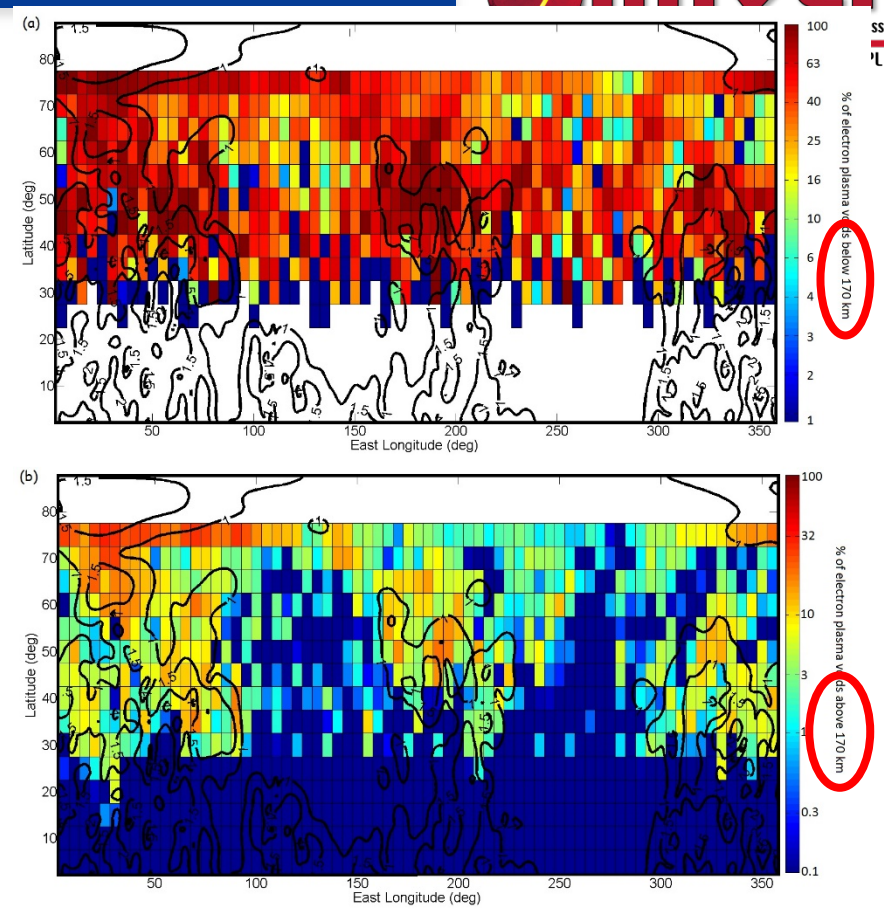
Steckiewicz et al. (2015)



MAVEN observes on almost each periapsis in the nightside ionosphere suprathermal electron depletions



Electron depletions are populated by 6 eV electrons resulting from absorption by atmospheric CO_2 and by 3eV O_2^+



The geographical distribution of nightside suprathermal electron depletions is highly dependent on altitude. The predominant process at the origin of the electron depletions seems to be:

- Below 170 km: absorption by atmospheric CO_2
- Above 170 km: strong crustal magnetic sources

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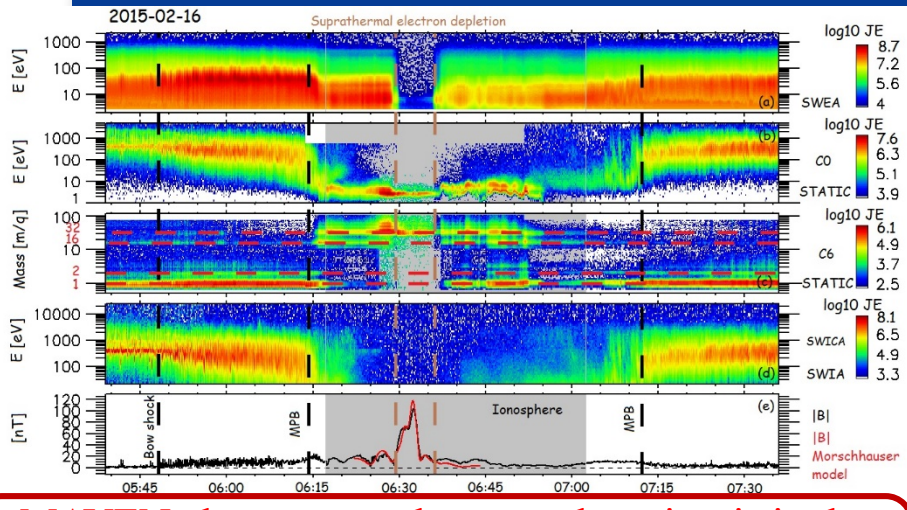

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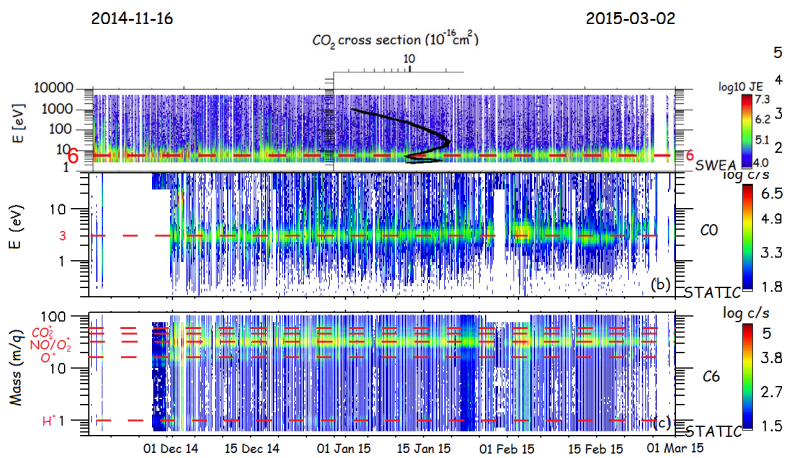

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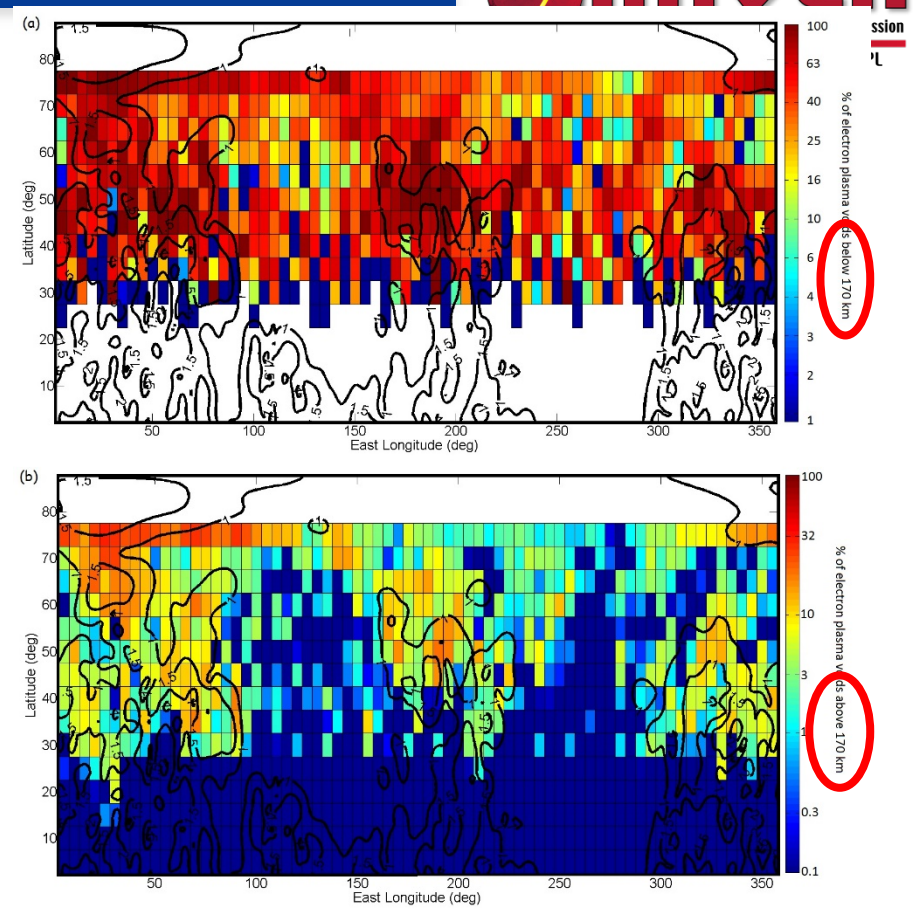

