Venus and Mars
Observing Induced Magnetospheres

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MPS Planetary Plasma Group

Outline

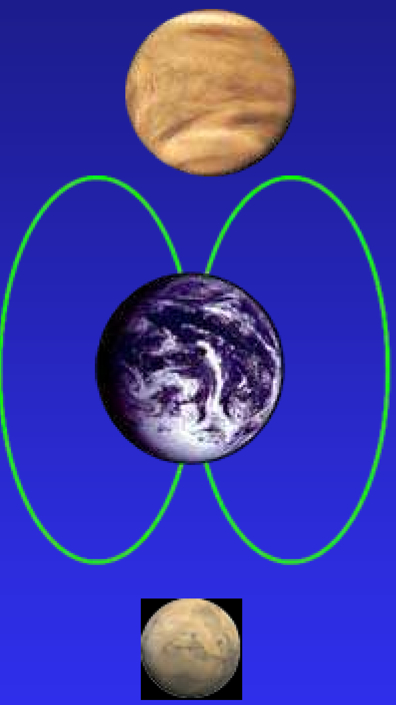
- Why Earth, Mars, Venus so different?
- Atmospheric evolution and escape
- Observing Exospheres
- Escape processes – predictions
- Observing Induced Magnetospheres
- ASPERA experiment at Mars and Venus
- Problems related to escape processes

Why Earth, Mars, Venus so different?

Property	Venus	Earth	Mars
Mass [10^{12}Gt]	4.9	6.0	0.64
Radius [km]	6049	6371	3390
SolarDistance [AU]	0.72	1.0	1.52
SolarConstant [W/m^2]	2613	1367	589
Atmosphere Mass[10^6Gt]	500	5.1	0.31
N_2 [%]	<2	78	<3
O_2 [%]	$<10^{-4}$	21	<0.25
CO_2 [%]	98	0.035	>96
H_2O[%]	<0.3	<4	<0.001
D/H ratio [10^{-4}]	240	1.5	9
EscapeVelocity** [km/s]	10.3	10.8	4.8
EscapeEnergy [eV]	H:0.54 O:8.64	H:0.61 O:9.69	H:0.12 O:1.91
ExobaseTemp* [K]	275	1000	300
ExobaseAltitude* [km]	200	500	250
IonosphereAltitude*** [km]	120	300	150
ThermalEscape H [t/a]	0.0013	2800	7800

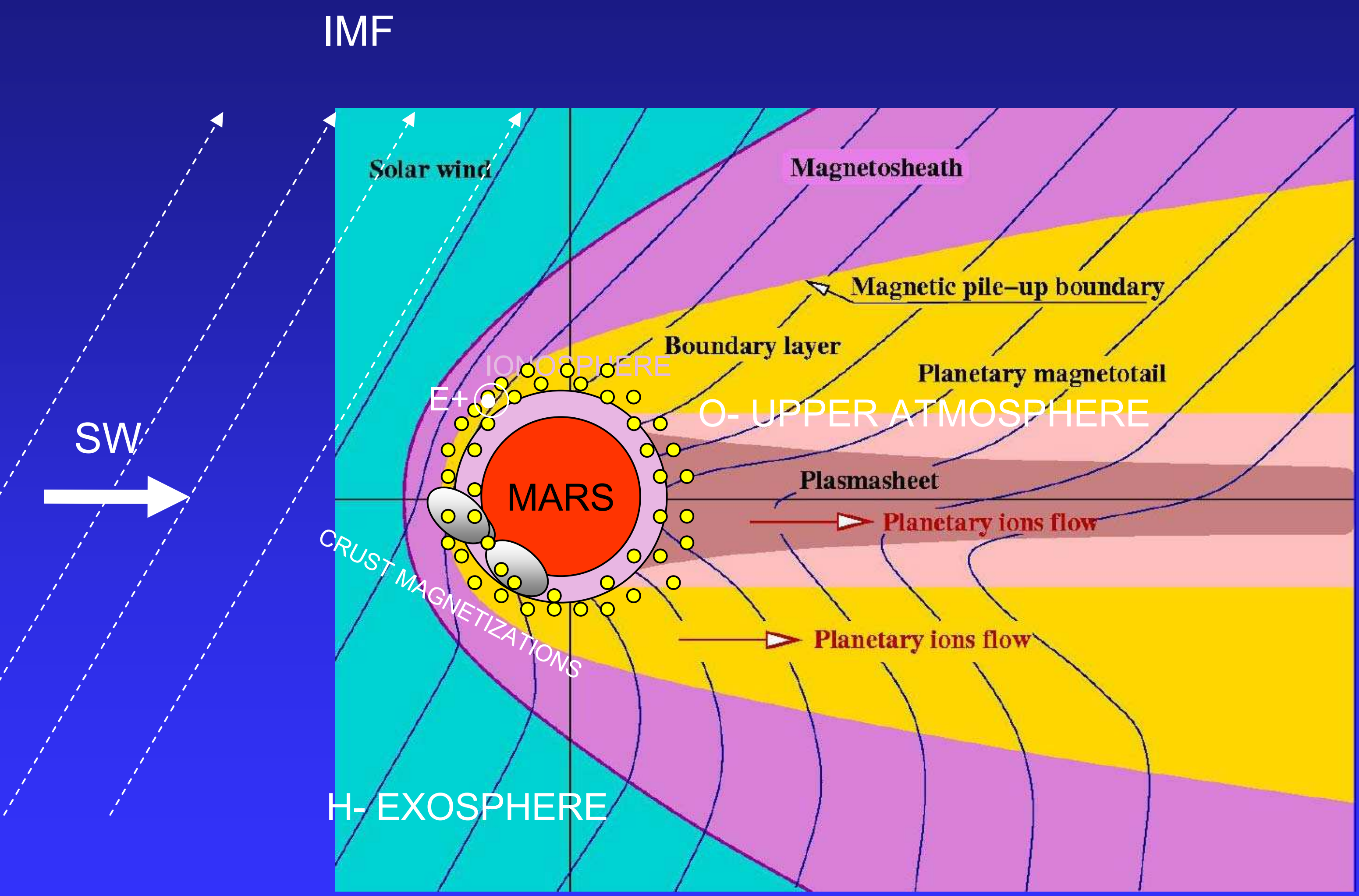
*Upper limit of collisional domain **at exobase ***electron peak density

Escape Problem



- At Venus thermal escape is negligible but D/H ratio and lack of hydrogen suggests a significant mass dependent escape of hydrogen.
- At Earth thermal and other escape mechanisms seem to have small influence on atmospheric composition.
- At Mars thermal escape of hydrogen seems very significant, but because hydrogen is coupled to water in atmosphere, oxygen must be lost as well.
- → Non-thermal escape must be important for Mars and probably Venus.

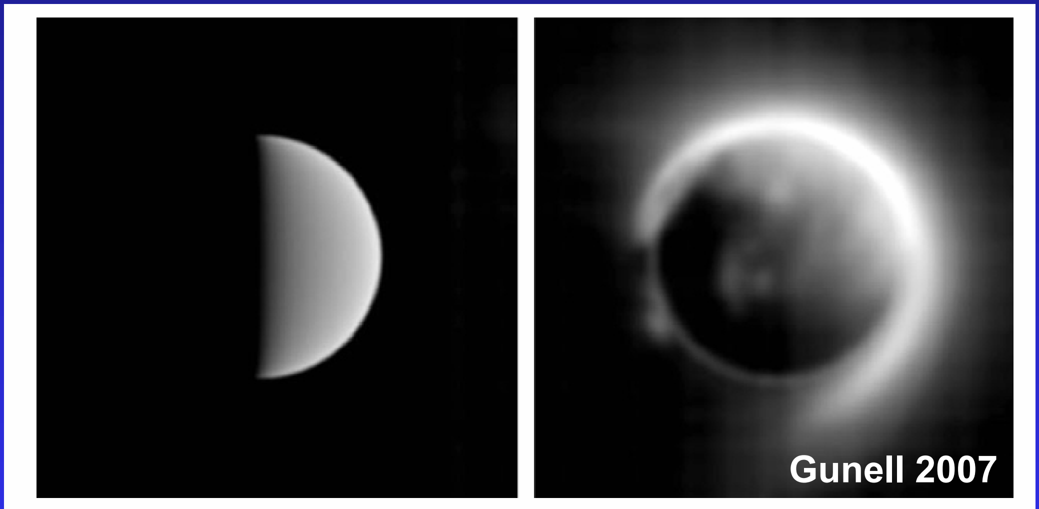
MARTIAN MAGNETOSPHERE



How can you observe a planets exosphere?

