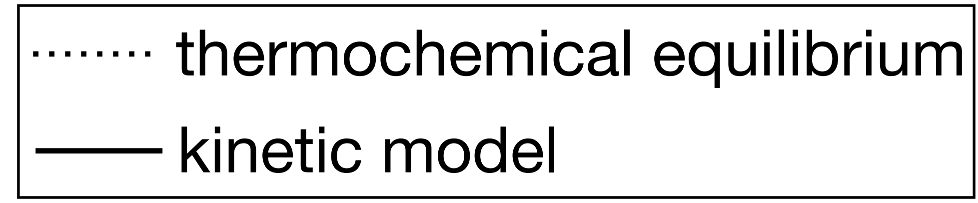
Photochemistry in Laboratory

Olivia Venot
olivia.venot@lisa.ipsl.fr

Exo-Atmospheres, Ecole de Physique des Houches, September, 19th 2022

STRUCTURE OF GIANT GASEOUS EXOPLANETS



- From their small density, we know that their atmospheres are dominated by Hydrogen (H_2 or H) and Helium

- **Photodissociations:** UV irradiation from the star destroys or produces molecules.

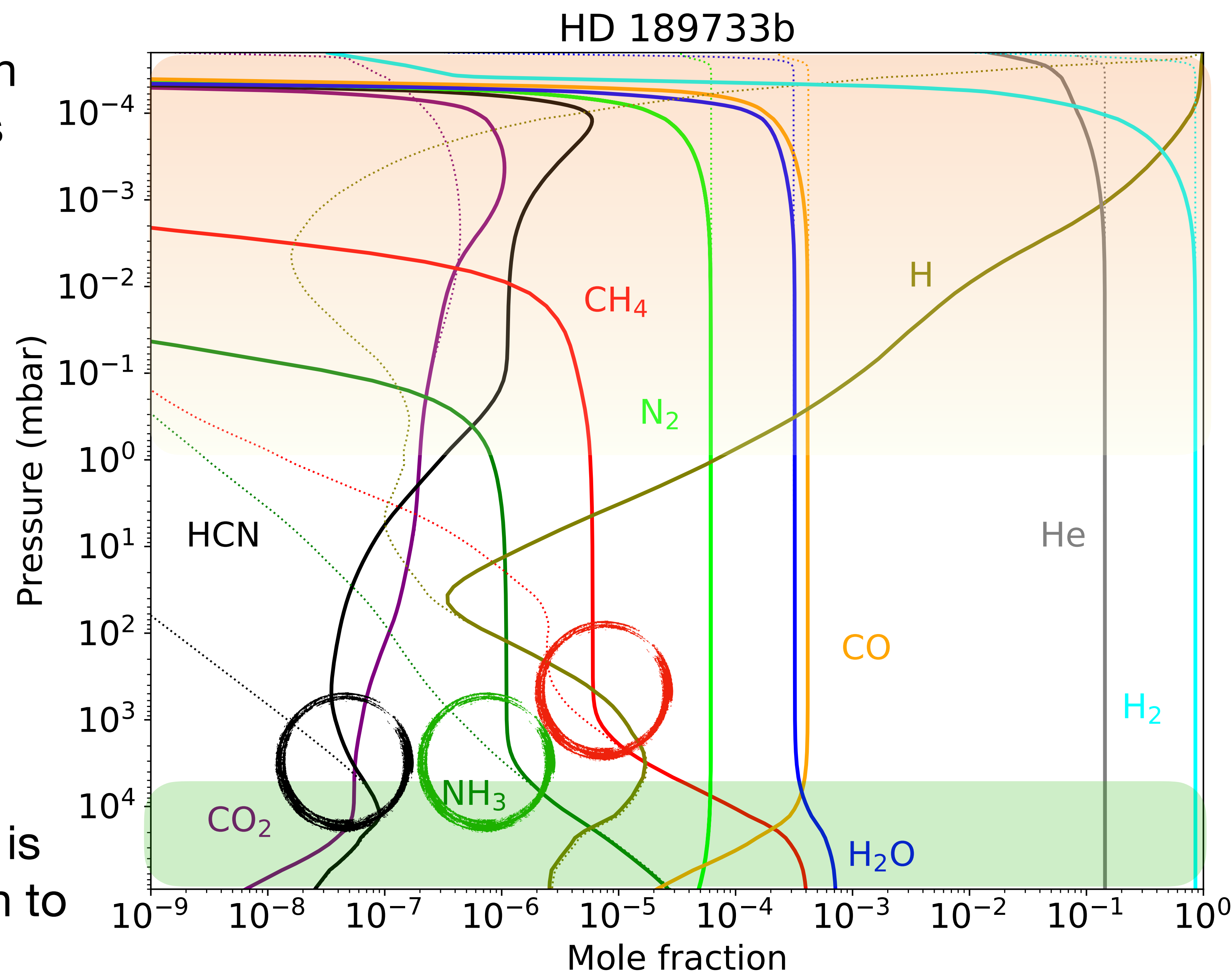
  Effect can be seen as deep as 10/100 mbar

- **Quenching:** abundances depart from thermo equilibrium.
  They are frozen when

  $\tau_{chemical} > \tau_{dynamical}$

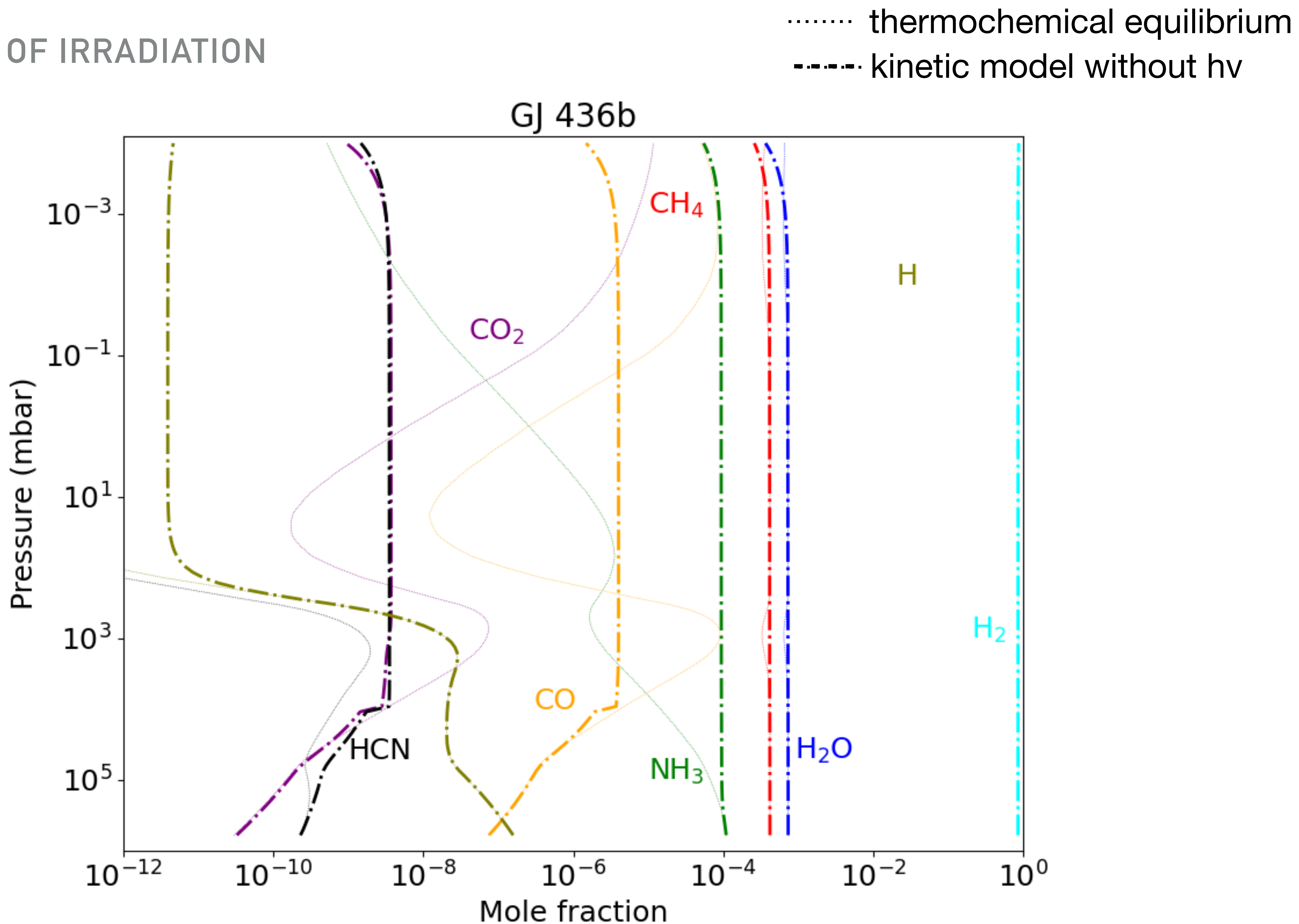
  This level depends on $\tau_{chemical}$ so is proper to each species

- **Thermo equilibrium:** temperature is very high so kinetics is fast enough to reproduce thermo equilibrium



