

Radiative transfer of the oxygen 130.4 nm triplet for Venus and Mars

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Goals

- Knowledge of the atomic oxygen concentration in the upper atmospheres of Mars and Venus.
- Determination of the thermodynamical state of the oxygen.
- Comparison with SPICAM and SPICAV.

- O 130.4 nm triplet because:
 - Observable with SPICAM / SPICAV
 - Can be excited by particle impacts *and* photoabsorption.
 - One of the most intense lines in the oxygen spectra corresponding to allowed transition. (This is not the case of the green and red lines).
 - The lower state is the ground state which allows a population at the temperature of these planets; on the contrary, the red line at 844nm is only produced by electron impact.
- A great proxy of the oxygen in the atmosphere of both these planets.

But is optically thick and in the UV domain.....

Radiative transfer problem

Two problems

- Overlap between the O {130.2 nm, 130.4 nm, 130.6 nm} triplet and lines of the CO fourth positive band ($A^1\Pi$).

Recent radiative transfer studies with a Monte-Carla method give results with too high Martian exospheric temperatures (Chaufray et al., 2009). Problem due to overlapping?

- Spectroscopic structure of the atomic oxygen and redistribution function

Problem of the overlapping between CO and the O 130.4 nm triplet

- CO lines of the fourth positive 9-0 band overlap with the 130.4 nm. **When considering $\pm 0.3 \text{ \AA}$ from each O lines of the triplet, 21 CO lines overlap!!!**

-On the Jovian case, it has been shown that such overlapping between H Lyman lines and H₂ could significantly change the intensities.

- Each line of the O triplet is in coincidence with different CO rotational levels
 - The 130.2 with low rotational levels (5-10).
 - The 130.4 with higher levels (from 17 to 21)
 - The 130.6 with more higher levels (19 to 25)
 - The rotational constant of CO is very low and the high levels could be populated. The energy of the 20th level is 806 cm^{-1} .
- In turn, one may expect from such study information on the rotational state of CO in the atmosphere.

The partial redistribution function in the case of a triplet with a common upper level

- Hummer redistribution function: On the profile of one line

$$R_{\Pi}(x', \mathbf{n}'; x, \mathbf{n}) = \frac{g(\mathbf{n}', \mathbf{n})}{\pi \sin(\theta)} \exp[-x^2 - (x - x')^2 \csc^2(\theta/2)] H\left[a \sec(\theta/2), \frac{x + x'}{2} \sec(\theta/2)\right]$$

$a \equiv \frac{\delta}{w}$ and $H(a, v)$ is the Voigt profile
 et $H(a, v)$ est le profil de Voigt.

- In the case of angle average (aapr).

$$R_{\Pi, A}(x', x) = \pi^{3/2} \int_{|x'-x|/2}^{\infty} du \exp(-u^2) \left[\frac{1}{\tan\left(\frac{\min(|x|, |x'|) + u}{a}\right)} - \frac{1}{\tan\left(\frac{\max(|x|, |x'|) - u}{a}\right)} \right]$$

- In the case of this triplet, we developed a new redistribution function

$$R_{II,A,j} = \sum_{i=1}^3 \frac{A_i}{\sum A_i} \pi^{\frac{3}{2}} \int_{|x'-\Delta_{i,j}-(x-\Delta_j)|/2}^{\infty} du \exp(-u^2) \left[\left(\tan \left(\frac{\min(|x-\Delta_j|, |x'-\Delta_{i,j}|) + u}{a} \right) \right)^{-1} - \left(\tan \left(\frac{\max(|x-\Delta_j|, |x'-\Delta_{i,j}|) - u}{a} \right) \right)^{-1} \right]$$

i represents the wavelength decay due to absorption
 j represents the wavelength decay due to re-emissions

We cross-sum on both of them, with an angle-average Hummer-like function.

It is then possible to redistribute each absorption on each re emission.

Internal Sources

- Could represent a non negligible part of the intensity even for the dayside.
- Intensity around 10% of the total
- Sources calculated from the TRANS-* kinetic simulations (see for example Simon et al, PSS, 2009 in press) and inserted into the radiative transfer code.

