3D SIMULATIONS OF THE HYDROGEN ESCAPE ON MARS

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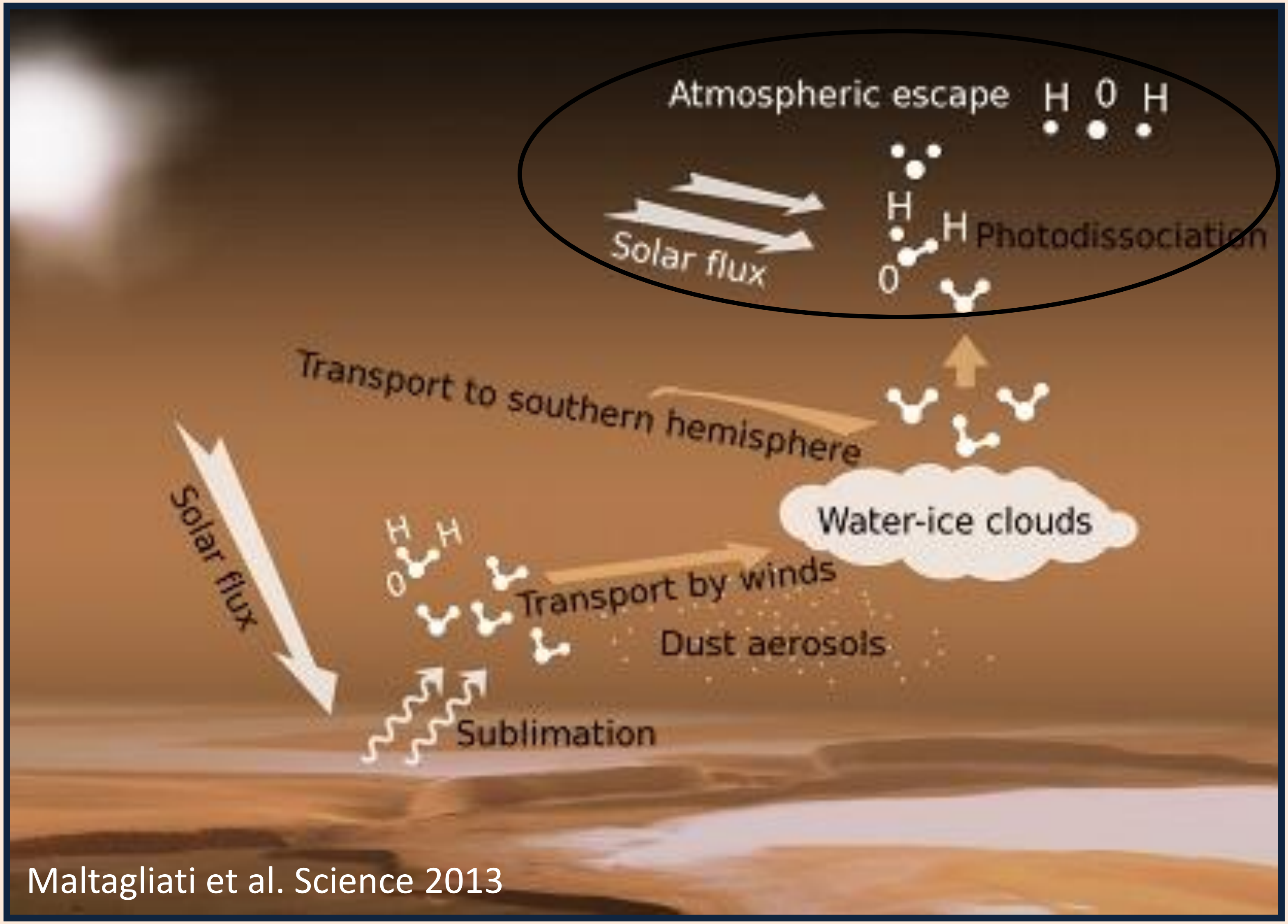
Water cycle on Mars