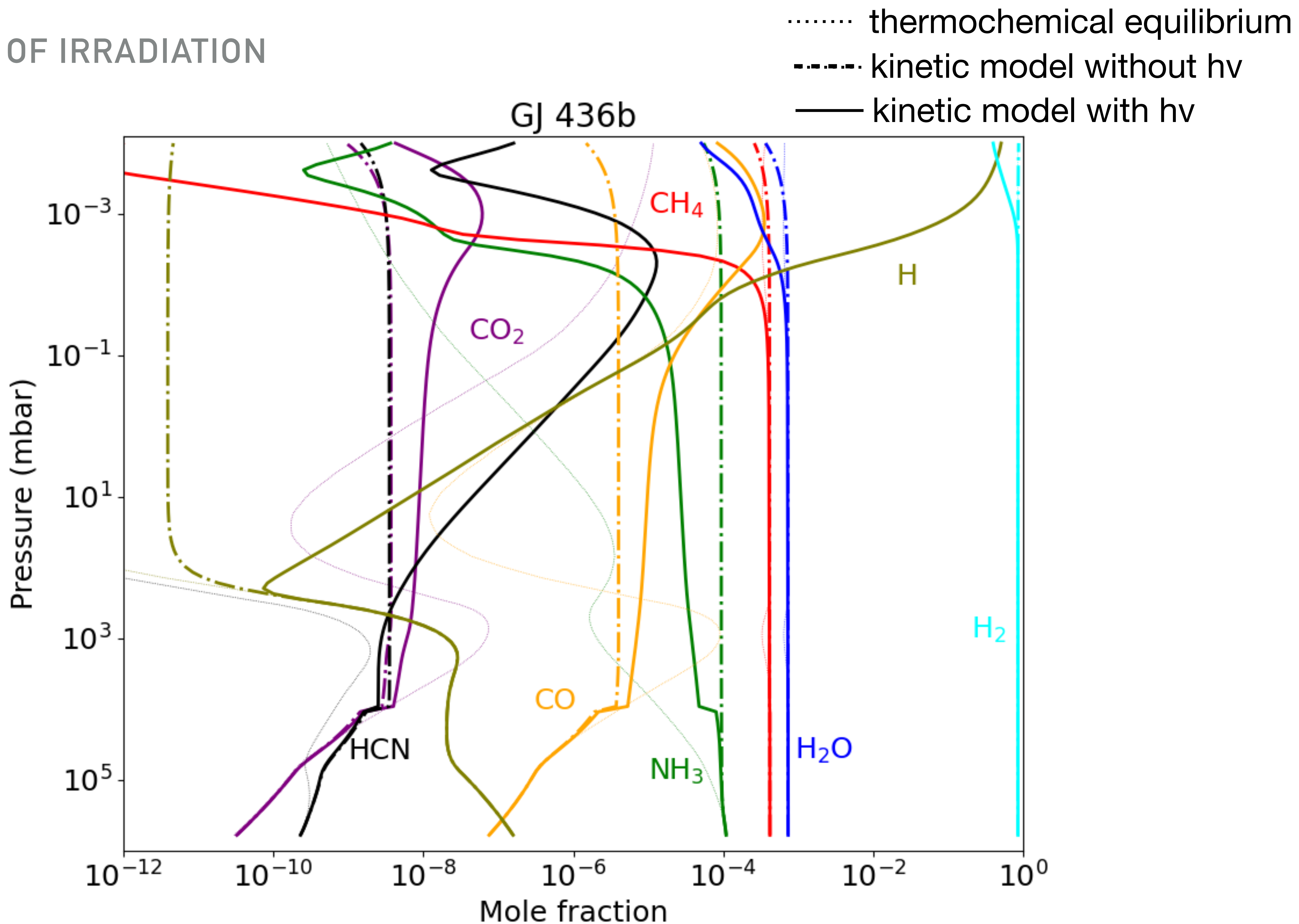
PHOTOCHEMISTRY AT HIGH TEMPERATURE

EFFECT OF IRRADIATION



PHOTOCHEMISTRY AT HIGH TEMPERATURE

EFFECT OF IRRADIATION

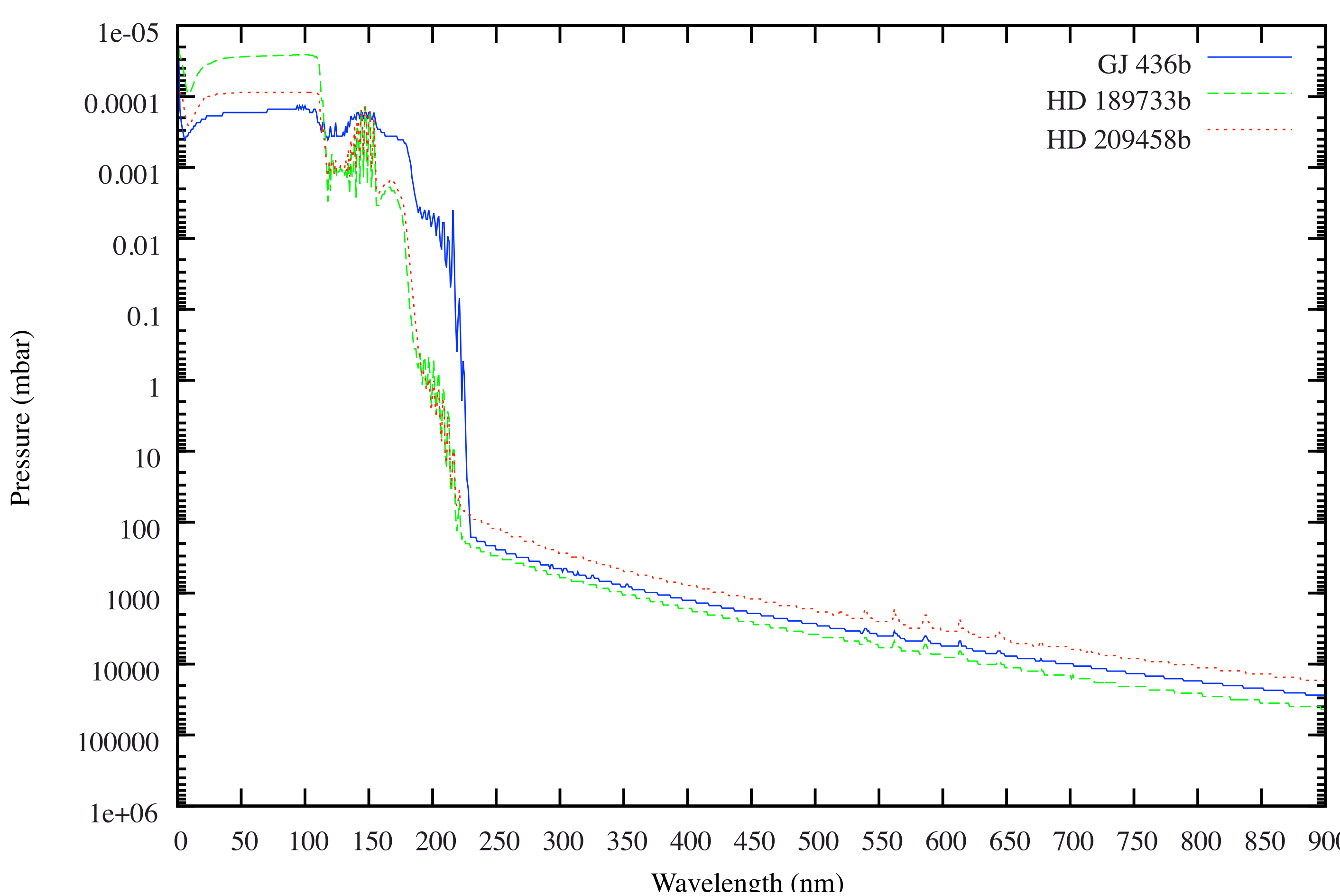


PHOTOCHEMISTRY AT HIGH TEMPERATURE

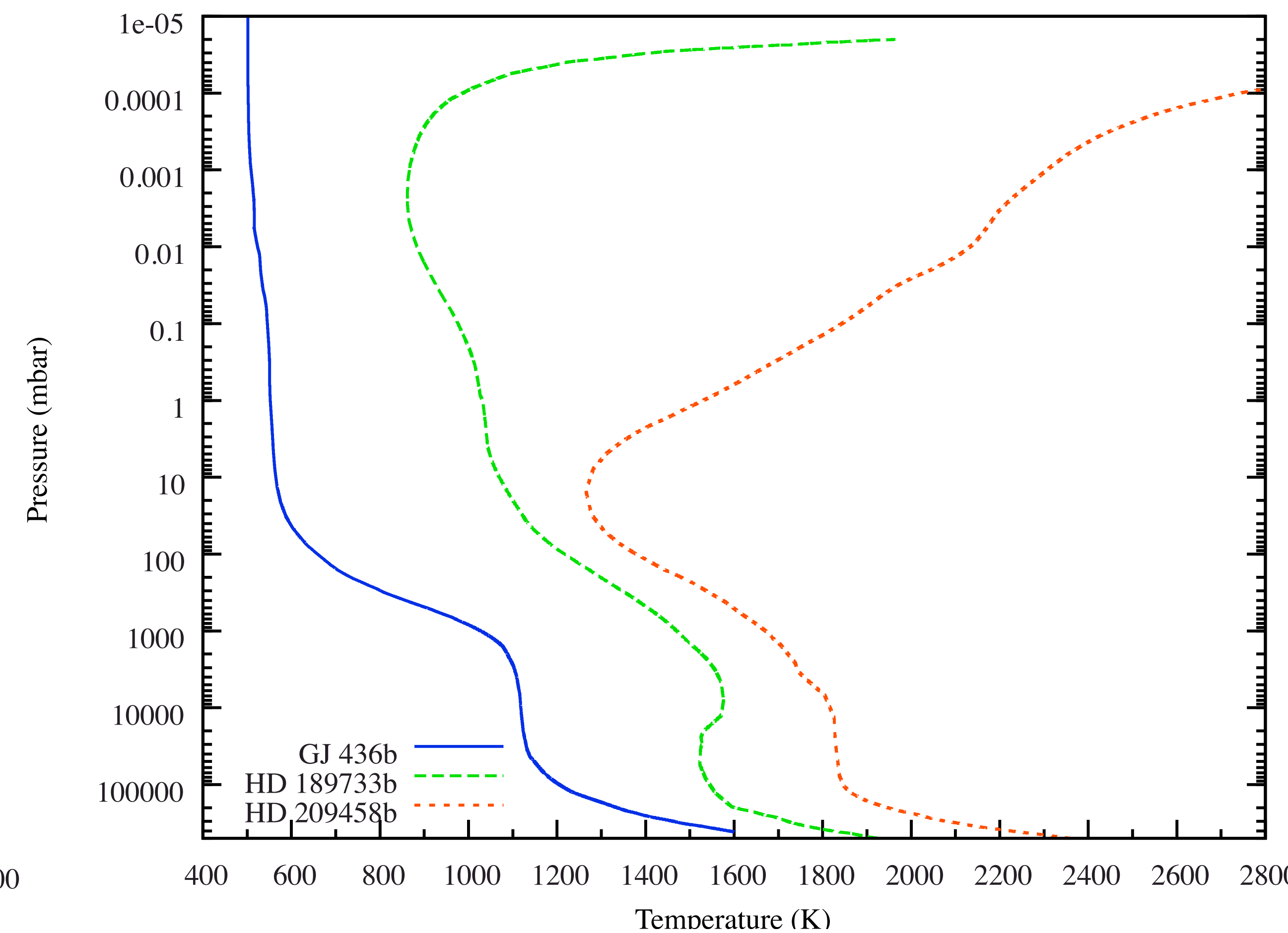
WHERE DO PHOTODISSOCIATIONS OCCUR ?

