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Jean-Yves Chaufray, Majd Mayyasi, Michael Chaffin, Justin Deighan, Dolon Bhattacharyya, et al.. Estimate of the D/H ratio in the Martian upper atmosphere from the low spectral resolution mode of MAVEN/IUVS. 22nd EGU General Assembly, May 2020, Online, Unknown Region. pp.id.13984, 10.5194/egusphere-egu2020-13984 . insu-04417907

HAL Id: insu-04417907

<https://insu.hal.science/insu-04417907>

Submitted on 30 May 2024

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Estimate of the D/H ratio in the Martian upper atmosphere from the low spectral resolution mode of MAVEN/IUVS

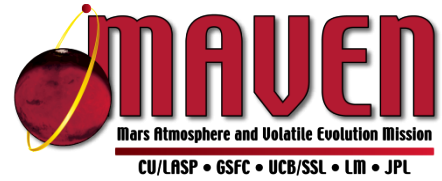
Chaufray, J-Y., M. Mayyasi, M. Chaffin, J. Deighan, D. Bhattacharyya, J. Clarke, S. Jain, N. Schneider, B. Jakosky

EGU 2020





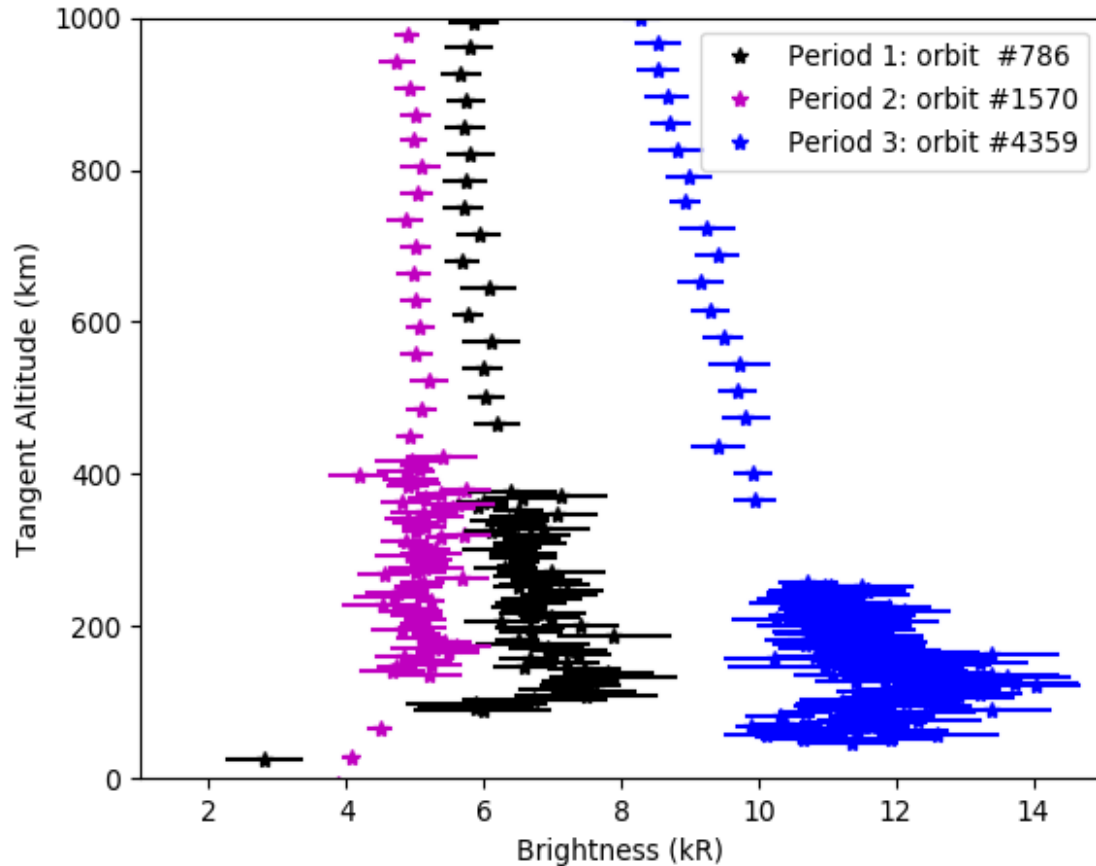
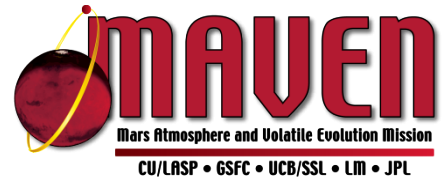
Motivation



- ❑ Large seasonal variations of deuterium observed with IUVS/echelle mode with a peak near $L_s = 270^\circ$ (Clarke et al. 2017)
- ❑ Chaffin et al. (2015) show some Lyman-alpha profiles observed with the « low resolution » mode not reproduced with only H population, especially at morning near $L_s = 270^\circ$
- ❑ The expected D emission should be present in the low resolution Lyman-alpha profile (also in SPICAM, Hubble Space Telescope,...) near $L_s = 270^\circ$ and could explain the discrepancy.



