Mars-solar wind interaction : coupling between hybrid, ionospheric, thermospheric and exospheric models

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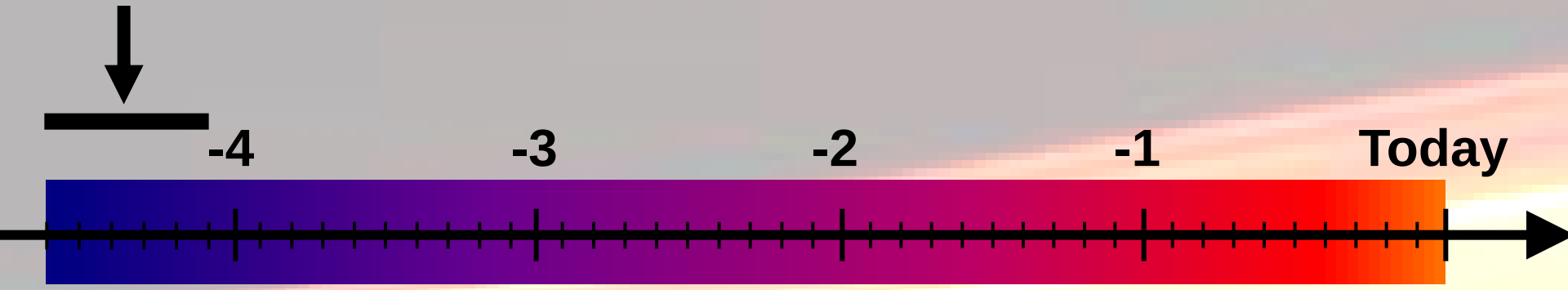
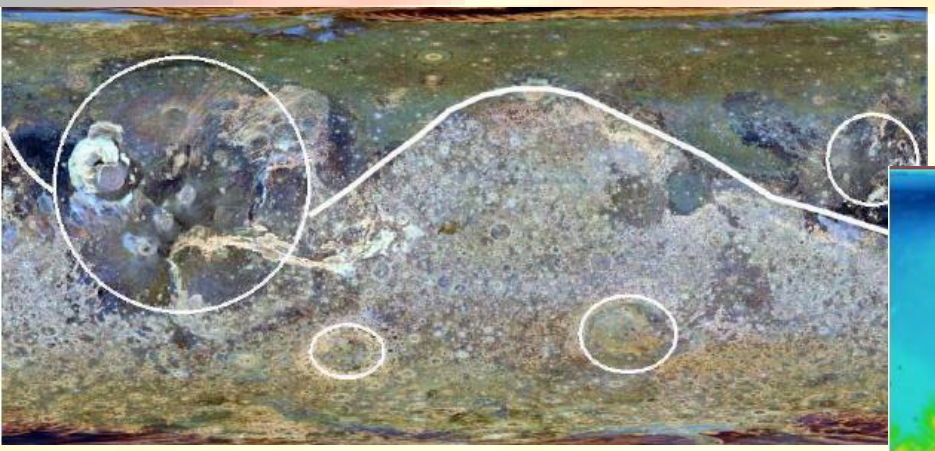
What do we know on Mars?

HELIOSARES

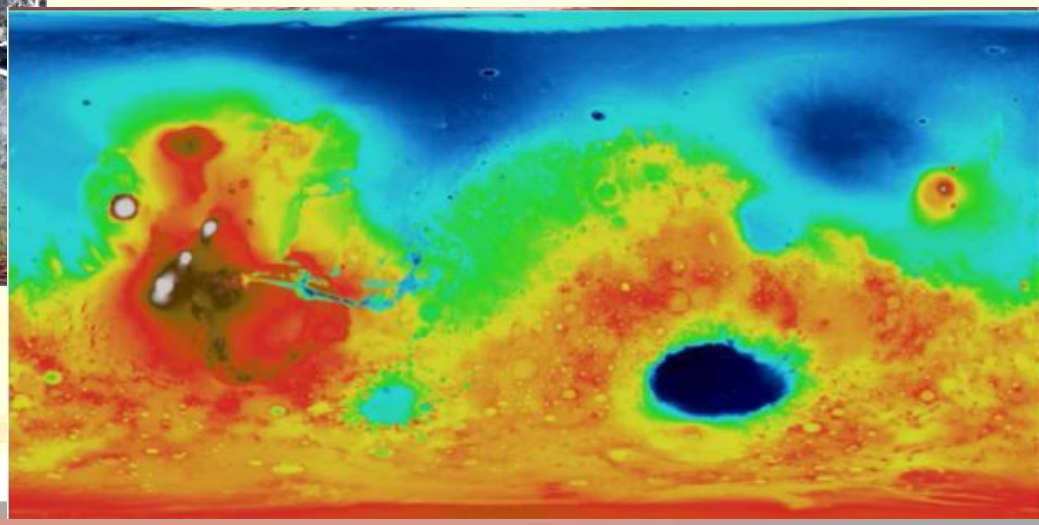
Volcanism & Giant impacts
(origin of the North/South dichotomy)



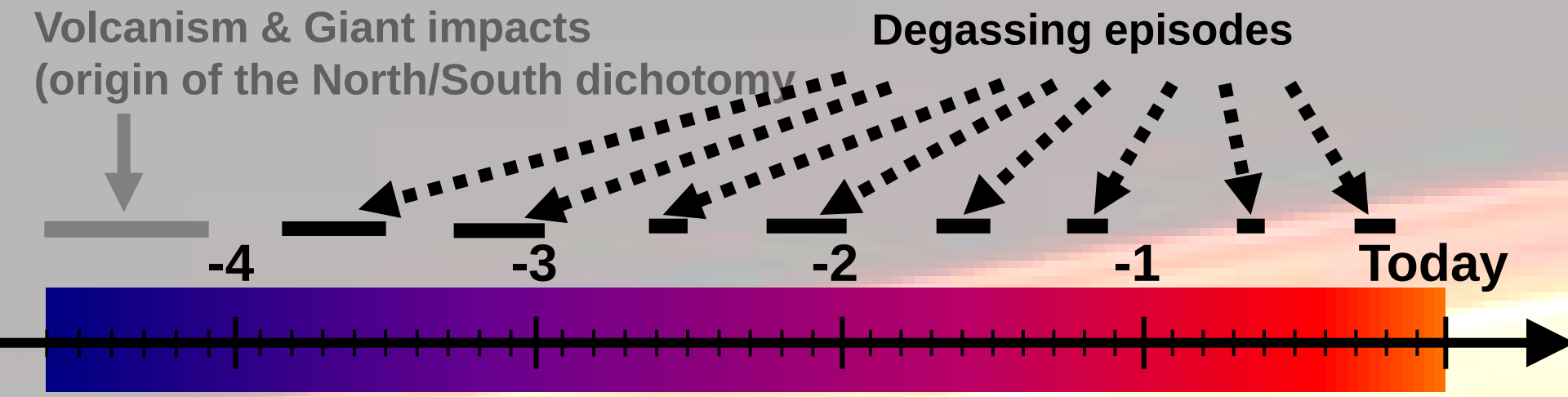


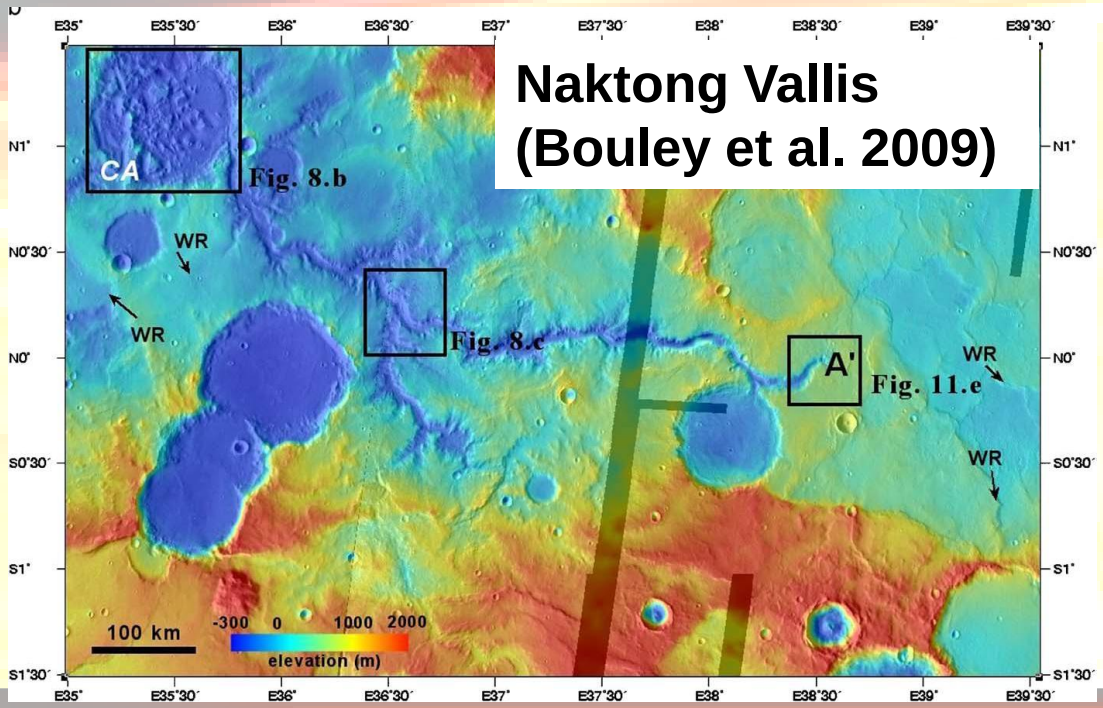
Surface rugosity
(Kreslavsky and Head 2000)

Surface altimetry
(MOLA/MGS)



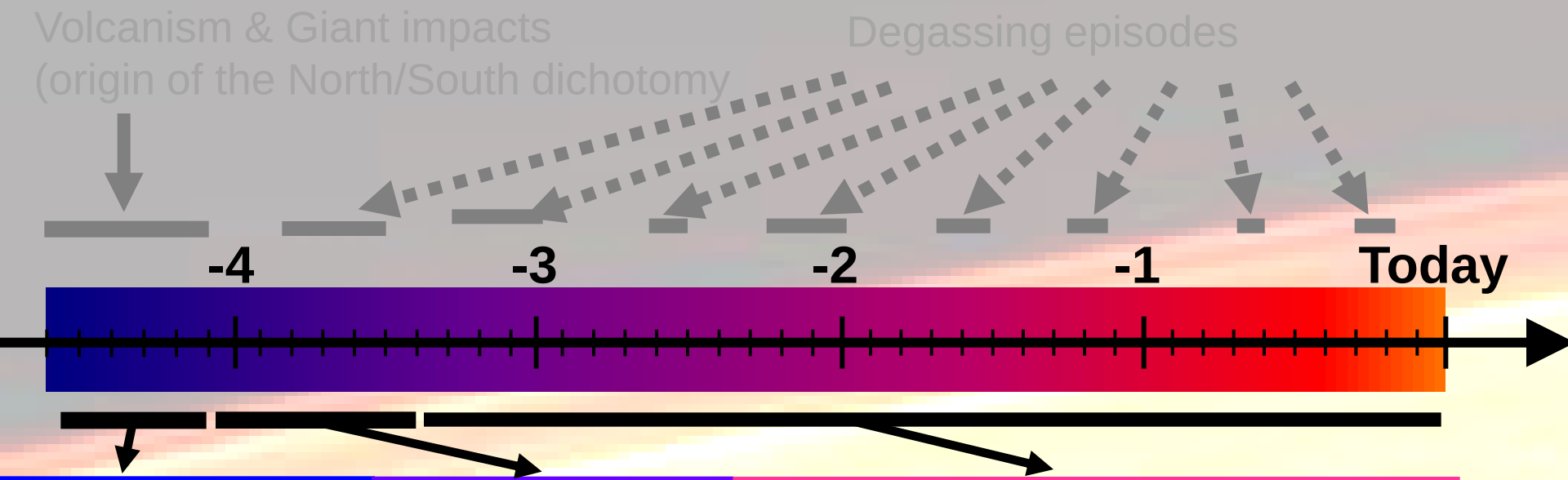
What do we know on Mars?





Beginning Hesperian, still fluvial activity (periodic few hundred mb atmosphere…)

What do we know on Mars?