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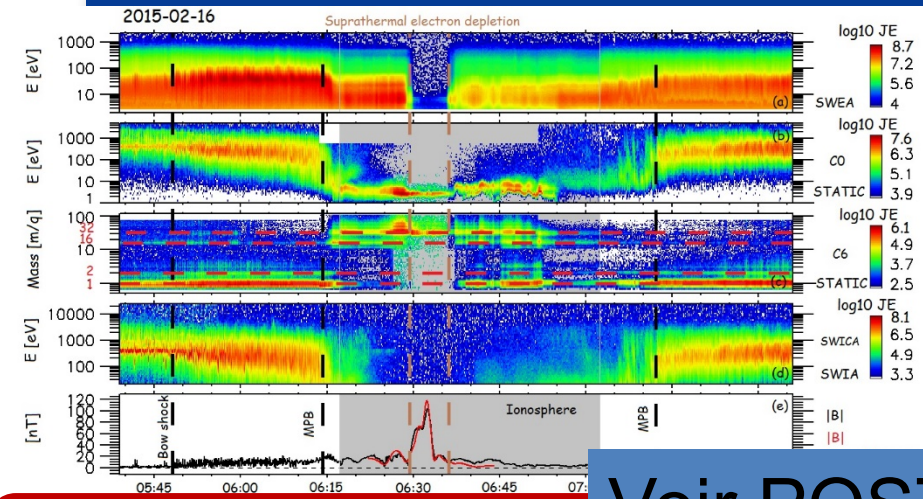
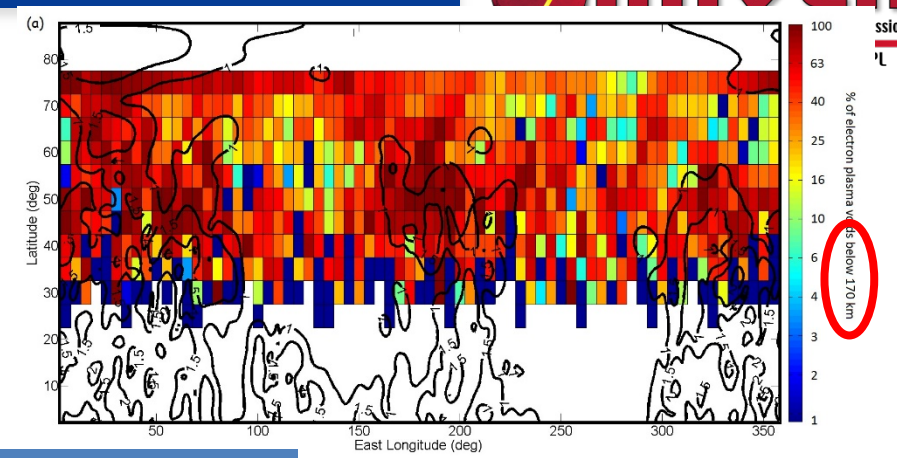
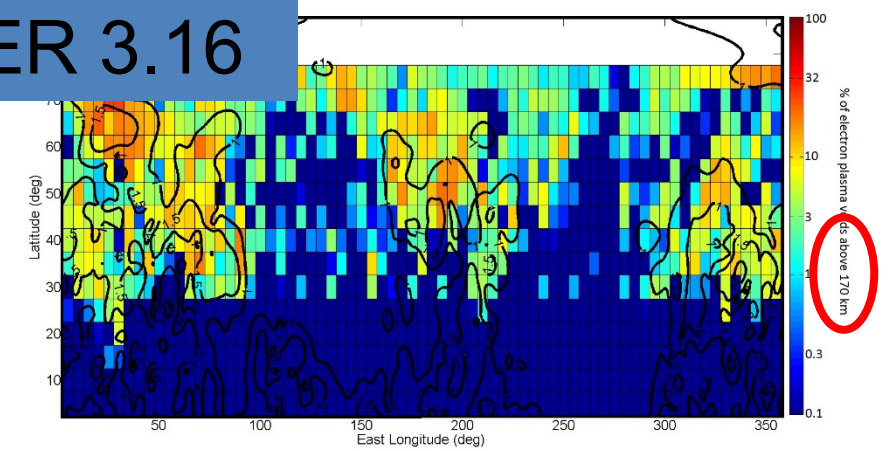
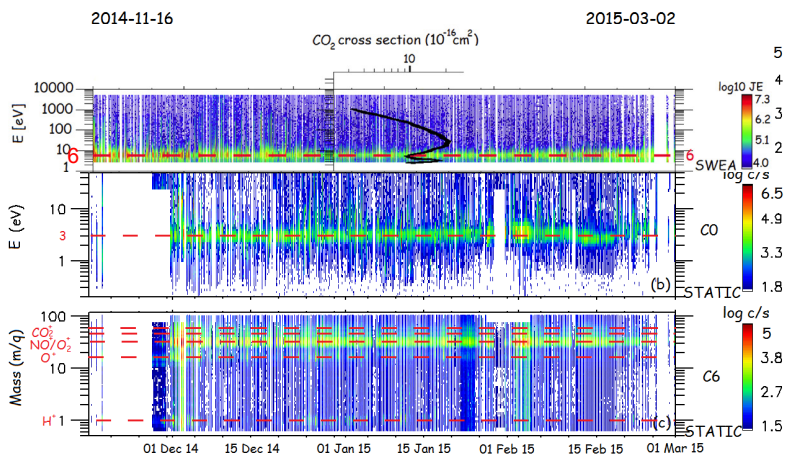






MAVEN observes on almost eac
nightside ionosphere suprathermal electron depletions

Voir POSTER 3.16

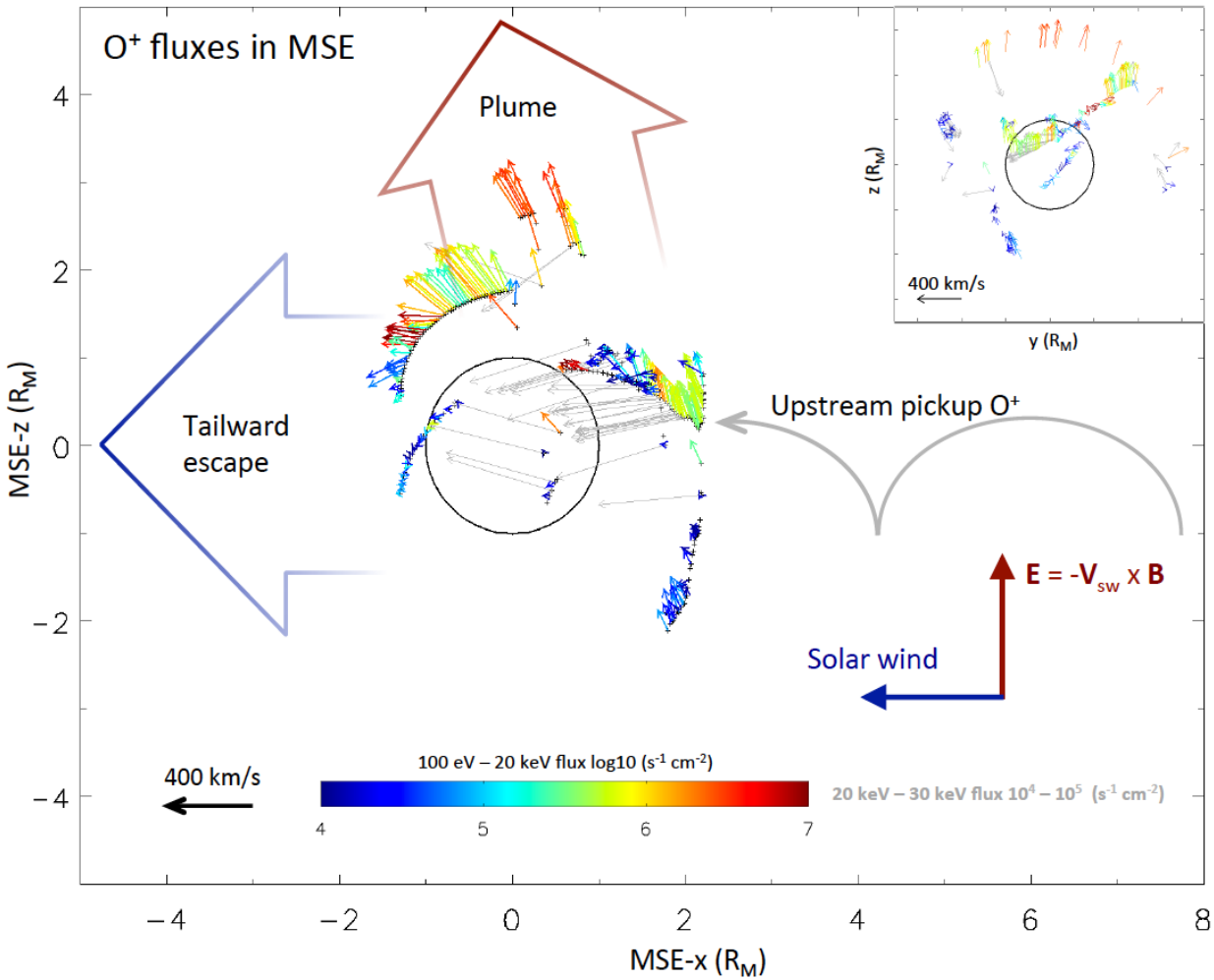


Electron depletions are populated by 6 eV electrons resulting from absorption by atmospheric CO_2 and by 3eV O_2^+

The geographical distribution of nightside suprathermal electron depletions is highly dependent on altitude. The predominant process at the origin of the electron depletions seems to be:

- Below 170 km: absorption by atmospheric CO_2
- Above 170 km: strong crustal magnetic sources

Ion Escape Driven by the Solar Wind (1 of 2)

