Photodissociations in hot exoplanet atmospheres

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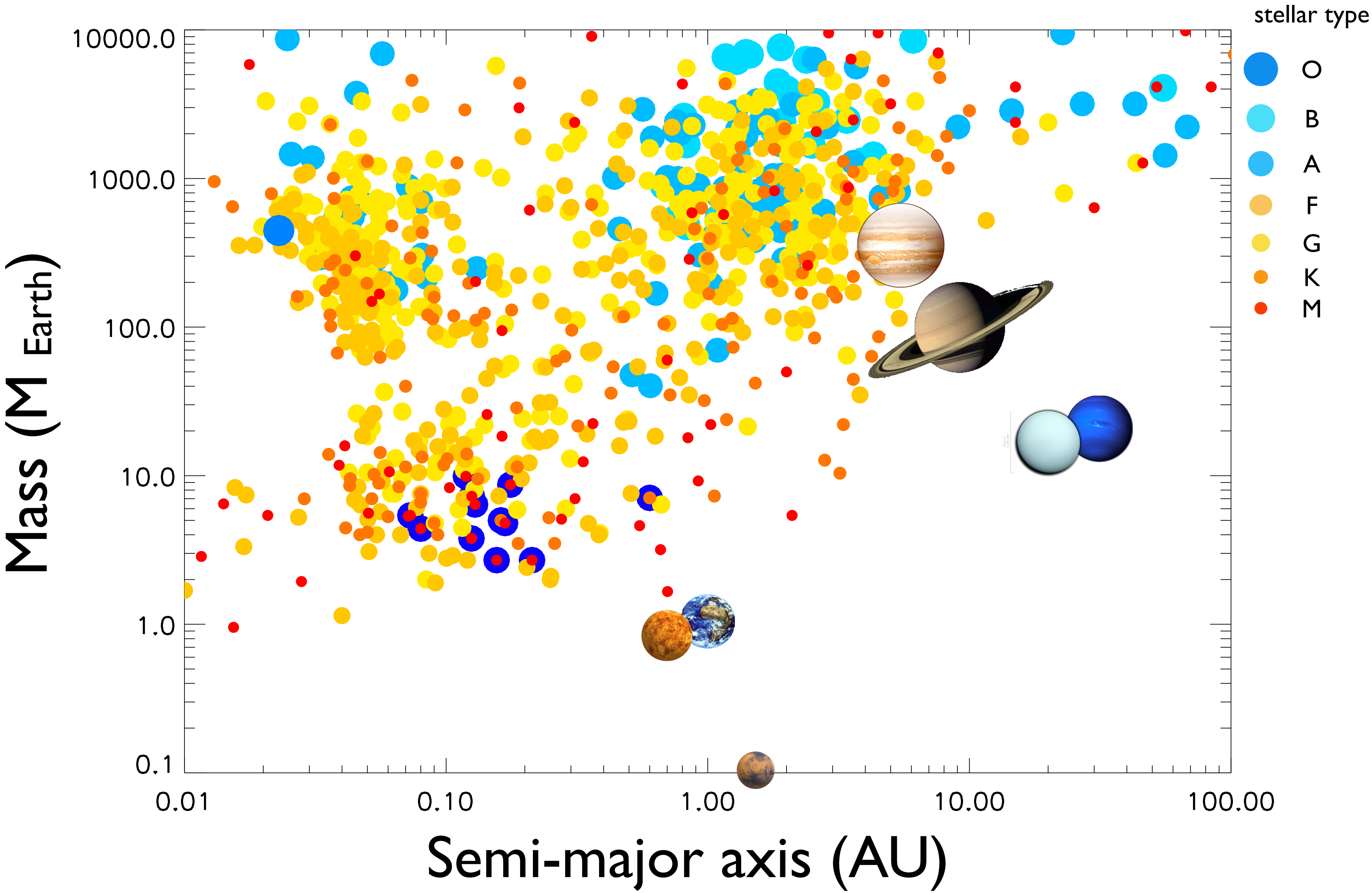
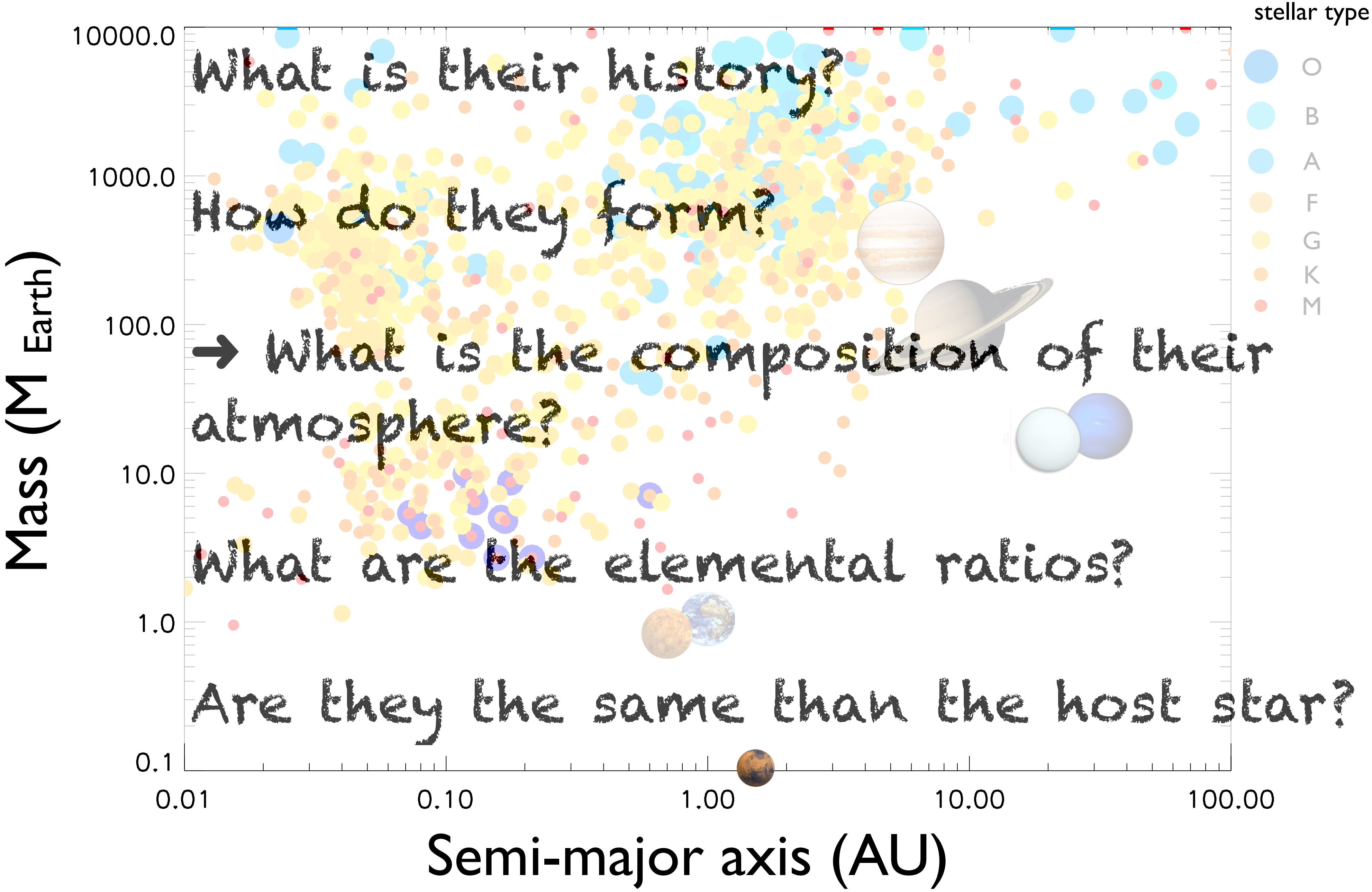


1880 exoplanets

source : exoplanet.eu (26 January 2015)



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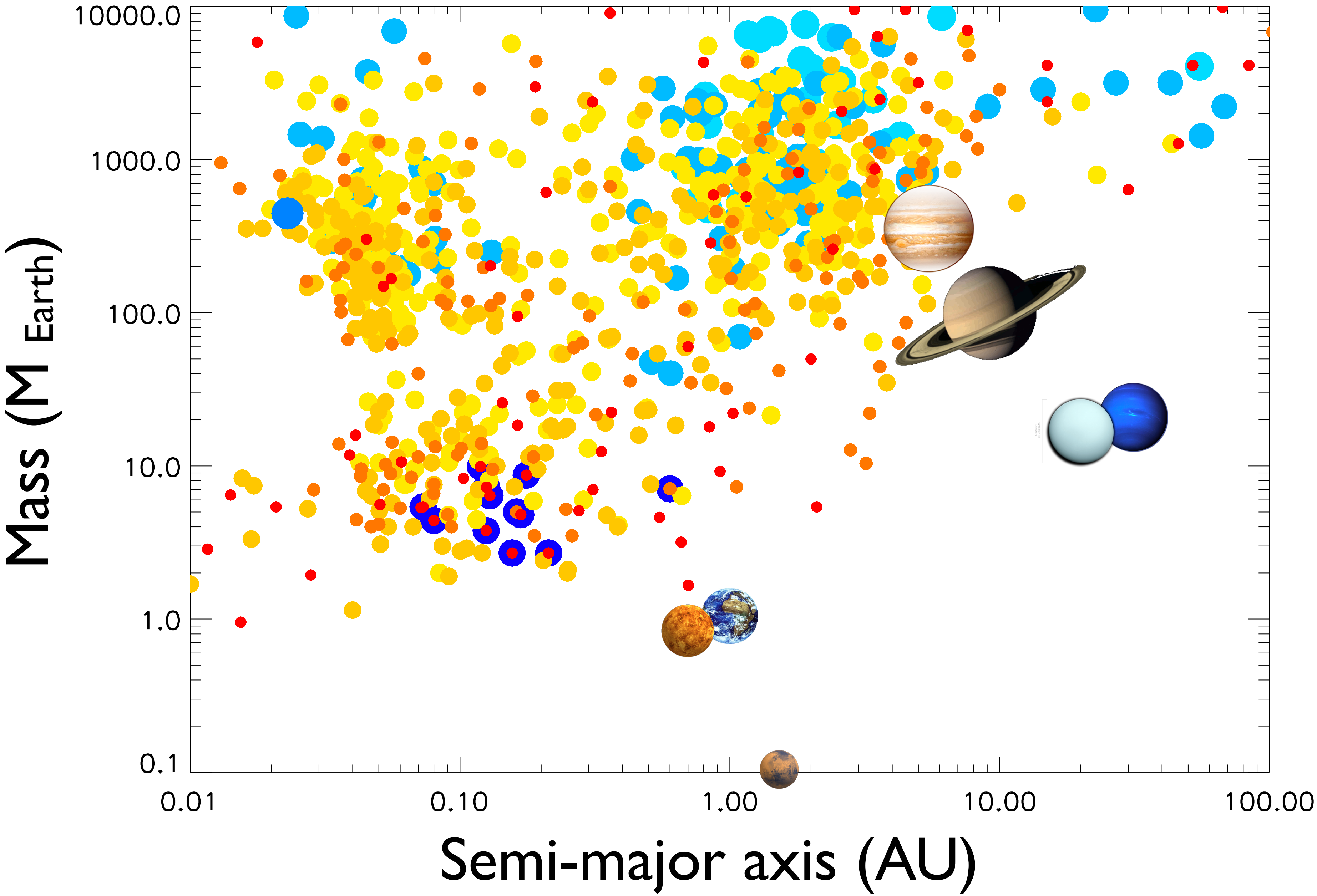

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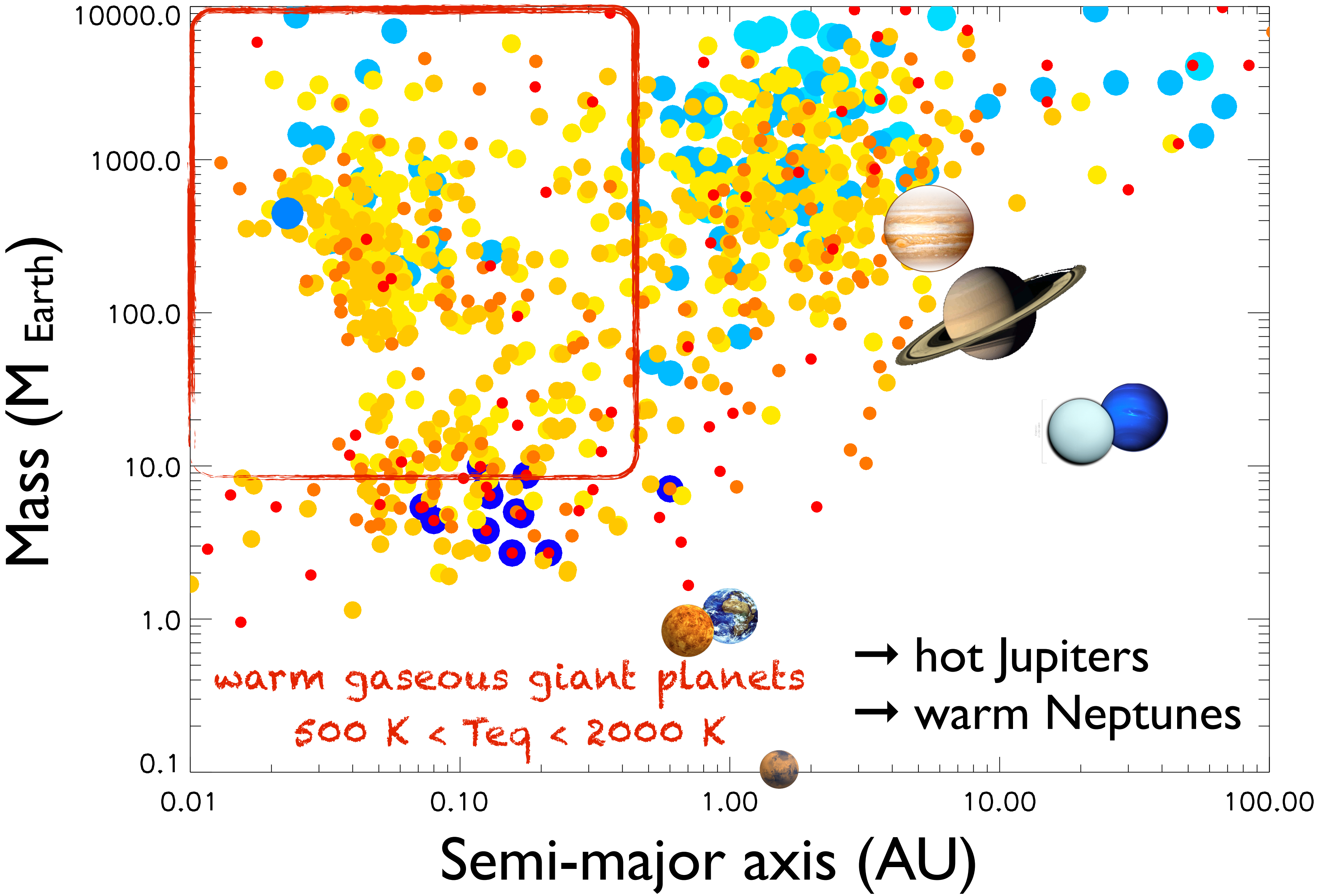

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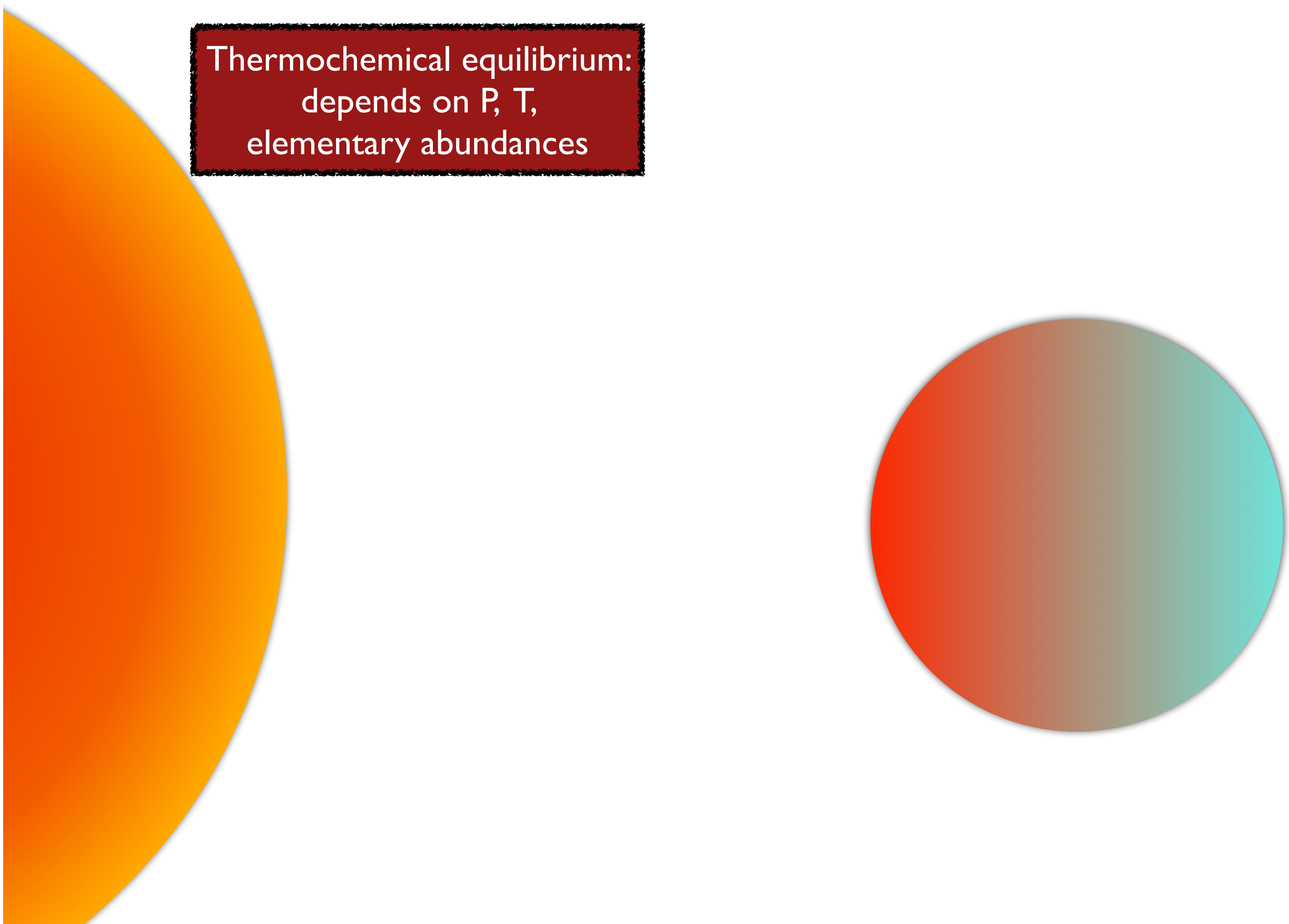
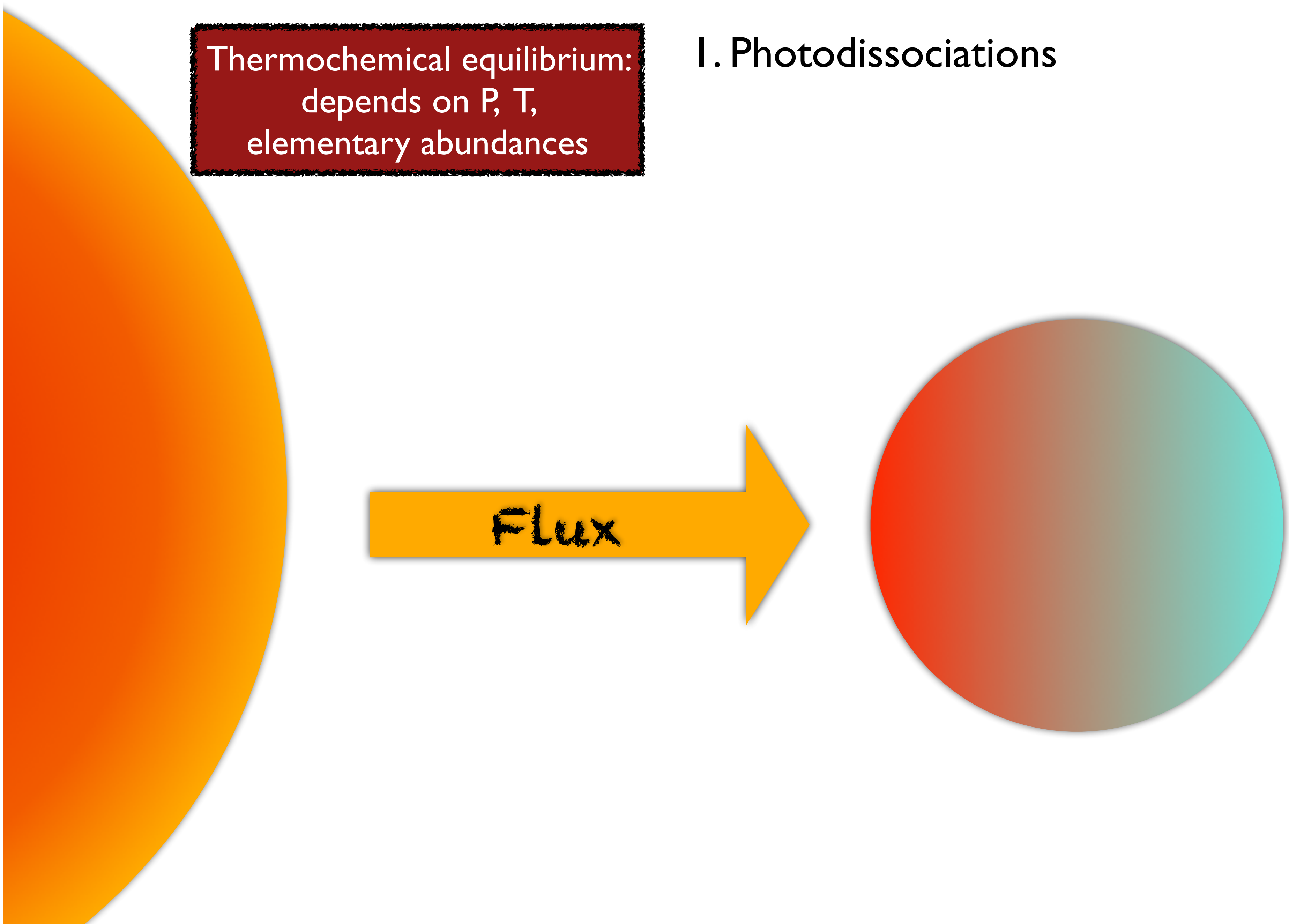
Out of equilibrium processes