Liquid water at the surface Nonacidic period Phyllosilicate formation

Liquid water at the surface Acidic period Sulfate formation

No liquid water permanently at the surface Anhydrous ferric oxyde formation

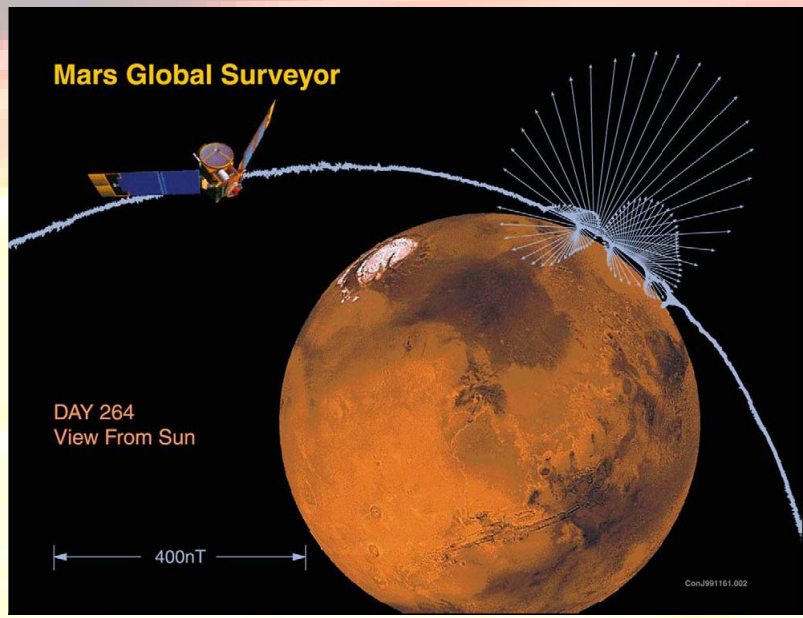
From Bibring et al. (2006)

4.1 Gyr ago: a major change at Mars

Mars Global Surveyor (1999 - 2006):

First mapping of Mars magnetic environment (Acuňa et al. (1999)

⇒ Discovery of a remanent magnetic field



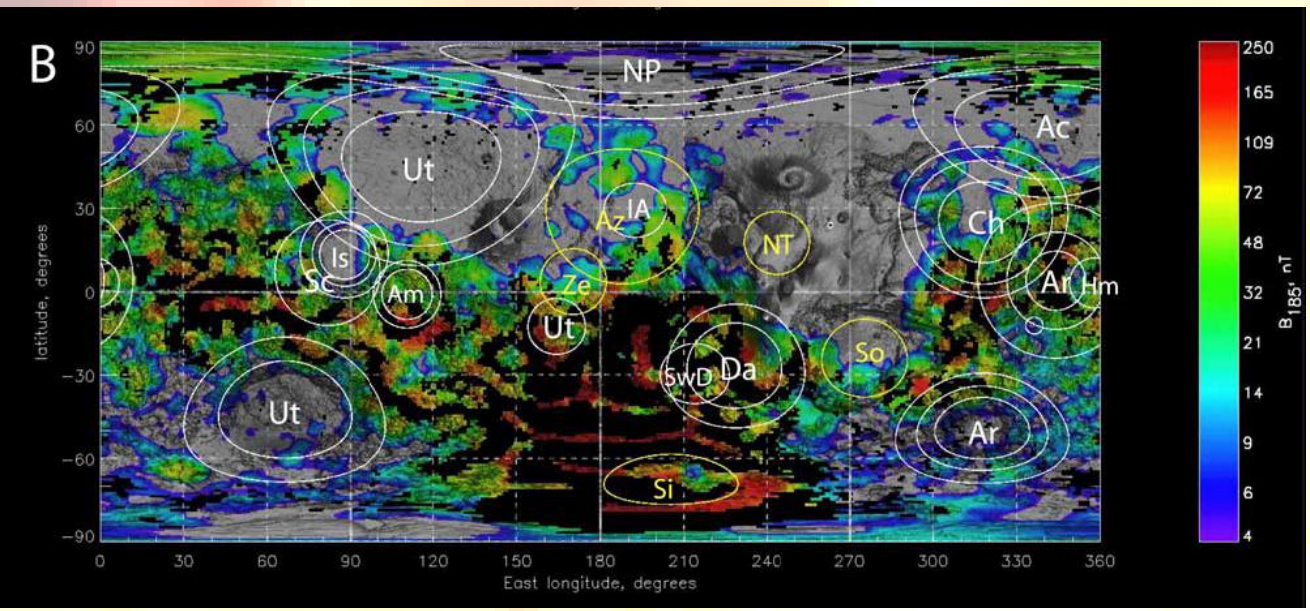
Magnetic field measured along MGS orbit (Connerney et al. 2004)

4.1 Gyr ago: a major change at Mars

Mars Global Surveyor (1999 - 2006):

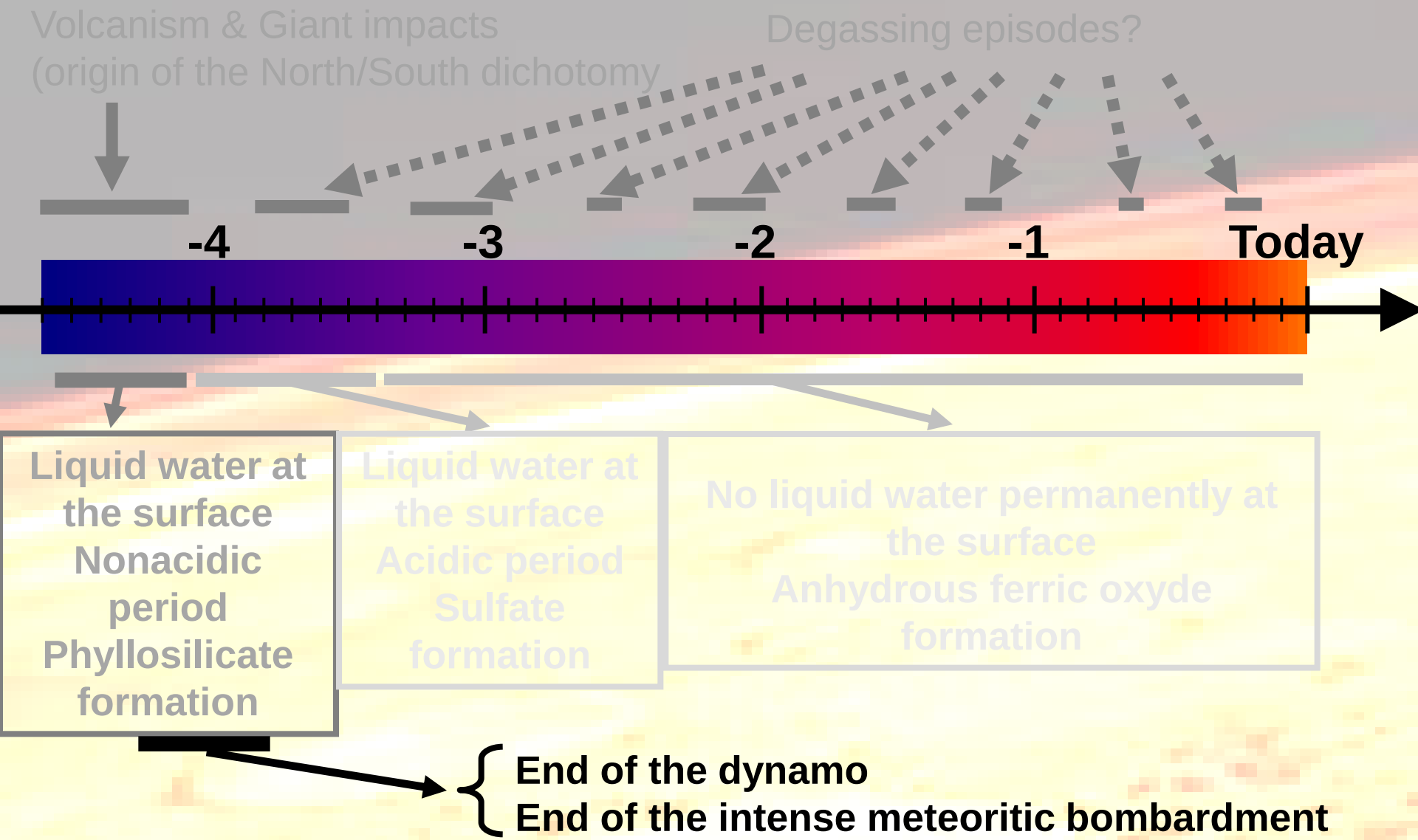
⇒ There was an active dynamo 4.11 – 4.13 Gyr ago

⇒ Correlated with the last large impacts (>1000 km)



Radial component of the B field deduced from electron measurements (Lillis et al. 2008)

Where did go Mars' atmosphere?



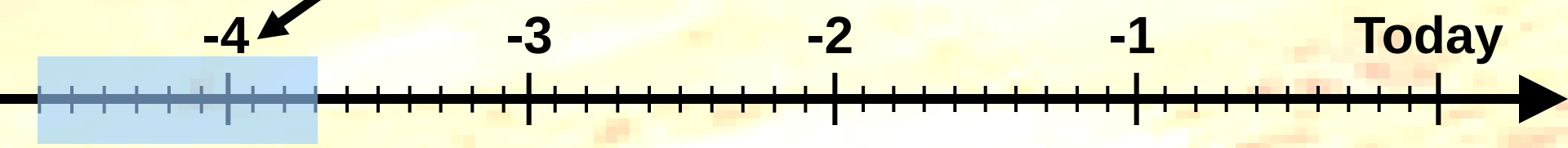
Our Sun was also much different than today…

Young SUN: 30% less radiating than today
(and 10% more radiating in 1 billion years)

BUT

First 0.5 – 1.0 Billion years = Active phase of young Sun

- **EUV/UV flux ~ 30 times higher**
- **Solar wind: 100-1000 times larger flux (?)**



An intense past atmospheric escape?

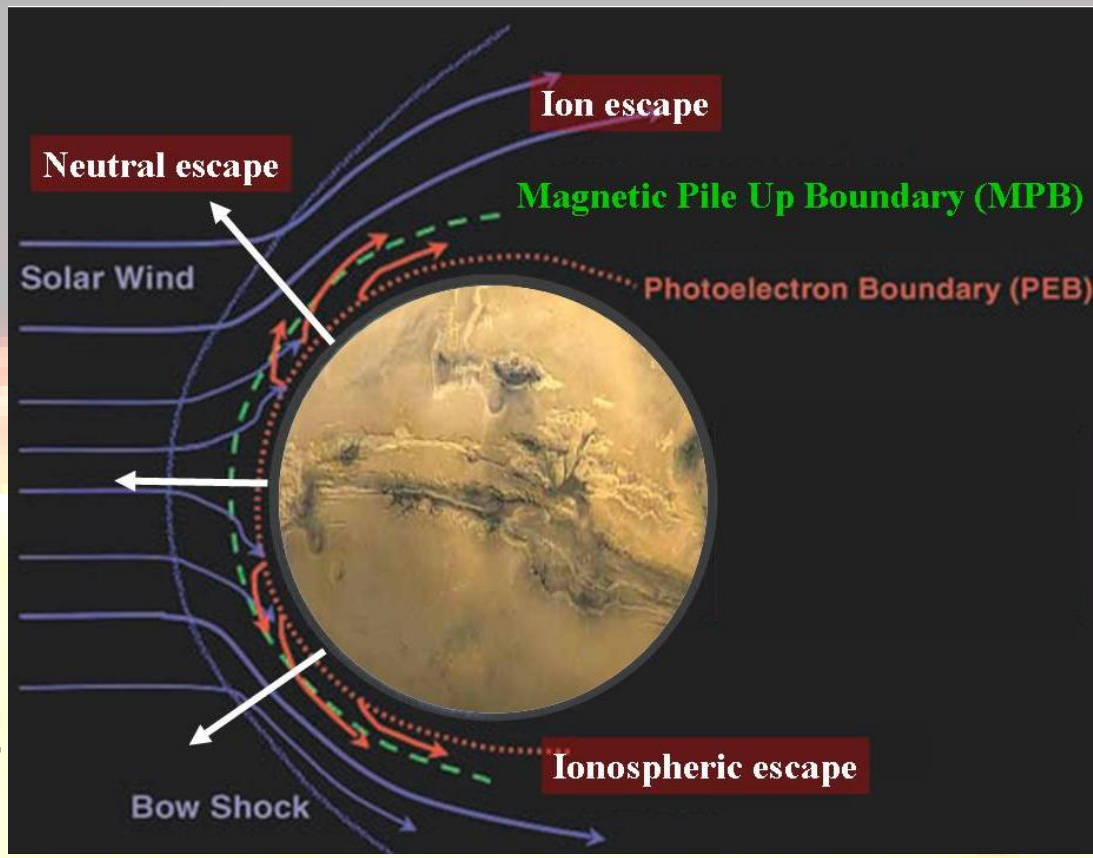
TODAY

Ion Escape

2 to 4 millibars of CO_2
+ few tens of cm of H_2O
during the last 3.5 Gyr
(ASPERA-3/MEX)