Jeans Escape

Few molecules at top of the atmosphere (exobase) have a velocity larger than escape velocity ➔ *Escape*

$$F(z_M) = n(z_M)w(z_M)$$

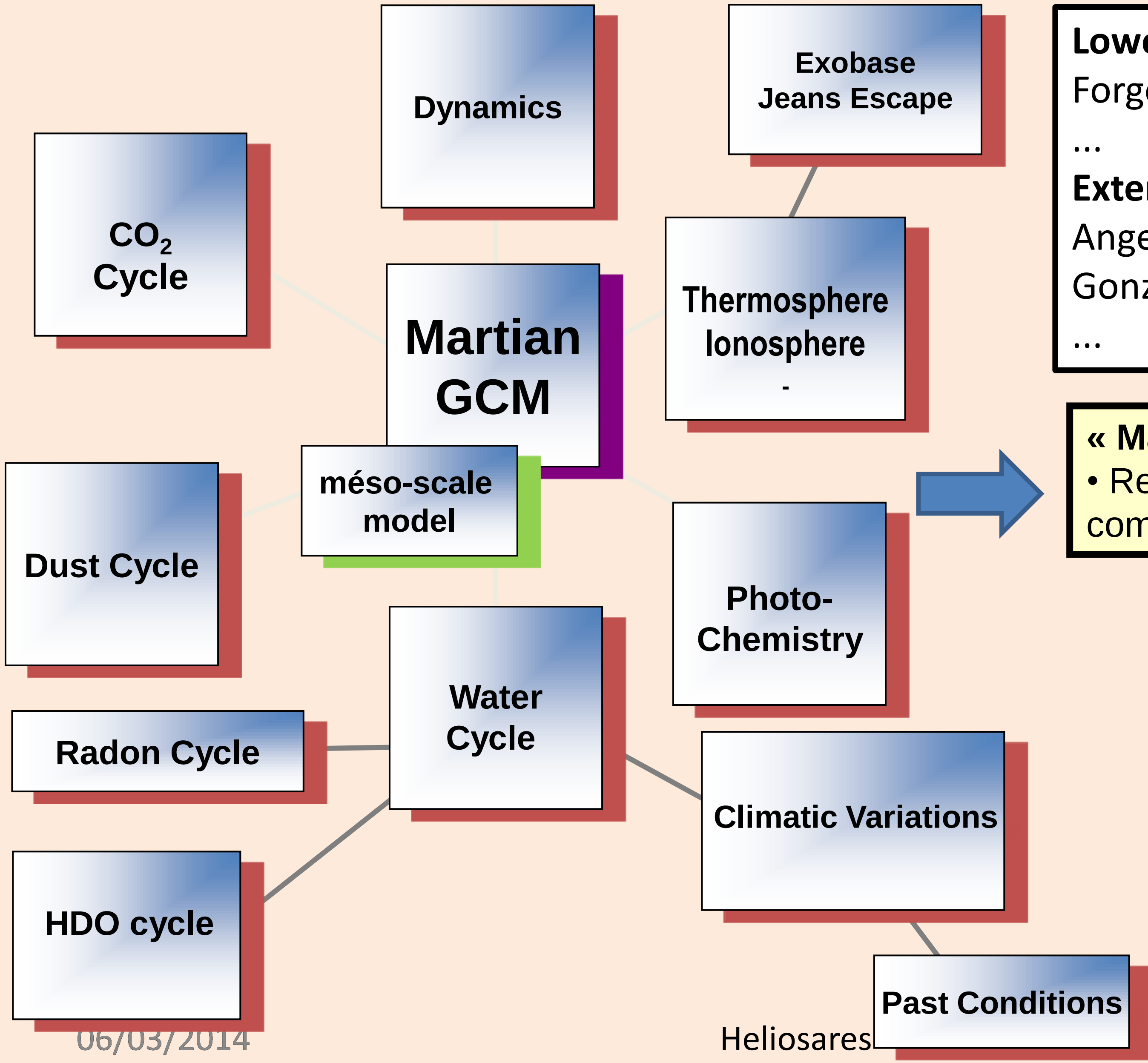
$$w(z_M) = \frac{U}{2\sqrt{\pi}}(\lambda + 1)e^{-\lambda}$$

$$\lambda = GMm/kTr$$

Exponential variation with escape parameter λ =f(m,T)