Out of equilibrium processes

Thermochemical equilibrium:
depends on P, T,
elementary abundances

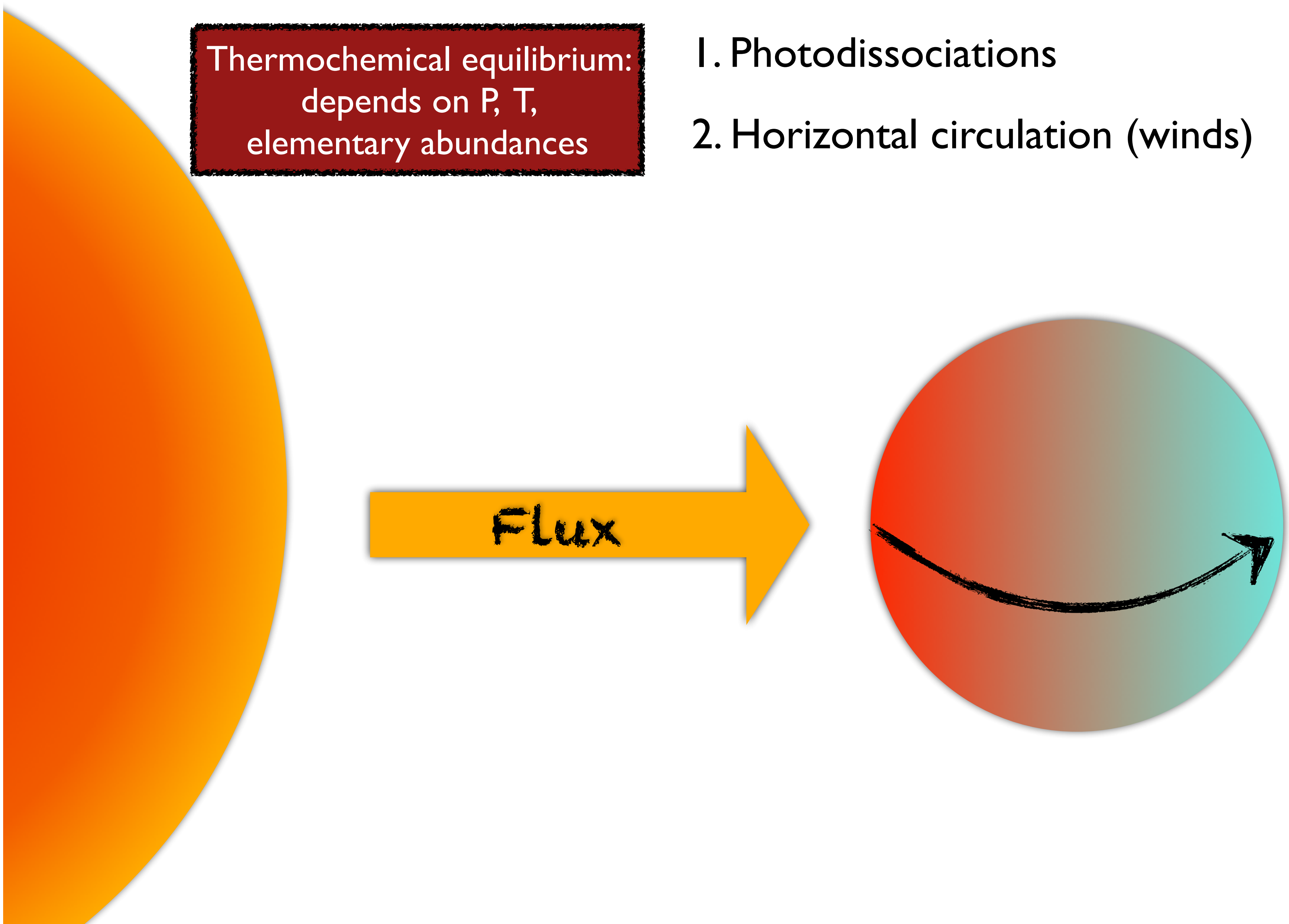
1. Photodissociations



Out of equilibrium processes

Thermochemical equilibrium: depends on P, T, elementary abundances

1. Photodissociations
2. Horizontal circulation (winds)



Out of equilibrium processes

Thermochemical equilibrium: depends on P, T, elementary abundances

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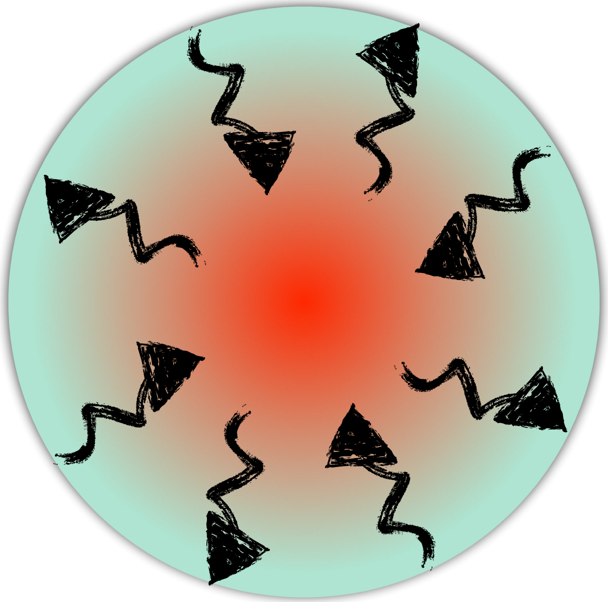
2. Horizontal circulation (winds)
3. Vertical mixing (convection, turbulence)



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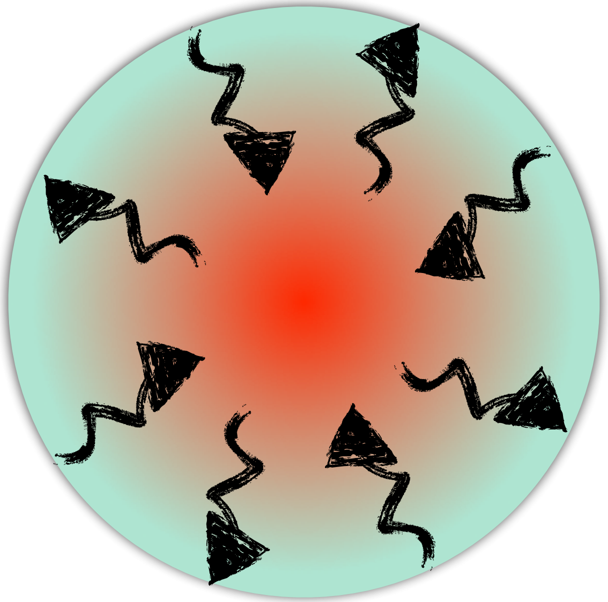
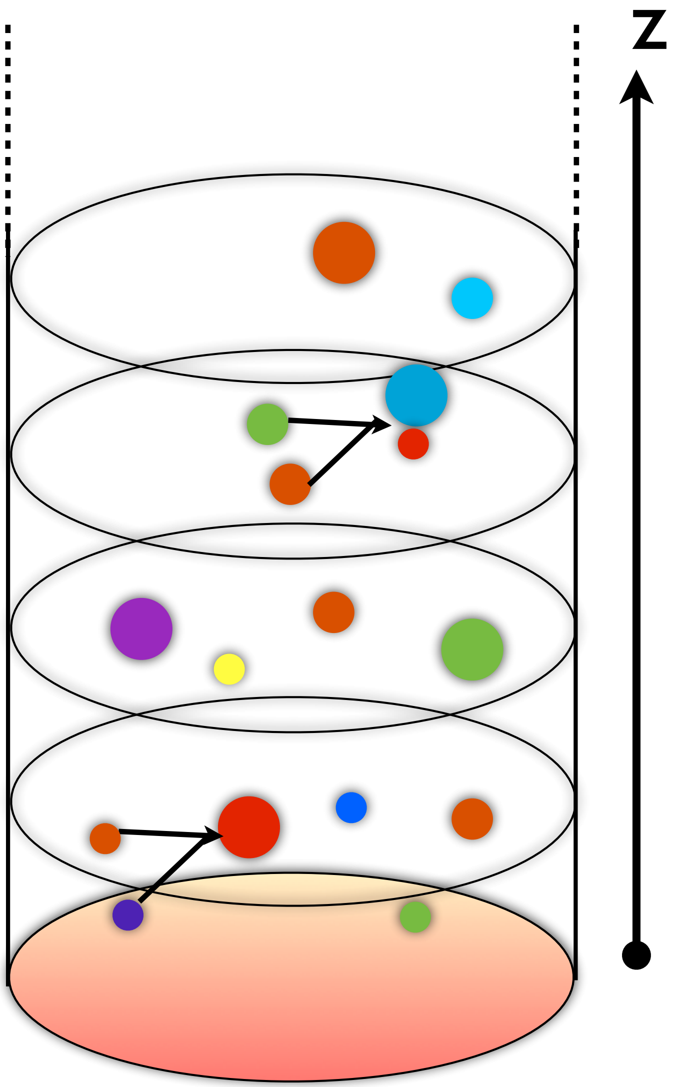


interpretation spectroscopy :
➡ need kinetic models

1D Model: kinetics, vertical mixing and photodissociations



column of atmosphere with PT profile
~100 levels
chemical reactions at (P,T)

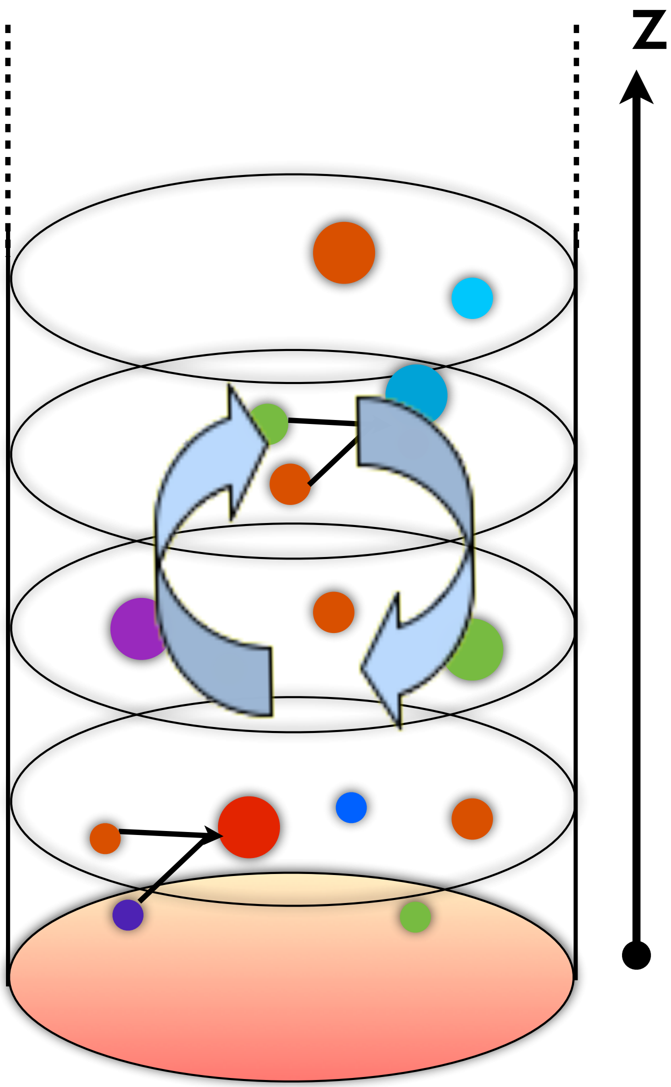
+ vertical mixing
+ UV flux → photodissociations

For each compound and for each level, resolution of the continuity equation:

$$\frac{\partial n_i(z)}{\partial t} = P_i(z) - n_i(z)L_i(z) - div(\Phi_i(z)\vec{e_z})$$

variation of the concentration ($cm^{-3}.s^{-1}$) | production rate | loss rate | vertical mixing

1D Model: kinetics, vertical mixing and photodissociations



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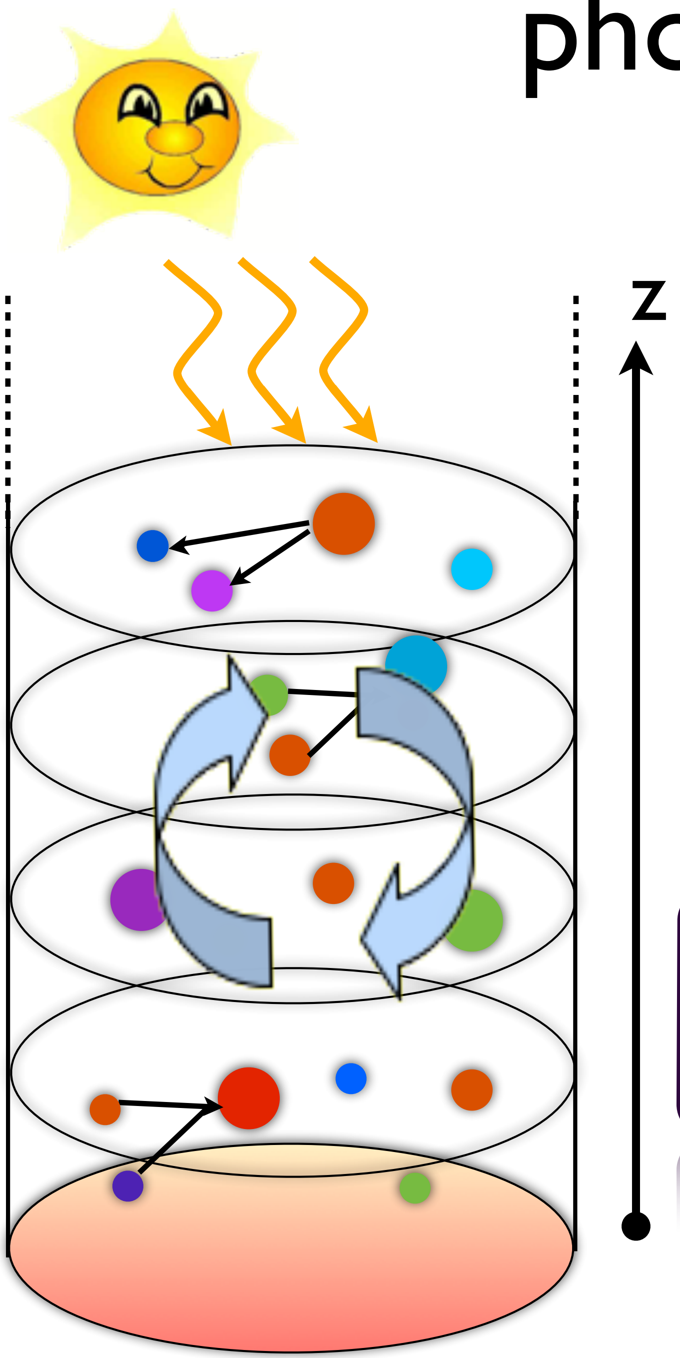

