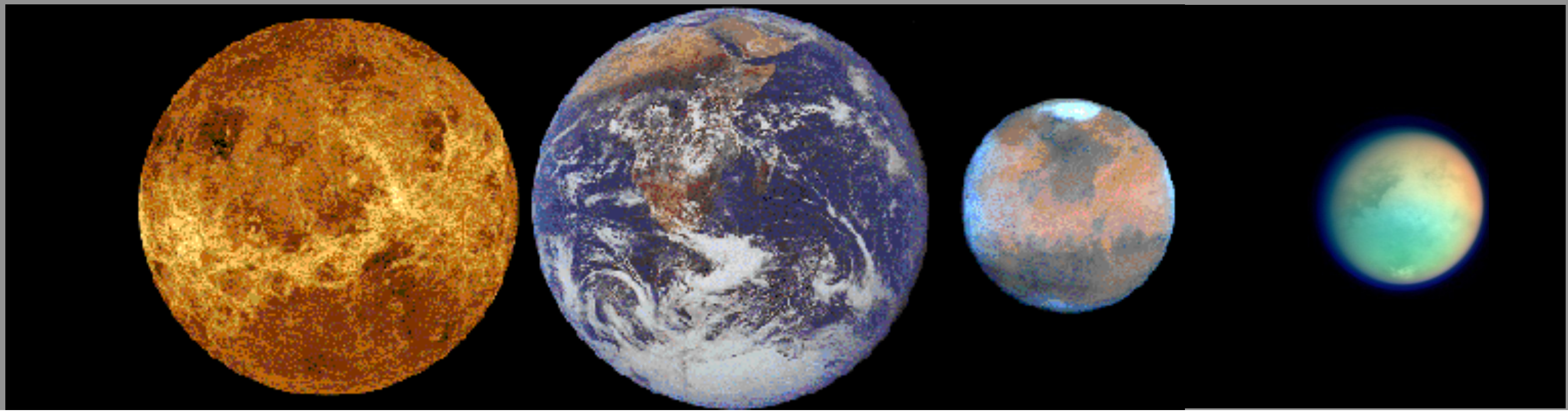
Atmospheric escape

A.J.Coates[1]

Mullard Space Science Laboratory, UCL, UK

With thanks to T.Cravens for some slides

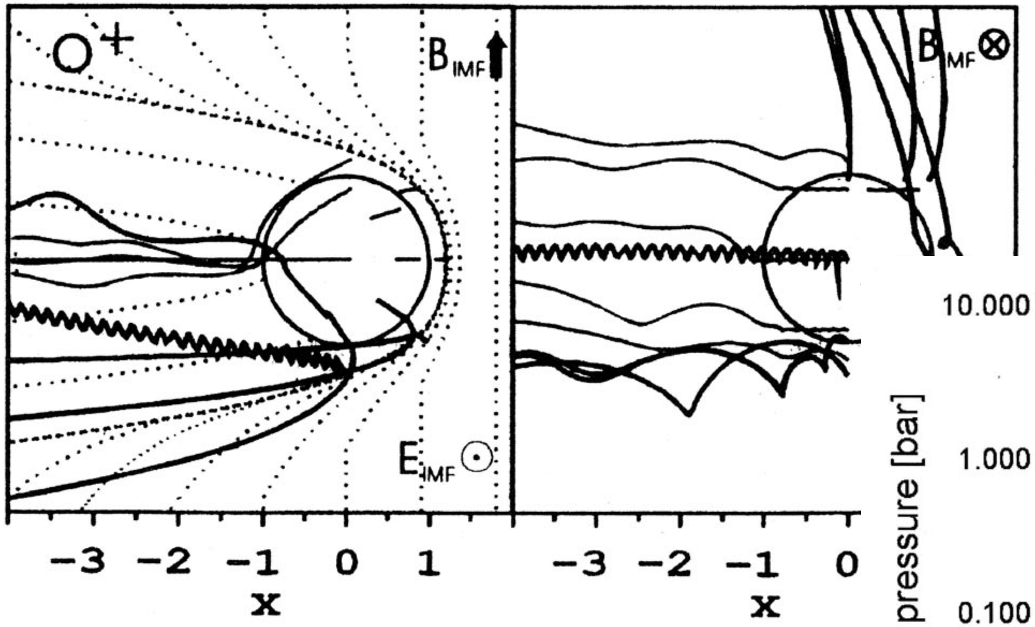


Atmospheric escape

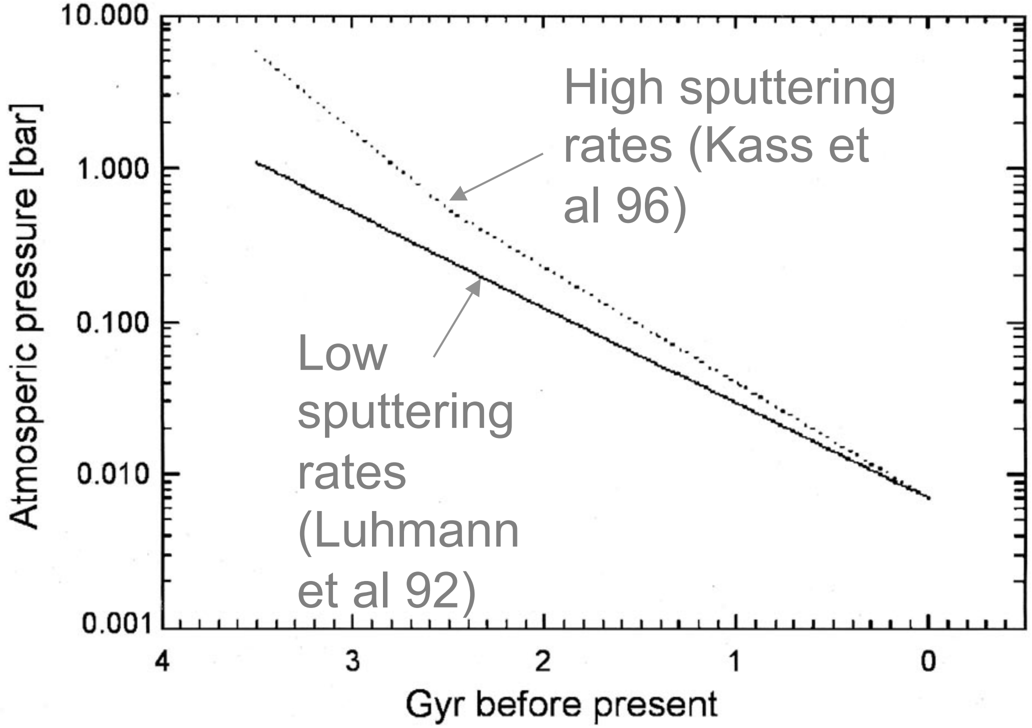
- Importance of escape to planetary evolution
- Escape mechanisms
  - Thermal escape
  - Non-thermal mechanisms
    - Ion pickup
    - Bulk plasma escape along tail
    - Photoelecton-induced ambipolar escape
- Measurements

Importance of escapee

- Mars has no global magnetic field
- Estimated loss rate ~10^{25} (0.1-0.5 kg) s^{-1} (Lundin et al) – significant on solar system timescale



Lammer et al 2002



Thermal escape mechanism

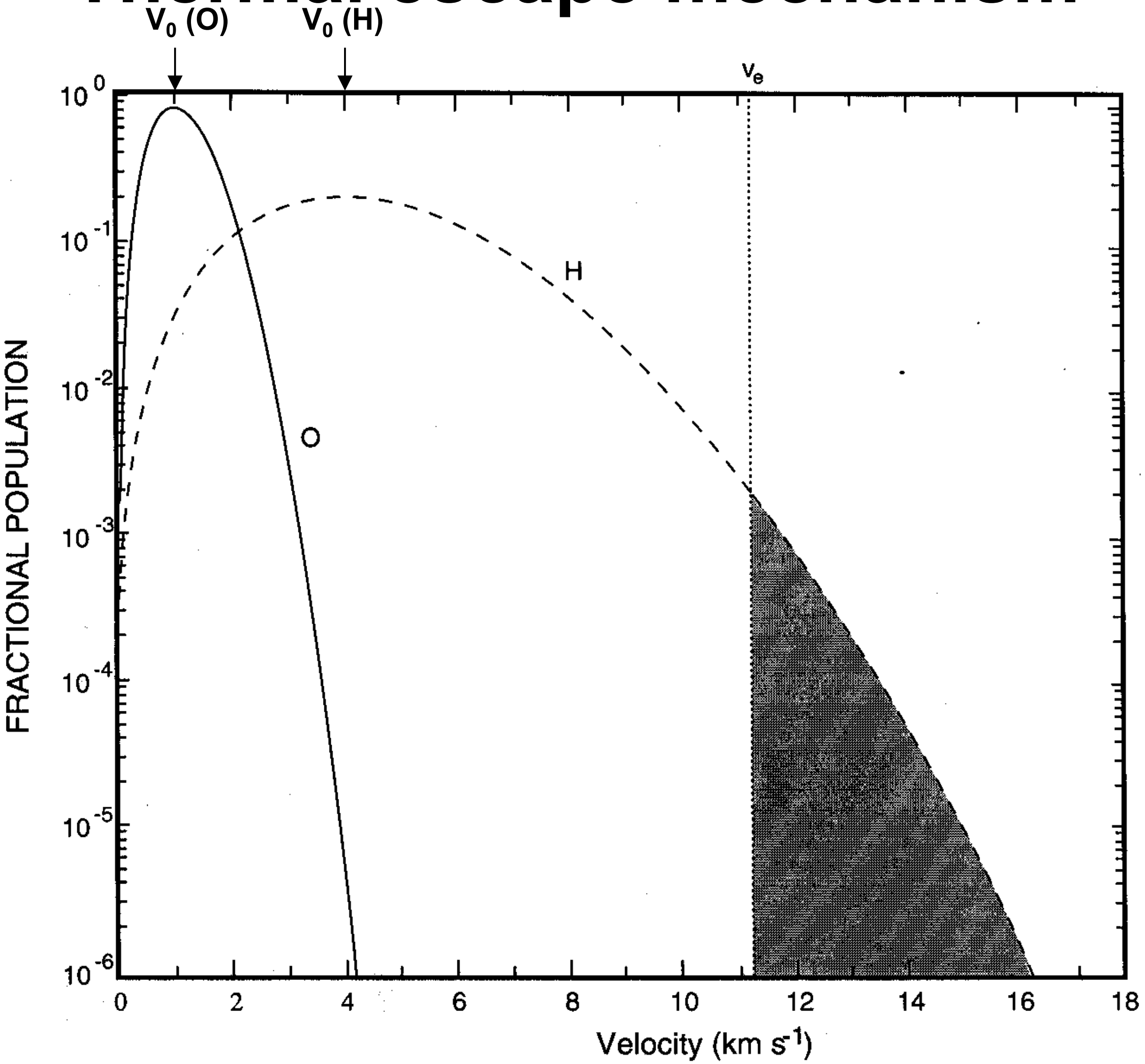


Figure 1.6 Boltzmann distribution of velocities for a molecular ensemble of oxygen atoms and hydrogen atoms. Escape velocity v_e for earth also indicated.

- Plot shows the speed distributions for oxygen & hydrogen atoms in Earth's exosphere, at a typical exosphere temperature T=1000 K
- The most probable value is v_0, which turns out to be

$$v_0 = \sqrt{\frac{2kT}{m}}$$

- The fraction of oxygen atoms above the escape velocity (11.2 km s^{-1}) is negligible, whereas a significant fraction of hydrogen atoms are above the escape velocity.
- (As the high velocity atoms escape, the distribution quickly returns to this equilibrium shape, so that more atoms can escape.)

Fig from Salby, Fundamentals of Atmospheric physics

Thermal (Jeans) escape

Given a Maxwellian distribution, the upward flux of escaping particles (per unit area) is given by the Jeans formula for escape by thermal evaporation:

$$\Phi_{ecape} = \frac{n(z)v_0}{2\sqrt{\pi}}\left(\frac{v_{esc}^2}{v_0^2}+1\right)\exp\left(-\frac{v_{esc}^2}{v_0^2}\right)$$ particles m^{-2} s^{-1}

where n(z) is the number density

$$v_0 = \sqrt{\frac{2kT}{m}}$$ is the most probable velocity, as above

$$v_{esc} = \sqrt{\frac{2GM_{planet}}{(R_{planet}+z)}}$$ is the escape velocity

–Important factor is the final exponential term.

- E.g. for Earth, v_{esc} = 11.2 km s^{-1}, and assuming exosphere temp T = 1000K:
  - For oxygen atoms,

$$v_0 = \sqrt{\frac{2\times1.38\times10^{-23}\times1000}{16\times1.66\times10^{-27}}}$$ = 1019 m s^{-1} = 1.02 km s^{-1}

» The exponential term is exp(–11.2^2/1.02^2) = exp(–120) ≈ 4 x 10^{-53} which is completely negligible

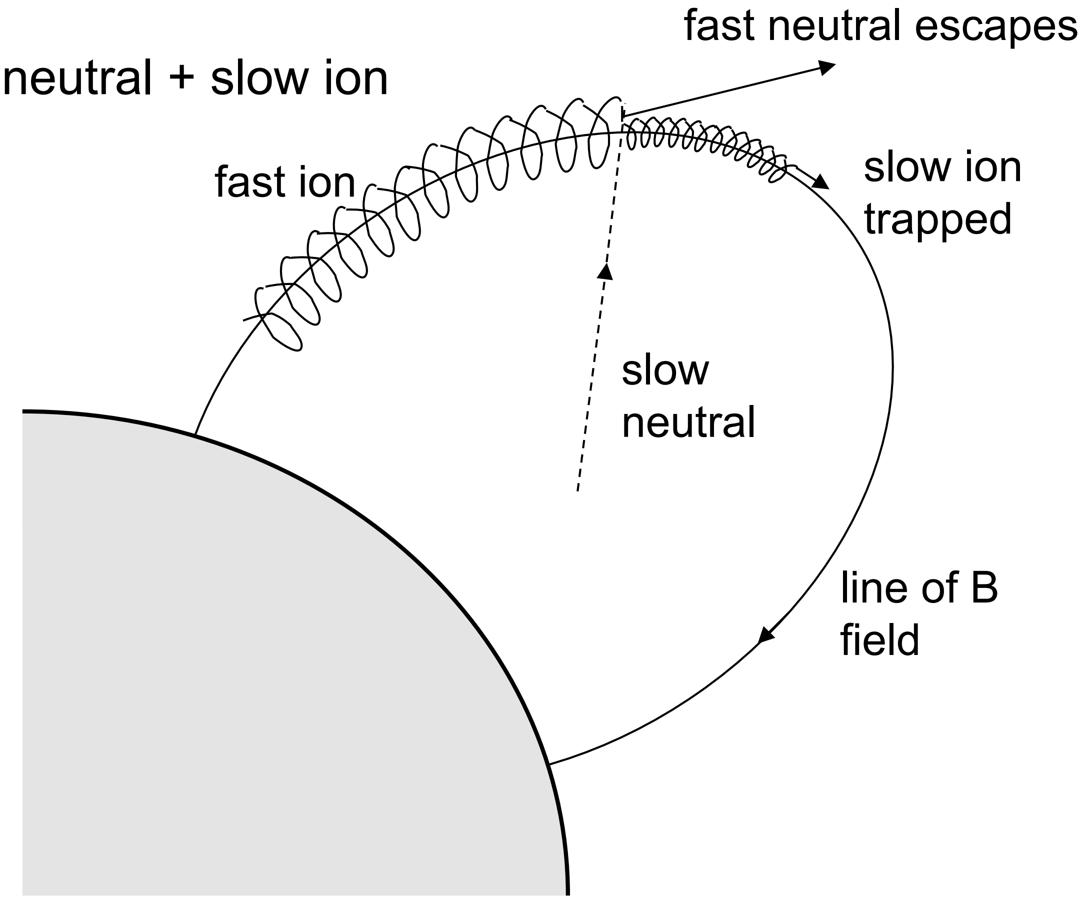
  - For hydrogen atoms, v_0 is 4 x larger, giving exp(–7.5) ≈ 5 x 10^{-4} . Allows rapid escape despite continuous production by H_2O photodissociation

Non-thermal escape mechanisms - 1

- Non thermal mechanisms need to give the escaping particles energies of
  - 0.6 eV/amu on Venus and Earth
  - 0.125 eV/amu on Mars.
  - This is relatively small in comparison with atomic energies and the energies which might be gained from an electric field.

<u>(b) Charge exchange</u>

- Slow neutral + fast ion → fast neutral + slow ion
- By exchanging charge, the fast ion (which was trapped by the planet's magnetic field) becomes a neutral and is able to escape.
- The resulting slow ion is trapped by the mag. field.