Neutral Escape

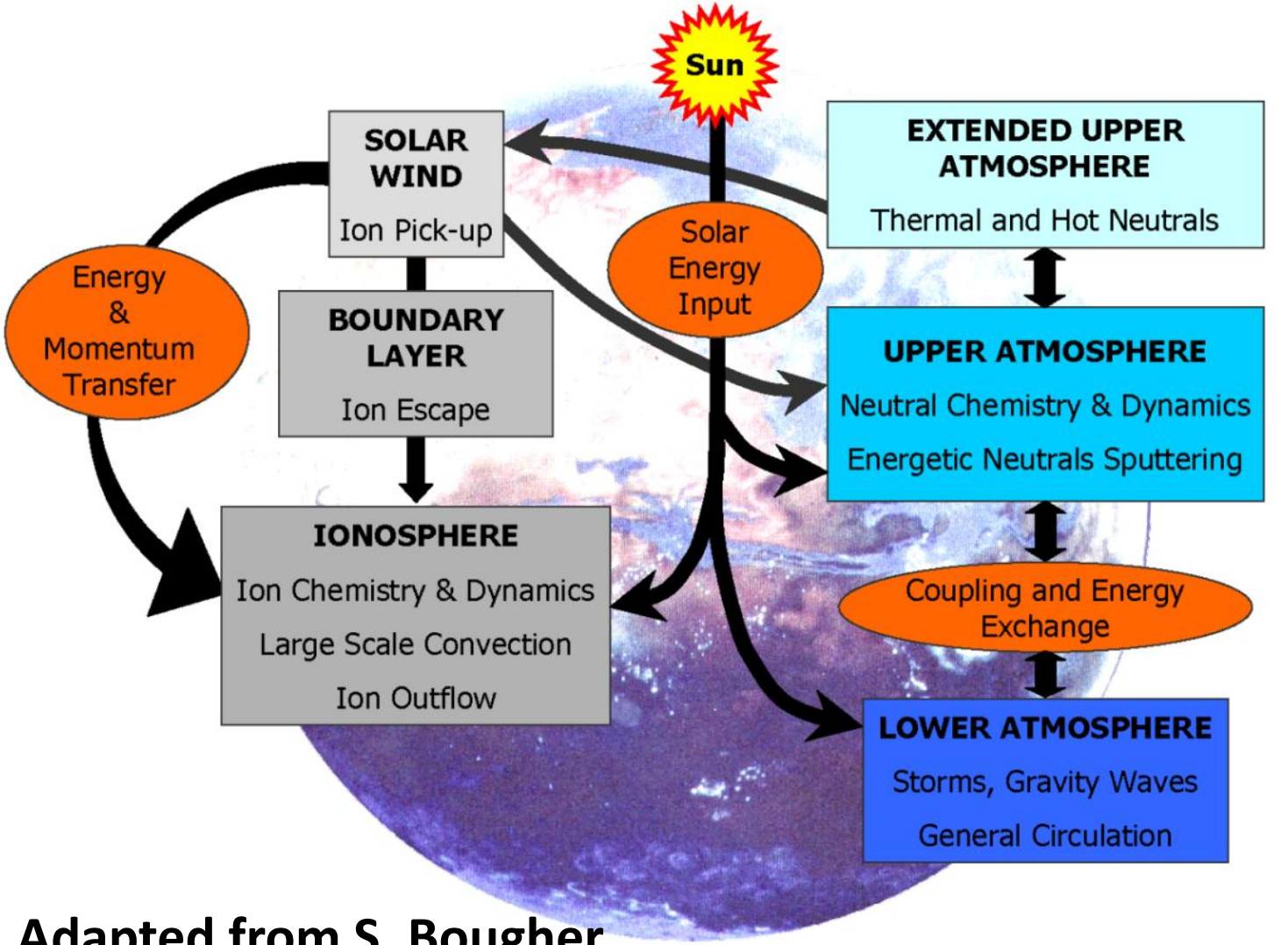
No direct measurement
but only indirect clues
(ALICE/ROSETTA)



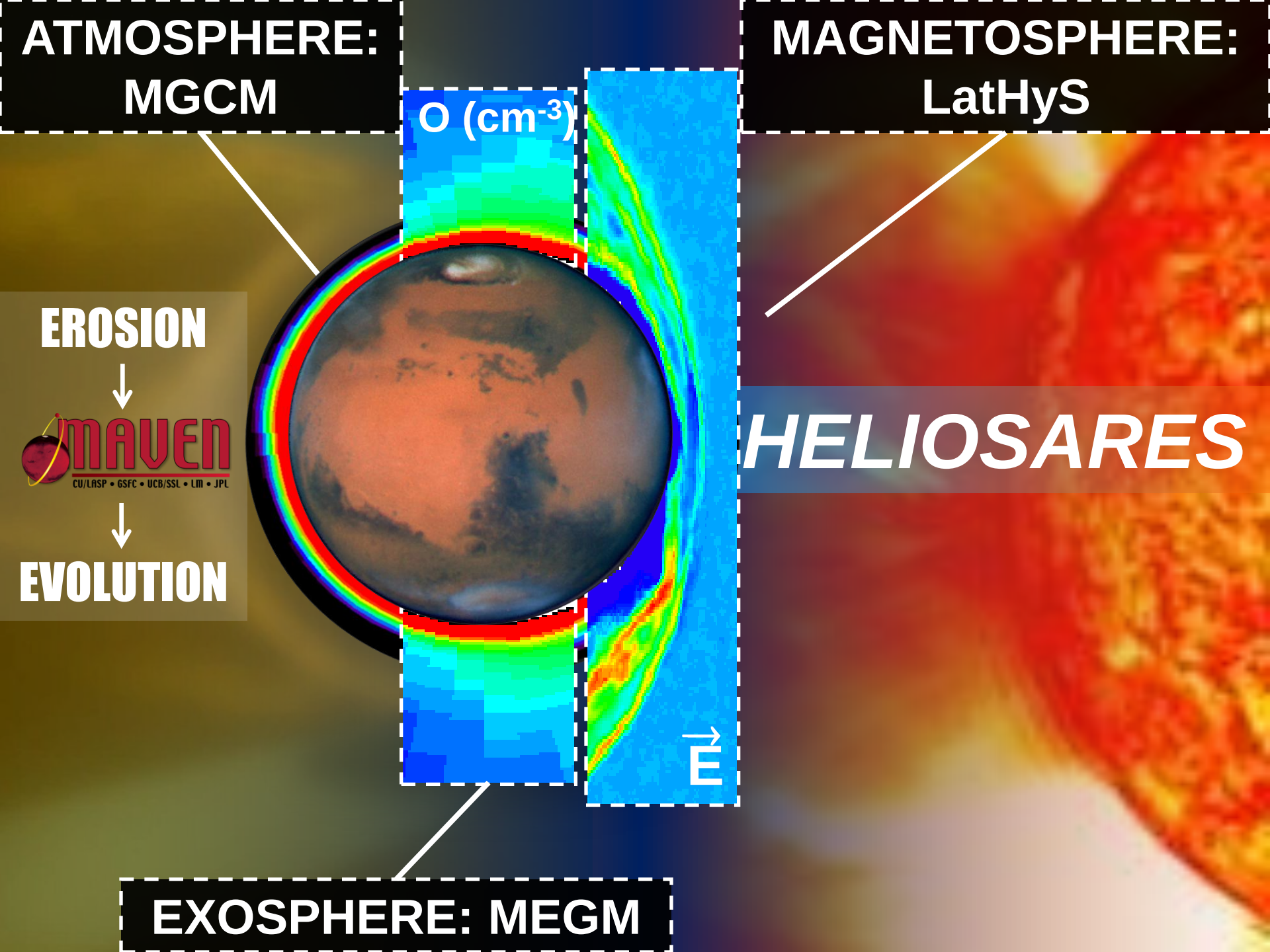
Lundin et al. 2004

⇒Present escape is small

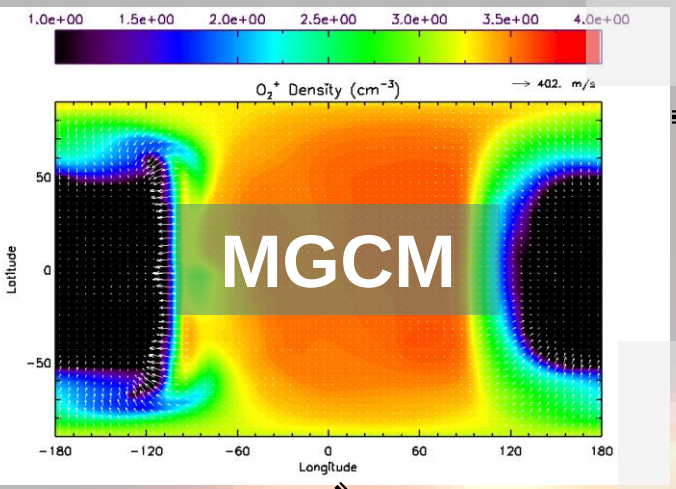
To extrapolate to the past, you need to describe

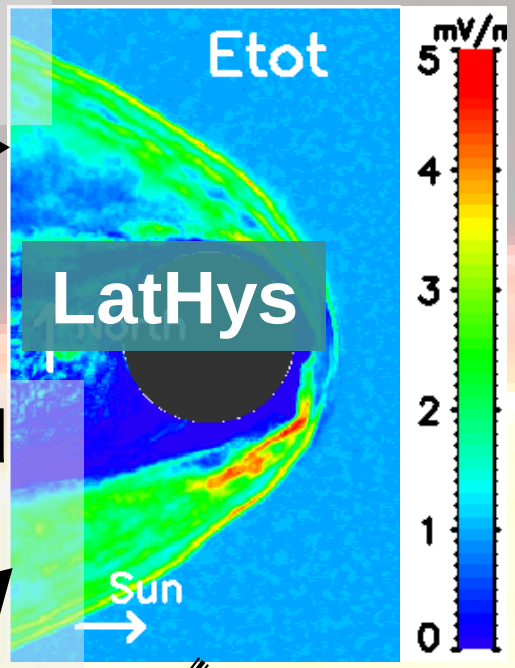


Adapted from S. Bougher


ATMOSPHERE:
MGCM
MAGNETOSPHERE:
LatHyS
O (cm-3)
EROSION
MAVEN
CU/LASP • GSFC • UCB/SSL • LM • JPL
EVOLUTION
HELIOSARES
E
EXOSPHERE: MEGM

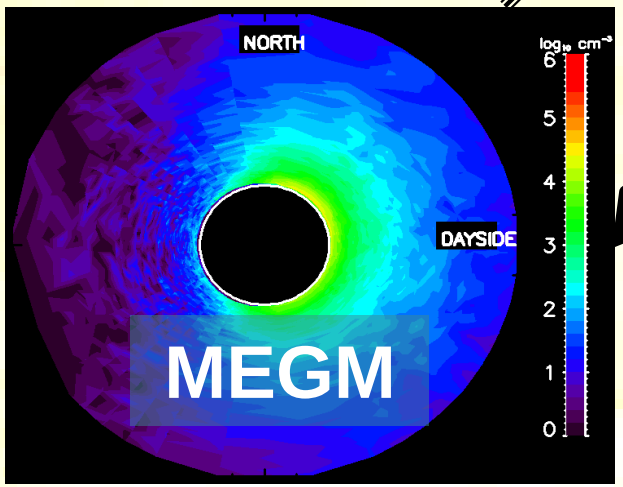
Use to mass-load the solar wind (ionosphere)





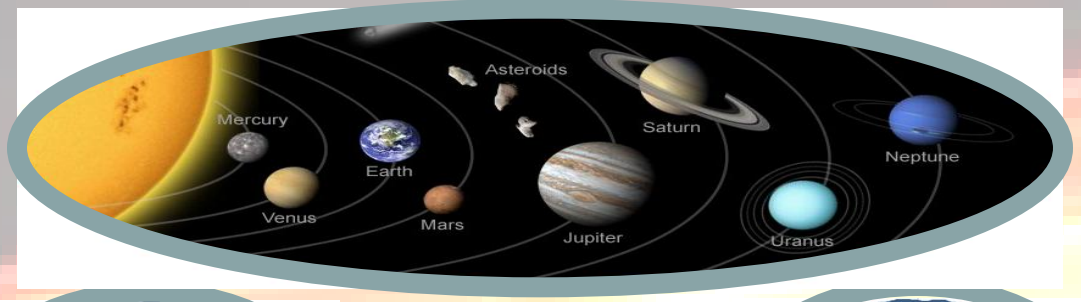
Use to mass-load the solar wind (exosphere)

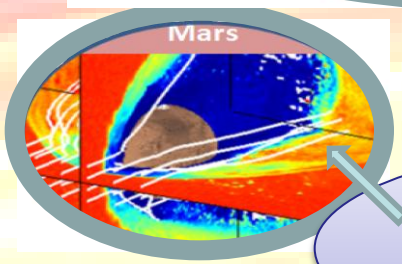
Use to reconstruct the exosphere

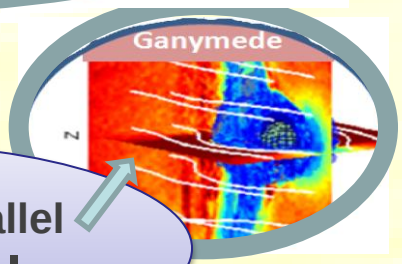


Use to reconstruct precipitation

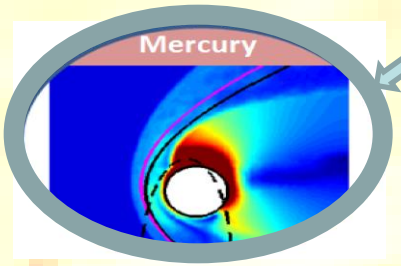
A generic 3D multi-species parallel hybrid model dedicated to plasma interaction with solar system objects