➔ Strong dependence with temperature at the exobase and mass specie

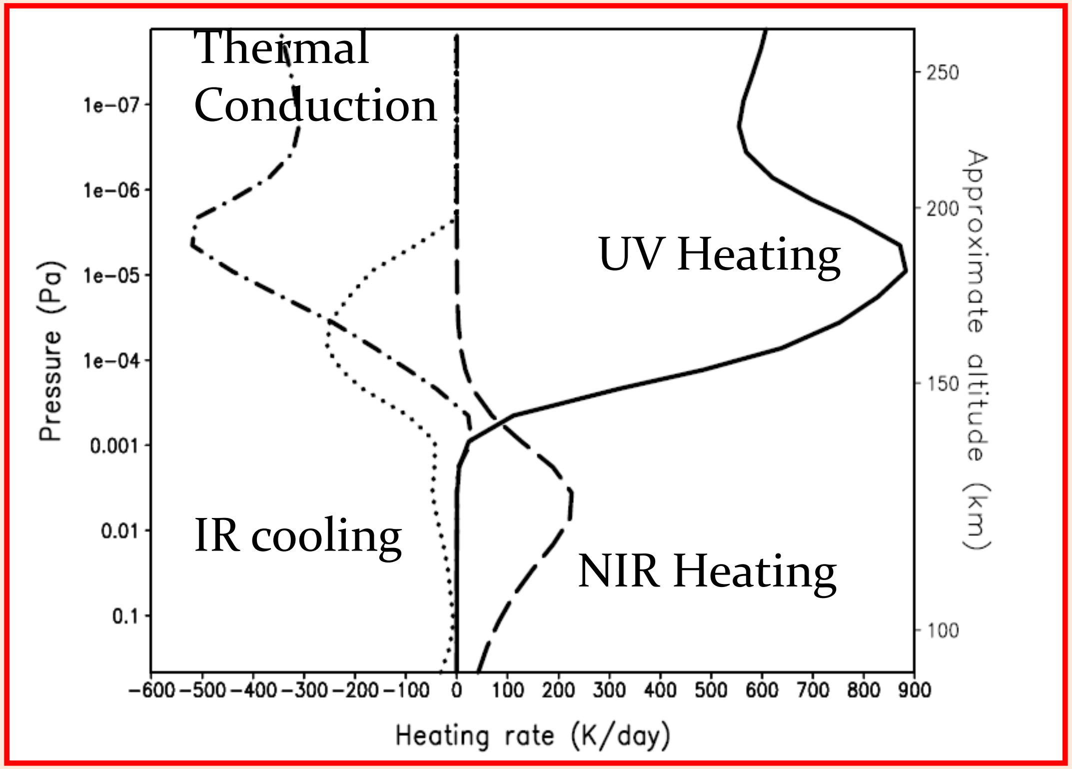
Mars LMD GCM



Lower atmosphere
Forget et al. 1999,
...
Extention to thermosphere
Angelats i coll et al. 2005
Gonzalez-Galindo et al. 2009
...

« Mars Climate database »
- Reference tool for scientific communaury

Mars LMD GCM



Gonzales-Galindo et al. 2005

- **Species :**

All Major neutral (CO_2, N_2, Ar, CO, O, H_2, H,…) + and ions (O_2^+, O^+, CO_2^+, NO^+, ..) +electrons

- **New parametrisation**

Production:

- Photochemistry (90 reactions)

Heating and cooling :

- EUV heating (36 bands)
- NLTE cooling
- Molecular conduction

Dynamics

- Molecular diffusion
- Viscosity

GCM Simulations

- Simulation of H & H2 Jeans escape during one full Martian year for three different solar activities :

- Solar Minimum conditions (F10.7 ~ 80)
- Solar Average conditions (F10.7 ~ 120)
- Solar Maximum conditions (F10.7 ~ 220)