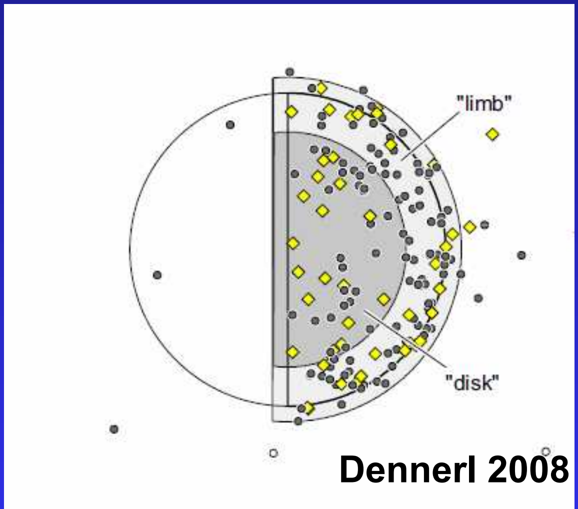
Venus Hydrogen Corona

Xray reflection from surface and by charge exchange simulation



Gunell 2007

Xray emission observation by Chandra satellite



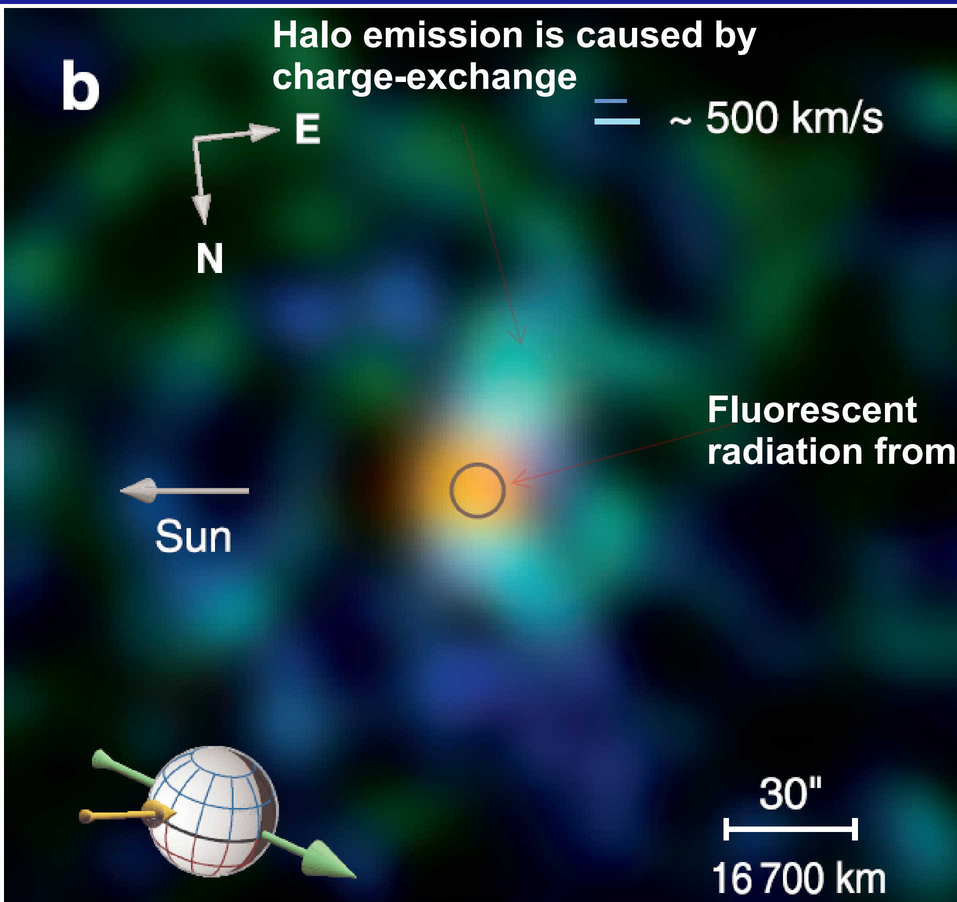
Dennerl 2008

Venus and Mars have comparable temperatures of the upper ionosphere (300K at 300km altitude)
The much larger gravity of Venus causes a much thinner exosphere
Because the hydrogen thermal escape rate is a function of

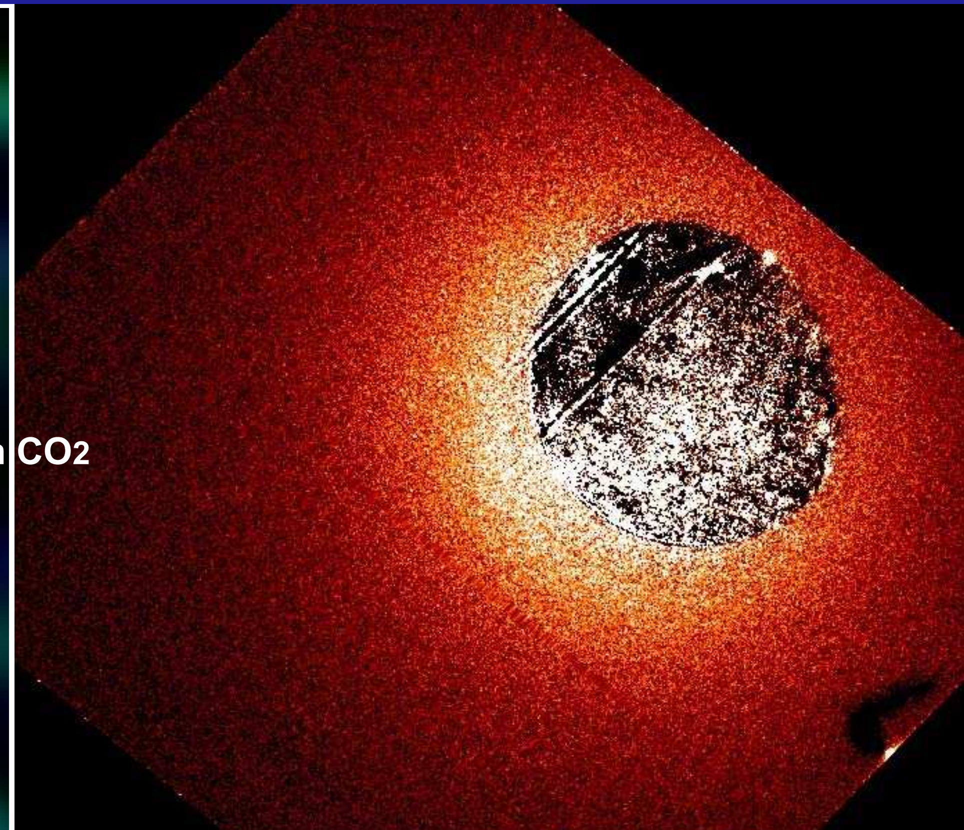
GMm/kTr
gravitation potential/thermal energy

Mars Hydrogen Corona

- X-ray halo (charge-exchange with solar wind heavy ions)
- Lyman –[illegible] excitation of neutral hydrogen



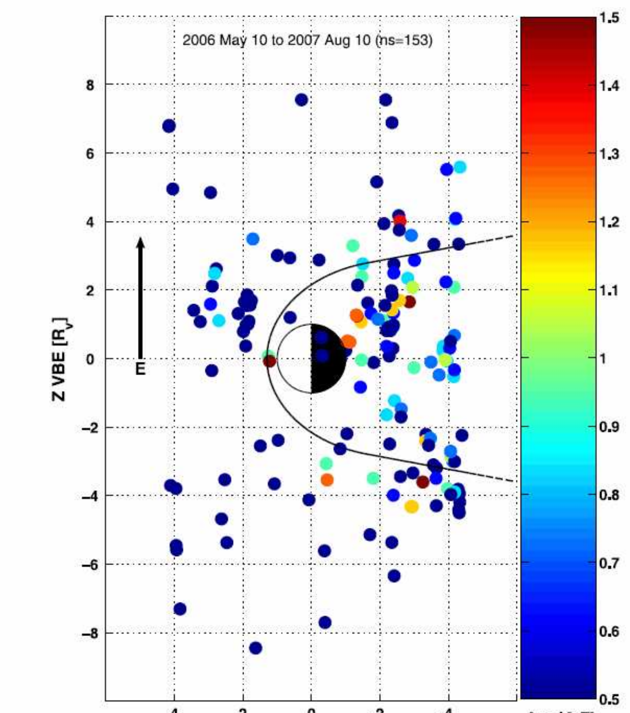
X-ray picture of Mars (XMM, Dennerl 2006)



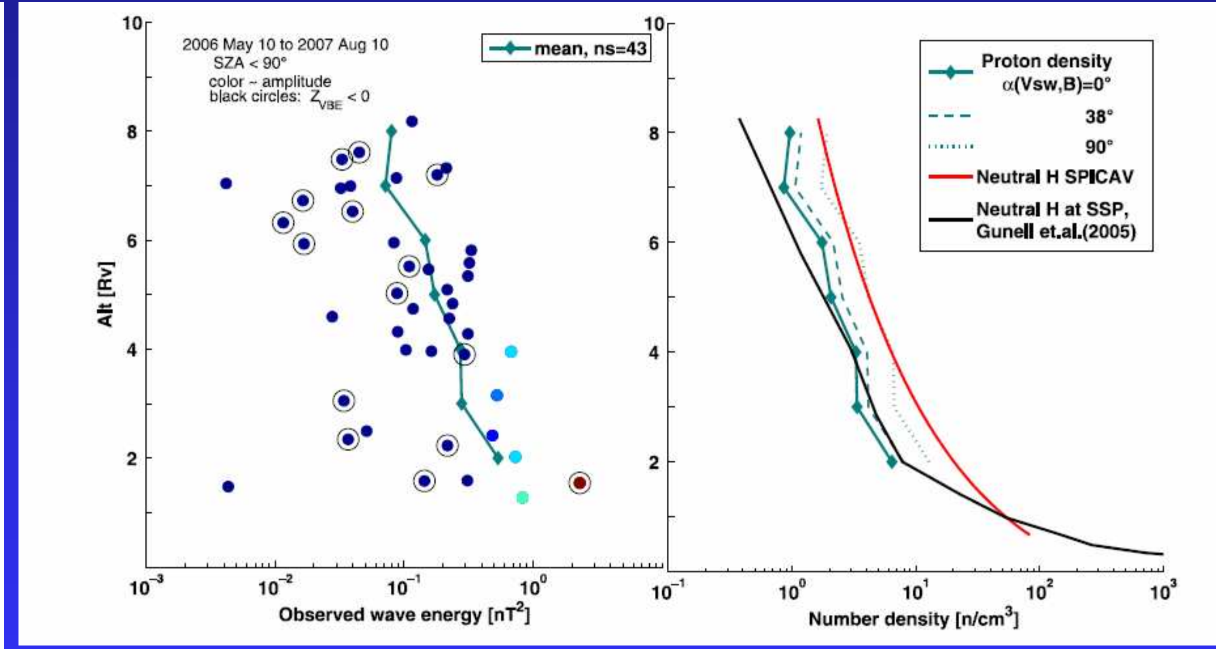
Lyman-[illegible] picture of Mars (HST, John Clarke)