Solar line input

- ◆ $\pi F = 4.89 \times 10^9 \text{ ph cm}^{-2} \text{ s}^{-1}$ for $L_s = 164^\circ$
- ◆ $\pi F = 3.85 \times 10^9 \text{ ph cm}^{-2} \text{ s}^{-1}$ for $L_s = 101^\circ$
- Double Gaussian shapes.
- Relative intensity of each line:
0.33 (130.2nm), 0.31 (130.4nm), 0.36 (130.6nm).

Martian case

-SPICAM data:

We choose for the moment 2 data sets with $L_s=101^\circ$ (15-21/10/04) and 164° (22/02/05)

-Overlapping:

Due to cold temperatures ($T_{\text{exo}}=200\text{K}$) only 5 CO lines play significant roles

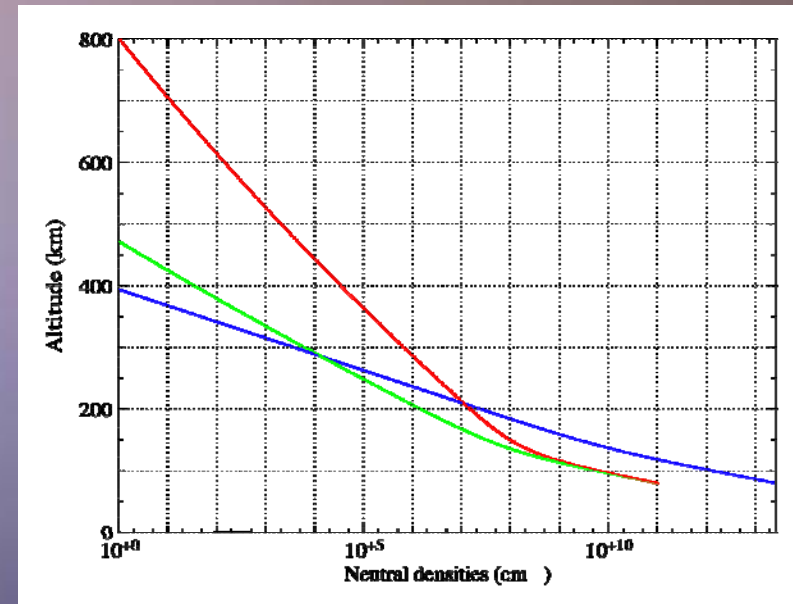
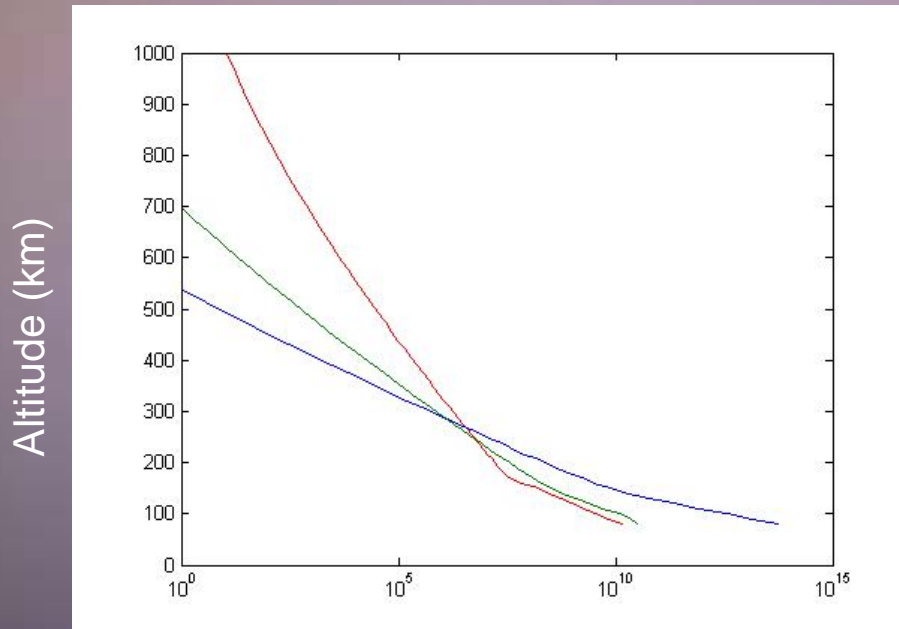
9-0 P(6) : $\lambda= 130.211\text{nm}$ (-0.0055nm)