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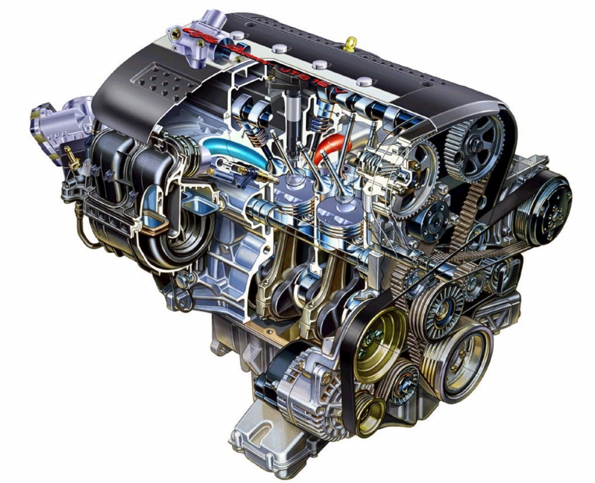
Development of the model:

Chemistry at high temperature

- Chemical networks **totally new** in planetology:

Venot et al. 2012, A&A,
Venot et al. 2013b, Ed. Springer
Venot et al., submitted



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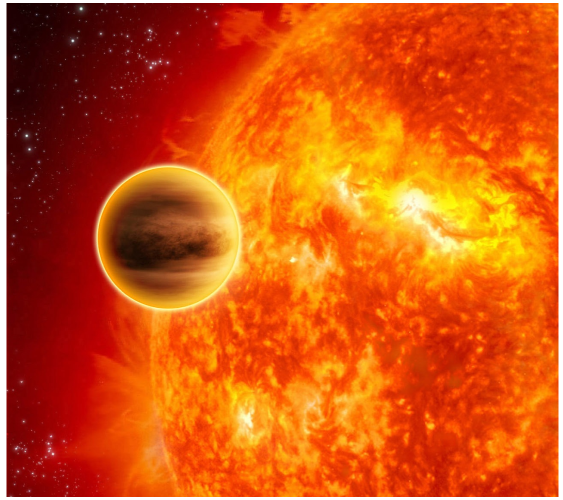
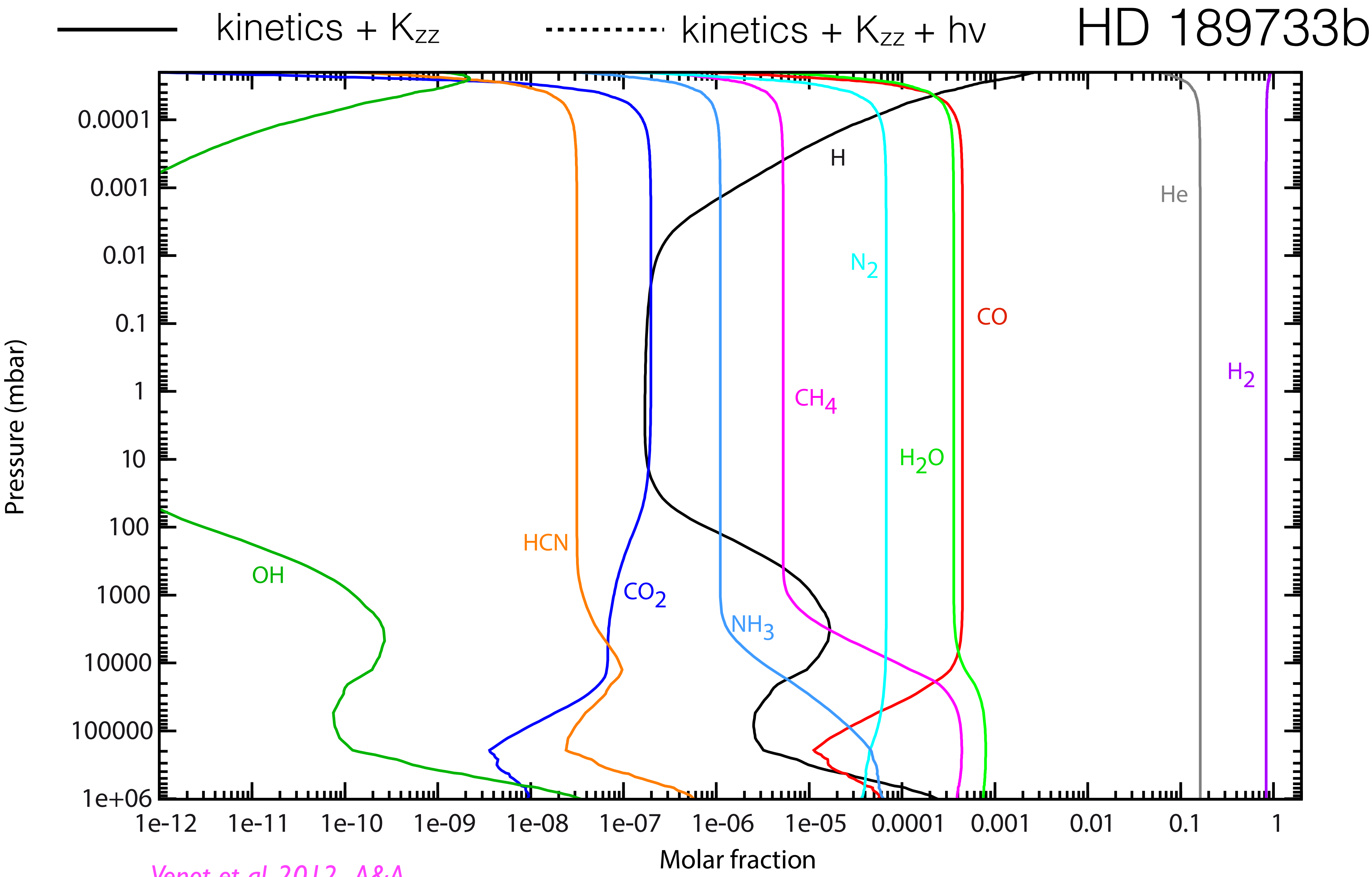


- **interdisciplinary** collaboration - specialist of combustion (LRGP, Nancy)
- schemes validated experimentally as **wholes** - large ranges P (10^{-3}-10^{2} bar) T (300-2500 K)
- 1920 reactions, 105 species (C,H,O,N), C_2
- 4002 reactions, 240 species (C,H,O,N), C_6 *Venot et al., submitted, A&A*
- **available** for the community on KIDA (http ://kida.obs.u-bordeaux1.fr/)

see Valentine Wakelam's talk at 16:40 today

Effect of photodissociations



Venot et al. 2012, A&A,

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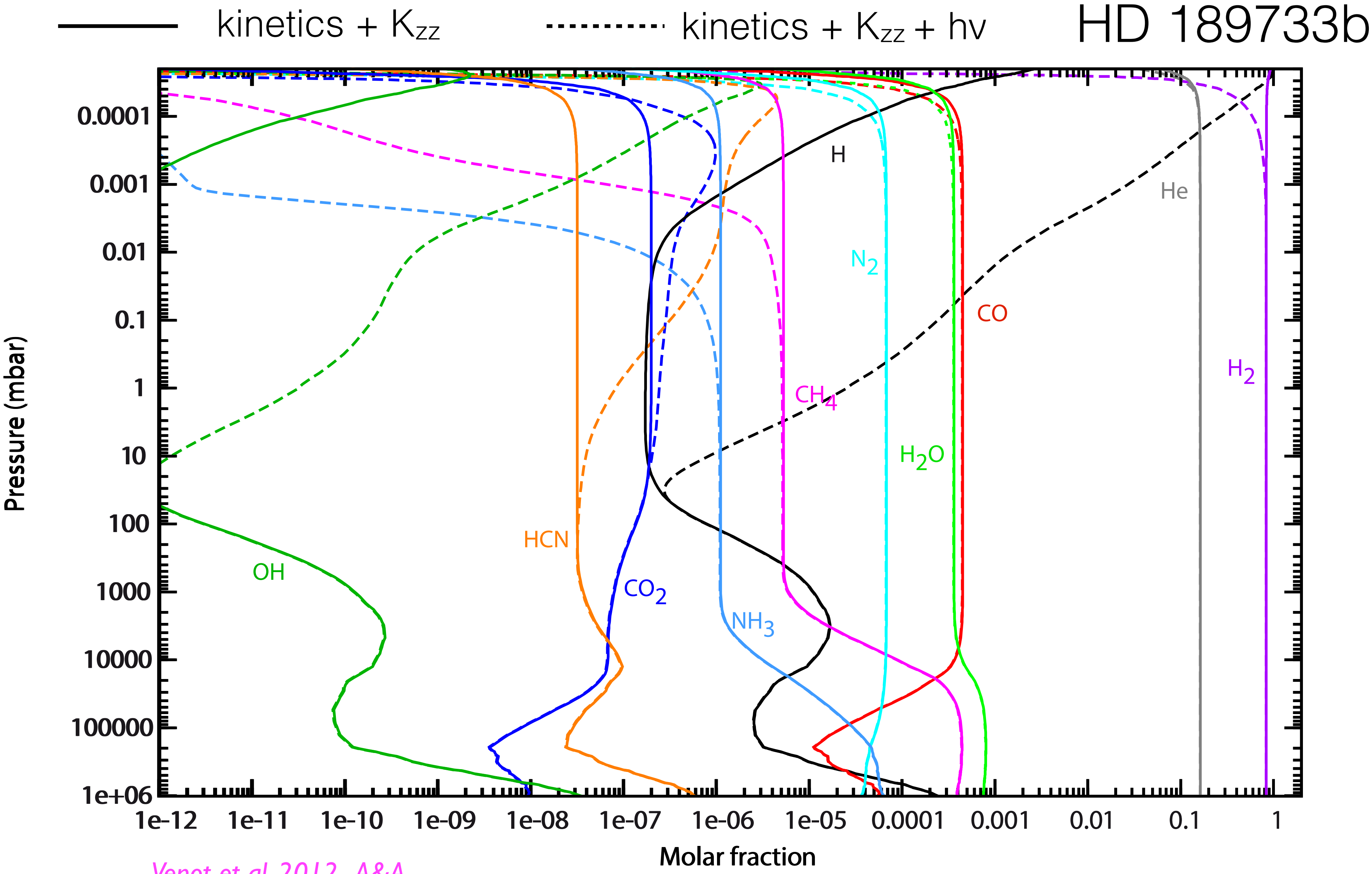

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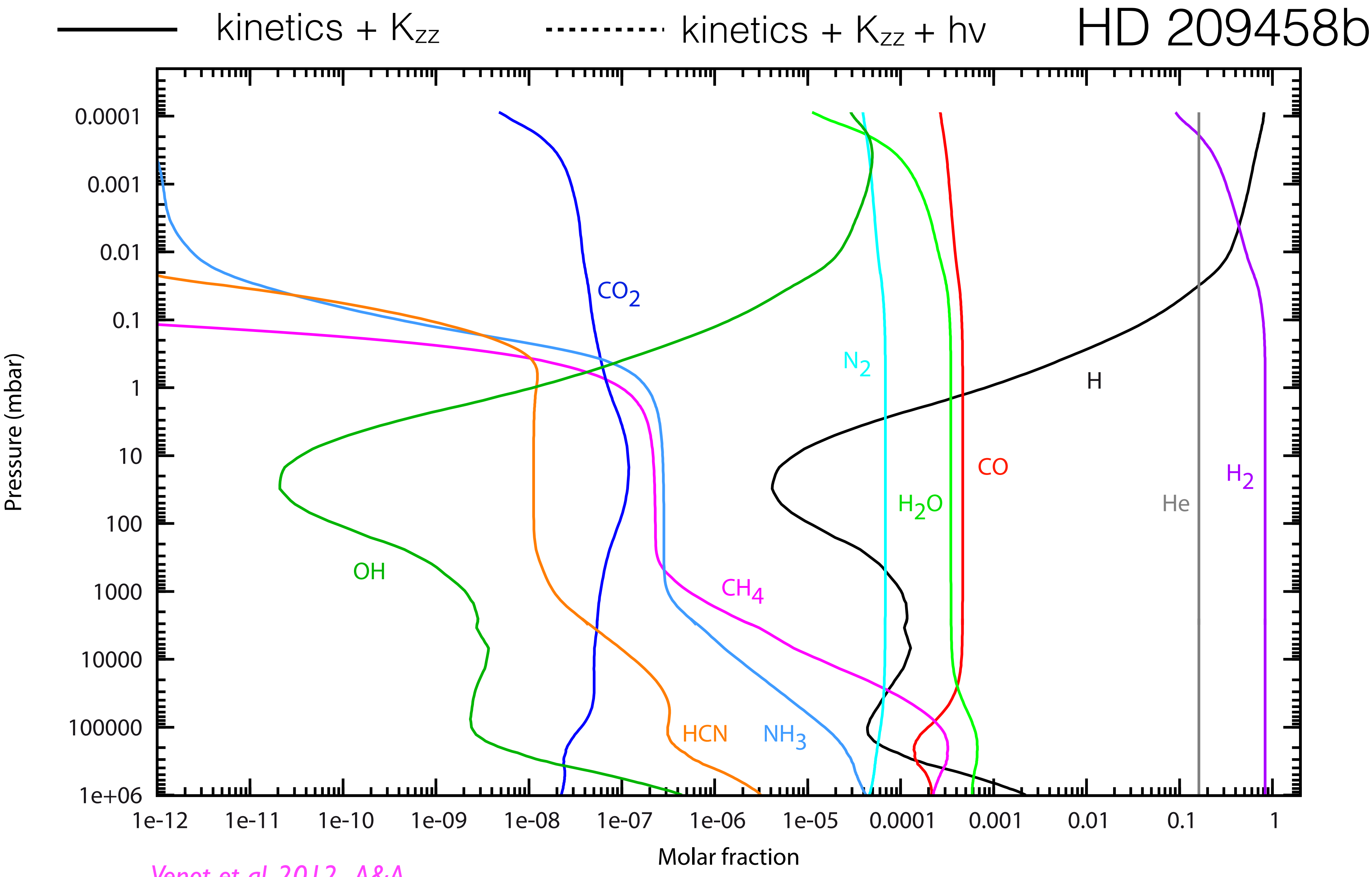

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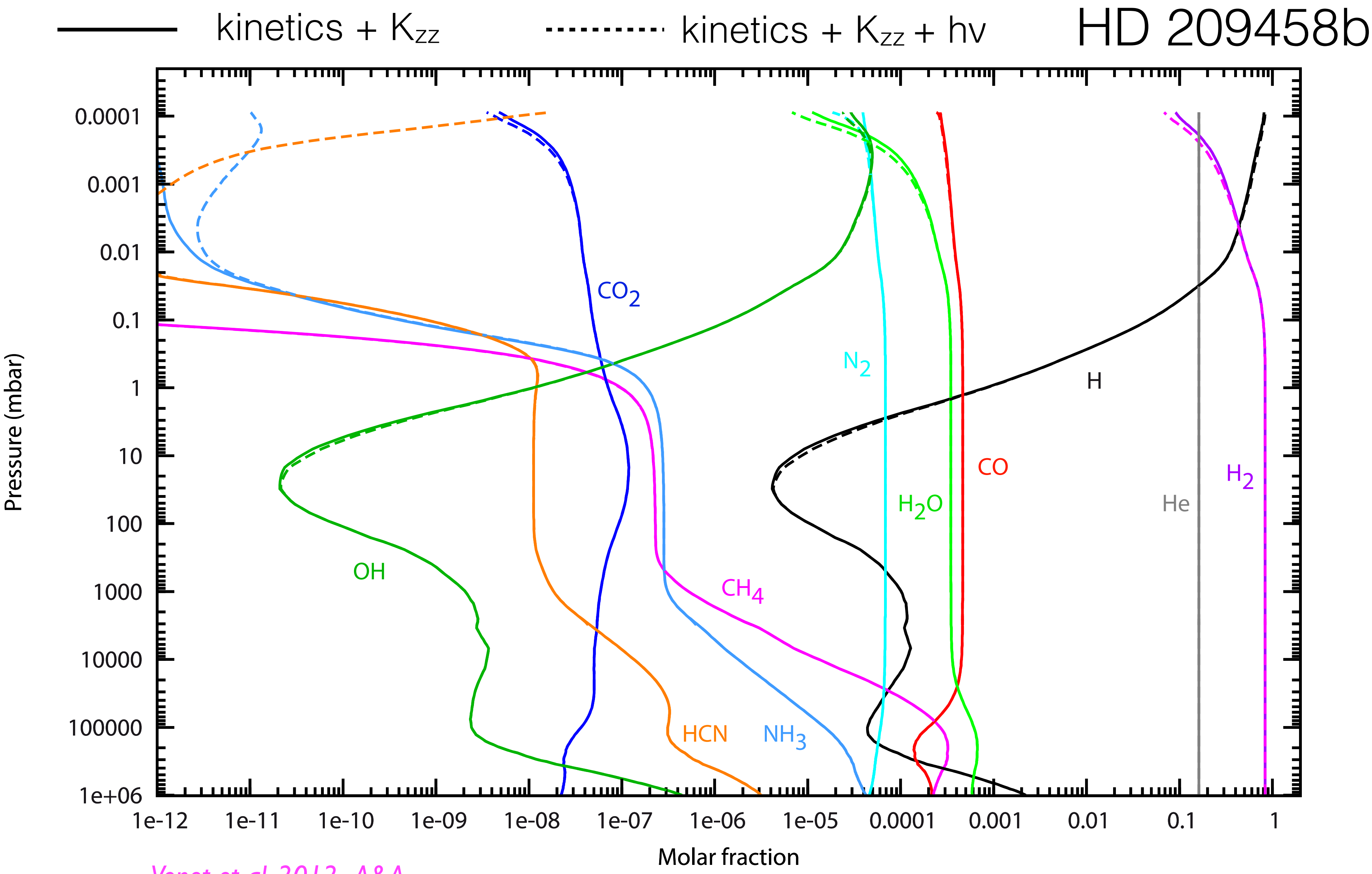