HD 189733b, HD 209458b (Hot Jupiters), and GJ 436b (Warm Neptune)

penetration of stellar flux (level τ=1)



thermal profiles

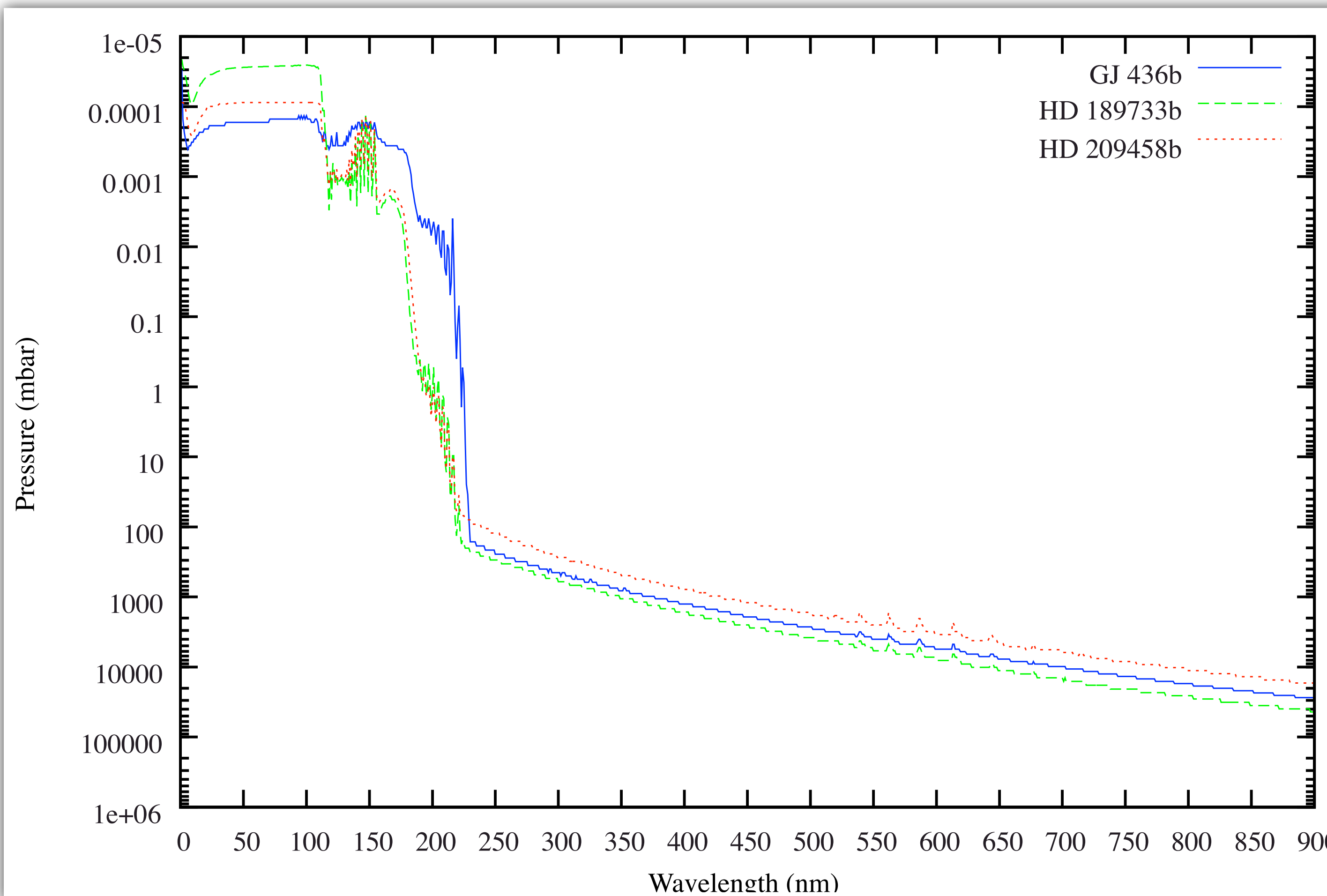


PHOTOCHEMISTRY AT HIGH TEMPERATURE

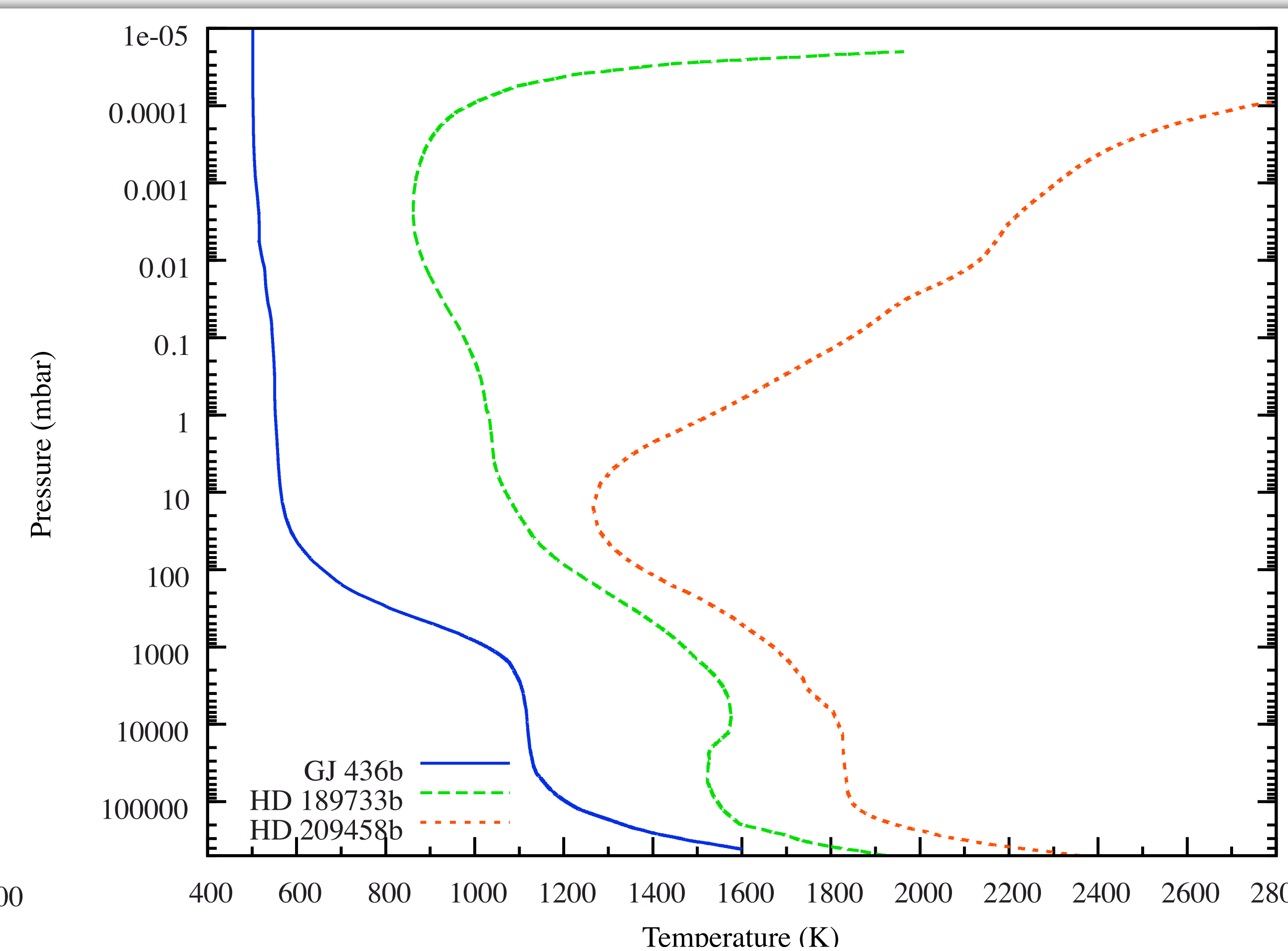
WHERE DO PHOTODISSOCIATIONS OCCUR ?

HD 189733b, HD 209458b (Hot Jupiters), and GJ 436b (Warm Neptune)

penetration of stellar flux (level τ=1)



thermal profiles



λ of interest for photochemistry: < 250 nm

penetrate down to P = 100 mbar

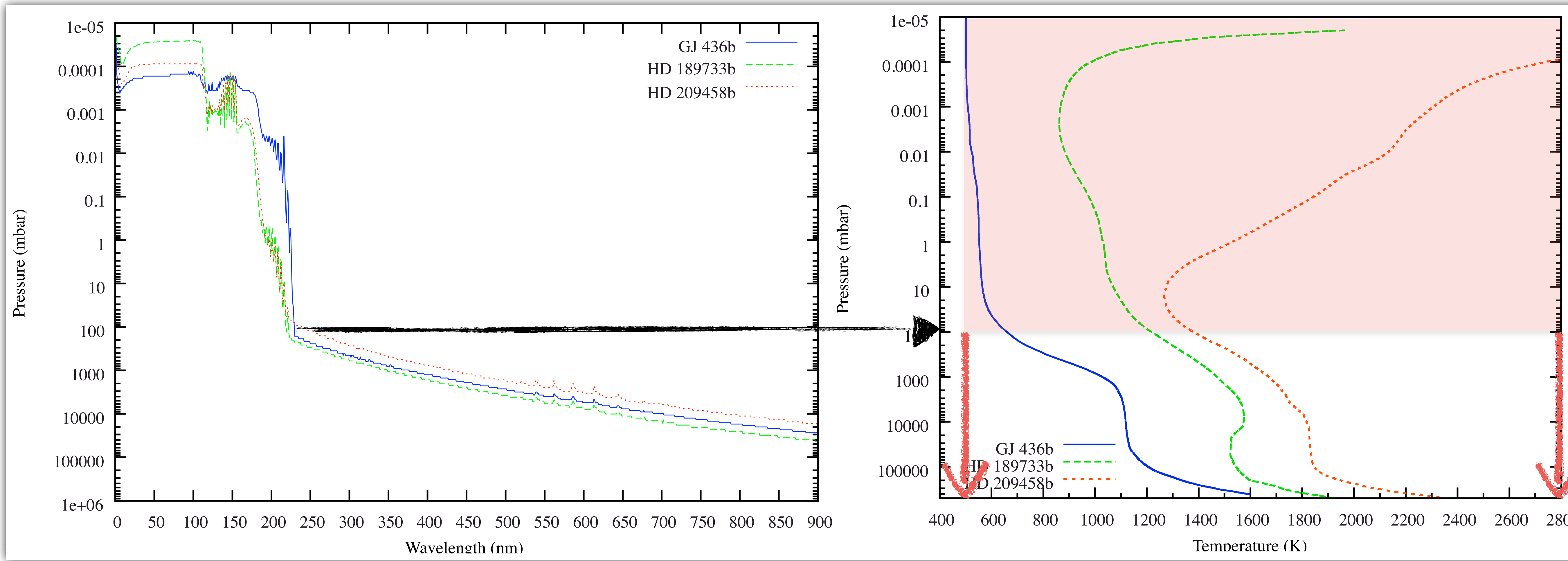
PHOTOCHEMISTRY AT HIGH TEMPERATURE

WHERE DO PHOTODISSOCIATIONS OCCUR ?