Data analysis



Period 1 : Feb 2015 (Ls ~290°-300°)
Bright limb.
No echelle observations

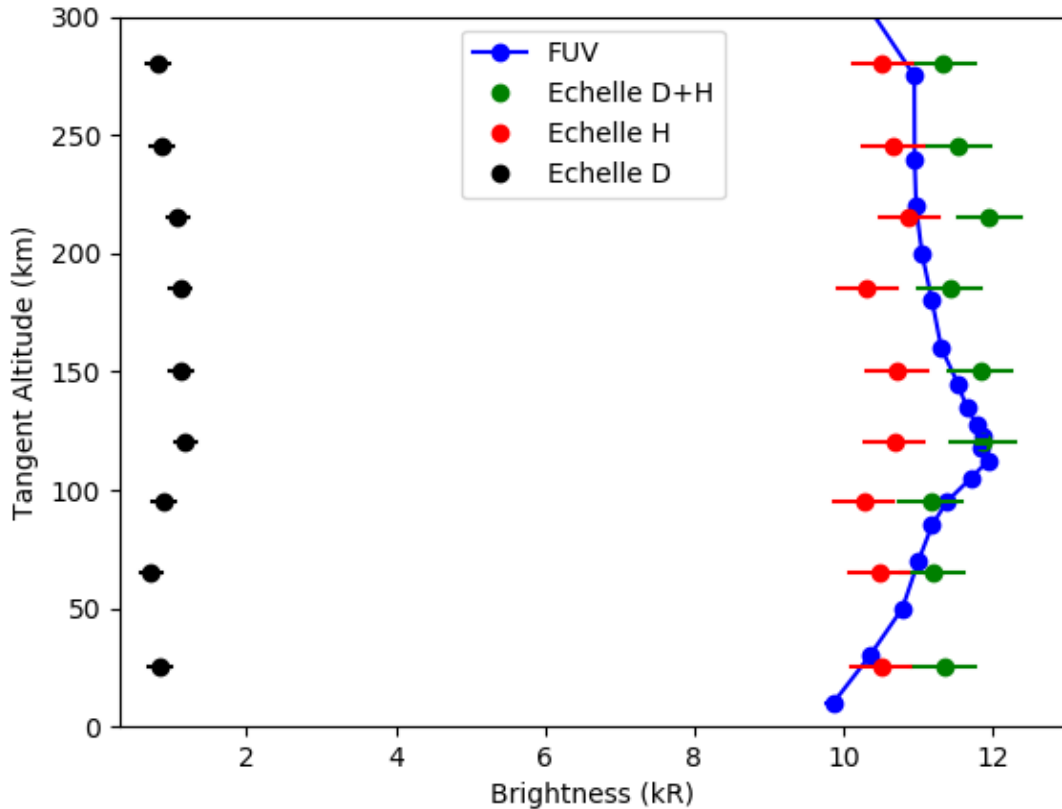
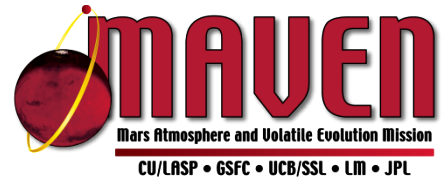
Period 2: Jul 2017 (Ls ~14-17°)
No bright limb
Echelle observations : no D detected

Period 3 : Dec 2016 (Ls ~287°-290°)
Bright limb
Echelle observations : D detected

Systematic observations of bright limb near southern summer



Data analysis

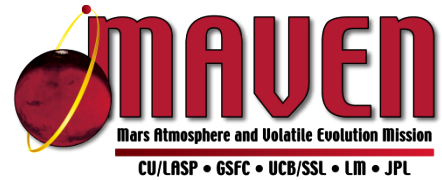


Average of 6 observations done with echelle mode and 8 observations with the FUV detector for Period 3 (Dec 2016)