9-0 Q(8) : $\lambda= 130.221\text{nm}$ (+0.0052nm)

9-0 Q(19) : $\lambda= 130.489\text{nm}$ (+0.0031nm)

9-0 Q(22) : $\lambda= 130.604\text{nm}$ (+0.0006nm)

Martian case: atmospheric model.

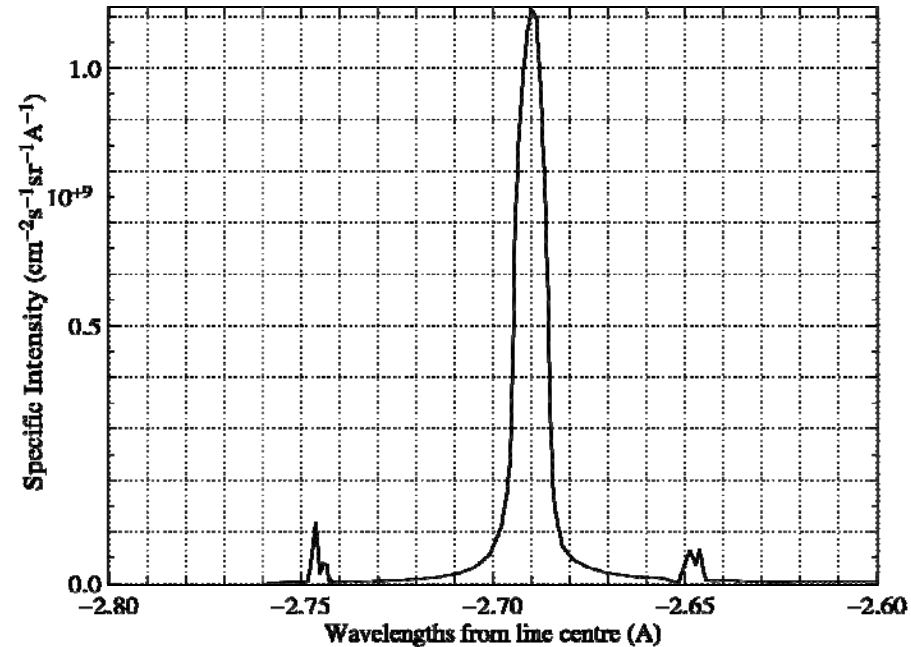
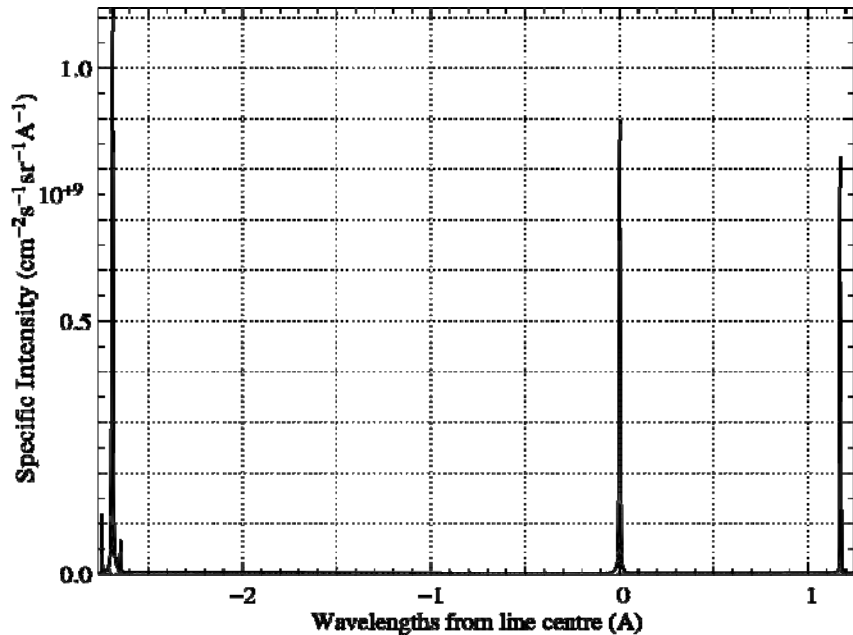


