Part II :

Atmospheric Extinction at selected wavelengths and in bands in libradtran & Auxtel Data

Sylvie Dagoret-Campagne

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StarDice Workshop

Standard (unmodified) Lambert attenuation Law

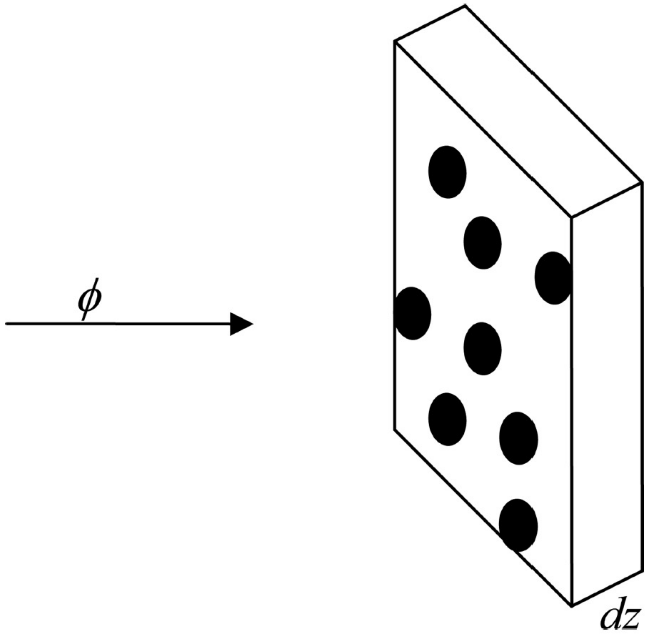

Fig. 1. A photon flux ϕ is impinging on a thin slab of thickness dz and area A. The density of the atoms is given by N_t, therefore, there are N_tdzA atoms in the thin slab. If the effective area of an atom is σ, the probability of a collision (i.e., absorption) is $\sigma N_t A \mathrm{d}z/A = \sigma N_t \mathrm{d}z = \alpha \mathrm{d}z$. Therefore the attenuation of the photon flux ϕ would be $-\alpha\phi\mathrm{d}z$. This model neglects the effect of stimulated emission and spontaneous emission.

$$\frac{\mathrm{d}\phi}{\mathrm{d}z} = -\alpha\phi. \qquad (1)$$

The solution of Eq. (1) yields Beer's absorption law:

$$\phi(z) = \phi(0)e^{-\alpha z}. \qquad (2)$$

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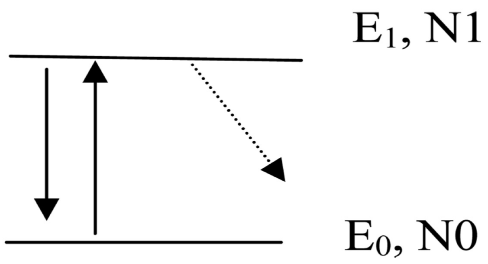
$$\alpha = n\sigma$$

Modified Lambert Law :
Application to a 2-level state : Absorption extinction follow a so-called Lambert-W or Write-Omega function

sity), this law breaks down. This is because at high photon flux the processes of stimulated emission and spontaneous emission cannot be ignored. They start



$$\frac{\mathrm{d}N_0}{\mathrm{d}t} = -\sigma\phi N_0 + \sigma\phi N_1 + \tau^{-1} N_1,$$

$$\frac{\mathrm{d}N_1}{\mathrm{d}t} = \sigma\phi N_0 - \sigma\phi N_1 - \tau^{-1} N_1.$$

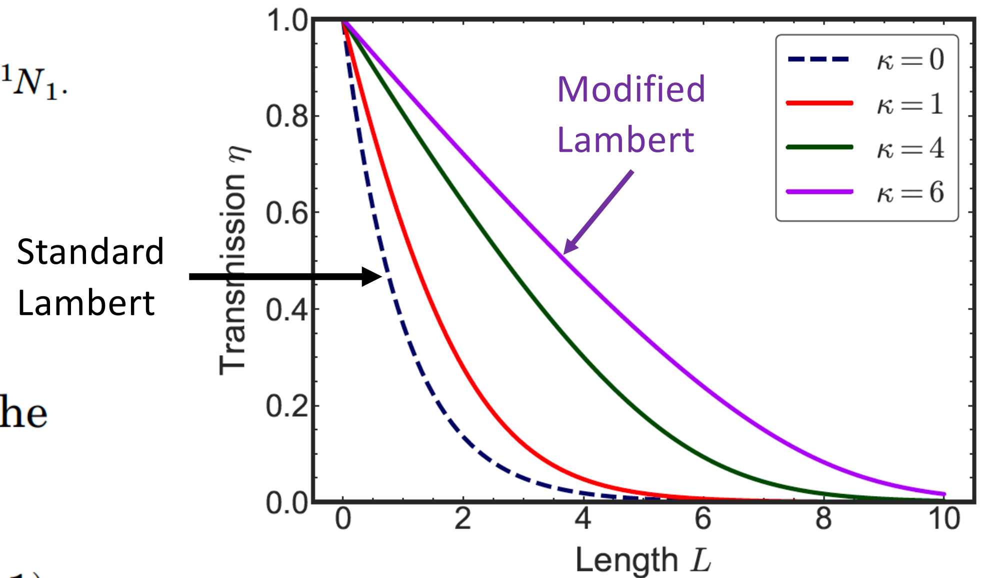
$$\mathrm{d}\phi = -N_t \sigma\phi \frac{1}{1+2\sigma\tau\phi}\mathrm{d}z.$$

We arrive at an expression for $\phi(z)$ in terms of the Lambert W-function:

$$\phi(z) = \frac{1}{2\sigma\tau} W(2\sigma\tau\phi(0)\exp[2\sigma\tau\phi(0) - N_t\sigma z]). \quad (11)$$

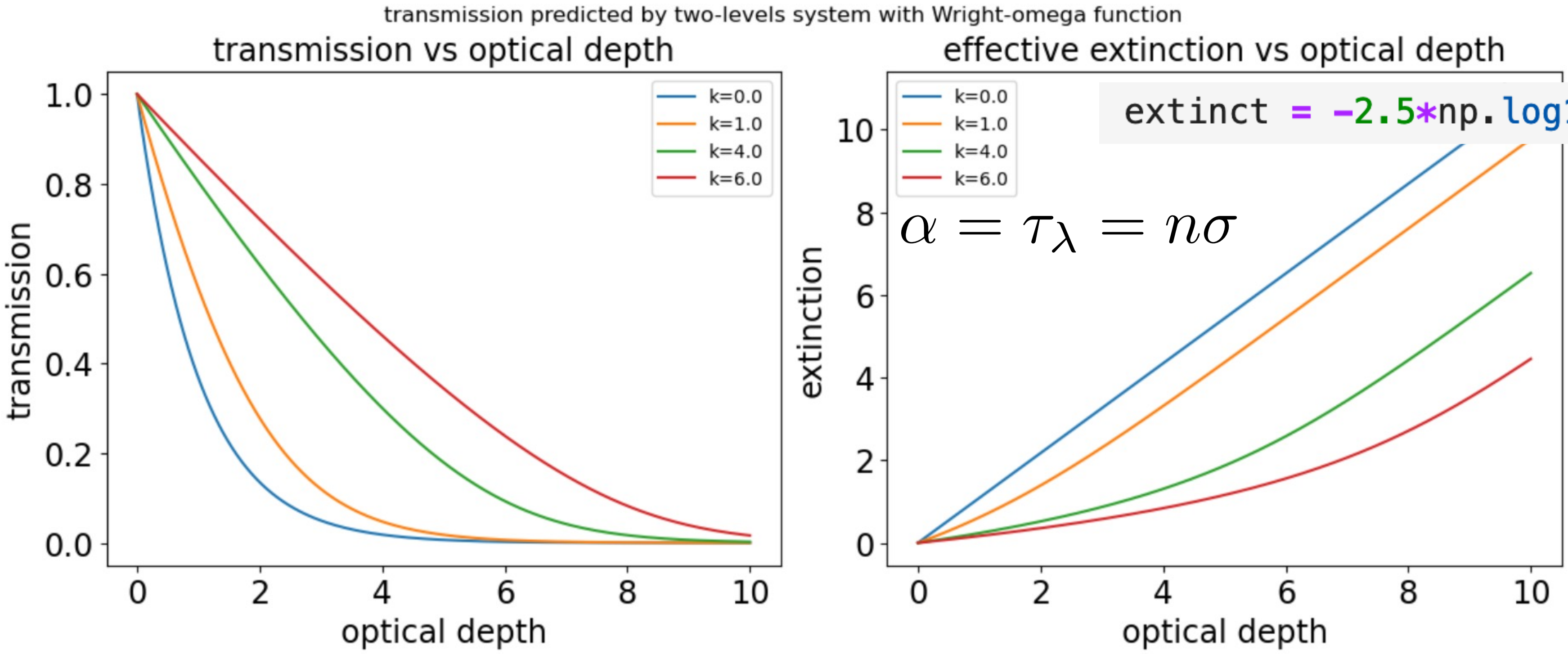
We introduce $\kappa = 2\langle\hat{n}\rangle_{in}/n_s$ as a dimensionless quantity:

$$\eta(\kappa) = \frac{1}{\kappa}\mathcal{W}(ln(\kappa) + \kappa - aL).$$



From "Correction to the Beer-Lambert-Bouguer law for optical absorption" (Abitan et al.,2008)

Predicted transmission and extinction for the modified Lambert Law (for 2-energy levels system)




```
extinct = -2.5*np.log10(T)
```