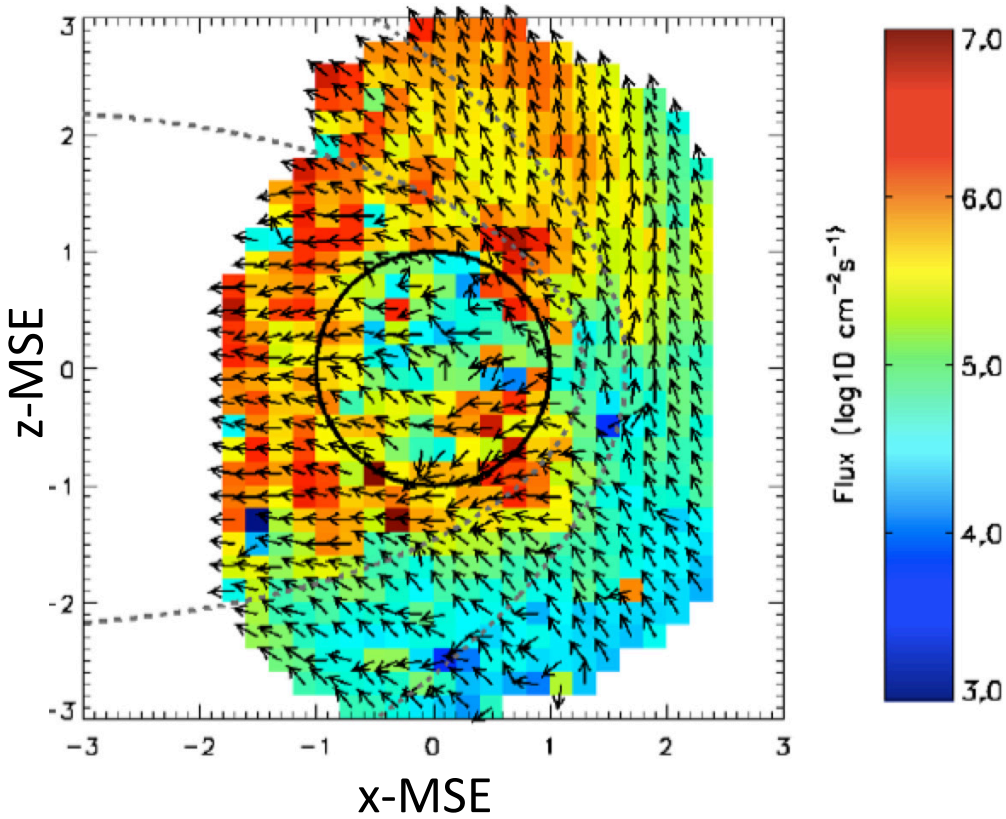


- Single orbit shows upstream pickup ions, tailward escape, and **polar plume** in STATIC observations

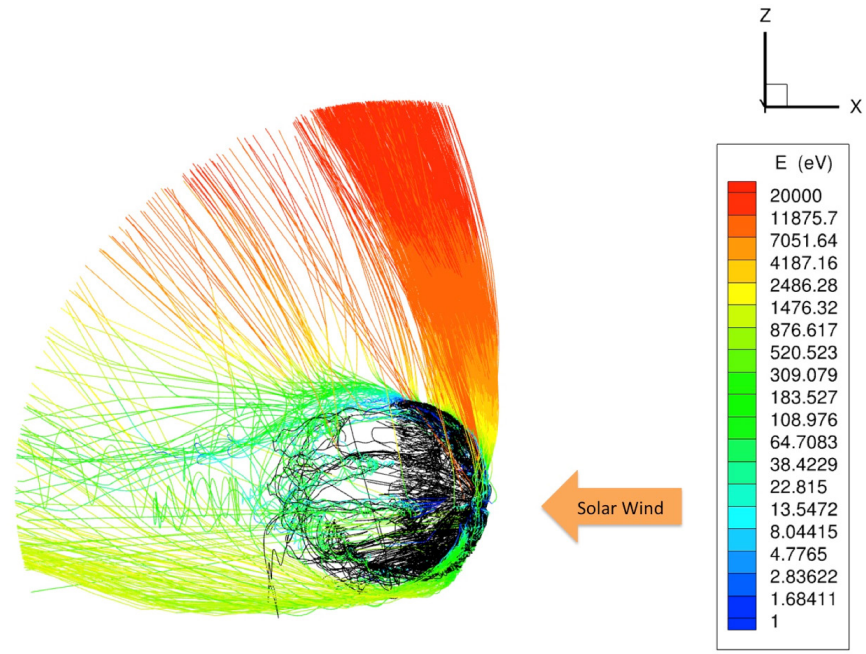
(Dong et al. 2015)

Ion Escape Driven by the Solar Wind (2 of 2)

O^+ fluxes



Model of the Polar Plume

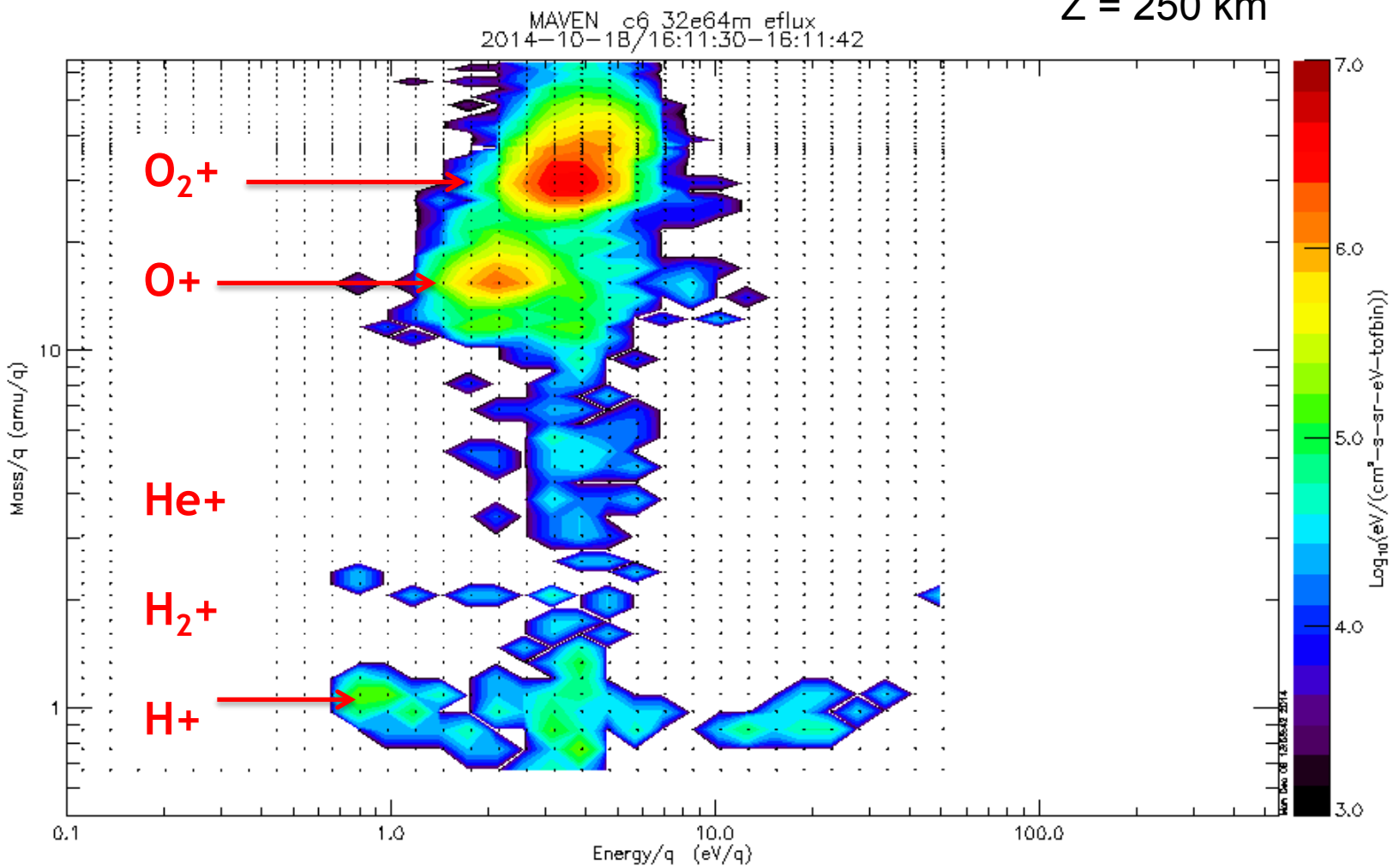


- Accumulation of all data shows that polar plume is a substantial and stable feature
- Accounts for significant fraction of total escape (~25 %)

(Dong et al. 2015)