Venus Hydrogen Corona by Pick-Up Ion Observations

Proton Cyclotron waves at Venus

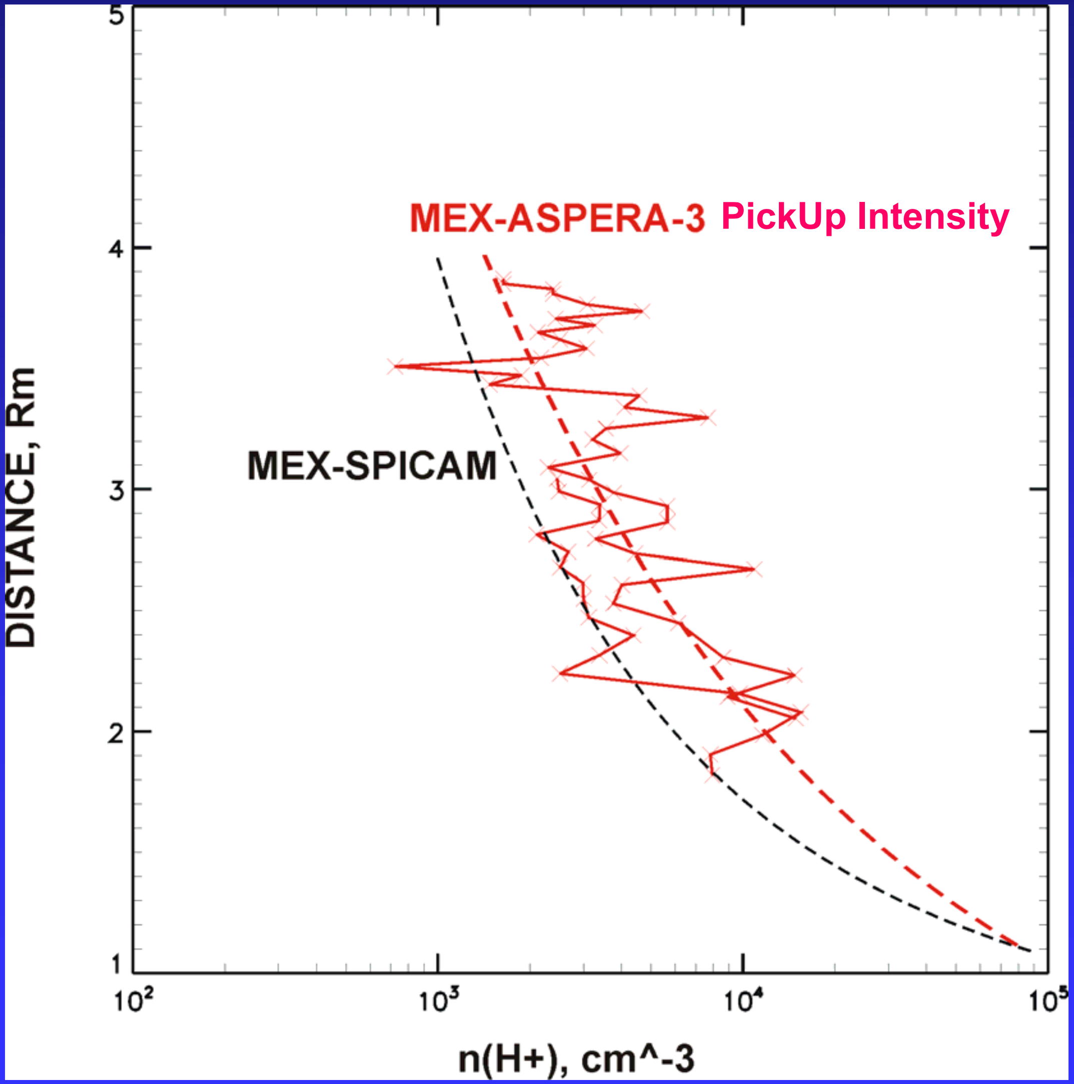


Delva 2009



The ionization rate of hydrogen can be determined by the wave power of proton cyclotron waves resulting in a hydrgen density profile with density < 10/cc above 3000km distance.

Determination of Jeans Escape by Indirect Observations at Mars

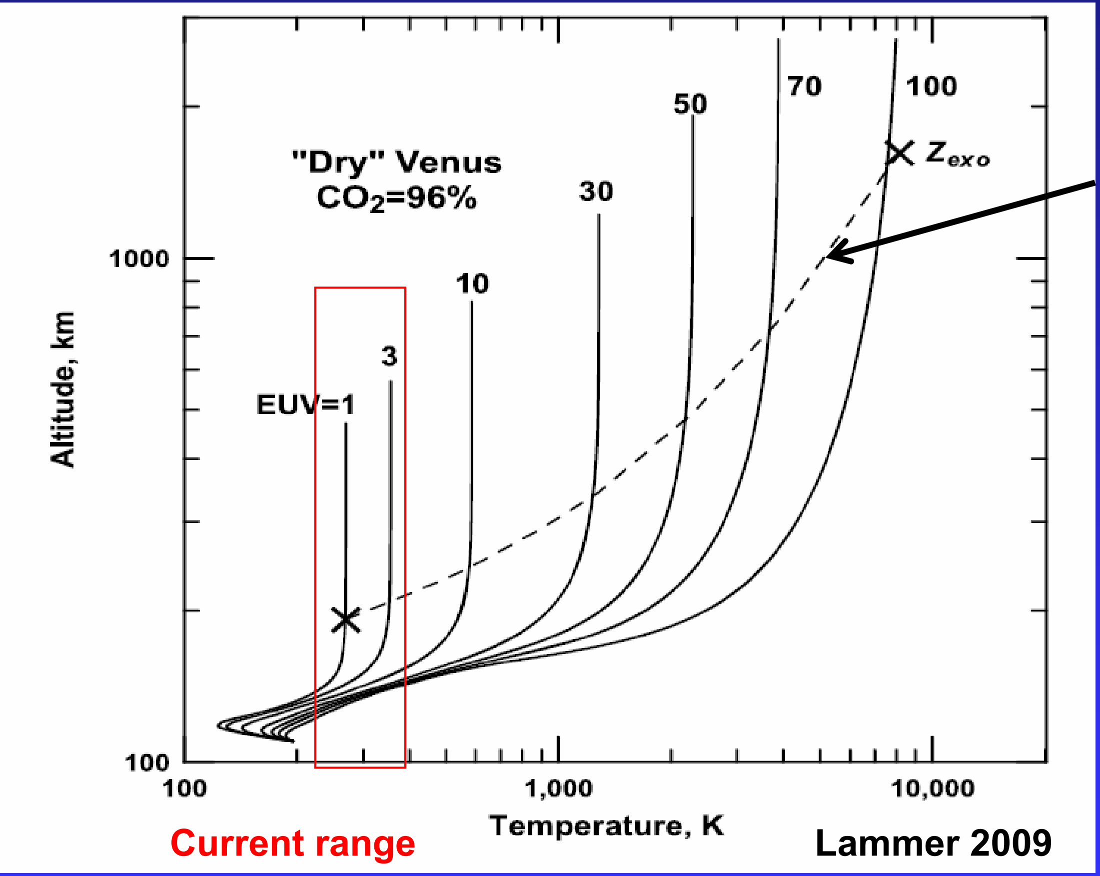


Dubinin et al., 2006

From PickUp:
Thermal escape: ~ $5x10^{26}$/s
Mariner6 (1971): $1.5x10^{26}$/s

Slightly higher than exobase density inferred from energetic neutral measurements by ASPERA-3 (Galli et al. 2007)

Influence of Solar EUV flux on Exosphere

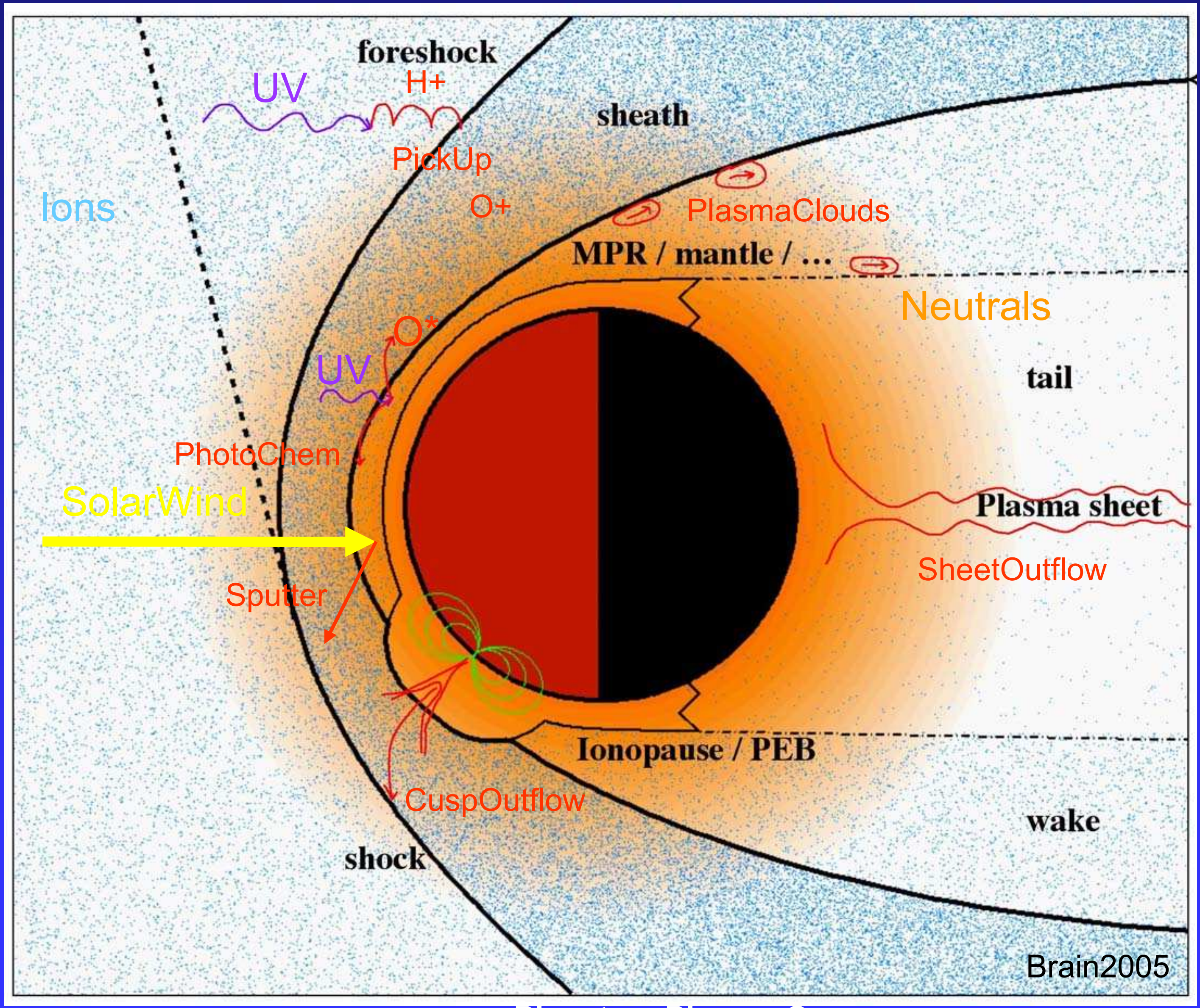


Exobase altitude
(scale height=mean free path)