<u>(c) Photochemical reactions</u>

- These convert the energy of absorbed X-ray photons to kinetic energy
  - Typical yield is a few eV
  - This may be enough to cause escape

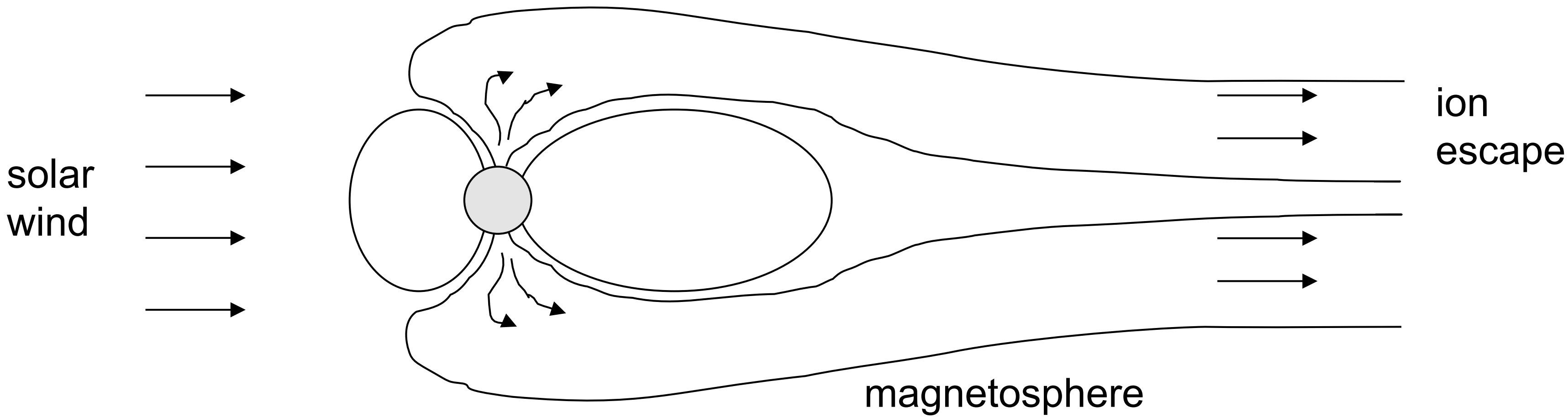
Non-thermal escape mechanisms - 2

<u>(d) Sputtering</u>

- Impact of fast ions knocks atoms out of the atmosphere. The fast particles could be solar wind or trapped radiation belt particles

<u>(e) Ion escape</u>

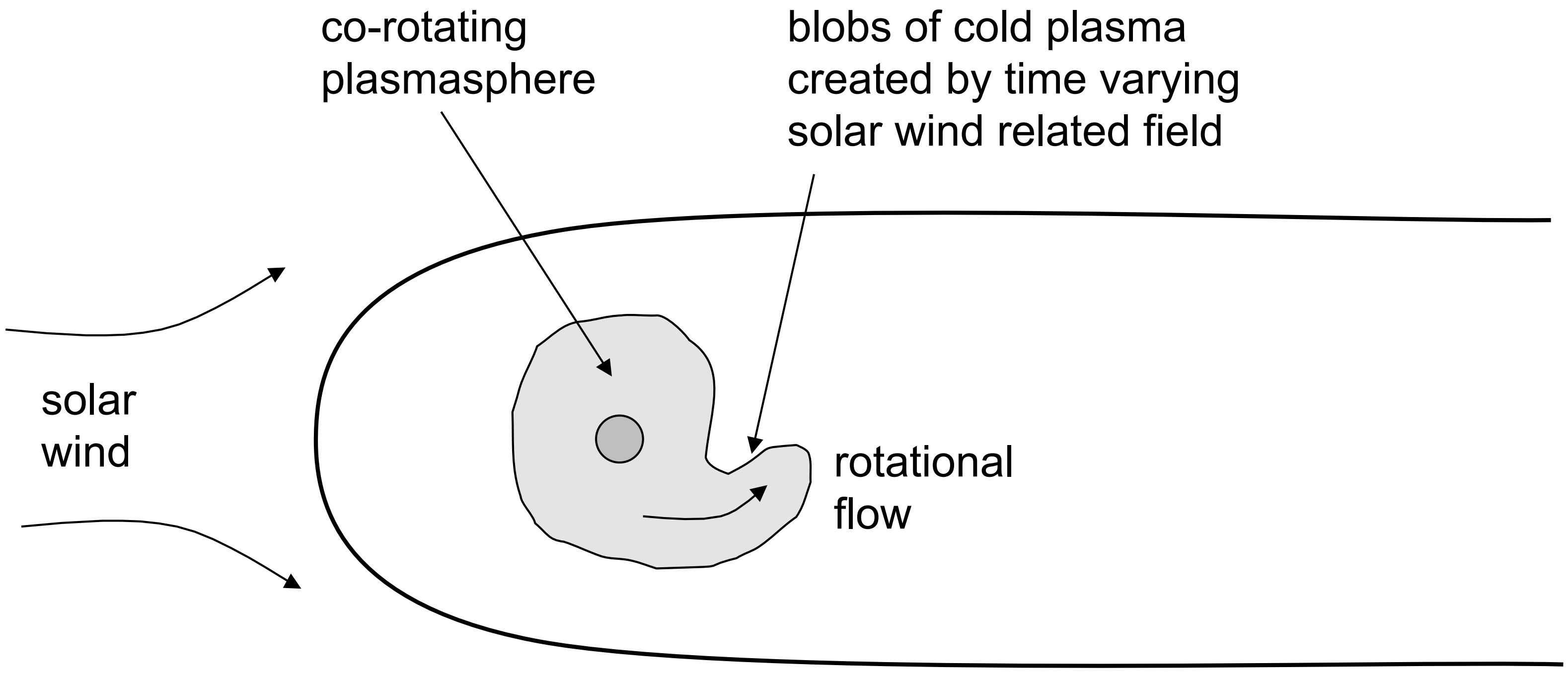
- Ions flow upward along polar field lines and escape down magnetic field lines
- They gain their energy from *ambipolar diffusion*, where the interaction of ions & electrons in a plasma causes them to diffuse at the same rate
- The electrons have much higher thermal velocities and can easily escape. This sets up an electric field by charge separation and the ions are dragged after the electrons
- Occurs in magnetospheres and also at Mars



Non-thermal escape mechanisms - 3

(f) Electric fields

- Neutral particles are ionised in the upper ionosphere
- The resultant ions are pulled out of the ionosphere by electric fields associated with auroral activity into the co-rotating plasmasphere above
- The solar wind sets up a cross-tail electric field (downwards in this diagram)
- Blobs of cold plasma spin off under the influence of this field as shown and are lost into the tail and eventually into the solar wind downstream

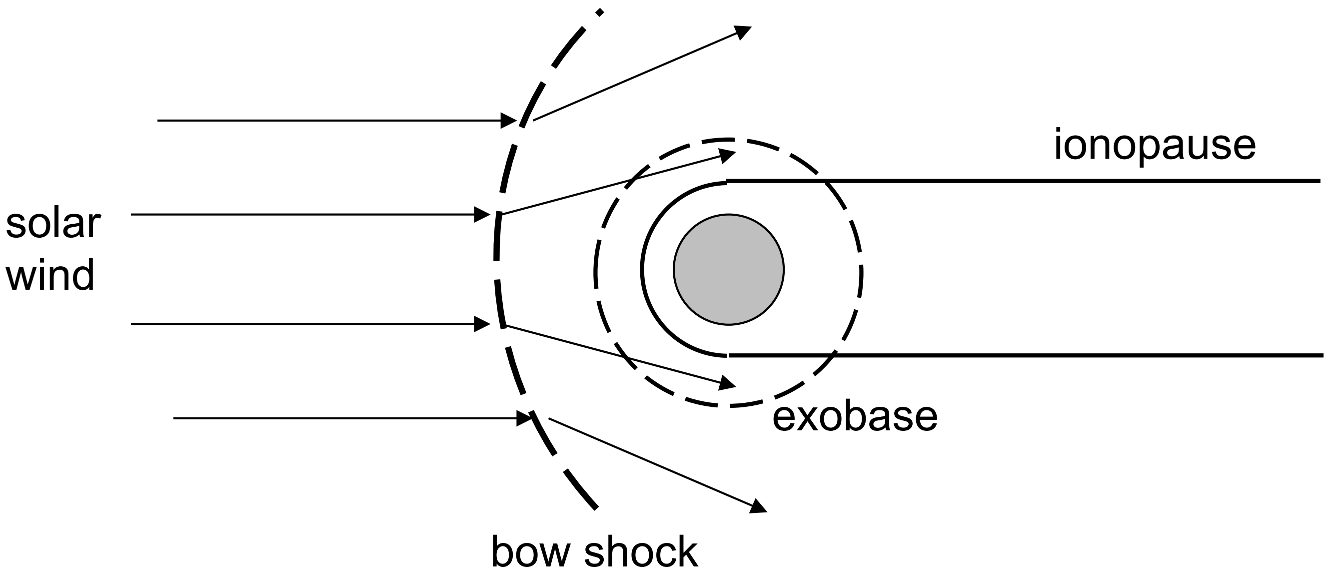


equatorial slice of magnetosphere

10.3 Non-thermal escape mechanisms - 4

(f) Ion pickup (solar wind scavenging)

- At Mars and Venus the exobase is above the boundary between the solar wind flow and the planet.
- Once the particles become photoionised they can be picked up directly by the solar wind flow and carried away.
- The energy is provided by the electric field in the solar wind.



Catastrophic escape mechanisms

- The following 2 processes are only important in catastrophic circumstances involving major impacts:

(g) Hydrodynamic escape (atmospheric blowoff)

- When the bulk of a light gas below the exobase moves fast enough it streams upward at supersonic speed and drags the rest of the atmosphere along
- This may have occurred due to heating by planetisimal impact during the late phase of accretion of the terrestrial planets

(h) Impacts

- If the impactor is larger than the atmospheric scale height, the shock heated air at the place of the impact will then form a hot bubble that rises at more than the escape velocity

Lundin et al., 1990 (**Phobos data**)
Estimated loss rate ~2×10^{25} s^{-1}

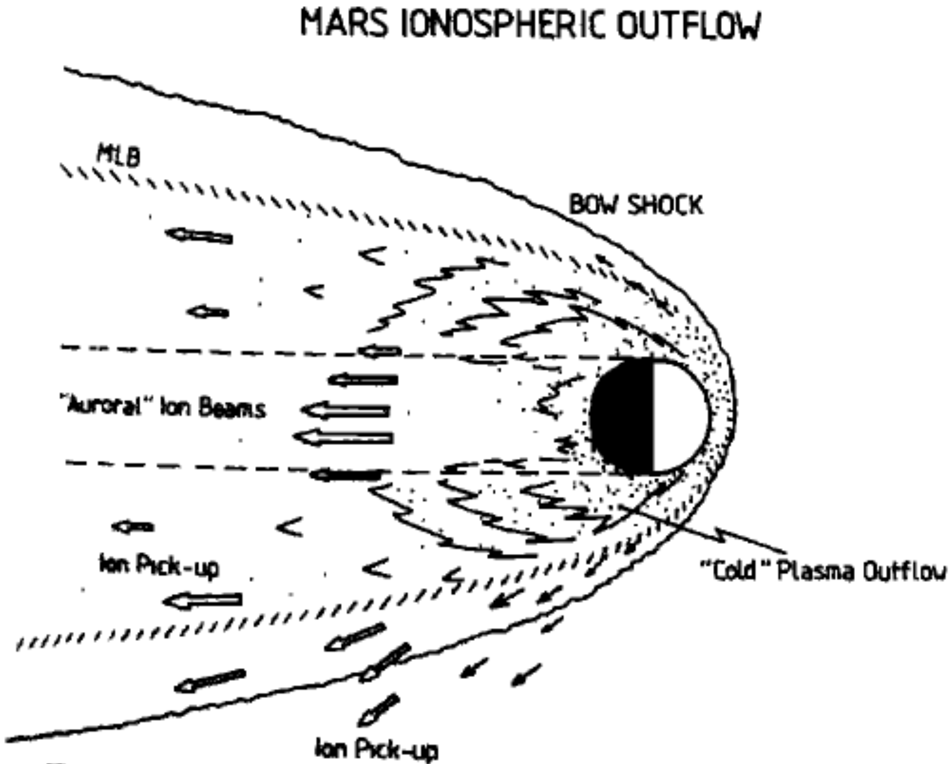


Fig. 4. Diagrammatic representation of the ionospheric ion outflow from Mars.

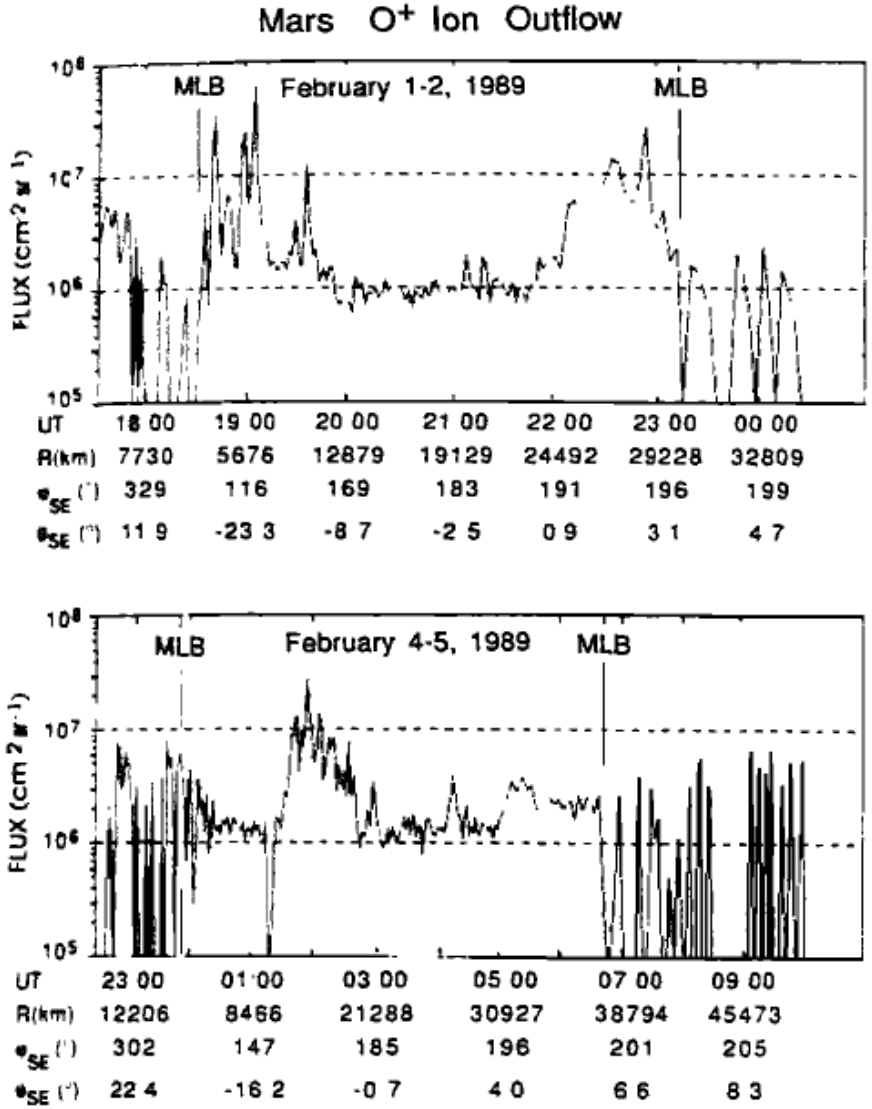
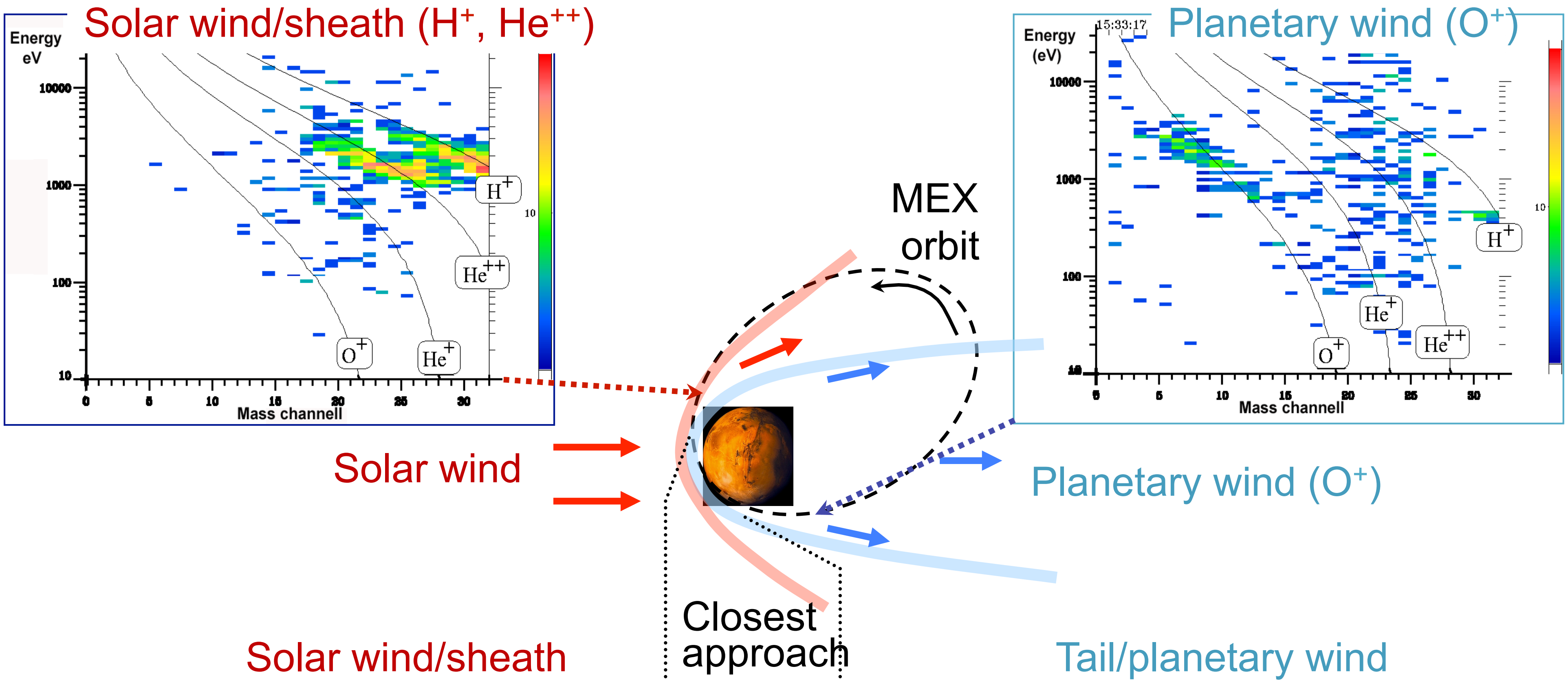
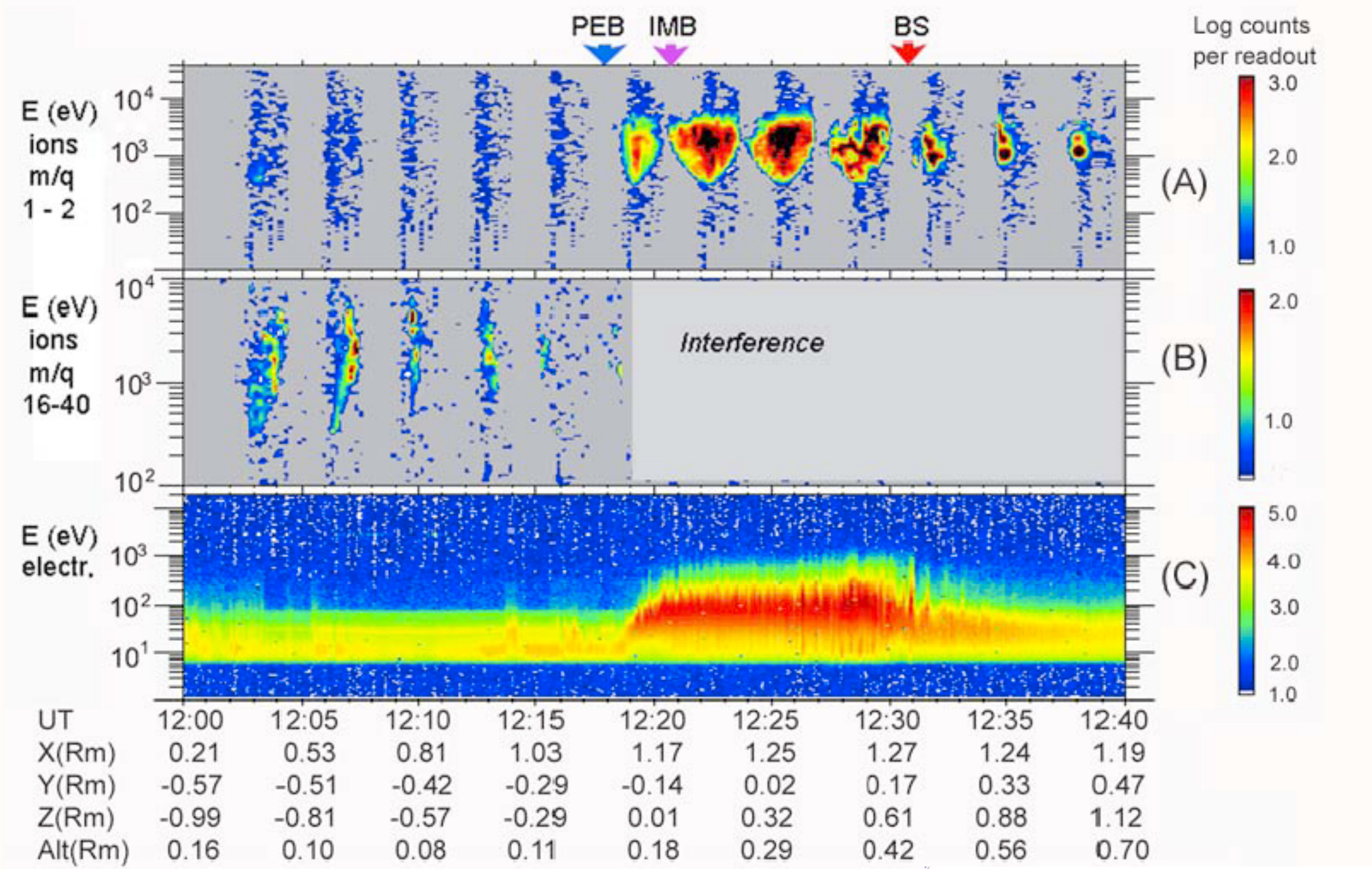


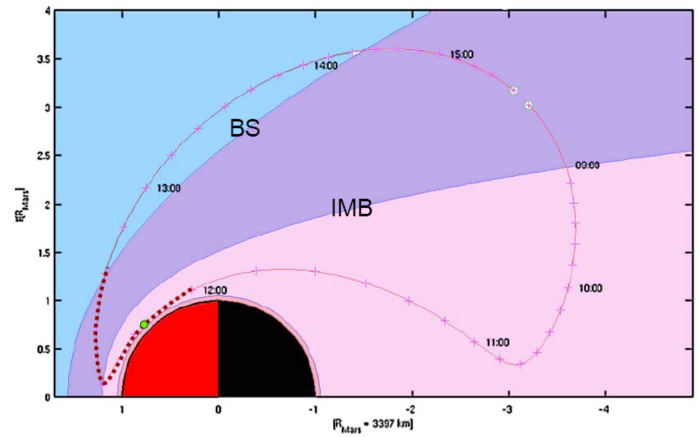
Fig. 3. Composite diagram of the outflow ($n \cdot v_x$) of ionospheric O^+ ions from Mars during orbits 1 and 2.