**Average of low resolution mode vs echelle mode
Difference ~ 10% in total brightness. The agreement is reasonable**

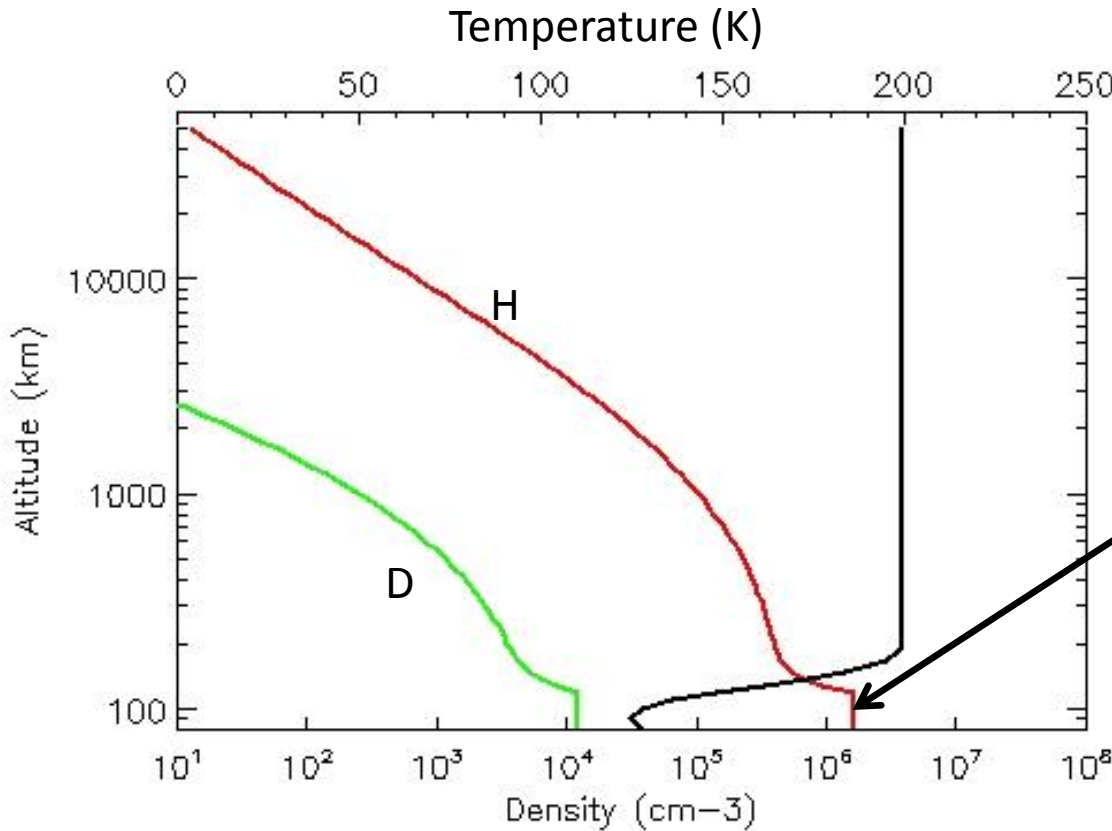


Models 1 for density derivation



1D density and temperature profile (spherical symmetry)

Free parameters : hydrogen and deuterium density and temperature at the exobase (200 km)



Models 1

$T(z)$ from *Krasnopolsky 2002* $f(T_{exo})$

n_H and n_D derived from the diffusion equation between 120 – 200 km

n_H and n_D constant below 120 km
represent the photochemical profile if the dominant source is ion – neutral reactions near 110 km.