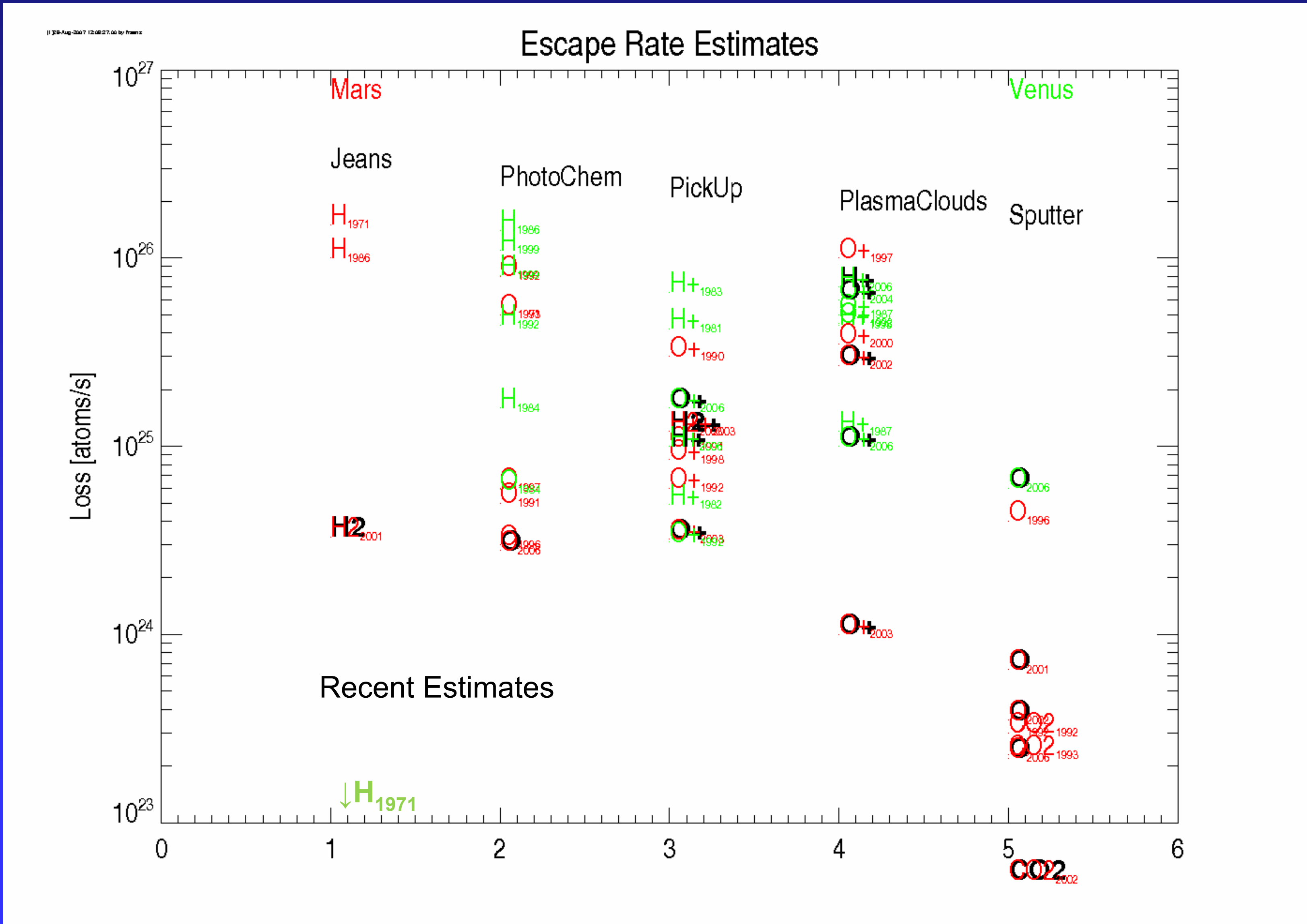
The increase of exobase should also move up the ionopause, but effects of increased solar magnetic flux on ionosphere is probably even more important. On geological time scales both effects can explain complete loss of water from induced magnetospheres.

How else can particles escape from an atmosphere into space?

Non-thermal escape processes at Mars and Venus



SOLAR WIND INDUCED ESCAPE
Estimates for Mars and Venus



How can we measure the escaping flux?

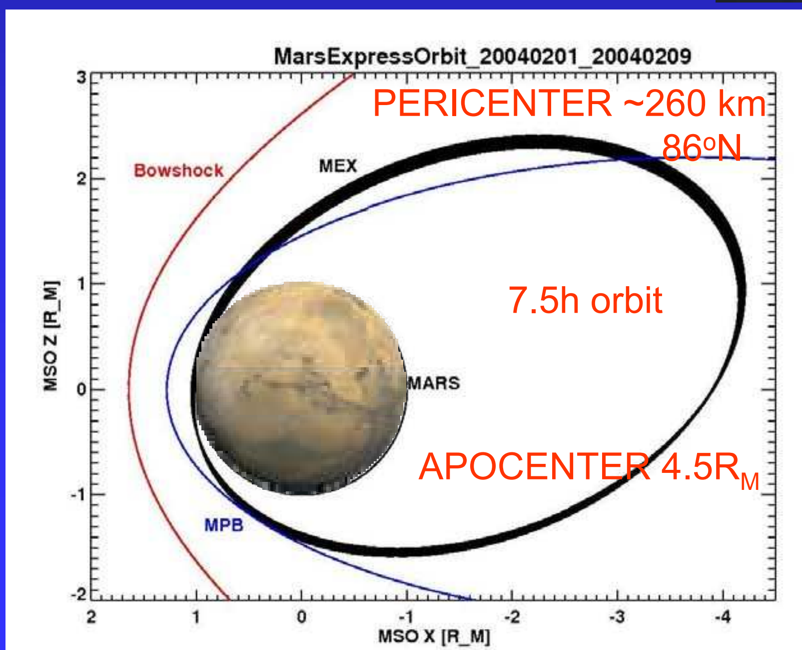
Measuring Atmospheric Escape

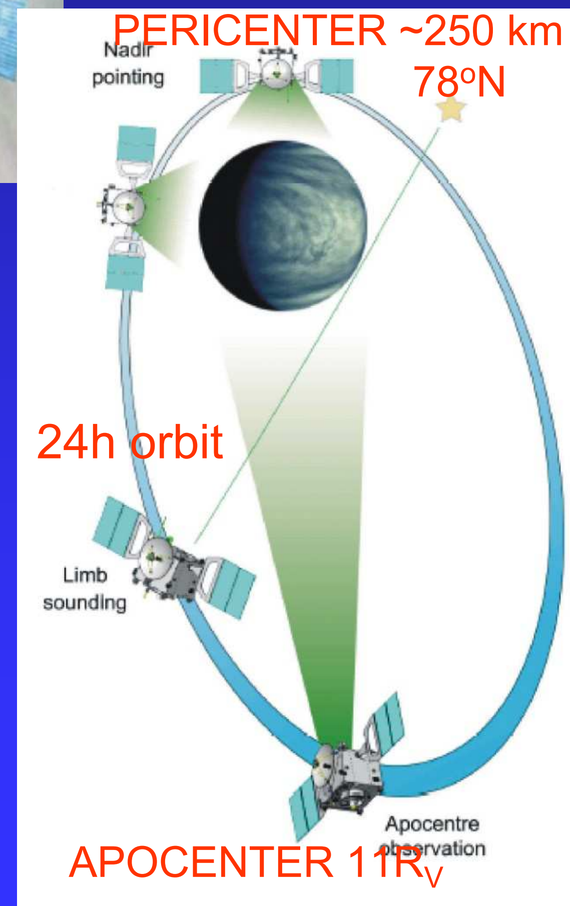
1. remote sensing exospheric UV glow and X-ray excitation
2. remote sensing production of energetic neutral atoms produced by solar wind charge exchange with exosphere
3. in-situ measurement of escaping ions
4. in-situ measurement of solar wind moment transfer into ionosphere

The ASPERA Experiments on Mars and Venus Express

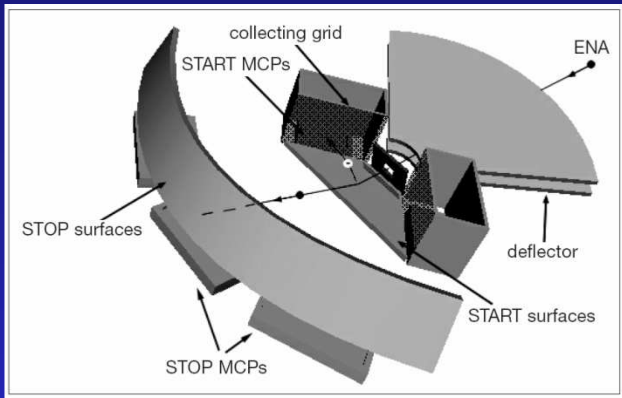
InOrbit 28 Jan 2004
Operation 2x680 days

Orbit Insertion 11 April 2006
Operation 2x500 days





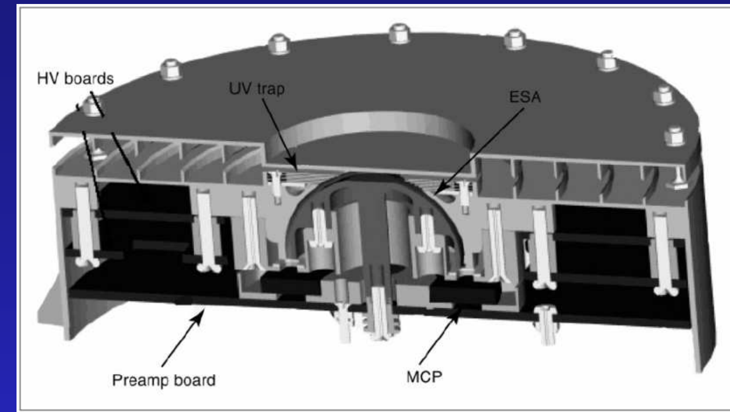
ASPERA Sensors



IRF, Kiruna
MPS, Lindau
IFSI, Rome

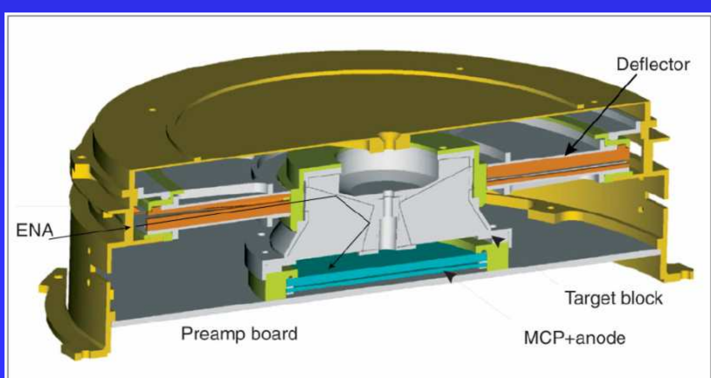
Neutral Particle Detector, 6 sectors
0.1-60keV with energy