ASPERA-3 — Preliminary results (IMA)

Confirmation of the planetary wind - O^+ and molecular ions

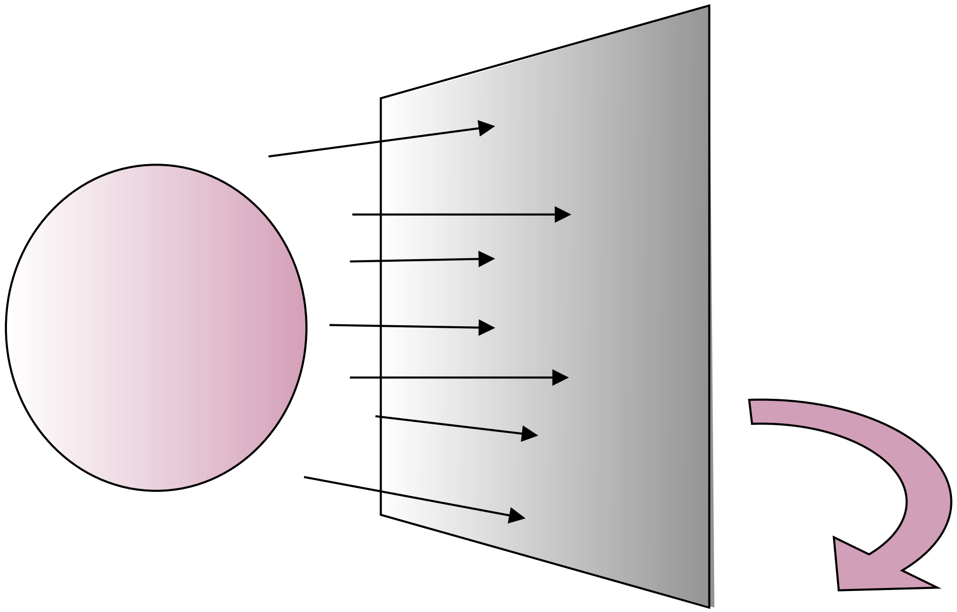


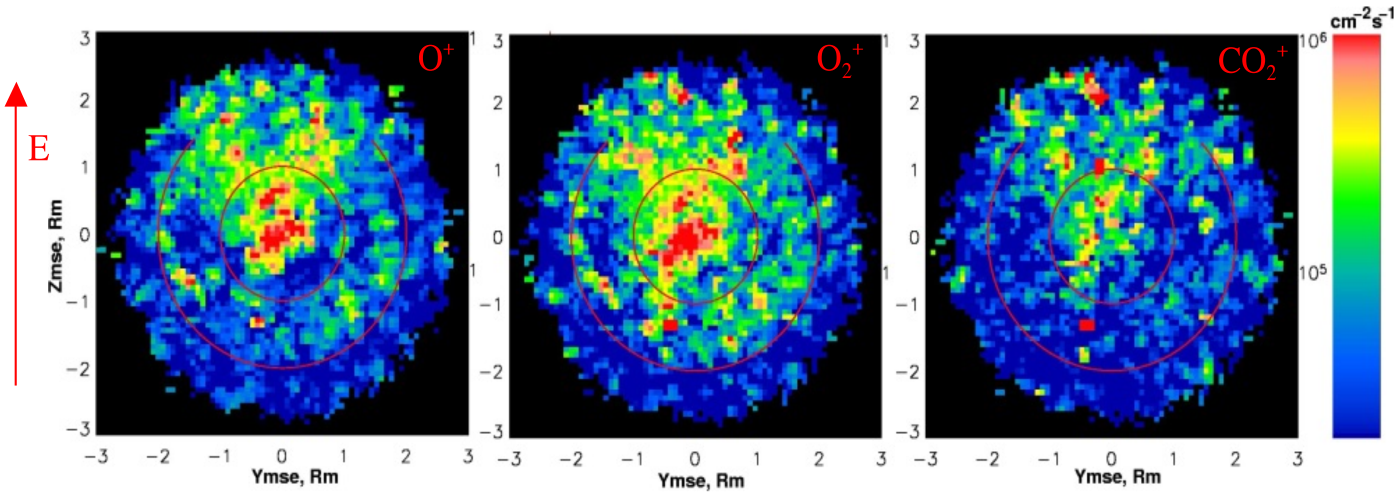




Lundin et al, Science, 2004

Escape through a plane

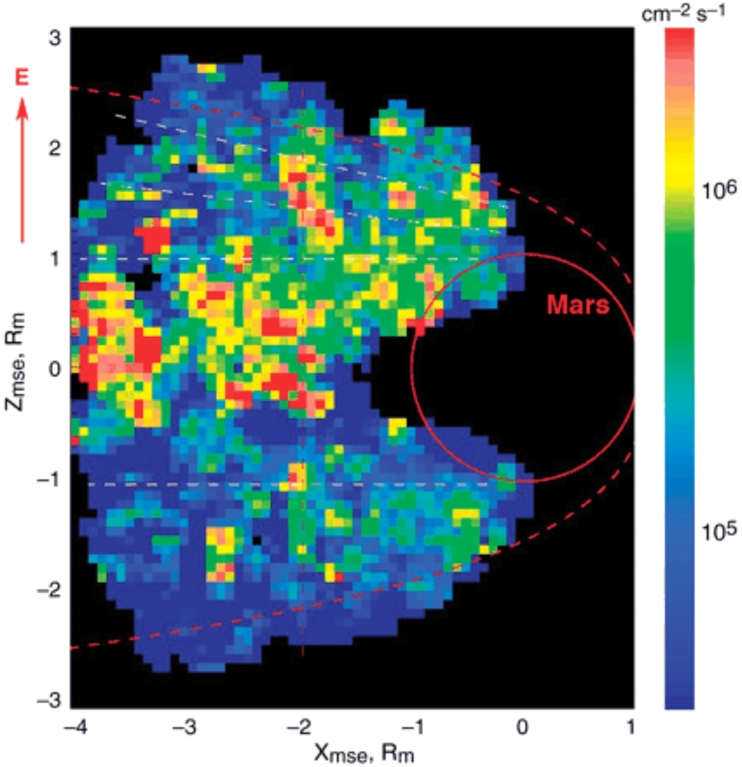


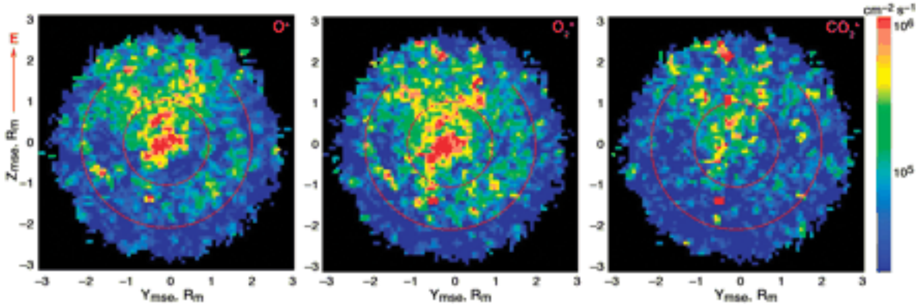


Barabash, Fedorov, et al, 2007

Figure 3. *ZY* maps of the integral fluxes (cm^{-2} s^{-1}) of O^+ , O_2^+ , CO_2^+. The direction of the interplanetary electric field is show by the red vector.

MarsExpress: low rates of loss from high energy ions





$Q(O+) = 1.6 \cdot 10^{23}\ s^{-1} = 4\ g\ s^{-1}$

$Q(O_2^+) = 1.5 \cdot 10^{23}\ s^{-1} = 8\ g\ s^{-1}$

$Q(CO_2^+) = 8 \cdot 10^{22}\ s^{-1} = 6\ g\ s^{-1}$, between 30 - 30,000 eV/q.

Propagated back 3.5 GY, gives 0.2 to 4 mbar of CO_2 and a few cm of H_2O.

Martian Atmospheric Erosion Rates, S. Barabash, A. Fedorov, R. Lundin, and J-A Sauvaud, Science 26 January 2007 315: 501-503 [DOI: 10.1126/science.1134358]

Escape rates

Planet	Escape rate		Reference
Venus	3×10^{24} O^+/s	*	VEX, *Fedorov et al., 2008*
Earth	5×10^{24} O^+/s (total escape)		Geotail, *Seki et al., 2001*
	43×10^{24} O^+/s (polar outflow, sol min)		DE-1, *Yau et al., 1988*
	22×10^{24} O^+/s (total escape)		Cluster, *Arvelius et al., 2008*
	67×10^{24} O^+/s (outflow)		
	45×10^{24} O^+/s (inflow)		
Mars	$(2\ldots9)\times10^{23}$ O^+/s	**	MEX, *Science, 2007*

* - 10^{25} from Barabash et al., 2008

** - under revision for low energy escape, e.g. 10^{25} s^{-1} from Lundin et al., 2008

- The absolute escape for the magnetized Earth may be **HIGHER** than non-magnetized Mars and Venus
- Strong debate in the community at the moment

Mars **Venus**

H$^+$

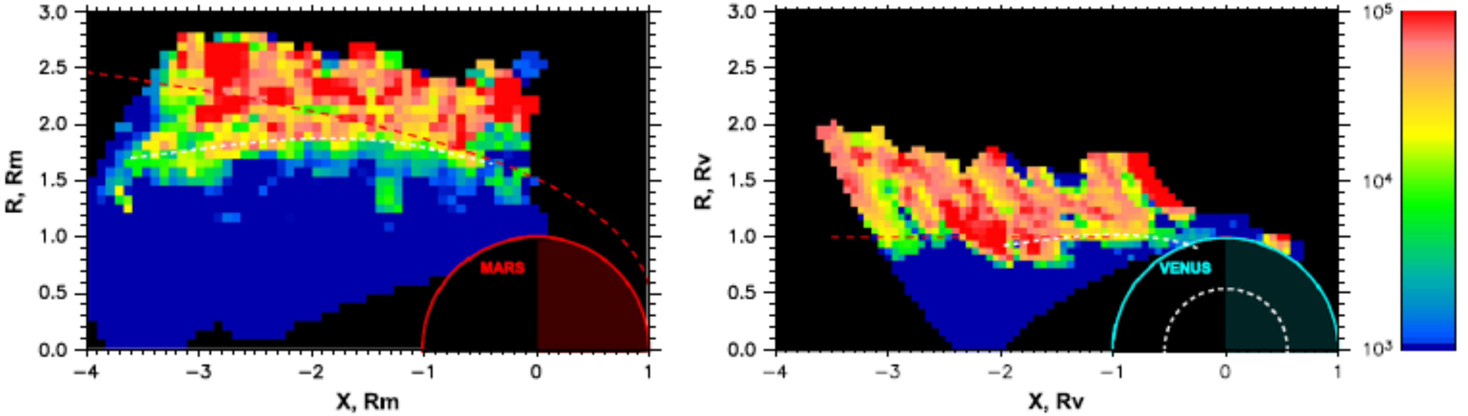


Fig. 1. Spatial distribution of the proton flux with energy greater than 300eV in cylindrical coordinates: X connects the planet center and the Sun; $R=\sqrt{Y^2+Z^2}$. All scales are in planet radii. The color scale is shown in arbitrary units. Blue color indicates zero flux, and black color shows the absence of the measurements. Left panel shows the Martian wake, and right panel shows the Venusian one. Red dashed curve in the left panel shows the theoretical position of the magnetosphere boundary after Kallio (1996). Similar dashed line in the right panel shows the wake boundary at Venus. White dashed curves are explained in the text.

M/Q>14

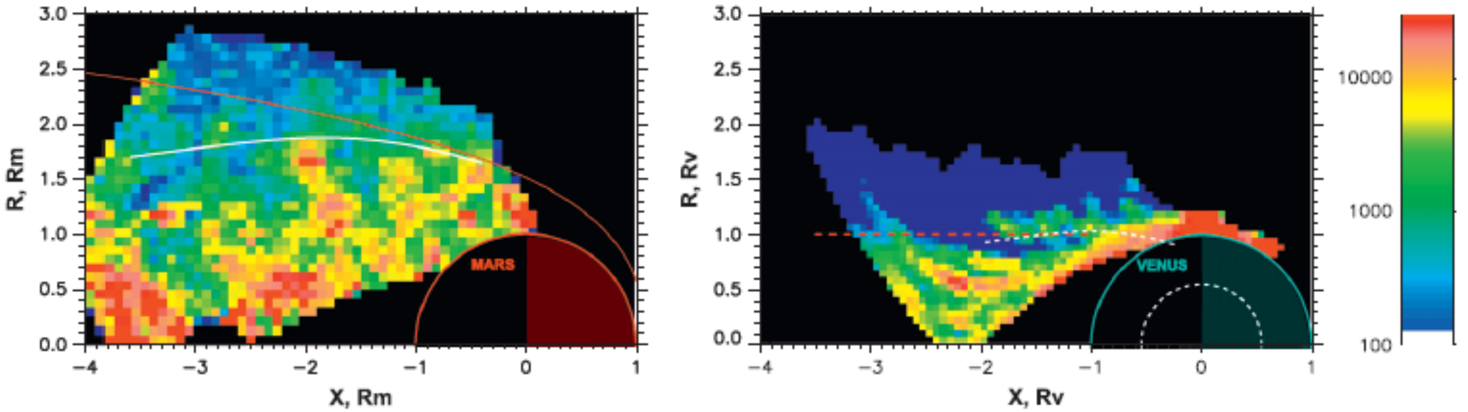
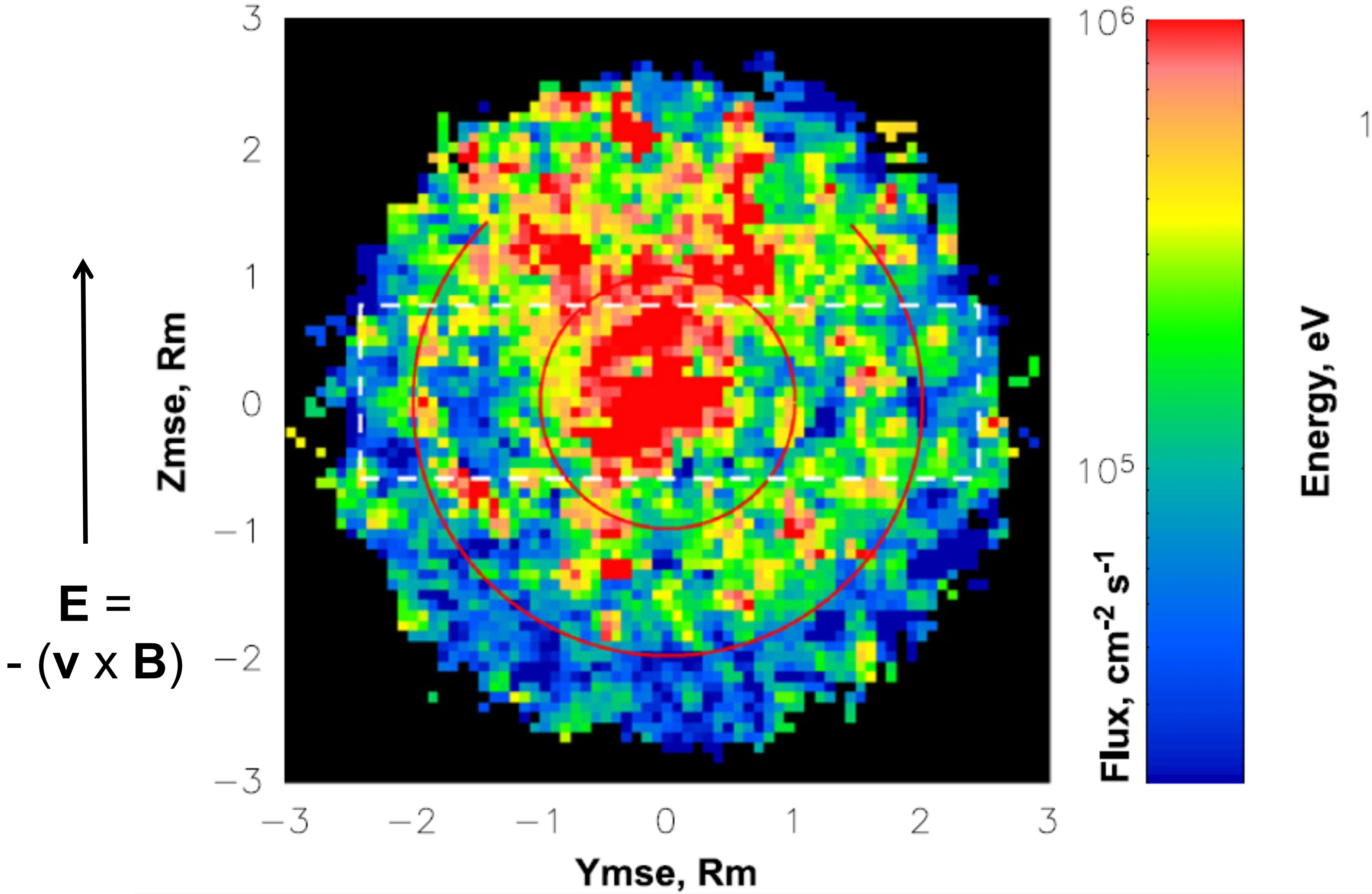
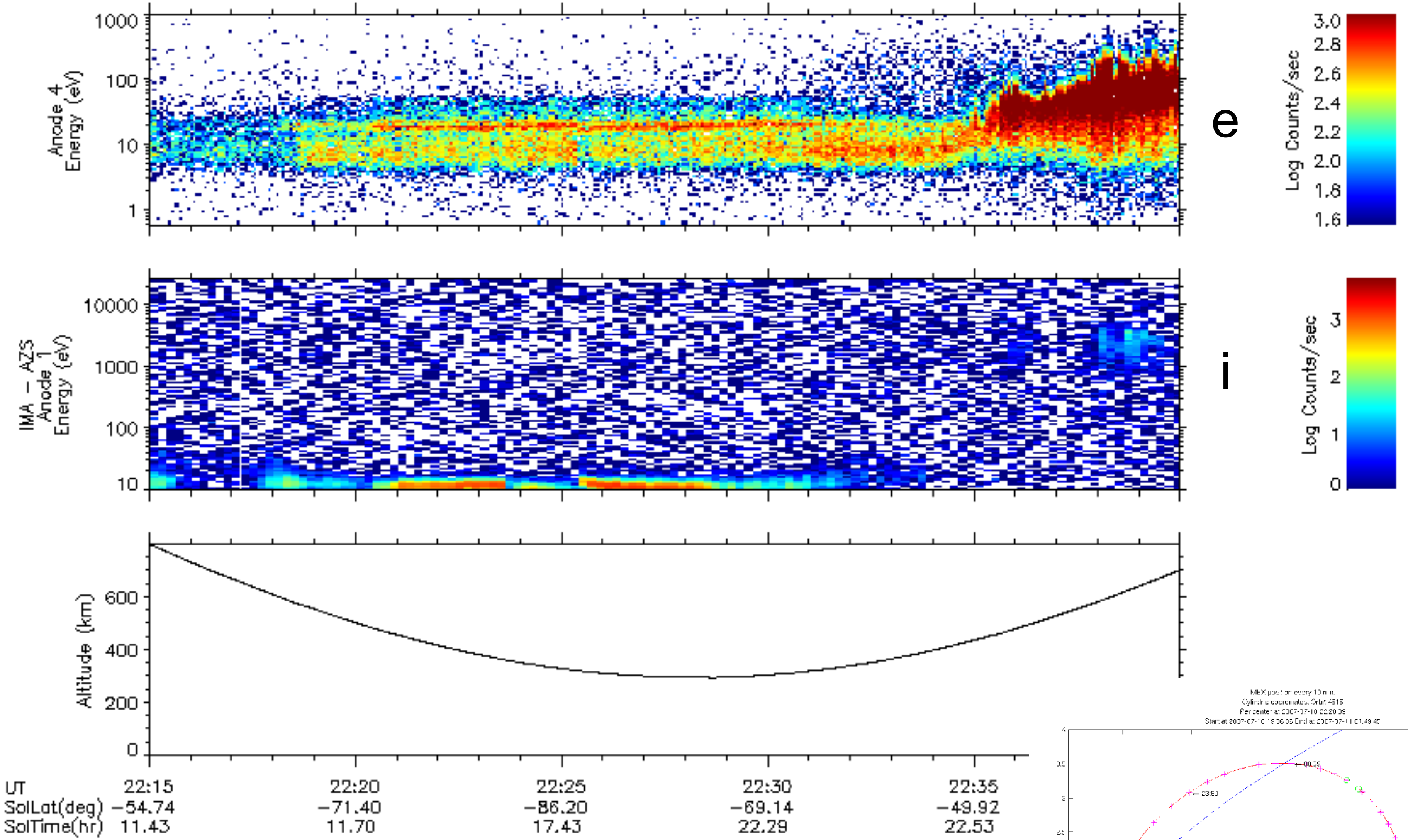