HD 189733b, HD 209458b (Hot Jupiters), and GJ 436b (Warm Neptune)

penetration of stellar flux (level τ=1)

thermal profiles



λ of interest for photochemistry: < 250 nm

500 – 2800 K !

penetrate down to P = 100 mbar

PHOTOCHEMISTRY AT HIGH TEMPERATURE

VUV ABSORPTION CROSS-SECTIONS

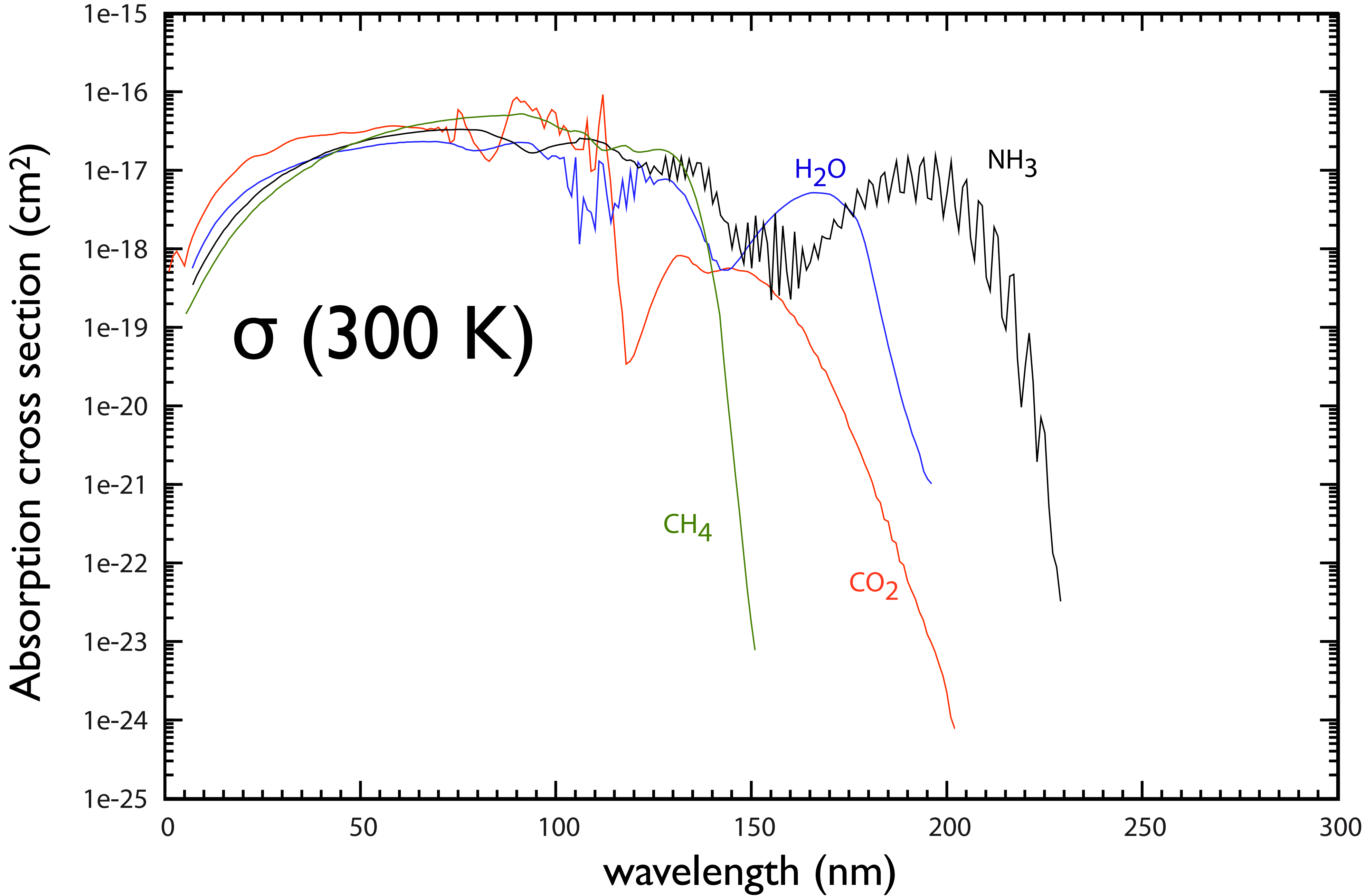
σ(λ, T) are crucial data for atmospheric models

Photodissociations rate :

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

Actinic flux :

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



PHOTOCHEMISTRY AT HIGH TEMPERATURE

VUV ABSORPTION CROSS-SECTIONS

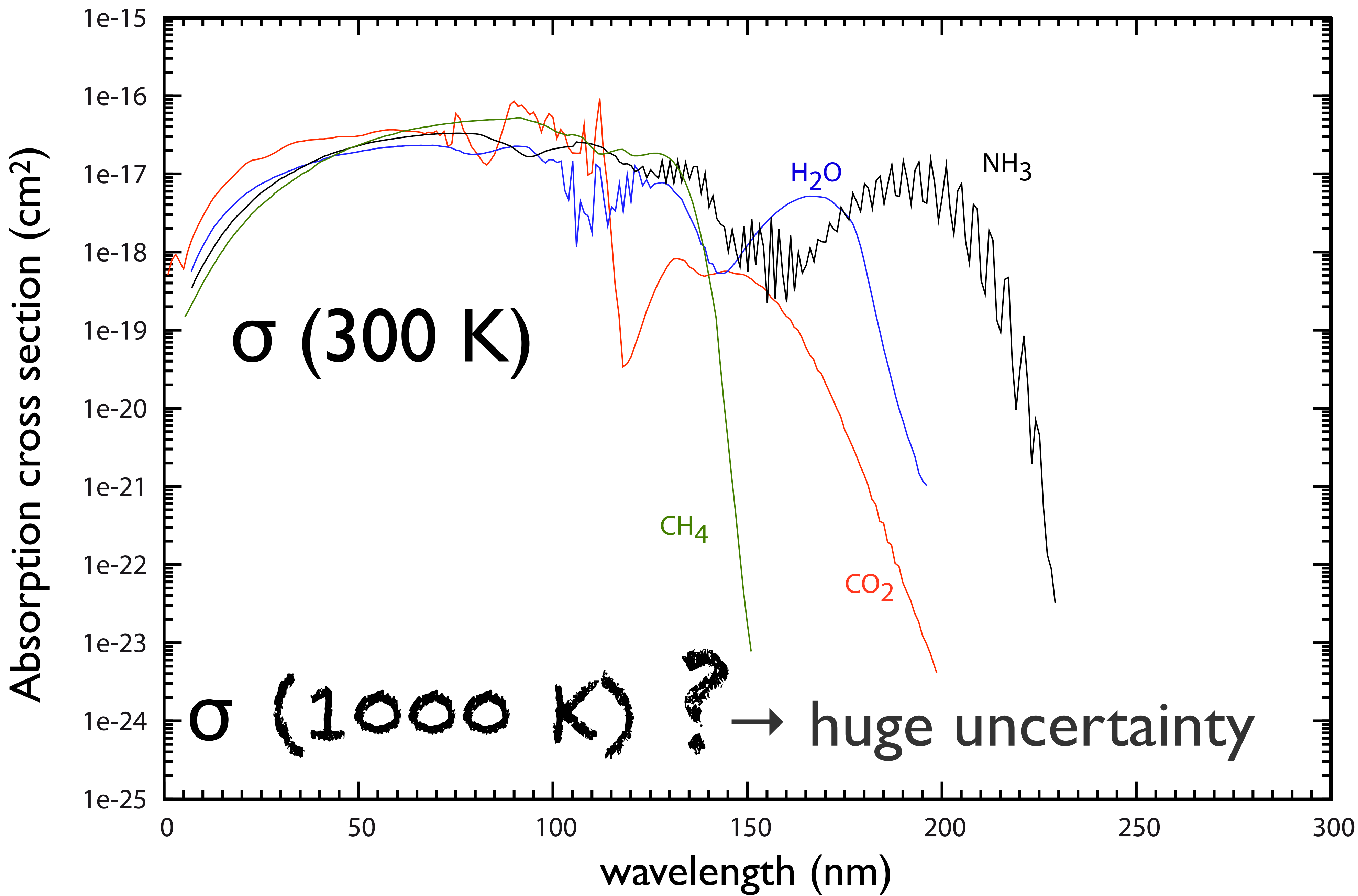
σ(λ, T) are crucial data for atmospheric models

Photodissociations rate :

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

Actinic flux :

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



EXPERIMENTAL SETUP

T up to 1200K

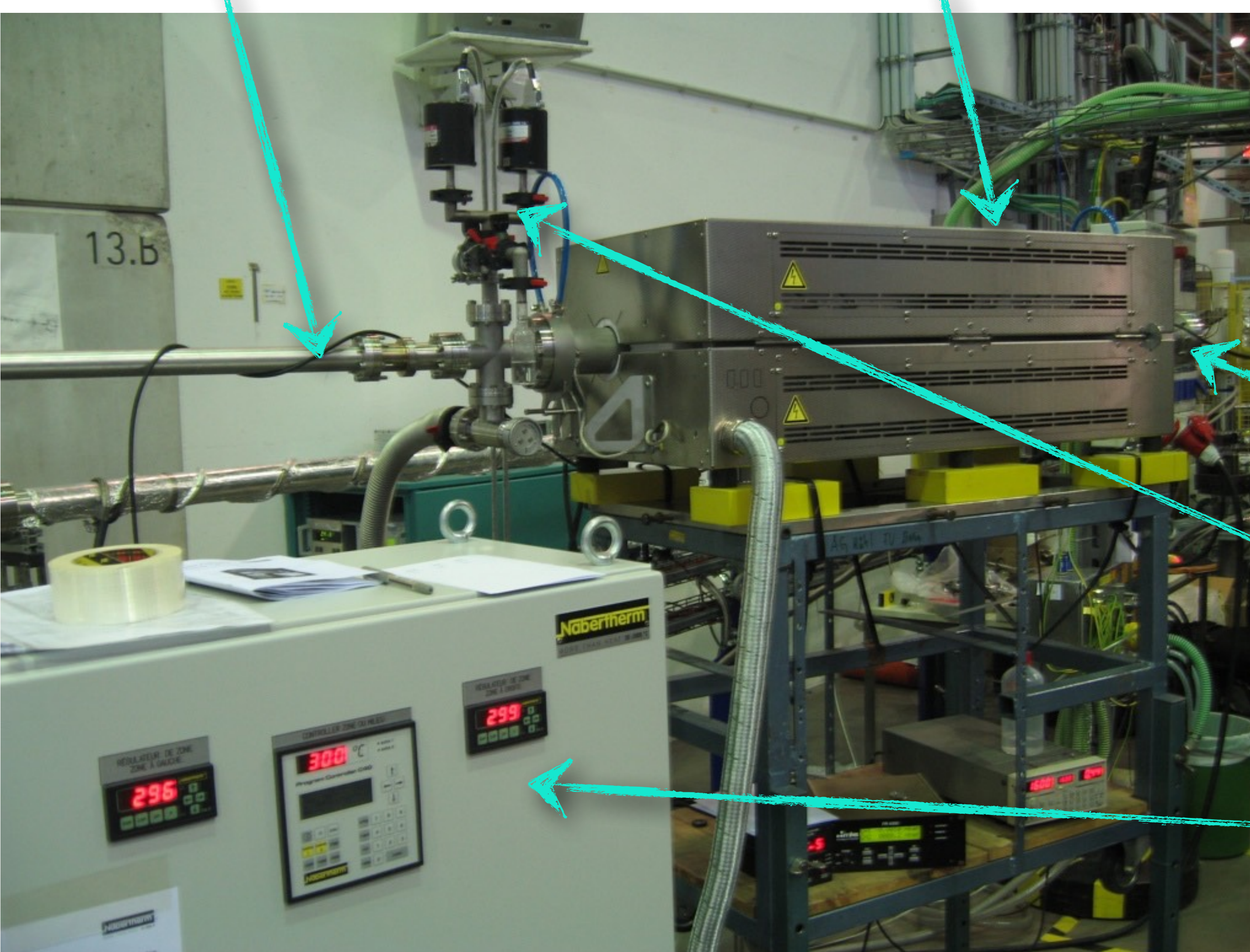
synchrotron BESSY / SOLEIL
115 < λ < 190 nm

