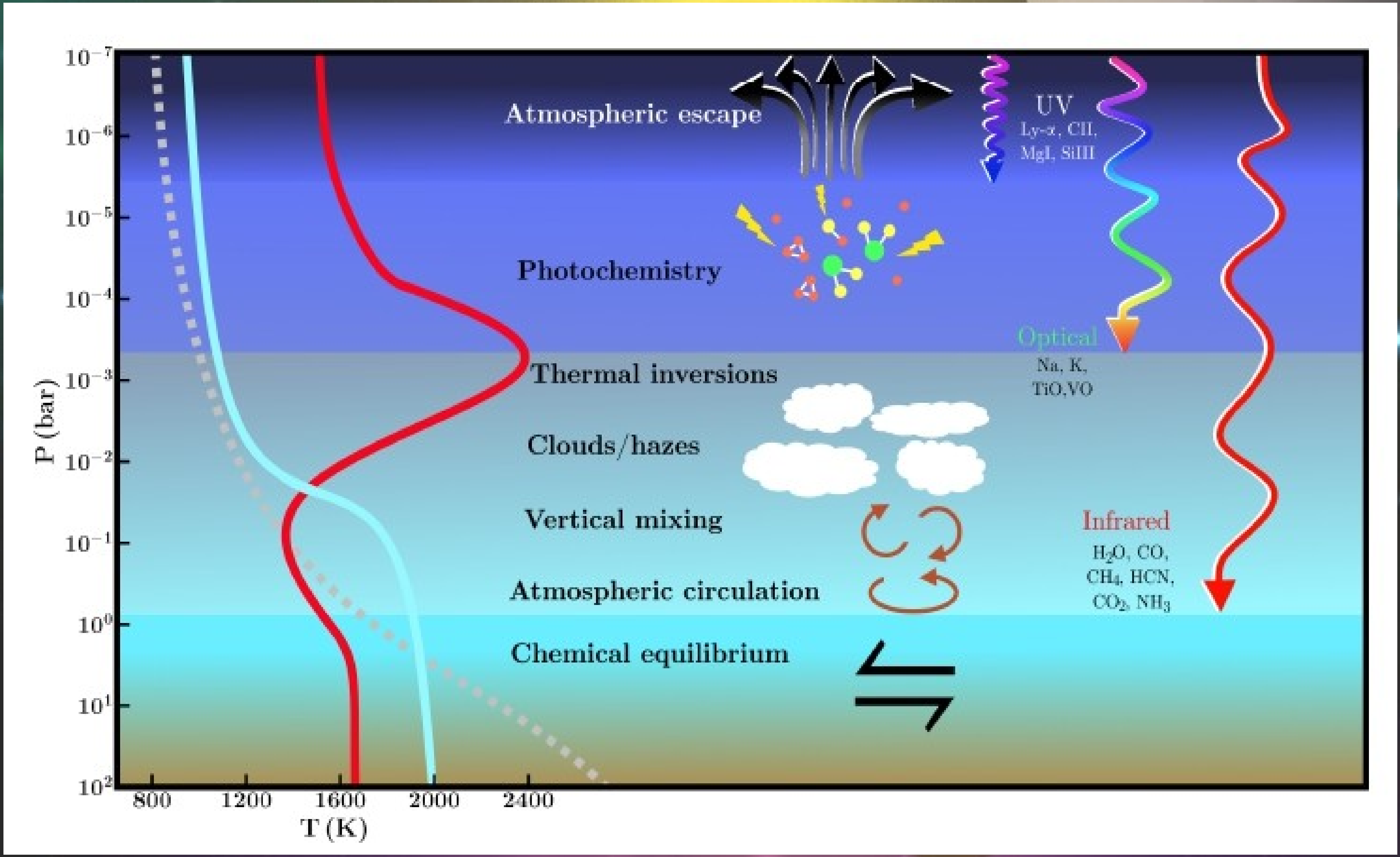
Chemical signatures in synthetic spectra induced by XUV radiation

Daniele Locci
A. Petralia, G. Aresu*, G. Micela, A. Maggio, A. Ciaravella, C. Cecchi-Pestellini
INAF – Osservatorio Astronomico di Palermo
*INAF – Osservatorio Astronomico di Cagliari