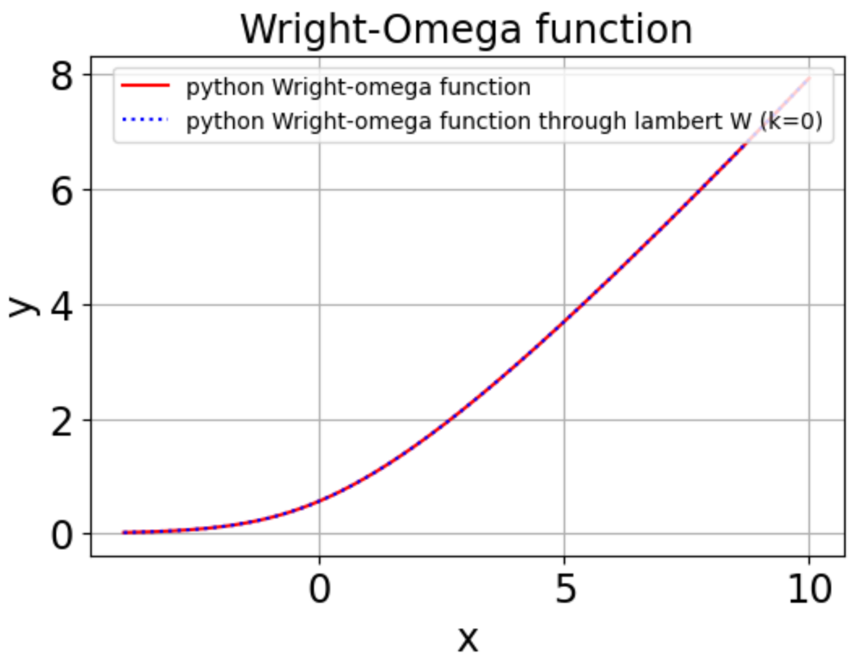
$$\alpha = \tau_\lambda = n\sigma$$

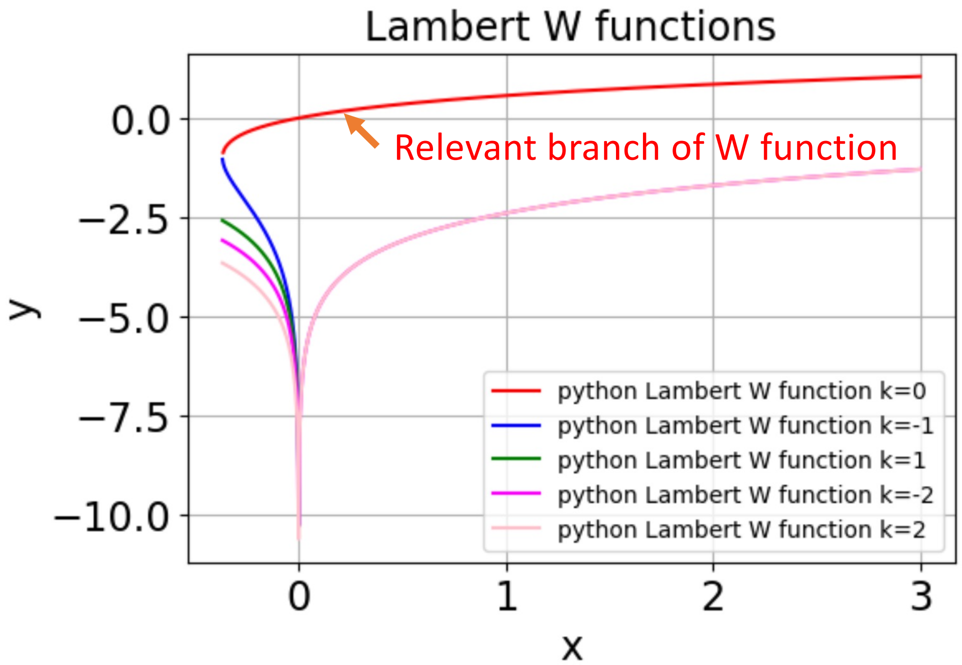
$$\eta(\kappa) = \frac{1}{\kappa}\mathcal{W}(ln(\kappa) + \kappa - aL).$$

```
T = 1/k*wrightomega(k+np.log(k)-x)
```

```
T = 1/k*lambertw(np.exp(k+np.log(k)-x))
```

Functions Wright-omega and Lambert-W





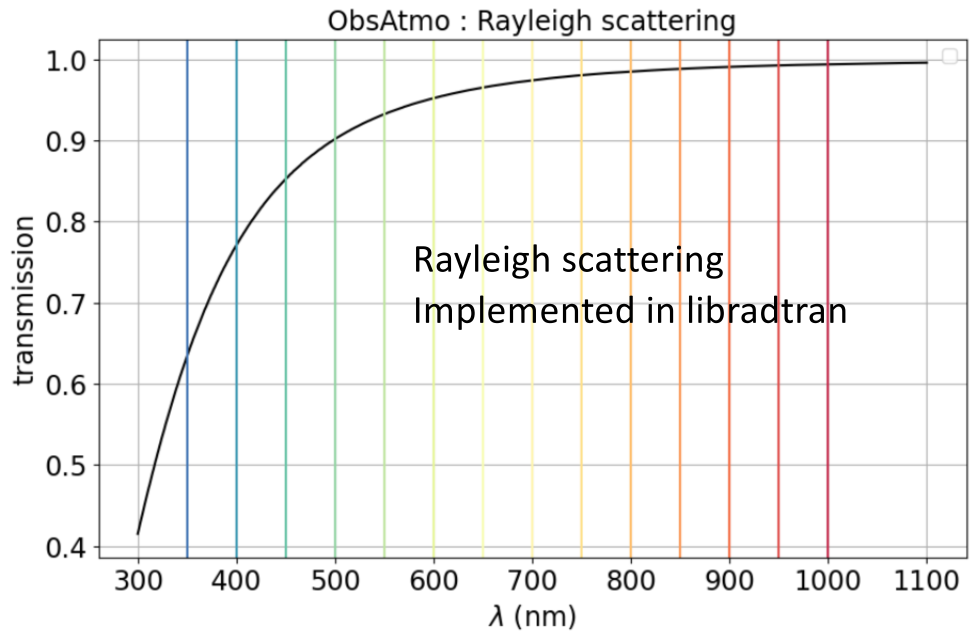
Rayleigh (scattering) extinction (libradtran)

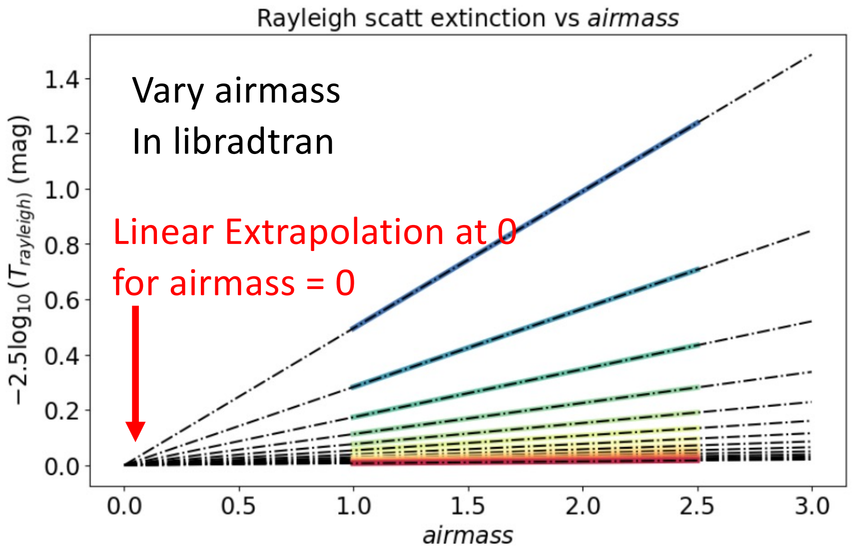
$$\tau(\lambda) = K_\lambda \cdot z$$

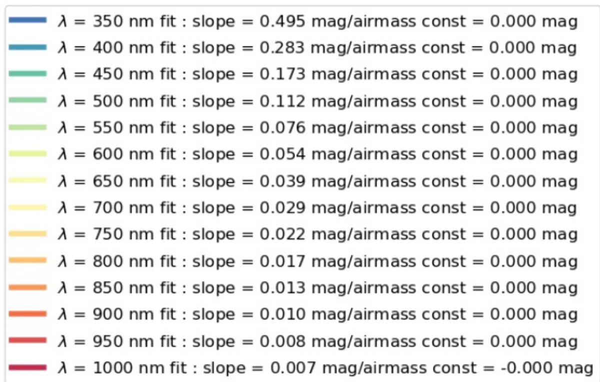
z : airmass

$$T(\lambda) = e^{-\tau(\lambda)}$$

$$m_{ext}(\lambda) = 1.086\tau(\lambda) = 1.086 K_\lambda \cdot z$$







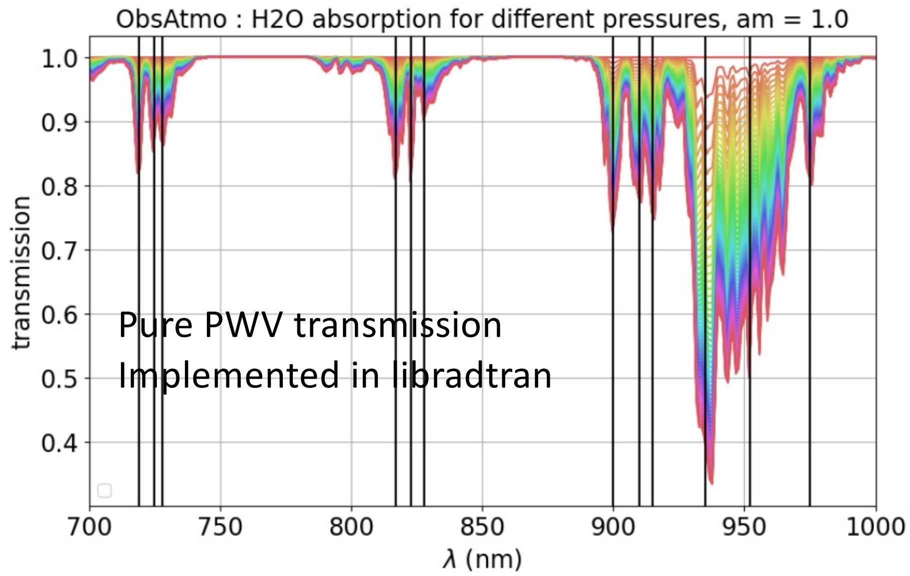
Bouguer-line extrapolation at the TOA (Top of Atmosphere)

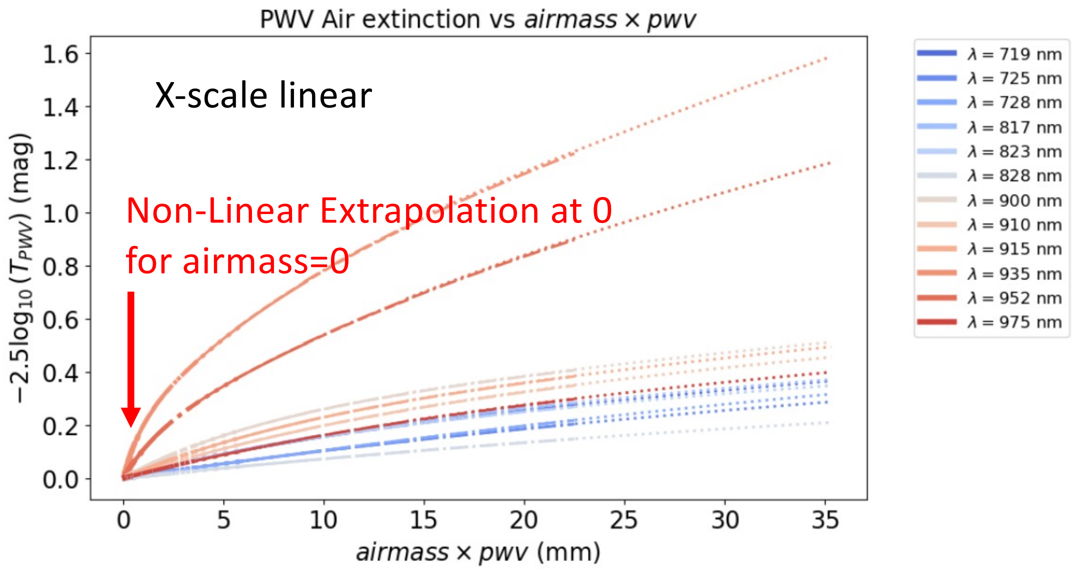
Behaves as expected like a pure original Lambert Law (exponential)