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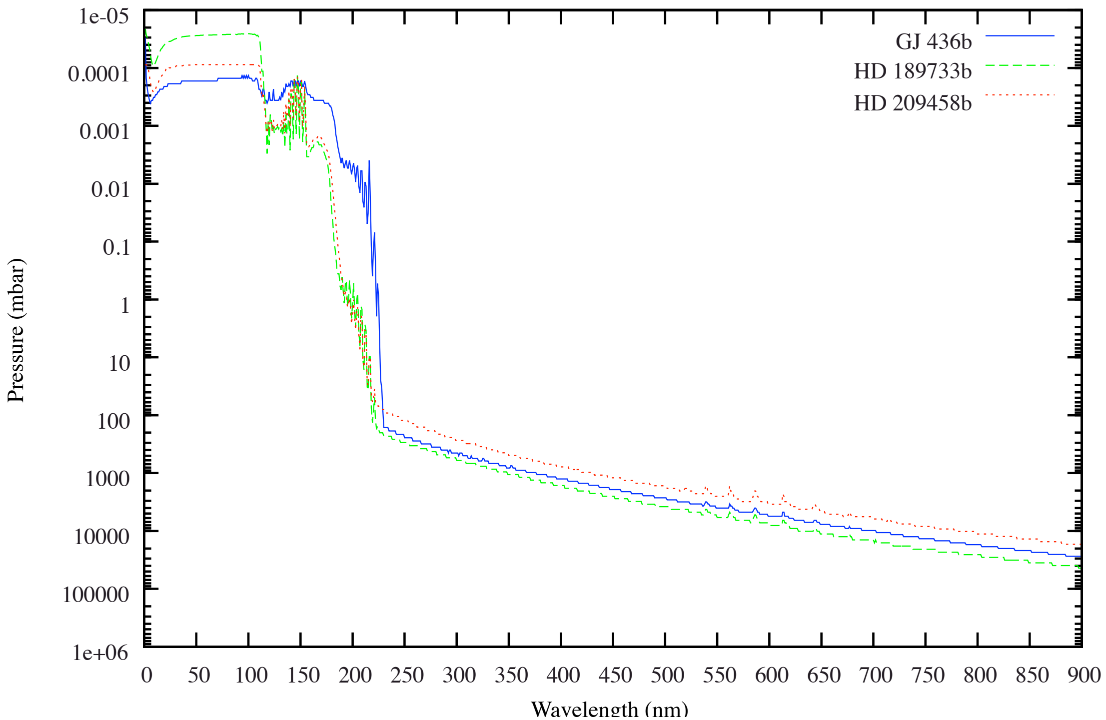
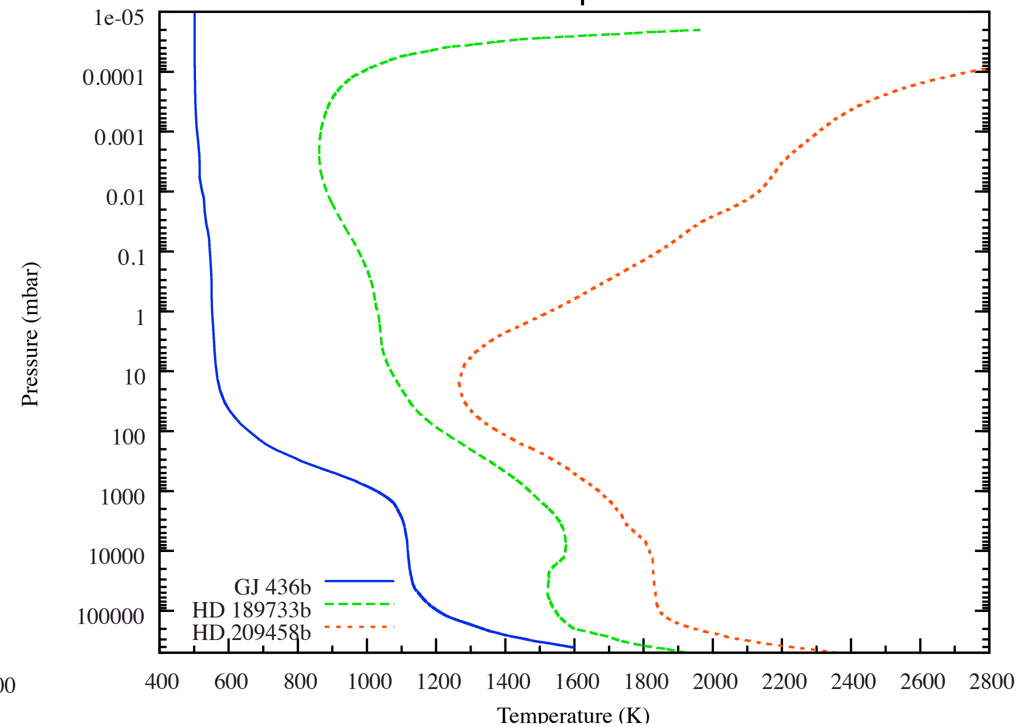
Effect of photodissociations

HD189733b, HD209458b (hot Jupiters), and GJ436b (warm Neptune)

penetration of UV flux (level where τ=1)



thermal profiles



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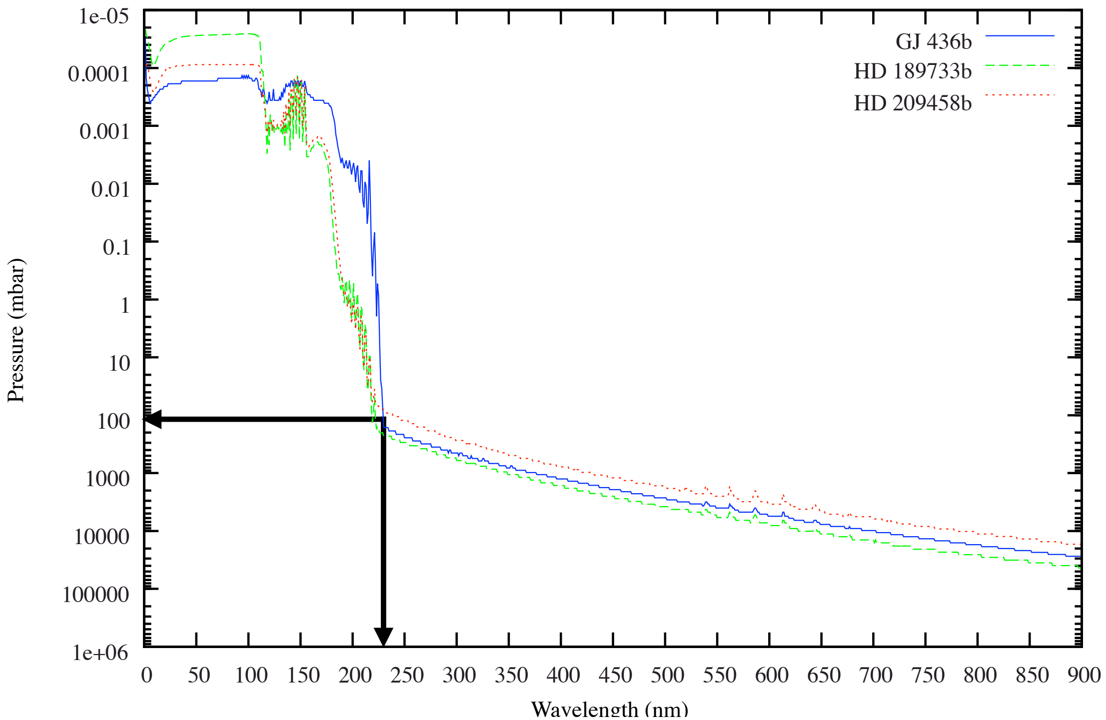

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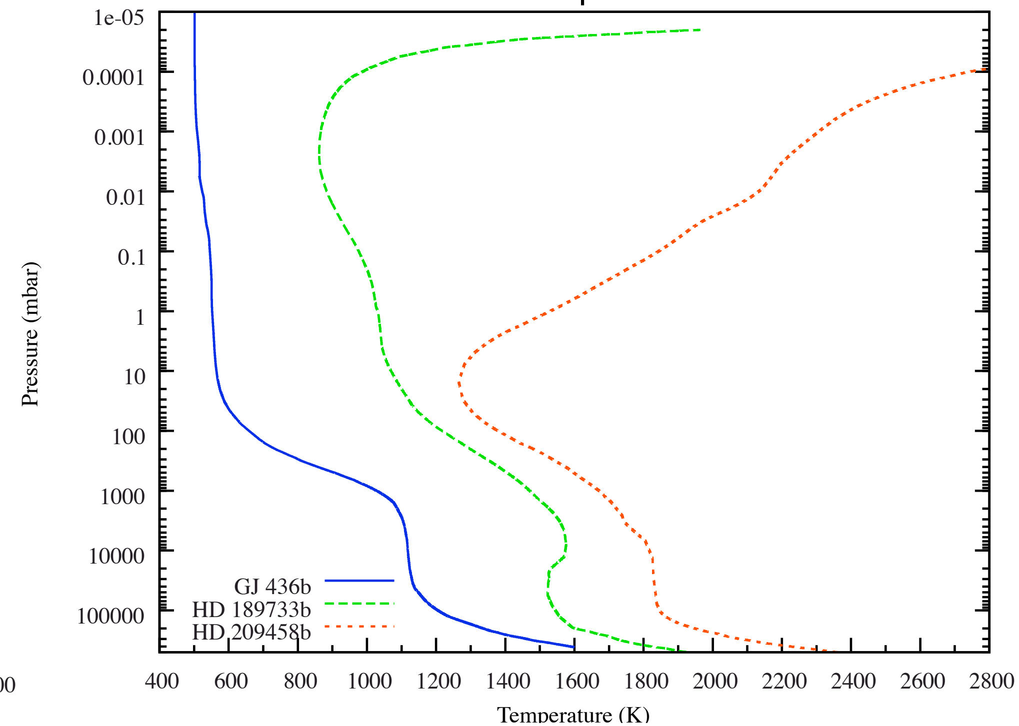

λ of interest : < 250 nm

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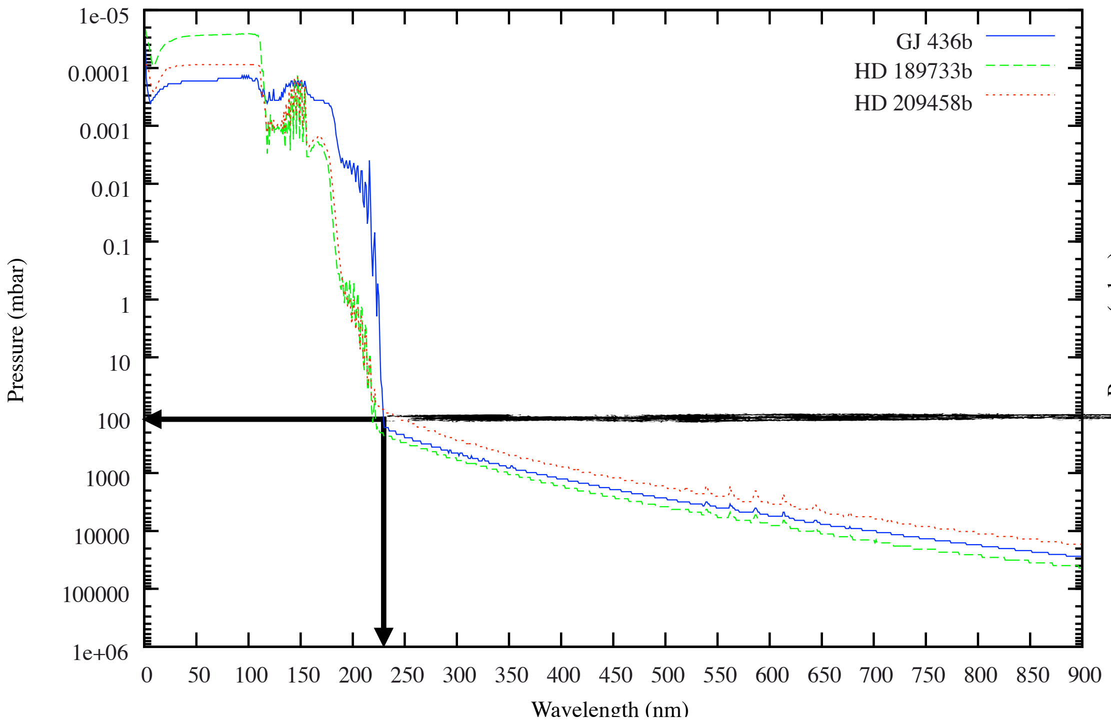

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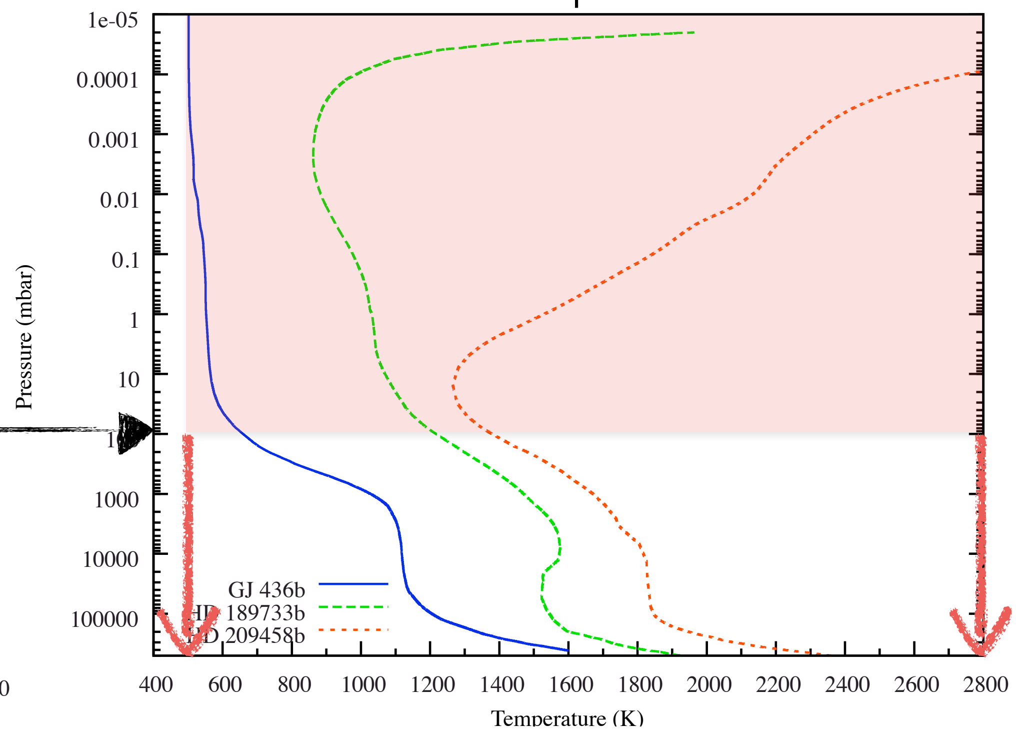


λ of interest : < 250 nm

500 - 2800 K !

Absorption cross sections

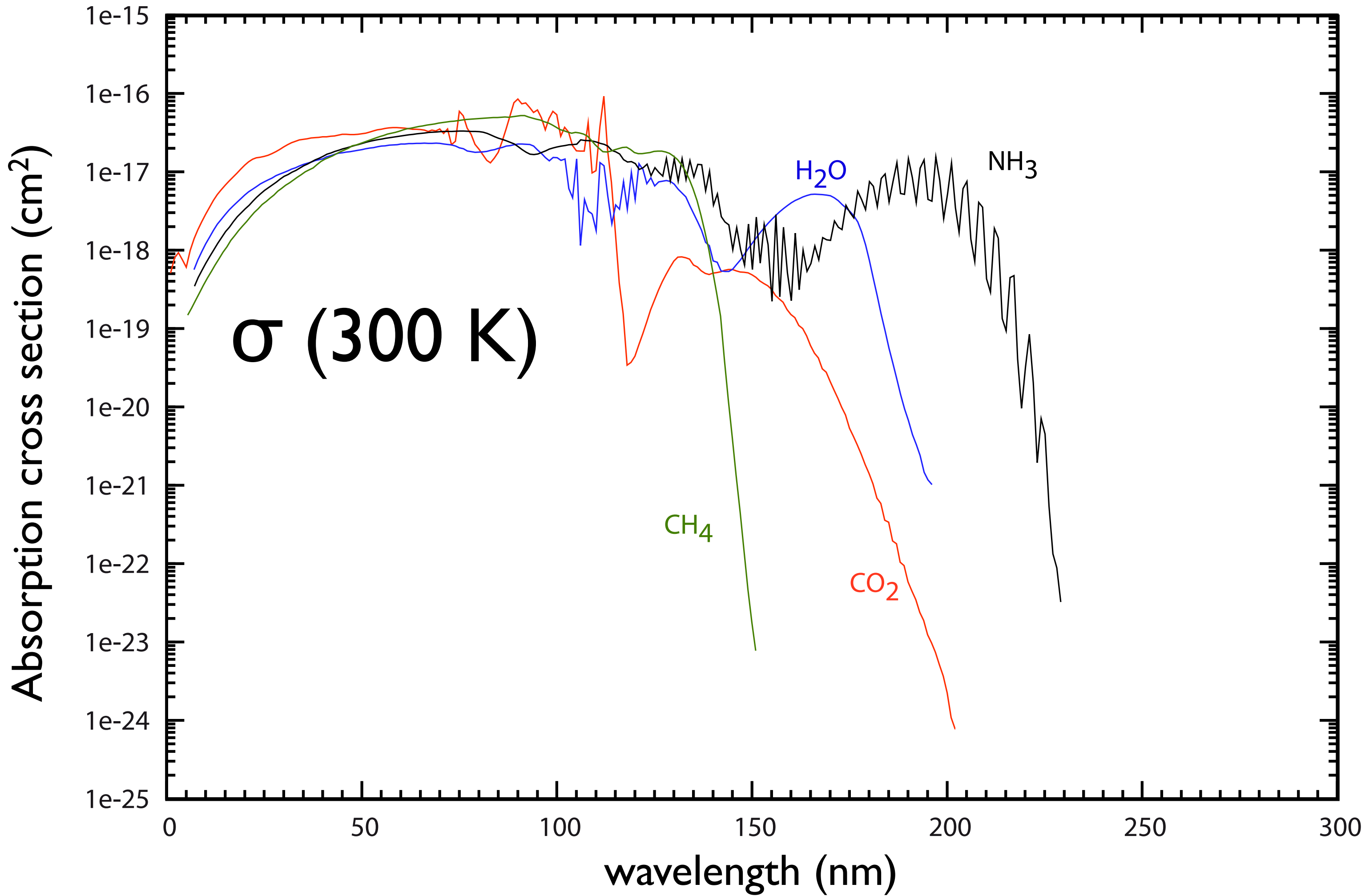
$\sigma(\lambda,T)$: capacity to absorb flux

Photodissociations rate:

$$J^k(z) = \int_{\lambda_1}^{\lambda_2} \sigma(\lambda,T)F(\lambda,z)q_k(\lambda,T)d\lambda$$

Actinic flux :

$$F(\lambda,z) = F_0(\lambda)\exp\left(-\sigma(\lambda,T)\int_z^{\infty} n(h)dh\right)$$