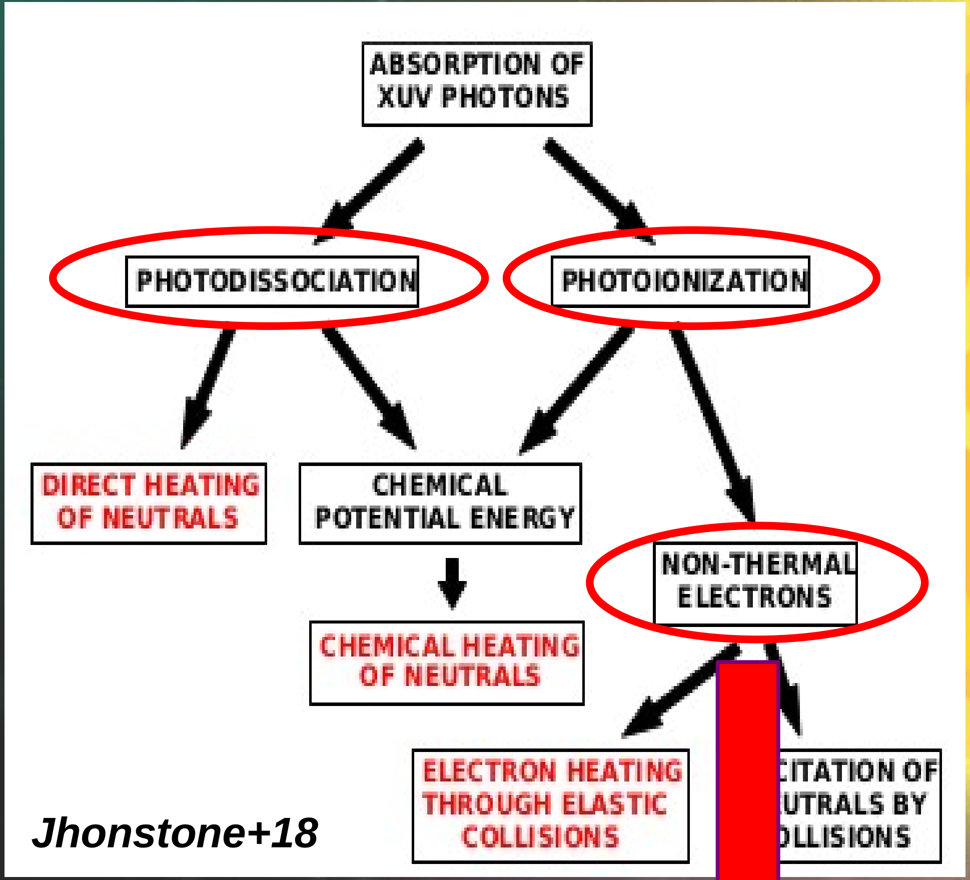
Ariel-It science
26th May 2022

Introduction

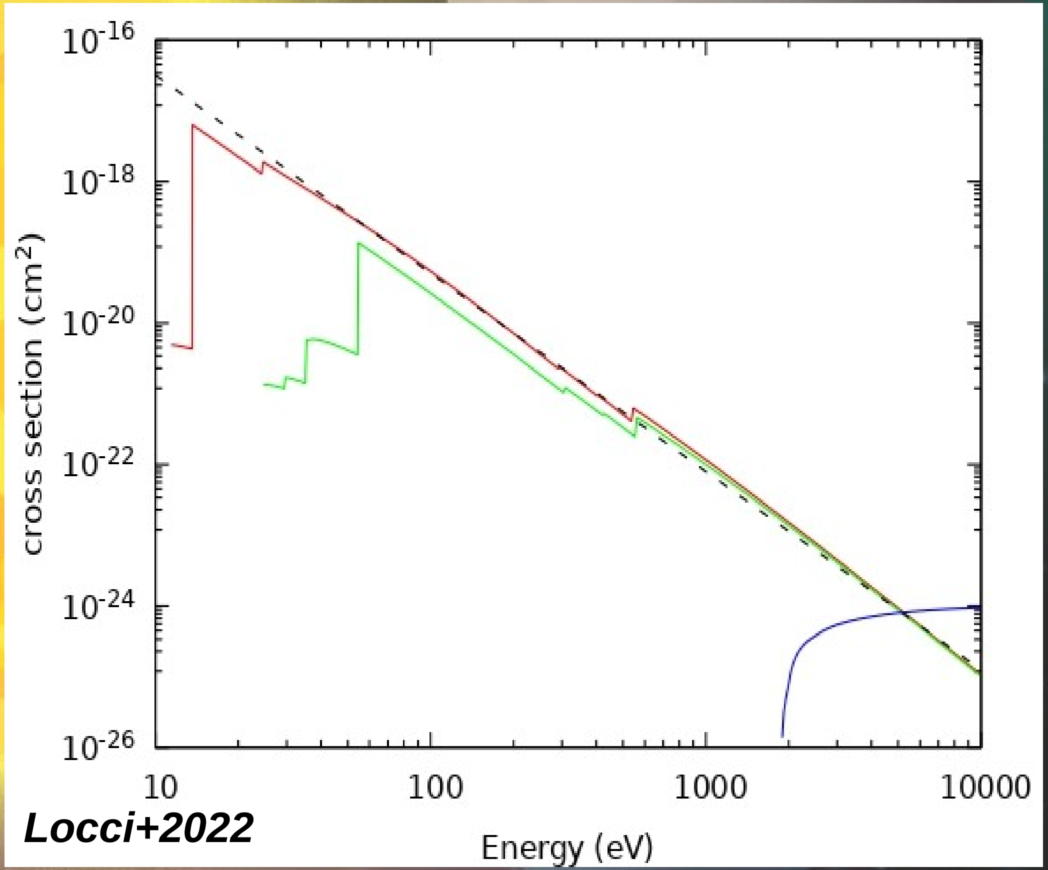


Madhusudhan 2019

XUV absorption



Jhonstone+18

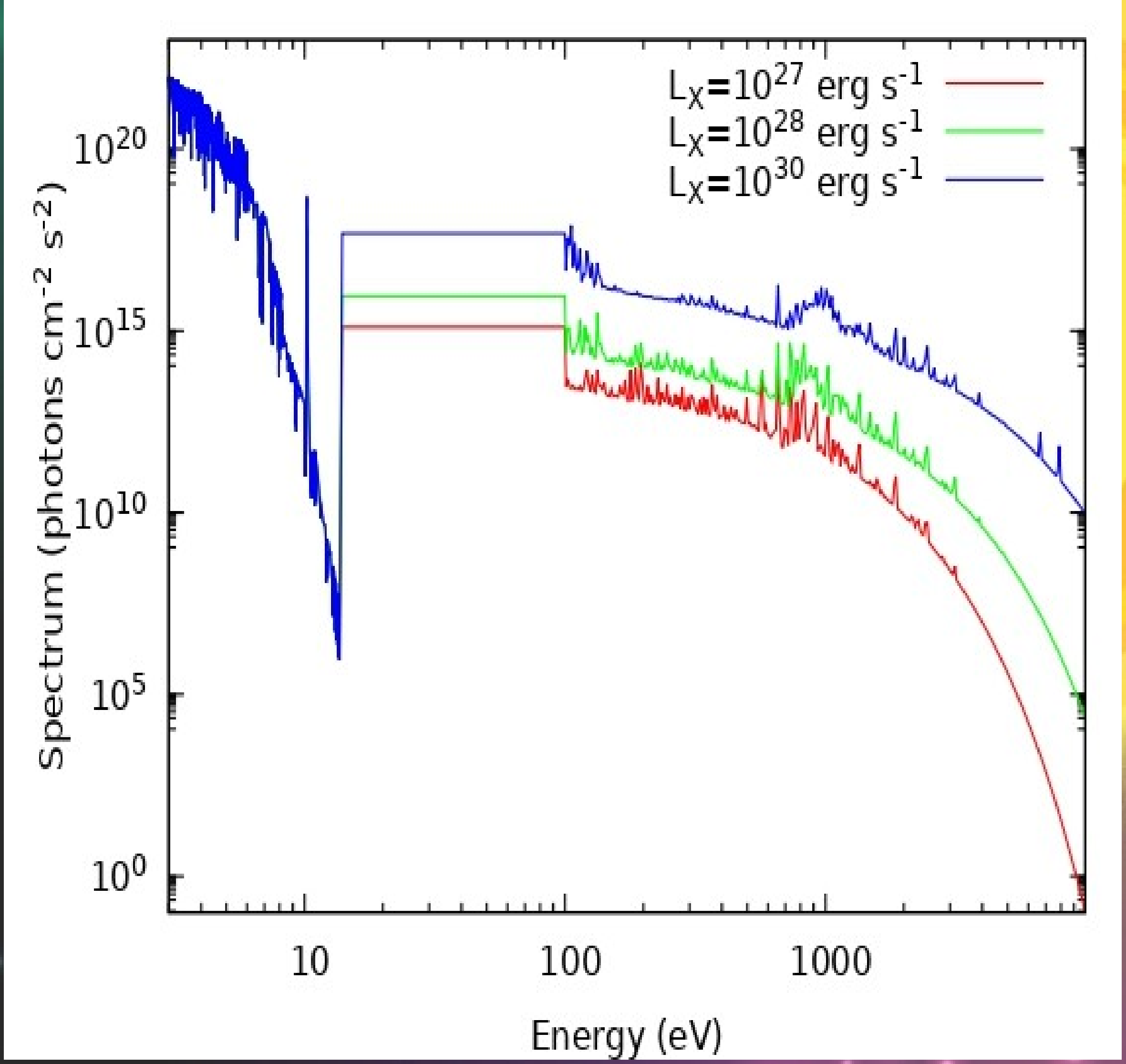


Locci+2022

Secondary ionization

$W(E)$ Energy to make a ion pair (*Cecchi-Pestellini+06*)

Adopted spectrum



Locci+22

UV (3 - 13.6 eV)

Stellar spectrum from Phoenix

Lyman-α from *Linsky+20*

EUV (13.6 - 100 eV)

Constant spectral shape

$$L_{EUV} = 6.31 \cdot 10^4 \times L_X^{0.86}$$ *Sanz-Forcada+11*

X-rays (0.1 - 10 keV)