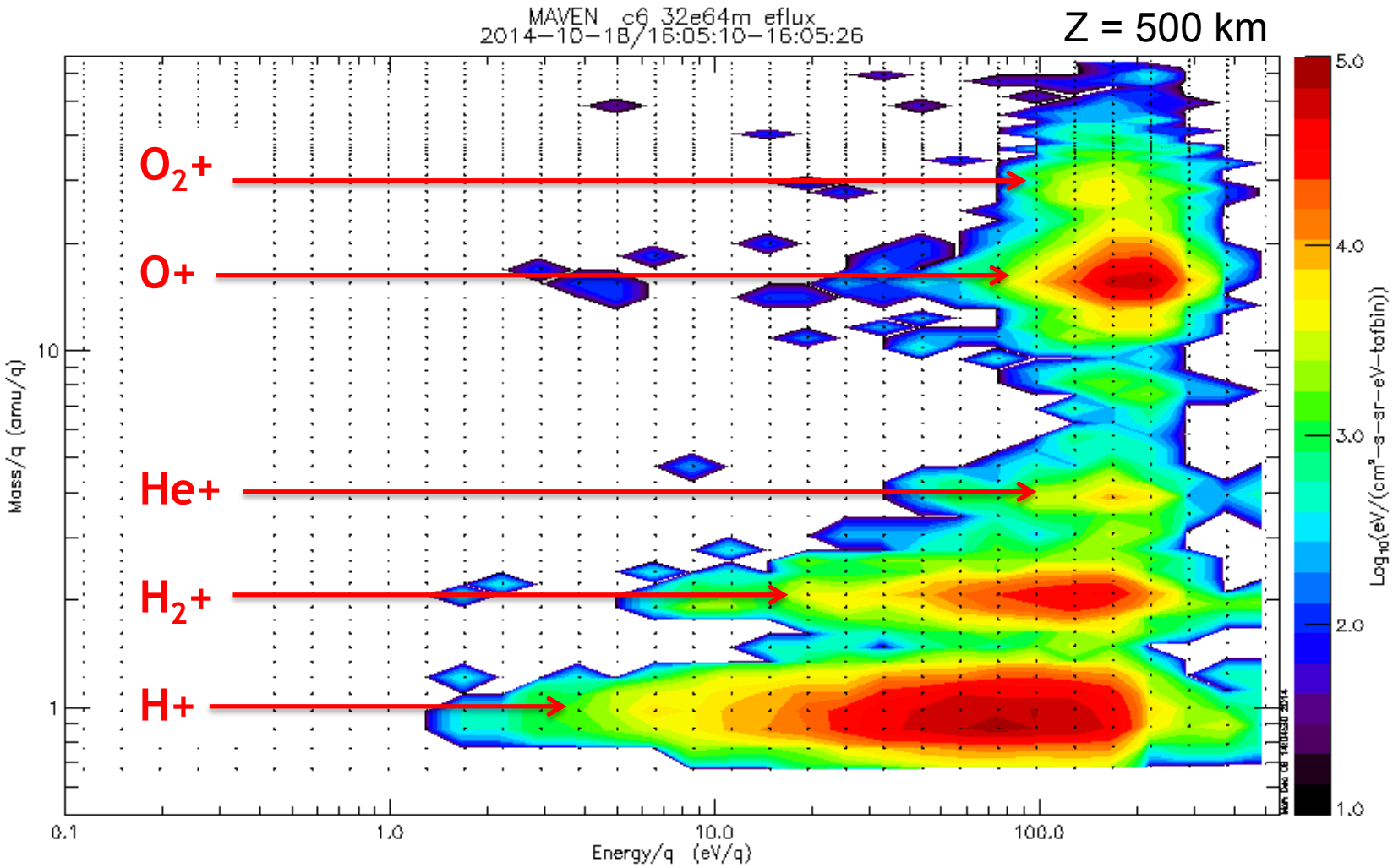
Acceleration in Polar Plume (1 of 2)

Z = 250 km



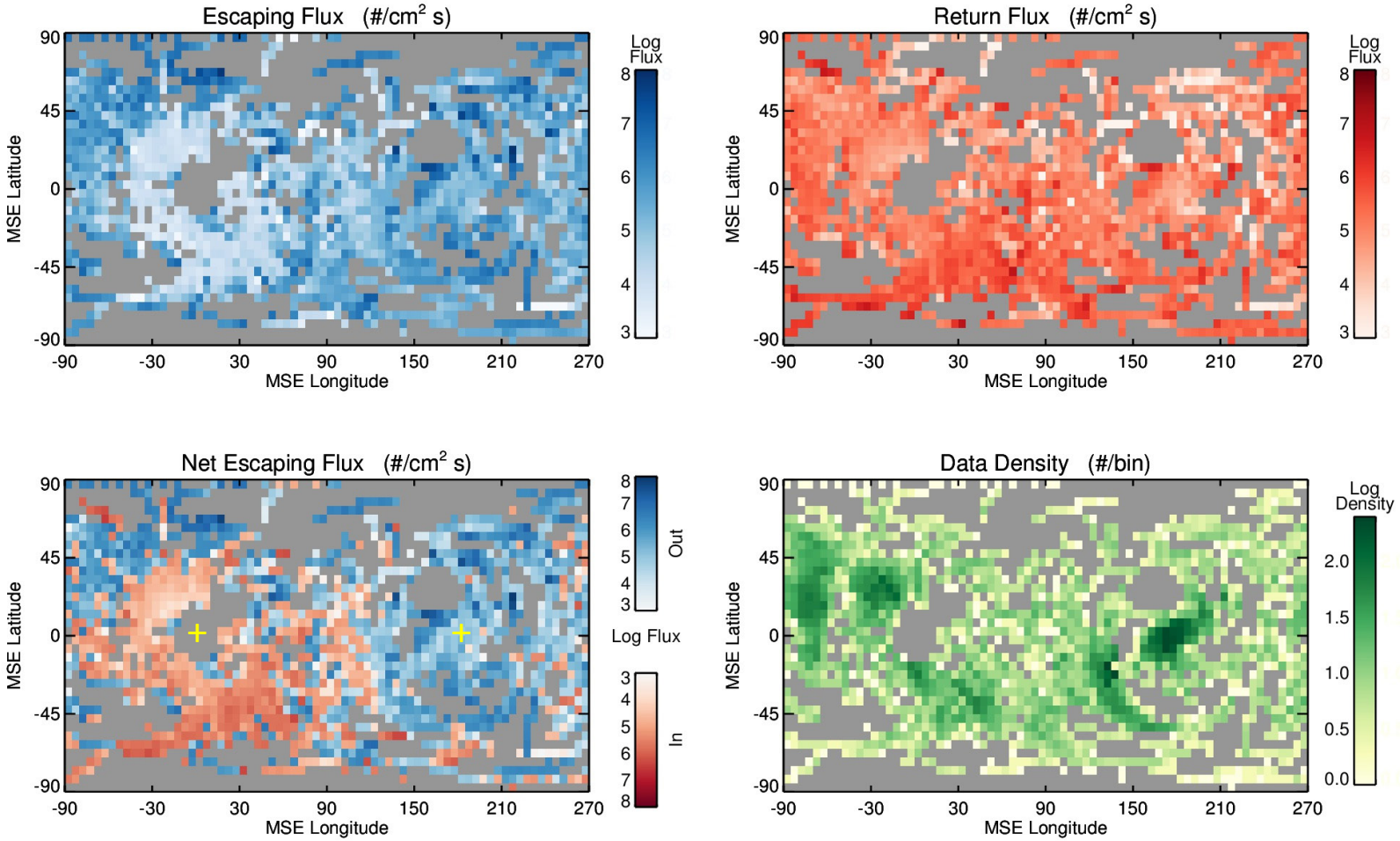
(McFadden et al. 2015)

Acceleration in Polar Plume (2 of 2)



(McFadden et al. 2015)

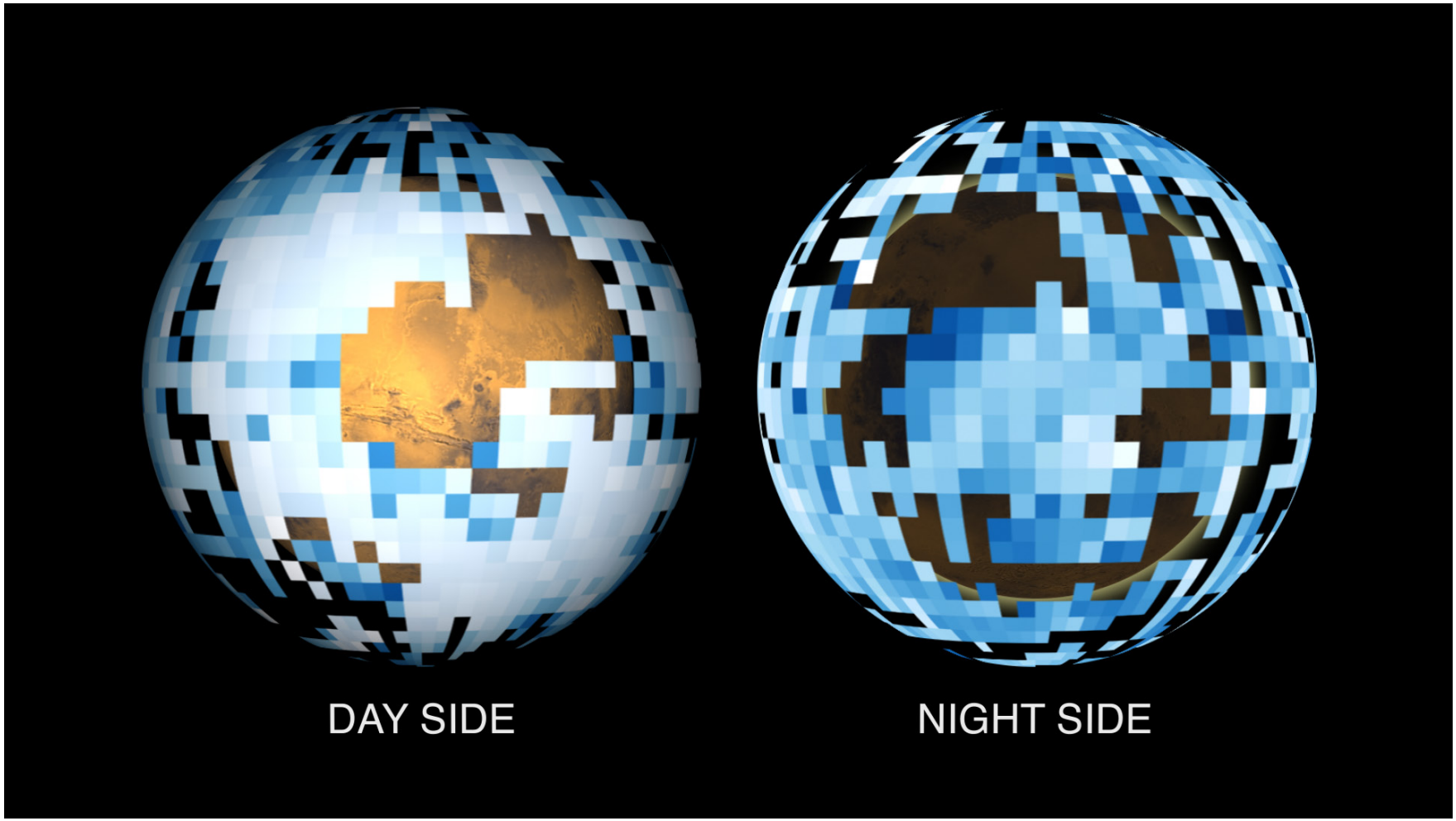
Total Escaping Flux



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

(Brain et al. 2015)