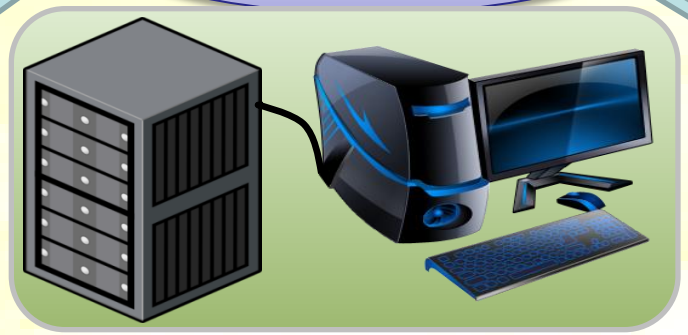


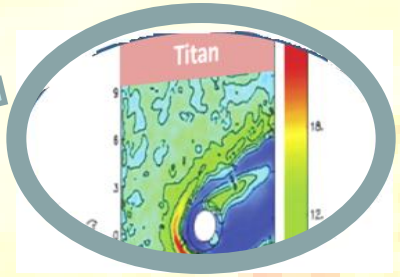




Generic 3D parallel Hybrid Model



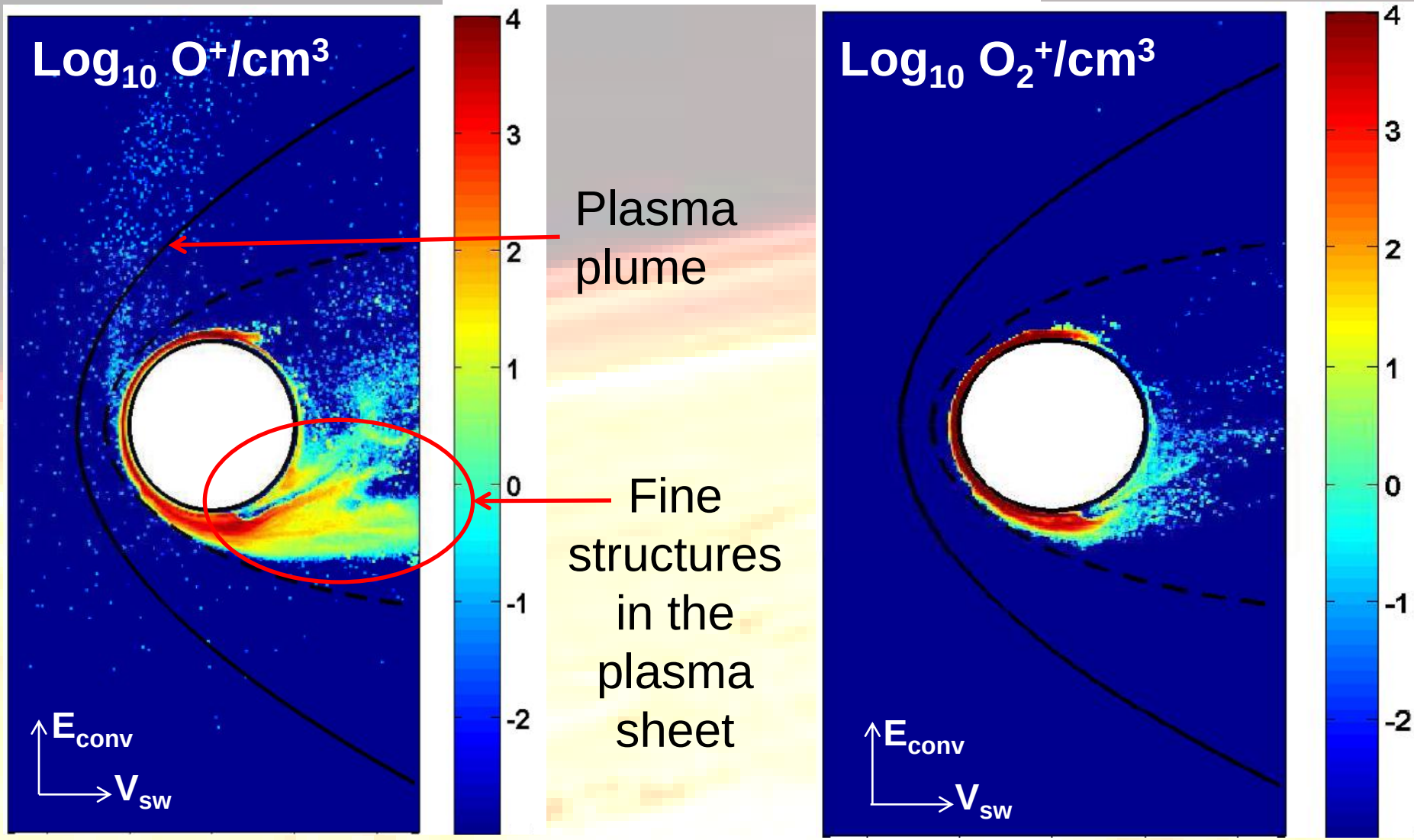


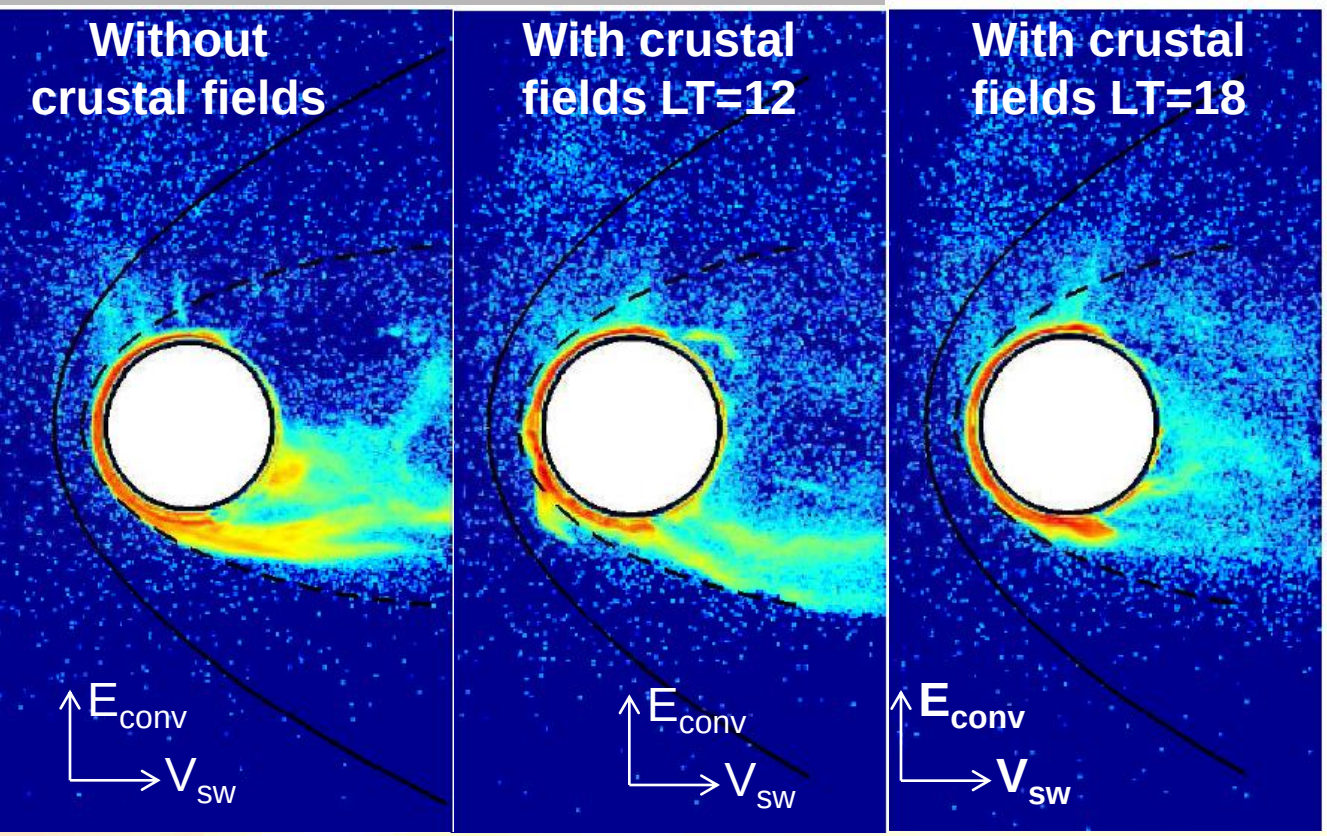


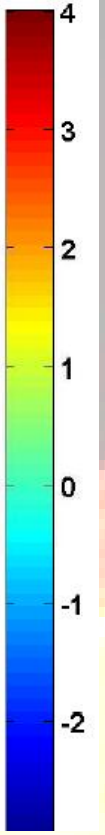
Magnetospheric simulation coupled with 3D exosphere and thermosphere