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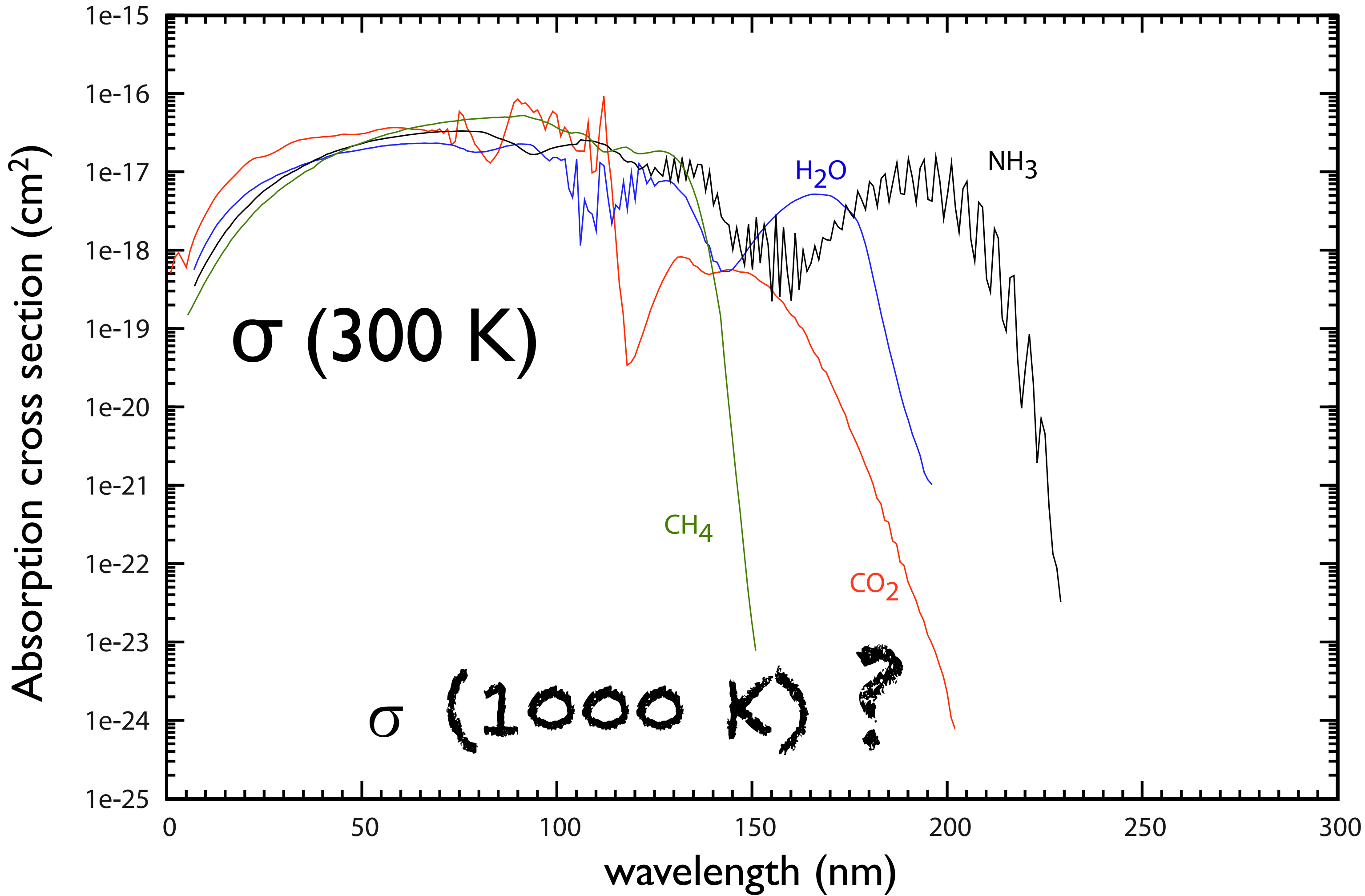


Absorption cross sections

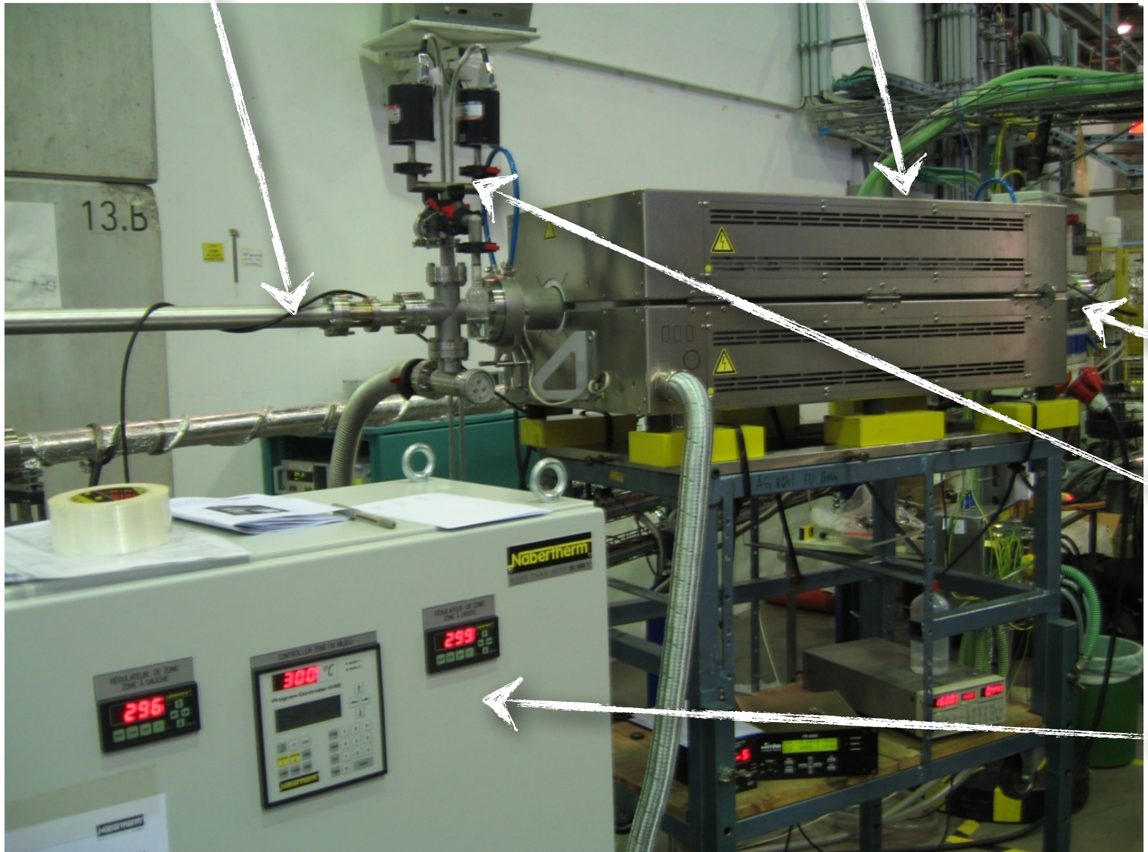
lisa

experimental setup:

T up to 1000K

incident monochromatic flux

oven + cell



photomultiplier

injection of gas

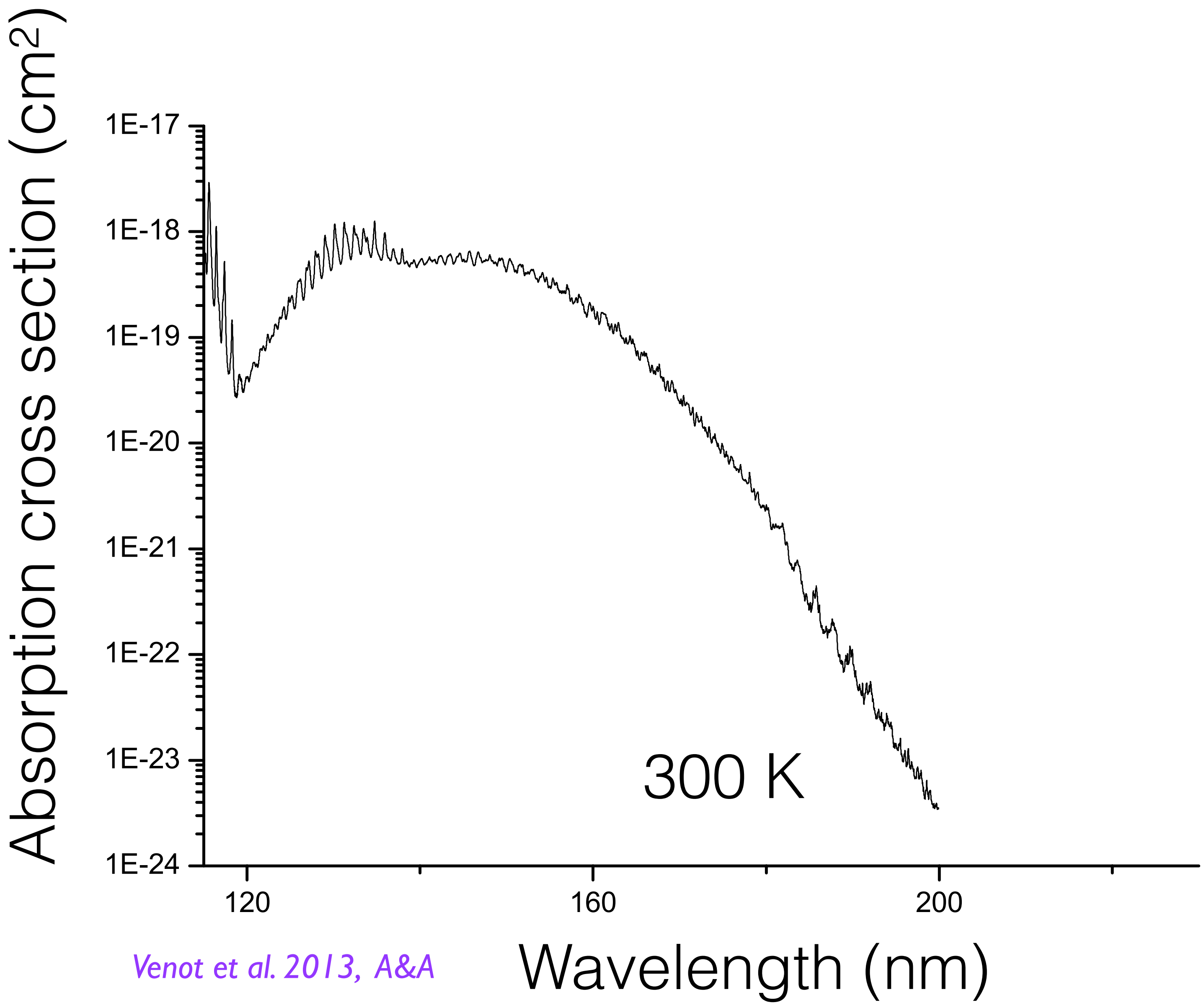
temperature control (3 zones)

115-230 nm

synchrotron facility BESSY (Germany) 115 < λ < 190 nm

UV lamp at LISA (France) 190 < λ < 230 nm

Absorption cross sections of CO_2



Venot et al. 2013, A&A

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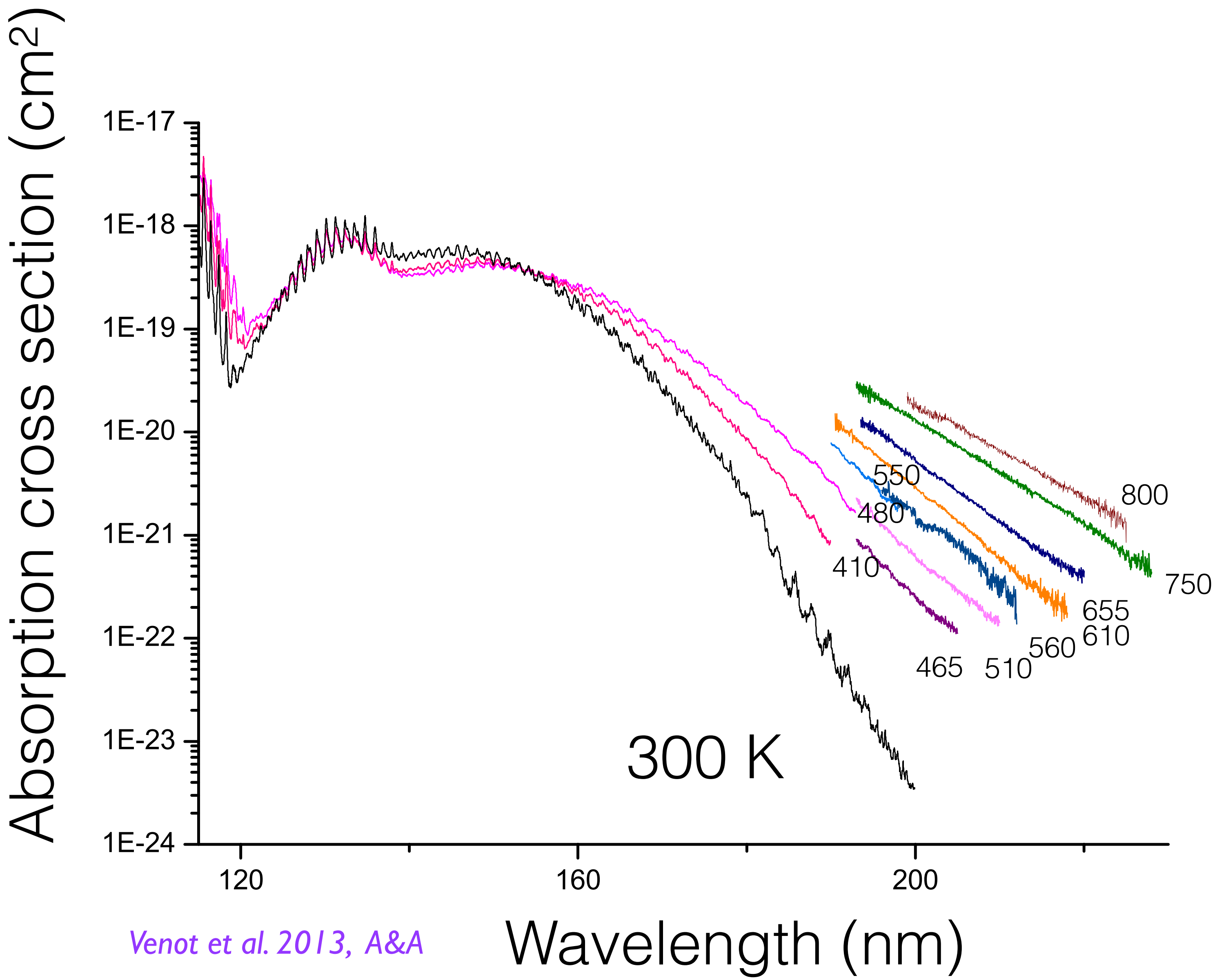

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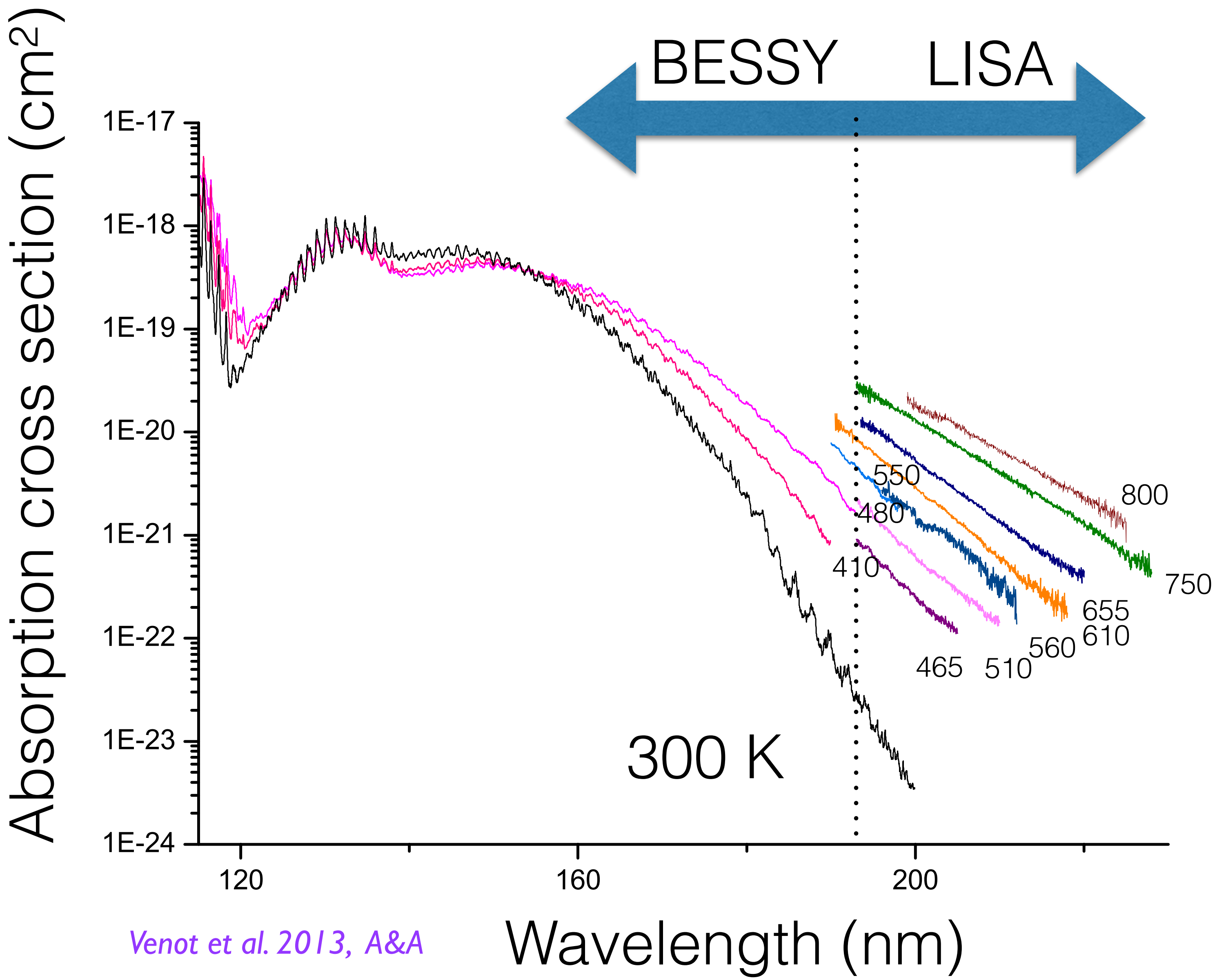

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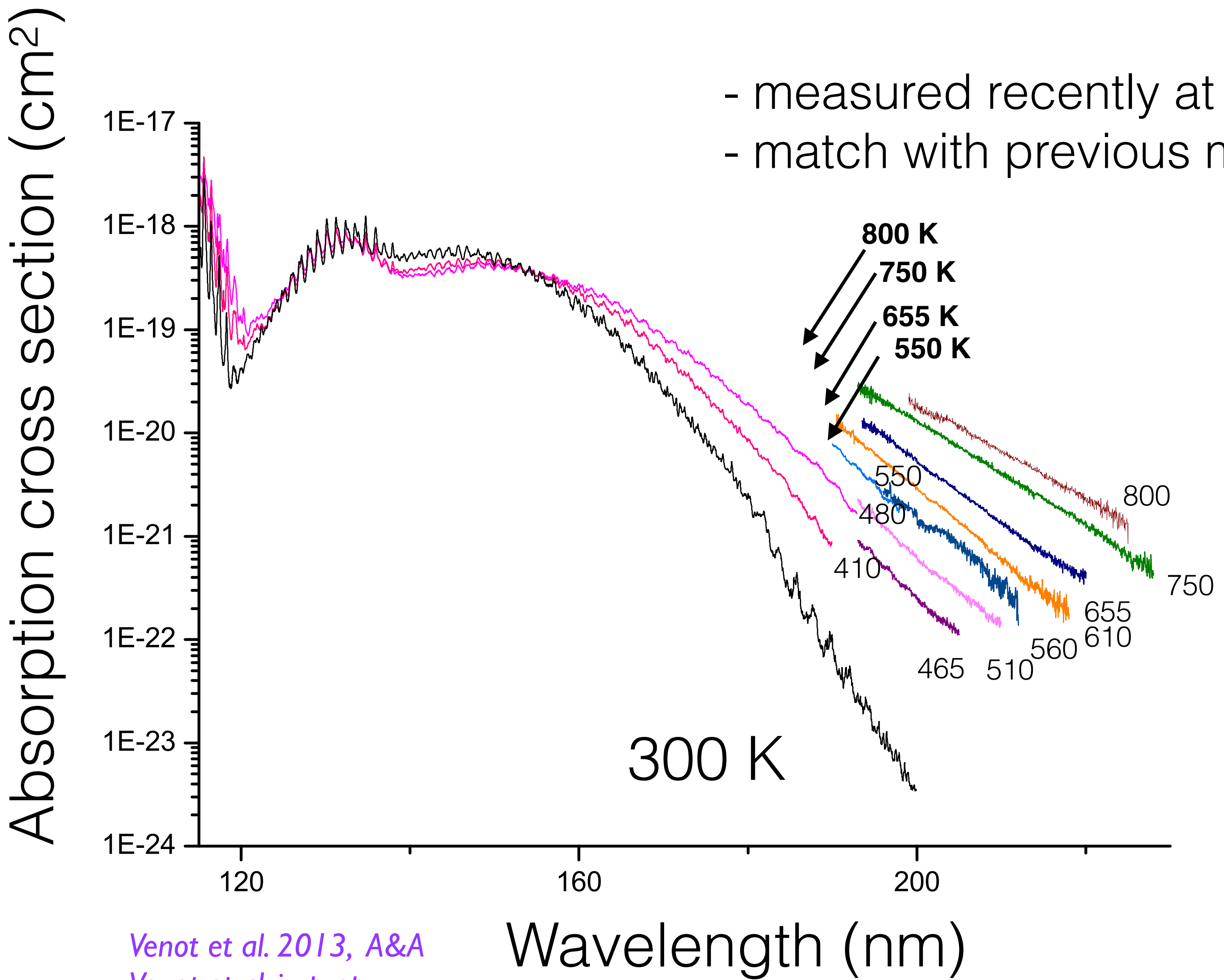

- measured recently at BESSY
- match with previous measurements

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Venot et al. in prep.