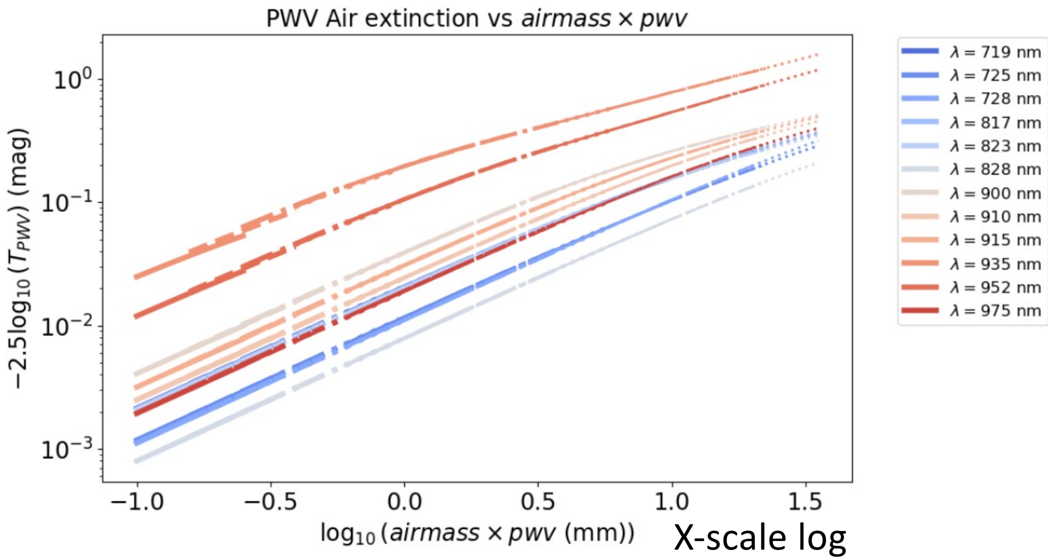
PWV extinction saturation at selected wavelength

- saturation

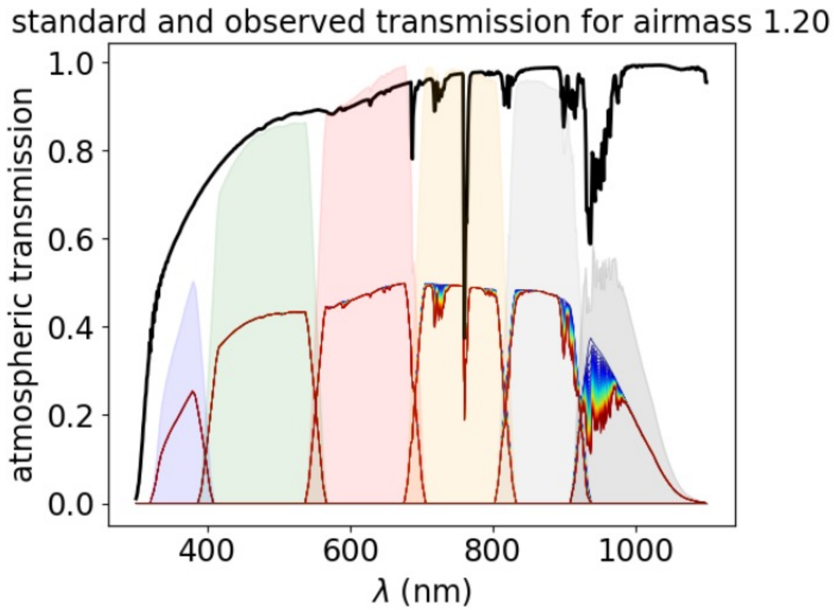
Not simple extrapolation at the TOA (Top of Atmosphere)
See the mathematics afterward

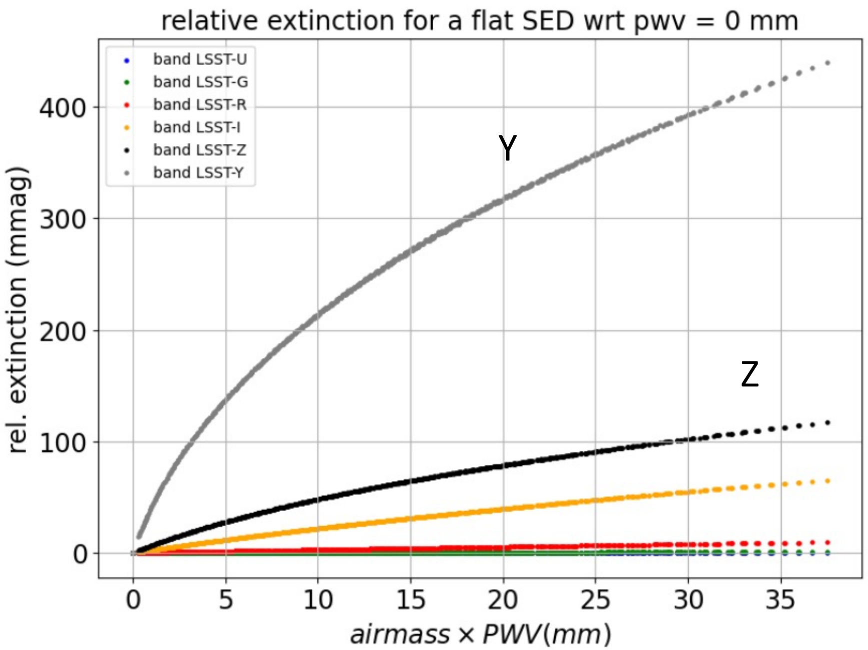






PWV extinction saturation in LSST bands





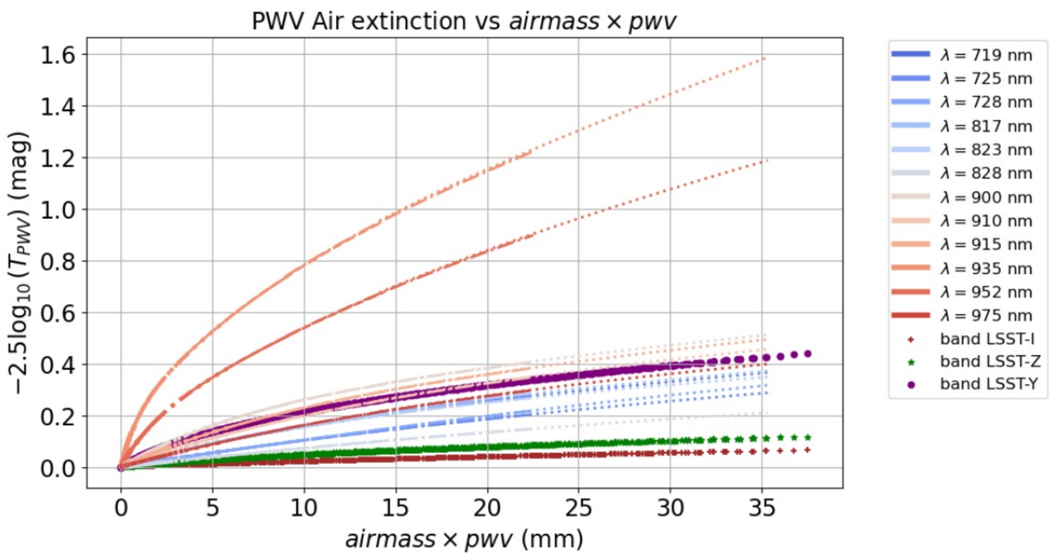
Procedure :

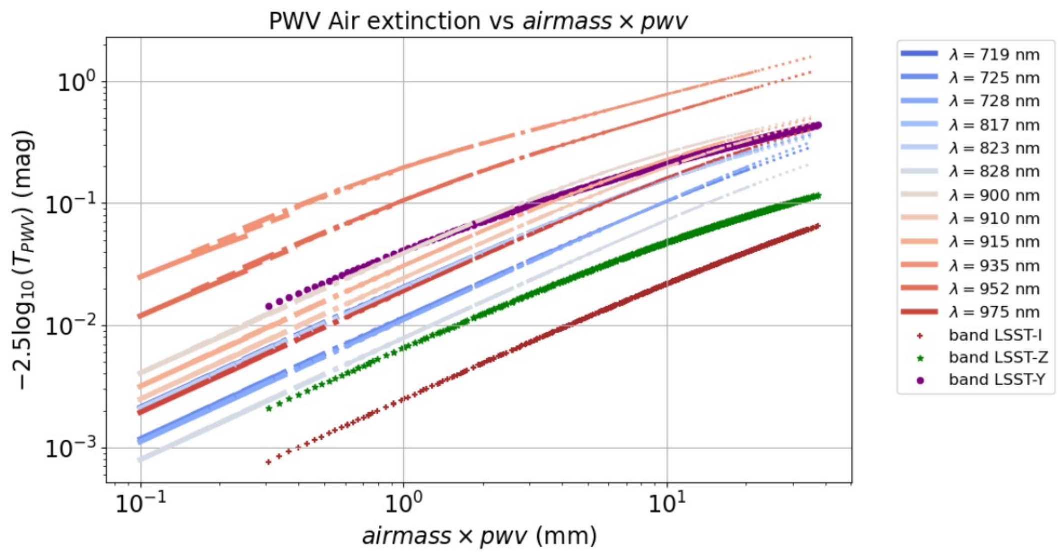
- Compute the instrumental magnitude for a flat SED for each airmass x PWV
- Subtract the instrumental magnitude for pwv = 0 mm at the same airmass