HELIOSARES

High resolution Δx=Δy=Δz=60km







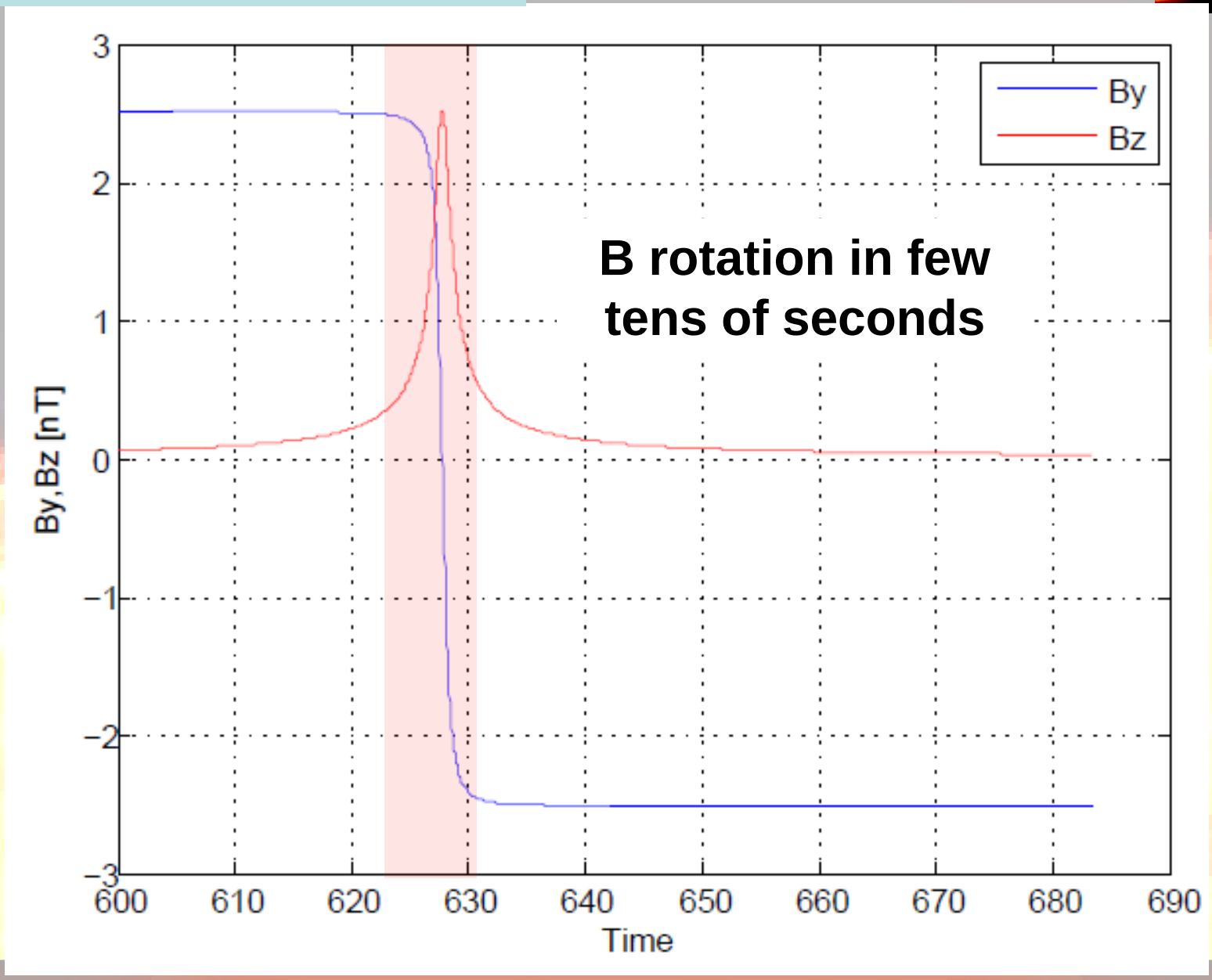
Log_{10} O^+/cm^3

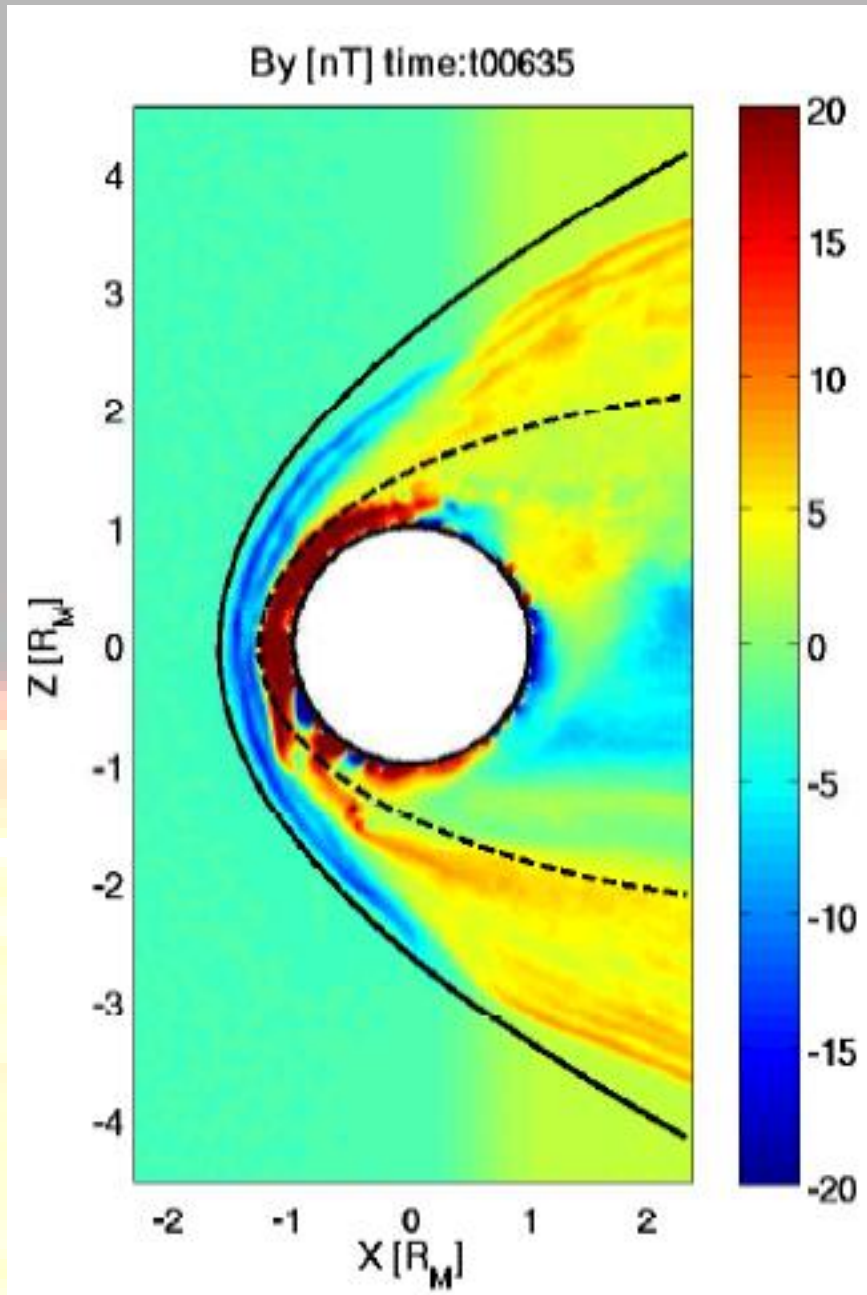
$\Delta x=\Delta y=\Delta z=80km$

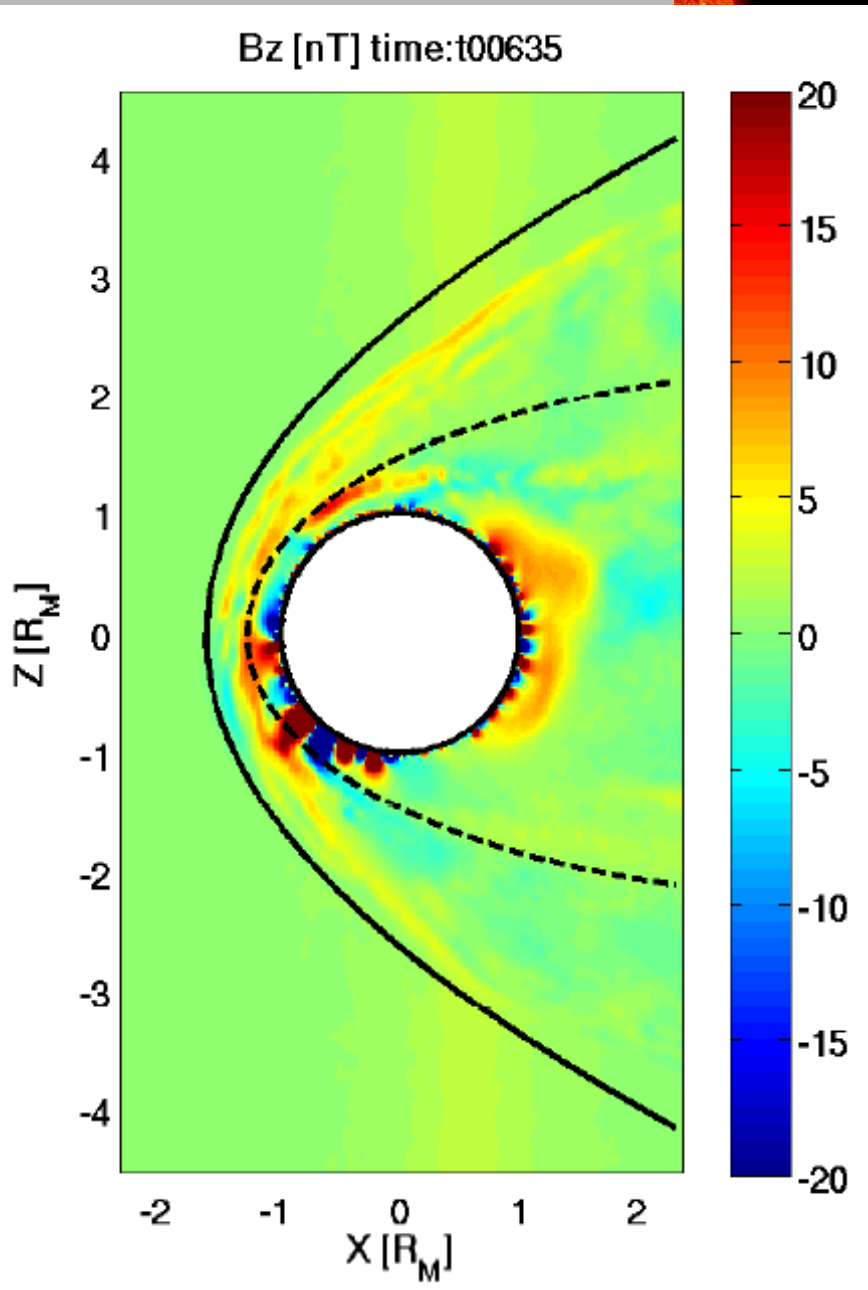
Solar maximum

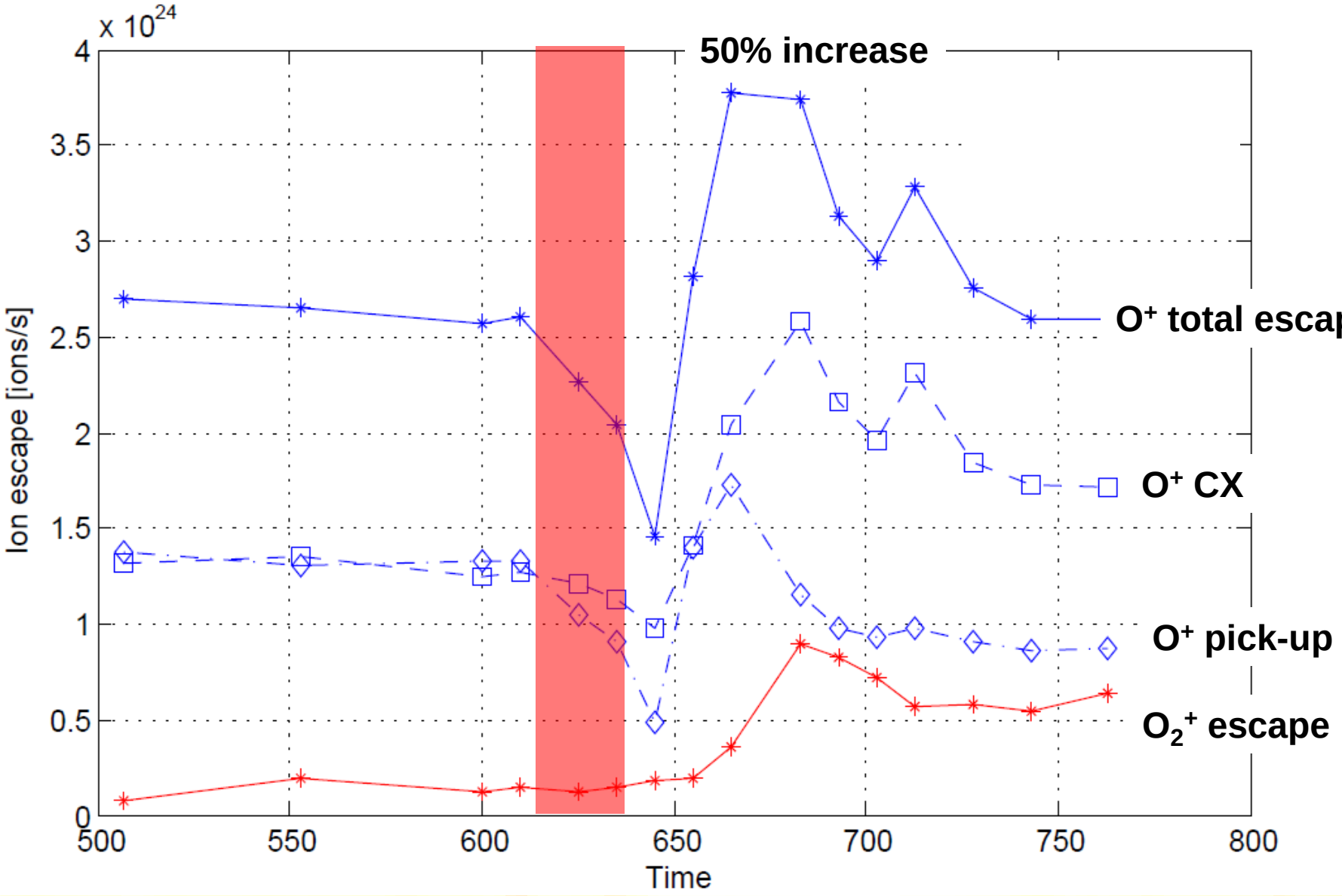
- BS position seems not affected by crustal fields
- MPB is locally affected
- Plasma sheet density and structure modified by CF.
- « Ionopause » higher in dayside close field lines region
- Up to 20% decrease in escape rates due to CF presence

Time Variations

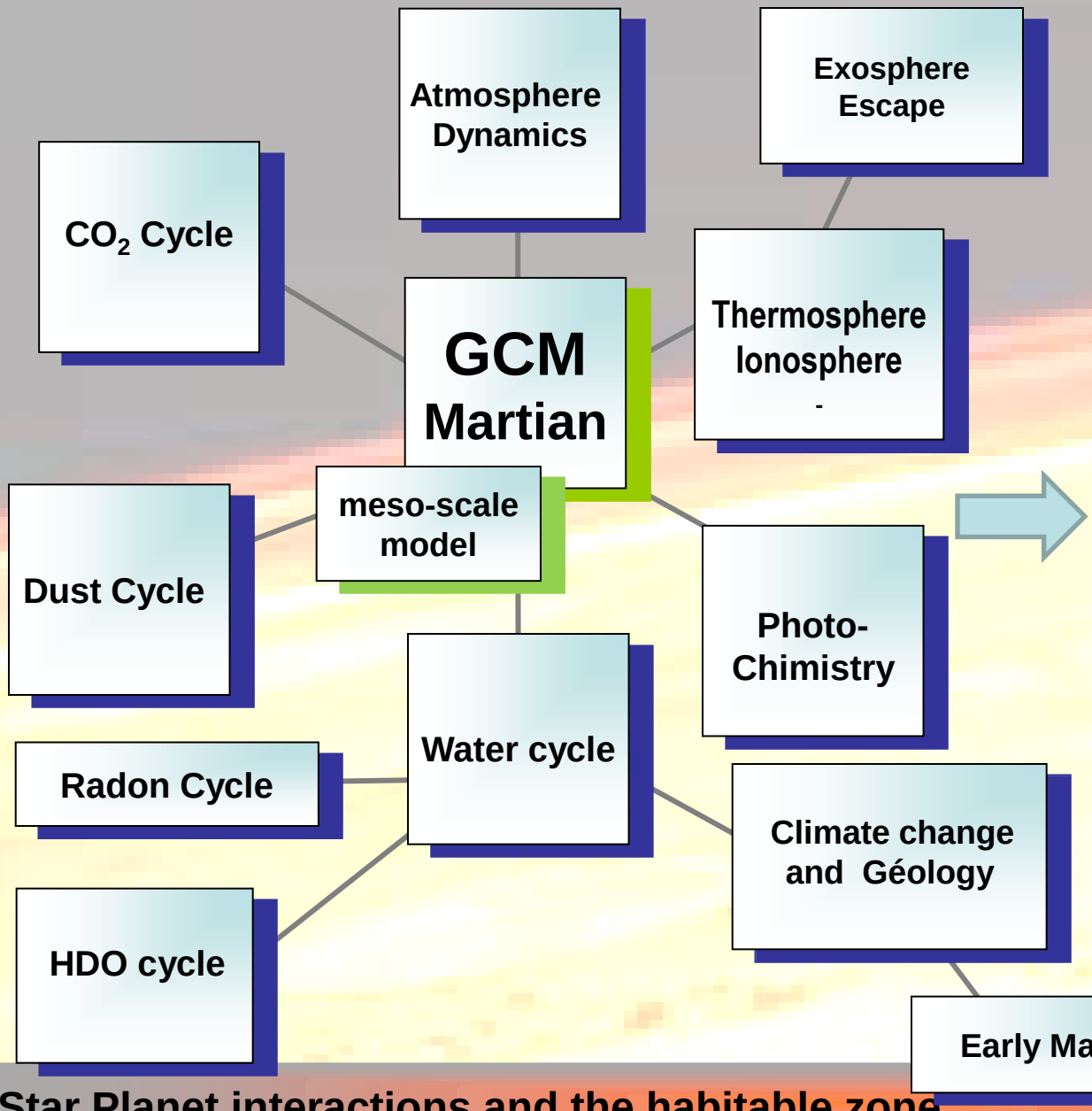



By [nT] time:t00635
Z [R_M]
X [R_M]
4
3
2
1
0
-1
-2
-3
-4
-2
-1
0
1
2
20
15
10
5
0
-5
-10
-15
-20