SwRI,
San Antonio



Electron Spectrometer, 16 sectors
1-20keV

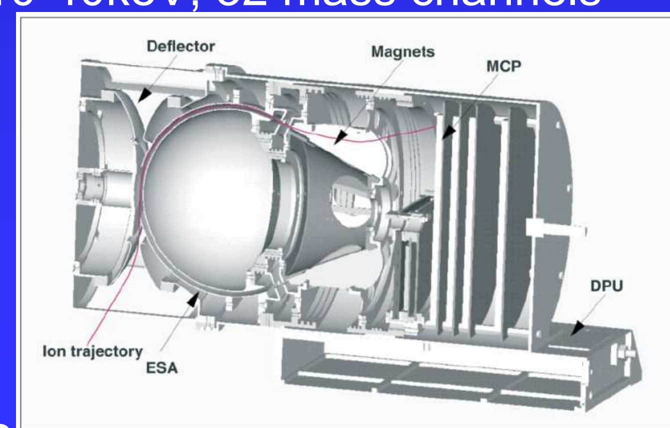
Neutral Particle Imager, 32 sectors



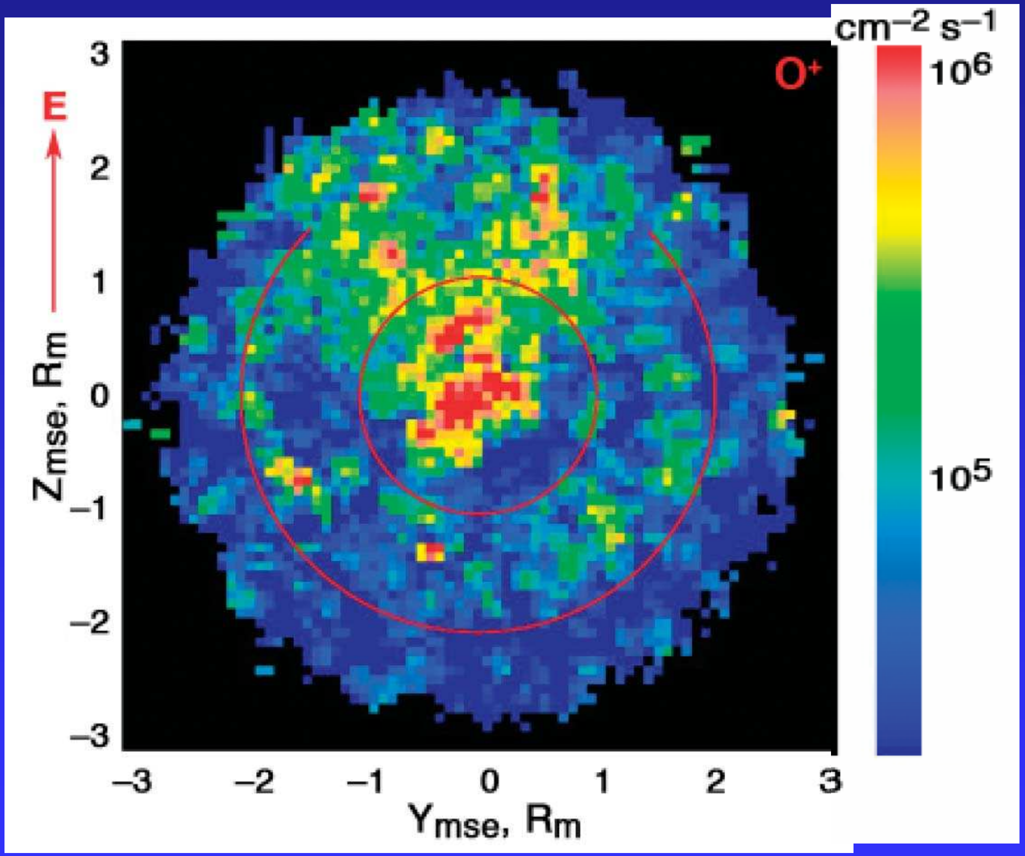
IRF, Kiruna

Ion Spectrometer, 16x16 sectors
10-40keV, 32 mass channels

CNES,
Toulouse
IRF, Kiruna



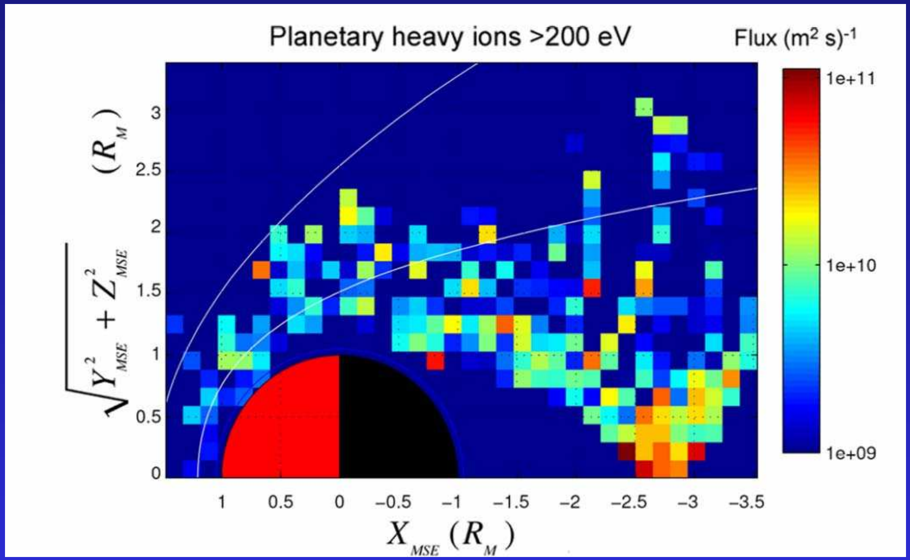
First direct O+ Escape Determination for Mars by ASPERA-3

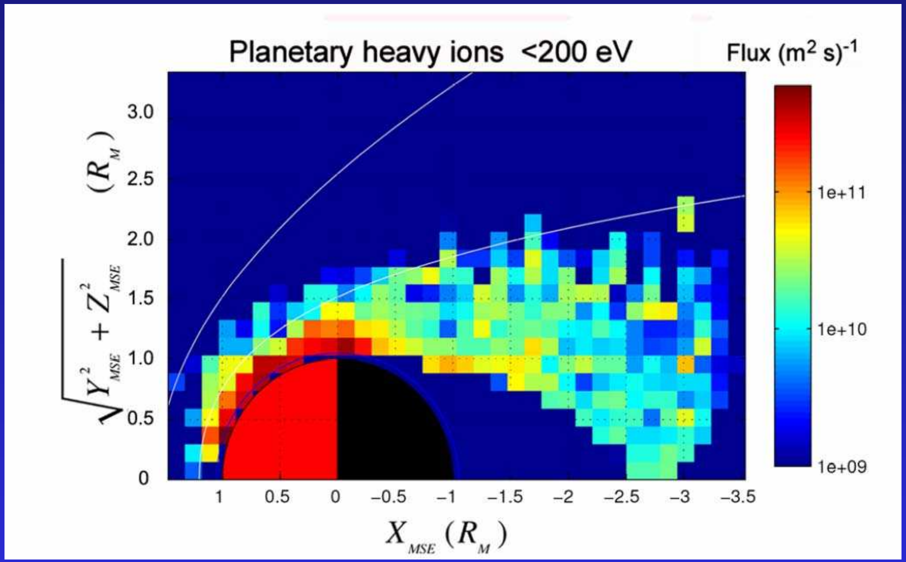


Total escape rate of O+ ions has been determined for the first time by ASPERA-3 on Mars Express to be
1.6×10^{23}/s
(Barabash et al. *Science,*2007)

Much lower than estimate by Phobos: 3×10^{25}/s
(Lundin et al., 1990)

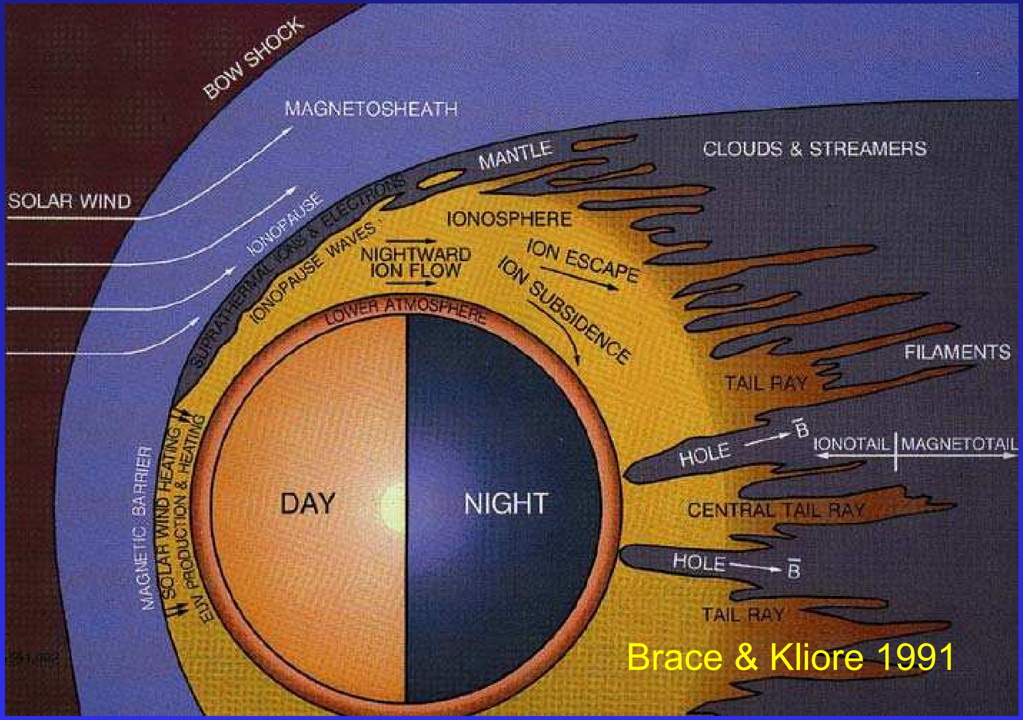
Mars Ion Escape - new estimates

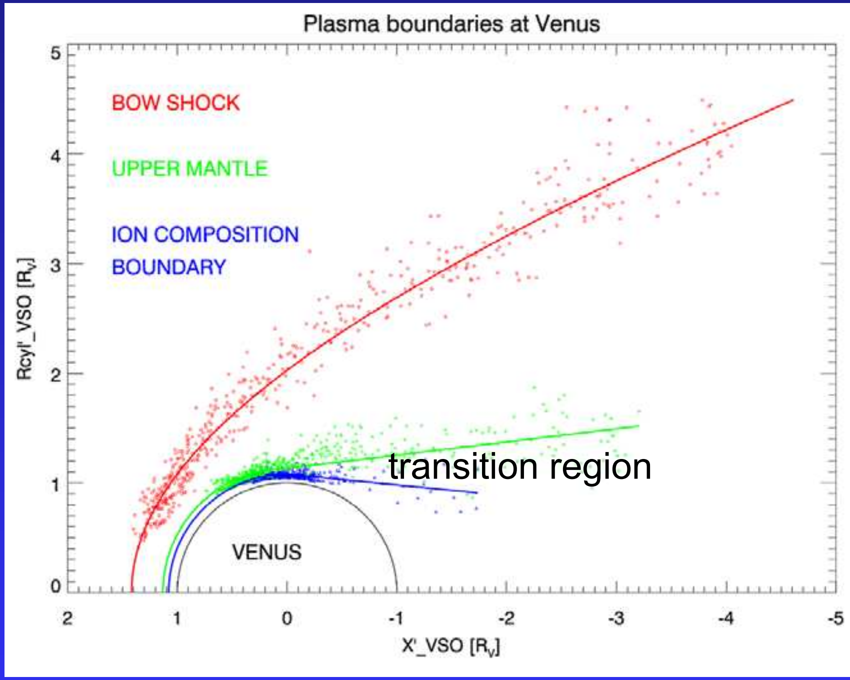




Previous estimate was based on ions with E > 200eV (left).
New estimate includes ions with E < 200eV:
Total loss in heavy ions: 3.3 10^{24} ions/s (Lundin et al., GRL 2008)