Note all in-band points are aligned along the same curve

- wrt airmass x pwv whatever the airmass is

Comparison of PWV attenuation at wavelengths or integrated over the band

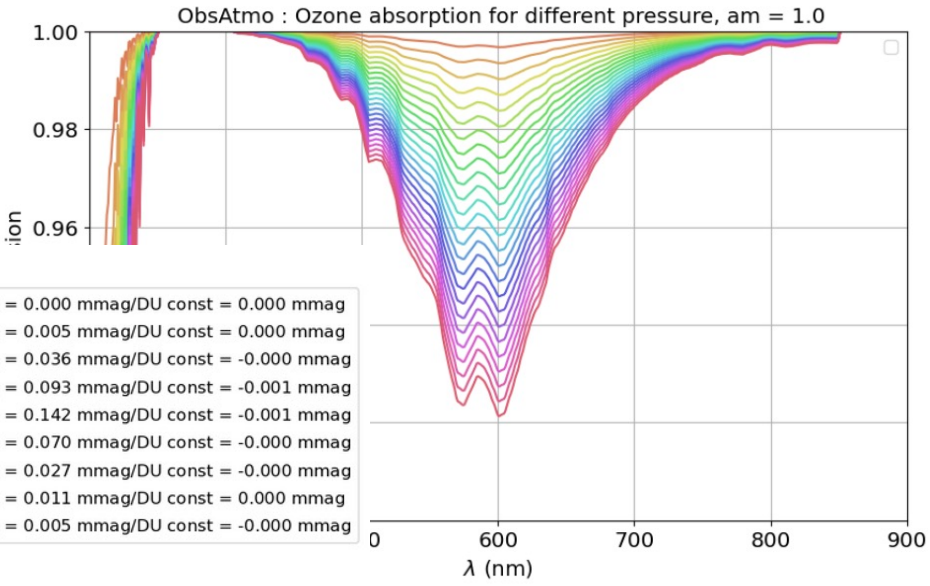


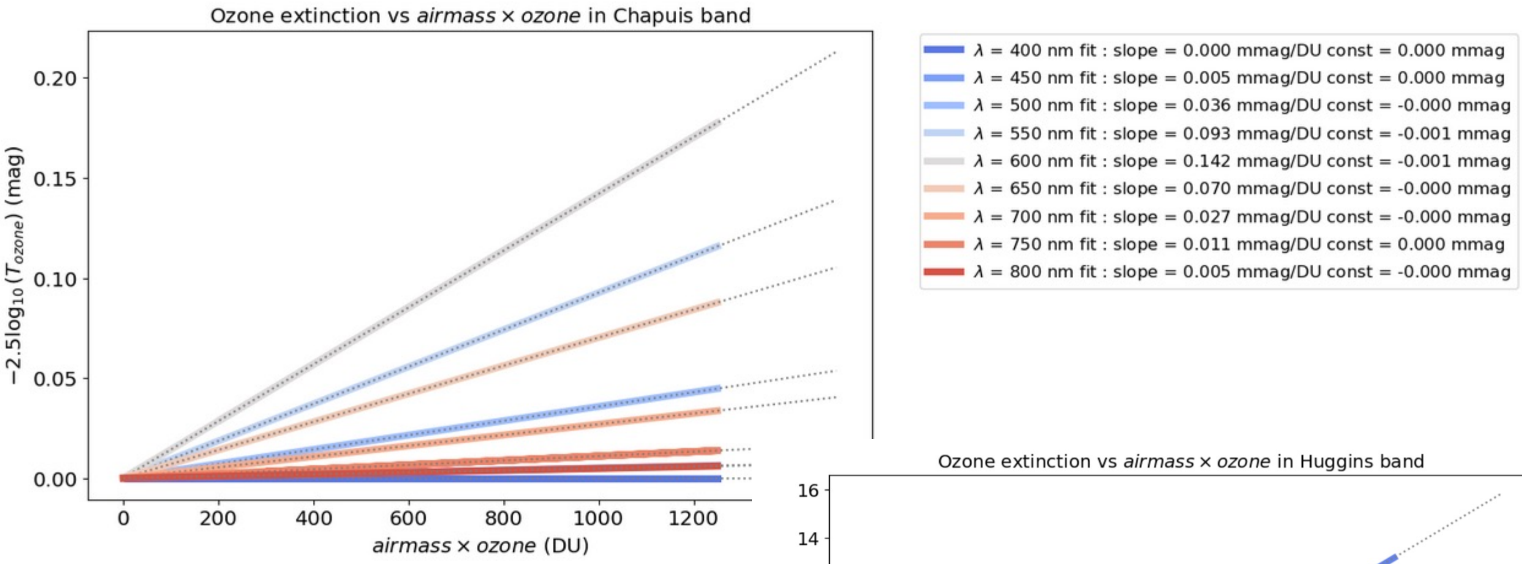


Take home message : strong saturation for PWV component

- Attenuation is driven by target density (H2O) not by the interaction strength

Ozone and saturation at selected wavelengths ?