UV lamp at LISA
190 < λ < 230 nm

115-230 nm

incident flux

oven + cell containing gas



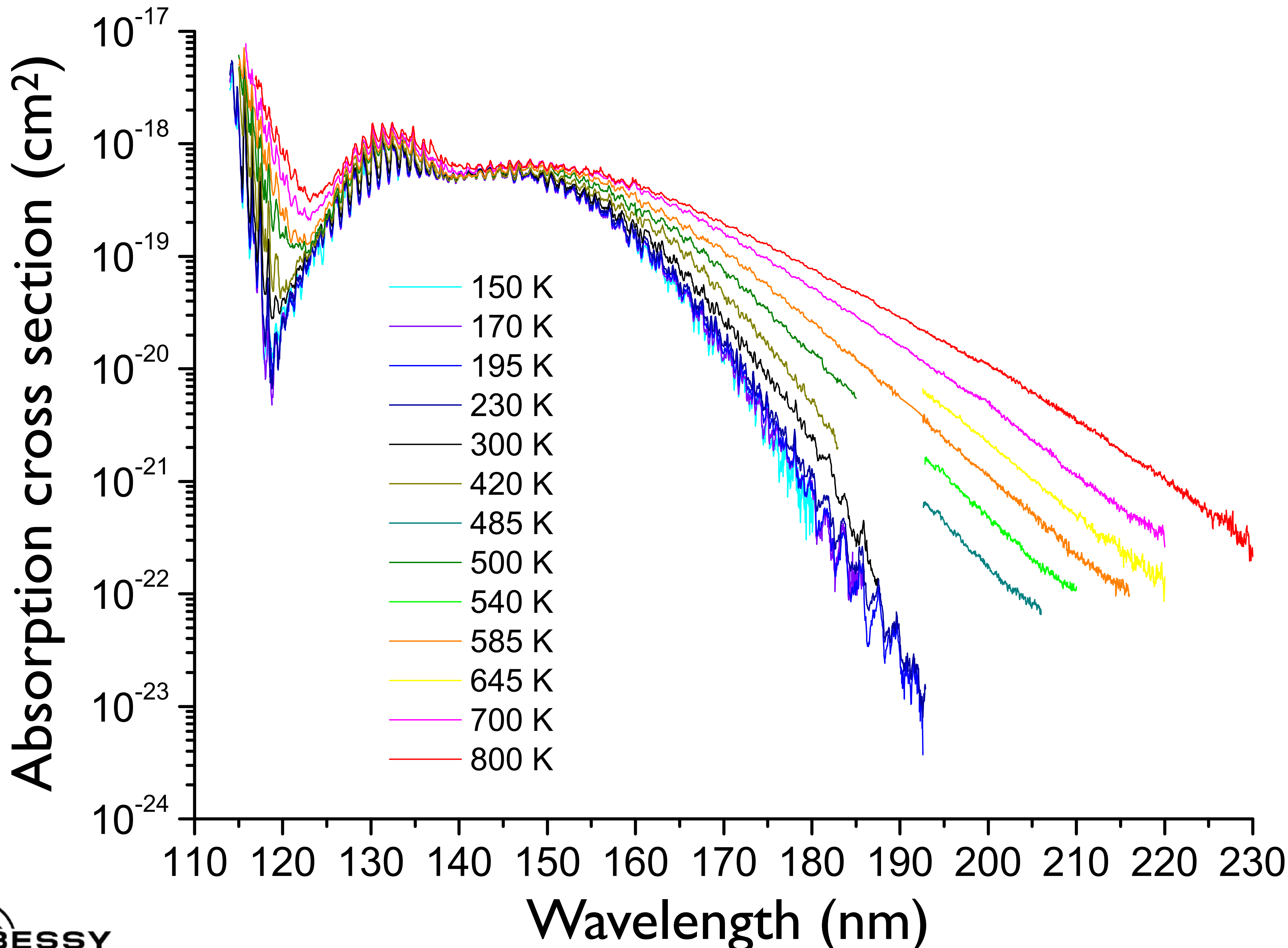
photomultiplier

injection of gas

control of temperature

CO_2 ABSORPTION CROSS-SECTION

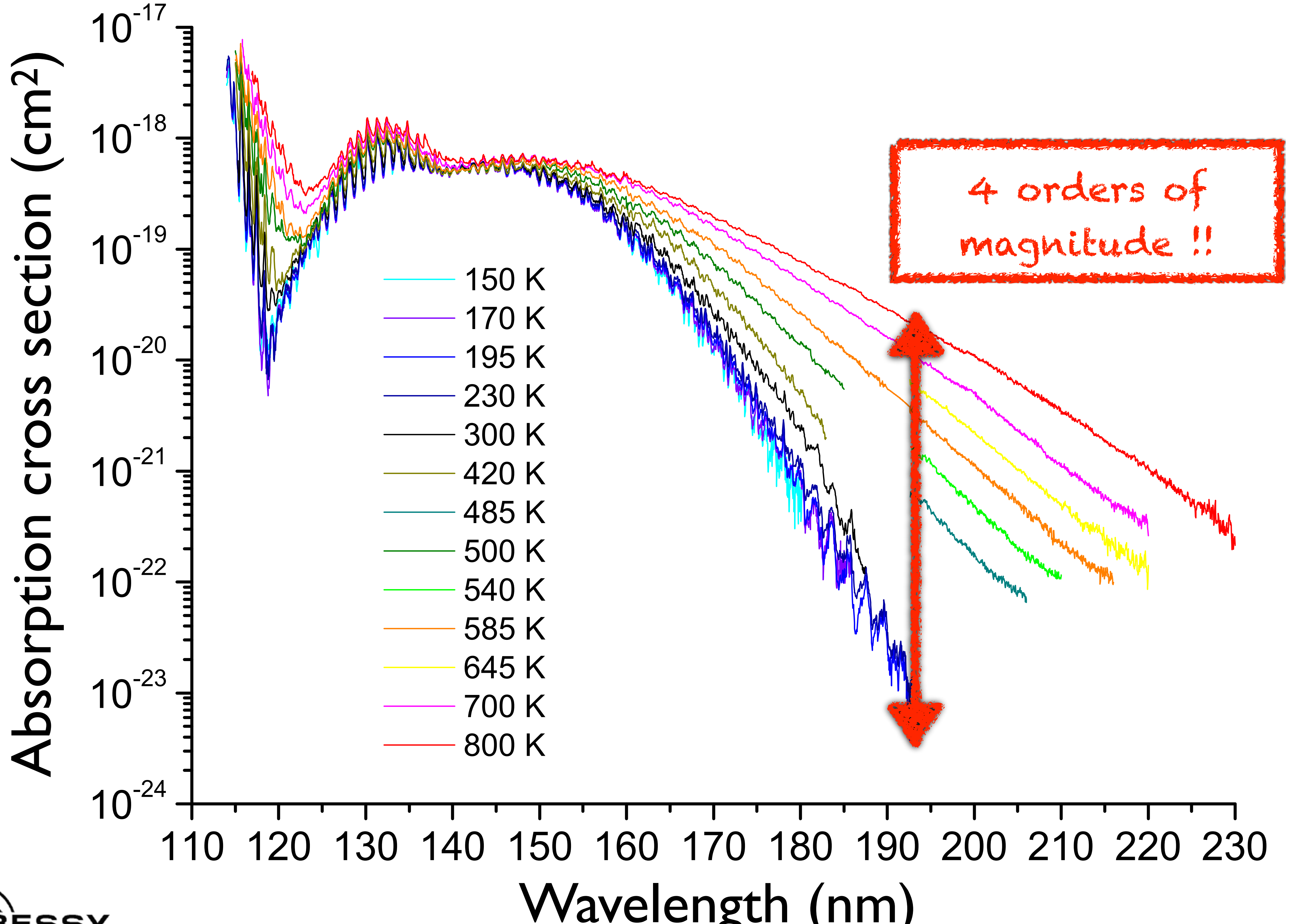
Venot et al. 2013, 2018, A&A



BESSY

CO_2 ABSORPTION CROSS-SECTION

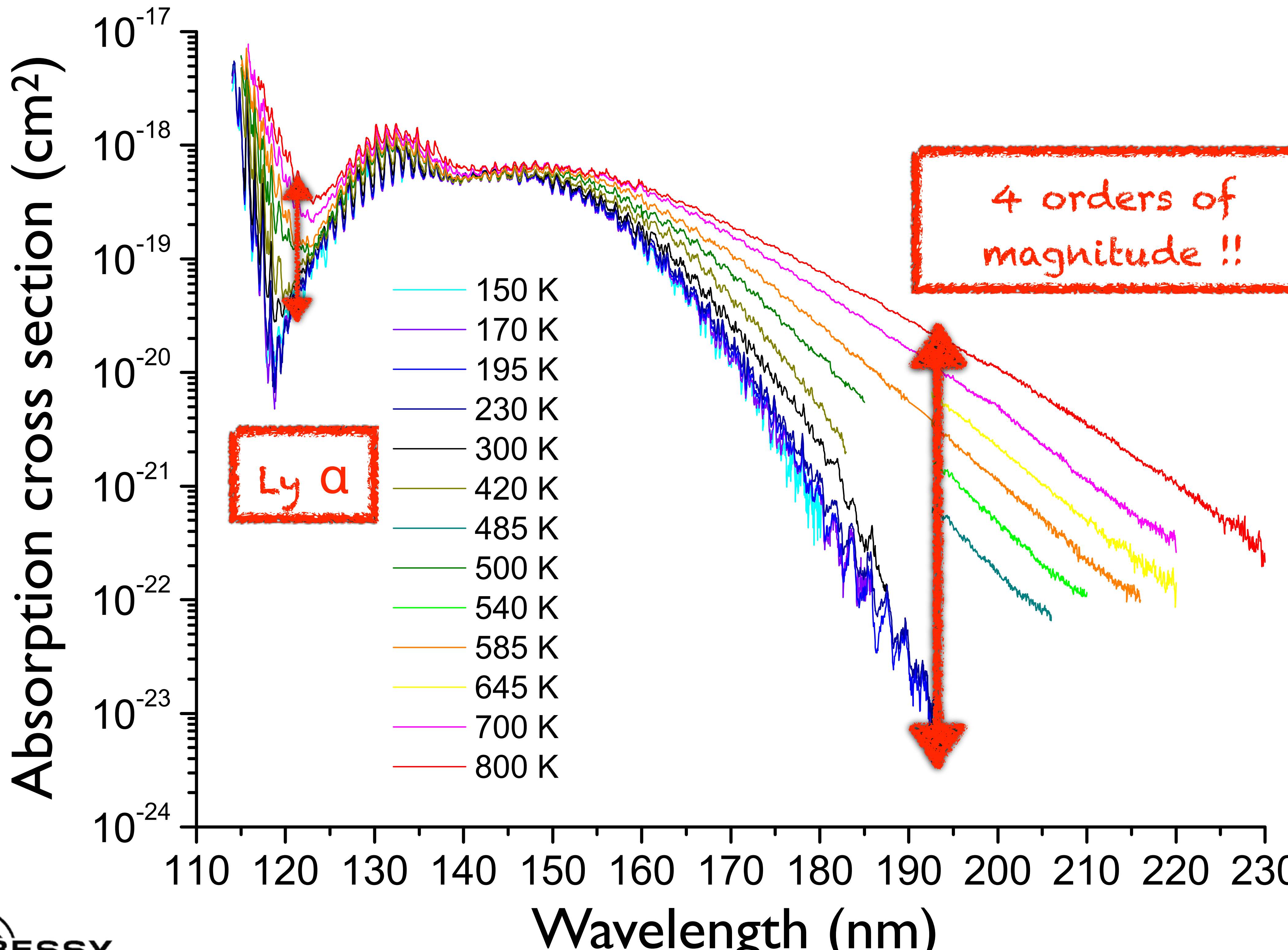
Venot et al. 2013, 2018, A&A



BESSY