What we know from Pioneer Venus Orbiter (1979-1992)



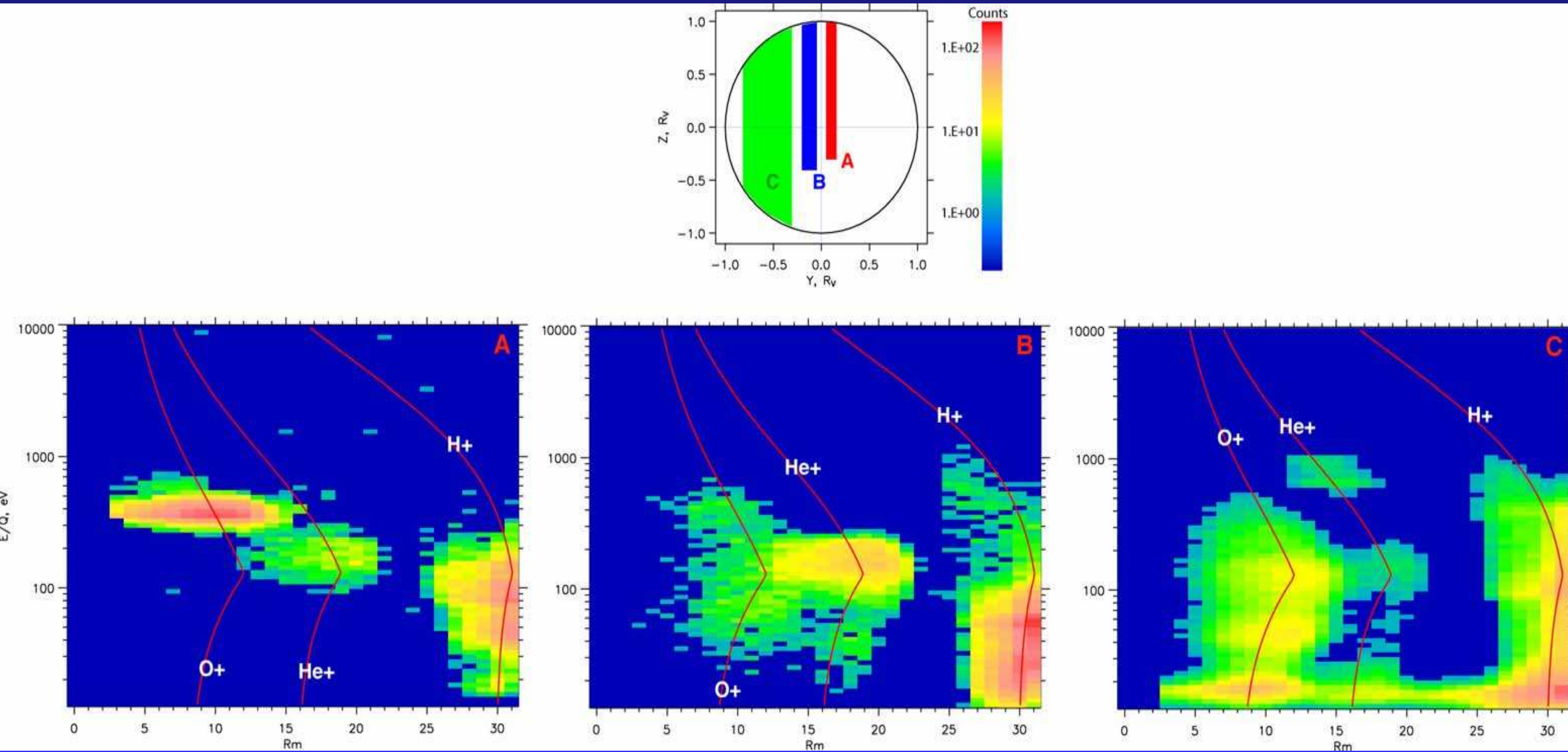


Extension of ionosphere strongly dependent on solar UV flux, large region of solar wind interaction leads to severe ionospheric erosion, extent of this transition region could not be studied by PVO

Bow shock position very stable
First determination of tail boundary indicates very broad transition zone from solar wind to planetary ions

Martinecz et al. Plan.SpaceSci,2008

Venus escaping plasma composition



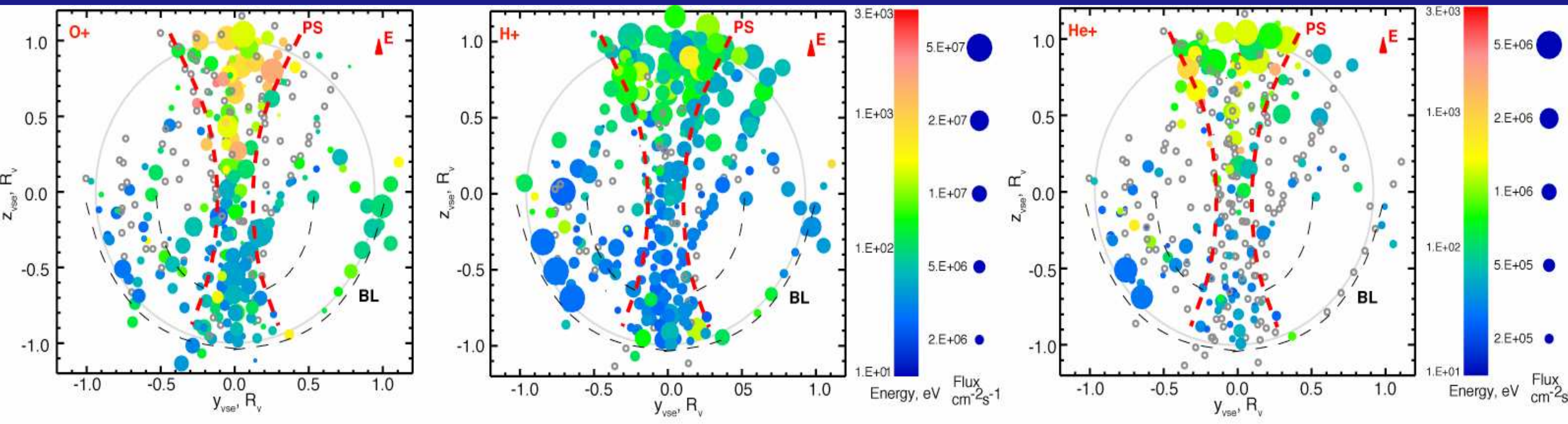
Energy depends on mass: ion-pick up

Energy does not depend on mass: polarization electric field

We observe mixture of both

Barabash et al. Nature, 2007

Venus escaping plasma location



Main escape channel is the tailward plasma sheet formed parallel to the convection electric field $-V_{SW} \times B$.

Within the plasma sheet escape intensity is highest in E+ hemisphere.

Barabash et al. Nature, 2007

Atmosphere oxidation. Mars vs. Venus

Current escape ratio observations are:

Mars: H (thermal)/ O (non-thermal) = 20

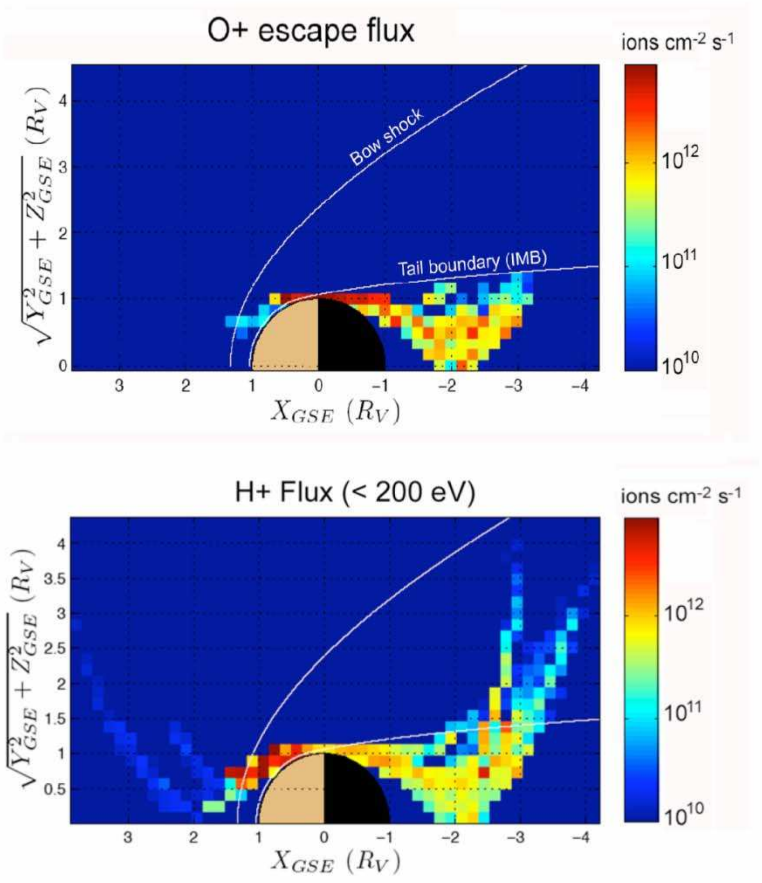
Venus: H/O (non thermal) = 2.2

But atmospheric chemistry tells us that all hydrogen must come from water. Where does the oxygen go?

Hydrogen originates from H_2O break-up. The balance between hydrogen and oxygen escape defines the atmospheric oxidation state.

This would mean that the atmosphere of Venus does not change its oxidation state while Mars atmosphere oxidizes the soil.