Bz [nT] time:t00635
Z [R_M]
X [R_M]
4
3
2
1
0
-1
-2
-3
-4
-2
-1
0
1
2
20
15
10
5
0
-5
-10
-15
-20


x 10^24
50% increase
O+ total escape
O+ CX
O+ pick-up
O2+ escape
Ion escape [ions/s]
Time
0
0.5
1
1.5
2
2.5
3
3.5
4
500
550
600
650
700
750
800

Ionospheric description (LMD-GCM)



« Mars Climate database »

- Reference tool for community
- Version « pro » on DVD-ROM commanded by ~150 teamss in ~20 pays
- Interactive website

Ionospheric description (LMD-GCM)

- Photochemistry (production, loss) (Instituto de Astrofisica de Andalucia) ~ 90 réactions
- Atmospheric transport
- Ions dynamics (multifluid approach)

Possibility to choose which ions are described dynamically

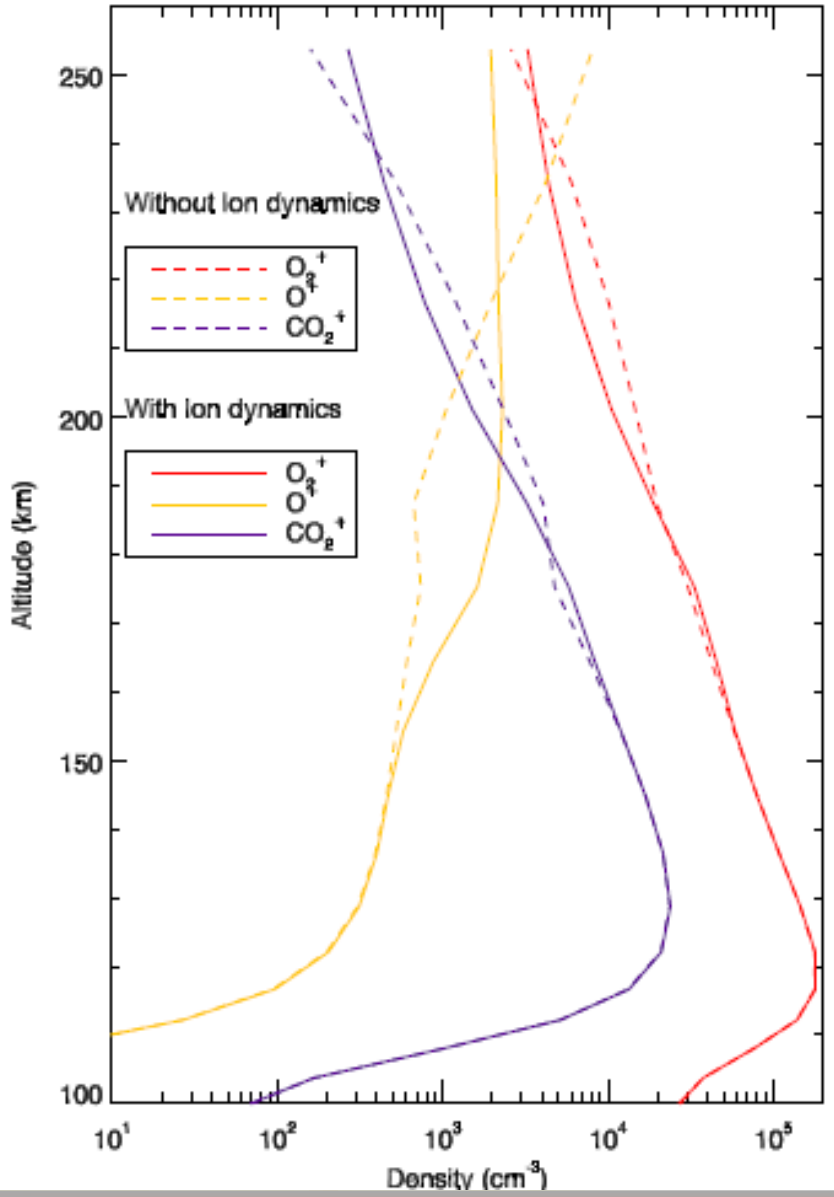
  - O_2^+ ; O^+ ; CO_2^+ ; C^+ ; N^+, NO^+

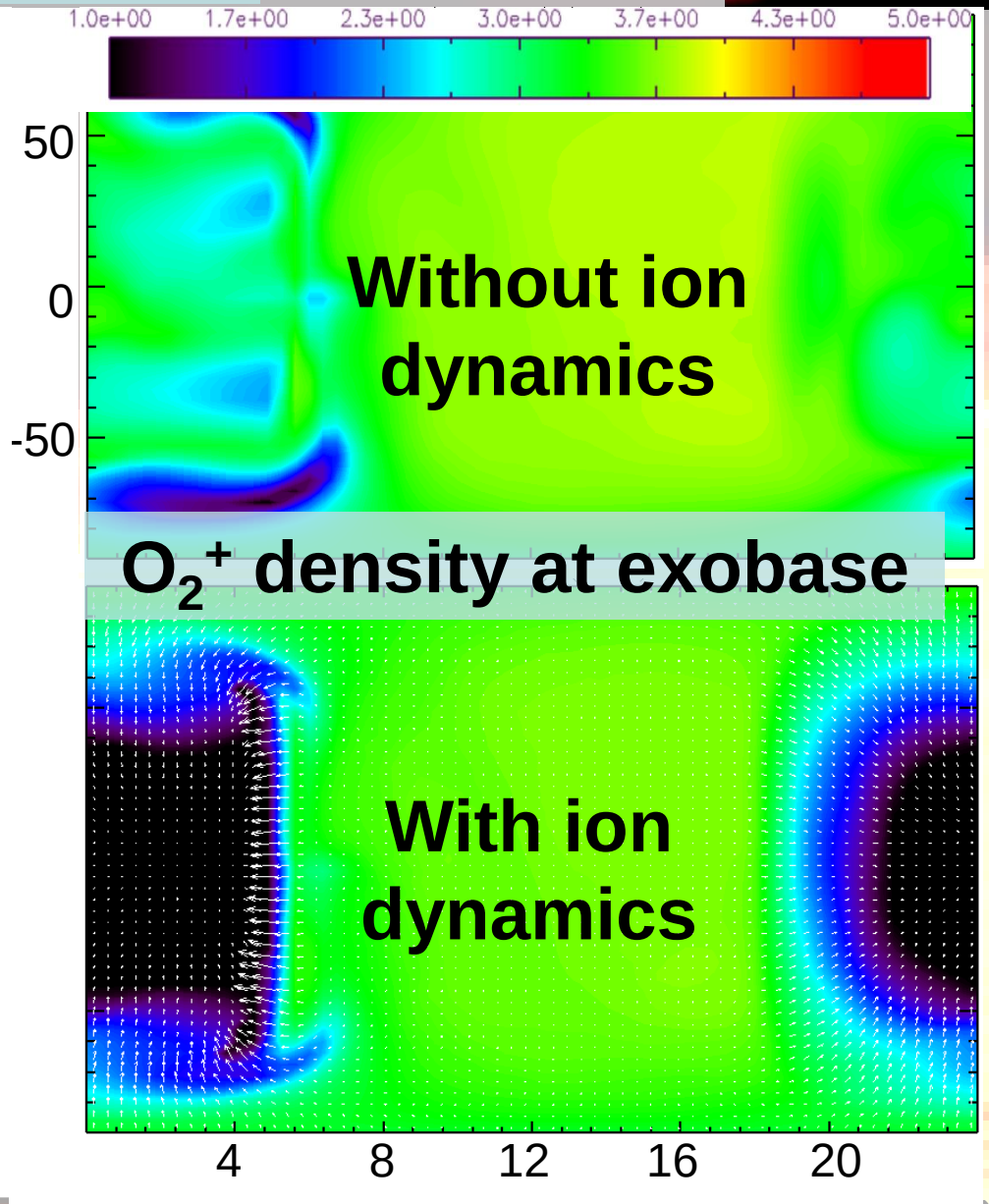
- Ion-Neutral Rétroaction
- Ambipolar E field

Processes not included yet

- Ionospheric currents and magnetic fields
- Energy equation

Effects of ions dynamics

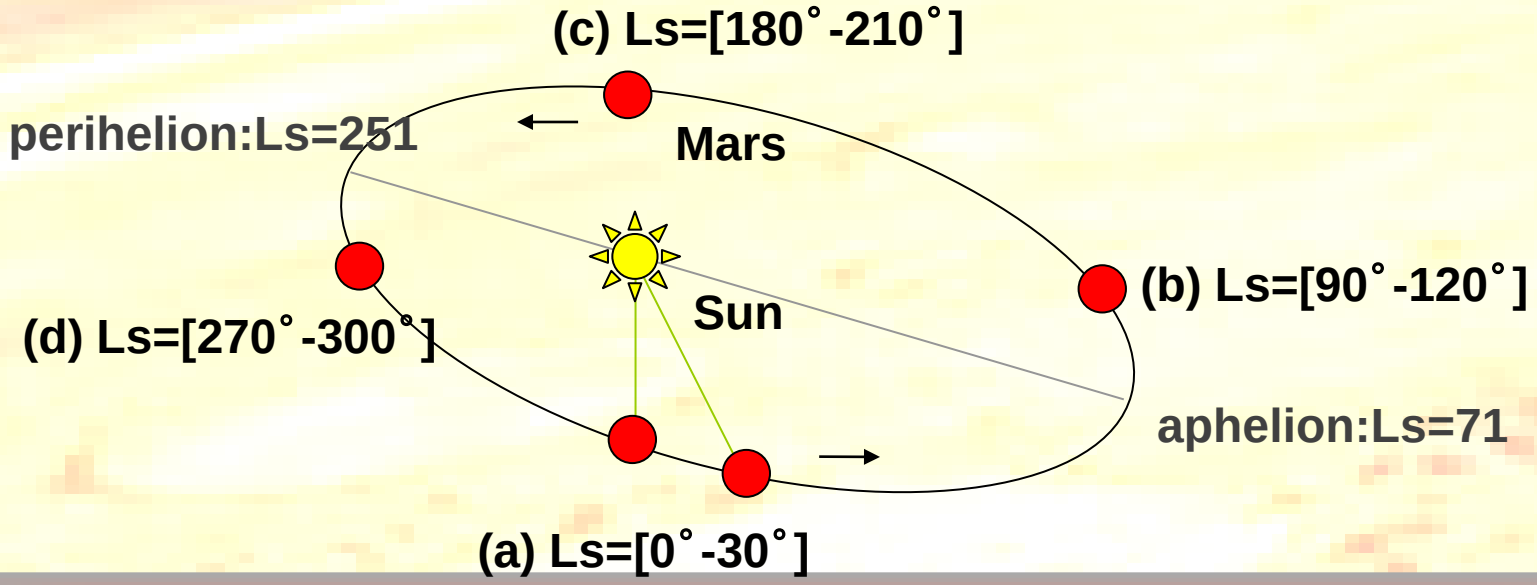




Exospheric description (MEGM)

I Thermal component

- Thermal exospheric density from velocity distribution at the collisional - collisionless boundary (from a critical altitude = ~200 km in altitude).
- Density and Temperature of O, CO and CO_2 at 200km from Martian GCM [Chaufray et al. 2014].



Exospheric description (MEGM)
II Non-thermal component: DR

- Main source of hot oxygen is O_2^+ dissociative recombination

  $O_2^+ + e- \rightarrow O^* + O^*$ [Chaufray et al., 2007].

- O_2^+ profile from Martian GCM [Chaufray et al. 2014]

  $CO_2^+ + O \rightarrow CO + O_2^+$,

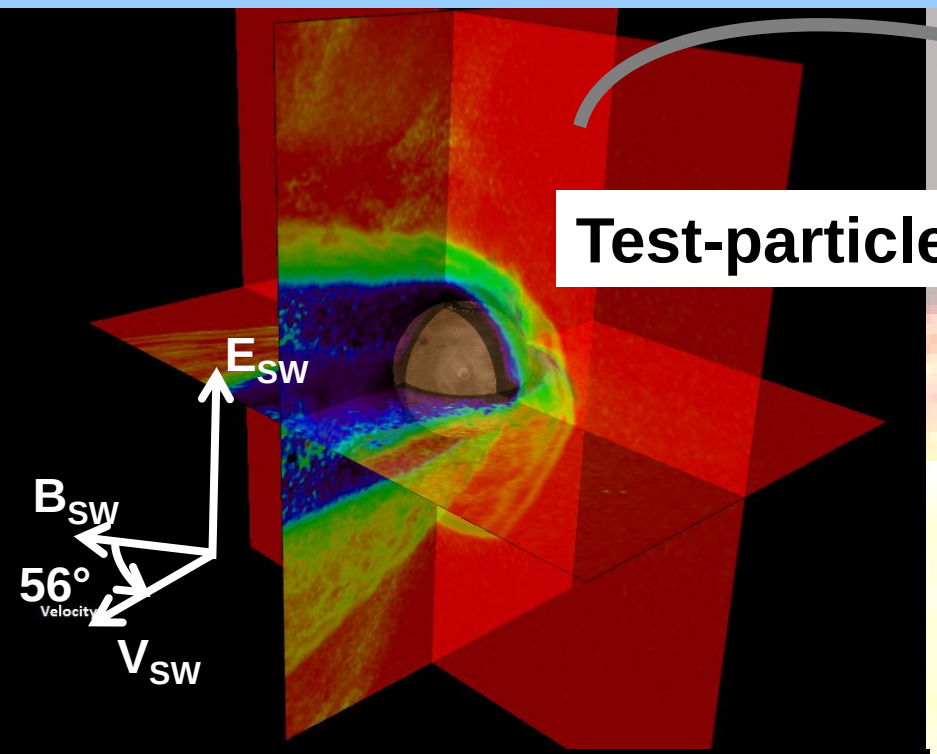
  $CO_2^+ O+ \rightarrow CO + O_2^+$

- Collisions between hot O and O background atmosphere (from O and CO_2 derived by GCM) simulated from 120km to ~300km.