Neutral densities (cm⁻³)

For both models
 $T_{\text{exo}}=200\text{K}$

From Witasse et al. 2002 (Left) and Chaufray et al. 2009 (Right)

Results on Mars: triplet profile.



Effects seems to be more important for low J levels ie for the 130.2nm line.

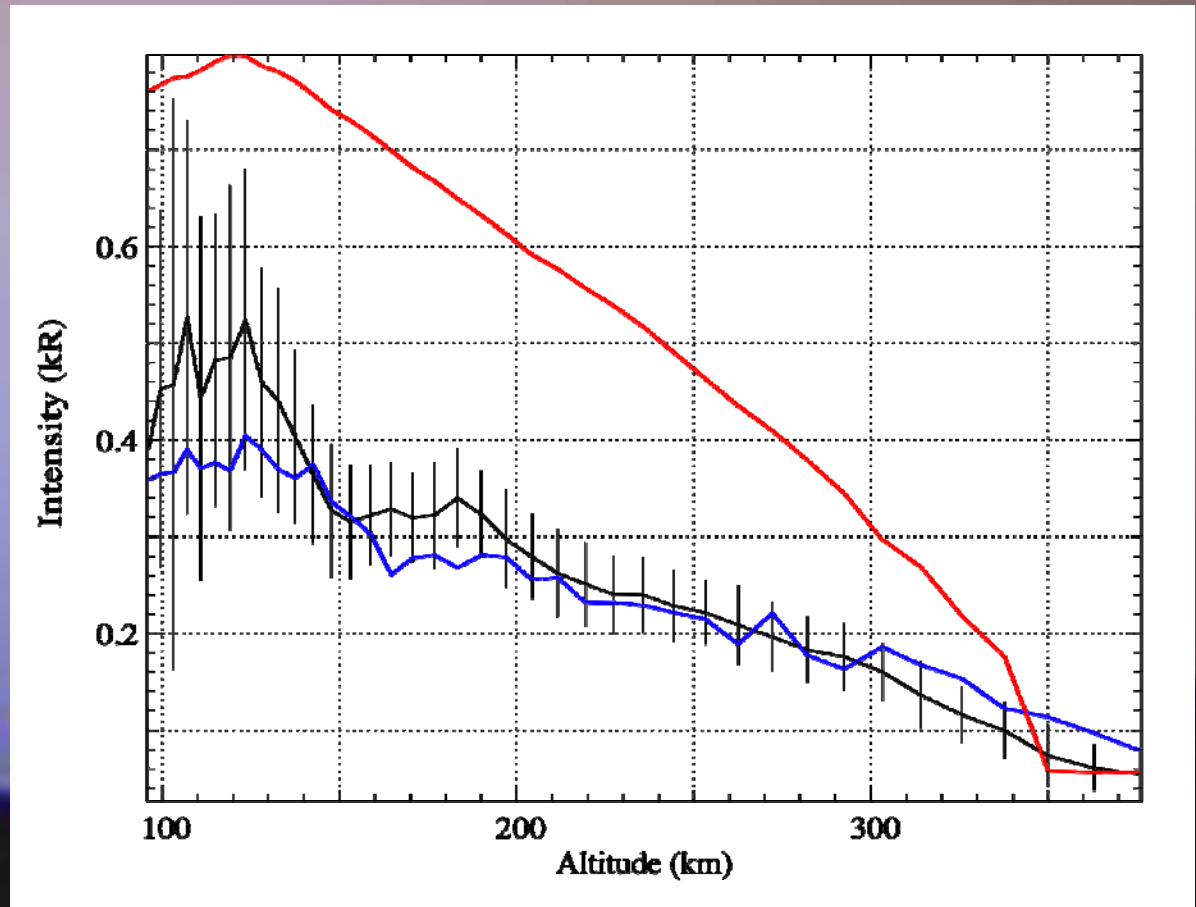
Not only an absorption effect due to the enhancement of the number of photons from the solar line playing a role.