Loss calculation by momentum transfer for Venus (Lundin 2008)



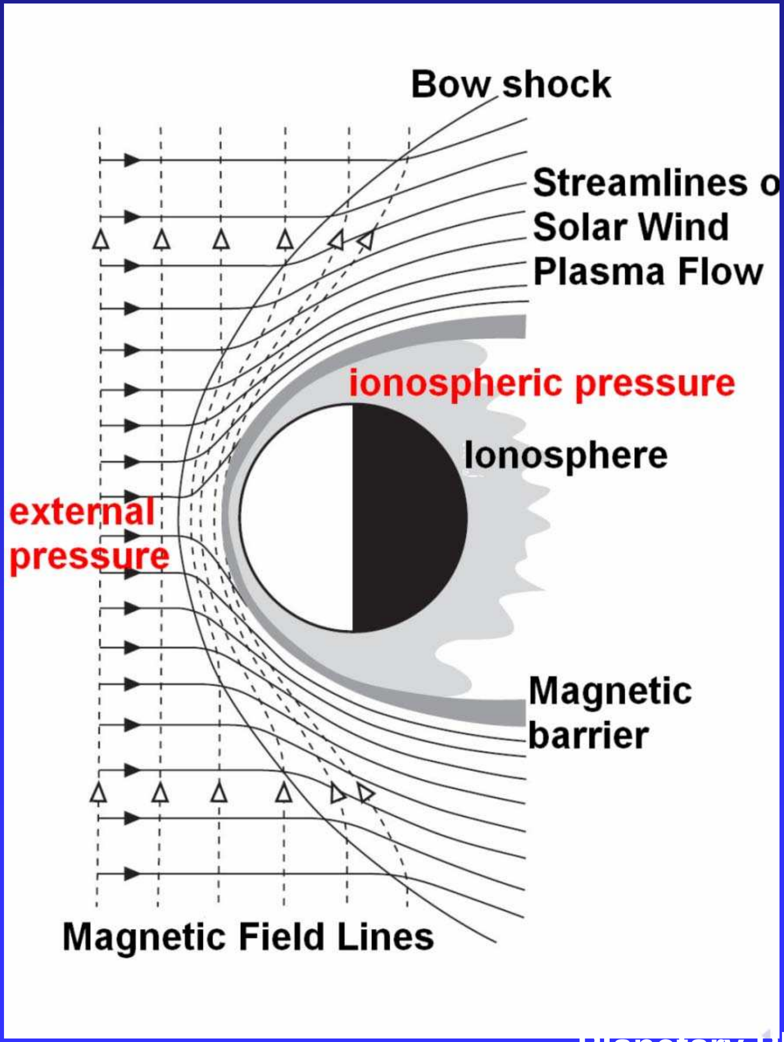
Venus Express (ASPERA-4) results agrees with the PVO "ionosphere extension" into the tail,
but the extension is really an escape of low energy ionospheric O^+, H^+, and He^+.

- H+/O+ flux ratio ≈1.9 !
- Preliminary escape rate:
  $O^+ \longrightarrow 1.4 \cdot 10^{26}$ ions/s
  $H^+ \longrightarrow 2.6 \cdot 10^{26}$ ions/s

R.Lundin (pers.comm.)

How can you measure bulk plasma parameters?

Which parameters are important to understand global structure?

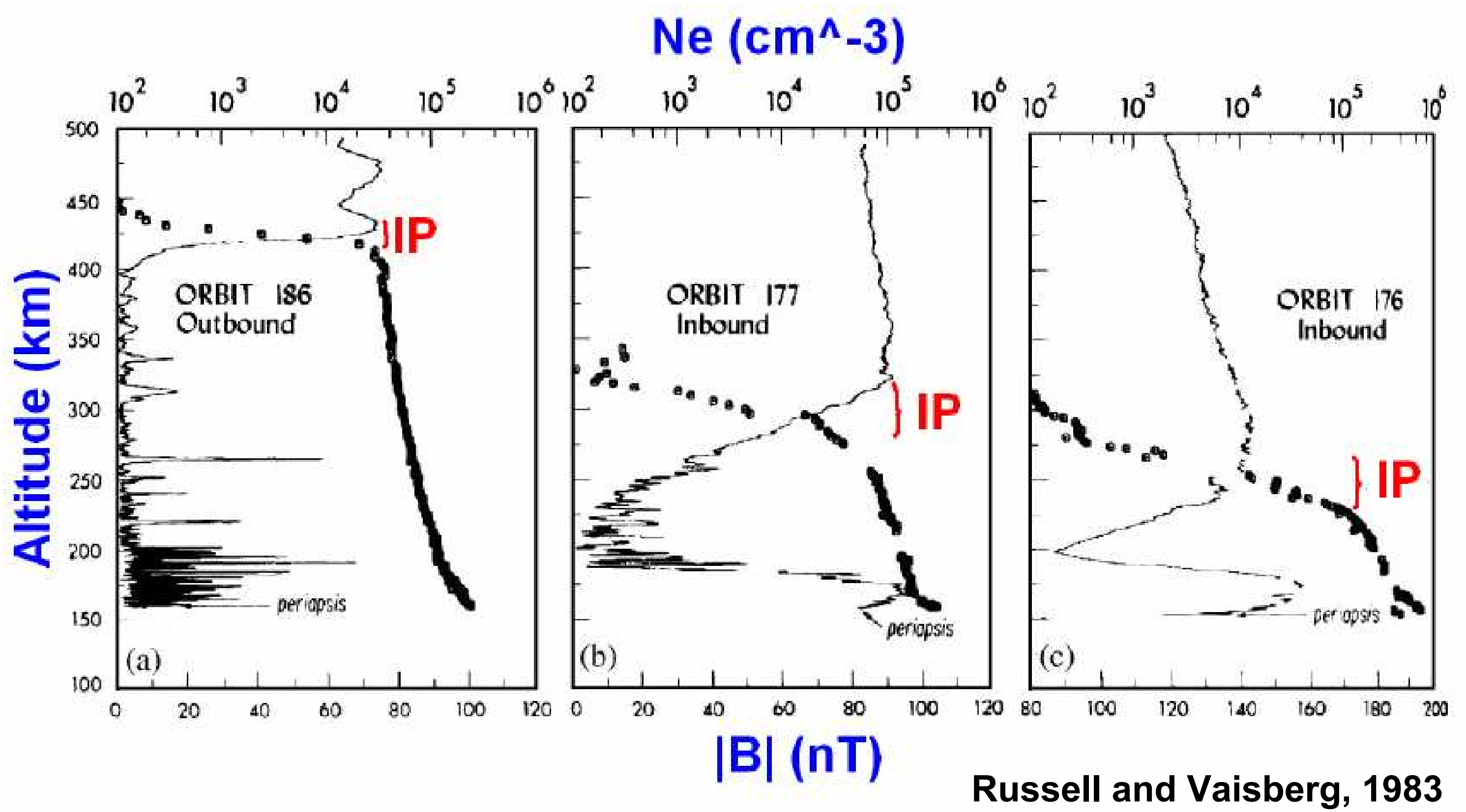


External pressure: nv^2

Ionosperic pressure: nkT

Magnetic pressure: B^2

Pioneer Venus Orbiter was dedicated plasma satellite



Russell and Vaisberg, 1983

At the Venus ionopause PVO could prove balance between exterior magnetic (B^2) and interior thermal (nkT) pressure.
Interestingly the ionosphere at Venus shows different states of magnetization.

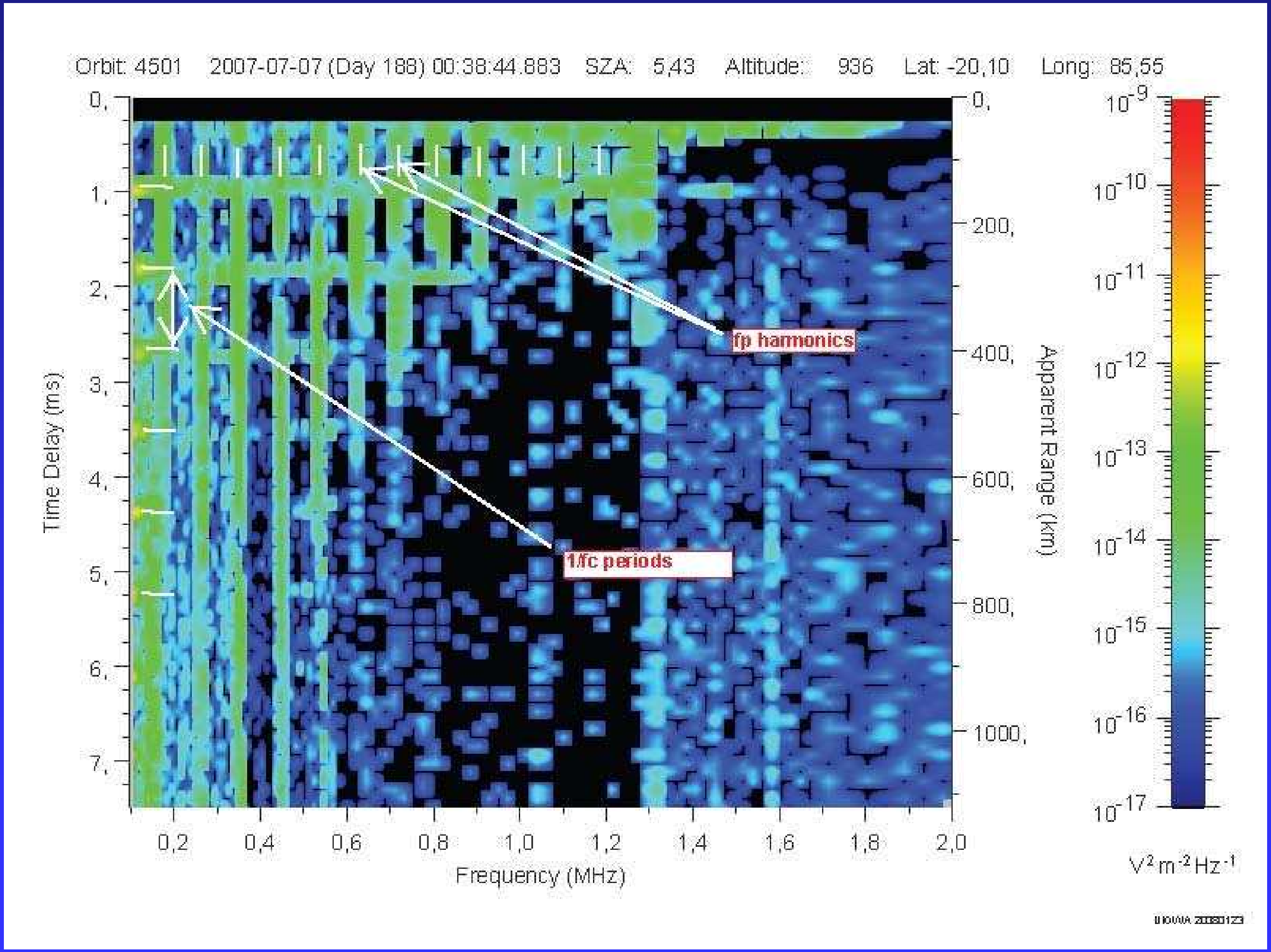
Situation at Mars

Previous Mars missions were limited by instrumental and orbital contraints in determining pressure balance.