$\Rightarrow$Products could be all atmospheric species

Exospheric description (MEGM)

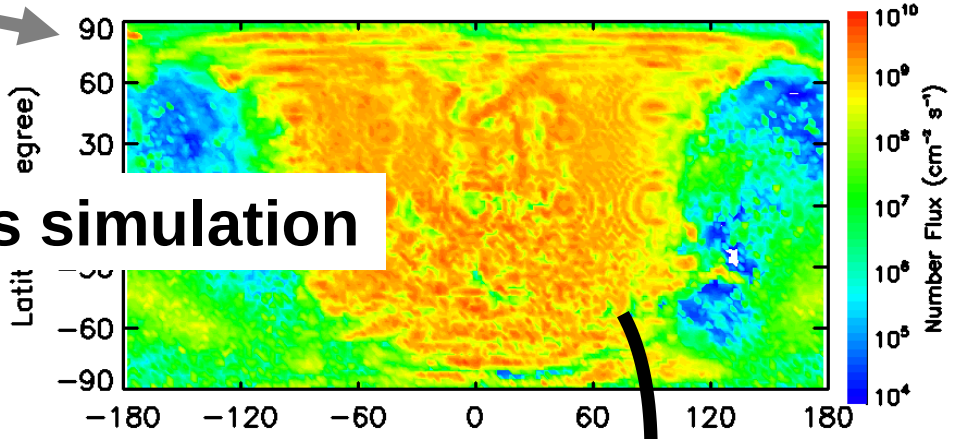
II Non-thermal component: Sputtering

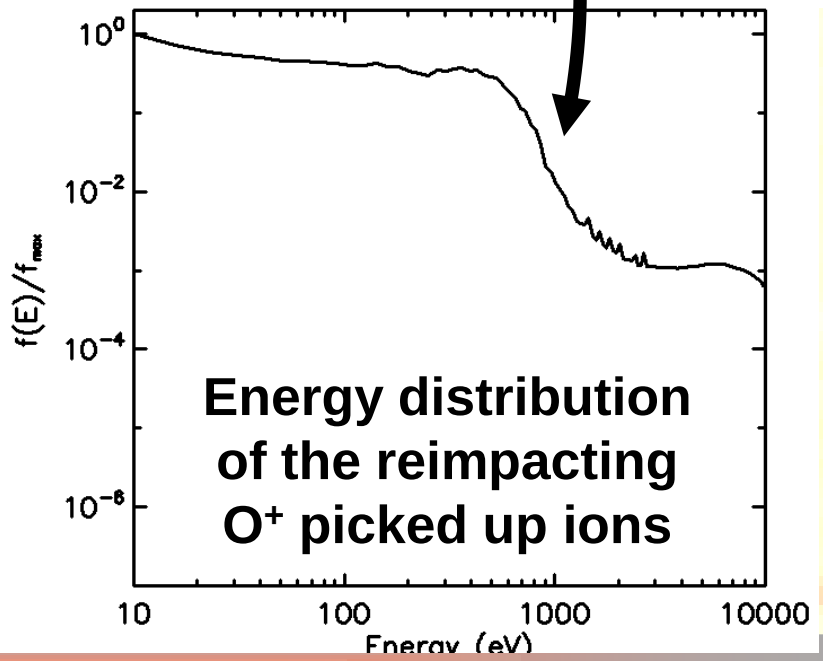


Simulated velocity field by the hybrid code (Modolo et al. 2014)

SW (4 cm^{-3}, 400 km/s), 3 nT Parker, Ls=90°-Northern summer, Solar Mean Crustal field at noon

Test-particles simulation

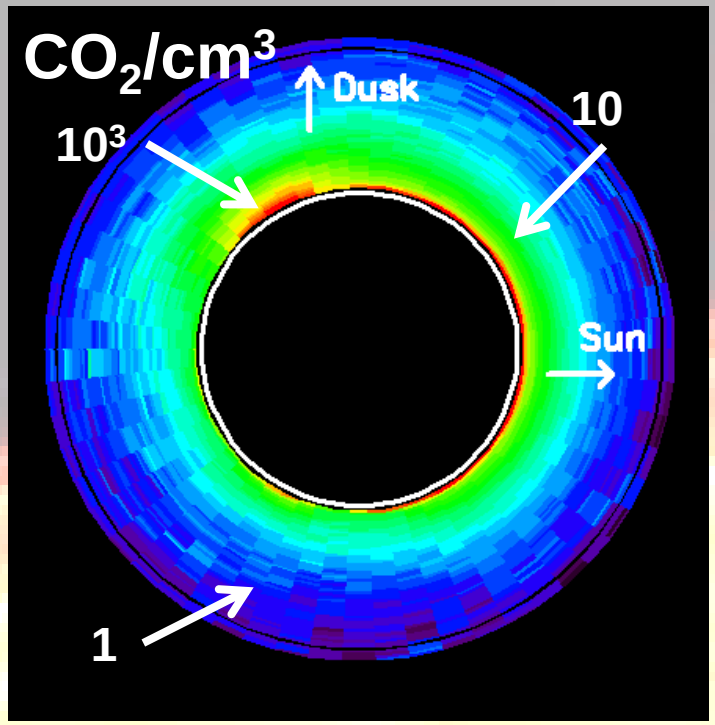


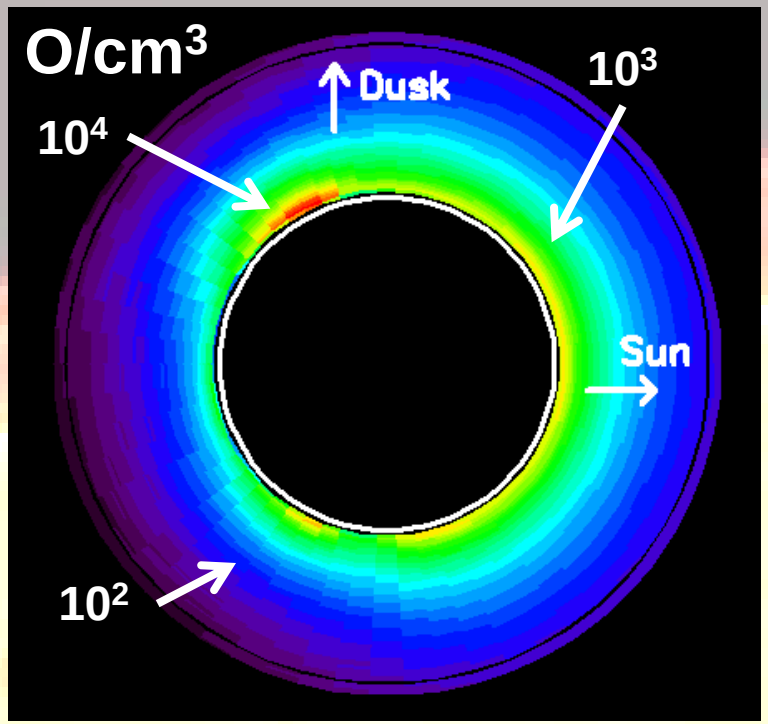


Energy distribution of the reimpacting O$^+$ picked up ions

Exospheric description (MEGM)

Thermal + Non-thermal





Ls=0°, Crustal fields on nightside, minimum solar activity and nominal solar wind

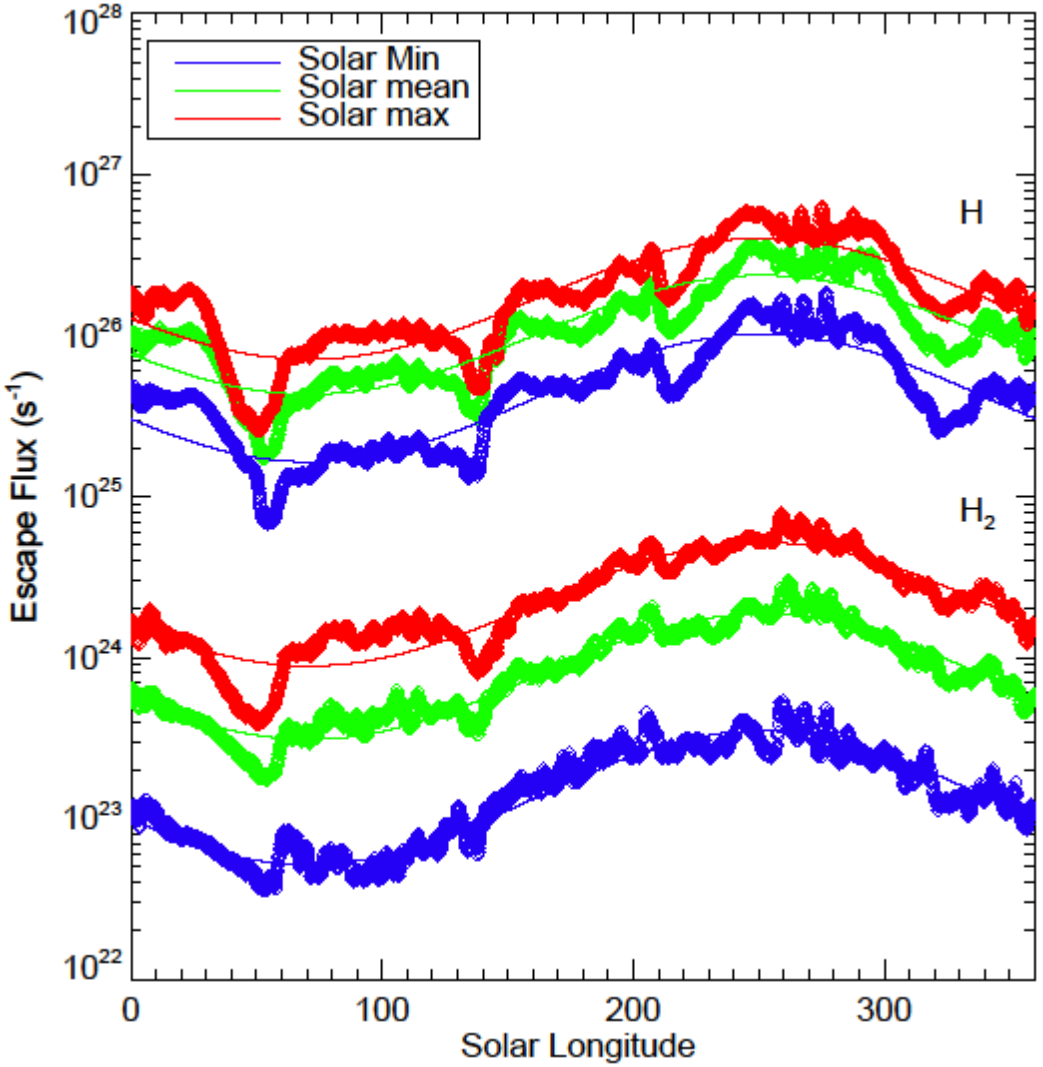
Escape of 4×10^{25} O/s, 2×10^{23} CO/s, 2×10^{23} CO_2/s, 3×10^{23} C/s, 5×10^{25} H/s, 1×10^{23} H_2/s, 2×10^{24} O^+/s

H & H_2 Escape Temporal variations

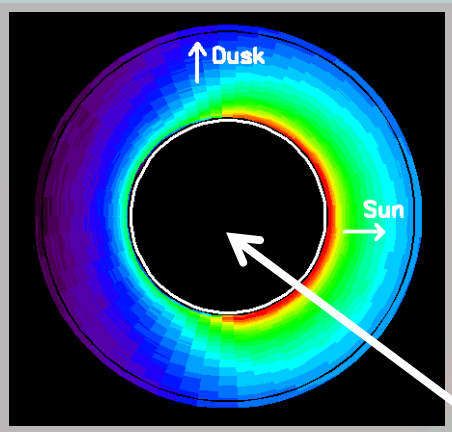
- Seasonal variations ~ 8
- Variations due to solar activity ~ 5
- Escape controlled by solar radiation

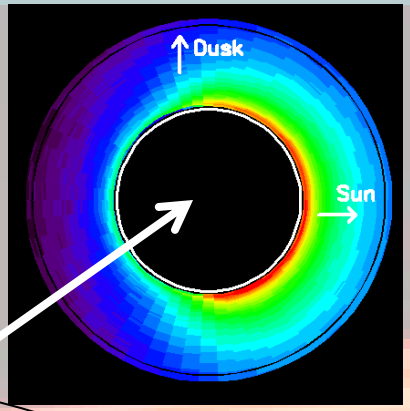
$$\Phi_{esc} = \Phi_{esc,0}\, e^{\alpha \sin(Ls-\varphi)}$$

Expected from small sinusoidal seasonal variations of the exospheric temperature (Forbes et al. 2008)