- Assumptions

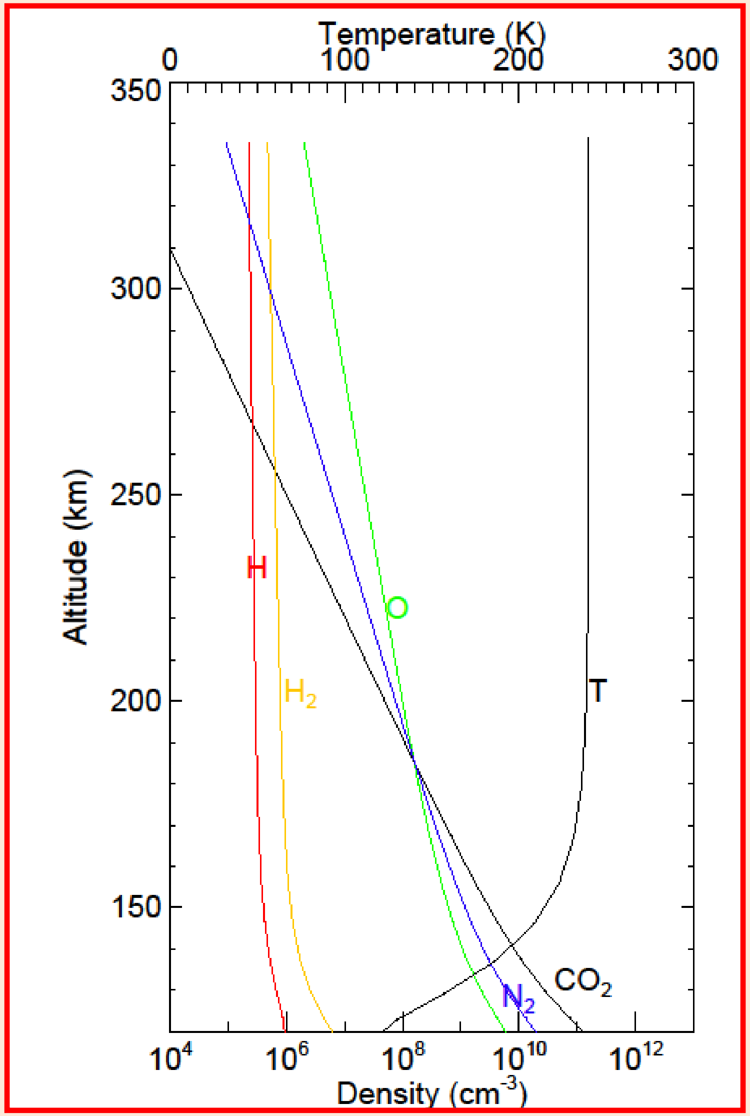
- Average dust scenario (Martian year 27 (MGS))
- EUV efficiency : constant and uniform = 0.21
- Neglect H and H_2 exospheric return flux : w_H and w_{H2} at top = w_{Jeans}

Vertical profiles

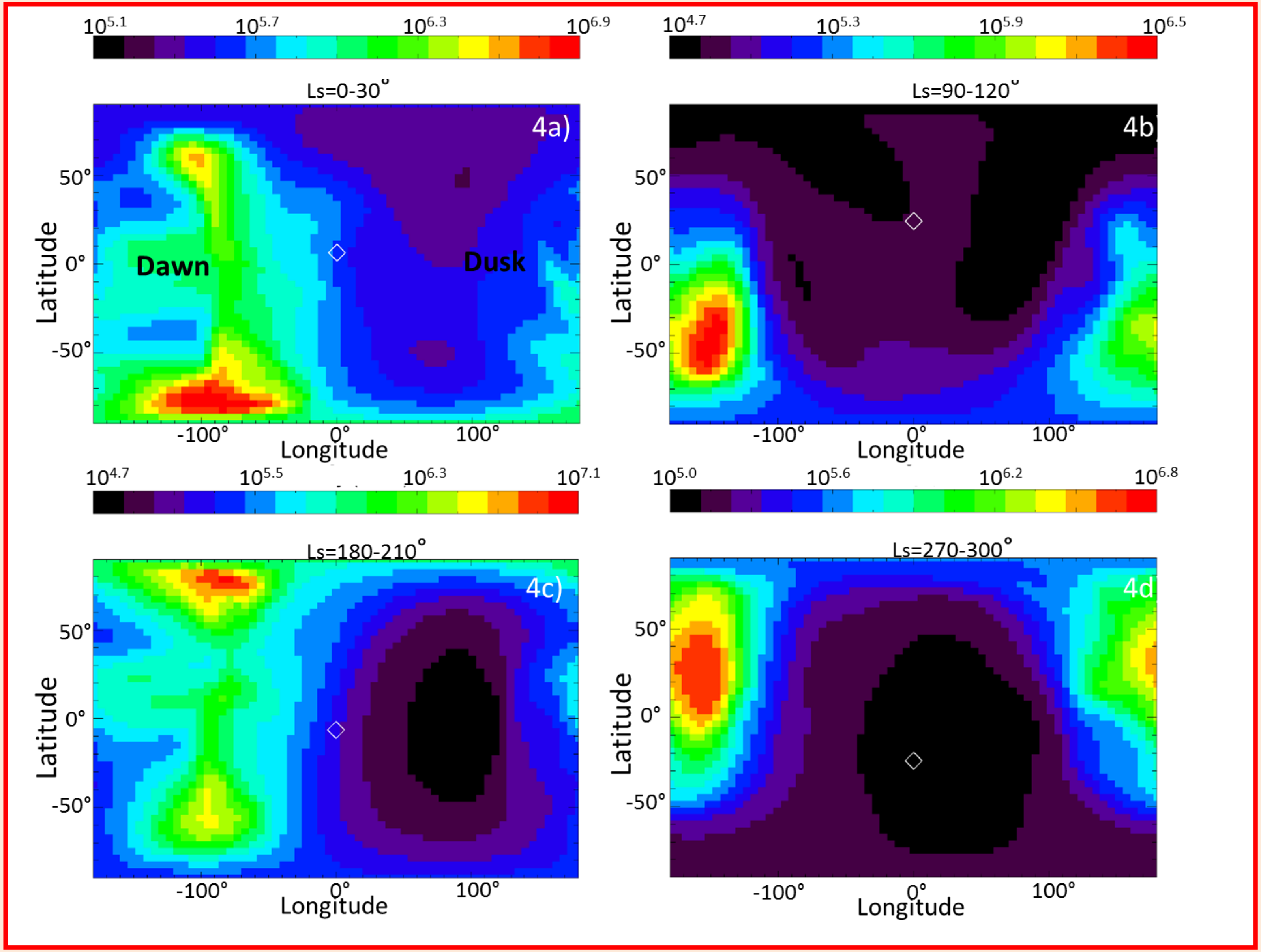
Typical composition of the neutral Martian upper atmosphere