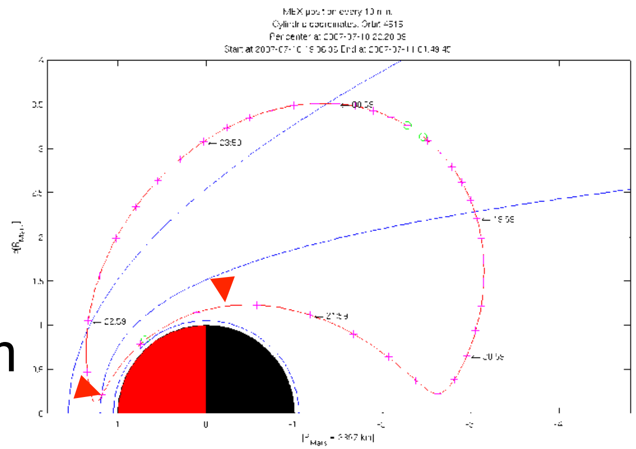
Fig. 2. The same as Fig. 1 but for ions of planetary origin with $M/Q>14$.

Fedorov et al., PSS 2009

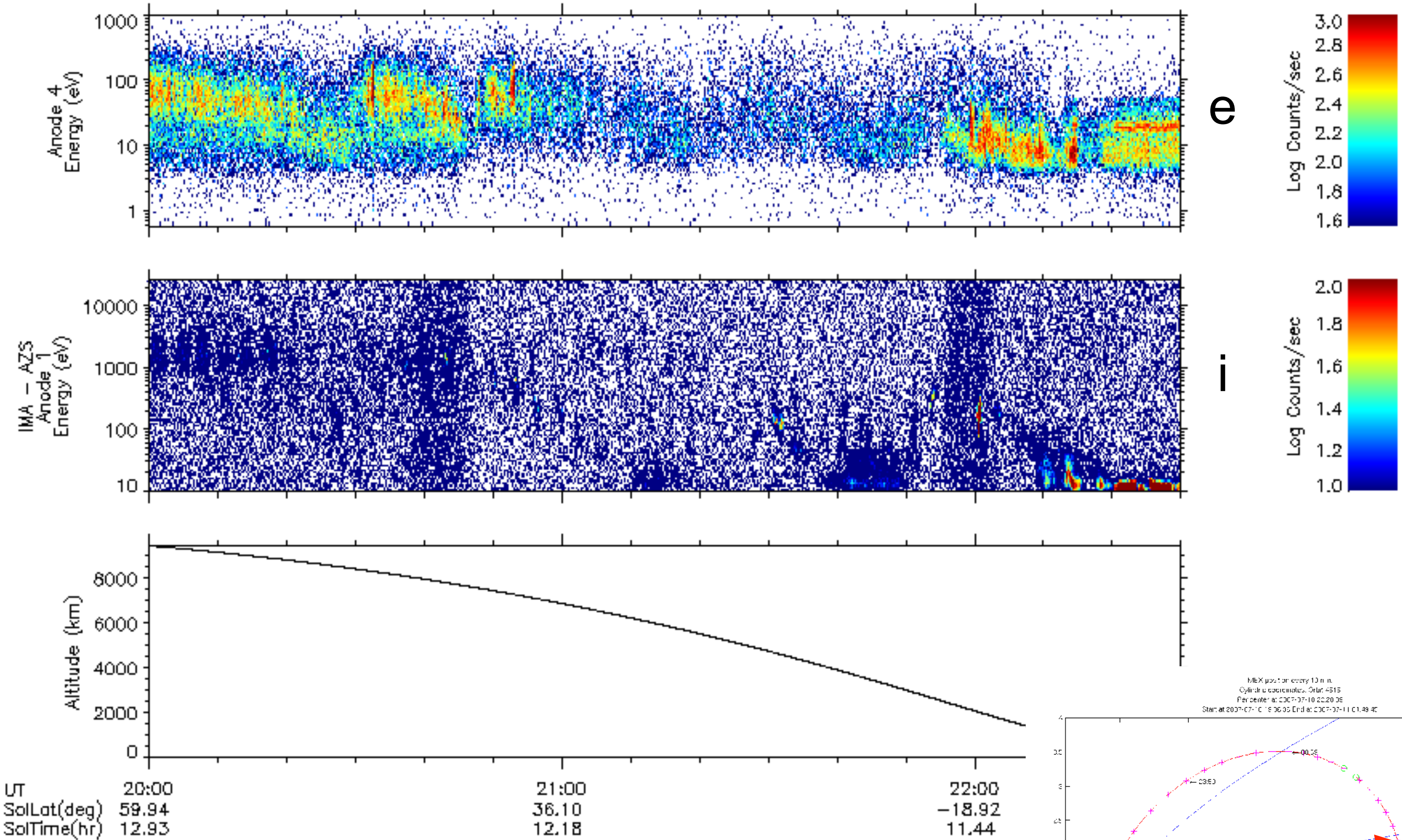


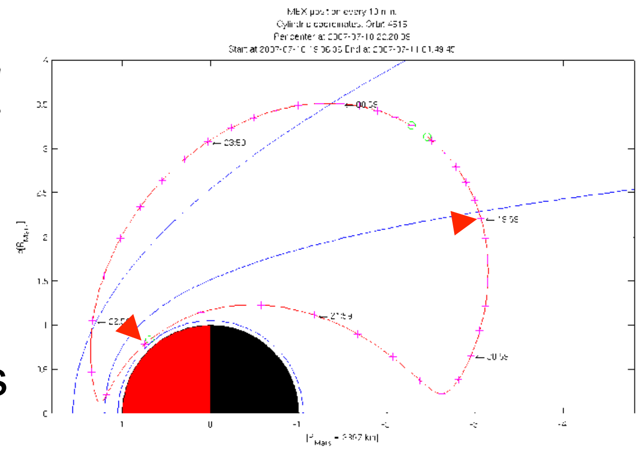
Mars – m/q>14 ion escape controlled by **E**, Fedorov et al., PSS 2009





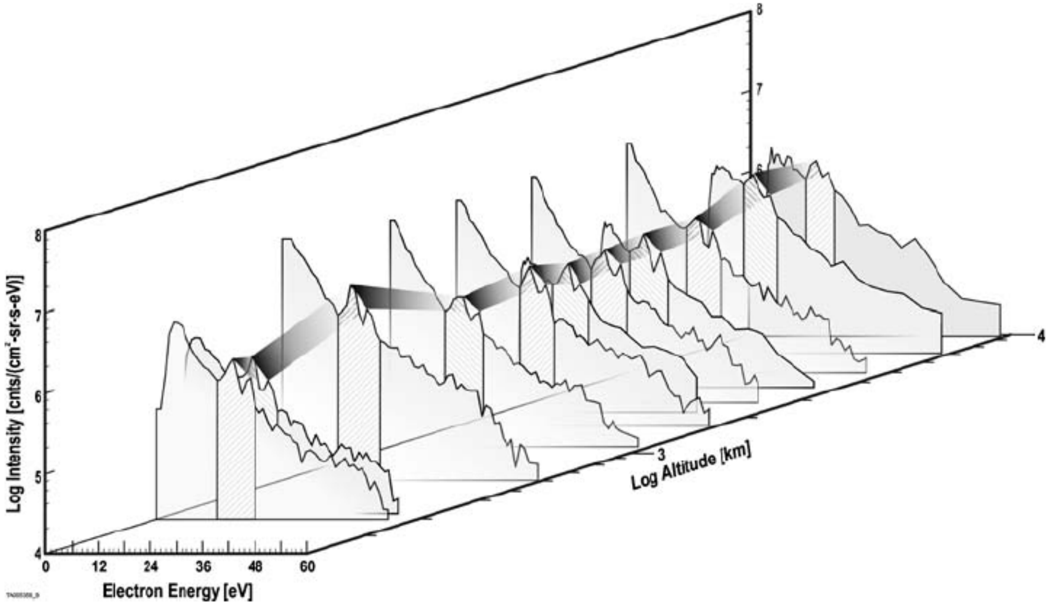
Mars Express 10 July 2007 – photoelectrons and escaping ions on day side (eg Lundin et al, Frahm et al, Coates et al EMSEC Nov 2007 ESTEC)

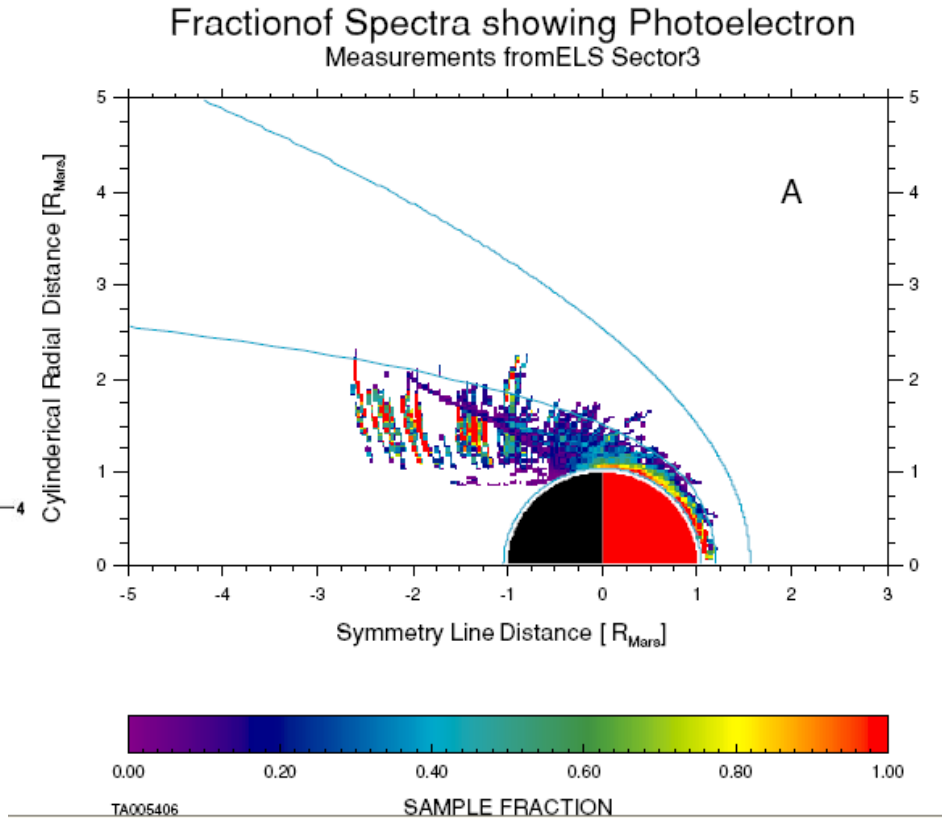




Mars Express – photoelectrons and escaping ions in Mars tail also

Frahm et al, 2006 (Icarus, Space Sci Rev) many examples



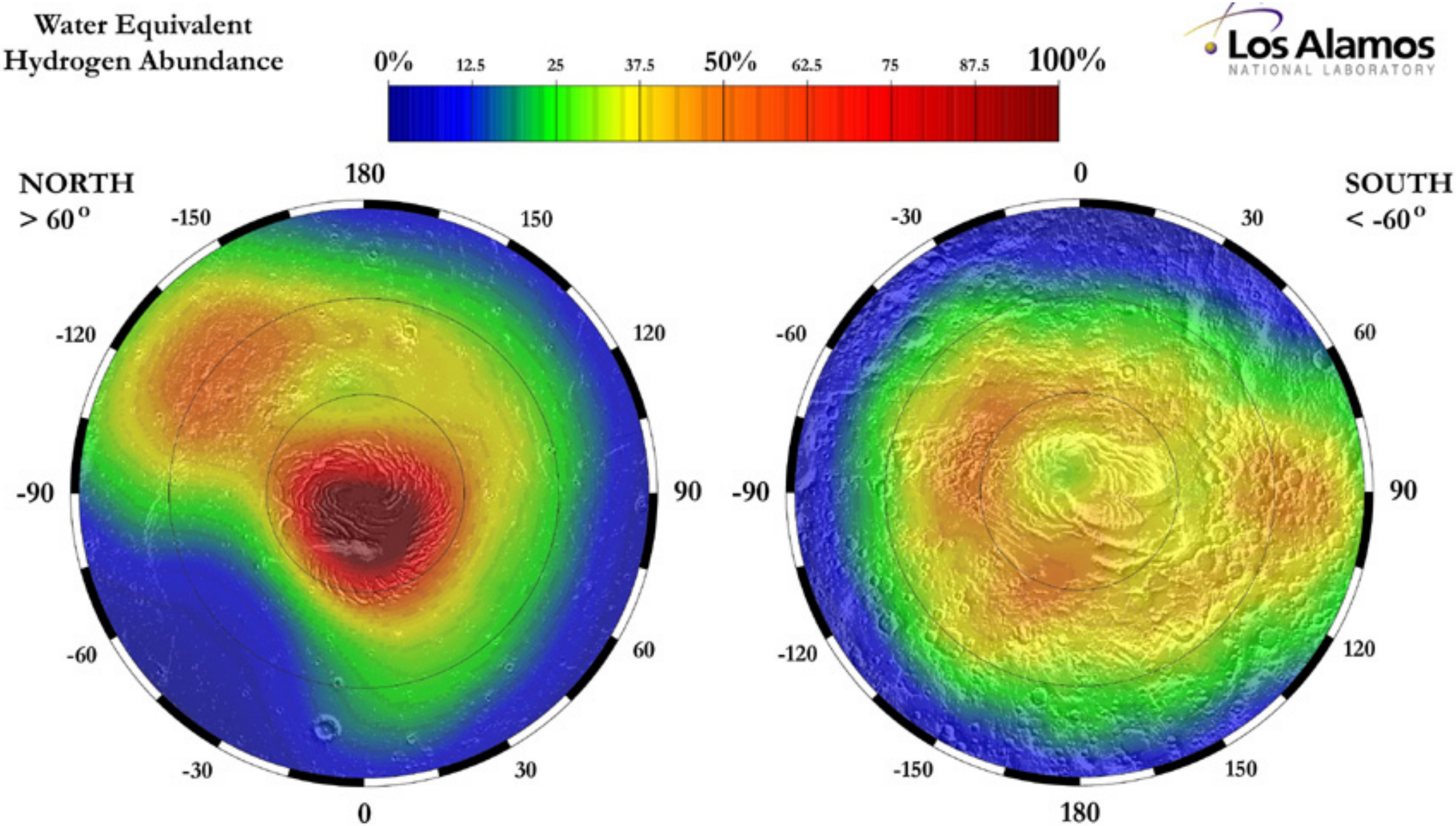


Frahm et al, Space Science Reviews 2006

Frahm et al., Icarus 2010, escape rate of photoelectrons 3.14 x10^{23} s^{-1}

The Martian Atmosphere and Water Reservoirs

- Current Atmosphere: 95% CO_2, 2.7% N_2, 1.6% Ar, …., .03 % H_2O. The upper atmosphere also has CO, O, NO….
- Surface pressure of 6 mb and average temperature of 210 K. Below H_2O triple point (no liquid H_2O).
- Exospheric temperature in 180 - 350 K range; exobase is near 200 km.
- Polar caps have both frozen CO_2 and H_2O.



Mars Odyssey neutron detection of hydrogen (H_2O proxy) at poles (Feldman et al., 2004).

This plus other observations: WEG (Water Equivalent Global Layer) of at least 30 m. Atmospheric WEG of 10^{-5} m.

Past Mars - Evolution of Water

- Evidence for past H_2O amounts far exceeding the current amount and in liquid form (unlike the present Mars) (c.f. *Catling and Leovy*, 2005; *Jakosky and Phillips*, 2001).
- Images showing gullies/channels formed by flowing liquid (probably about 3.8 Ga).
- Issues - what provided sufficient greenhouse gas to keep temperature above water triple point temp?, and where did all the water go?
- Isotope ratios (particularly D/H ratio of five times Earth values) suggests loss of H and O (water) over 3 billion years.