Mars Express has good orbital coverage but no magnetometer and no cold plasma sensor

How can you determine pressure balance?

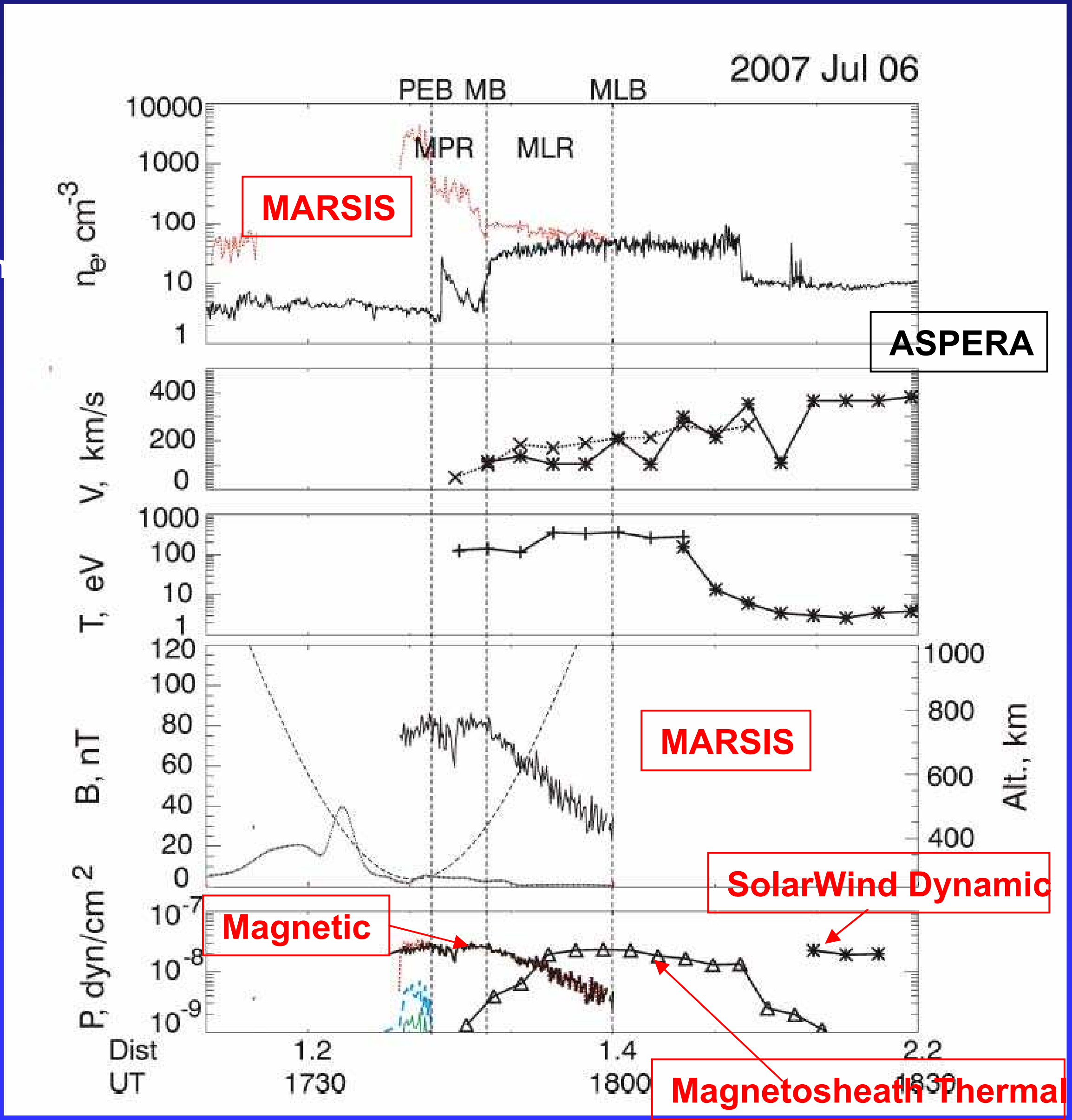
Combining MARSIS radar and ASPERA data



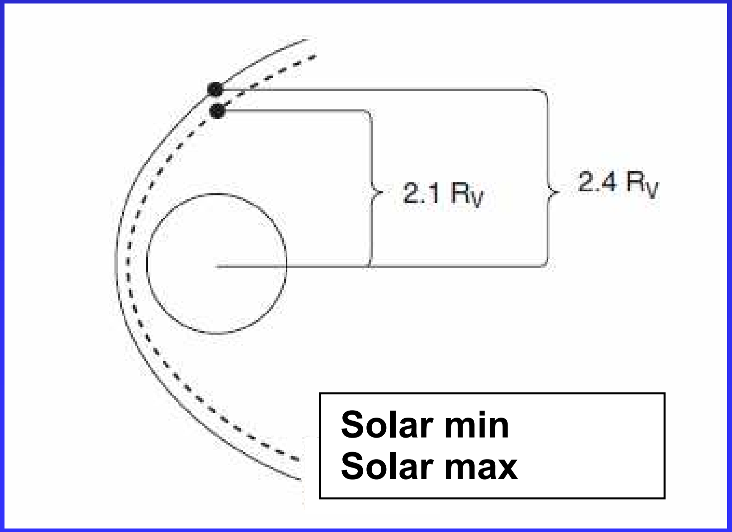
Pressure Balance
Solar Wind - Ionopause

Combined MEX MARSIS&ASPERA3 observations show that solar wind dynamic pressure is balanced by magnetosheath thermal and MB magnetic pressure. The induced field penetrates ionopause.

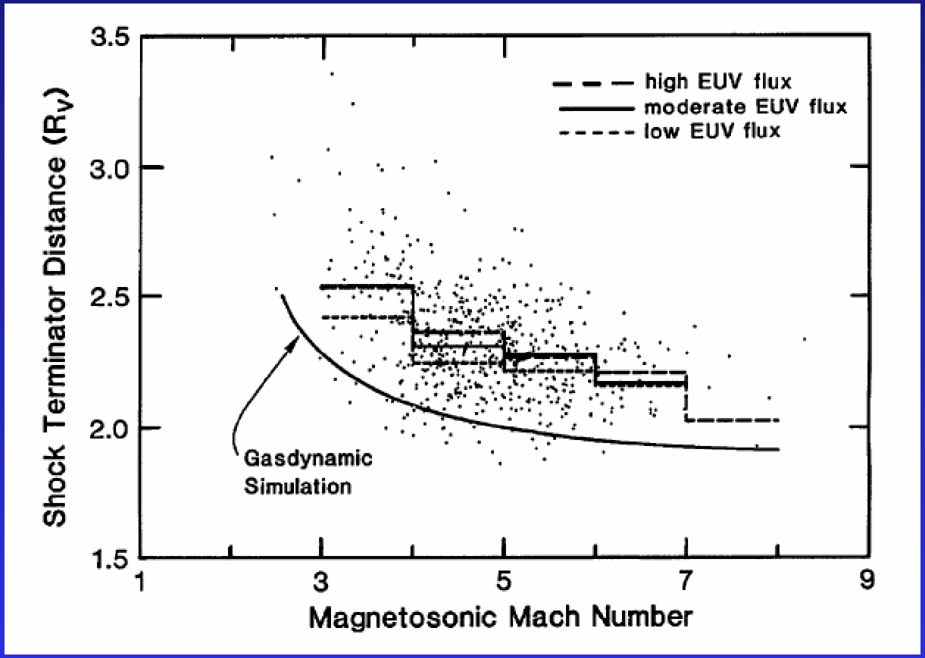
Dubinin et al., GRL 2008

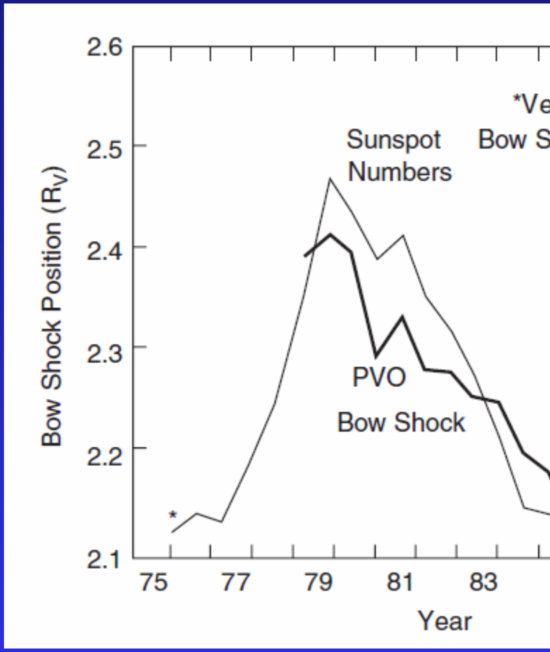


How do induced magnetospheres change with solar activity?



Variations in Venus bowshock location





Russell 2006

Main effect on bow shock position is by solar wind magnetosonic Mach number: $V_{SW} / \sqrt{V_A^2+V_S^2}$
Because position is determined by wave propagation backwards from the obstacle (magnetopause).
Secondary effect is by increase of exosphere by higher solar EUV flux.

Venus and Mars
Induced Magnetospheres
Summary

The interest in the induced magnetospheres of Venus and Mars is based on the large differences in atmospheric evolution of the terrestrial planets.

Measurements of the thermal escape indicate that only at Mars hydrogen can escape in significant amounts via the exosphere.
This indicates that magnetospheric escape must be important.

The ASPERA experiments on Mars and Venus Express deliver for the first time synchronous measurements of planetary ion escape at low energies.

First estimates of the total ion escape show values of
for Venus: 10^{25} ions/s (7.6 t/day)
for Mars: 3 $\times 10^{24}$ ions/s (6.6 t/day)
Current escape ratios H/O are 2.2 for Venus and 20 for Mars,
indicating a steady oxidation state for Venus and ongoing soil-oxidation for Mars.

To understand the physical processes relevant in induced magnetospheres determining plasma bulk parameters is essential:
kinetic, thermal, magnetic pressure
local magnetic structure, induction processes
dependence on solar activity

Topics not covered in this talk

- Role of plasma sheet (global magnetic configuration)
- Kelvin-Helmholtz instabilities at the magnetopause
- Effects associated with crustal magnetization at Mars
- Magnetic flux tubes entering the ionosphere
- Reconnection of field lines
- How far does the magnetspheric tail reach?
- ....