Emission from a optically thin plasma *Raymond & Smith+77*

L_X is an input parameter

Chemical network

105 different chemical species plus their ions
2535 chemical and 165 photochemical reactions
Possibility to choose a reduced set of elements

- Bimolecular
- Termolecular
- Thermo-dissociative
- Ion-neutral
- Photodissociation
- Photoionization

Exploratory runs with ~70 species: H, He, O, C, N

$$\frac{\partial n_i(r)}{\partial t} + \frac{\partial \varphi_i(r)}{\partial r} = P_i(r) - n_i L_i(r)$$

Exploratory runs

Reference model

Parameter	Value
Mass	150 M⊕
Radius	12 R⊕
Temperature	1000 K
Zenit angle	60°
X-rays luminosity	10^{28} erg s^{-1}

Ionization provided by EUV radiation is the dominant process in the upper layers

Due to the small cross section of atmospheric constituents X-rays penetrate deeper in the atmosphere giving rise to a characteristic chemistry

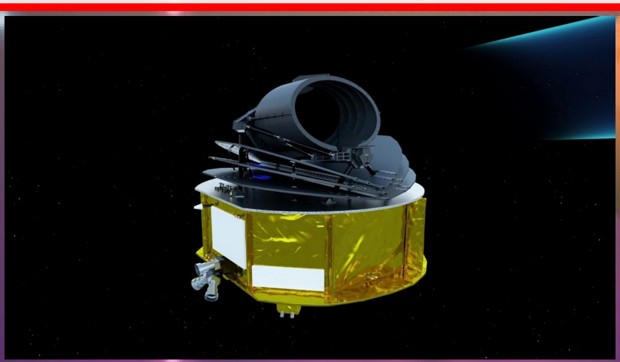
We found two classes of elements:
Species like hydrocarbons or ammonia that increase their abundance with the increase of X-rays luminosity
Species like water or carbon monoxide that decrease their abundance with the increase of X-rays luminosity

Transmission spectra
(working in progress)

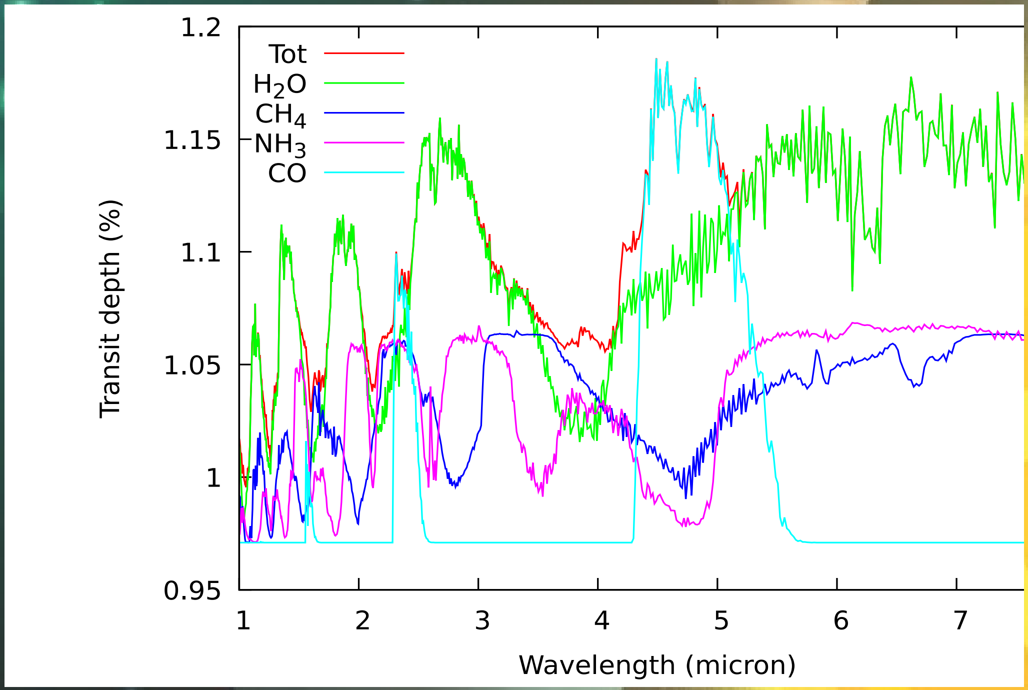
We build up total absorption cross-section taking into account several neutral species such as H_2O, CH_4 and NH_3 and some ionic species such as H_3O^+, H_3^+

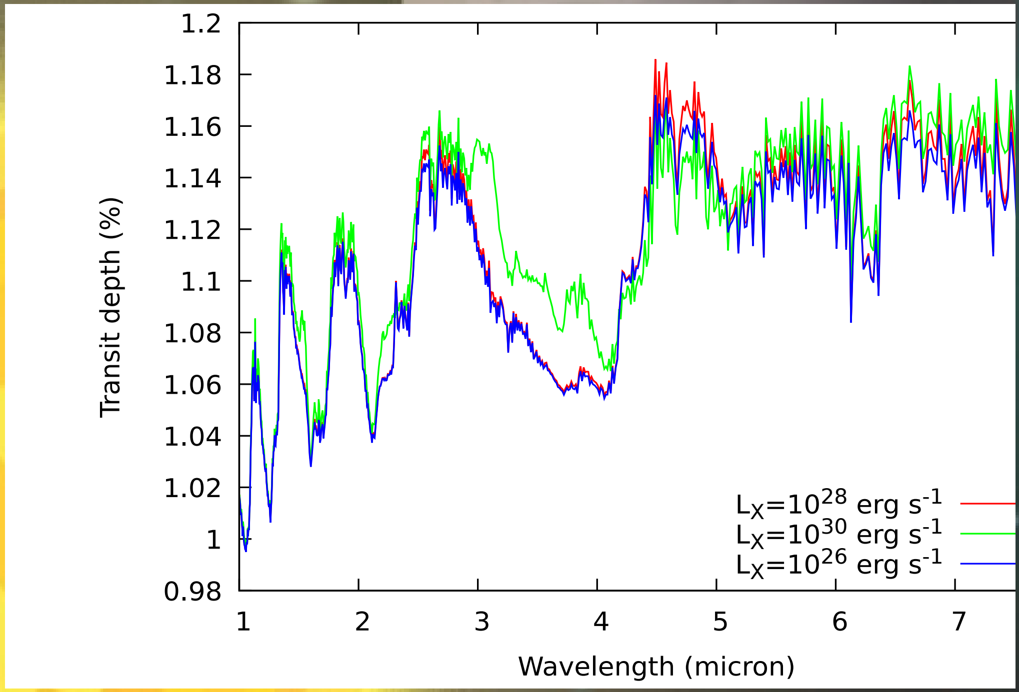
We assembled absorption coefficients exploiting the molecular spectroscopic databases ExoMol and HITRAN in the interval 0.24-1000 μm