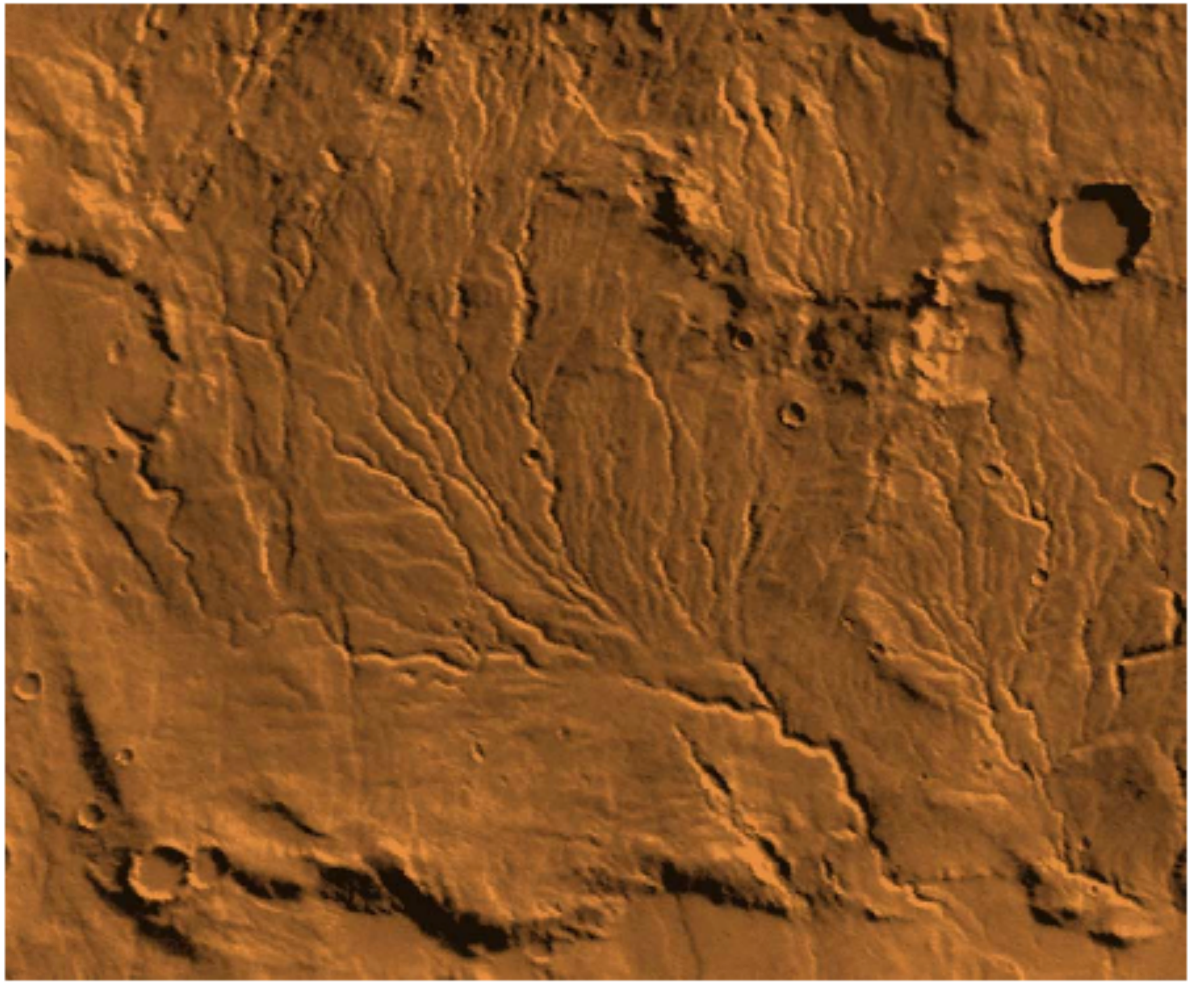


Fig. 3b. A valley network, centered near 42°S, 92°W. The image is about 200 km across. This false color mosaic was constructed from the Viking Mars Digital Image Map (From NASA/Lunar and Planetary Institute Contribution No. 1130).

Current Interpretation (courtesy of B. Jakosky)

[From Jakosky and Phillips, 2002]

Table 1 Martian isotope ratios and atmospheric loss*

Isotope ratio	Measured value†	Amount lost to space (%)‡
D/H	5	~60–74
$^{38}Ar/^{36}Ar$	1.3	~50–90
$^{13}C/^{12}C$	1.05–1.07	~50–90
$^{15}N/^{14}N$	1.7	~90
$^{18}O/^{16}O$	1.025	~25–50

*Values taken from refs 57–59, 62, 77 and 78, and references therein.
†Value estimated, observed or derived for martian atmosphere relative to terrestrial.
‡Calculated assuming Rayleigh fractionation. D/H range includes uncertainty in escape processes. Other ranges are based on uncertain timing of outgassing relative to escape.

- Based on current best estimates from SNC meteorites and telescopic measurements.
- Range of amounts lost includes uncertainty in structure of upper atmosphere, loss processes, and effects of outgassing over time.
- See also recent review by Lammer et al (Space cience Reviews 2008) for Mars and other planets through time

Mars Evolution contd.

- Evidence that Mars had a global magnetic field in its early history.
- The dynamo is thought to have turned off about 3.8 billion yrs ago. Now just remanent crustal B remains (MGS magnetometer data). The presence of a global field affects atmospheric loss.
- How did Mars lose its H_2O (H and O) in the past and what are the current atmospheric loss processes?

Mars has some remanent crustal magnetism, concentrated in the Southern hemisphere -- Mars Global Surveyor magnetometer data.

J.E.P. CONNERNEY ET AL.

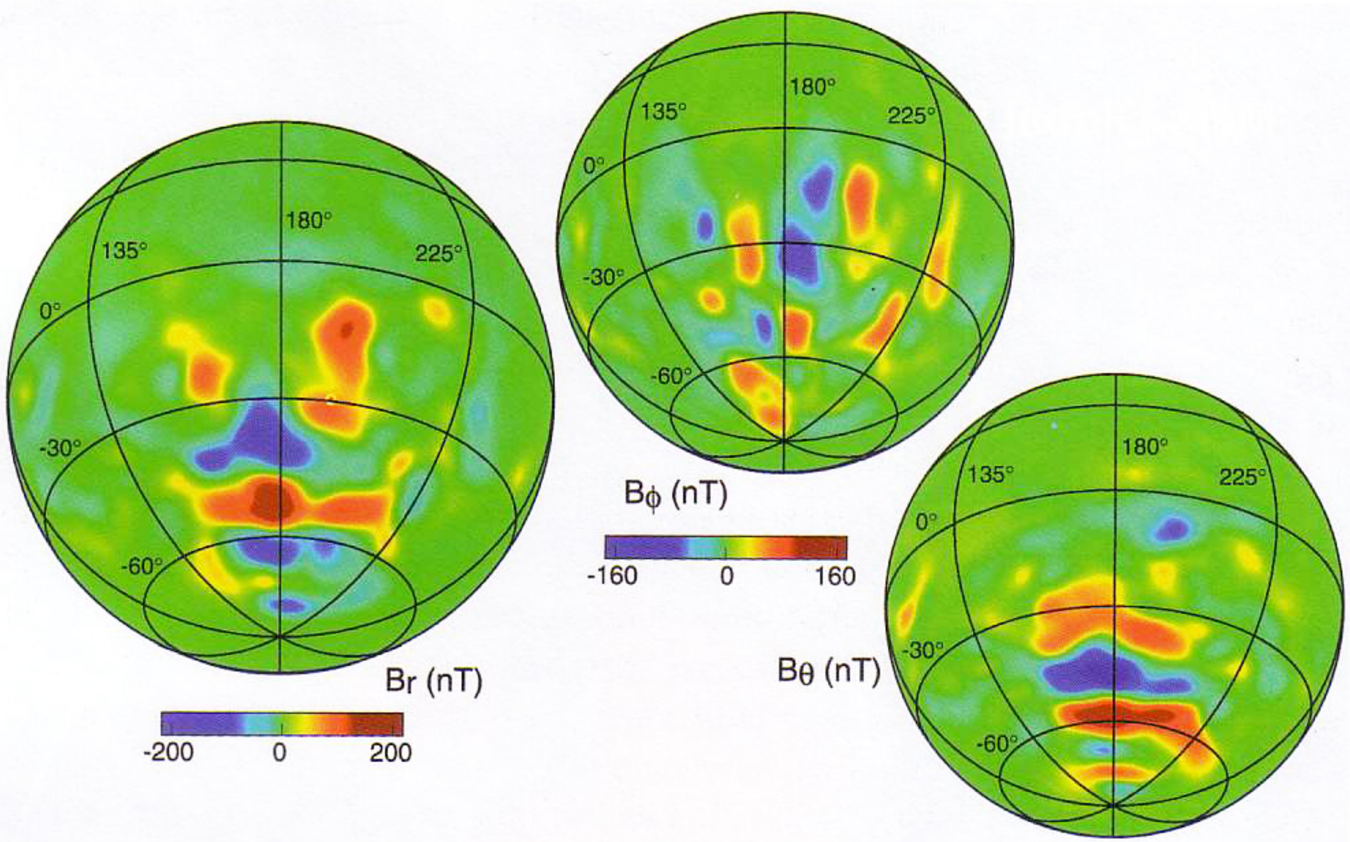


Figure 2. Orthographic projections of the three components of the magnetic field (B_r, B_θ, B_ϕ) at a nominal 400 km mapping orbit altitude, viewed from 30 deg S and 180 deg East longitude (after Connerney *et al.*, 2001).

Requirements for Atmospheric Escape

Atoms/molecules must:

(1) Be present in the exosphere.

(2) Have speeds exceeding the escape speed.

$$v_{esc} = \sqrt{\frac{2GM}{R}}$$

Atmospheric Escape Mechanisms

(1) Hydrodynamic escape (neutral or ion). **

(2) Jeans (or thermal) escape (loss of H).

(3) Nonthermal/photochemical escape (e.g. hot oxygen)

(4) Nonthermal escape -- planetary ion pickup by the solar wind (or other external plasma flow). **

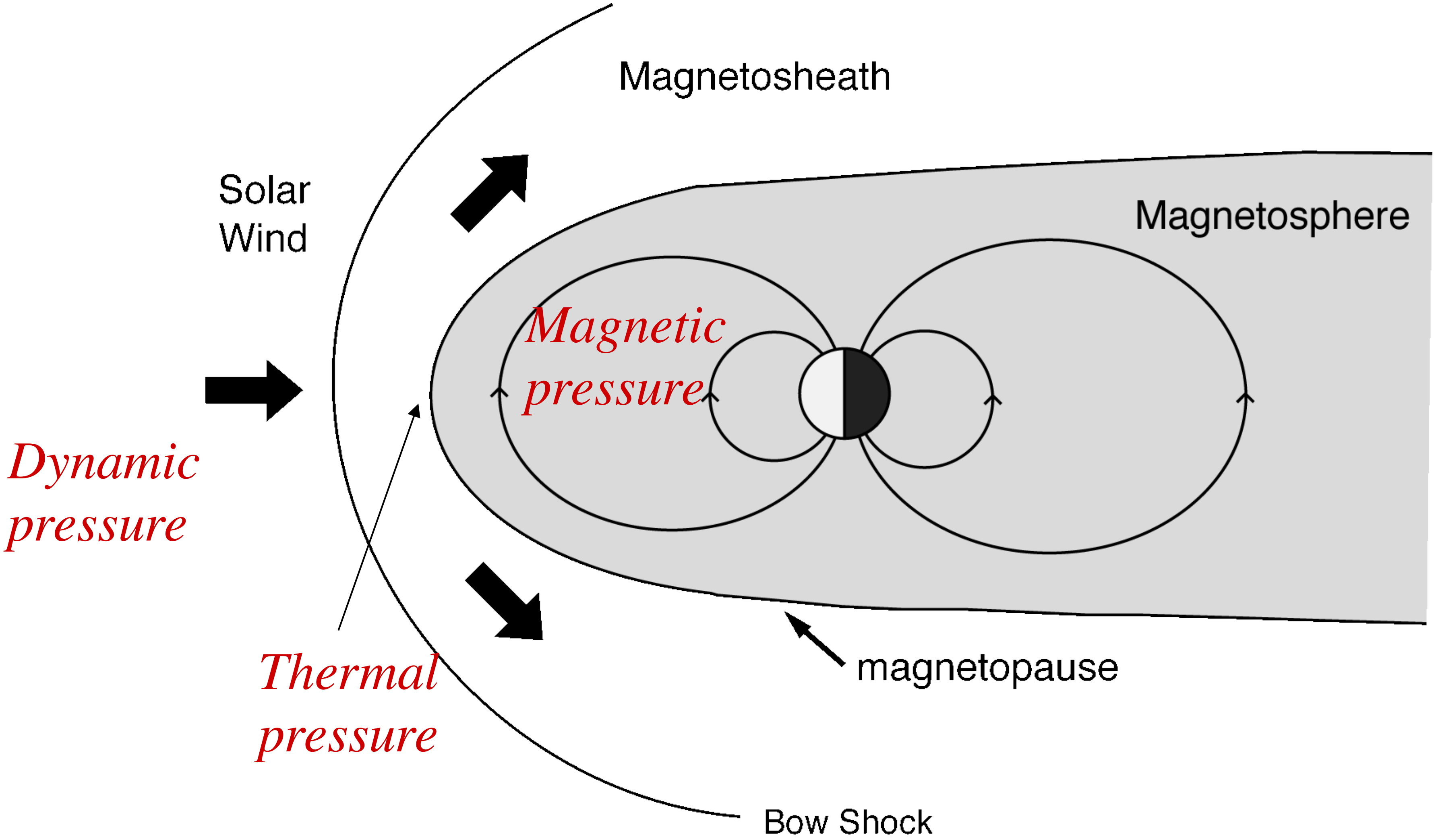
(5) Nonthermal escape -- sputtering due to energetic ion impact on an atmosphere. **

** Solar wind interaction

Types of Solar Wind Interaction

- Earth-like (strong intrinsic magnetic field acts as obstacle to solar wind flow)
- Venus-like (ionospheric thermal pressure)
- Comet-like (ion pick-up and mass-loading)
- {“real” interactions are a “mixture” of the archetypical interaction types - ***all 3 are relevant to Mars***}

Earth-Type Interaction
The Magnetosphere



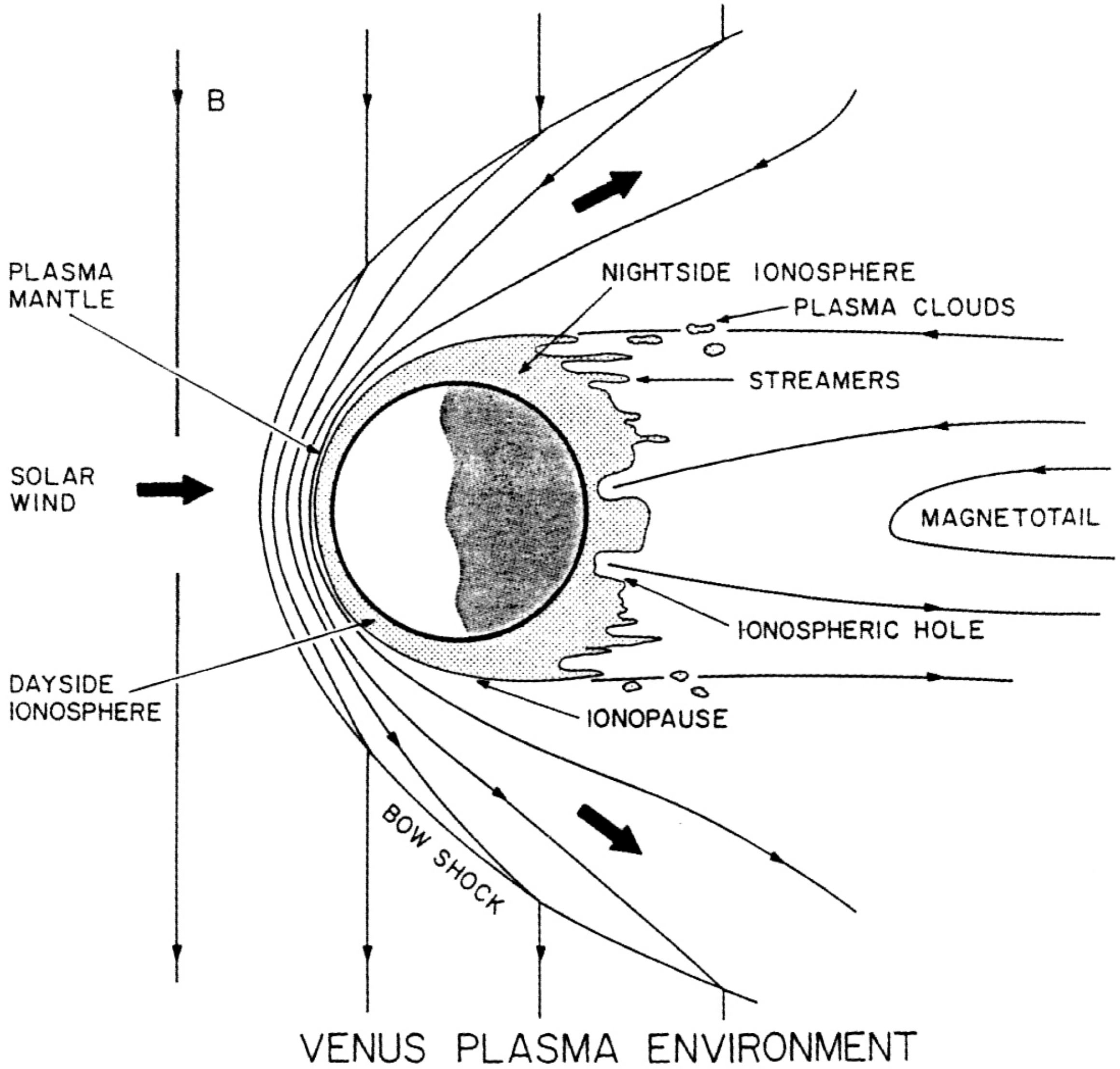


Figure 1. Schematic of the solar wind interaction with Venus. Interplanetary magnetic field lines are shown as are the bow shock and ionopause surfaces.

Schematic of

VENUS-LIKE SOLAR WIND ATMOSPHERE INTERACTION

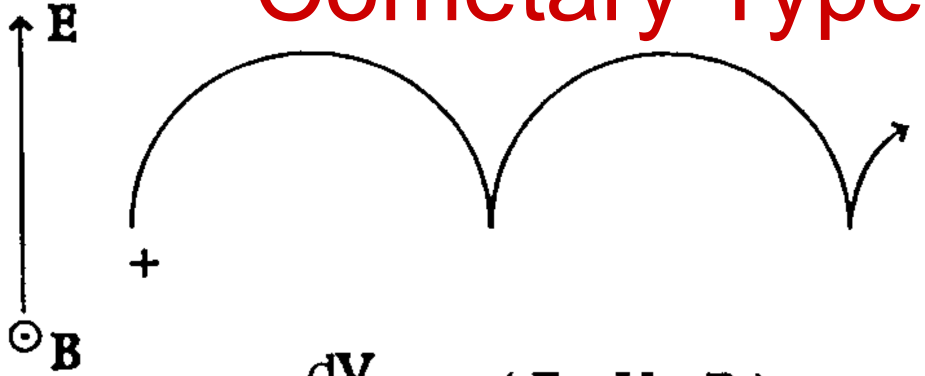
Ionospheric thermal pressure acts as main obstacle to the solar wind.