Results on Mars : atmosphere of Chaufray et al. 2009

Red curve: curve with
taking into account
CO effects
Blue curve: with CO
effects

Black error bars:
Spicam data;
Ls=101°; sza ~30°;
f10.7 =80

The code is run with
conditions close to
Spicam ones (ie
same f10.7, same
season, same sza)



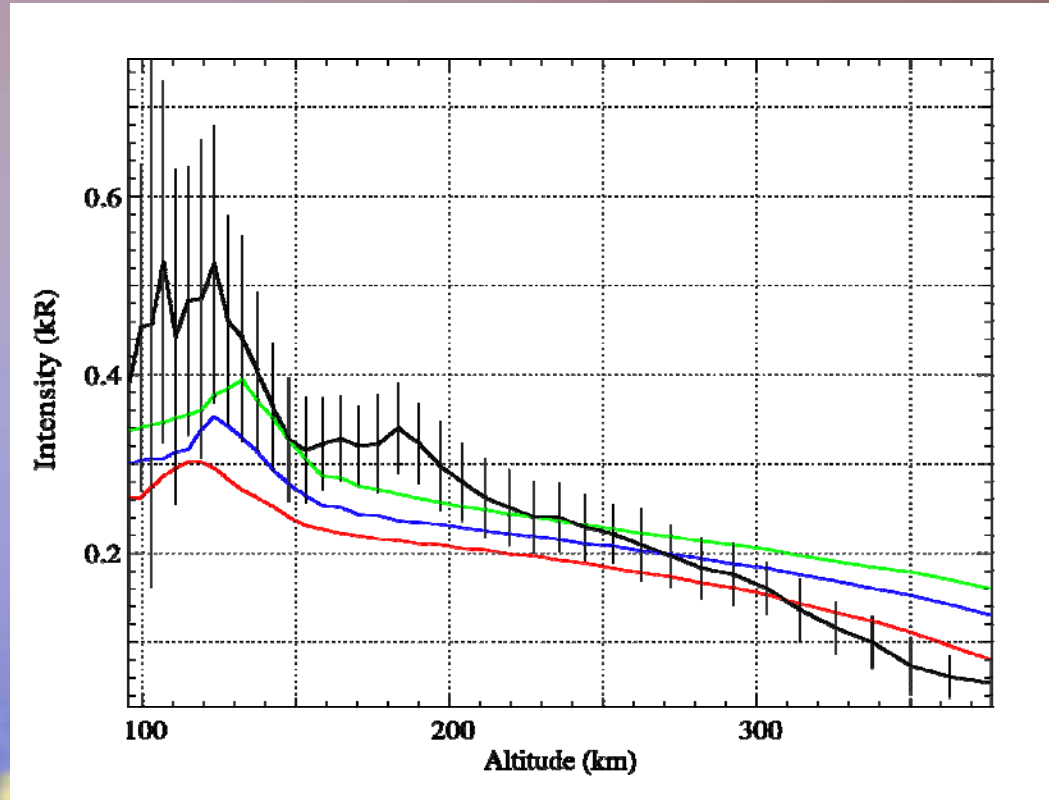
Results on Mars

Black error bars: Spicam data Ls=101°.

Green line: calculation with Atmospheric model (Witasse et al. 2002) in Viking conditions.