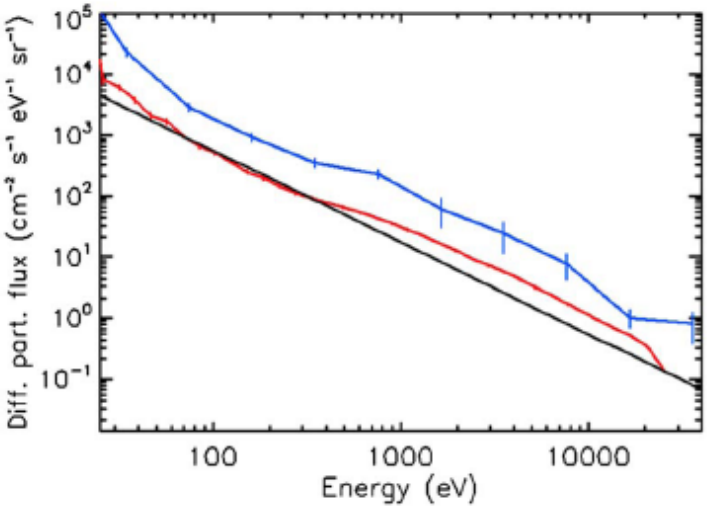
Total Escaping Flux



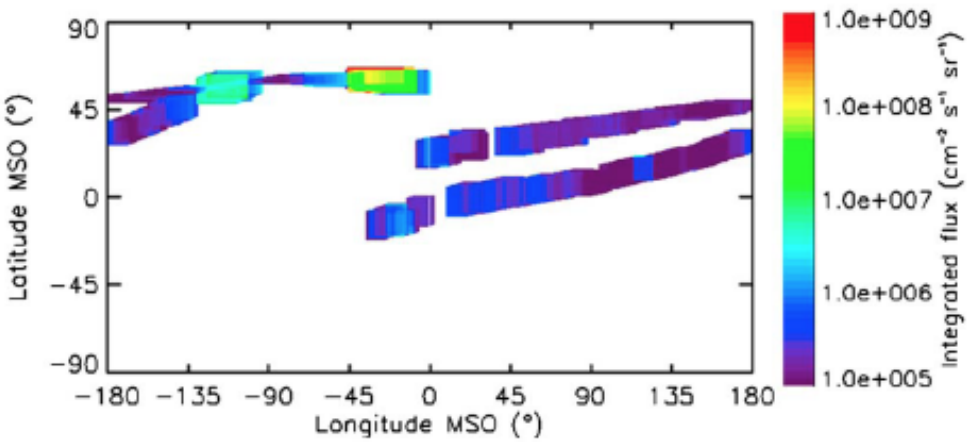
- Ion escape rate ~ 3 x 10^{24} s^{-1}, or ~100 g/s
- Not expected to be constant through time

(Brain et al. 2015)

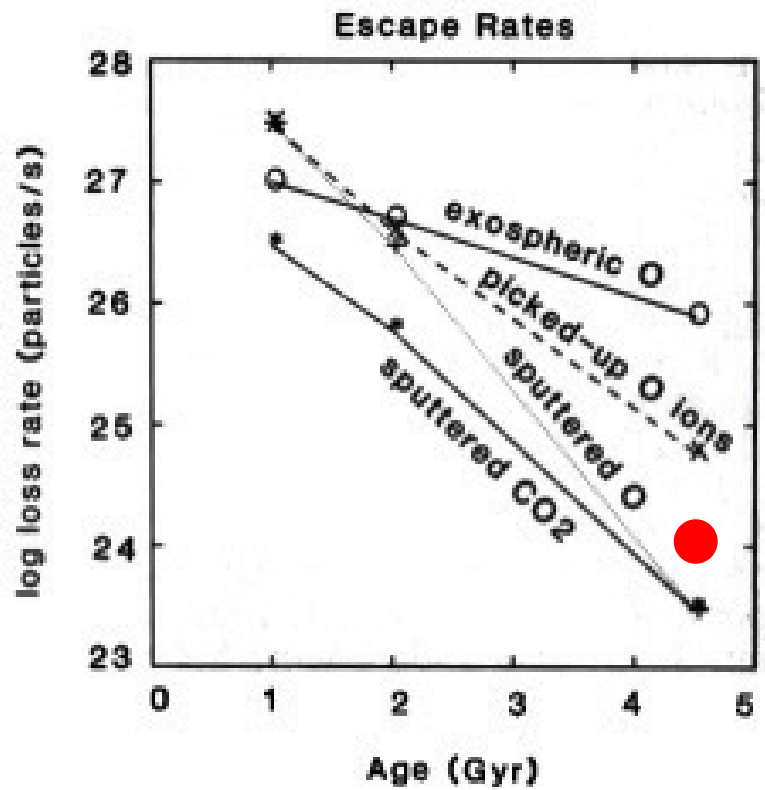
Loss Resulting From Sputtering



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

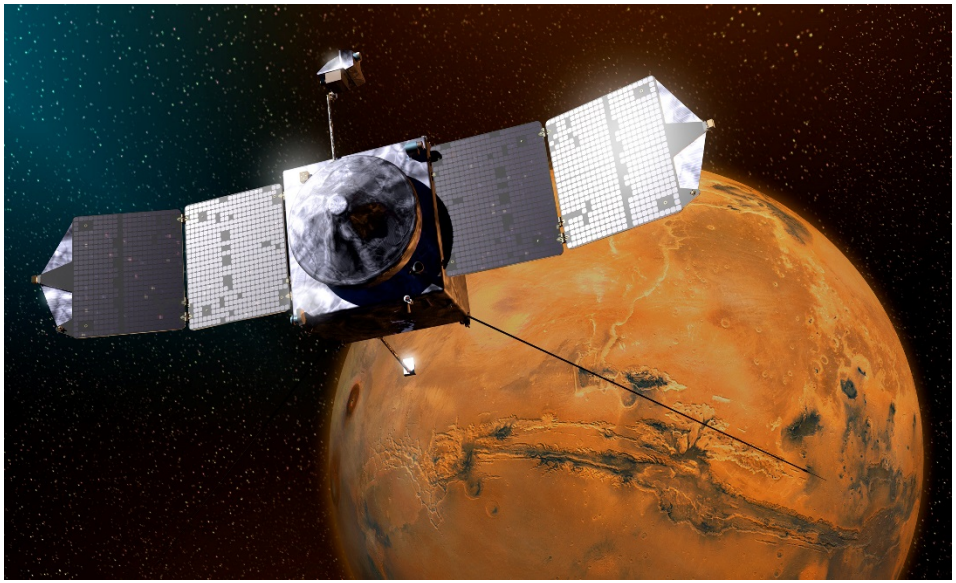
(Leblanc et al. 2015)

Conclusion

- MAVEN continues to operate well after it completed its one-Earth-year primary mission (on November 15, 2015).
- First round of science results published in *Science* (4) and *GRL (44)*

  all on November 5 (+ some more recently) with IRAP and LATMOS contrib.
- First four releases of data to the community have taken place via the PDS every 3 months

  + **CDPP (AMDA)** + **CLWeb** developed at IRAP by E. Penou (on demand).
- MAVEN has been approved for an initial extended mission (up to October 2016). Science team preparing next extended-mission proposal.