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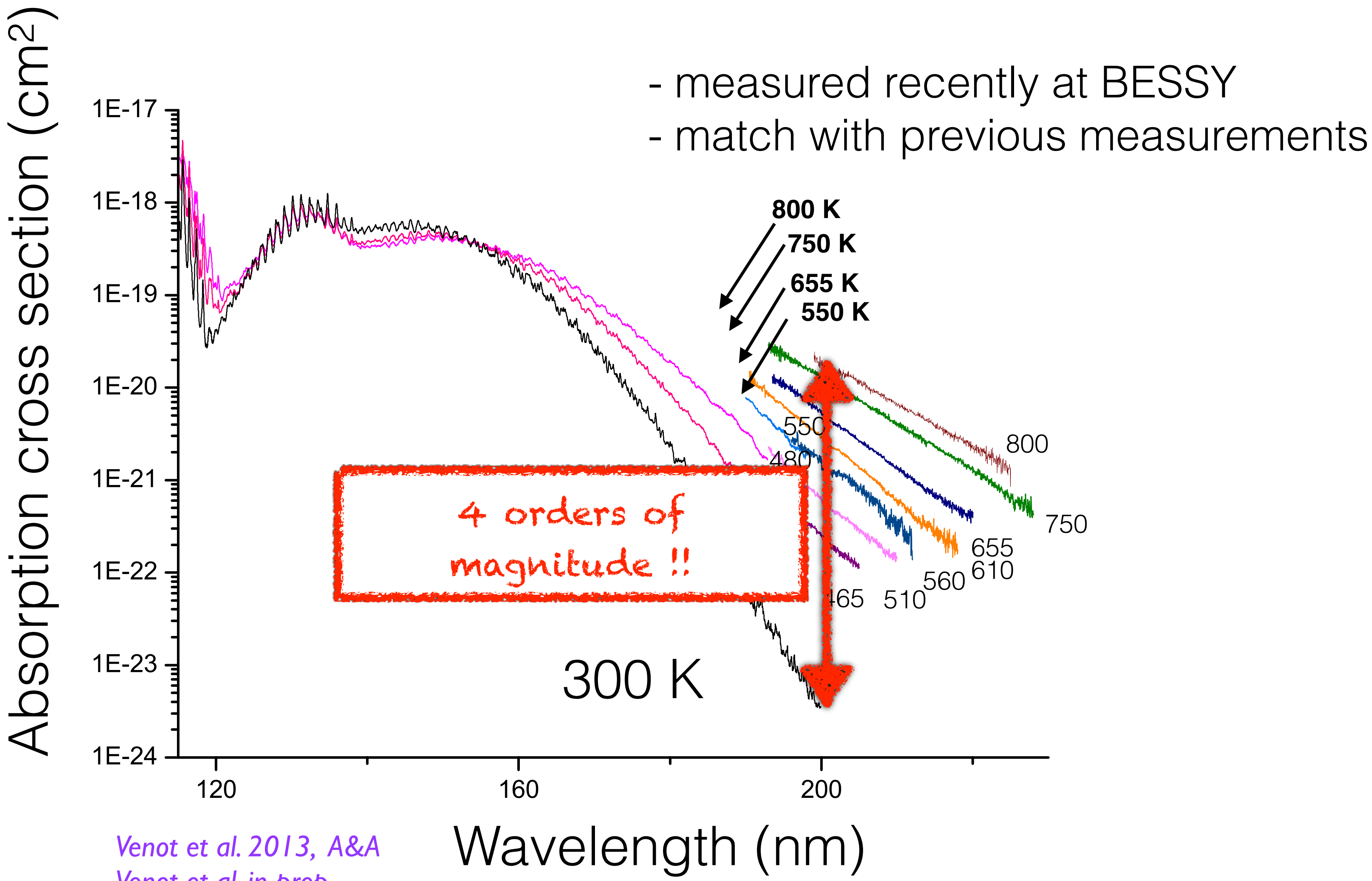

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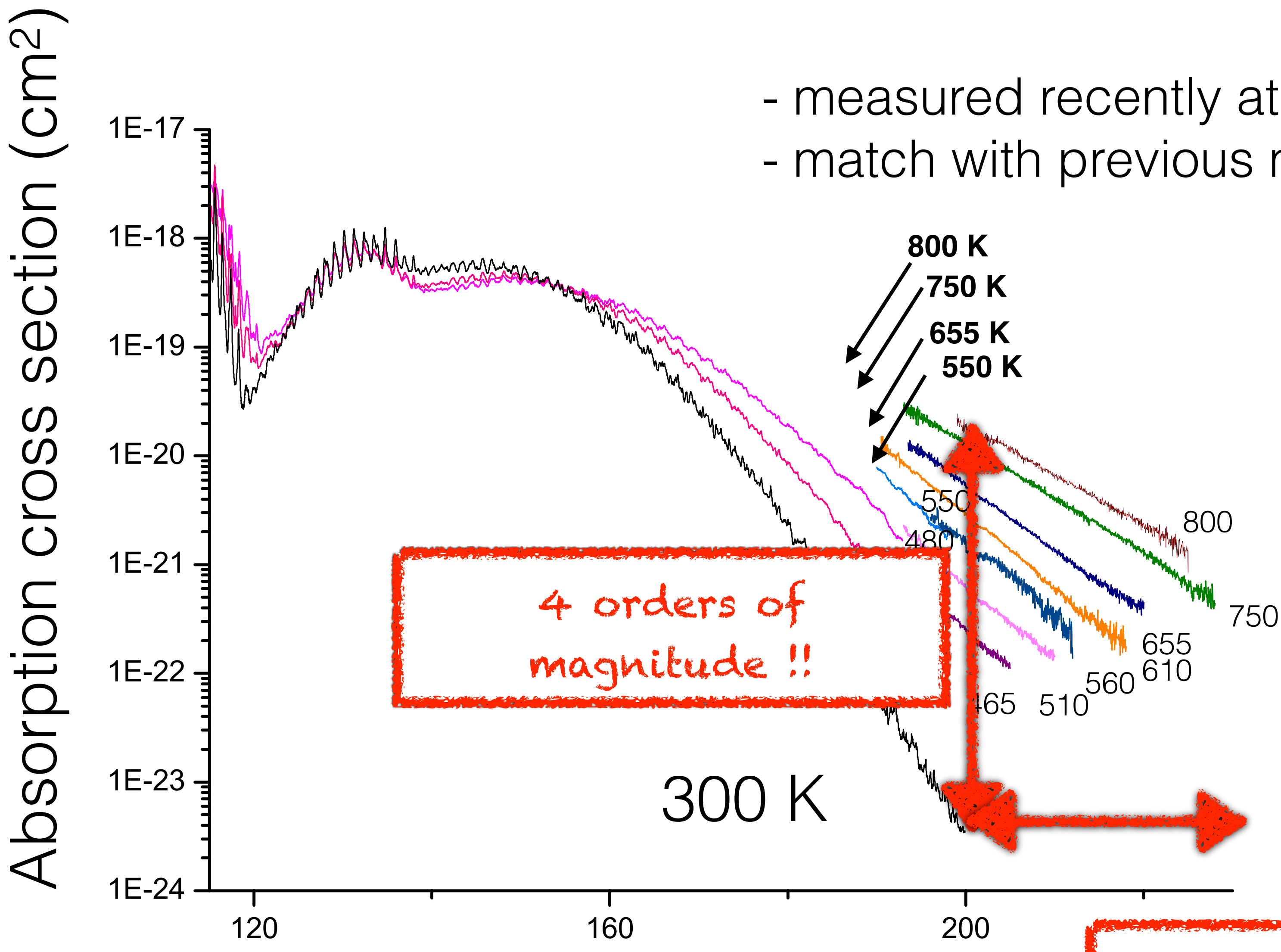

larger λ range of absorption !!

Venot et al. 2013, A&A
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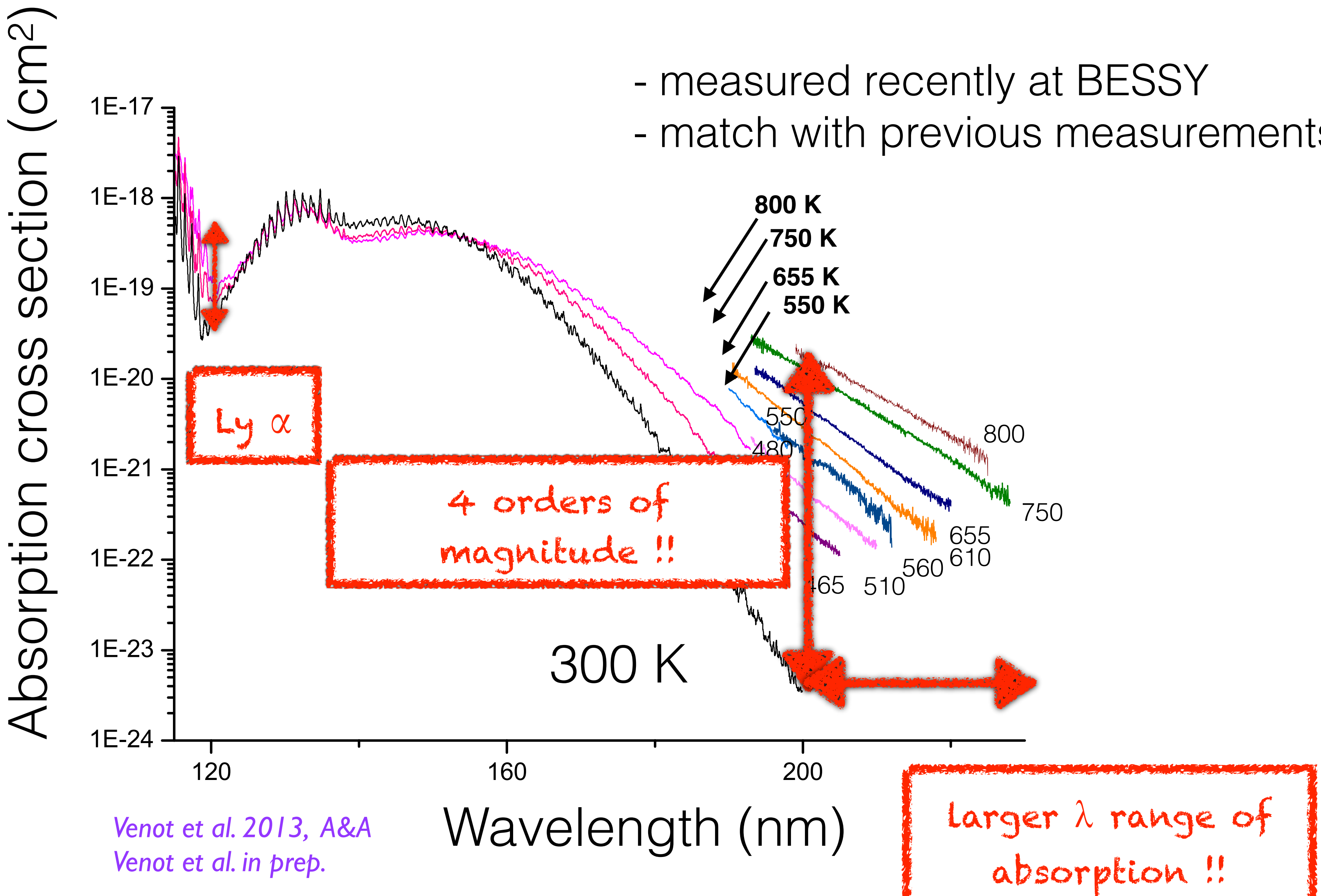

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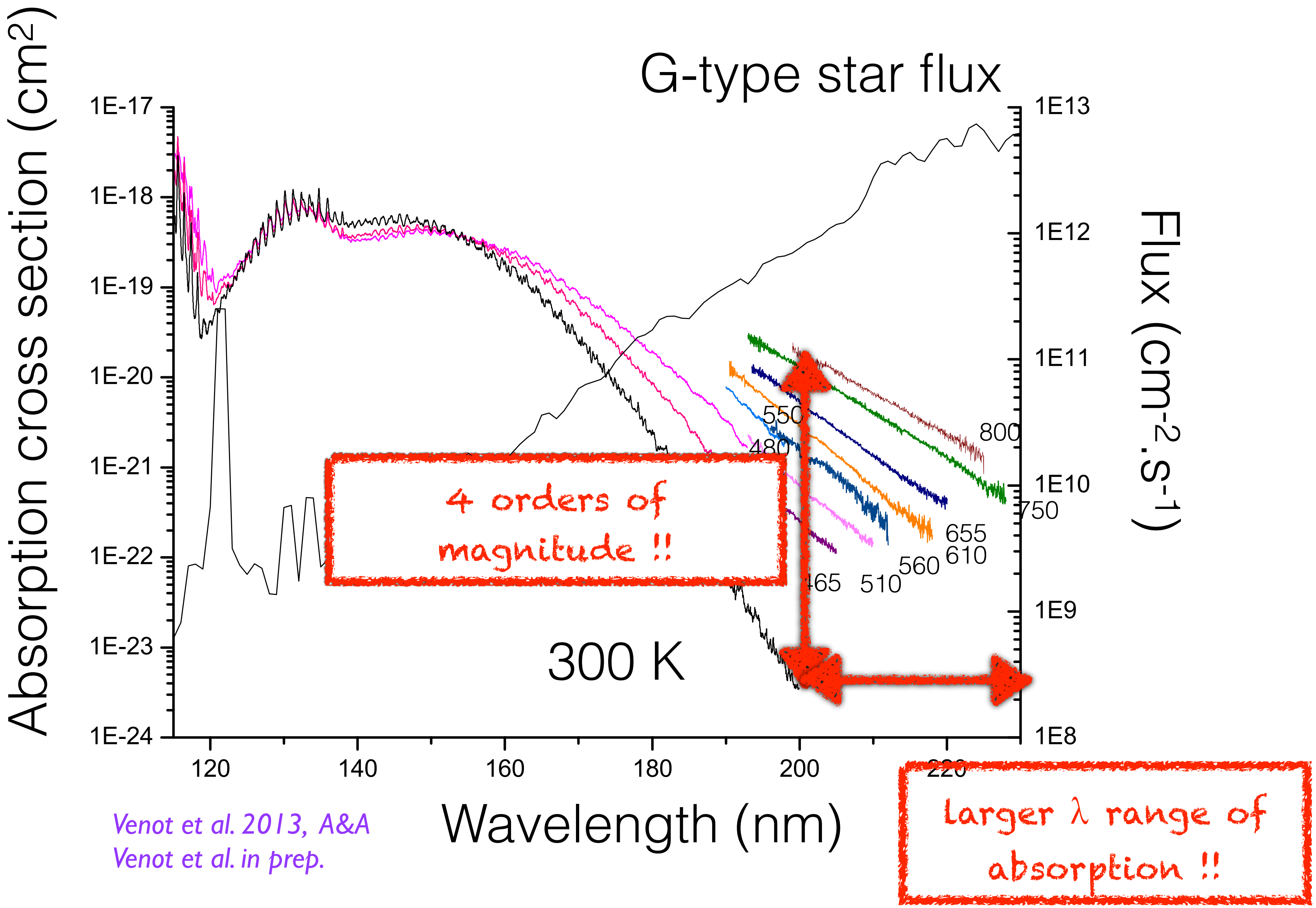


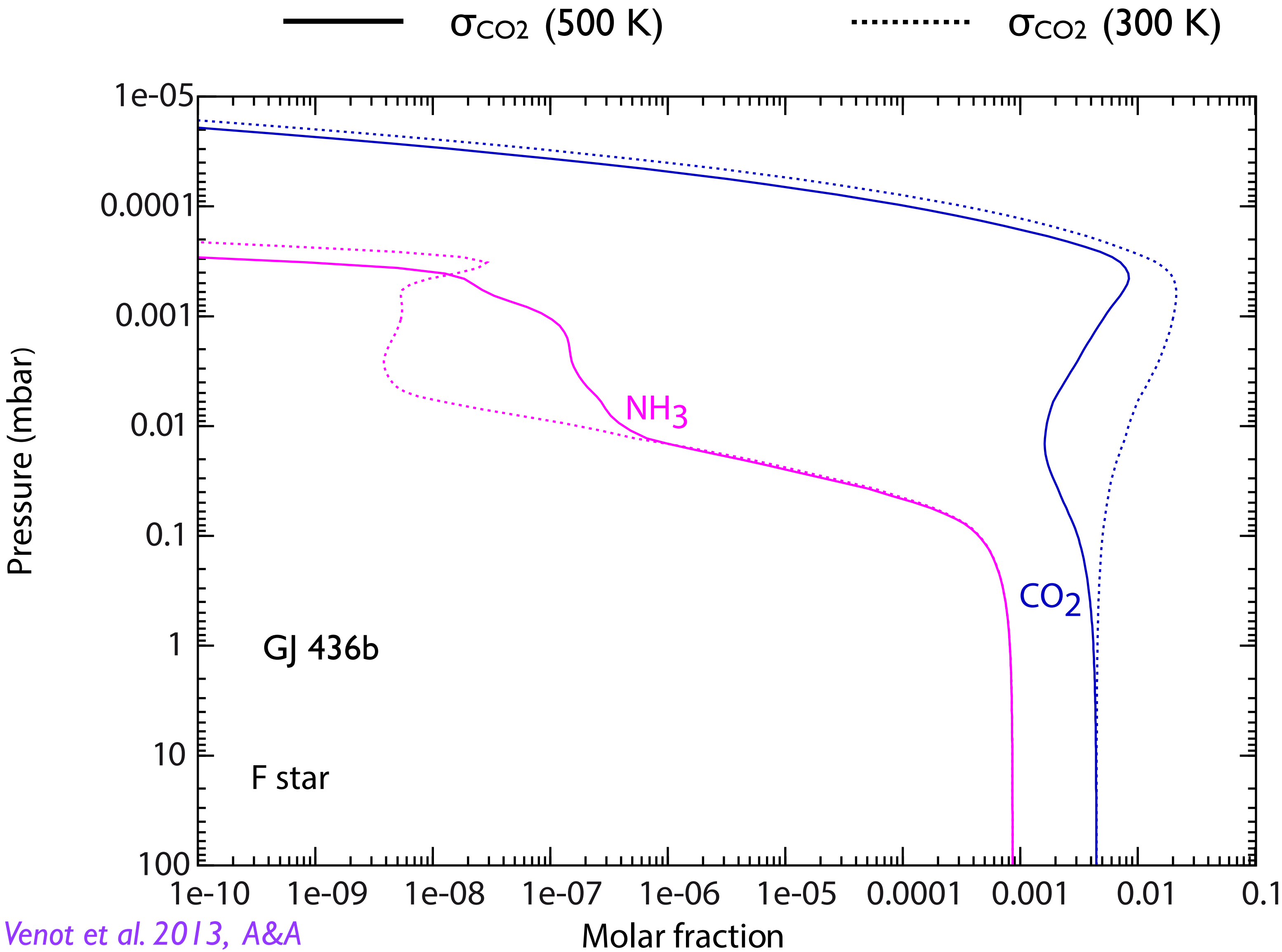
Venot et al. 2013, A&A
Venot et al. in prep.