- ❑ Strong increase of the temperature near 150 km due to EUV heating

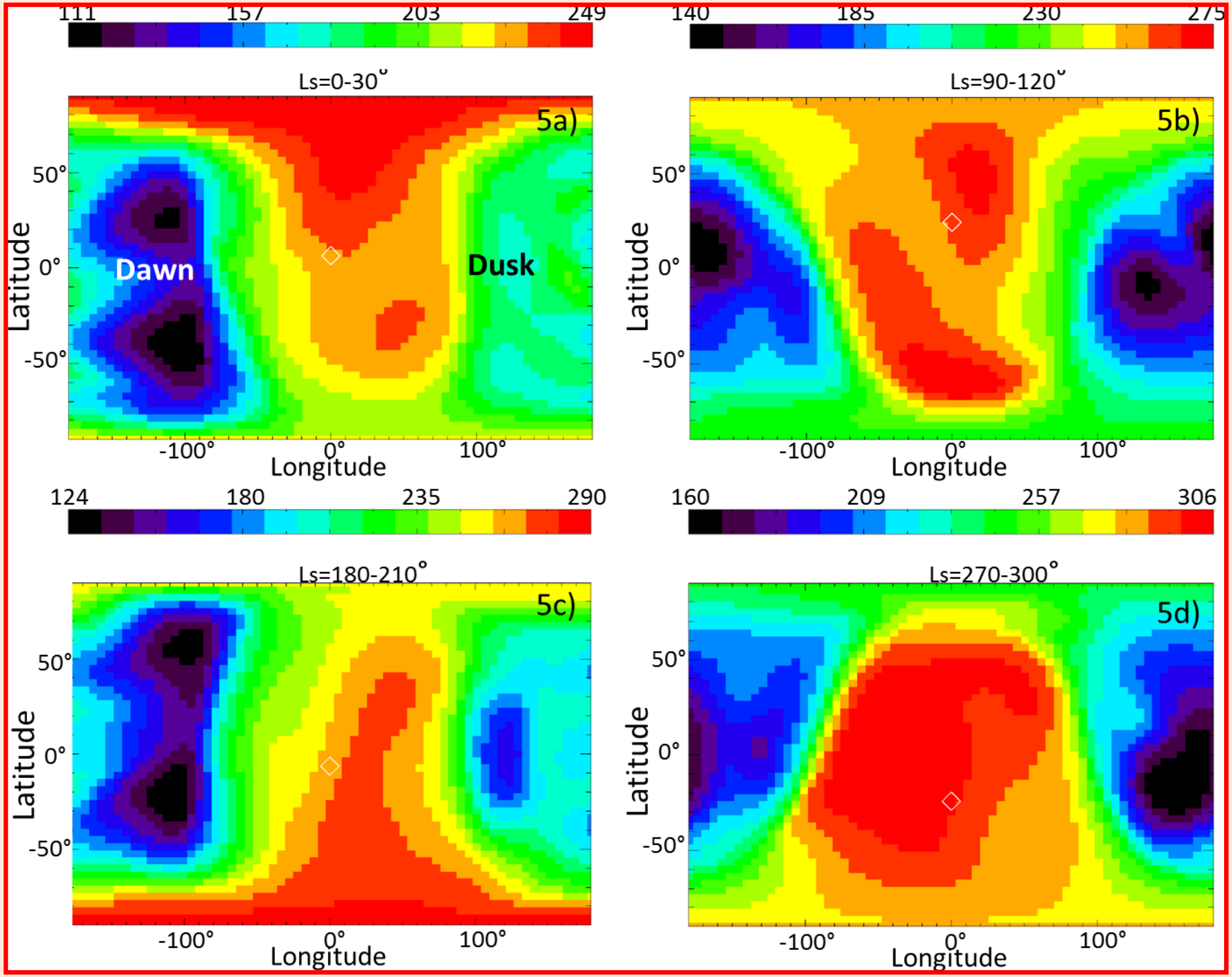
- ❑ Each specie have its own scale height ➔ Light species are dominant