MAVEN

irap

astrophysique, planétologie

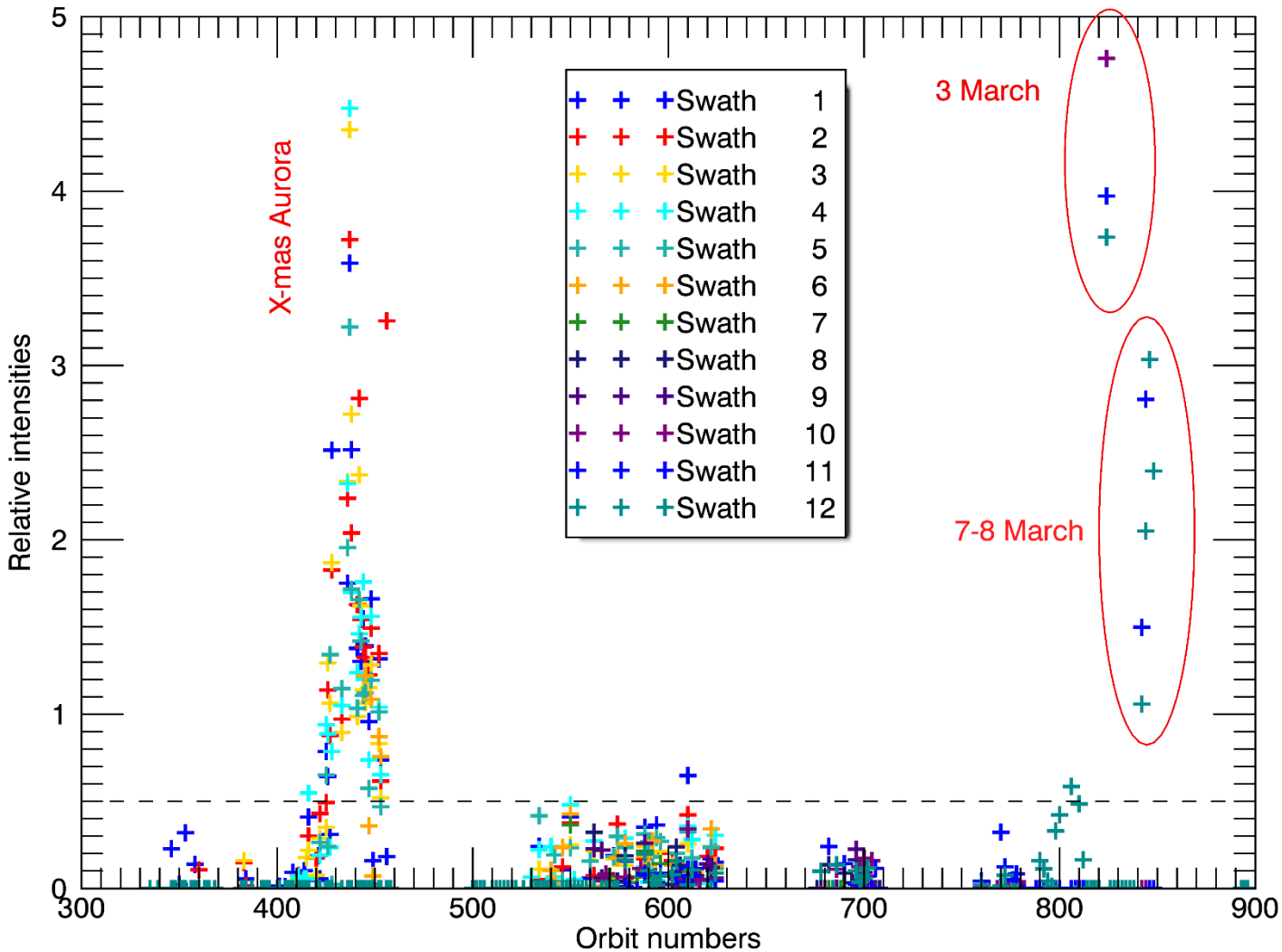
Mars Atmosphere and Volatile EvolutioN (MAVEN) Mission