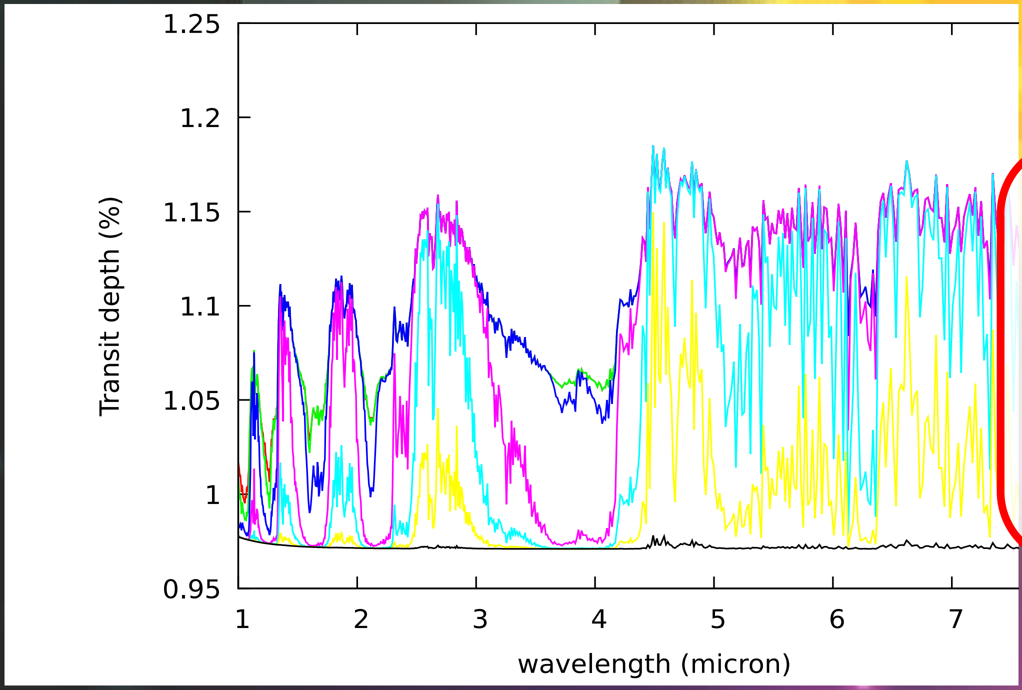
Exploiting the chemical code we computed vertical chemical profiles for different values of X-ray luminosity. For each model and for each pressure grid point we calculated absorption cross-sections