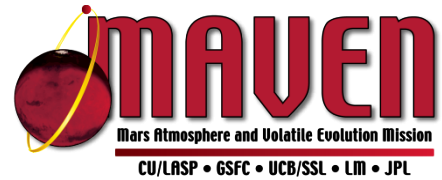
Above 200 km : Chamberlain's profile

Example of parametrized density profile of H and D

Consider interplanetary Lyman-alpha emission = 500R

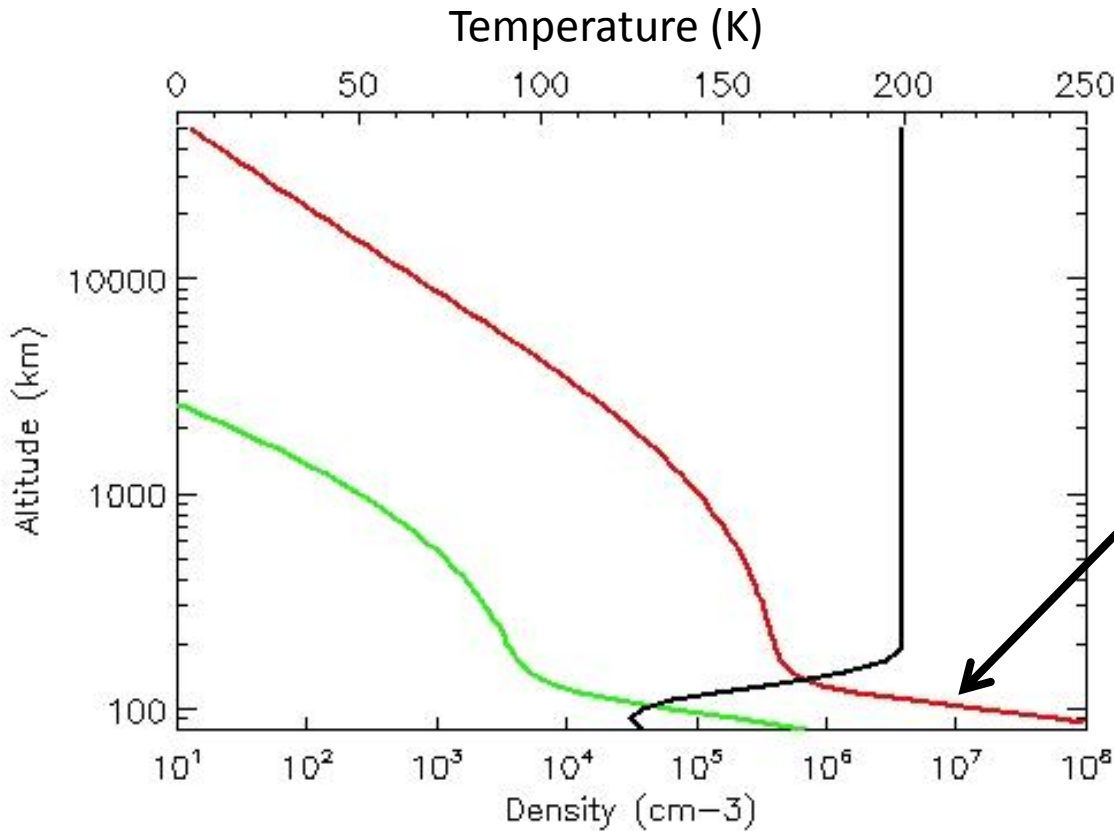


Models 2 for density derivation



1D density and temperature profile (spherical symmetry)

Free parameters : hydrogen and deuterium density and temperature at the exobase (200 km)



Models 2

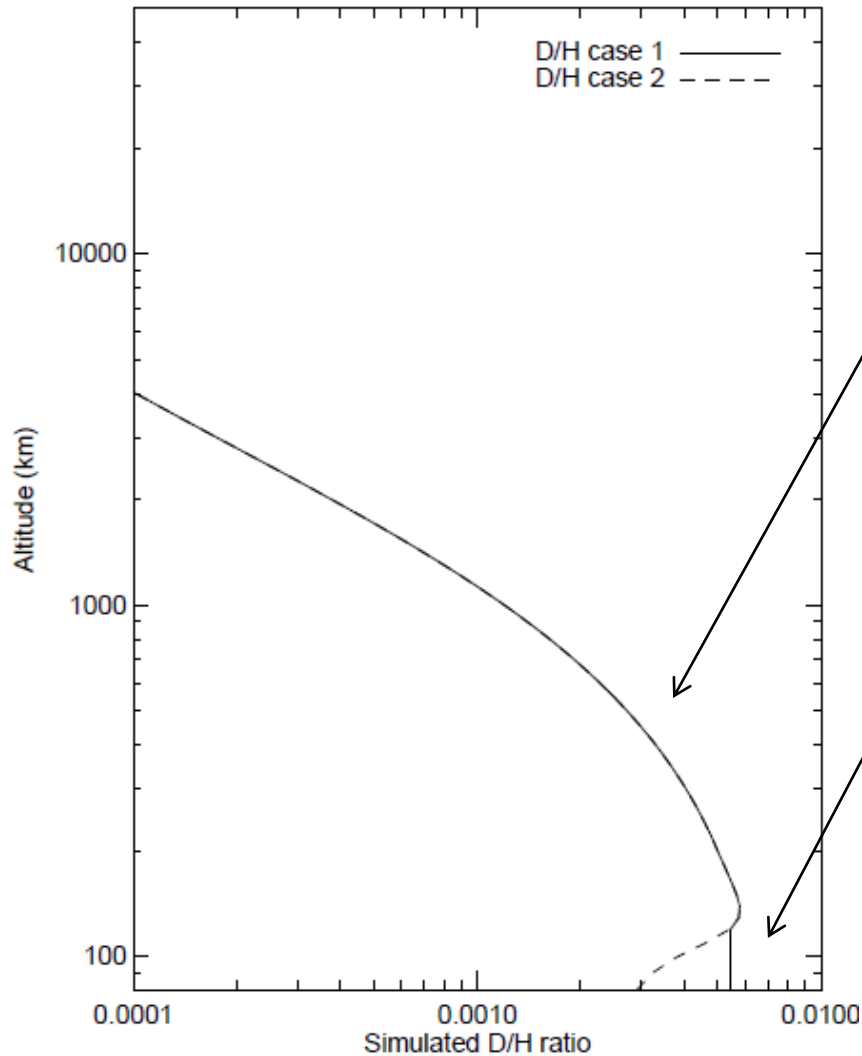
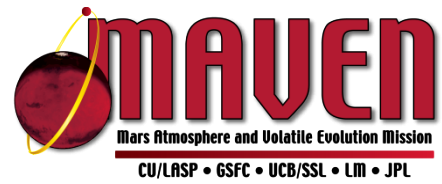
If the main source of H and D is water photodissociation in the mesosphere, we could expect this profile.