Blue line: same atmosphere divided by 2

Red line: divided by 5



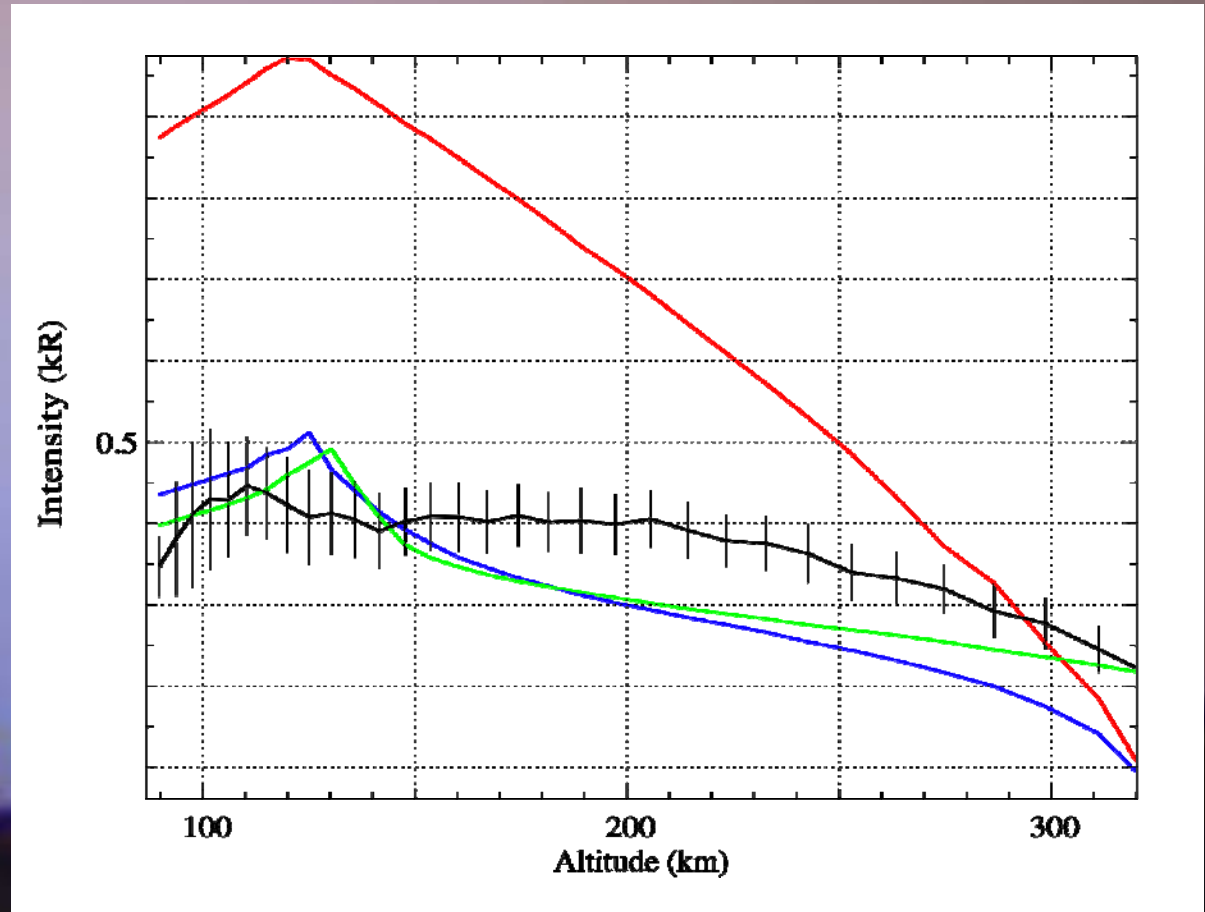
Results on Mars: seasonal variation

Black error bars:
Spicam data $L_s=164^\circ$.

Red line: Atmosphere
of Chaufray et al.
without CO
overlapping.

Blue: Atmosphere of
Chaufray et al. with CO
overlapping

Green: Atmosphere of
Witasse et al. with CO
overlapping



Results on Mars: seasonal variation

Black error bars: Spicam data Ls=164°.