Dynamic pressure - thermal - magnetic and - ionospheric thermal.

Pick-up Ion Trajectory in the Solar Wind

Cometary Type Interaction

$E = - u_{sw} \times B$



$$m\frac{d\mathbf{V}}{dt} = q\,(\mathbf{E} + \mathbf{V} \times \mathbf{B})$$

$$\mathbf{V}(t) = \mathbf{V}_{gyro}(t) + \frac{\mathbf{E} \times \mathbf{B}}{B^2}$$

Figure 7.17. Trajectory of an ion in solar wind **E** and **B** fields. The ion is initially at rest. The ion velocity can be broken down into a gyration part, v_{gyro}, and an $\mathbf{E} \times \mathbf{B}$ drift part. The ion follows a cycloidal trajectory.

Ionization of a neutral by a photon, electron,.. creates a new ion which is "picked-up" by electric and magnetic fields and partially assimilated into the flow. The mass loaded flow slows.

SOLAR WIND INTERACTION WITH MARS

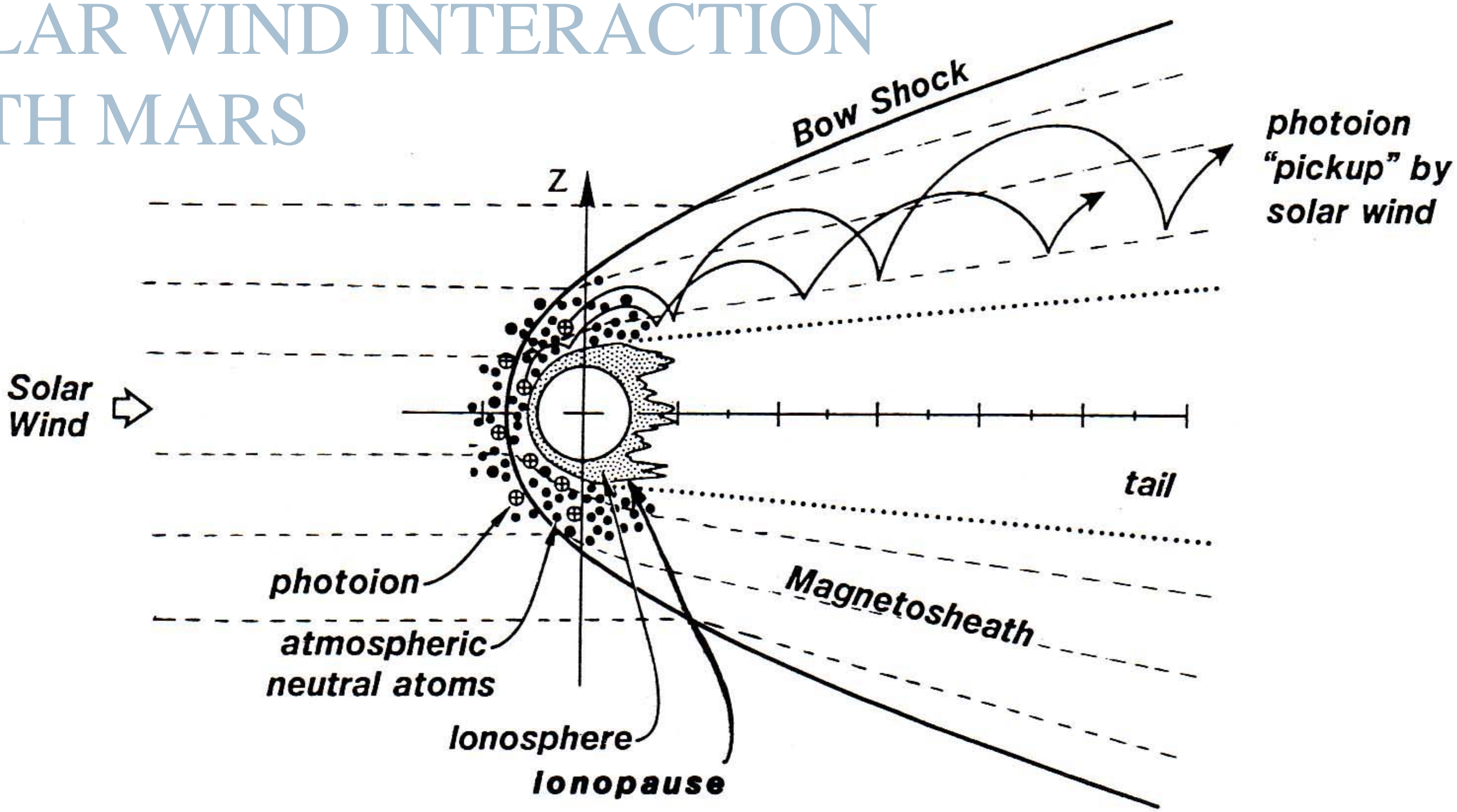


Fig. 1. Illustration of the space environment of a weakly ionized planet [from Luhmann and Kozyra, 1991], showing the close-in bow shock, the magnetosheath in which the shocked solar wind plasma flows around the ionopause, and the upper atmosphere extending above the ionopause. Ions produced in the solar wind plasma, by processes such as photoionization, are "picked up" by the ambient plasma which carries an embedded magnetic field. Because the ions gyrate around the field, they may escape into the wake, or they may reenter the atmosphere.

Ion Pick-up and Loss From Mars Due to the Solar Wind

From Luhmann and Kozyra (1991); also see Luhmann and Bauer, 1992)

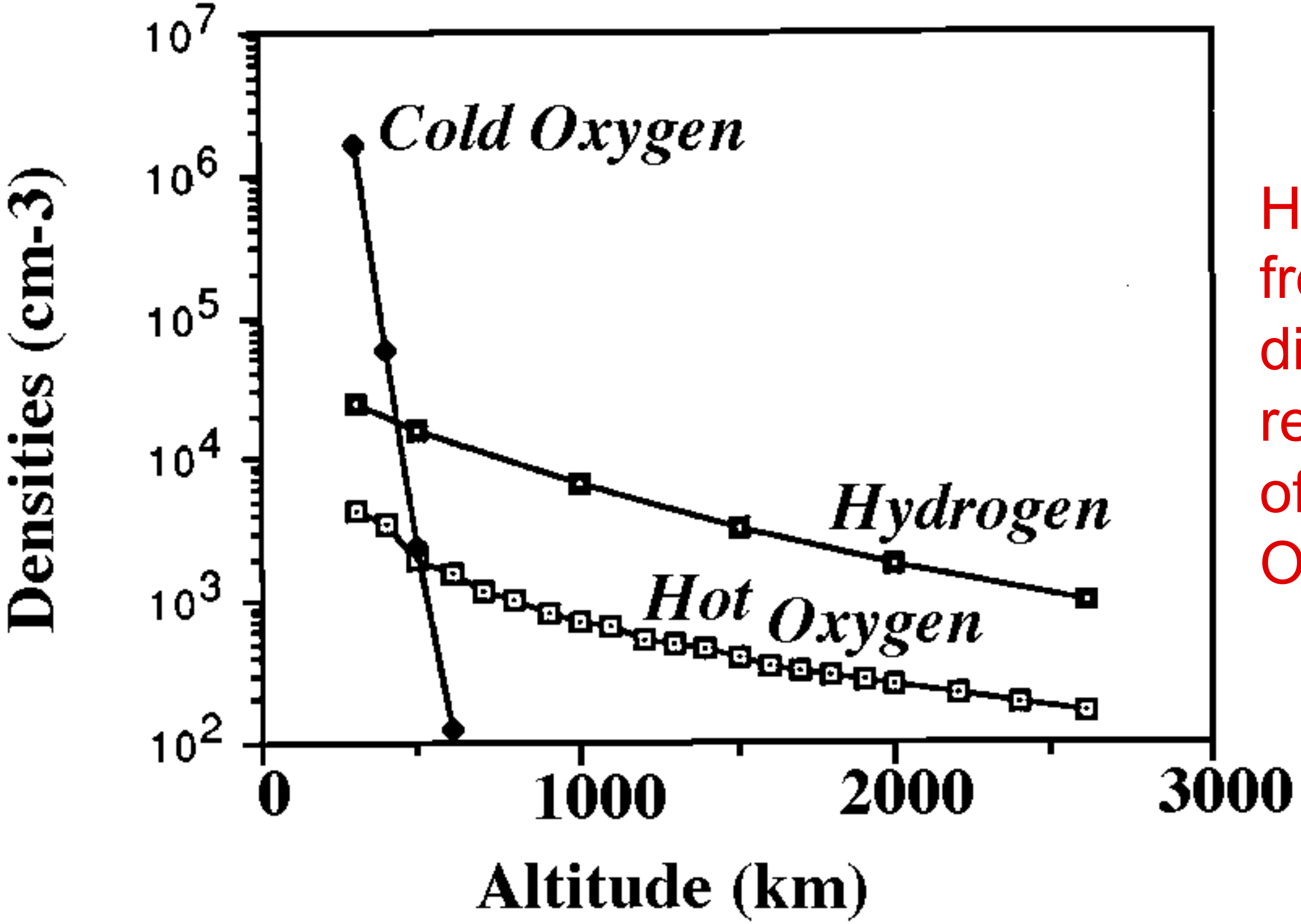
Solar Wind Interaction with Mars

- The solar wind interaction with Mars has characteristics of Venus-like, Earth-like, and comet-like interactions although it appears that the Venus-like is dominant.
- Mars has significant crustal magnetic fields in the southern hemisphere (but limited global extent).
- Mars has an extensive exosphere (H and O) which leads to pick-up ions and solar wind mass-loading.

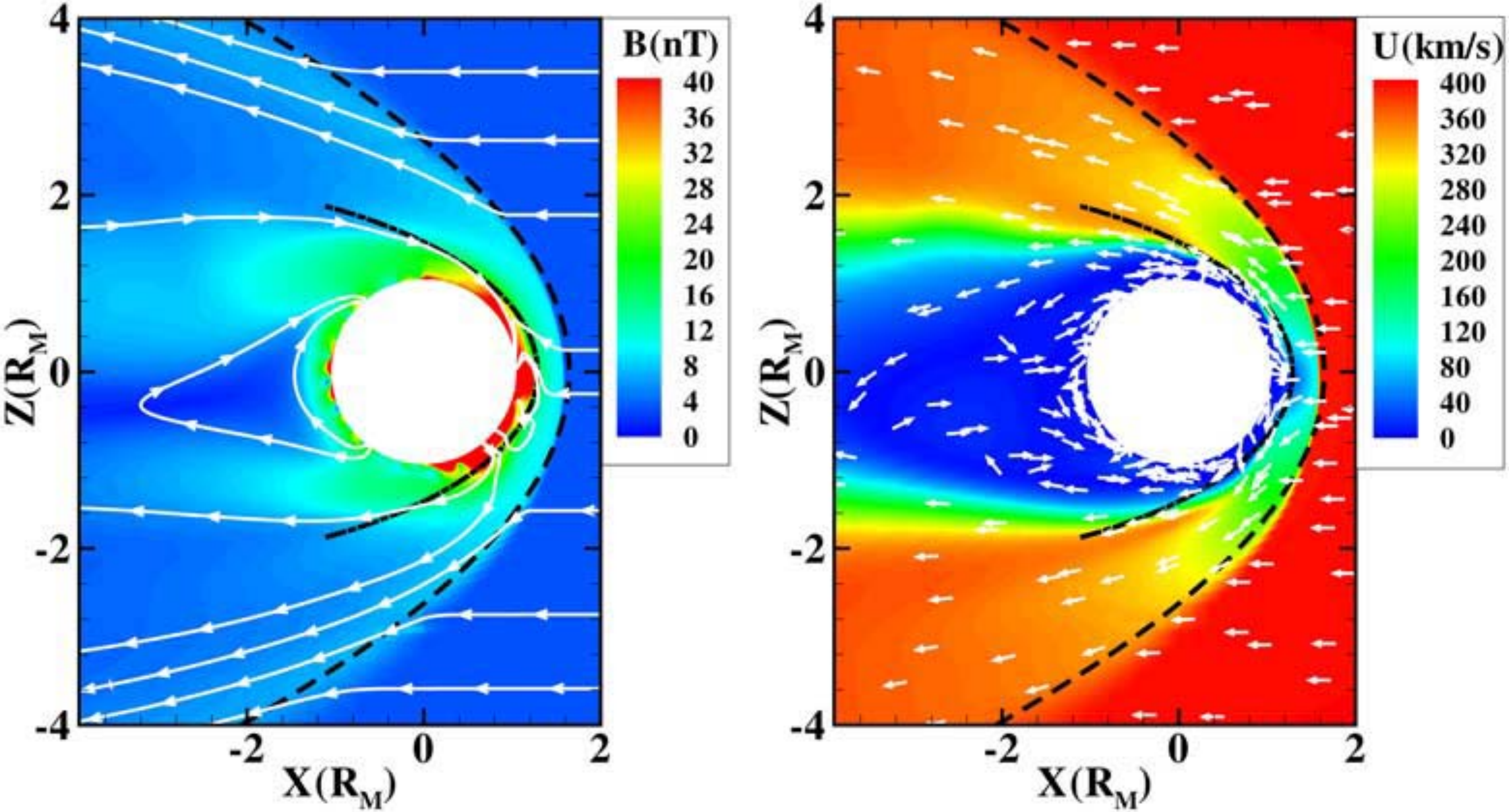
Experimental Measurements Related to Martian Plasma Environment (key spacecraft missions:)

- Mars-5
- Viking 1 and 2
- Phobos-2
- Mars Global Surveyor
- Mars Express
- YingHuo-1 (launch 2011)
- MAVEN (launch in 2013)

A partially "cometary" interaction partially applies to Mars due to its extended hydrogen and oxygen exosphere.



Hot O from dissociative recombination of ionospheric O_2^+ ions



Multi-species Global MHD Model: Flow and Magnetic Field Results. From Ma et al. (2004).

Many other global MHD and hybrid code models of solar wind interaction with Mars also exist.

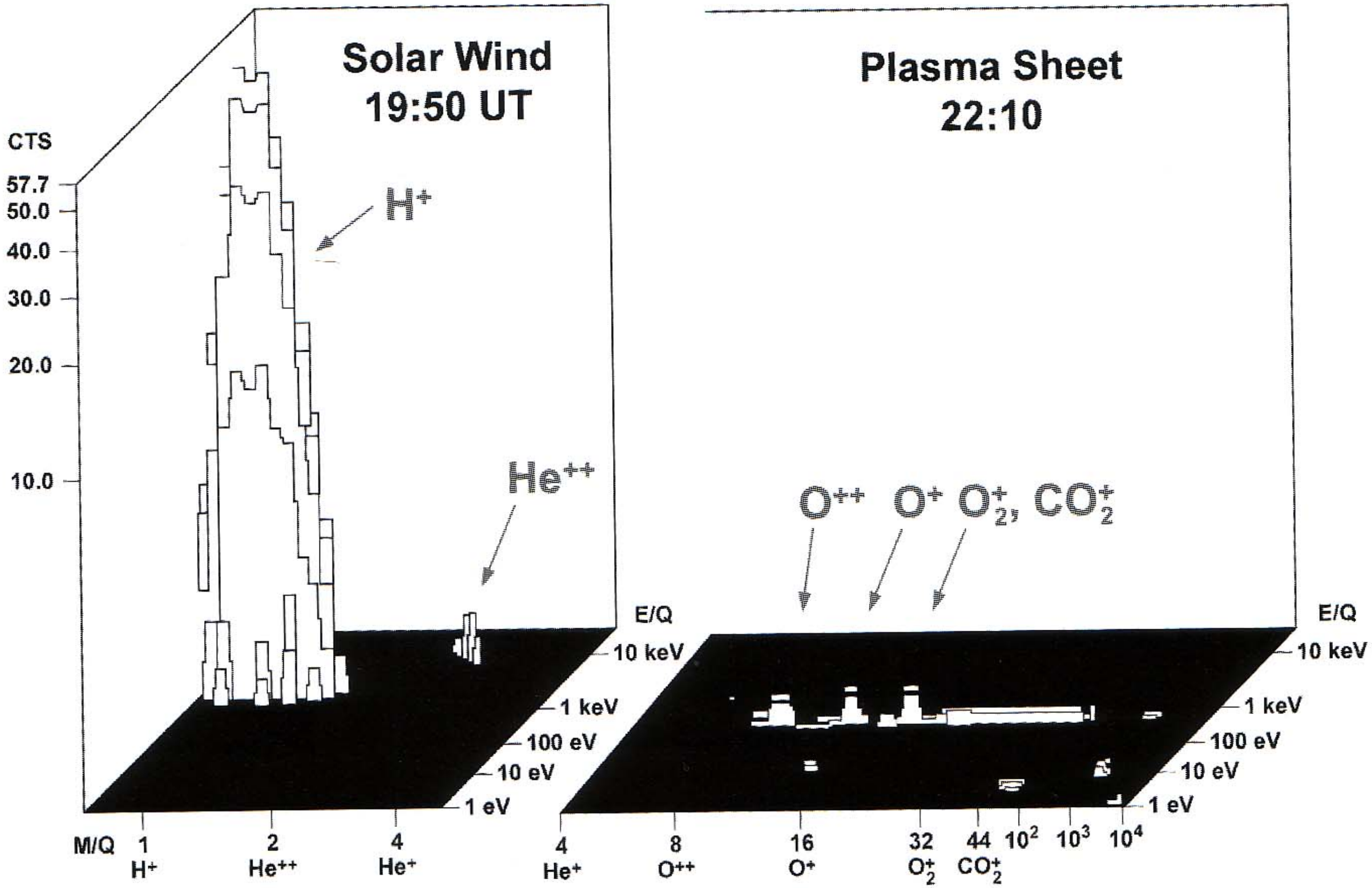


Figure 4.6. $E/q - M/q$ matrix measured by the ASPERA instrument on March 25, 1989 in the solar wind and plasma sheet. The plasma sheet contains mainly ions of the planetary origin. The planetary ions gain the energy (E/q) of about 1 keV q^{-1} (from Dubinin *et al.*, 1993a).