Example of parametrized density profile of H and D

Consider interplanetary Lyman-alpha emission = 500R



Models for density derivation



Simulated D/H profiles for models 1 and 2.

Above ~130 km D/H decreases due to the larger atomic mass of D.

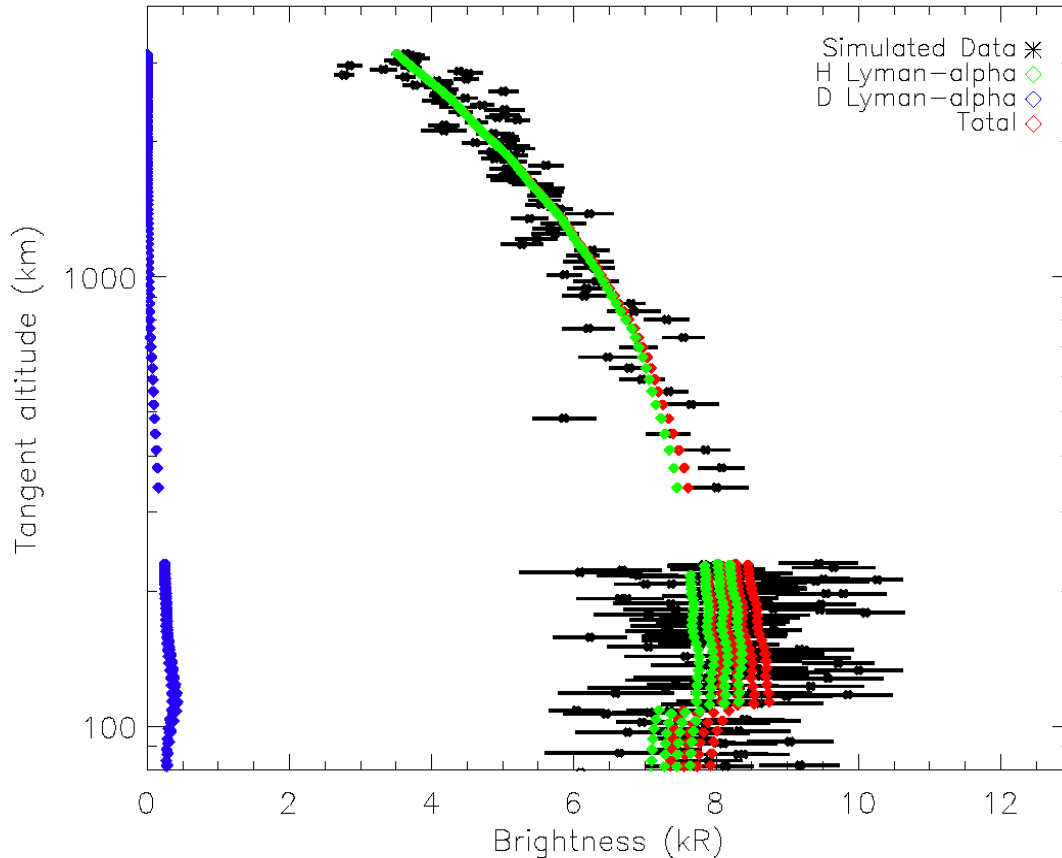
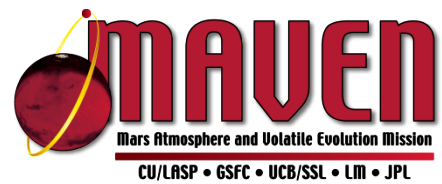
$$D_{mol}(z) \left(\frac{dn}{dz}(z) + n(z) \left(\frac{m_{eff}(z)g}{kT} + \frac{1 + \alpha}{T} \frac{dT}{dz} \right) \right) = 0$$

$$m_{eff} = m_H + m_a \frac{w(z)}{w_l(z)} = m_H + \frac{F_H kT}{bgX_H}$$

Below ~ 130 km, the hydrogen scale height is reduced due to escape → D/H increases