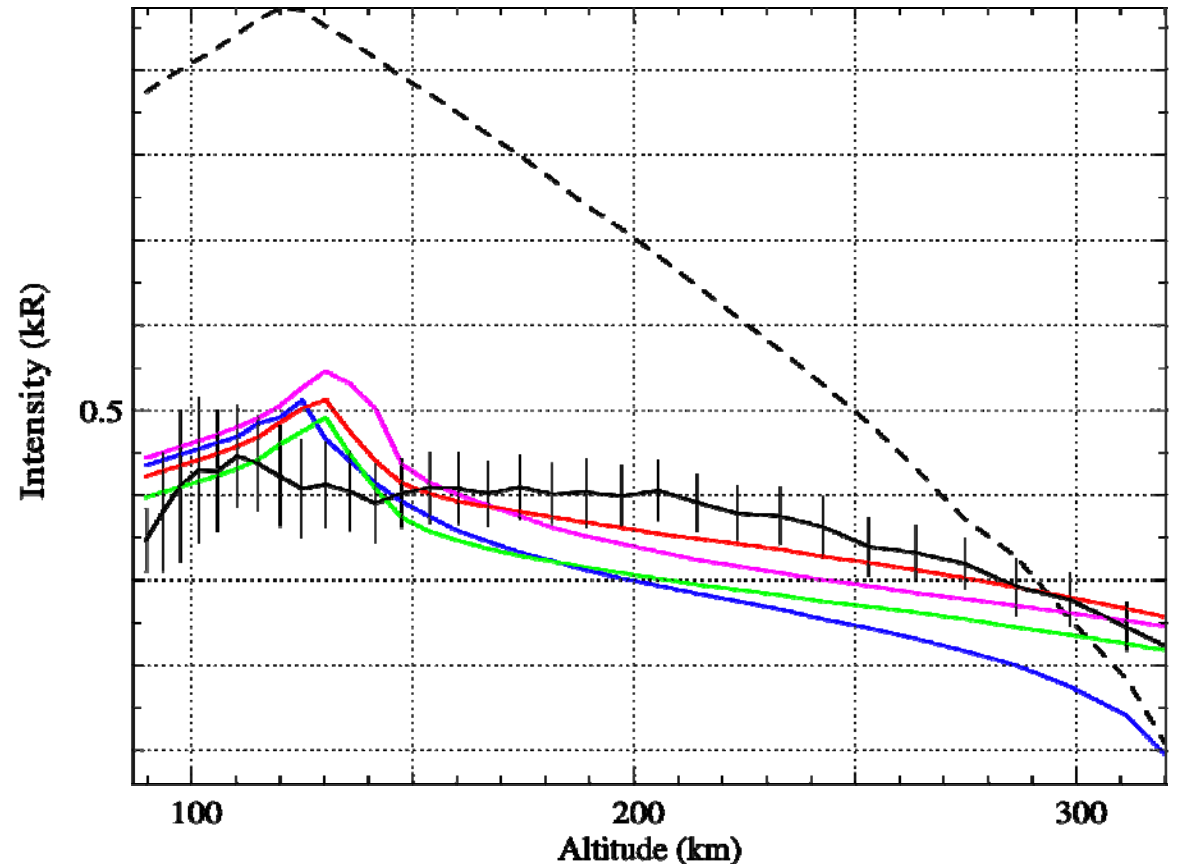
Red line: Atmosphere of Chaufray et al. without CO overlapping.