ASPERA experiment on PHOBOS-2 (Dubinin et al., 1993)
Also see Nagy et al. (2004). **Heavy ions in tail (escaped!)**

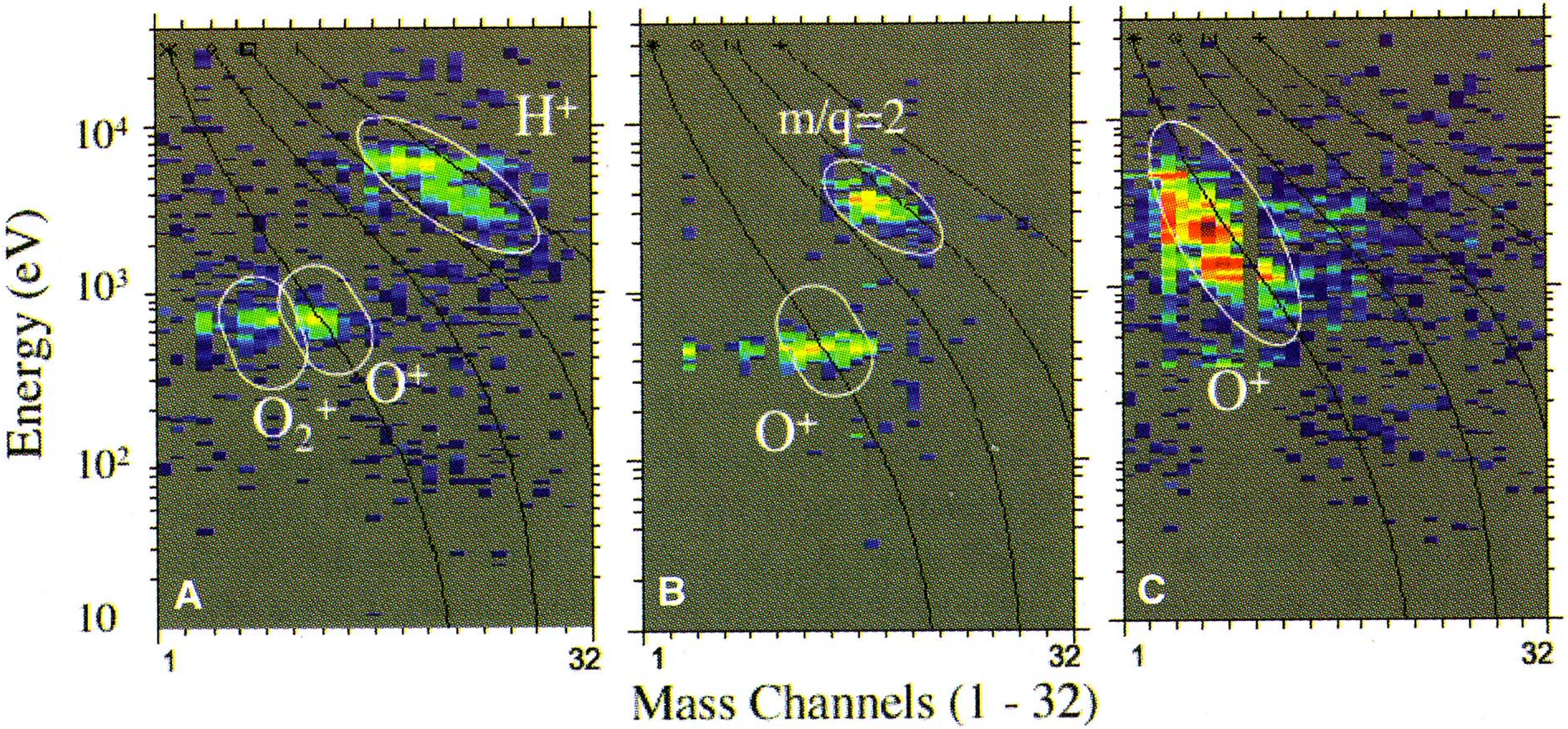


Fig. 2. Three examples of energy-*m/q* spectra for energized ions. Skewed lines indicate nominal mass identifications for *m/q* of 1, 2, 4, and 16, respectively. (**A**) 27 February 2004, 2- to 7-keV H^+ and ~700-eV heavy ions (O^+ and O_2^+) at an altitude of ~290 km. (**B**) 25 January 2004, ~500-eV heavy ions and keV ions with $m/q = 2$ (possibly He^{++}, H_2^+, and D^+) at an altitude of 900 km. (**C**) 22 March 2004, strong energization of heavy ions at an altitude of ~330 km.

Ion measurements by the ASPERA-3 instrument onboard Mars Express. From Lundin et al. (2004)(Science) Several hundred eV ions in upper ionosphere - probably escaping.

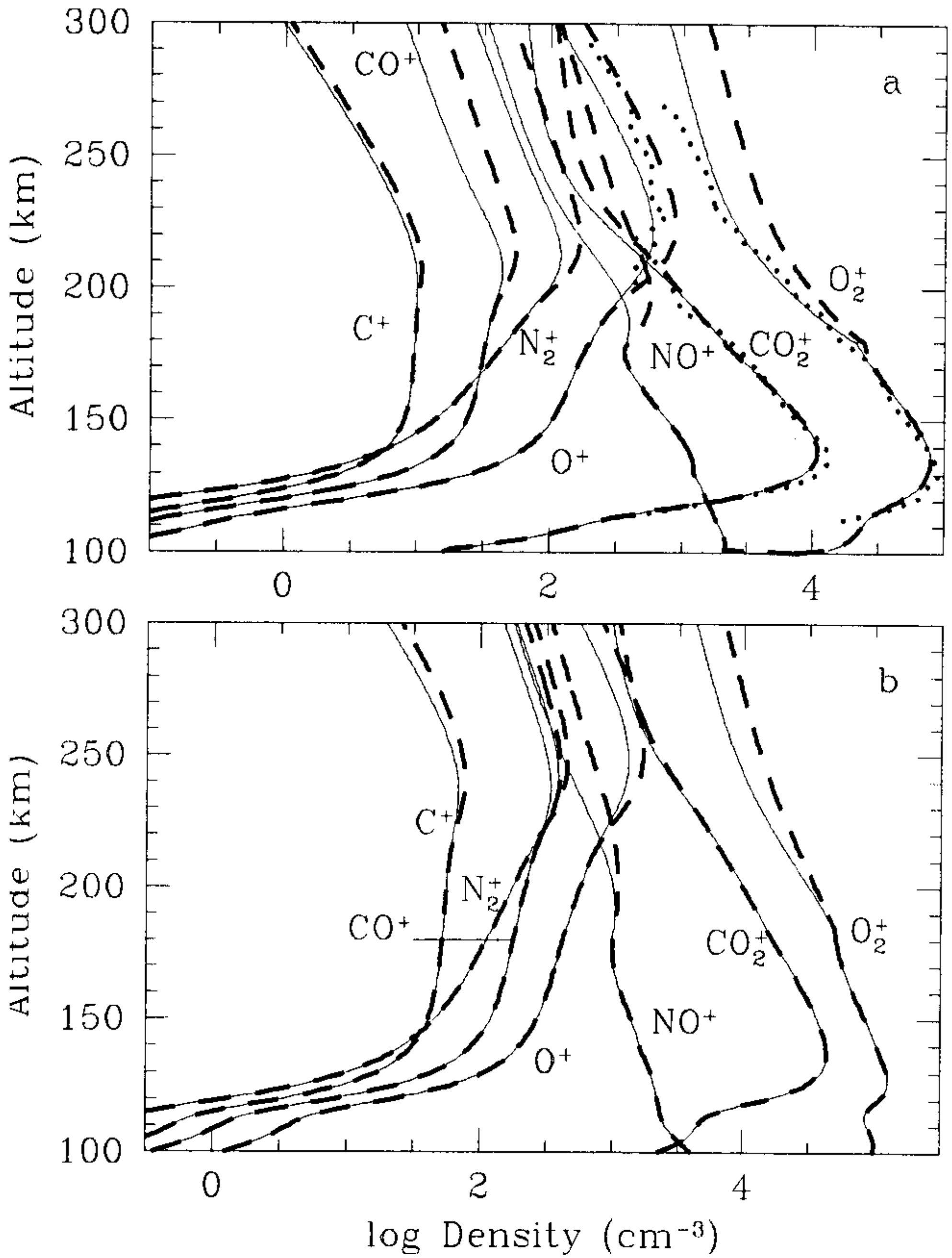
Photochemical Escape -- Ionospheres of Mars (& Venus)

- $h\nu$ (or e) + CO_2 ------> CO_2^+ + e
- CO_2^+ + O ------> O_2^+ + CO
- O^+ + CO_2 ------> O_2^+ + CO
- (O_2^+ is the major ion species)
- ……..

Dissociative Recombination

- **O_2^+ + e -----> O + O (*source of hot oxygen*)**

- **Electron temperature ≈ 1000 - 2000 K and ions temperature ≈ 200 - 1000 K**



Jane Fox
Several papers

1D ionosphere model

O_2^+, O^+,..

Main Non-Thermal Loss Process for Oxygen

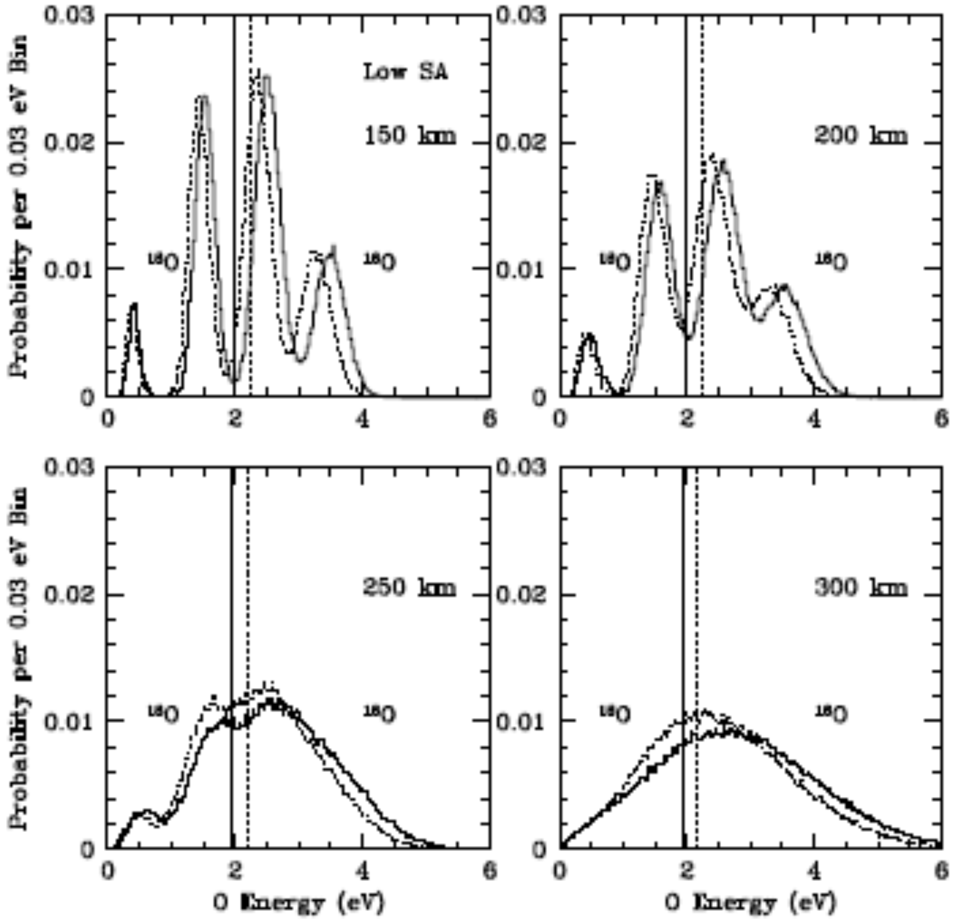
Dissociative Recombination of Ionospheric O_2^+

$$O_2^+ \quad + \quad e \quad ----> \quad O \quad + \quad O$$

About 50% of the O atoms produced above the exobase escape at Mars (Fox and Hac, 1997).

$$\text{Prod} = 2\, \alpha(T_e)\, [O_2^+]\, n_e$$

Energy distributions of ^{18}O and ^{16}O in O_2^+ DR



Fox and Hac (1997); Fox (2003)- hot oxygen energy distribution
At several altitudes (200 km exobase).

Nonthermal/photochemical loss at Mars

(Fox, 1993; Lammer and Bauer, 1991; Fox et al., 1995; Fox and Hac, 1997; Kim et al., 1998; Hodges, 2000; Fox, 2003)

ESCAPE H FLUX $\approx 10^8$ cm^{-2} s^{-1}
(Lyman alpha obsv.)

$(Q \approx 2 \times 10^{26}\ s^{-1})$

ESCAPE O FLUX $\approx$ $3 \times 10^6 - 2 \times 10^8\ cm^{-2}\ s^{-1}$

$(Q \approx 0.3 - 4 \times 10^{26}\ s^{-1})$

Summary of Present Oxygen Loss at Mars

(A) Phobos-2 Taus and Aspera (tail/pick-up): 1- 4 $\times 10^{25}$ s^{-1}

(B) Sputtering contribution $< 10^{25} s^{-1}$

(C) Deduced From Ionosphere: 2 - 6 $\times 10^{25} s^{-1}$

(D) Direct photochemical O escape: 0.3 - 4 $\times 10^{26}$ s^{-1}

(E) Global MHD model: $\approx$ 0.3 $\times 10^{25} s^{-1}$

Discrepancies between models and data (global?) and issue of how to extrapolate back in time. “Better” data/models needed – YH-1, MAVEN.

Table 4 Modeled thermal and non-thermal loss rates of atomic and molecular hydrogen, oxygen, nitrogen and carbon species (neutrals and ions) from Mars at present time moderate solar activity conditions (1 EUV), at 2 EUV periods and for 6 EUV (~ 3.5 Gyr ago)

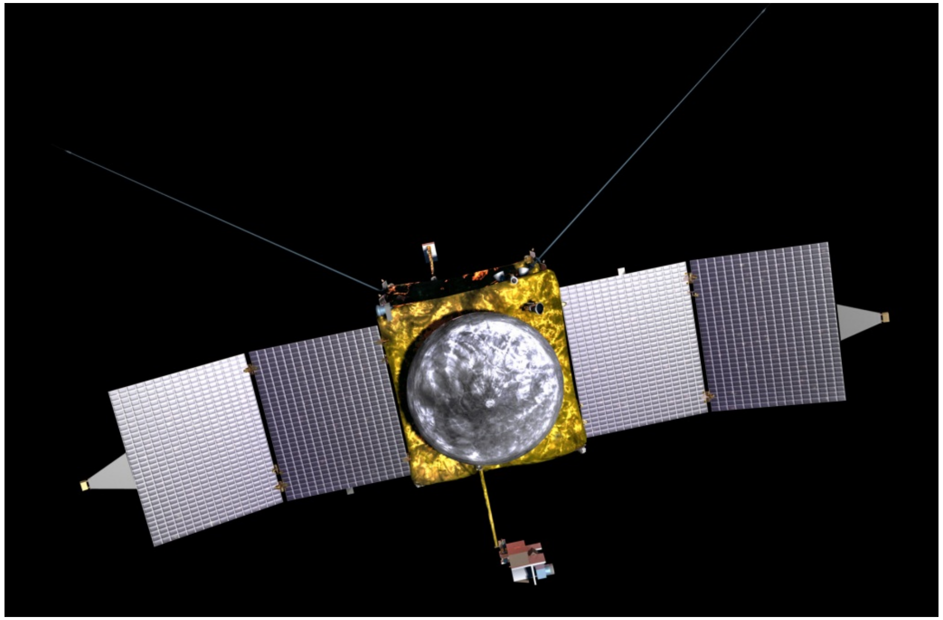
Species	EUV	Jeans	Photochem.	Sputtering	Pick up	Plasma clouds	Cool ion outflow
H	1	1.5×10^{26} [1]	?	?			
H_2	1	3.3×10^{24} [2]	?	?			
H^+	1				1.2×10^{25} [3]	?	?
H_2^+	1				$\sim 10^{25}$ [3]	?	?
O	1		2.8×10^{24} [4]	3.5×10^{23} [5(3)]			
	2		$3.0\times^{25}$ [4]	1.3×10^{23} [5(3)]			
	6		8.0×10^{25} [4]	1.5×10^{27} [5(3)]			
O^+	1				$3.0\times^{24}$ [3]	$1.0\times^{24}$ [6]	$\sim 10^{25}$ [7]
	2				4.0×10^{25} [3]	$8.0\times^{24}$ [7]	$5.0\times^{2}$ [7]
	6				8.3×10^{25} [3]	2.0×10^{26} [6]	3.0×10^{27} [7]
N	1		4.5×10^{23} [8]	?	?	?	?
O_2^+	1				1.8×10^{24}– 3.6×10^{24} [9]		
C	1		3.0×10^{24} [10]	?	?	?	?
CO	1		8.0×10^{23} [11]	3.7×10^{22} [5(3)]	?	?	?
	2			$2.0\times^{24}$ [5(3)]	?	?	?
	6			2.5×10^{23} [5(3)]	?	?	?
CO_2	1			$5.0\times^{22}$ [5(3)]			
	2			2.3×10^{24} [5(3)]			
	6			4.0×10^{25} [5(3)]			
CO_2^+	1				8.0×10^{23}– 2.0×10^{24} [9]		

[1] Anderson and Hord (1971), [2] Krasnopolsky and Feldman (2001), [3] Lammer et al. (2003a), [4] Luhmann (1997) for 1 EUV, 2 EUV, 6 EUV also in agreement with Kim et al. (1998) for 1 EUV, [5] Leblanc and Johnson (2002), [6] Penz et al. (2004), [7] Lammer et al. (2003b), [8] Fox and Dalgarno (1983), [9] molecular ion outflow is estimated (Carlsson et al. 2006), [10] Nagy et al. (2001), [11] Fox and Bakalian (2001)

	Pick up	Plasma clouds	Cool ion outflow	EUV Flux
	$3.0\times^{24}$ [3]	$1.0\times^{24}$ [6]	$\sim 10^{25}$ [7]	1
O^+	4.0×10^{25} [3]	$8.0\times^{24}$ [7]	$5.0\times^{2}$ [7]	2
	8.3×10^{25} [3]	2.0×10^{26} [6]	3.0×10^{27} [7]	6 (3.5 GY ago)
O_2^+	1.8×10^{24}– 3.6×10^{24} [9]			
CO_2^+	8.0×10^{23}– 2.0×10^{24} [9]			