Transmission spectra



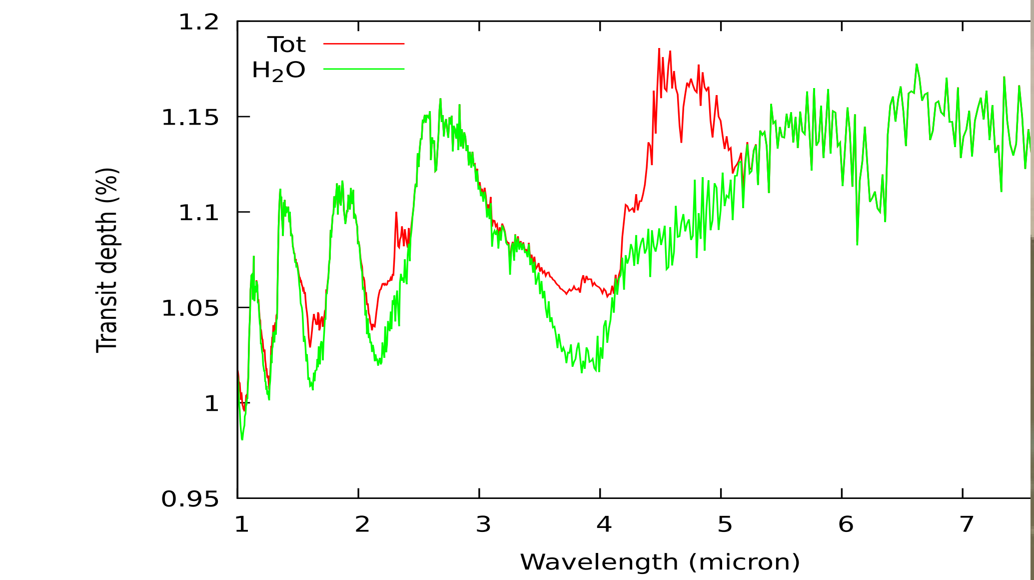


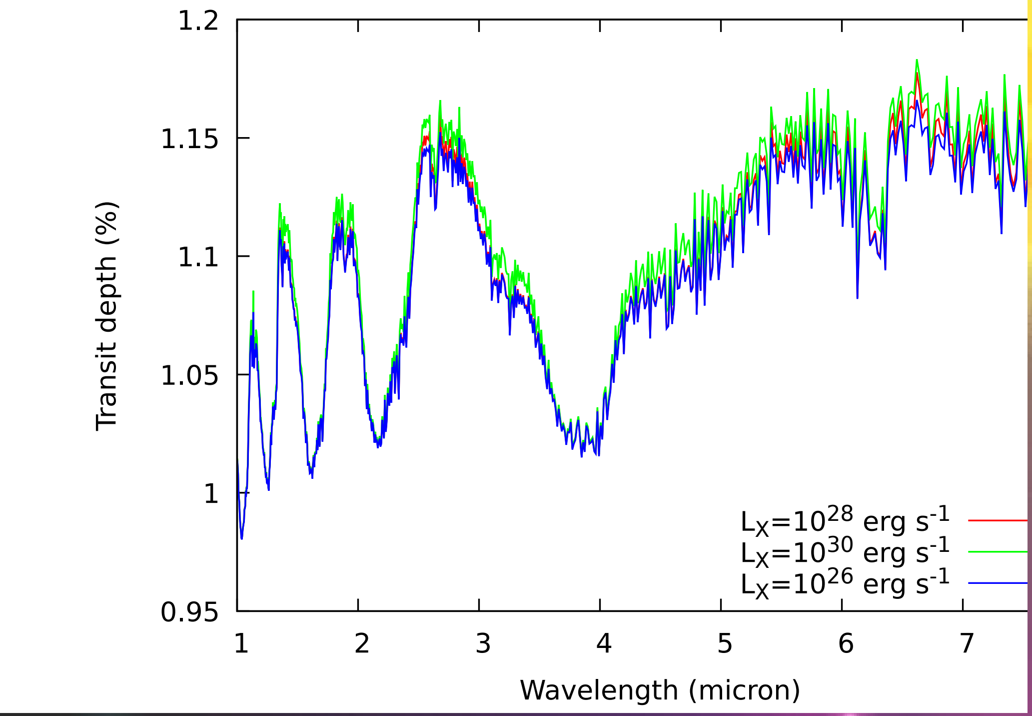


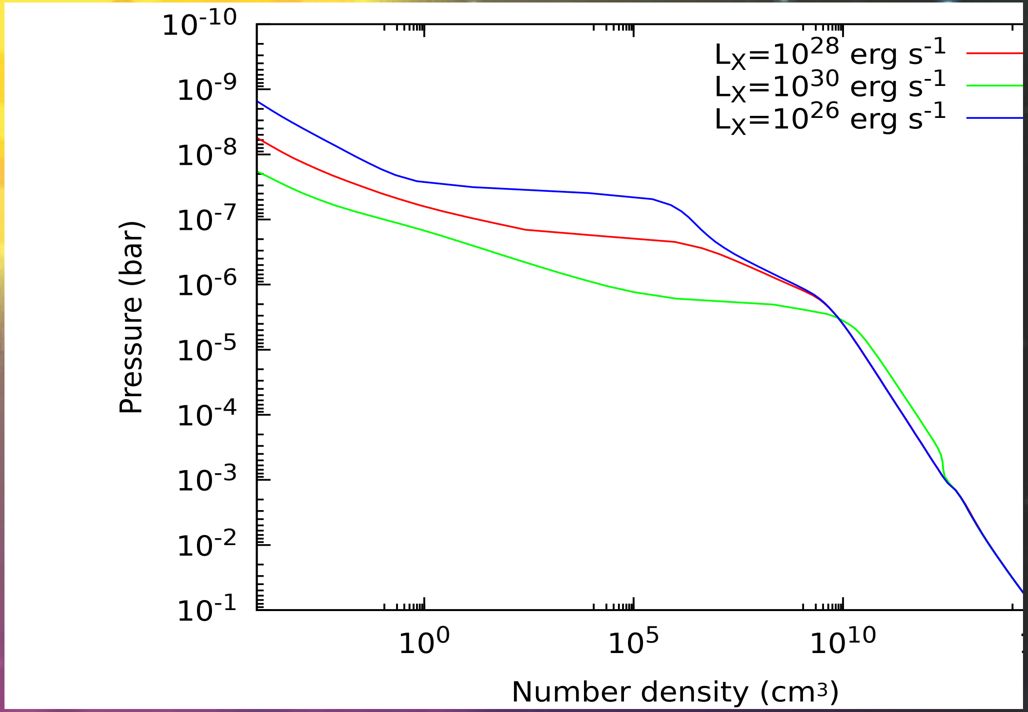
Red: contribution from all layers
Green: contribution from layers with $P<10^{-1}$ bar
Blue: contribution from layers with $P<10^{-2}$ bar
Purple: contribution from layers with $P<10^{-3}$ bar
Light Blue: contribution from layers with $P<10^{-4}$ bar
Yellow: contribution from layers with $P<10^{-5}$ bar
Black: contribution from layers with $P<10^{-6}$ bar