FIN

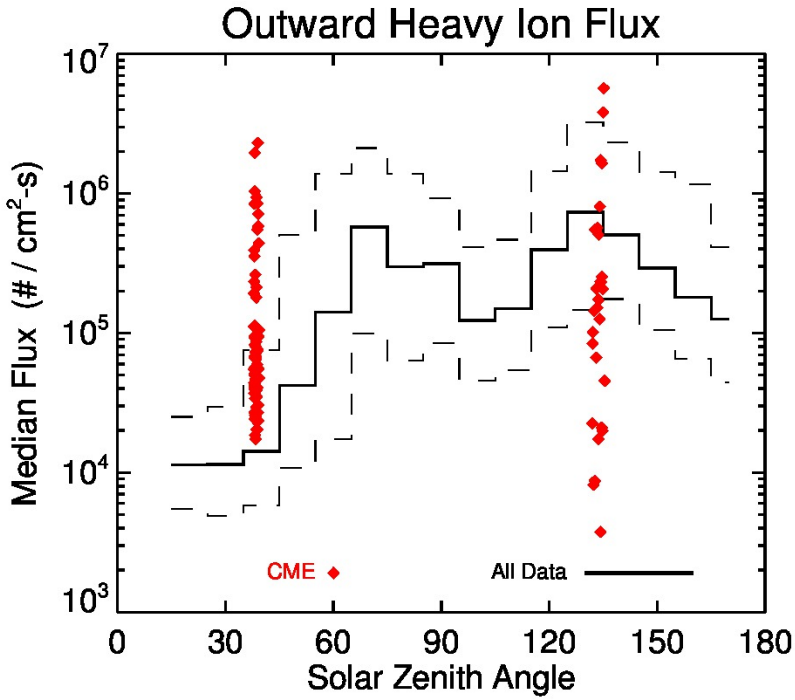
BACK-UP SLIDES

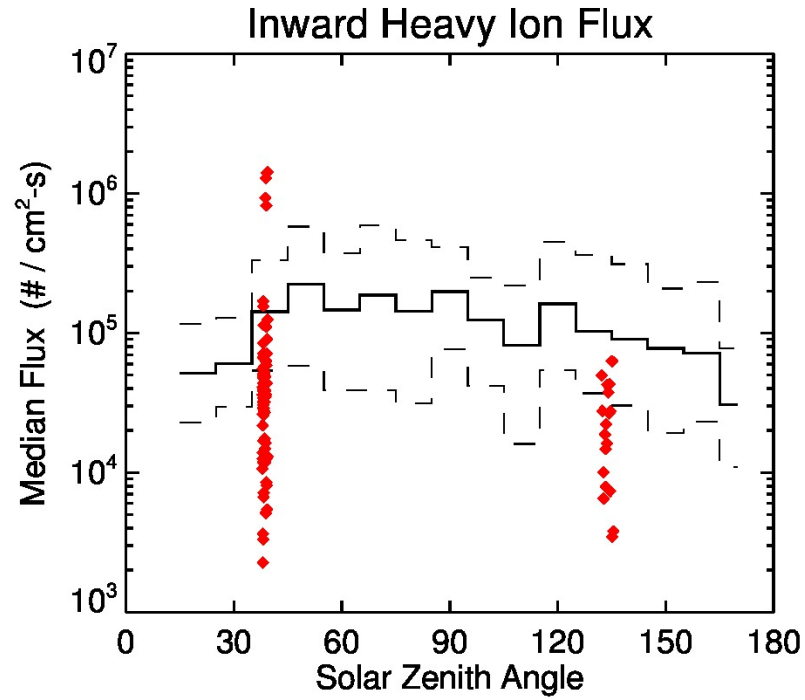
Aurora Triggered by Both Events

…and compared to the earlier "Christmas lights" aurora



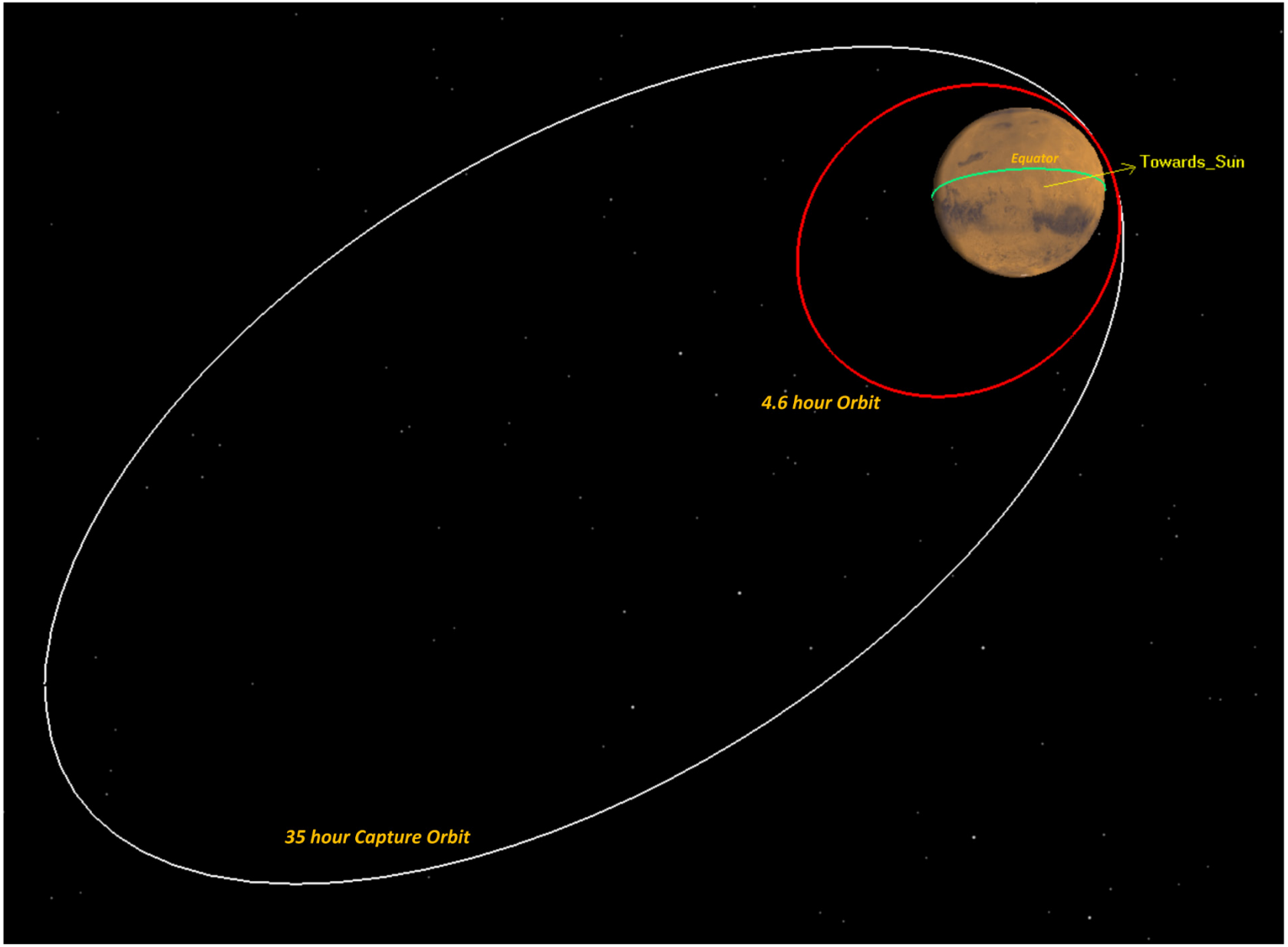
Escape Resulting From ICME



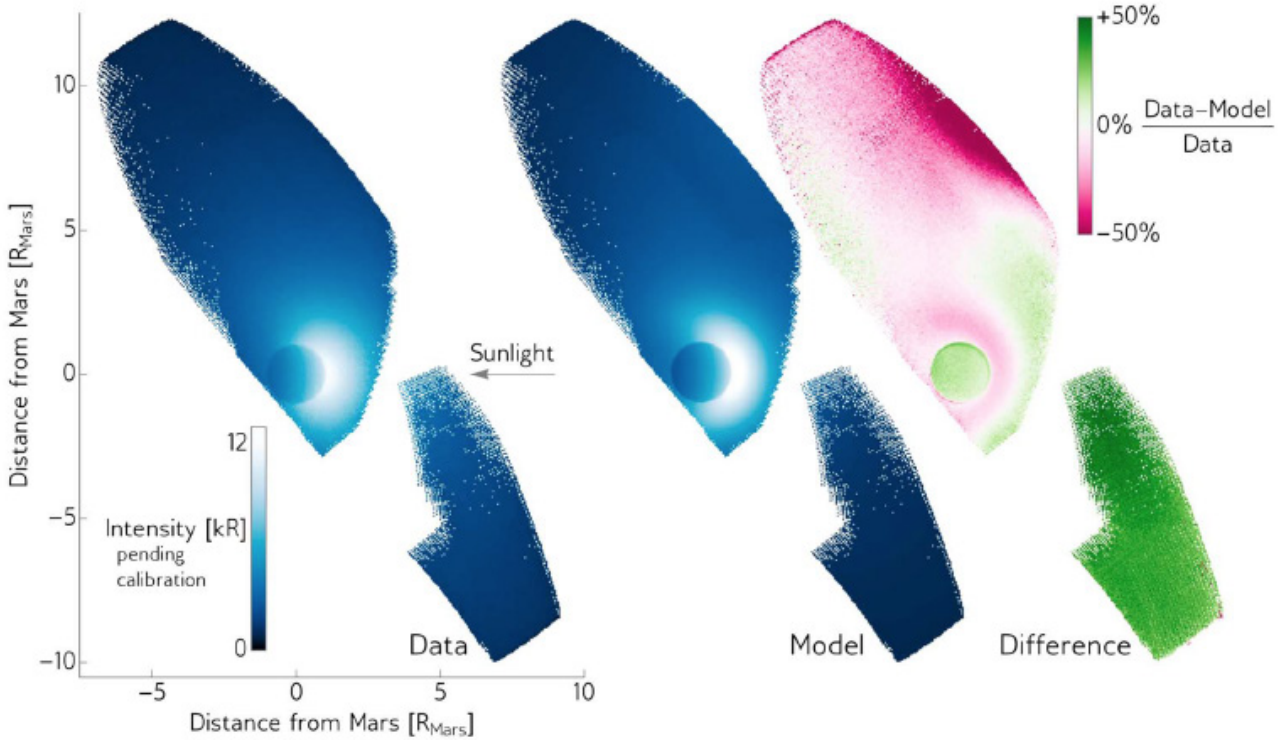


- Limited geographic coverage during ICME precludes unique determination of total escape, integrated over all angles
- Measurements indicate minimal change to tailward flux, and significant enhancement of flux on sunward side

Orbit Insertion: 22 september 2014



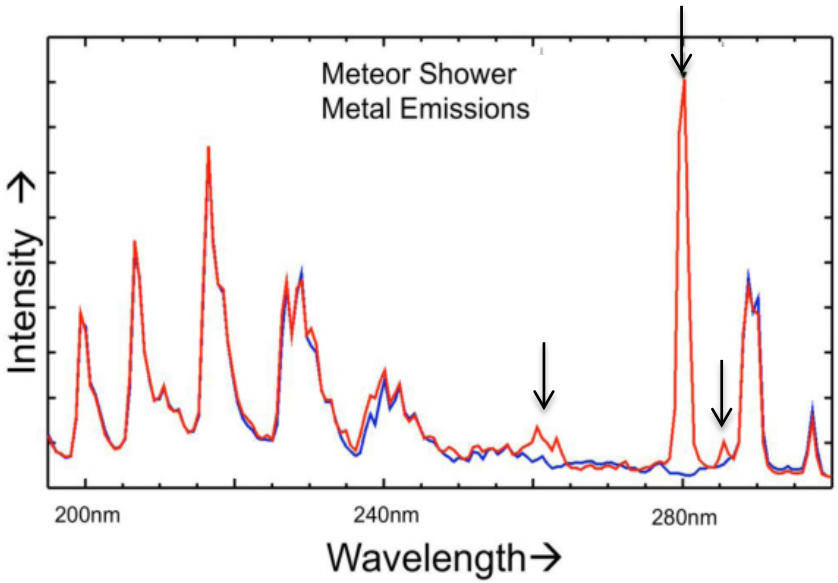
Hydrogen Distribution and Escape



- Hydrogen distribution not modeled well by single-component, spherically symmetric model
- Analysis ongoing in order to derive unique density profile and infer escape rate

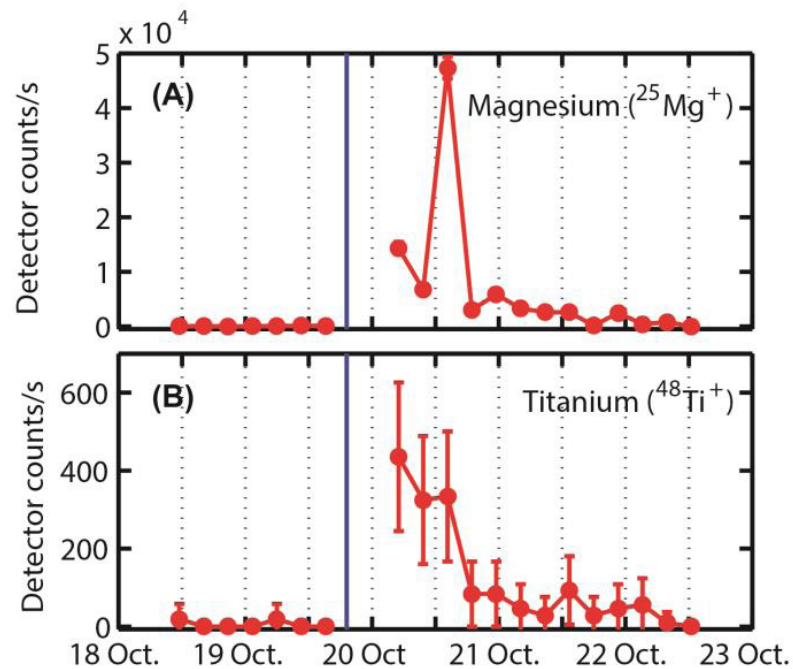
(Chaffin et al. 2015)

Discovery 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

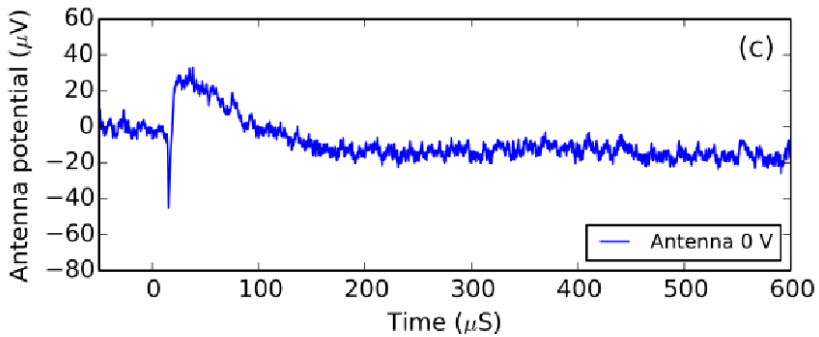


(Schneider et al. 2015, Benna et al. 2015)

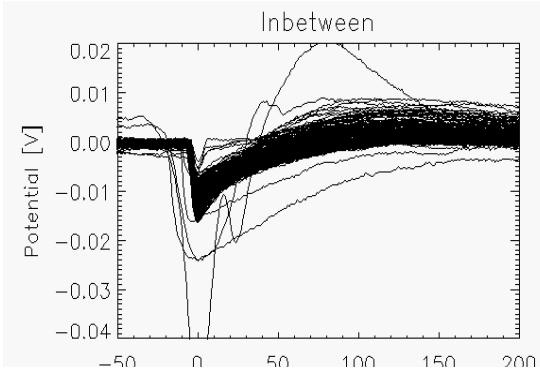
Discovery of Dust Cloud Surrounding Mars, Observed by LPW