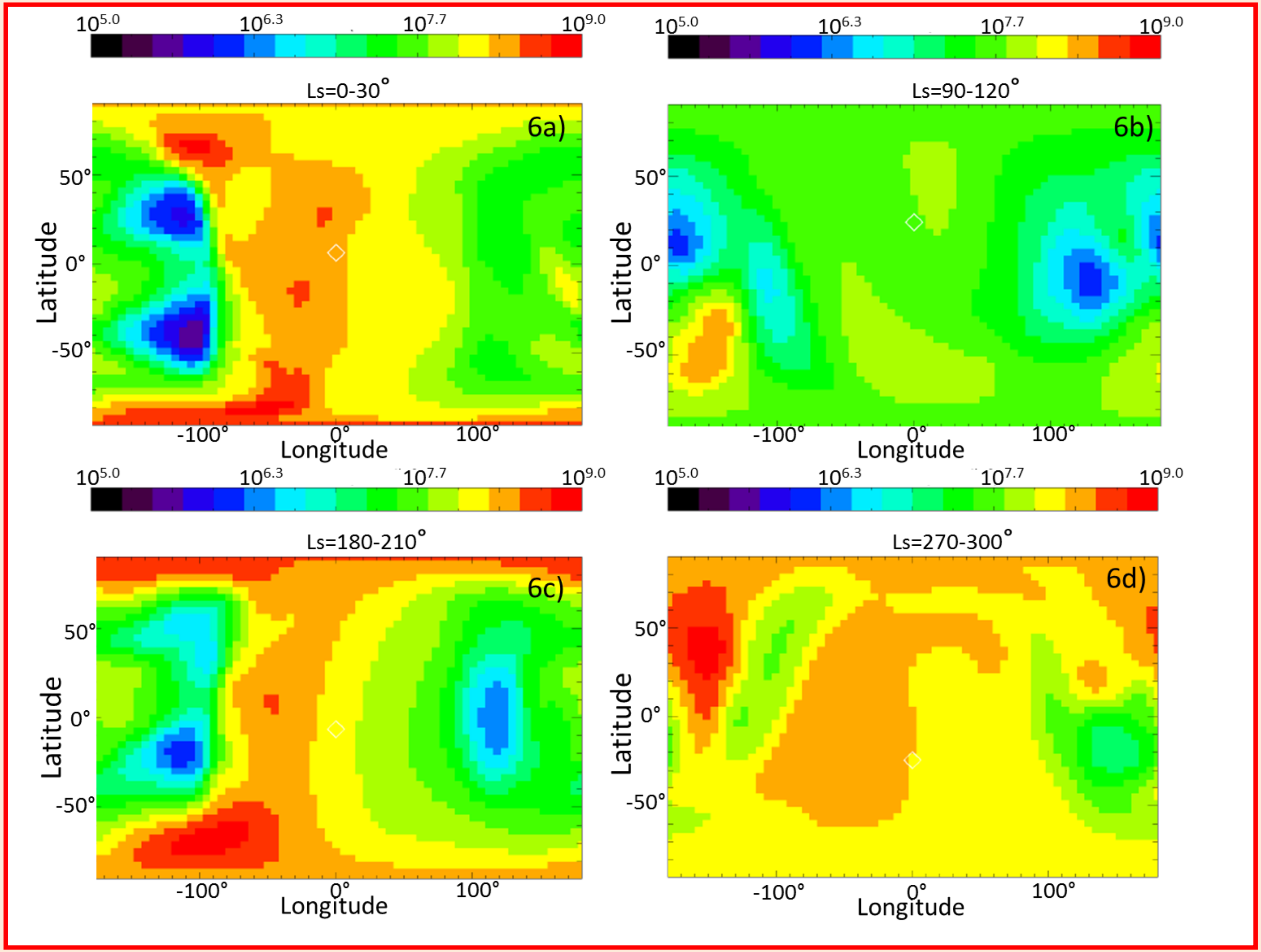
H density at the exobase



Temperature at the exobase



H Jeans escape at the exobase

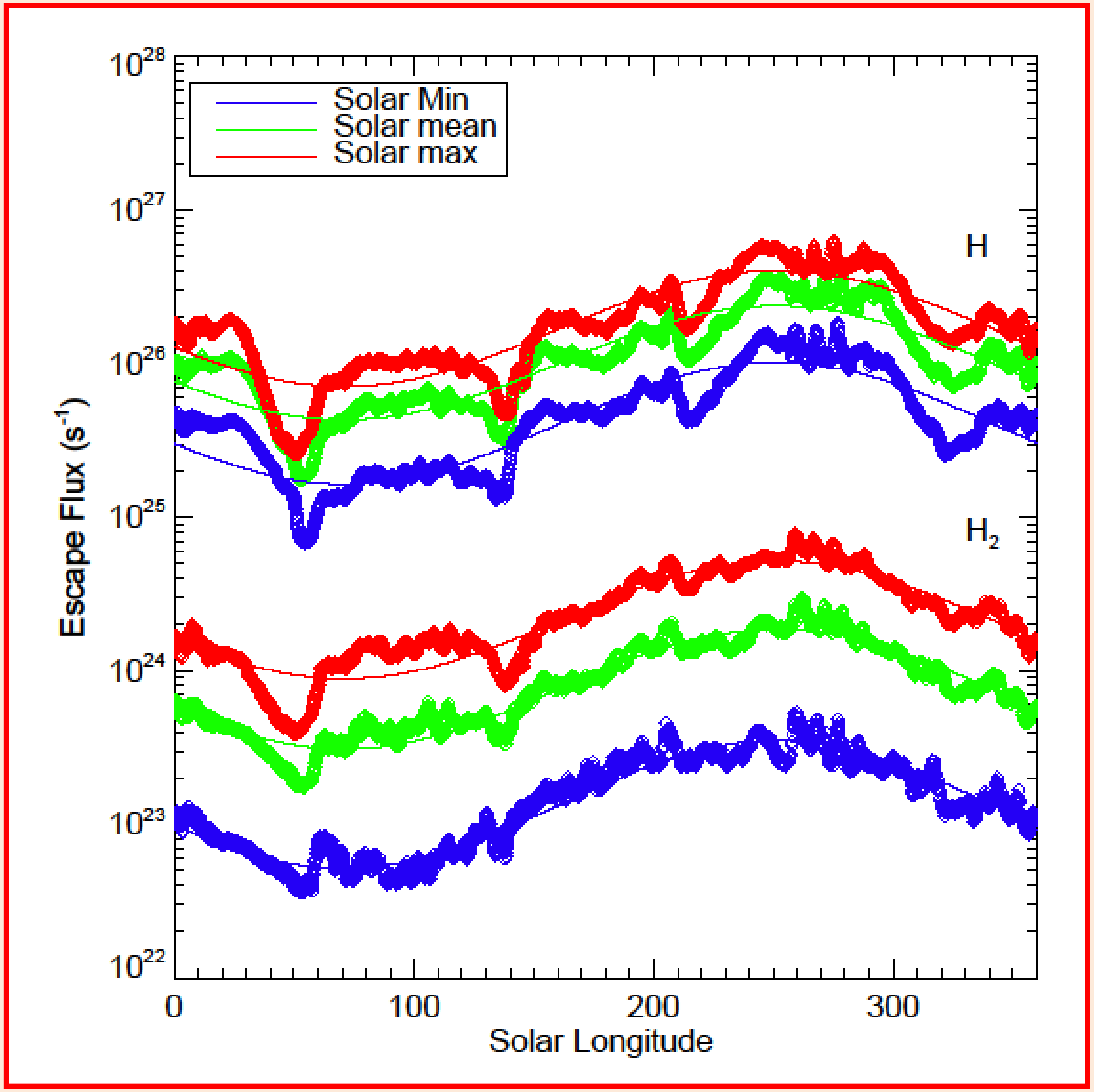


H & H2 Jeans escape : variability

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

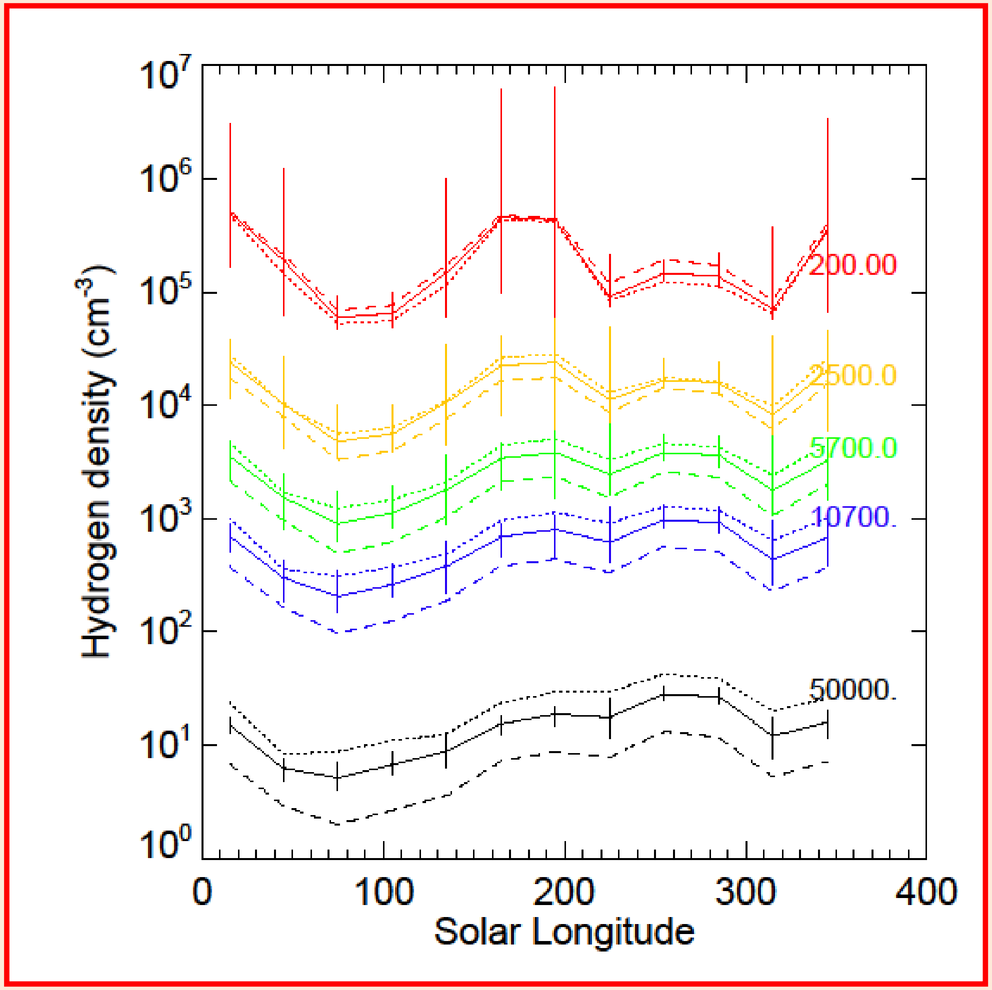
$$\Phi_{esc} = \Phi_{esc,0}\, e^{\alpha \sin(Ls-\varphi)}$$

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



Exospheric hydrogen

- Seasonal variations controlled by H density at the exobase at altitudes < 5000 km
- Seasonal variations controlled by temperature at the exobase at altitudes > 5000 km