Transmission spectra

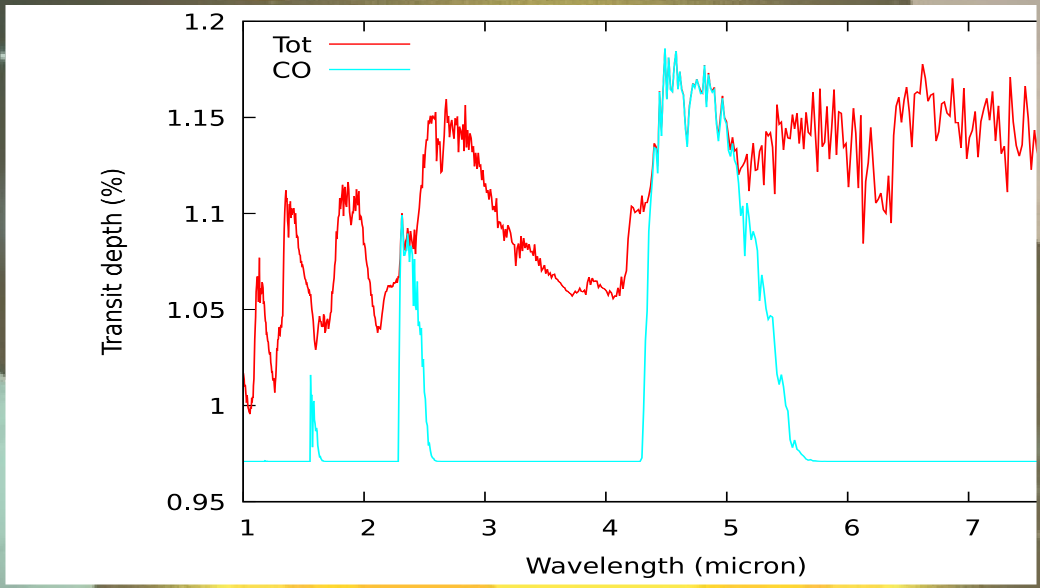
H_2O

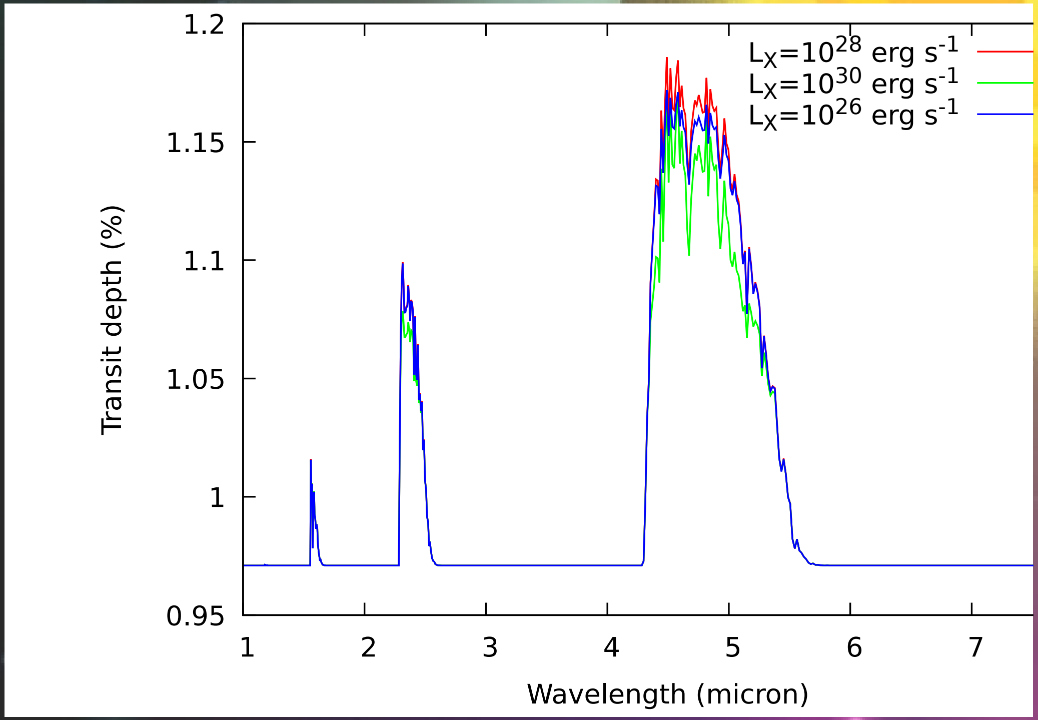


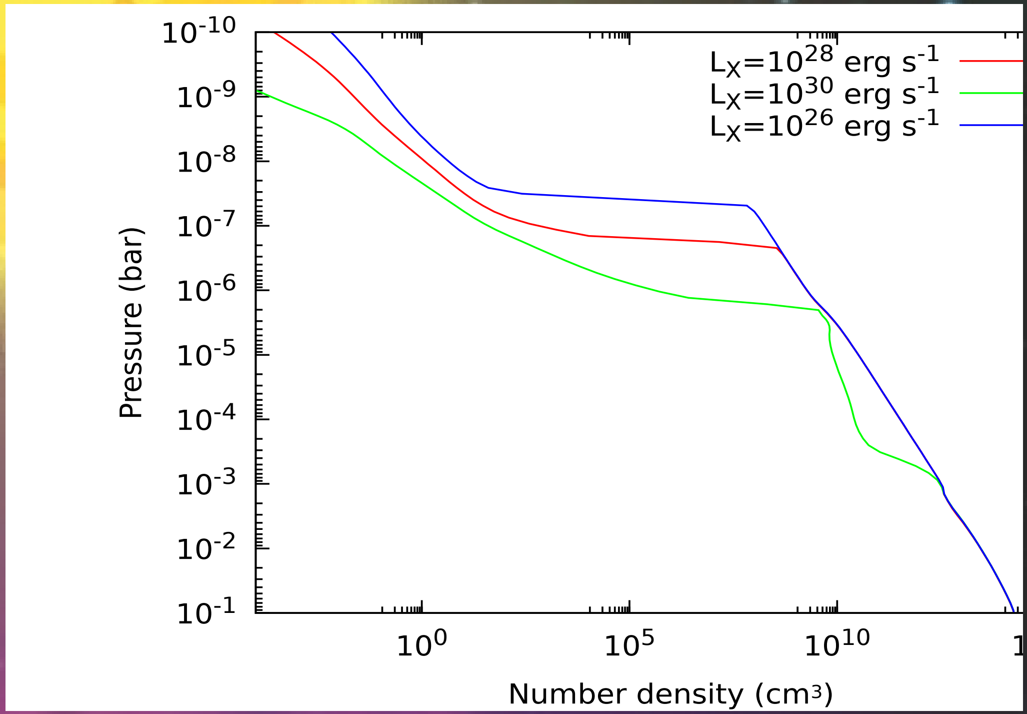




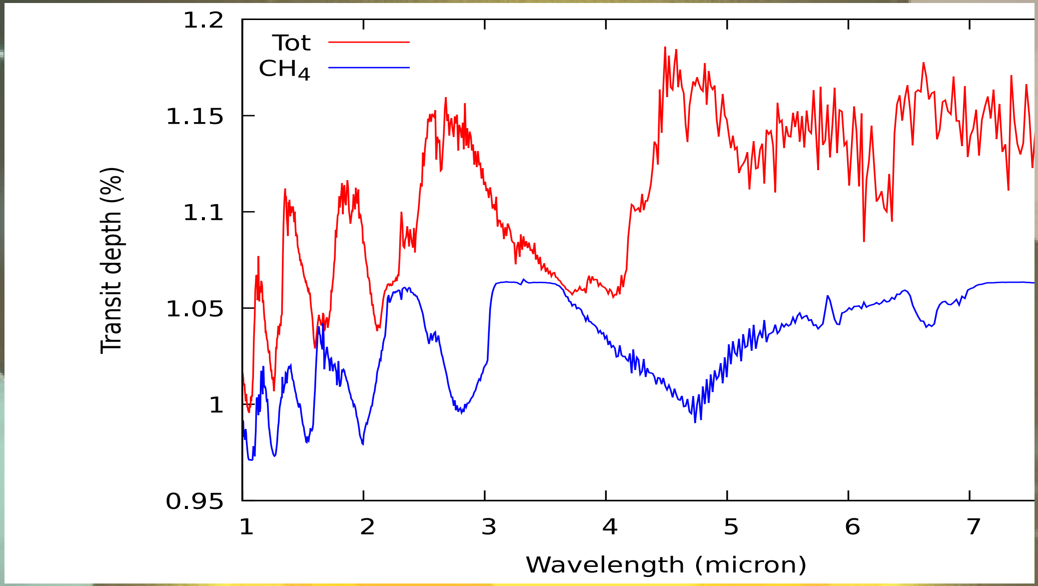
Transmission spectra
CO

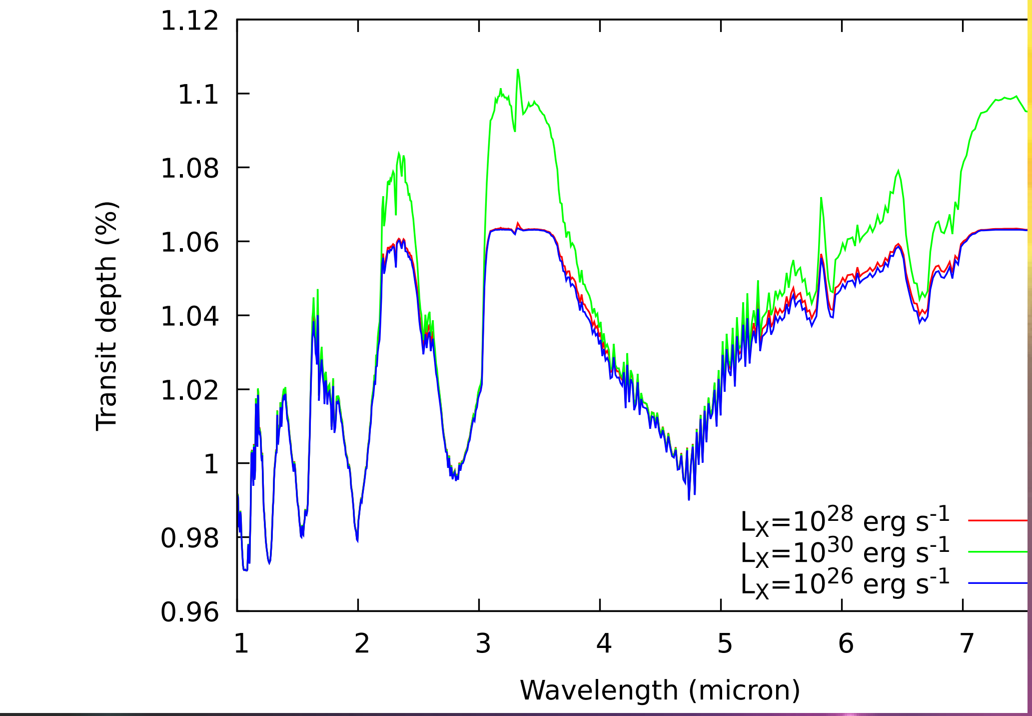


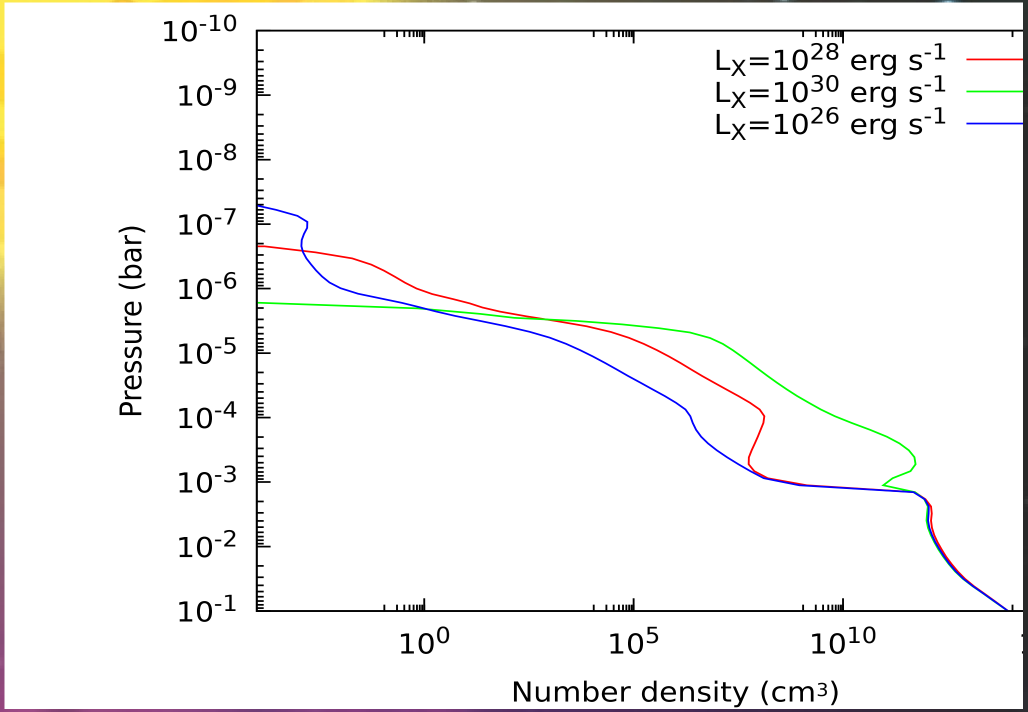




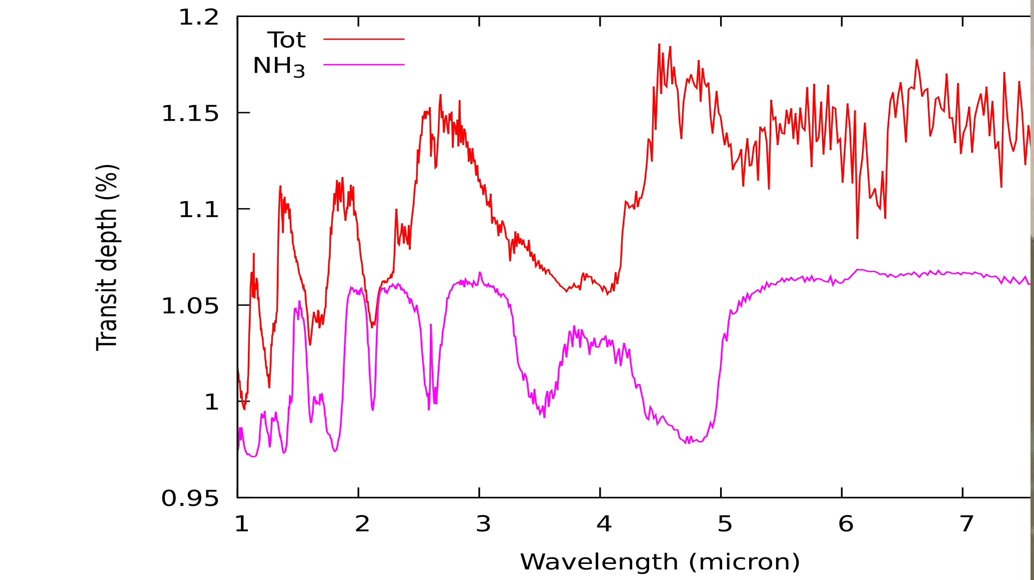
Transmission spectra
CH_4

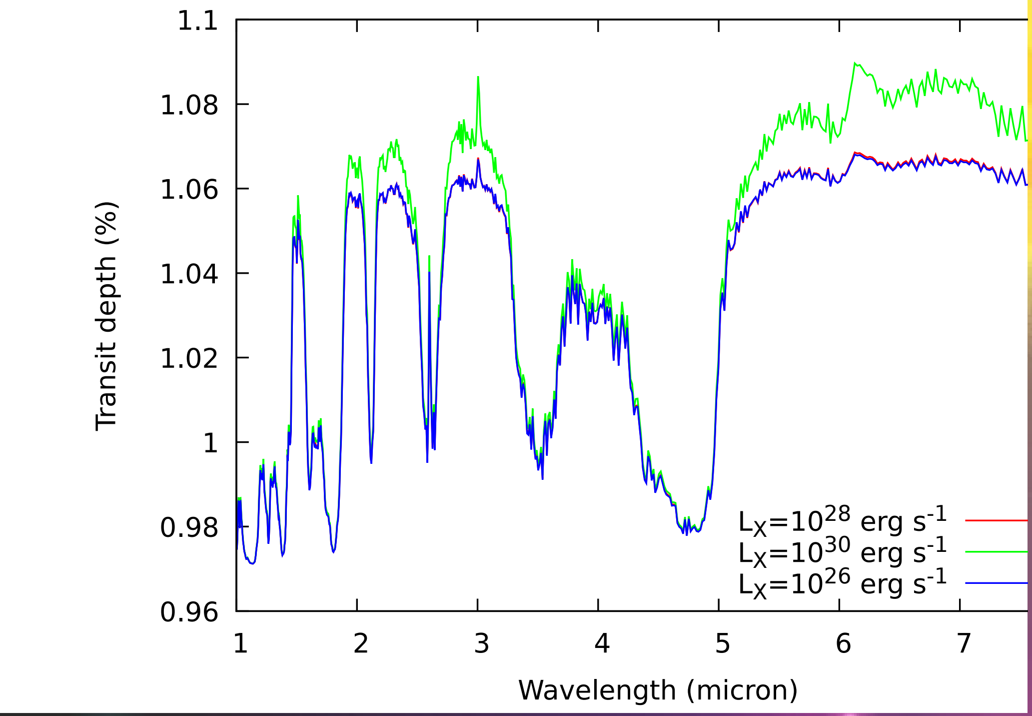