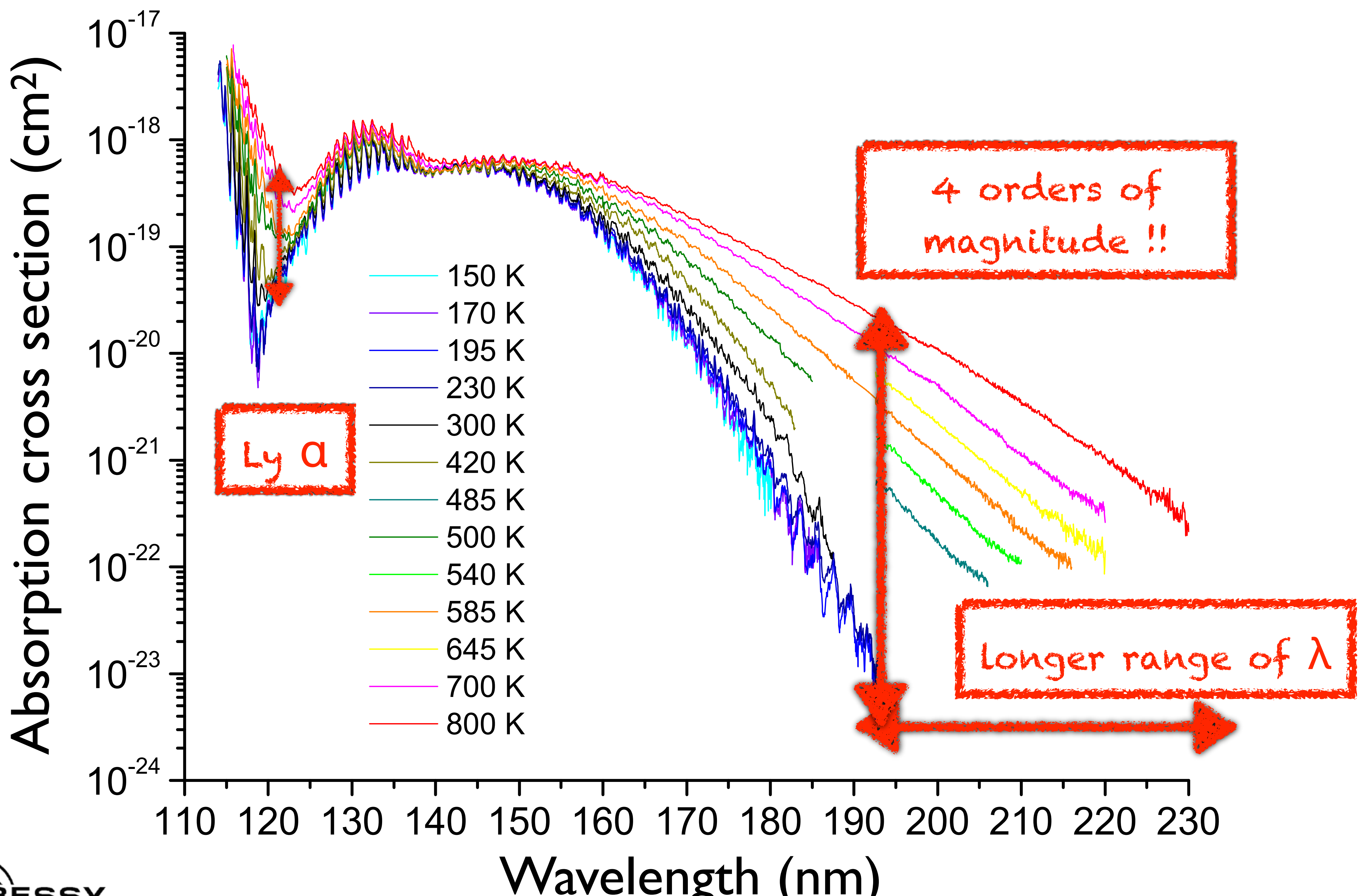
CO_2 ABSORPTION CROSS-SECTION

Venot et al. 2013, 2018, A&A



CO_2 ABSORPTION CROSS-SECTION

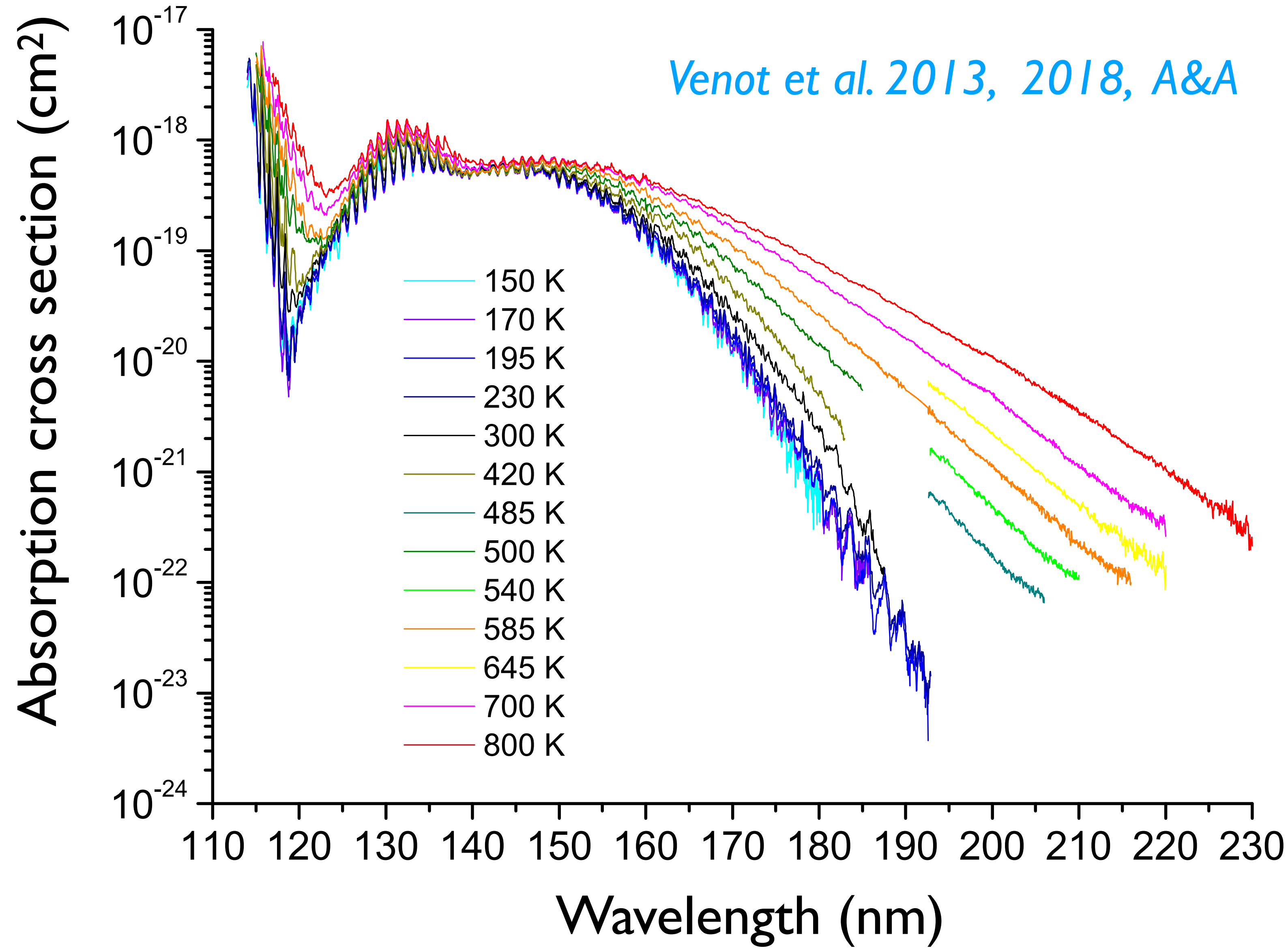
Venot et al. 2013, 2018, A&A

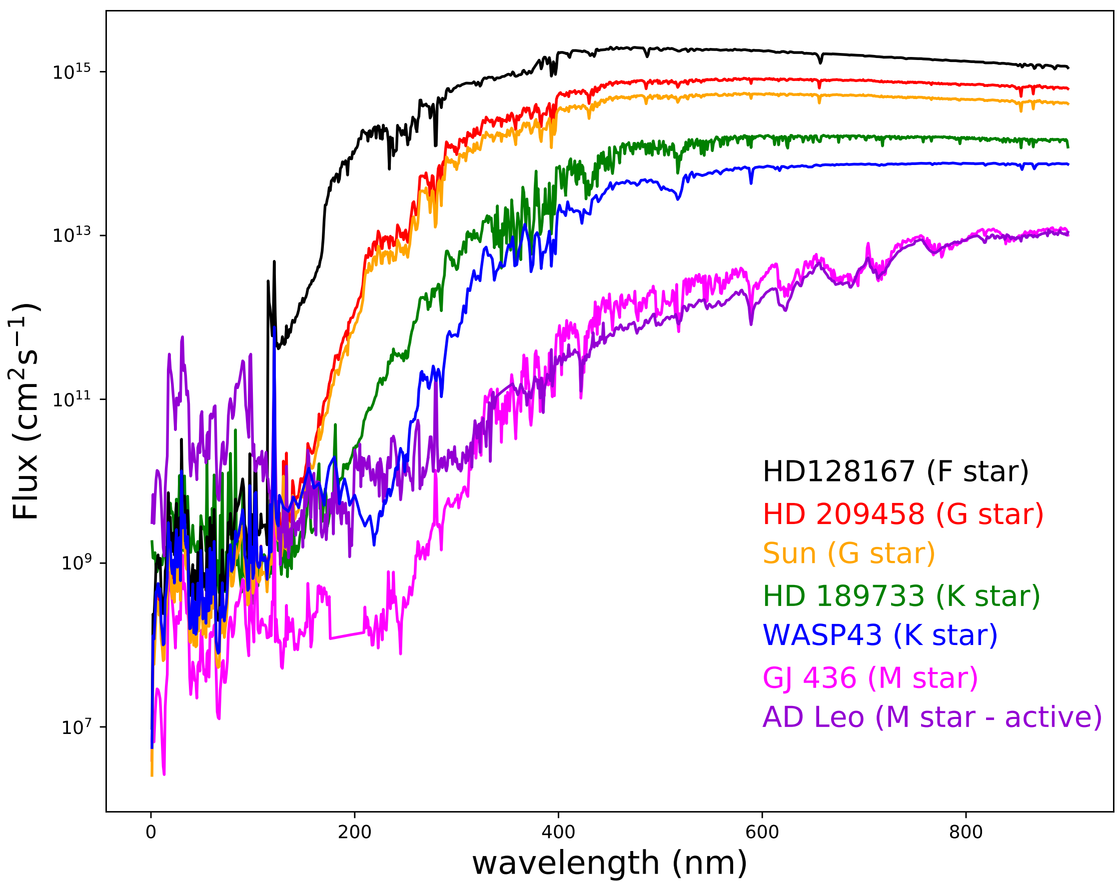


CO_2 ABSORPTION CROSS-SECTION

between 150 and 230 nm a stellar flux generally increases by several orders of magnitude

→ photodissociations rate highly impacted !