Validation of the method: Simulated data



Monte Carlo simulated D + H
(black) profile (D/H brightness
peak = 0.14)

Simulated Noise :
0.8 kR below 300 km
0.4 kR above 300 km

(chosen from data due to
different integration time)

Best fit derived from the models
(D blue, H green, D+H red)

**Given the IUVS noise, D/H ratio better than 50% could be expected
But Larger systematic uncertainties due to model assumptions**



Source of systematic uncertainties from model assumptions

- **Exospheric temperature (T estimated between 160 – 200K)**

D/H ratio at 200 km : factor 10

D/H ratio at 80 km : factor 2

- **Shape of density profile (model 1 vs model 2)**

D/H ratio at 200 km : factor 1.3

D/H ratio at 80 km : factor 2.5

- **Absolute calibration (estimated ~ 10%)**

D/H ratio at 200 km : factor 1.4

D/H ratio at 80 km : factor 1.4

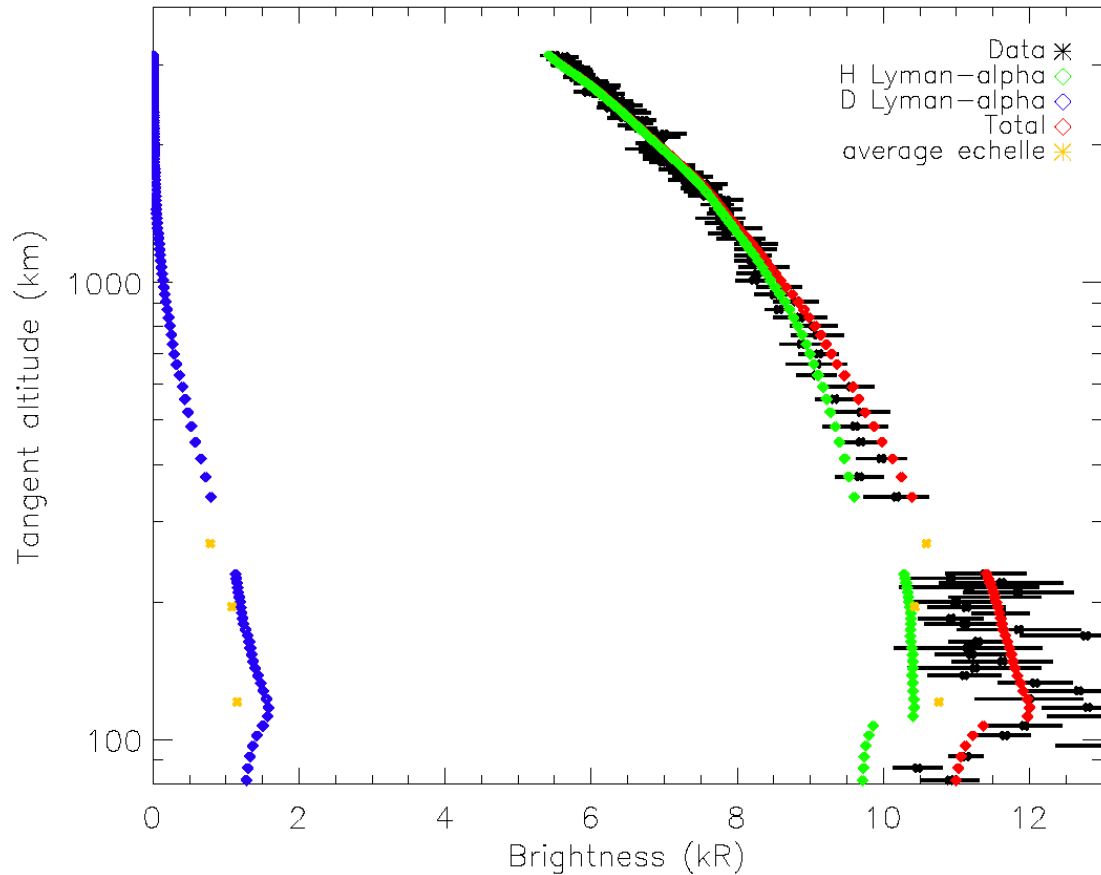
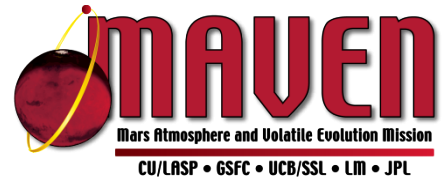
- **Interplanetary hydrogen emission (estimated between 0.2 – 0.8 kR)**