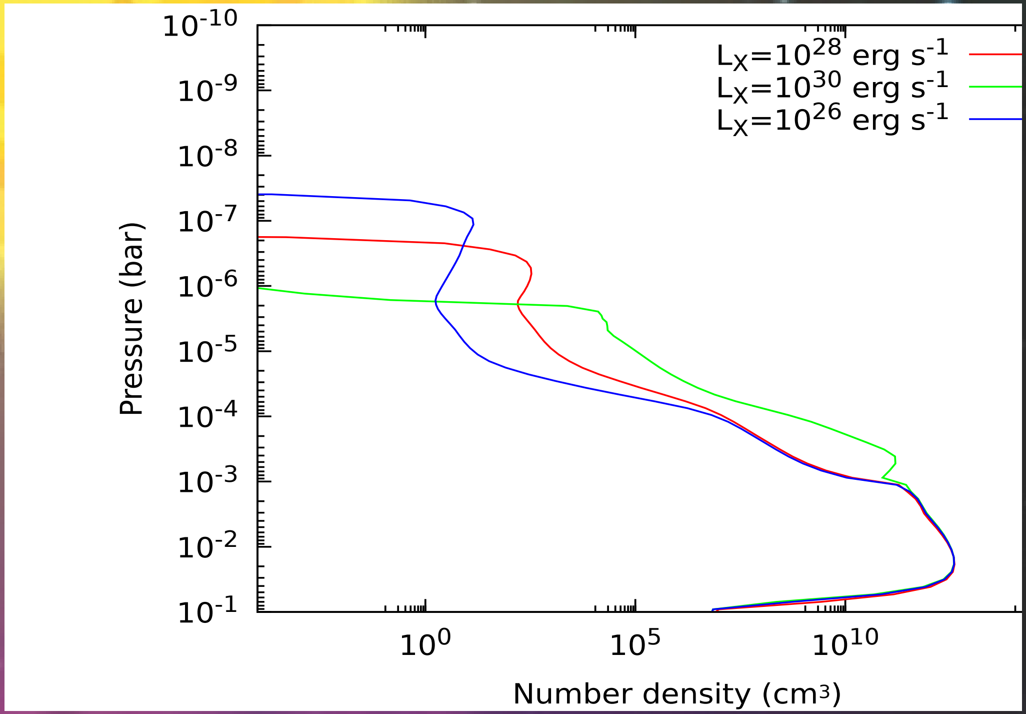




Transmission spectra
NH_3

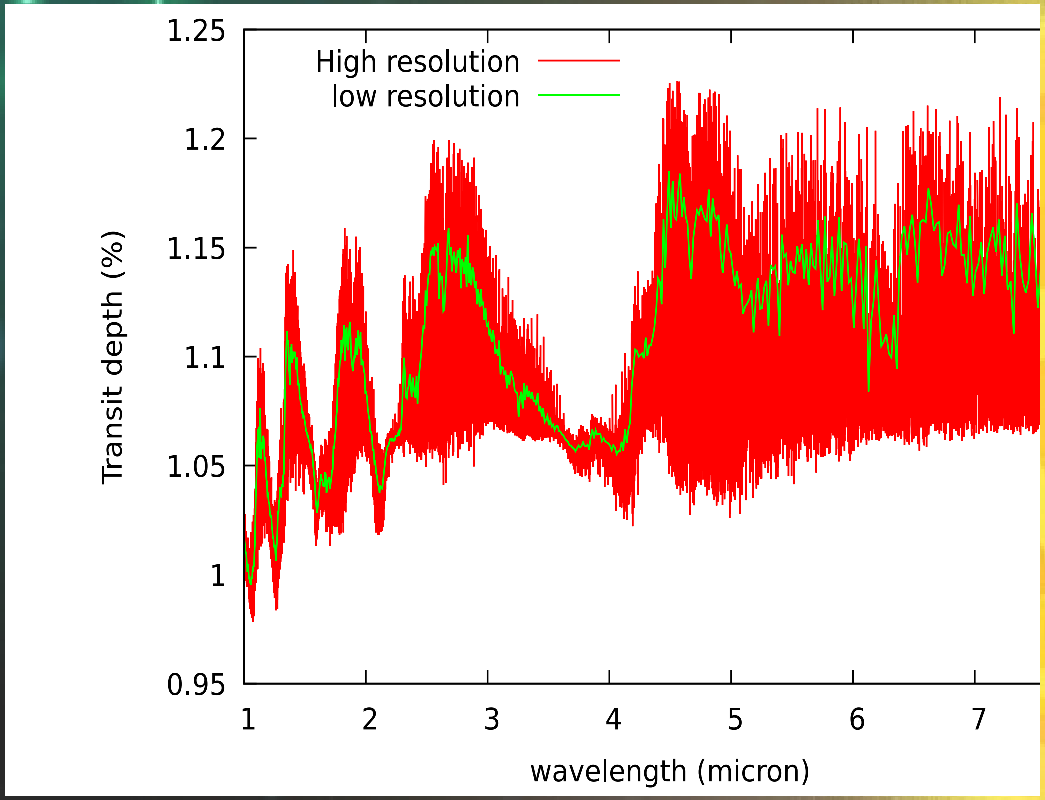


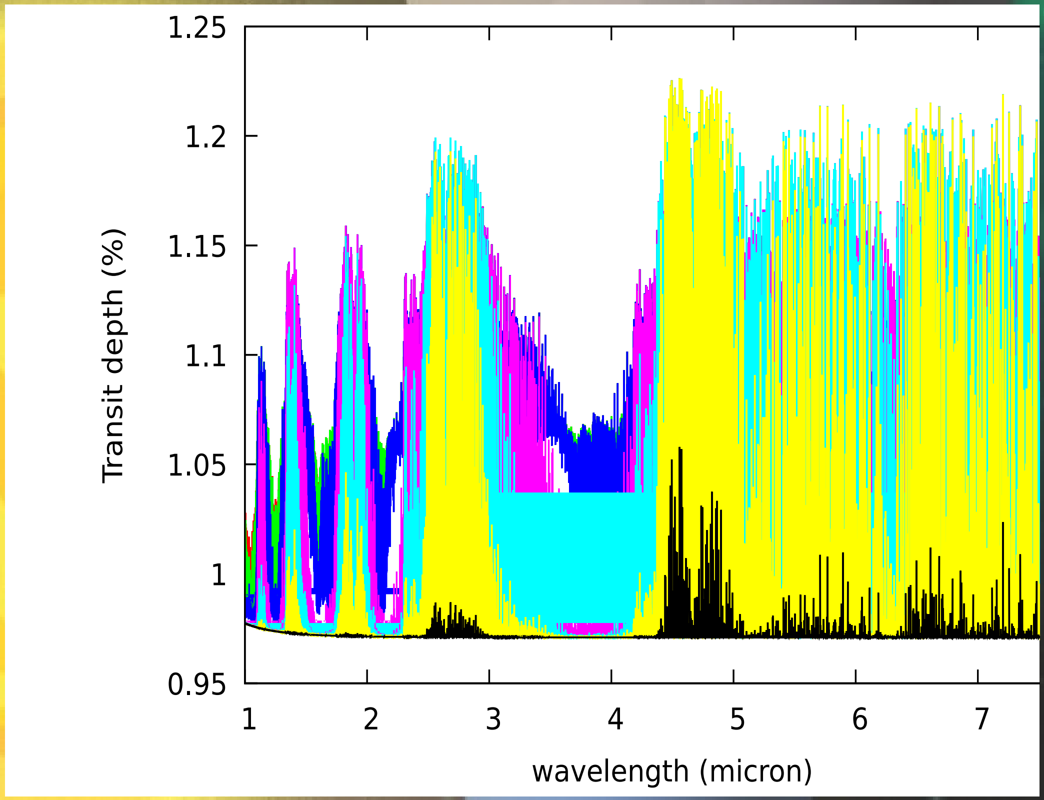




Transmission spectra

High resolution (R=10000)





Red: contribution from all layers
Green: contribution from layers with $P<10^{-1}$ bar
Blue: contribution from layers with $P<10^{-2}$ bar
Purple: contribution from layers with $P<10^{-3}$ bar
Light Blue: contribution from layers with $P<10^{-4}$ bar
Yellow: contribution from layers with $P<10^{-5}$ bar
Black: contribution from layers with $P<10^{-6}$ bar

Next steps

Account for vertical mixing

Calculate pressure-temperature profiles and chemical profiles in a self consistent way

Explore the role of metallicity or of C/O ratio

Evaluate if in extreme cases it is possible to observe spectral features due to ionic species