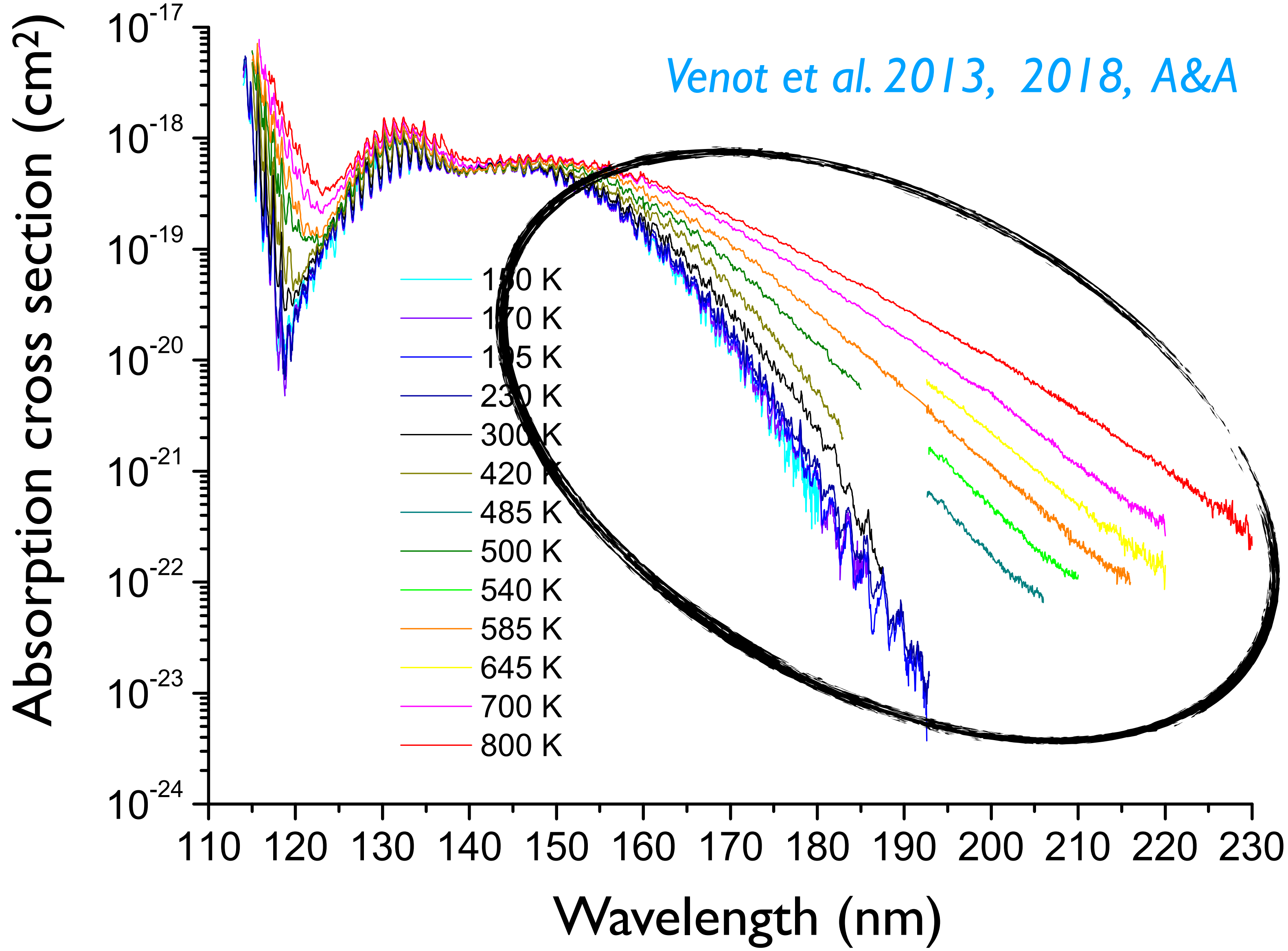
Photodissociations rate :

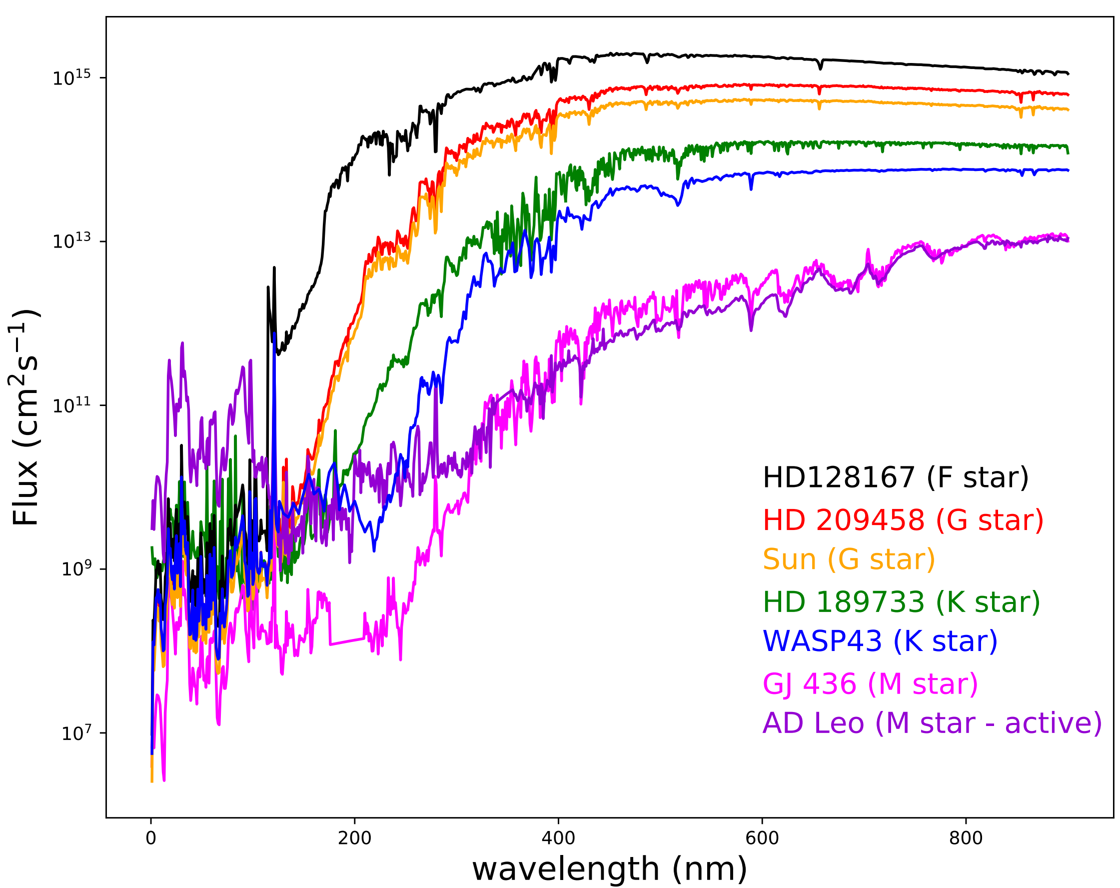
$$J^k(z) = \int_{\lambda_1}^{\lambda_2} \sigma(\lambda, T) F(\lambda, z) q_k(\lambda, T) d\lambda$$

CO_2 ABSORPTION CROSS-SECTION

between 150 and 230 nm a stellar flux generally increases by several orders of magnitude

→ photodissociations rate highly impacted !





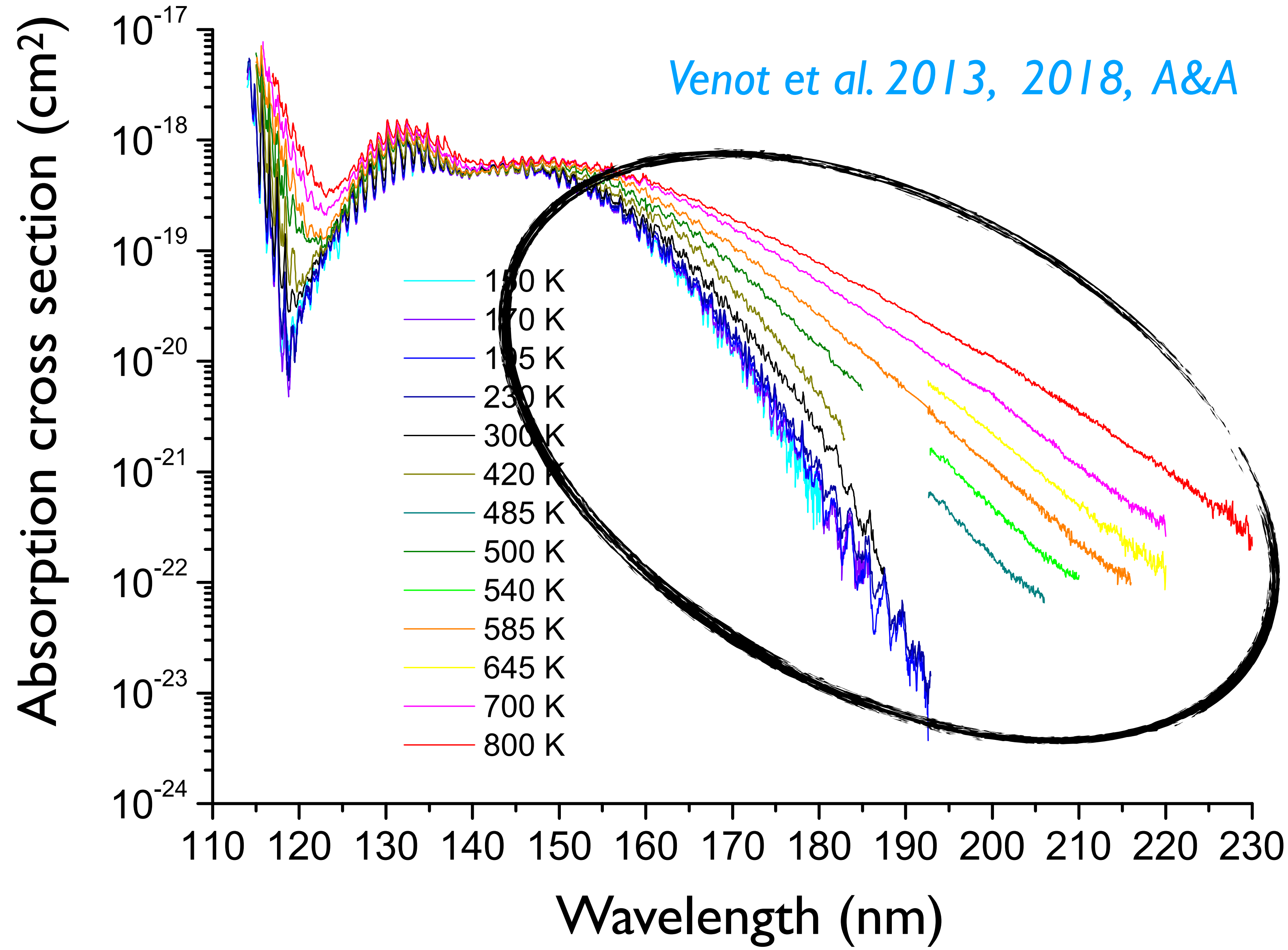
Photodissociations rate :