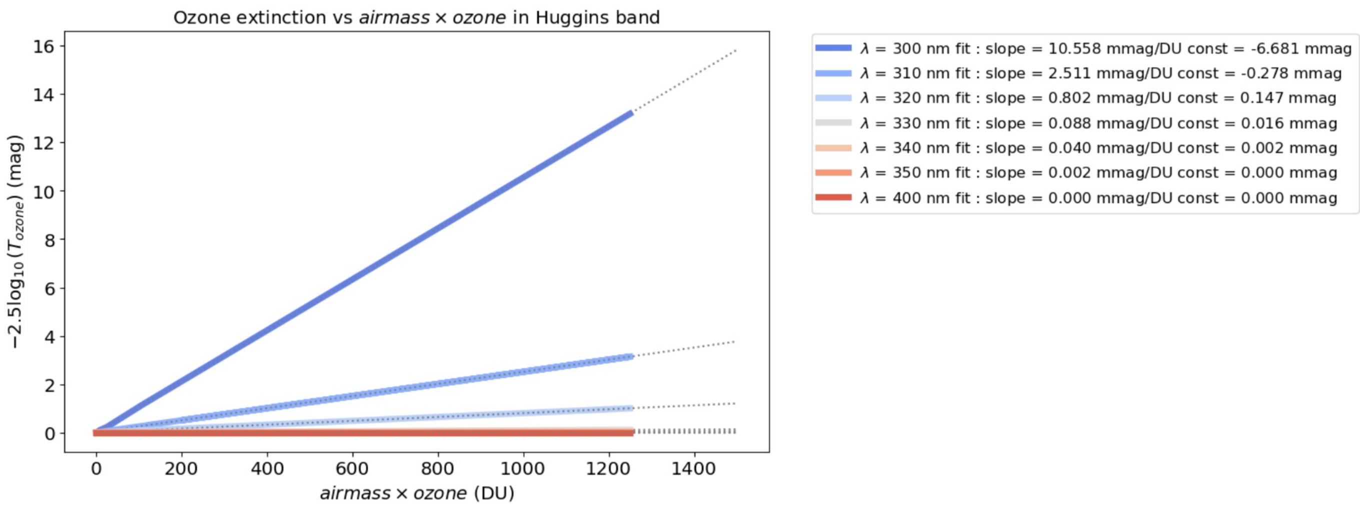




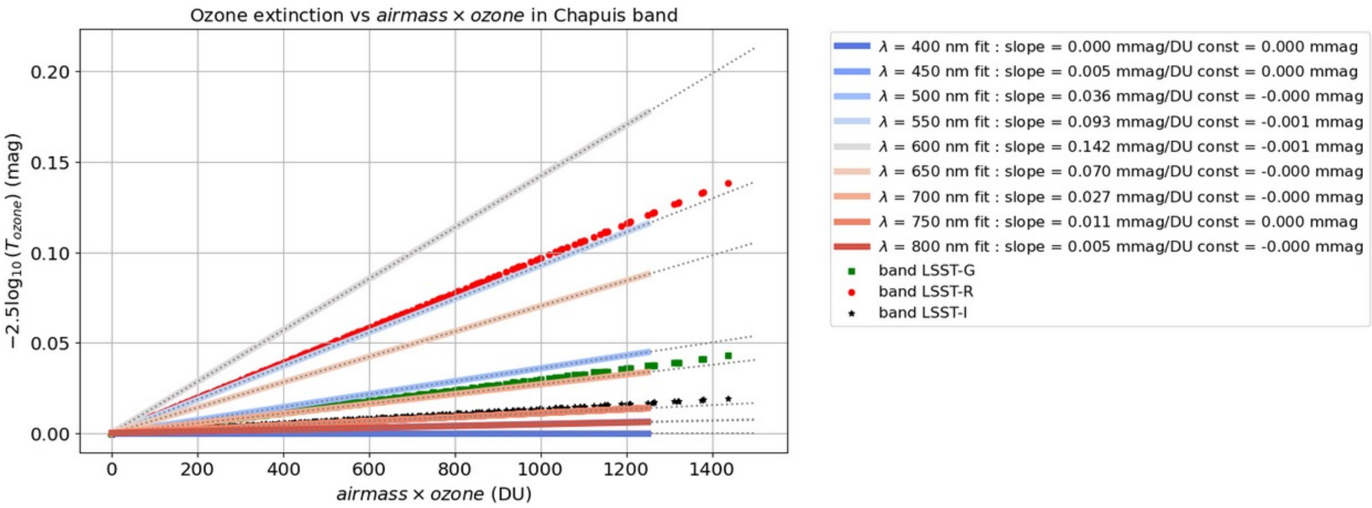
No ozone saturation

→ Even in Huggins band

→ Low density number of absorption molecules



Comparison of Ozone extinction at wavelengths and in bands

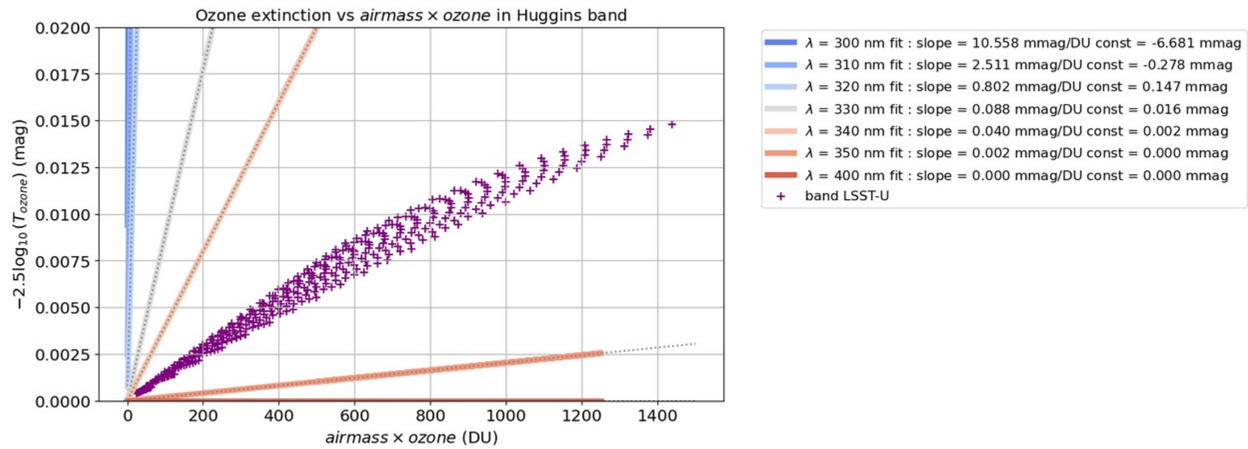


Compare extinction at
Wavelengths and in-bands

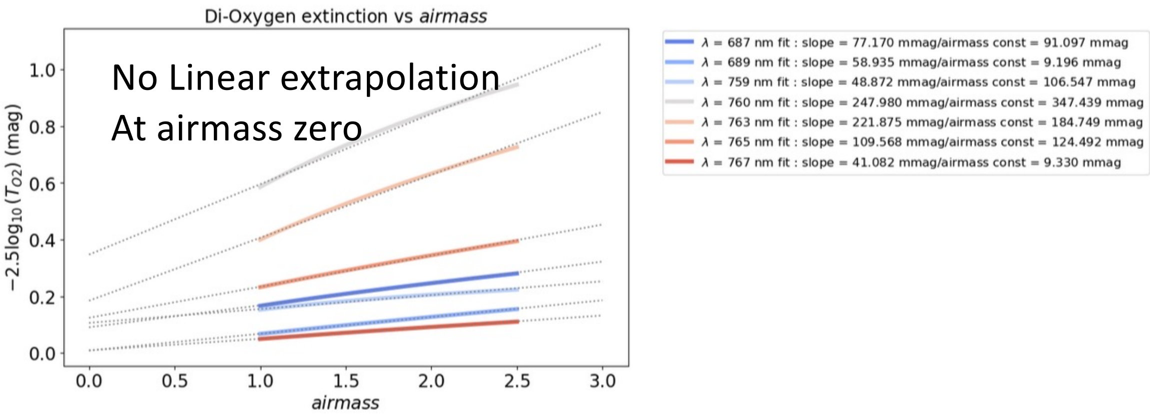
No ozone saturation

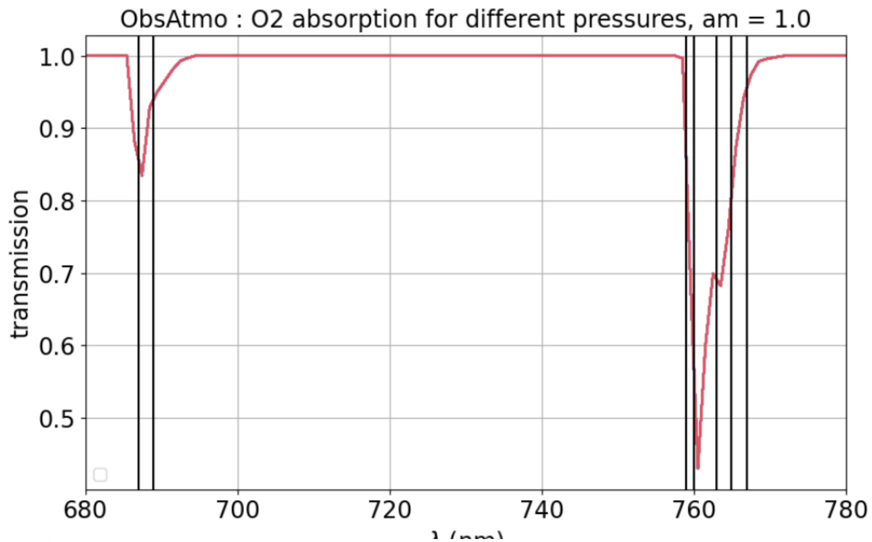
→ Even in Huggins band

→ Low density number of absorption molecules

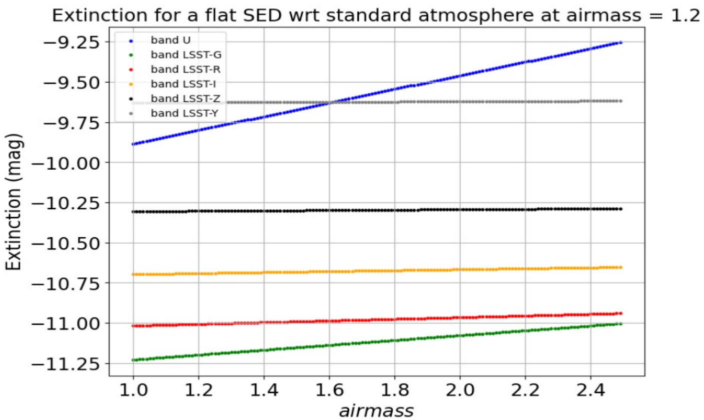


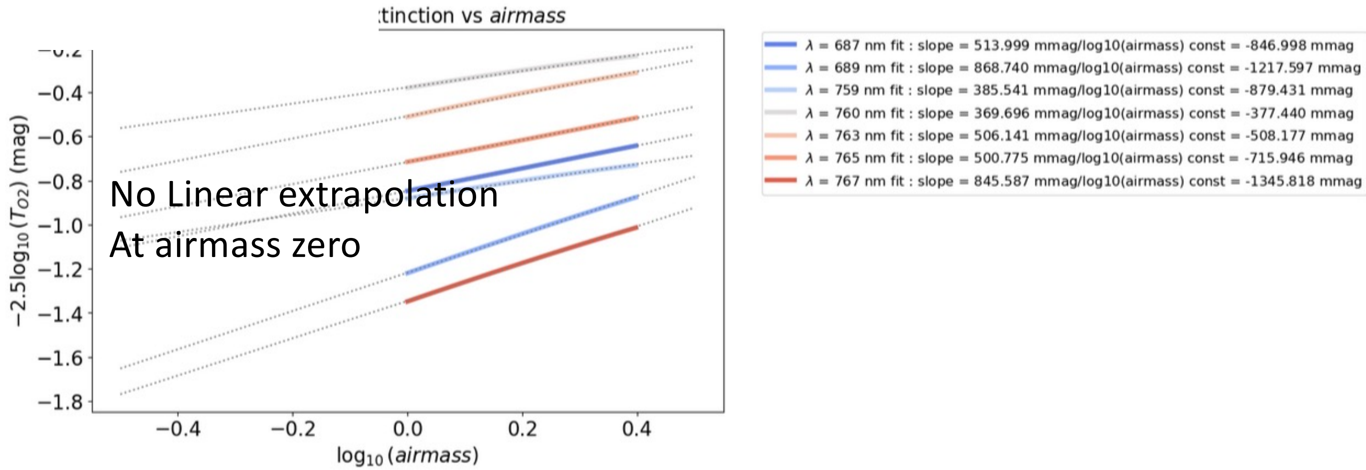
Di-Oxygen extinction





- (Cannot decrease O2 in libradtran)
- Plot vs airmass only
- Probably highly saturation due to O2



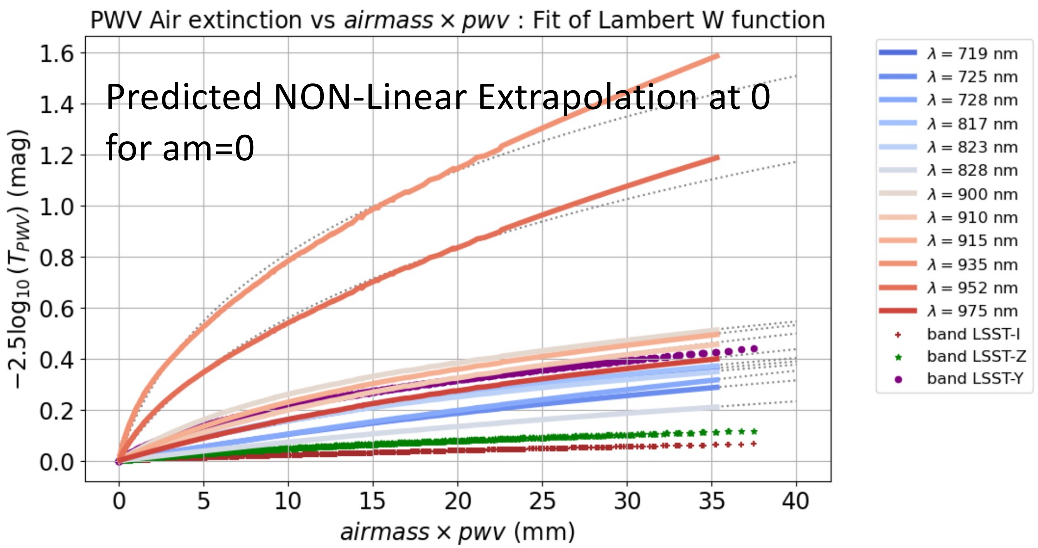


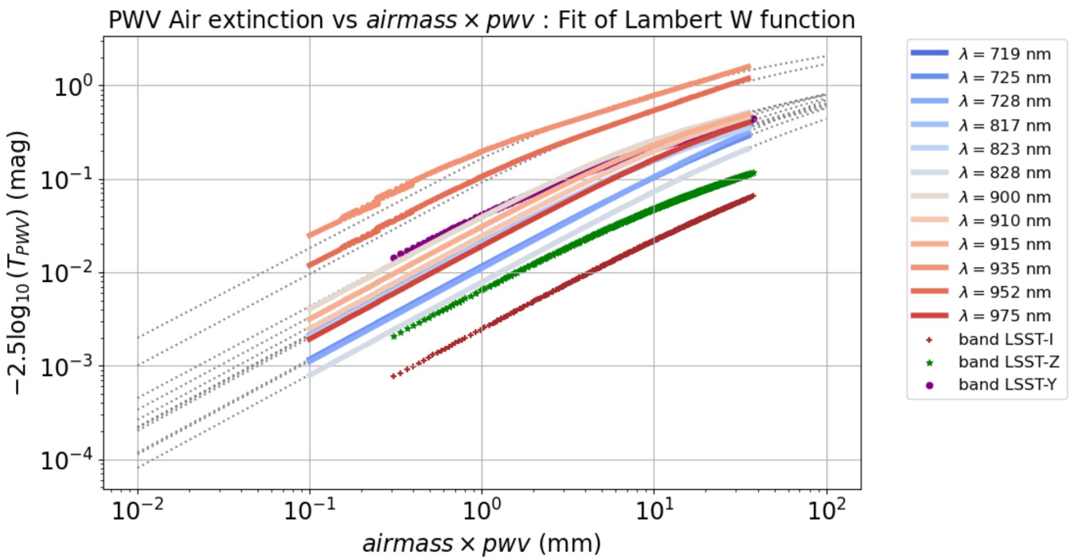
➢ Take home message : strong saturation for O2 component

PWV Extinction in libradtran fit with the Lambert-W function (2 params)

```python
from scipy.special import wrightomega, lambertw
from scipy.optimize import curve_fit

def absorption_lambertw(x, a, b ):
    return np.real((a * lambertw(x*b ,0)))
```





Perhaps PWV absorption is not fully saturated

O2 Extinction in libradtran fit with Lambert-W function (2 params)

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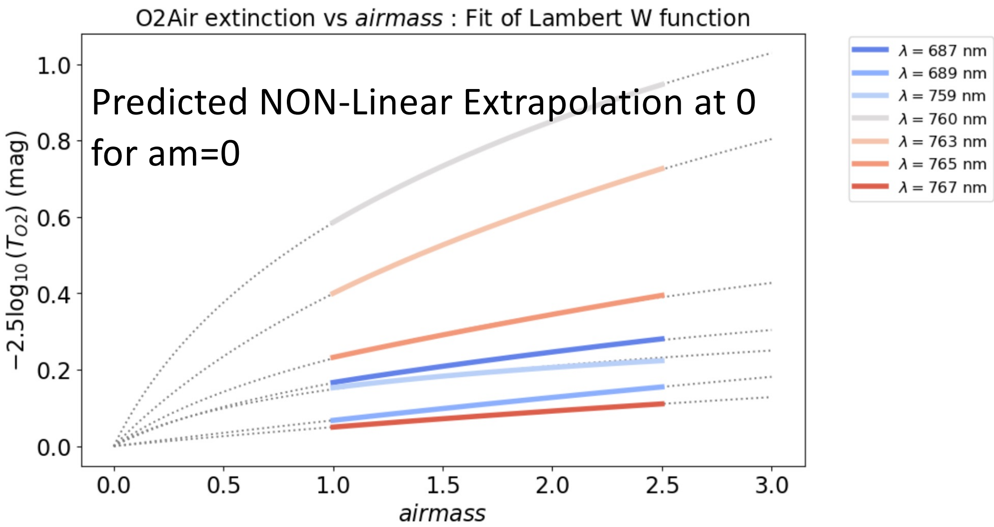
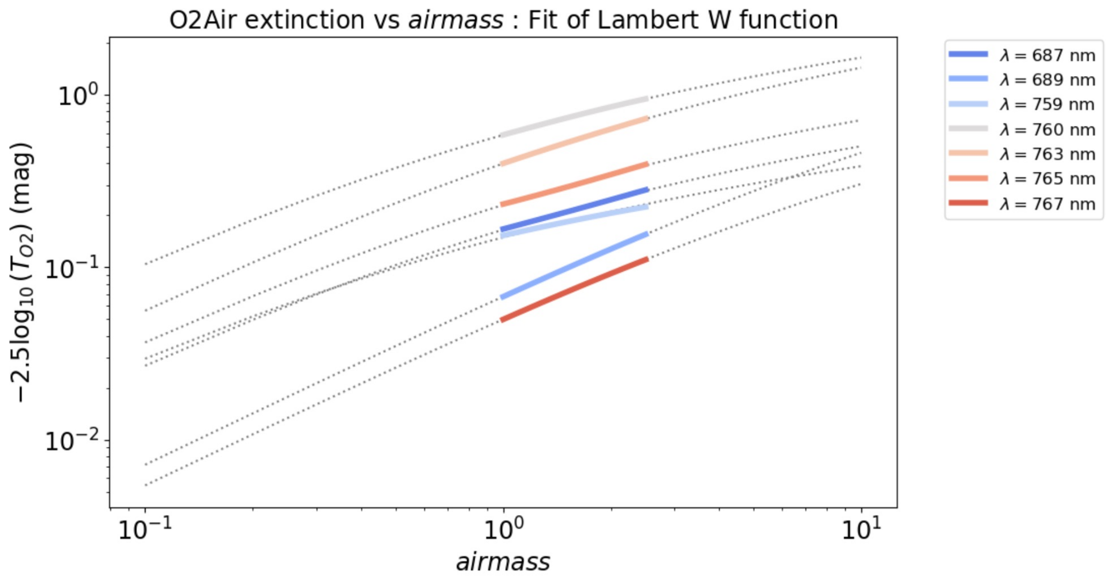