D/H ratio at 200 km : factor 1.3

D/H ratio at 80 km : factor 1.3



Results for the period 3



Example of fit during period 3

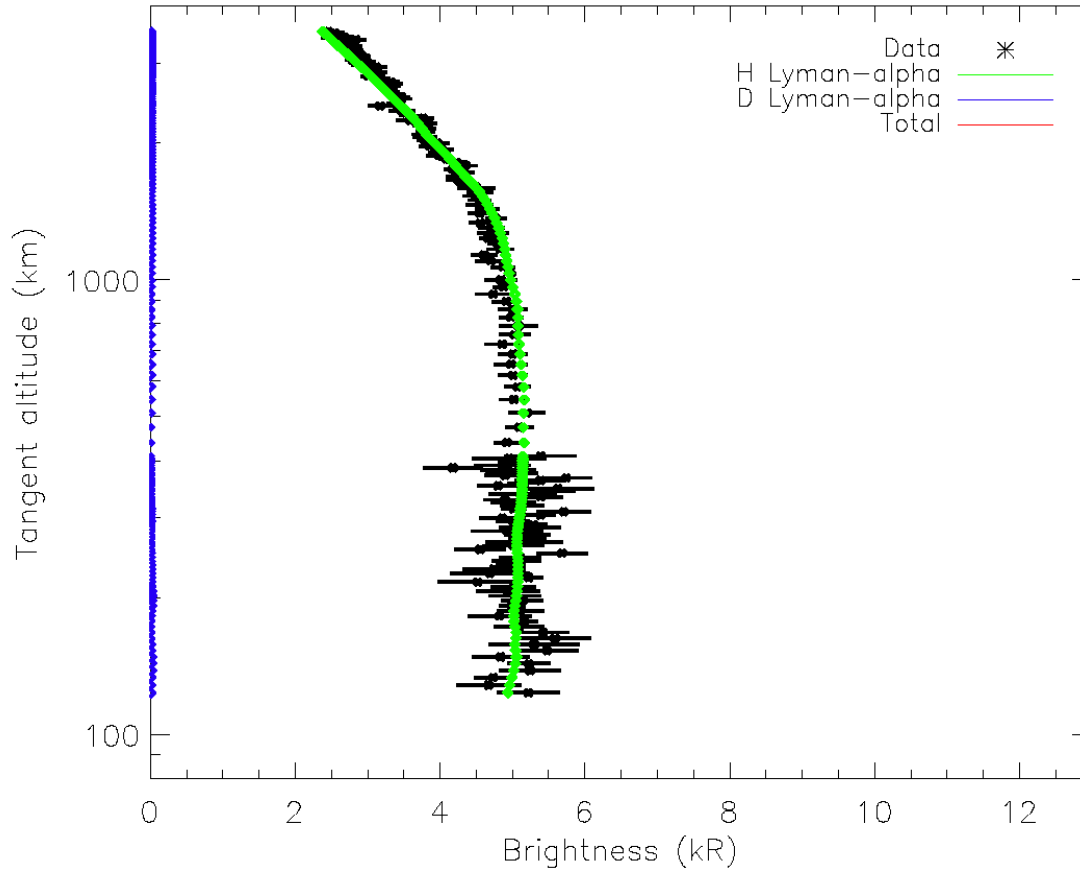
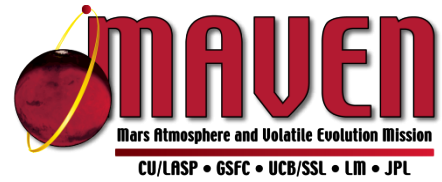
good fit for $T = 180$ K

Derived D and H brightness in reasonable agreement with echelle average profile (differences $\sim 10\%$ expected due to differences between small differences between echelle and FUV brightness).

Simultaneous observations from echelle and low spectral mode
Average D/H at 80 km : $2.5 - 4.7 \times 10^{-3}$ (water vapor : $9 \pm 4 \times 10^{-4}$)
Average D/H at 200 km : $2.5 - 14.0 \times 10^{-3}$