- Seasonal variations in agreement with plasma observations (H+ cyclotron waves observations, altitudes of magnetospheric boundaires, X-emissions) (Brain et al. 2006, Koutroumpa et al. 2012, Bertucci et al. 2013)



Conclusion

- First simulation of the H escape temporal variability with a 3D model

Variations controlled by the EUV solar radiation

- Seasonal variations ~ factor 8
- Variations due to solar activity factor ~ 5

Paper submitted to Icarus

Perspectives

- Simulate Lyman-alpha emission / Comparison with observations
- Model coupled with exosphere and solar wind interaction model to study the variability of the Martian plasma environment (Heliosares project / MAVEN mission), X emissions....
- Simulate past EUV flux
- Coupling with balistic exospheric transport code

Diffusion-Limited flux

H must be transported vertically toward the exobase to escape, if the vertical transport is too slow, the hydrogen density at the exobase will reach a value such as Escape flux = diffusion limited flux

It has been suggested that H escape could be controlled by the thermospheric vertical diffusion (e.g. Zhanle et al. 2008)

From our simulations :

$$\Phi_{lim,\ diff} = 1 \pm 0.3 \times 10^{27}\ s^{-1} > \Phi_{Jeans} \sim 1 \times 10^{25} - 4 \times 10^{26}\ s^{-1}$$

- ➔ *If H escape is Jeans escape only, the hydrogen escape is probably not controlled by diffusion in current conditions*
- ➔ *Effect of stronger EUV radiation (past conditions) ; strong dust storm need to be studied*