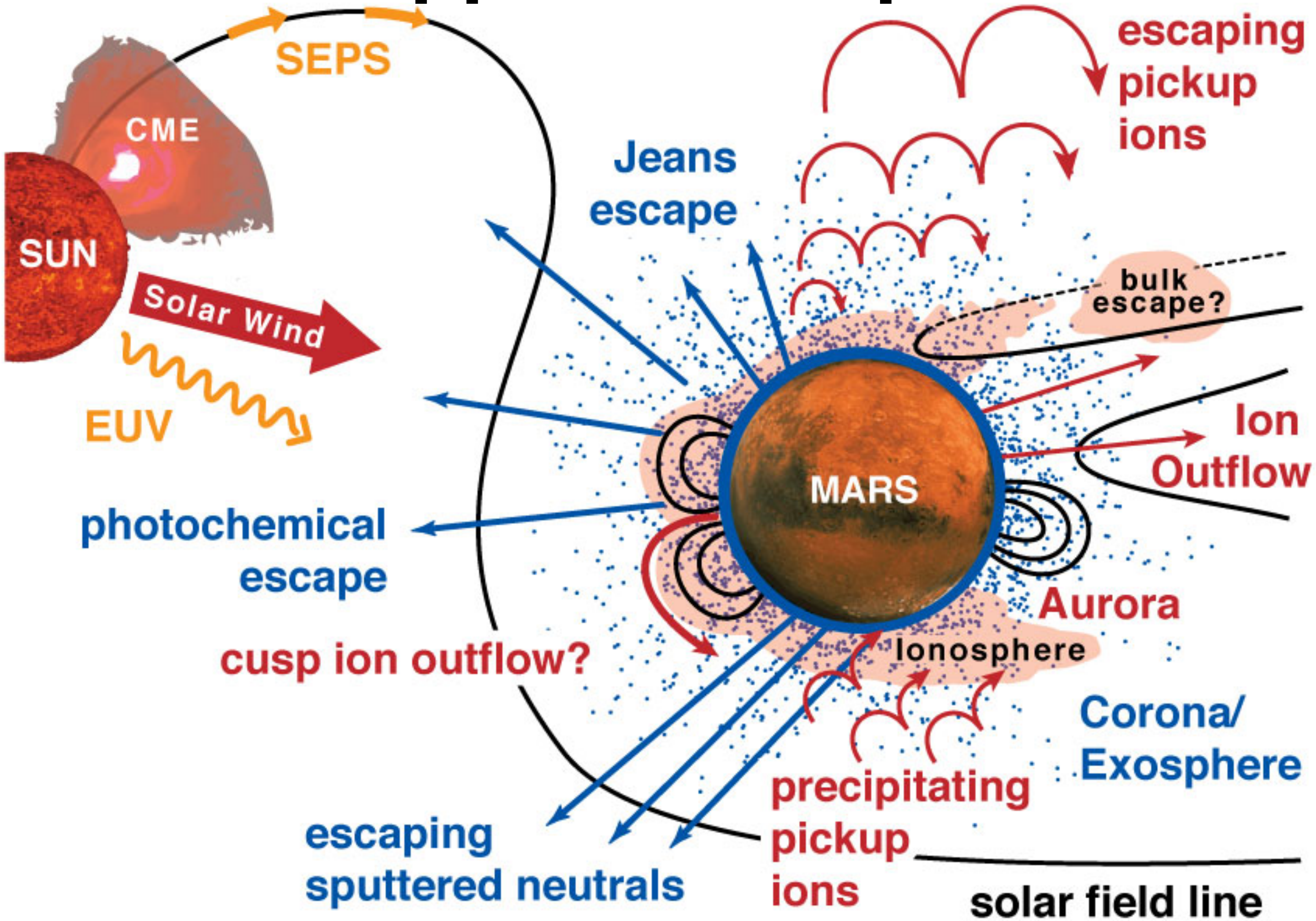
Lammer et al., Space Science Rev., 2008

MAVEN Space Craft images



Images courtesy of Lockheed Martin

MAVEN Will Explore the Ionosphere and Upper Atmosphere of Mars



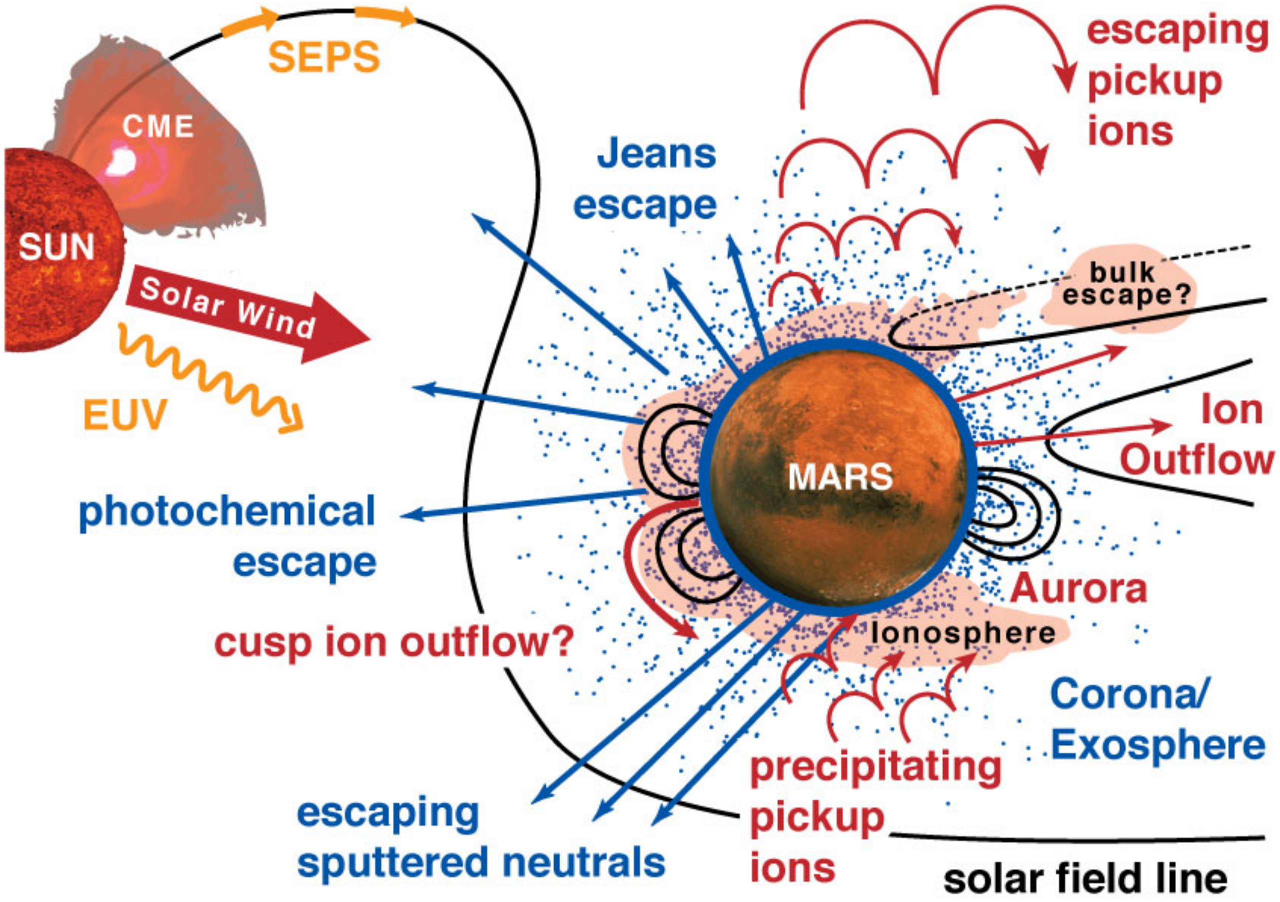
MAVEN will determine the present state of the upper atmosphere and today's rates of loss to space.

Key measurements allow determination of the net integrated loss to space through time.

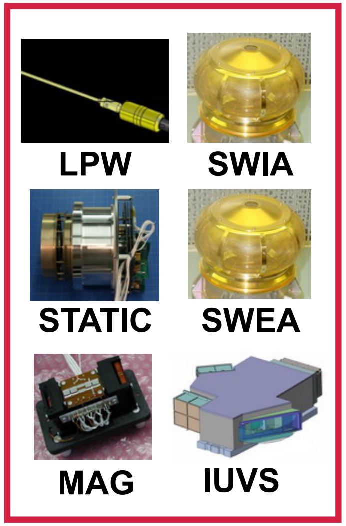
MAVEN will provide a definitive understanding of the history of Martian volatiles.

Three Instrument Packages, Eight Instruments

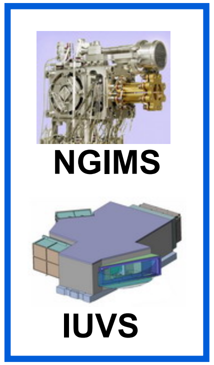
Solar Inputs



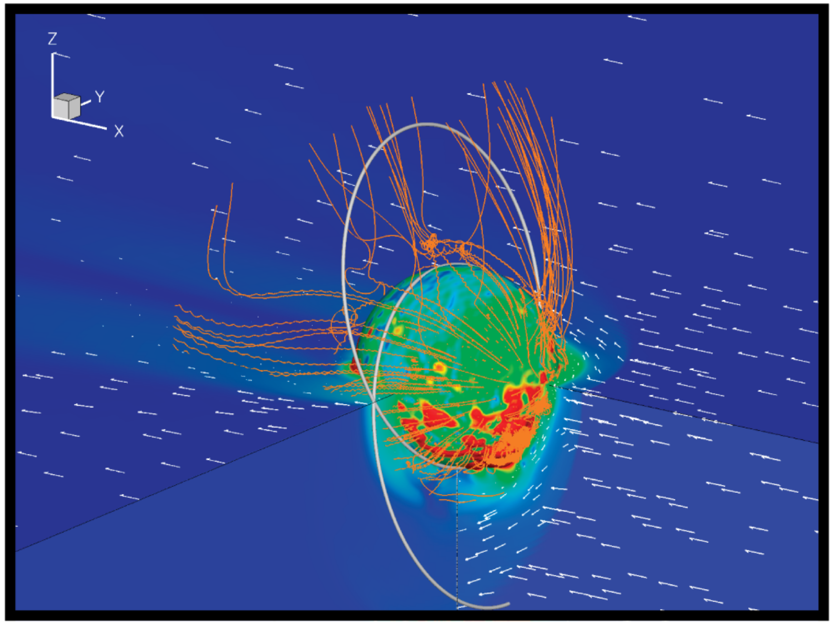
Plasma Processes

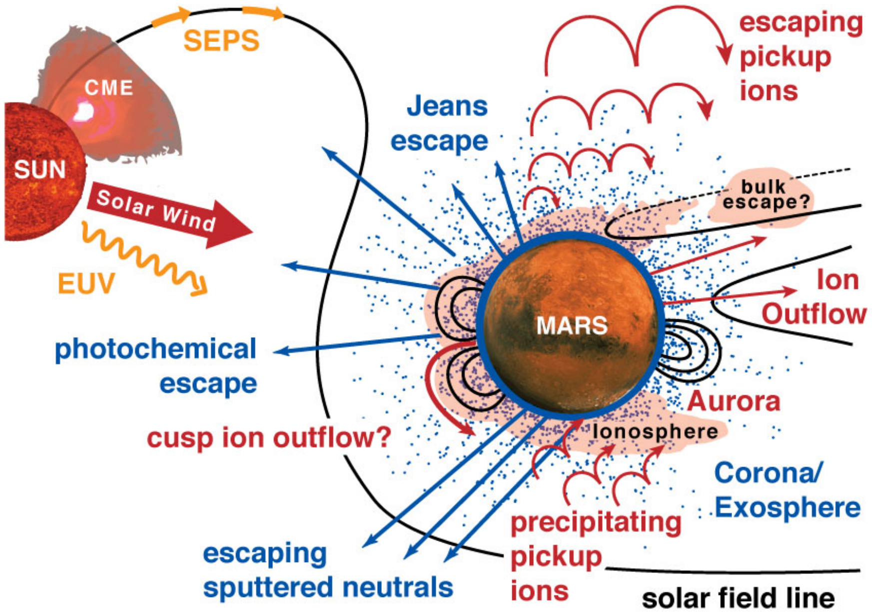


Neutral Processes



MAVEN
Mars Atmosphere and Volatile Evolution Mission
CU/LASP • GSFC • UCB/SSL • LM • JPL





Best time resolution for escape measurements expected ~4s at one orbital location

MAVEN (NASA, launch 2013) will measure several aspects of ion escape – but low energy escaping population must be measured at higher time resolution (~100ms, near escaping ion gyroperiod, to fully study the physics of ion escape) – and better electron measurements, multi-point measurements are required

Summary

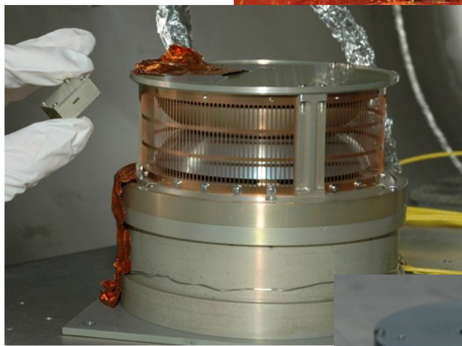
The solar wind interaction with Mars and its atmosphere requires the physics represented in all 3 simple interaction archetypes - cometary-like (mass-loading), Venus-like (ionospheric thermal pressure), and Earth-like (intrinsic magnetic field).

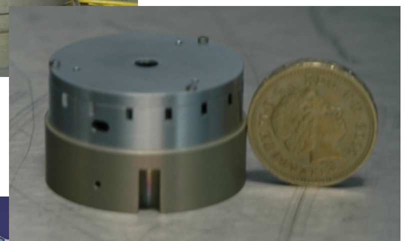
Atmospheric Escape on Mars depends on the details of the solar wind interaction as well as on the aeronomy of the upper atmosphere and ionosphere.

YH-1 will make important measurements relevant to this problem

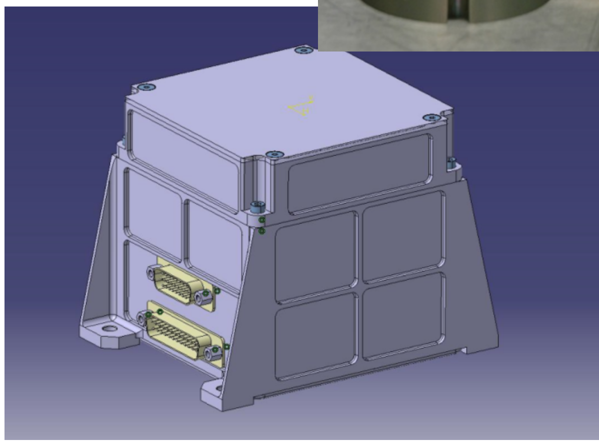
The MAVEN mission will be in an excellent position to help unravel escape processes at Mars and to provide information for estimating past loss and its implications for volatile (e.g., water) inventories on this planet.

Instrument development at MSSL - including TechDemoSat (TDS)





- Heritage of plasma instrumentation at MSSL: Cluster and Double Star PEACE, Cassini CAPS Electron Spectrometer, Mex and VEx particiption
- Instrument development for Solar Orbiter SWA
- TDS: UK technology demonstration mission
- Demonstrate miniaturised instrumentation under development at MSSL
- Low-resource Electron/Ion instrument. No mass identification
- Delivery Oct. 2011, Launch ~ Q2 2012



Schematic of TDS instrument

- Lundin, R.N., et al., ASPERA PHOBOS MEASUREMENTS OF THE ION OUTFLOW FROM THE MARTIAN IONOSPHERE, GEOPHYSICAL RESEARCH LETTERS Volume: 17 Issue: 6 Pages: 873-876, 1990.
- Jakosky, BM and R.J. Phillips, RJ Mars' volatile and climate history, NATURE Volume: 412 Issue: 6843 Pages: 237-244, 2001
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- Barabash, S., A. Fedorov, R. Lundin, J.A. Sauvaud, JA, Martian atmospheric erosion rates, SCIENCE Volume: 315 Issue: 5811 Pages: 501-503, 2007
- Barabash, S., et al., The loss of ions from Venus through the plasma wake, Nature 450, 650-653, doi:10.1038/nature06434, 2007.
- Frahm, R.A., et al., Estimation of the escape of electrons from Mars in 2004 Liberated by the Ionization of Carbon Dioxide and Atomic Oxygen, Icarus, Volume 206, Issue 1, p. 50-63, doi 10.1016/j.icarus.2009.03.024, Mar 2010.

Space Weather at Earth

- Enhance auroral activity (T3)
- Magnetospheric and ionospheric disturbances (T1, T3, T4)
- Disruption of radio communication (T1)
- Disruption of satellite operations (T1, T2, T3, T4)
- Disruption of electrical power grids (T3)
- Malfunction of nuclear power plants (T2)

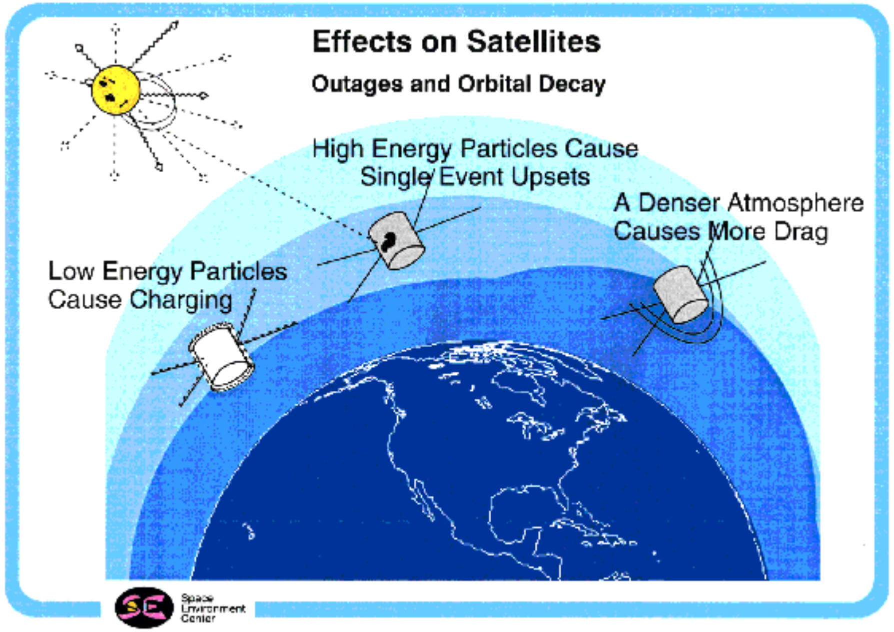
Timescales (after solar event):

T1 – electromagnetic radiation reache Earth (8 minutes)

T2 – SEPs reach Earth (20-60 minutes)

T3 – Plasma reaches Earth (1-3 days)

T4 – Radiation belt intensifications (T3+2 days)



http://www.swpc.noaa.gov/Media/graphics/Satellite.gif

Space Weather at Mars

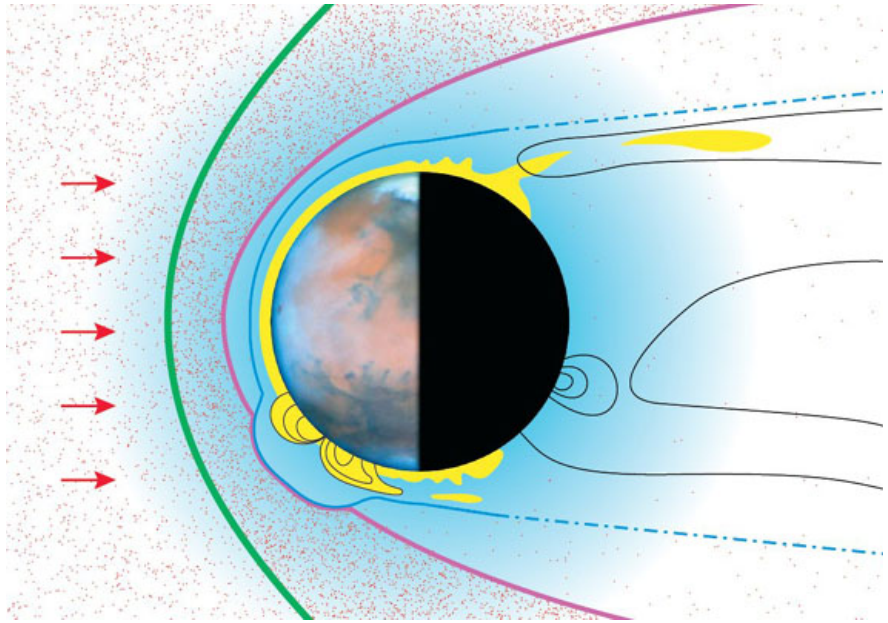
- Magnetospheric and ionospheric disturbances (T1, T3)
- Disruption of radio communication (T1)
- Disruption of satellite operations (T1, T2, T3)

Timescales:

T1 – electromagnetic radiation reaches Mars (12 minutes)

T2 – SEPs reach Mars (30-80 minutes)

T3 – Plasma reaches Mars (1.5-4.5 days)



http://mepag.jpl.nasa.gov/science/5_Planetary_Magnetism/mars_plasmoid_Steve_Bartlett_NASA_sm.jpg