Dust-impact signature

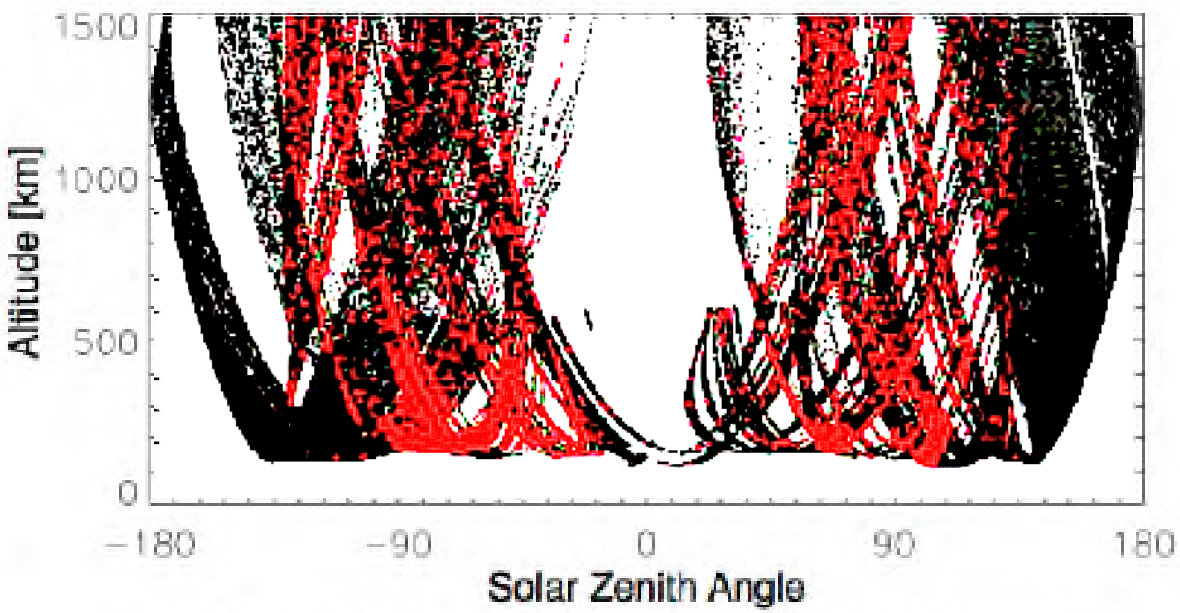
In the lab:

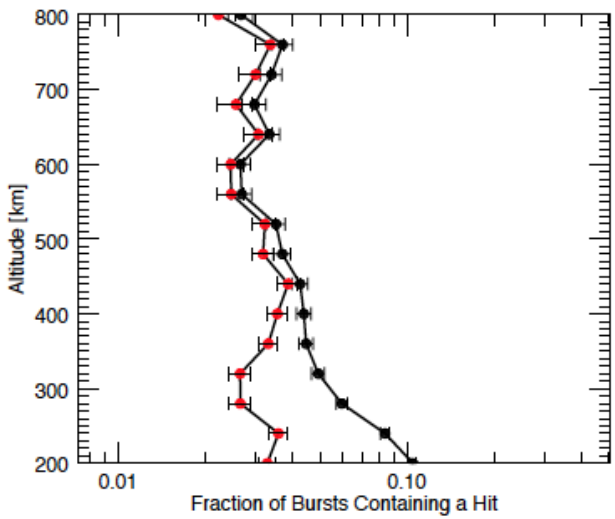


And at Mars:



Observed distribution of dust impacts:



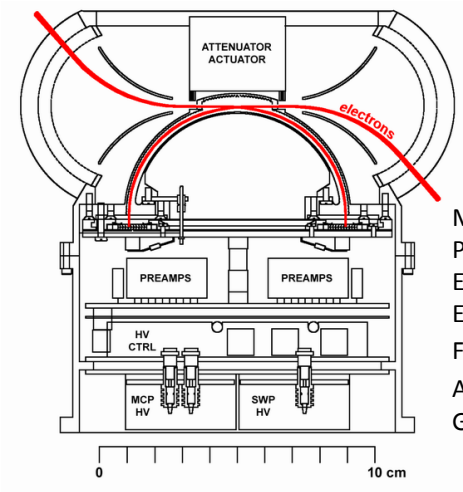


(Andersson et al. 2015)

Solar Wind Electron Analyzer (SWEA)

Science Objectives

- Electron impact ionization rate (total ionization rates, pickup ions)
- Magnetic field topology (with MAG)
- Plasma regime (solar wind interaction)
- Photoelectron energy spectra (photochemistry)
- Auroral electron features



SWEA

Hemispherical top-hat electrostatic analyzer with deflection system

Mass	1.4 kg
Power	1 Watt
Energy range	3 eV - 5 keV
Energy res.	17% ($\Delta E/E$)*
Field of view	360° × 130°
Angular res.	22.5° × 7°
Geom. factor	0.01 cm^2 ster

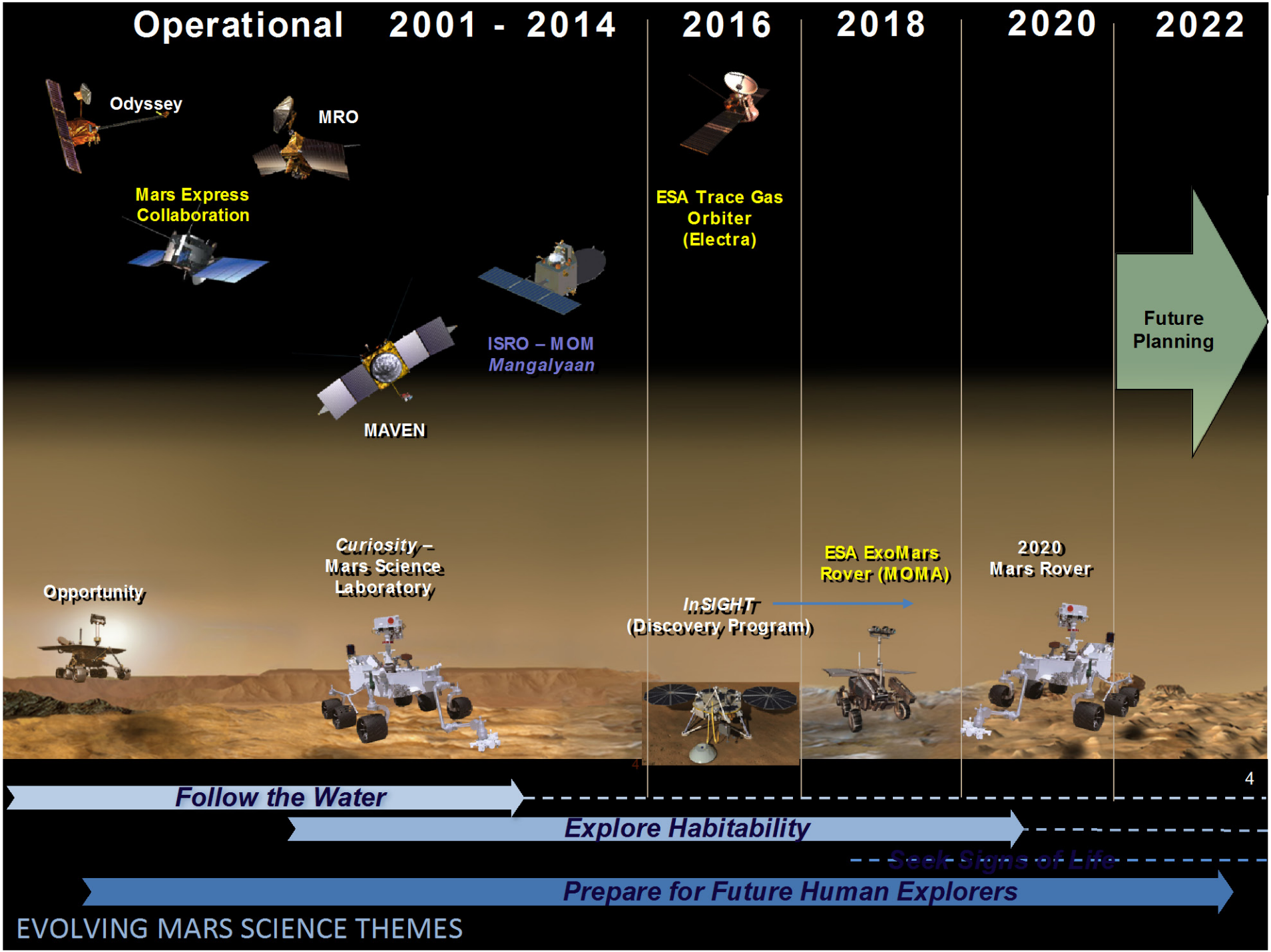
*adjustable from 9% to 17%

Technical details and heritage:

- Electrons with energies from 3 eV to 4.6 keV
- FOV: 360° x 120° (Azimuth x Elevation) (Spacecraft obstructs 8% of FOV)
- Angular Resolution: 22.5° x 20° (Az x El)
- Energy fluxes: 10^3 to 10^9 eV/cm^2-s-ster-eV
- Energy resolution: $\Delta E/E$ = 17%, FWHM (capability for 9% below 50 eV)
- Time resolution: 2 sec
- Mounted at end of 1.5-meter boom
- Based on STEREO SWEA

Data Products

- 3D distributions (energy, angle)
- Pitch angle distributions
- Energy distributions


Operational 2001 - 2014
2016
2018
2020
2022
Odyssey
MRO
Mars Express Collaboration
ESA Trace Gas Orbiter (Electra)
ISRO – MOM Mangalyaan
MAVEN
Future Planning
Opportunity
Curiosity – Mars Science Laboratory
InSIGHT (Discovery Program)
ESA ExoMars Rover (MOMA)
2020 Mars Rover
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers
EVOLVING MARS SCIENCE THEMES