Perhaps O2 absorption is fully saturated

Take home message on Absorption model

Absorption components in libradtran:

Extinction is fitted by a Lambert-W function

- Ozone → No-saturation
- PWW → Strong-saturation but not complete
- O2 → Maximal saturation

2-level Model:

- Transmission follows a Lambert-W/Write-Omega function

Absorption in atmosphere is not exactly a 2-level model (absorption band)

- Note : Absorption law could be checked on HiTrans model (applied to light crossing homogenous density medium)

Atmospheric absorption is not a 2-electronic levels system

Simple 2-electronic levels atomic model following Lambert modified law for absorption

More realistic Atmospheric absorption atomic &molecular model

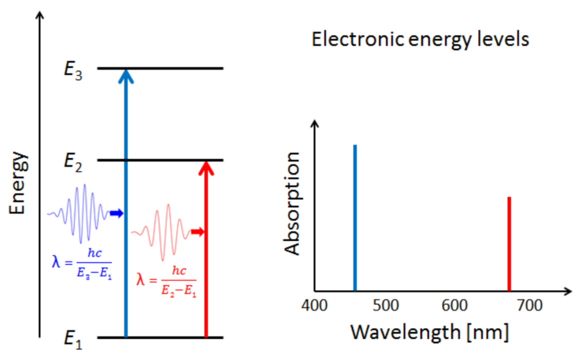
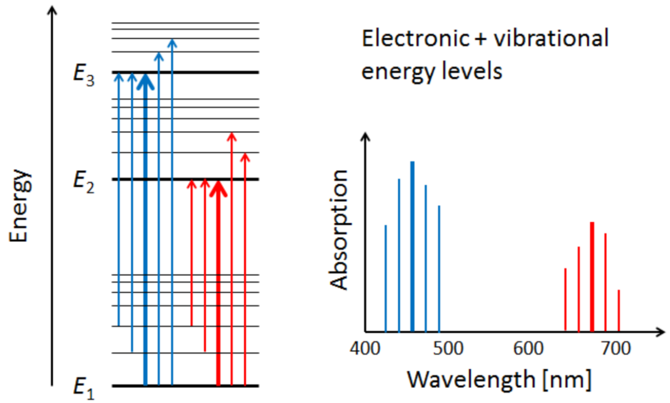
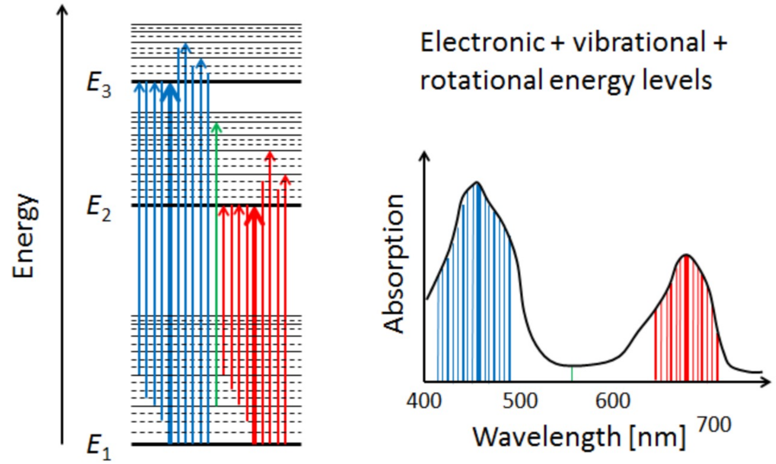


Figure 4: Illustration of three electron energy levels in a molecule and absorption of blue and red light.



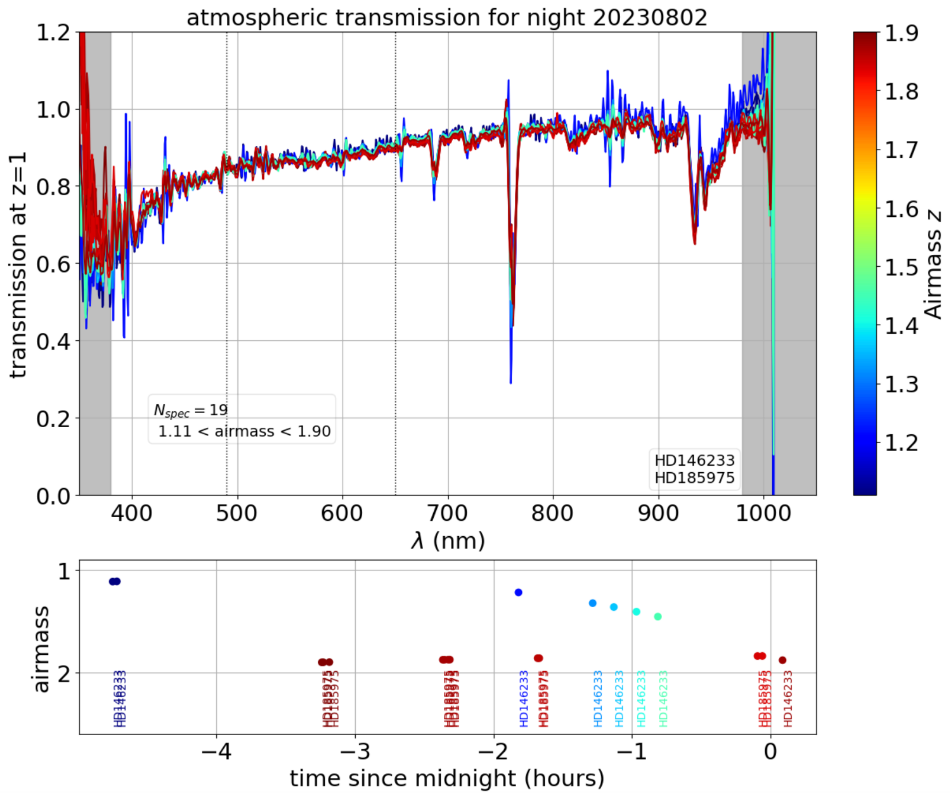


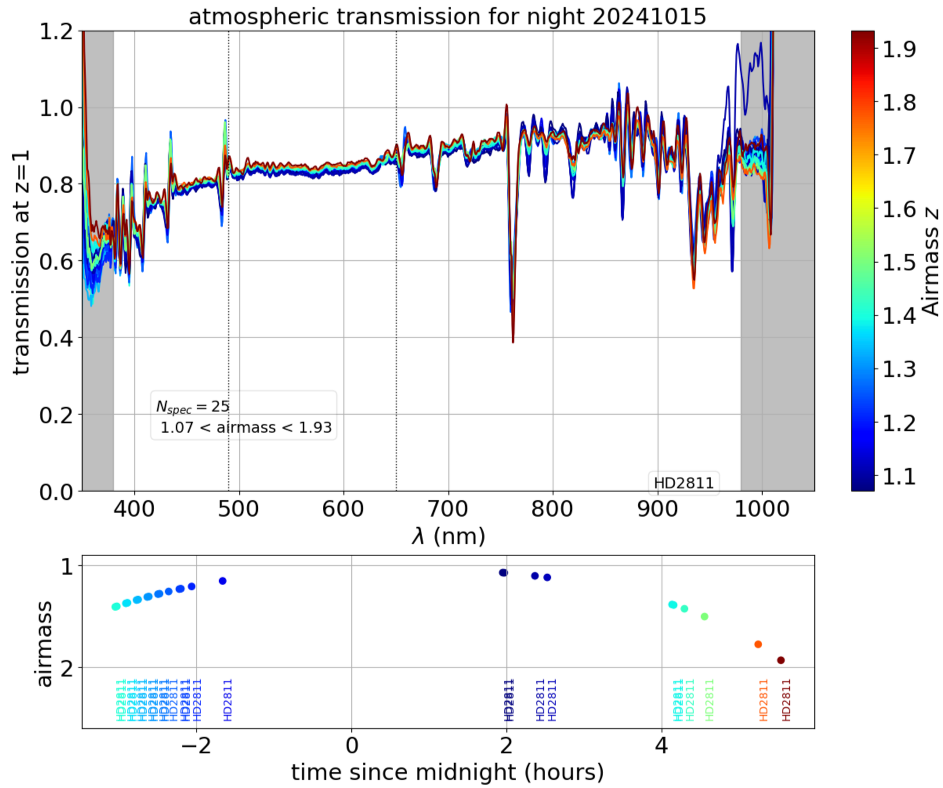
From https://oceanopticsbook.info/view/absorption/physics-of-absorption

Thus it is not mandatory that the Lambert modified function applies itself to atmospheric absorption

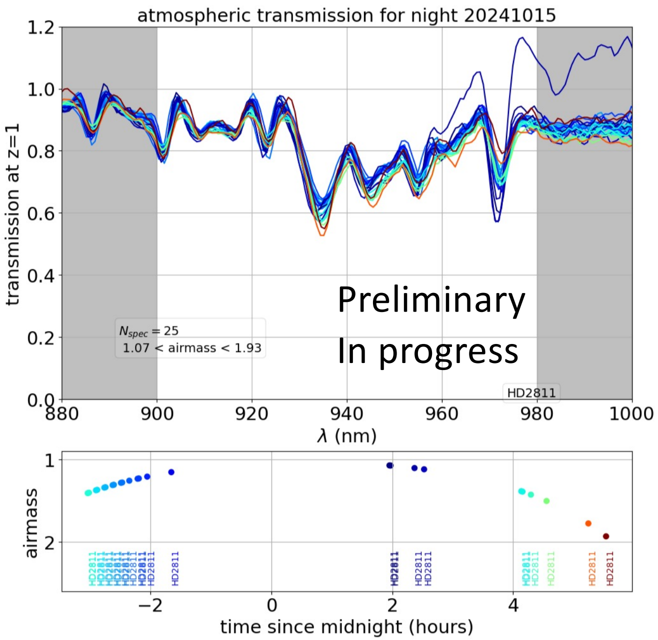
Transmission extrapolated at airmass =1 (1 night)