O Escape seasonal variations





Escape
4×10^{25} O/s

Autumn equinox

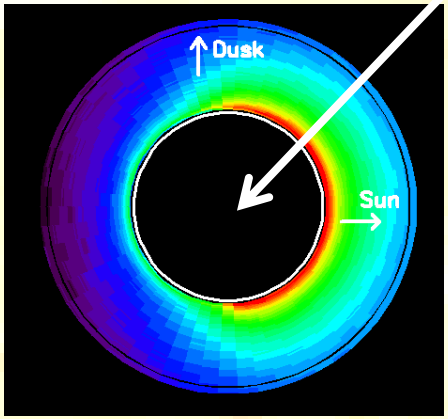
Perihelion

Escape
3×10^{25} O/s

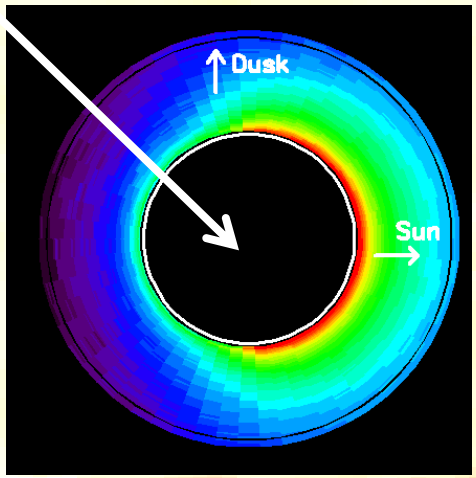
Aphelion

Escape
1×10^{25} O/s

Spring equinox

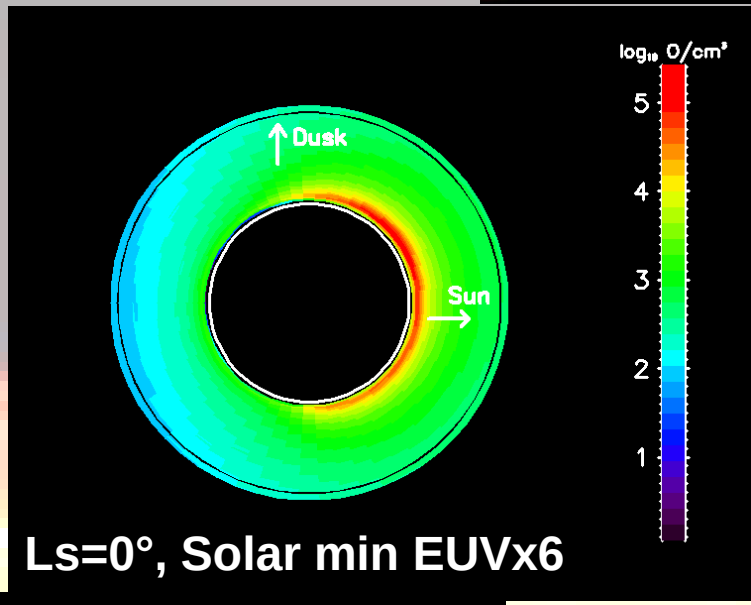


Escape
4×10^{25} O/s

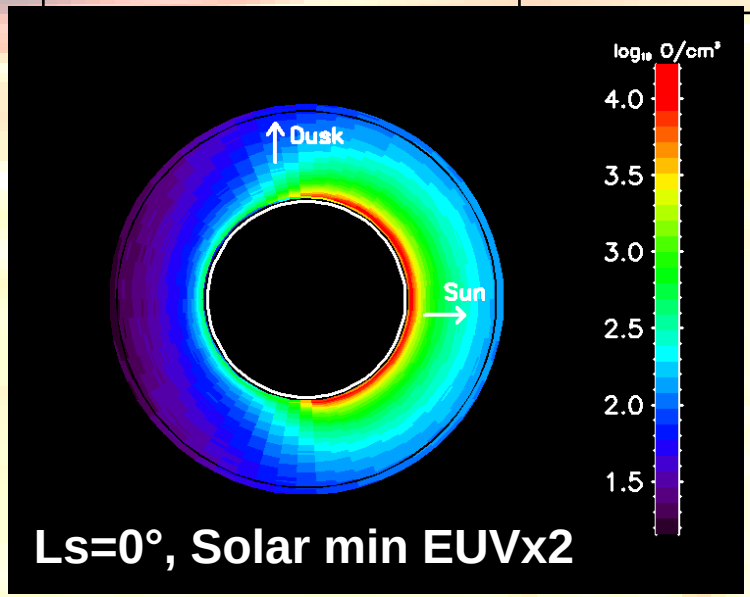


O Escape EUV dependency

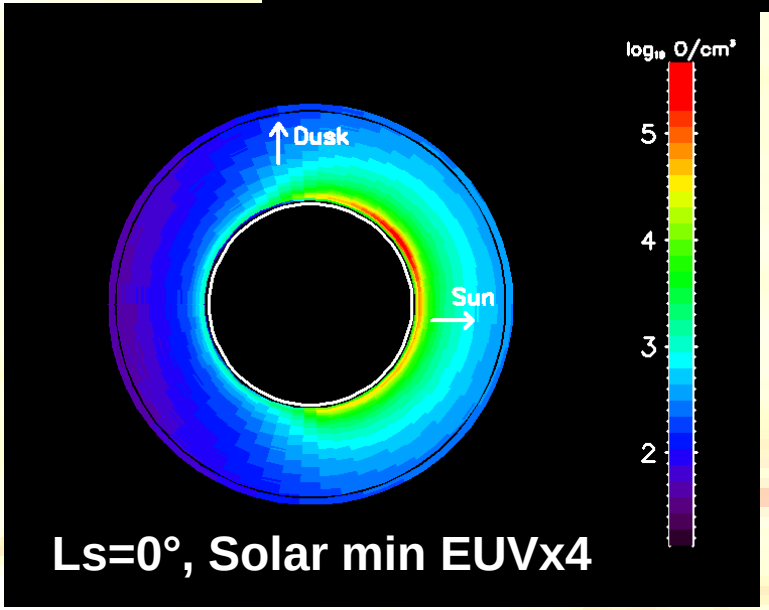
Ls =0°	O escape rate / s
EUV × 1	4.0×10^{25}
EUV × 2	6.0×10^{25}
EUV × 4	1.5×10^{26}
EUV × 6	2.5×10^{26}
EUV × 8	4.0×10^{26}



Ls=0°, Solar min EUVx6



Ls=0°, Solar min EUVx2

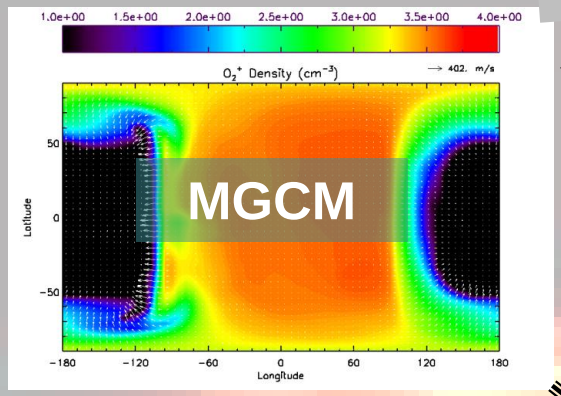


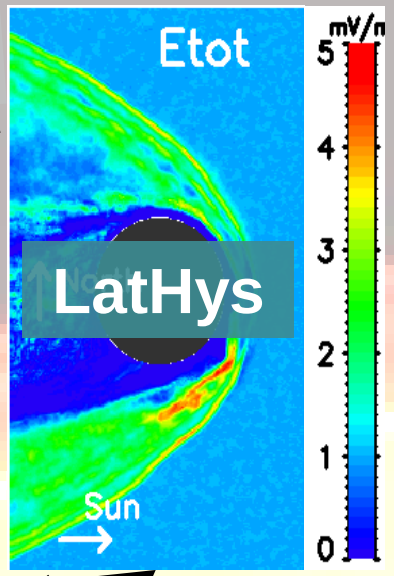
Ls=0°, Solar min EUVx4

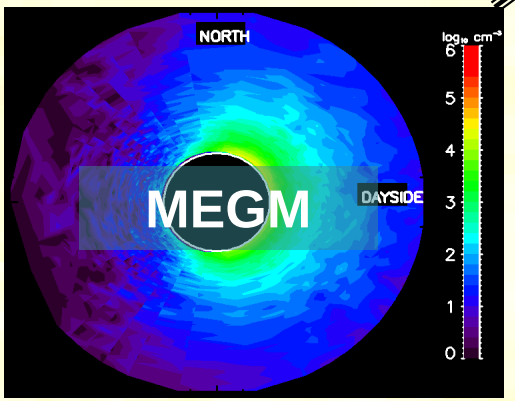
Developments: to be done

HELIOSARES

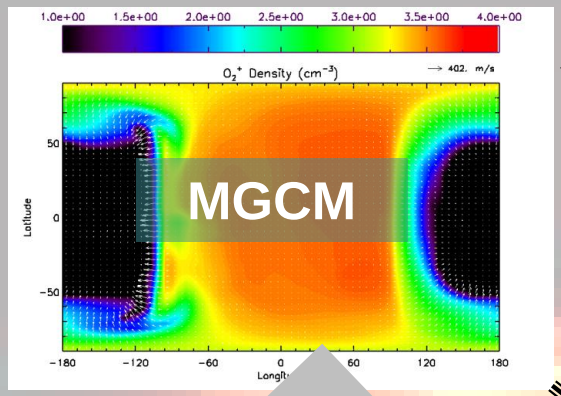
Missing B-field

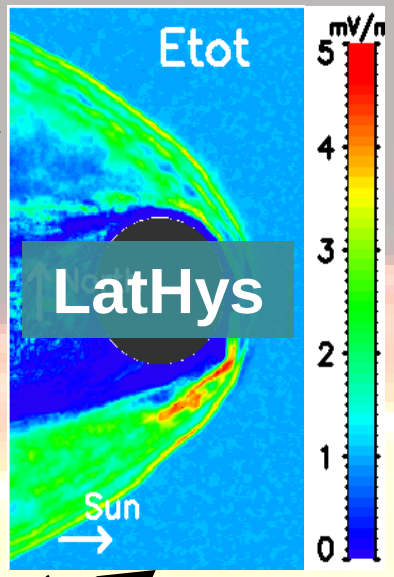




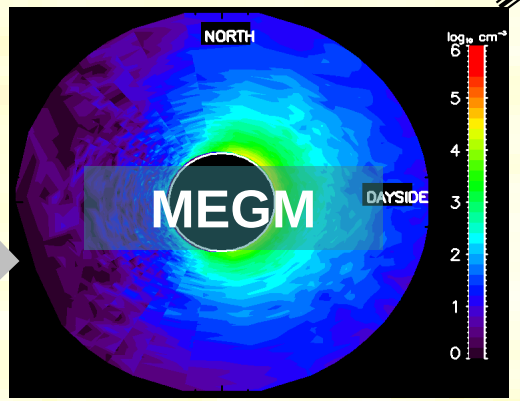


Developments: to be done

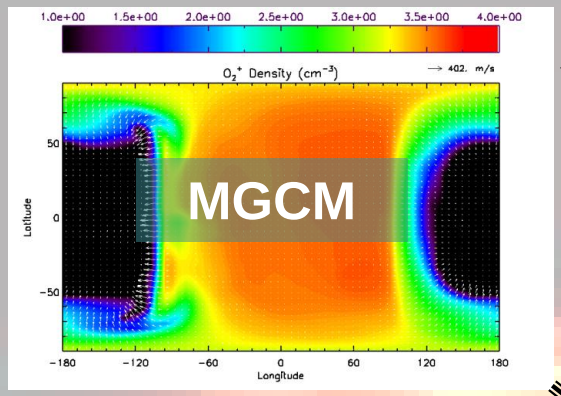


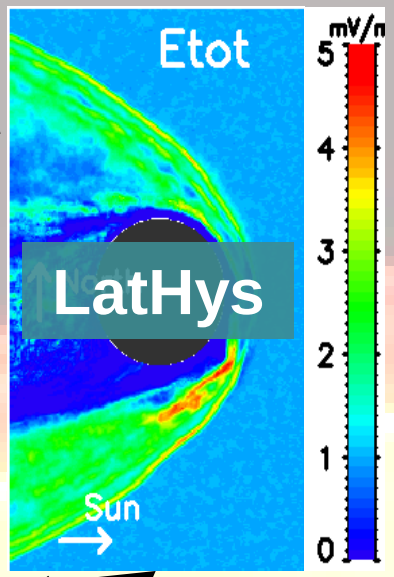


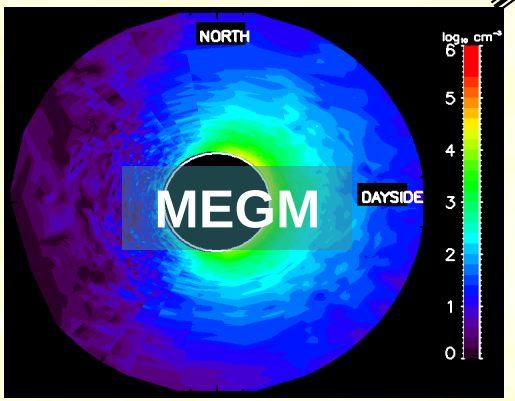
Missing heating term



Final objectives







Early Sun/extreme conditions

A NASA Scout mission
(PI B. Jakosky USA)

MOI: 21 september 2014

Scientific objectives

- **Measurement of the present ion and neutral atmospheric escapes**
- **Measurement of its dependency on the solar activity**
- **Measurement of the isotopic ratio in the upper atmosphere**
- **Characterization of Mars' upper atmosphere**

⇒Towards a much better understanding of Mars-Solar wind Interaction