Blue: Atmosphere of Chaufray et al. with CO overlapping

Green: Atmosphere of Witasse et al. with CO overlapping

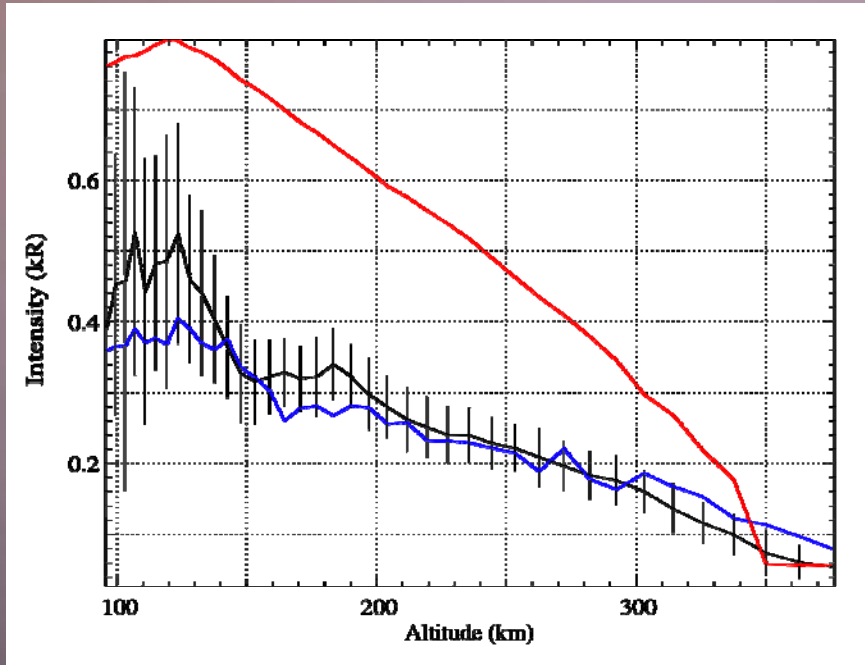
Purple: Atmosphere of Witasse et al. multiplied by 2

Red: Atmosphere of Witasse et al. with $T_{\text{exo}}=300\text{K}$

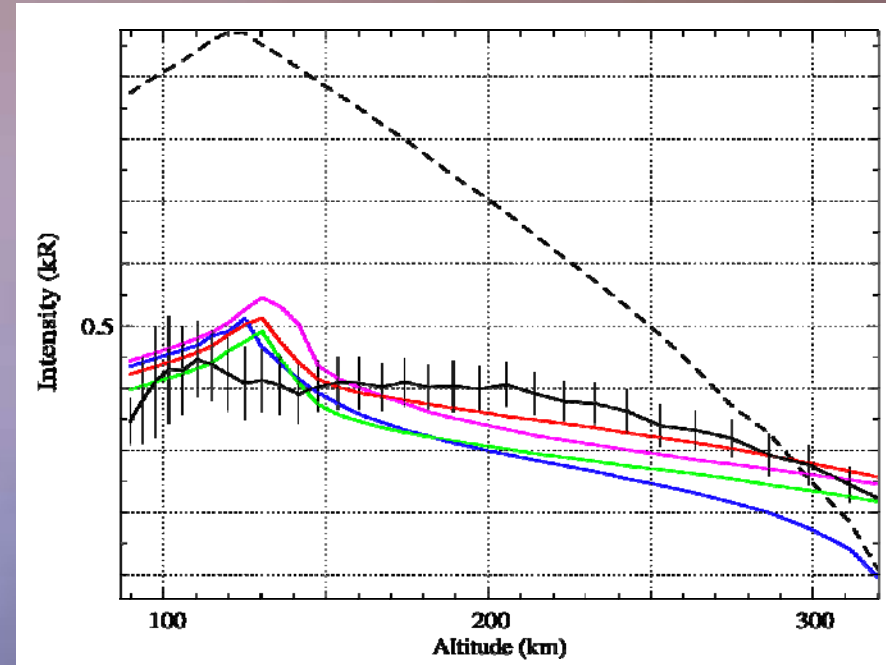


Results on Mars

Ls=101°



Ls=164°



For Ls=101°

- Good fitting with Chaufray's atmospheres with $T_{\text{exo}}=200\text{K}$
- CO overlapping allowed to fit the data
- No fitting neither with the other atmospheric model nor when dividing the atmosphere by a factor.

For Ls=164°

- Best fit with $T_{\text{exo}}=300\text{K}$. Still discrepancies around 200 km.

Summary

- Important CO effect.

Important modification in the radiative transfer for O 130nm line.

- Represents a new constraint for atmospheric models.

- Seasonal variation at high altitudes.

- Limits of the blind approach for fitting the data

- A several parameters problems with correlations between them.

- Such an approach gives only the tendencies needed to fit the data.

- Need for really accurate atmospheric models to fit the data

Conclusions

- CO overlapping with the O 130nm line is a strong new phenomena for radiative transfer calculations
- Required to fit with accuracy the O concentration from UV data in the cases of Mars and Venus.