Results for the period 2



Example of fit during period 2

good fit for $T = 200$ K

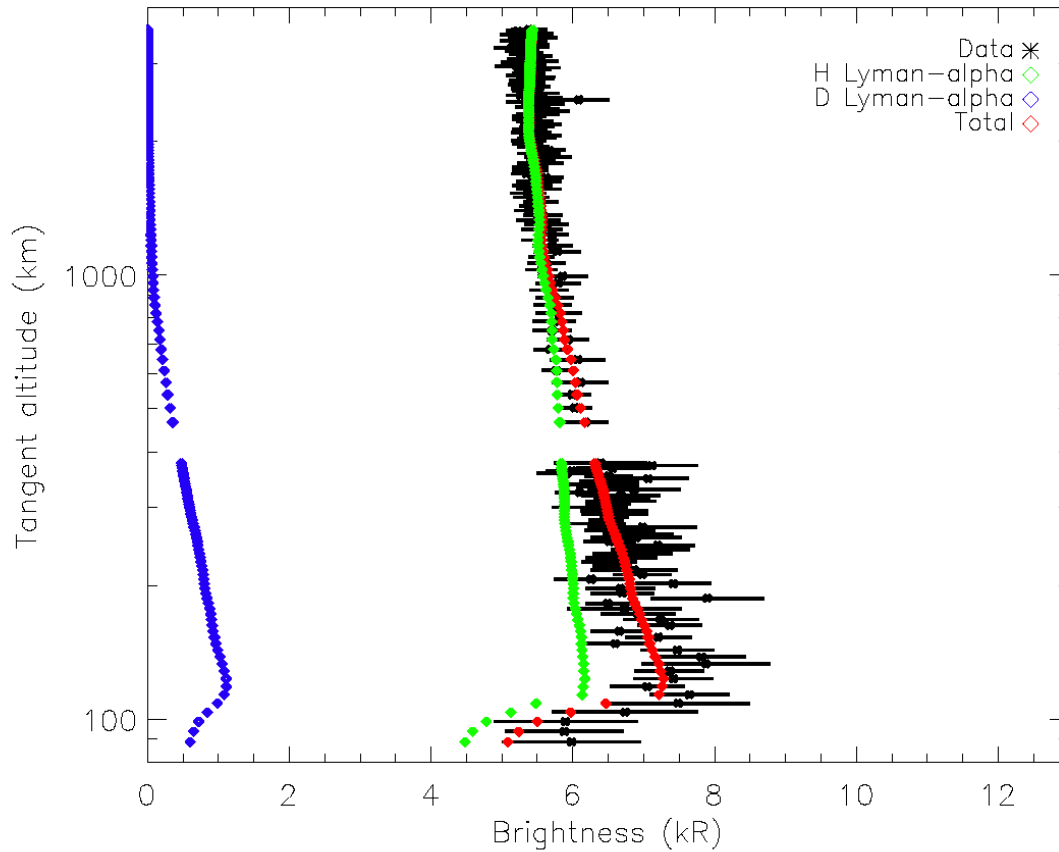
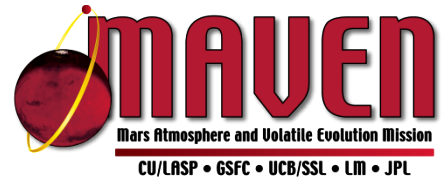
The profile can be fitted without deuterium

Assuming $D/H = 10^{-3} \rightarrow D$
density at 200 km $\sim 80 - 150$
 cm^{-3}

The observed profile can be well fitted without deuterium in agreement with a low deuterium brightness ($< 300\text{R}$) from echelle mode



Results for the period 1



Example of fit during period 1

good fit for $T = 180$ K

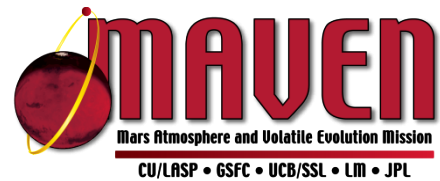
The shape of the profile can be reproduced with H and D. No echelle observations, but the D brightness (peak ~ 1 kR) is comparable to observations done during period 3.

Average D/H at 80 km : $0.6 - 3.4 \times 10^{-3}$ (water vapor : $9 \pm 4 \times 10^{-4}$)

Average D/H at 200 km : $1 - 16.0 \times 10^{-3}$



Conclusion



- Systematic presence of a bright limb observed with the low spectral resolution mode (FUV detector) of MAVEN/IUVS at southern summer (dayside) when large deuterium brightness is observed with echelle mode
- We can reproduce the shape of the Lyman-alpha profile observed with the FUV detector of MAVEN/IUVS when D Lyman-alpha emission is included
- The major source of uncertainty is not the data noise, but the model assumptions used to derive the D/H values, particularly the density shape profile and exospheric temperature.
 - ➔ Possibility to improve the retrieved values with more accurate models (e.g. 3D empirical, validated numerical models).
- A source of H and D below the homopause could provide better fit of the total brightness increase.

Future Work

- Need to study other observations
- Improve models to derive more accurate values.