Consequences on atmosphere

warm Neptune orbiting around a F star
$T_{atm} \approx$ 500 K (P < 100 mbar)

influence of UV flux: complex interaction between molecules

under or over-estimation of photodissociations !



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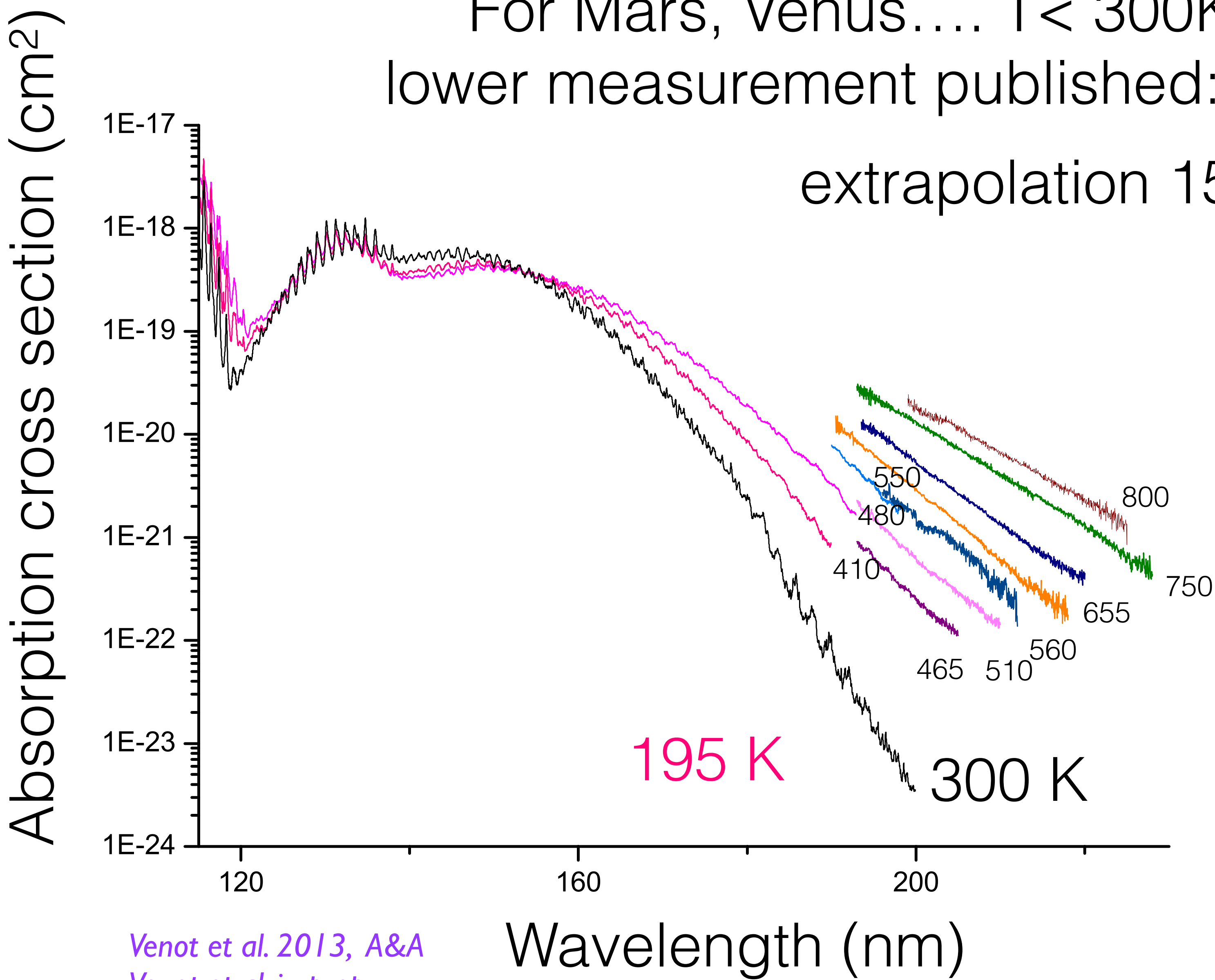
Absorption cross sections of CO_2

For Mars, Venus…. T< 300K…
lower measurement published: 195K

extrapolation 150 K ?



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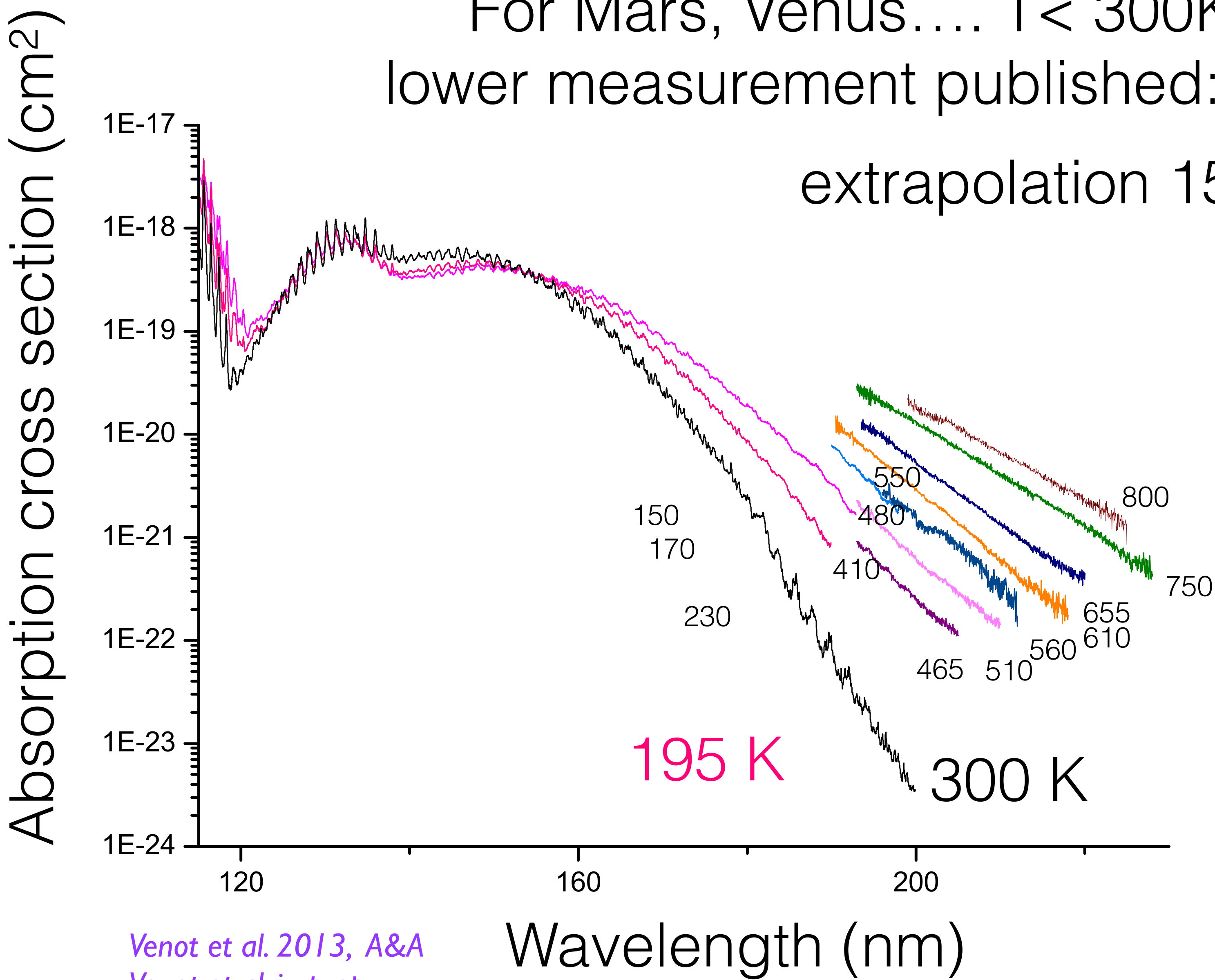

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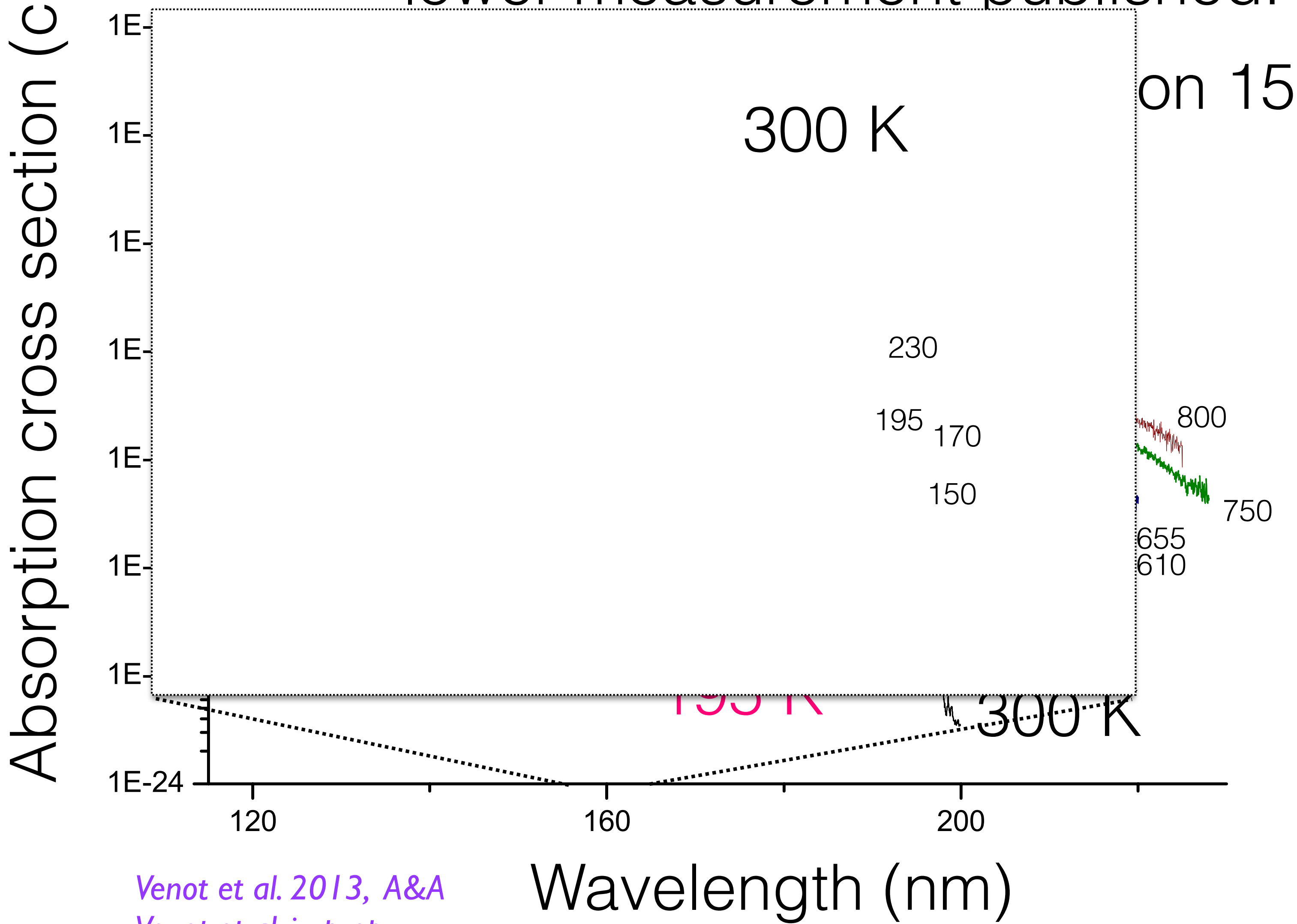

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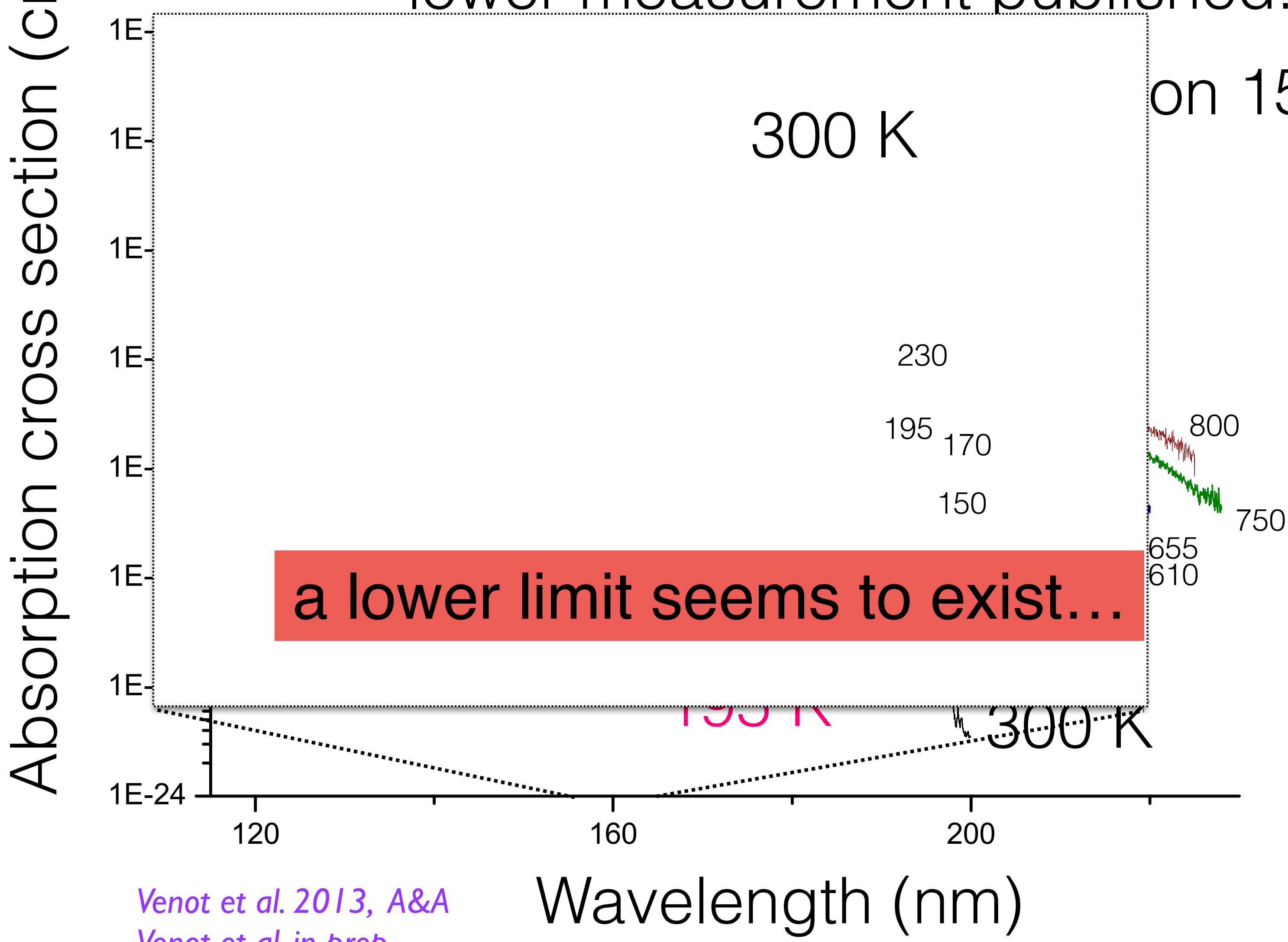