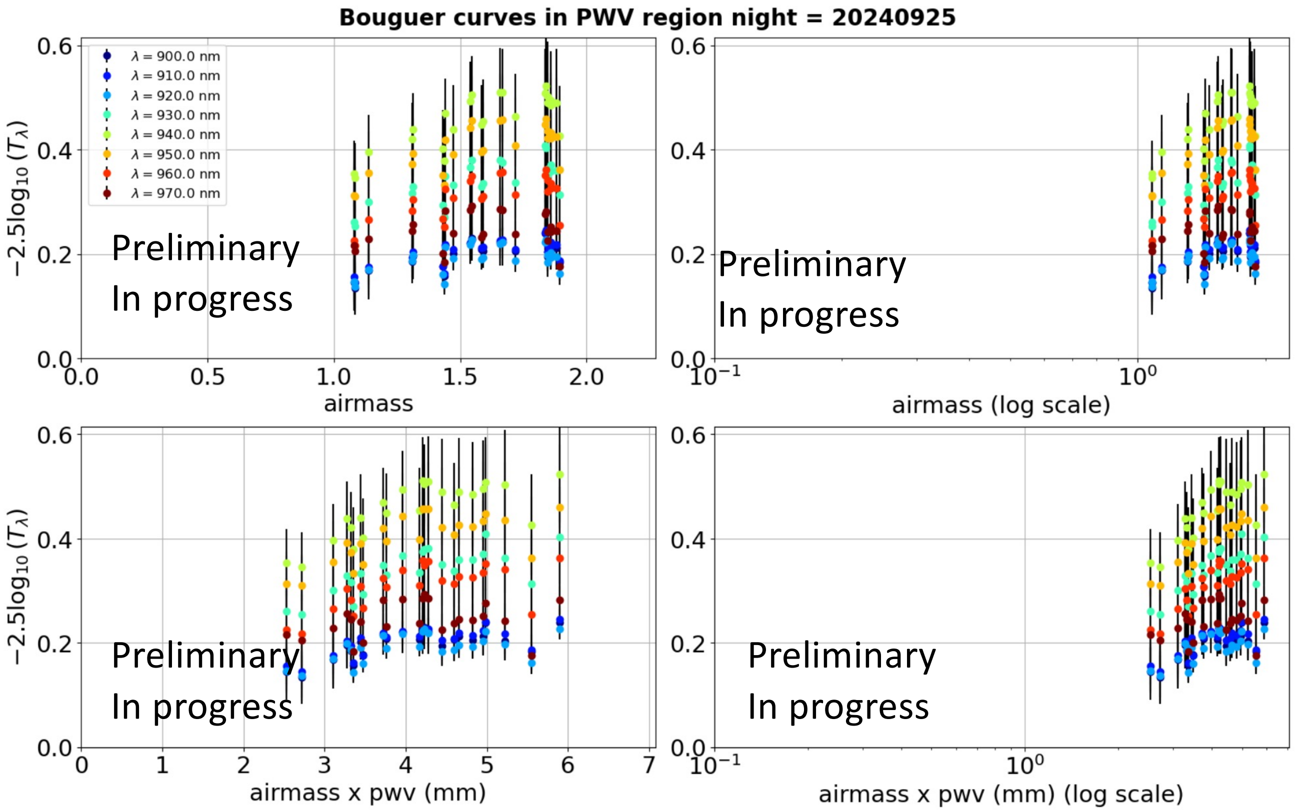
- Divide the measured spectrum by the SED x throughput
- Predict transmission at airmass =1 Assuming transmission follow Lambert law

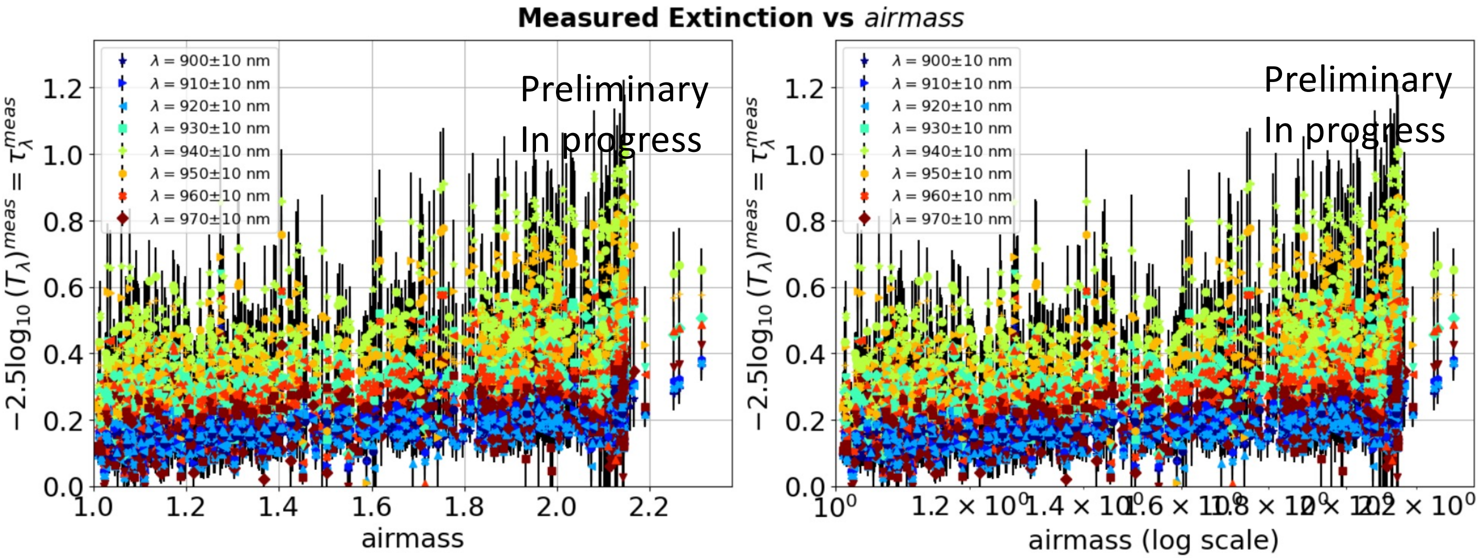


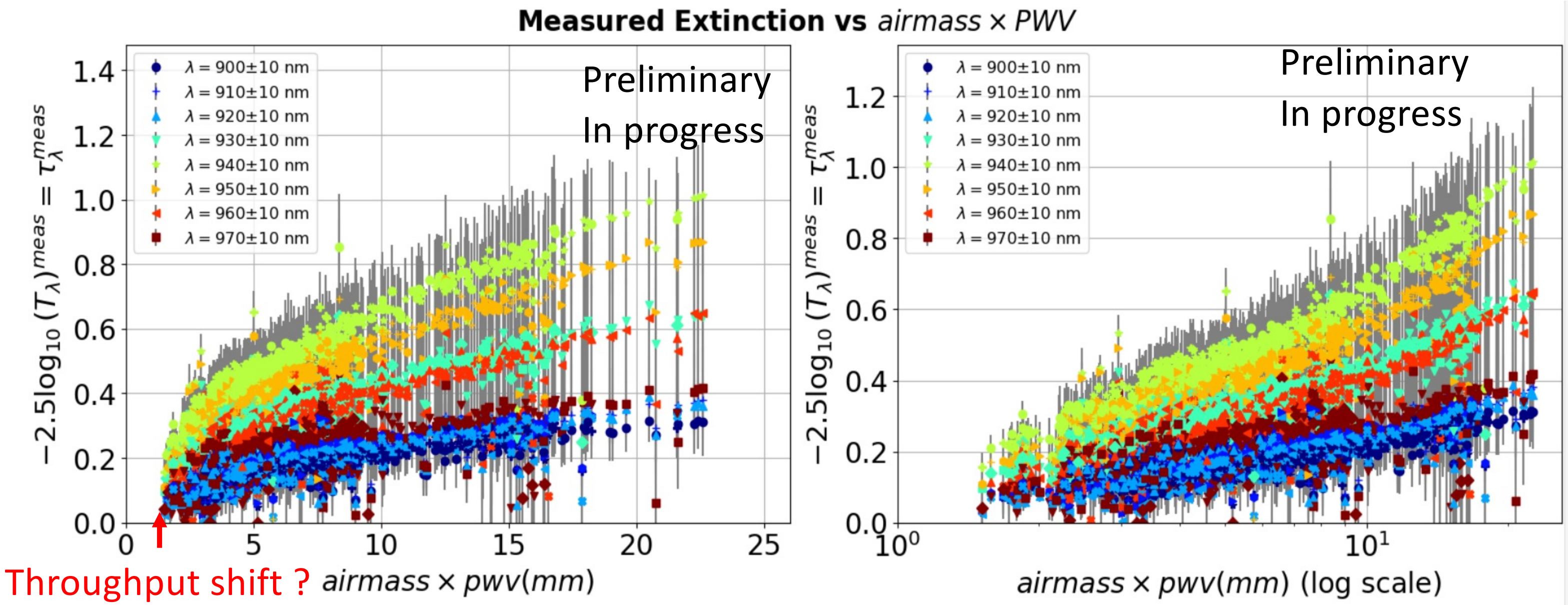


Extinction curve in PWV absorption region (1-night)







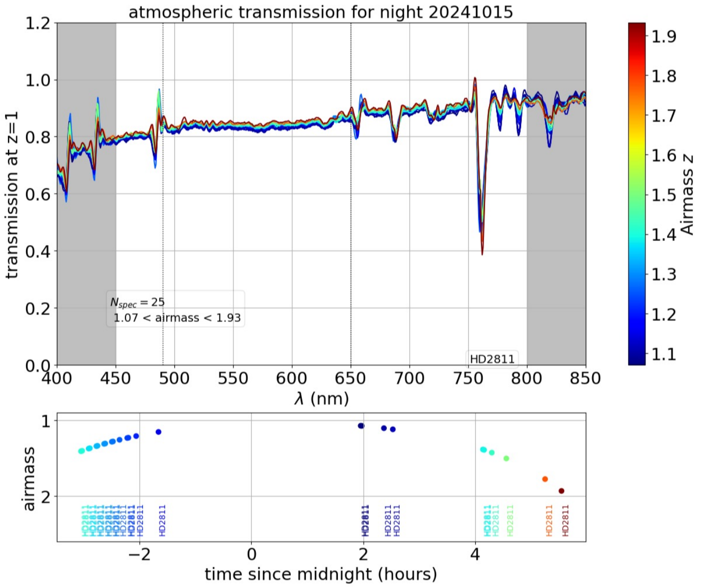


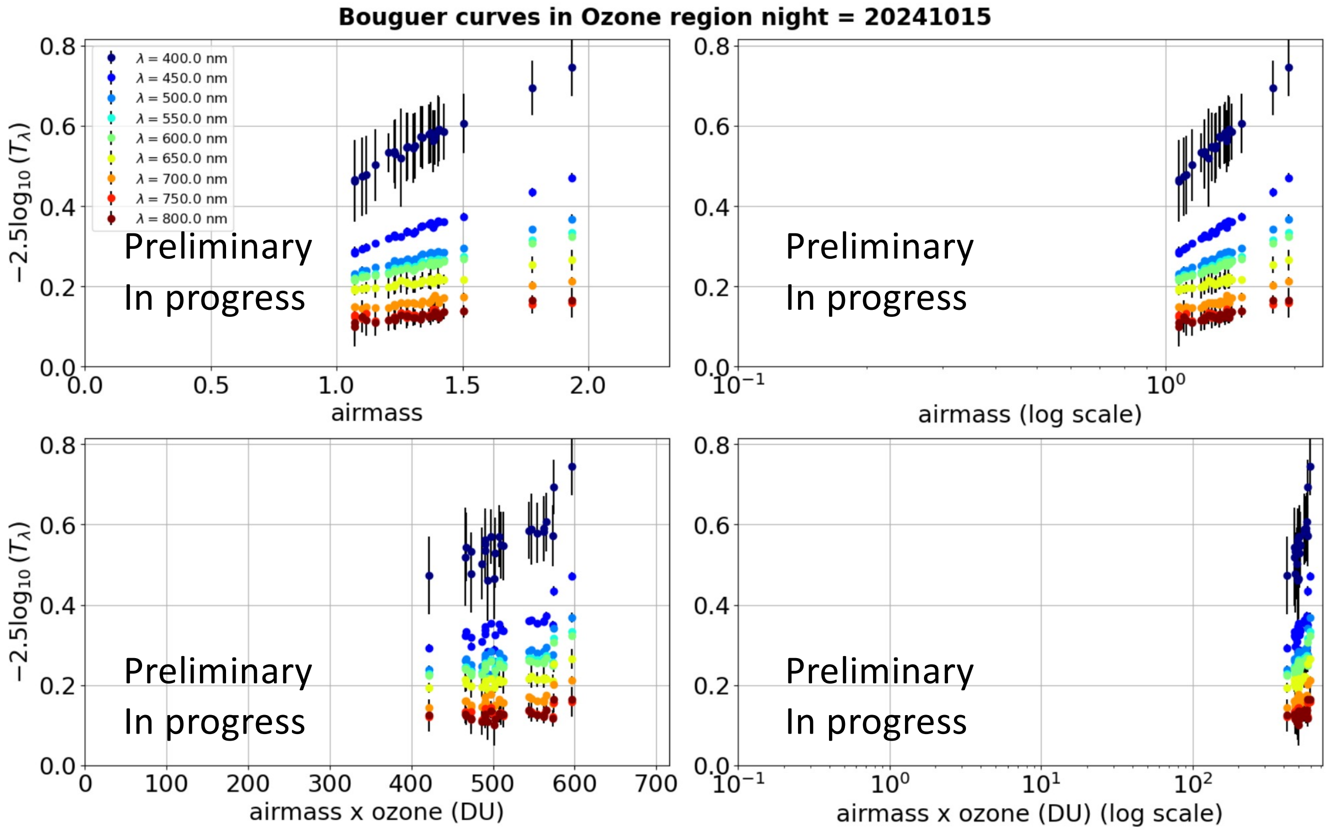
Extinction : "all selected Photometric nights"