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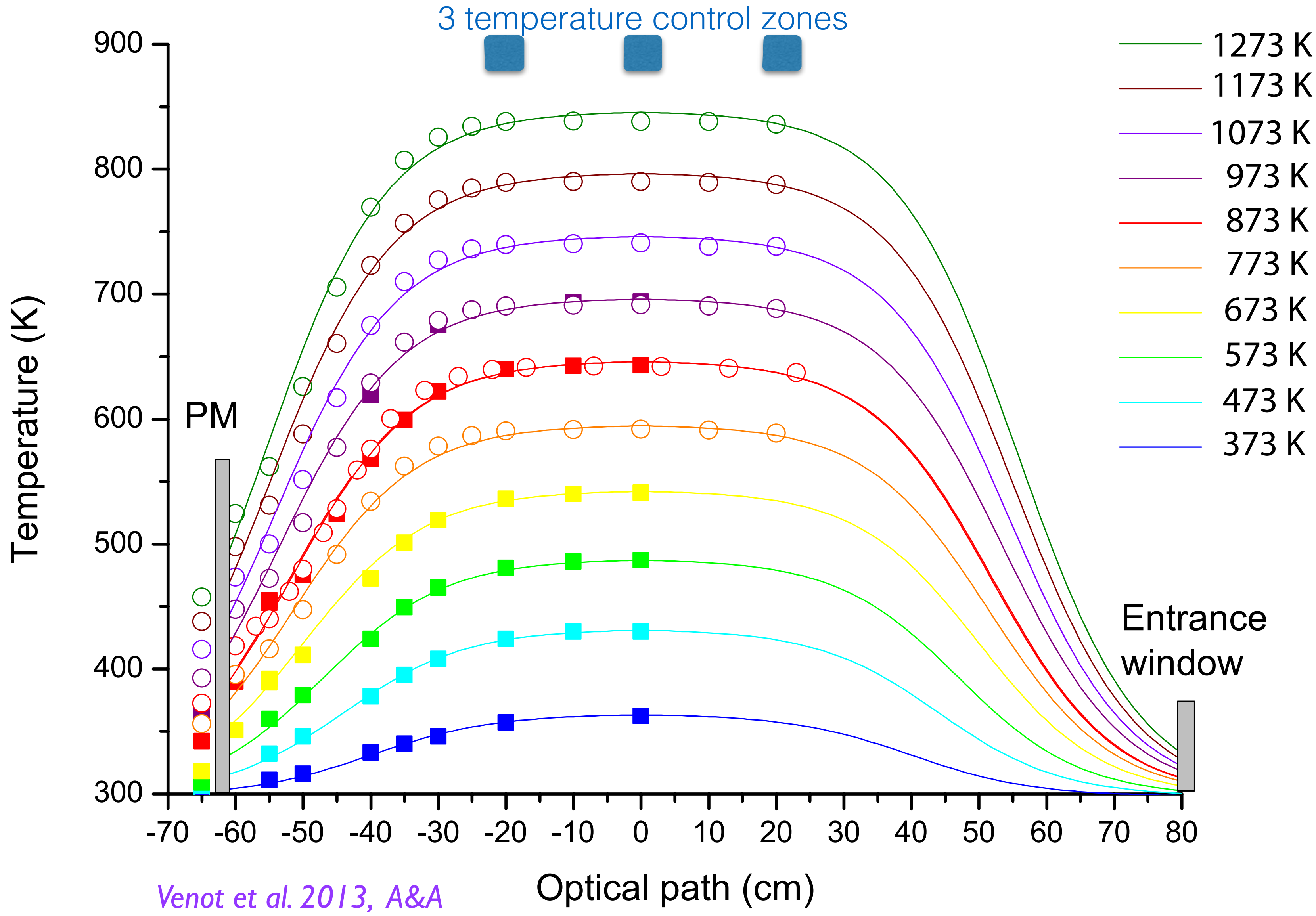
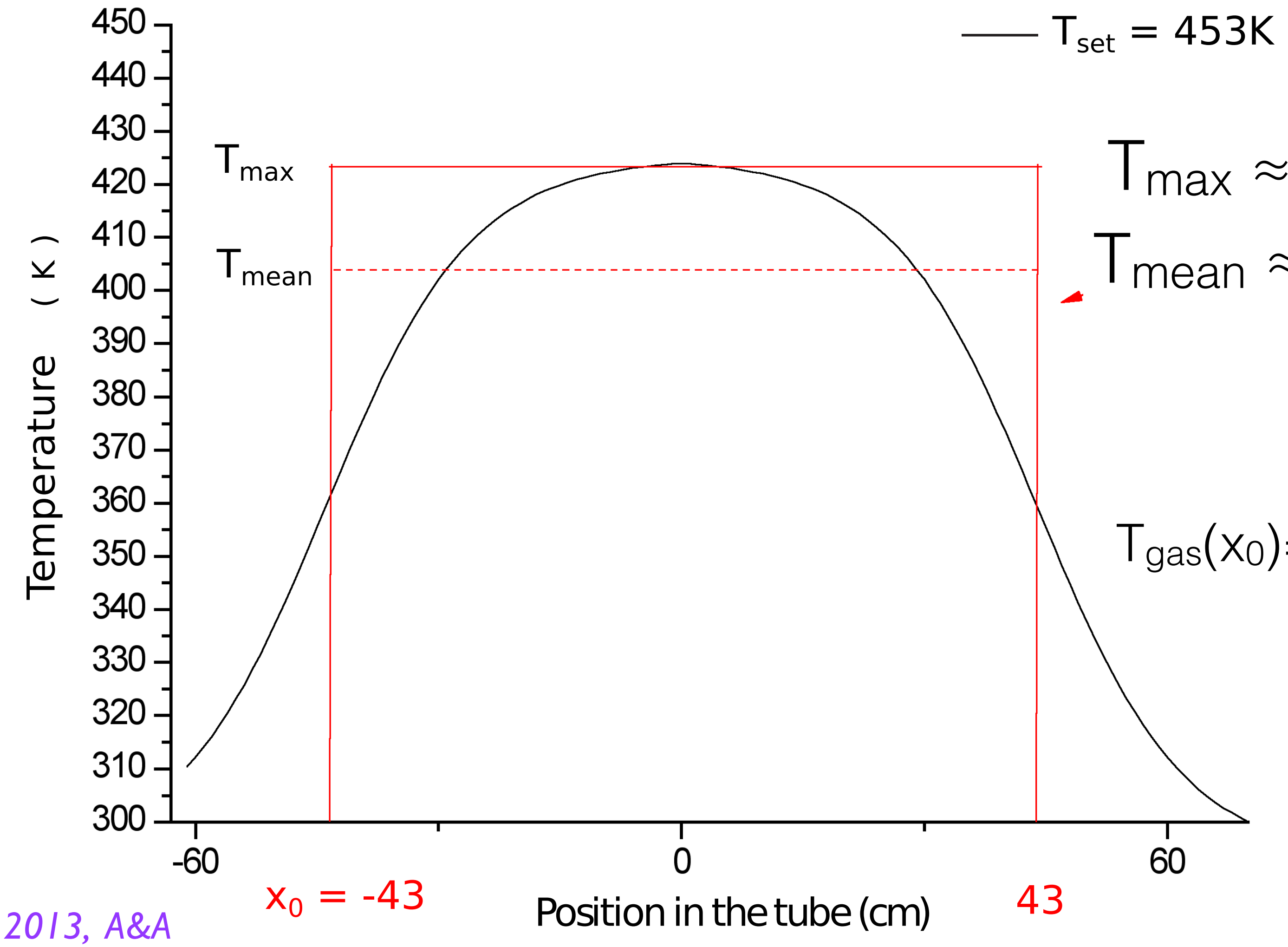
Experimental issues

⇒ Temperature gradient



Experimental issues

⇒ Approximation : between x_0 and $-x_0$ → T_{mean}
elsewhere → T_{amb} (300K)



$T_{max} \approx 420$ K

$T_{mean} \approx 405$ K

$T_{gas}(x_0) = (T_{max} + T_{amb})/2$

Venot et al. 2013, A&A

Experimental issues

⇒ Thermal decomposition

Absorption cross section (cm^2)

Wavelength (nm)

Experimental issues

⇒ Thermal decomposition

Absorption cross section (cm^2)

CO !!

Wavelength (nm)

Experimental issues

⇒ Thermal decomposition

Absorption cross section (cm^2)

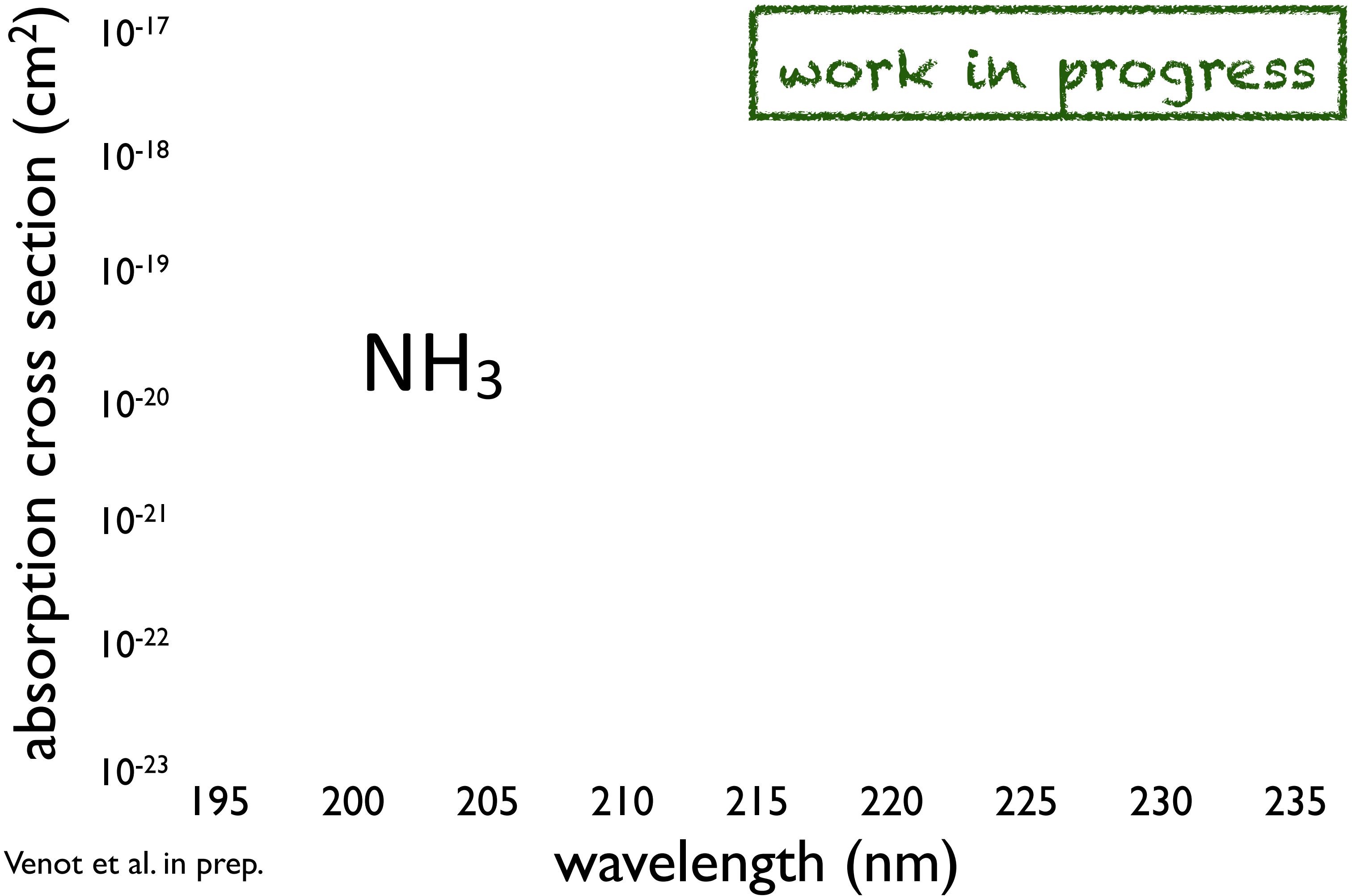
CO !!

⇒ isolation of CO features by subtracting two CO_2 spectra

⇒ remove CO from CO_2 spectra

Wavelength (nm)

Experimental issues

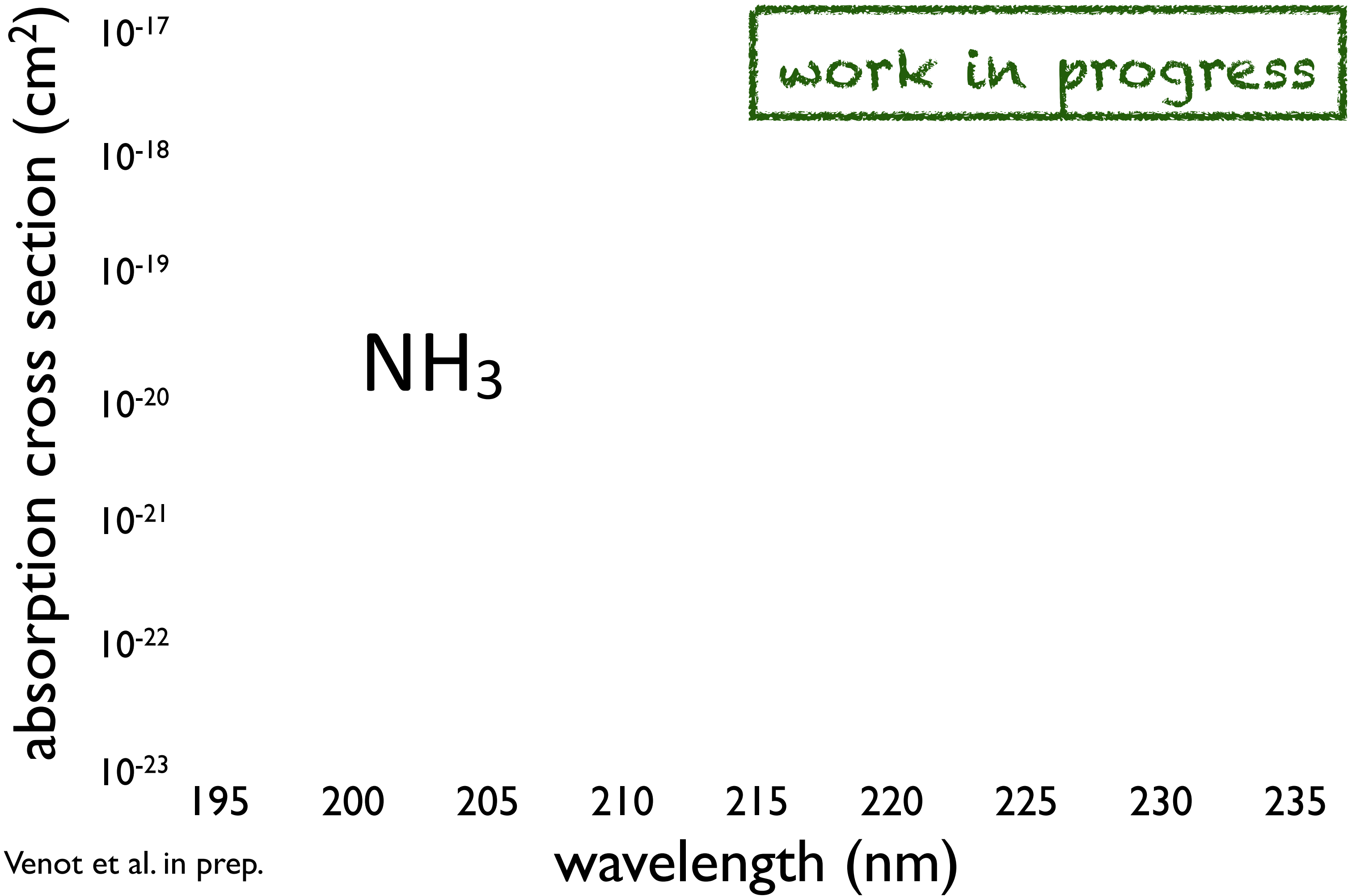


Venot et al. in prep.

Experimental issues

but....

$NH_3 \rightarrow NH_2 + H$



Venot et al. in prep.

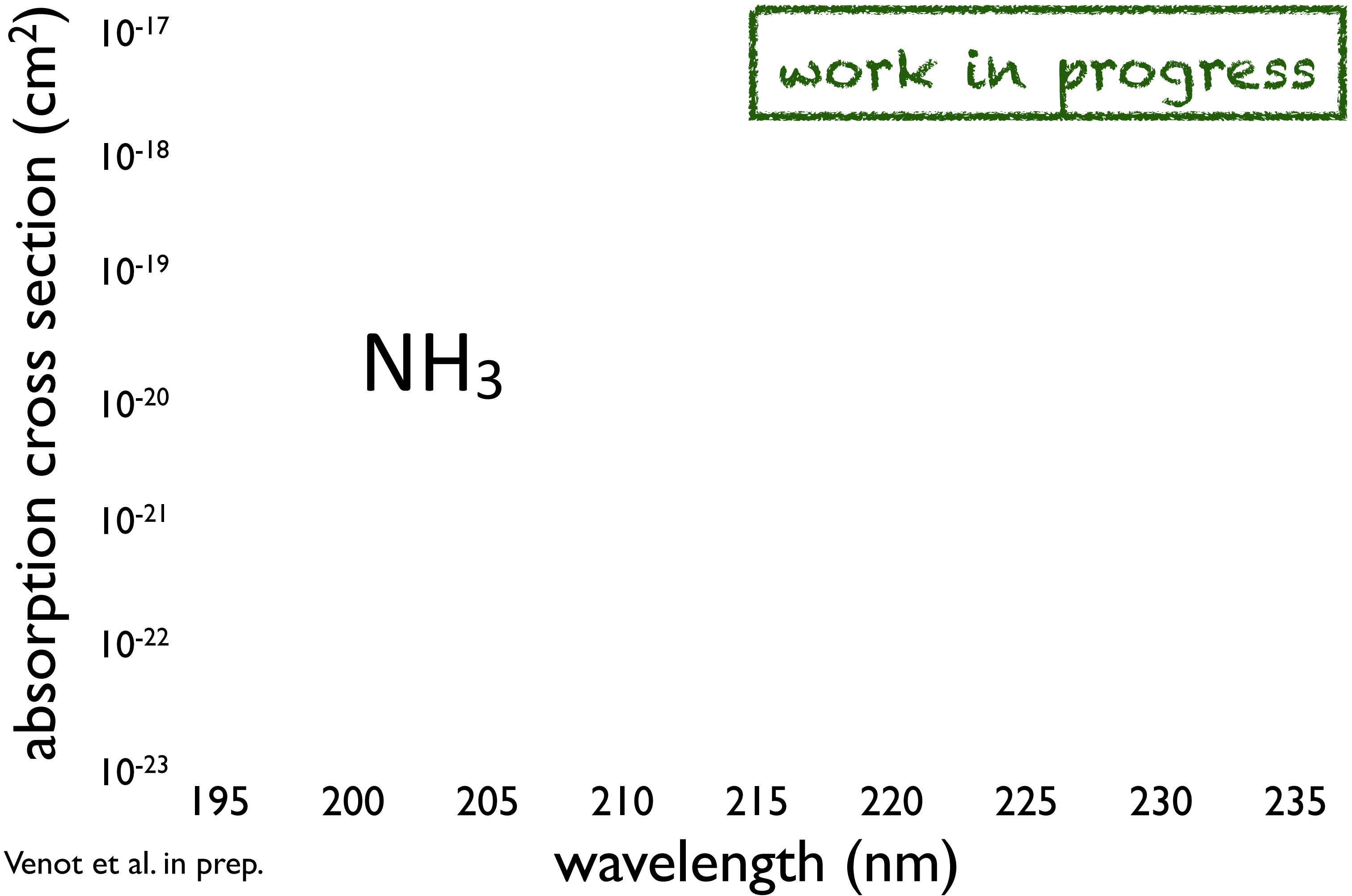
Experimental issues

⟹ solution: measurements at SOLEIL SYNCHROTRON in May 2015

but....

$NH_3 \rightarrow NH_2 + H$

Beamline with a FT spectrometer and a mass spectrometer - (DESIRS) - polychromatic acquisition



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Conclusions & Perspectives

- In very hot atmospheres, photodissociations have no effect
- Important need of data at T > 300K !
- Dependency of CO_2 VUV absorption cross section measured between 150 and 800 K
- Experimental issues (T gradient and thermal decomposition)
- May 2015: NH_3, C_2H_2 at SOLEIL SYNCHROTRON
  line DESIRS with a FT spectrometer: will allow us to overcome the thermal dissociation issue (PI: O. Venot)
- And more in the coming years….(HCN, C_2H_4, CO,… ask for specific request…)

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Thank you for your attention…