- Can further improve by correcting transmission for a grey term
- Extinction wrt (*z x PWV)* looks slightly different from a Lambert-W function
- CBP will provide instrumental transmission
- Include more data from non photometric nights

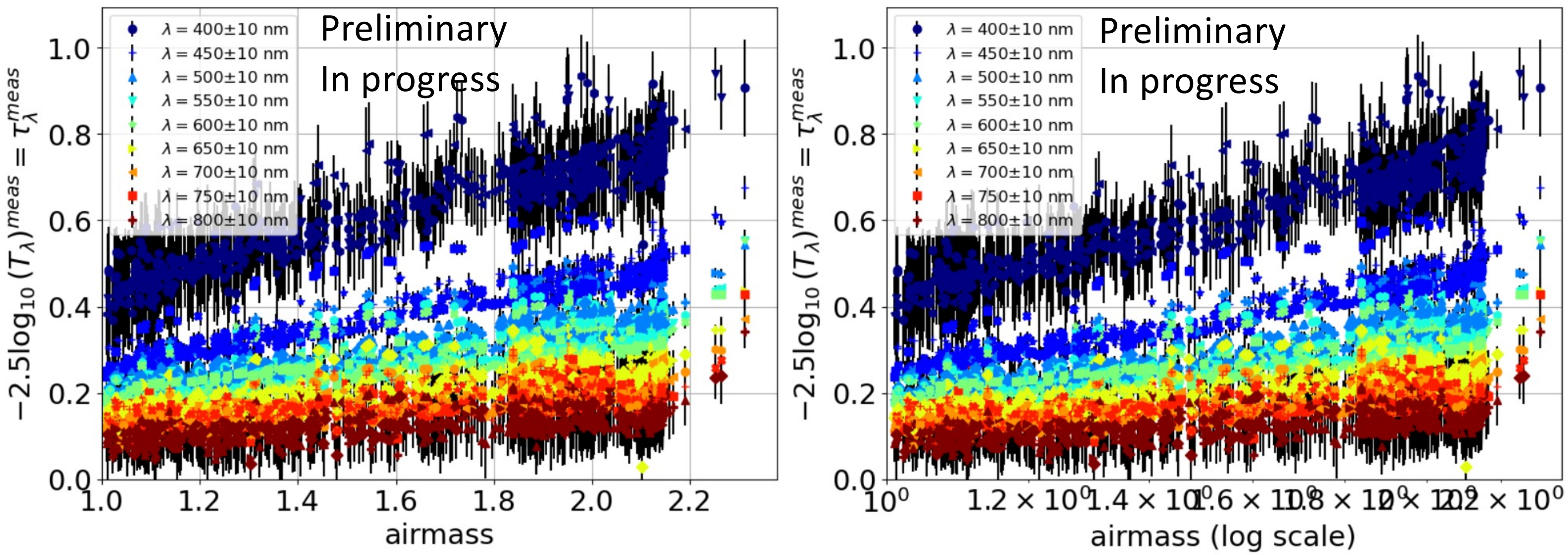
Extinction curve in Ozone absorption region (1-night)

Ozone mixed with Rayleigh scattering depending on Pressure





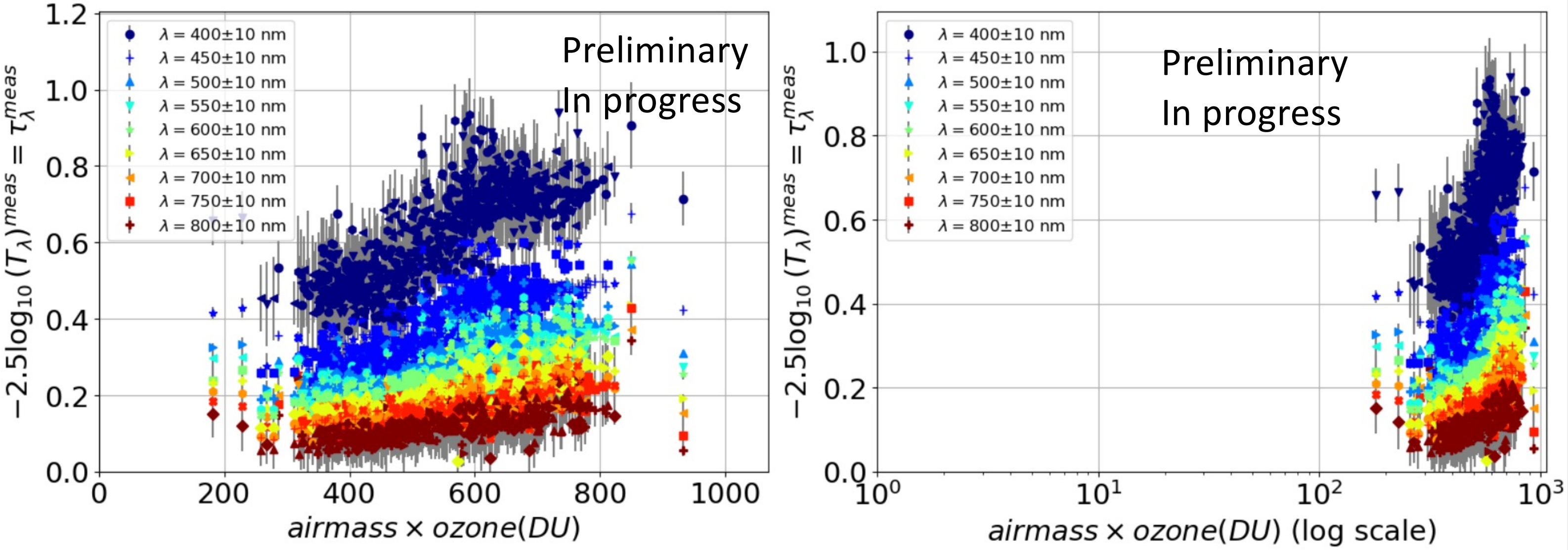
Measured Extinction vs *airmass*



Need to fit a standard Lambert attenuation Law

- ➢ Check extrapolation at airmass = 0 by fit
- ➢ In progress

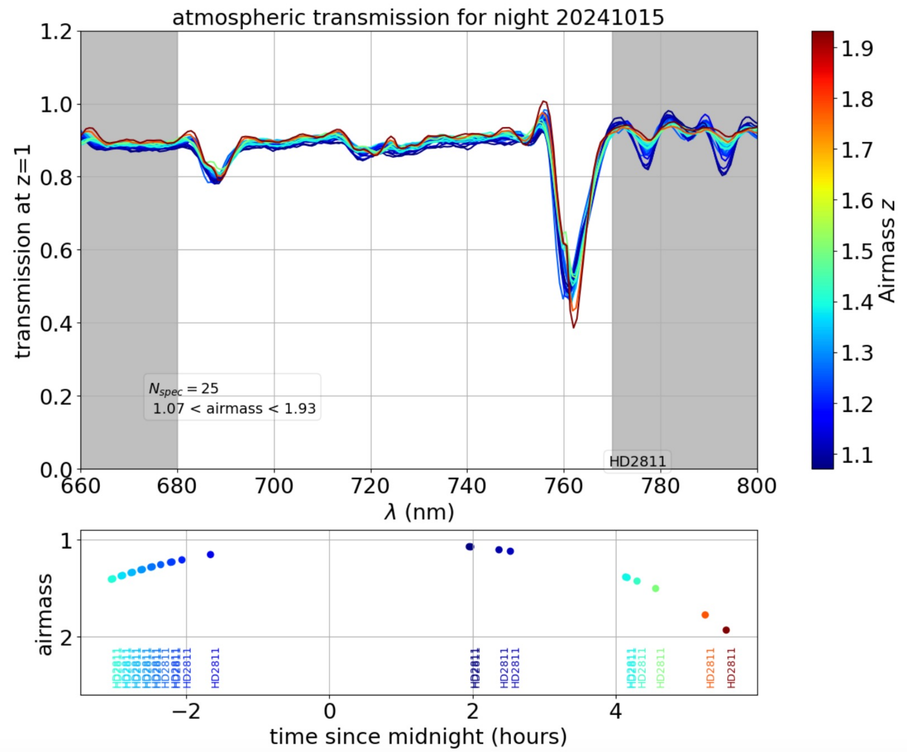
Measured Extinction vs *airmass × Ozone*

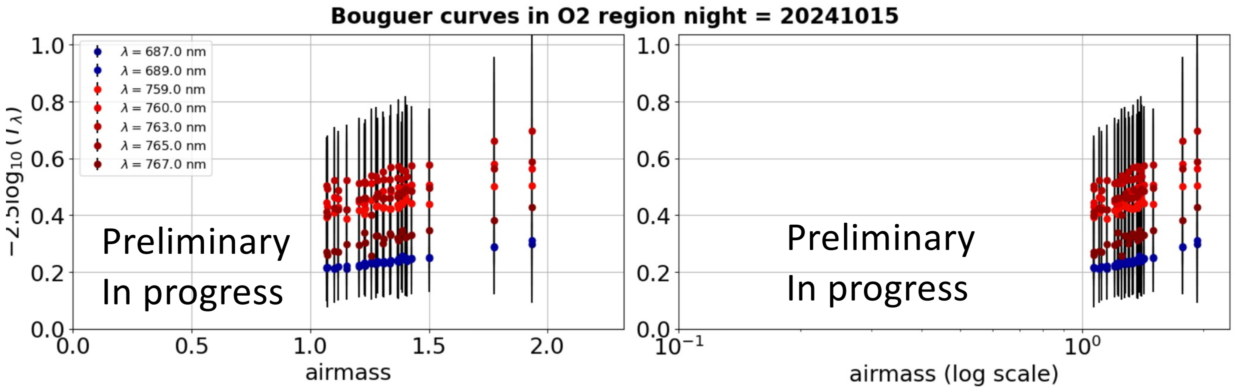


Need to separate O3 dependence from Pressure dependence In Rayleigh scattering

- ➢ In progress

Extinction curve in O2 absorption region (1-night)





Rayleigh scattering is mixed with O2 absorption

➢ Difficult to see O2 absorption saturation

Take home message

- Understanding atmosphere means understanding extinction with airmass
  - ➢ Not only transmission at airmass = 1 or atmospheric parameter values derived from a librdtran model
- Different extinction curves in different wavelength regions
  - Scattering (Rayleigh & aerosol) → Standard Lambert law for atm. Attenuation
  - Absorption by components →
    - Modified Lambert law in some cases
    - Strong saturation for PWV & O2
    - Libradtran absorption (PWV,O2) is more compatible to a Lambert-W function applied to extinction (optical depth)
    - In progress : check of these attenuation on Auxtel Spectroscopic Data