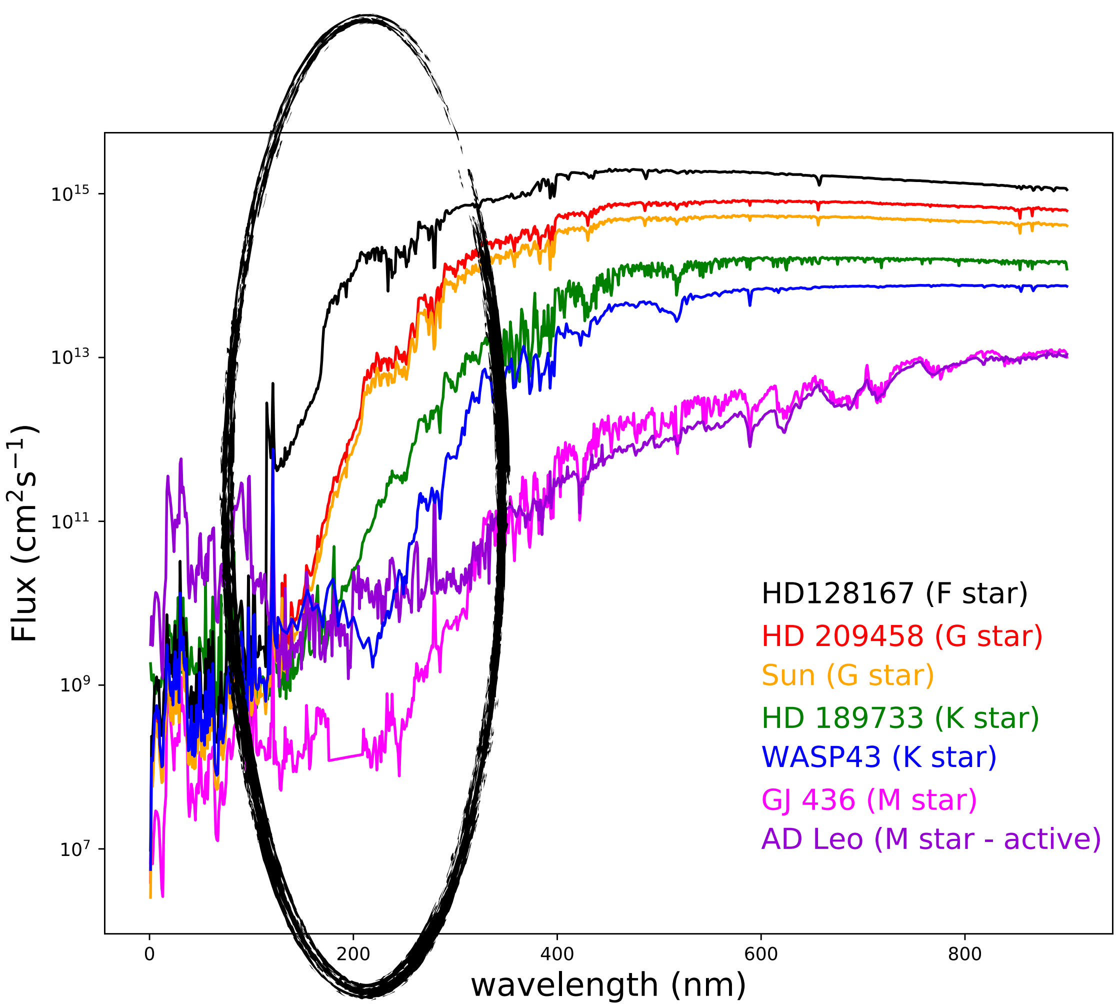
$$J^k(z) = \int_{\lambda_1}^{\lambda_2} \sigma(\lambda, T) F(\lambda, z) q_k(\lambda, T) d\lambda$$

CO_2 ABSORPTION CROSS-SECTION

between 150 and 230 nm a stellar flux generally increases by several orders of magnitude

→ photodissociations rate highly impacted !





Photodissociations rate :

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

EFFECT ON THE ATMOSPHERIC COMPOSITION

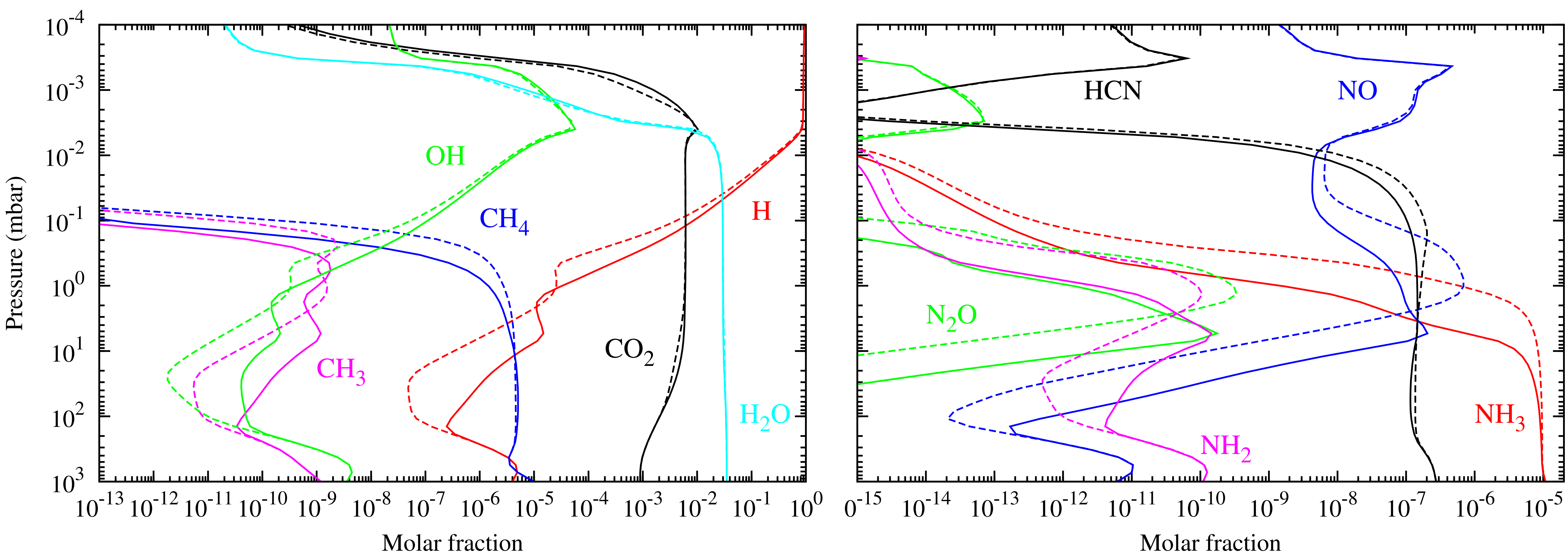
- shielding + strong coupling between molecules through the continuity equation:

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

➡ change of σ_{CO_2} affects many species. Some species see their abundance more modified than that of CO_2 !

$\sigma_{CO_2}(300K)$ $\sigma_{CO_2}(800K)$

Venot et al. 2018, A&A

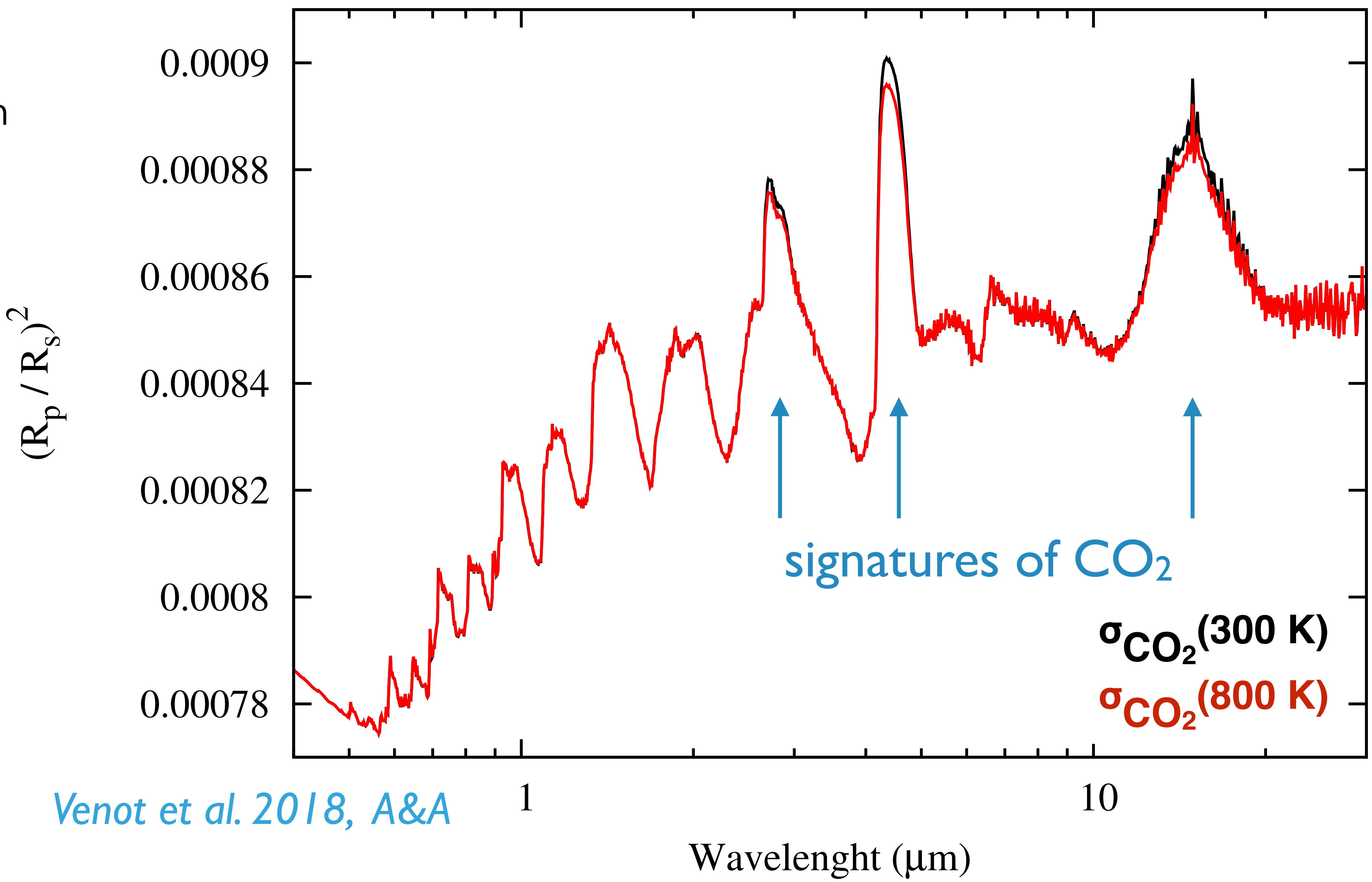


EFFECT ON OBSERVATIONS

IR transmission synthetic spectrum calculated with Tau-REx (Waldmann et al. 2015a,b)

differences only in CO_2 absorption bands

small departures (< 5 ppm)
→ not detectable !



Venot et al. 2018, A&A

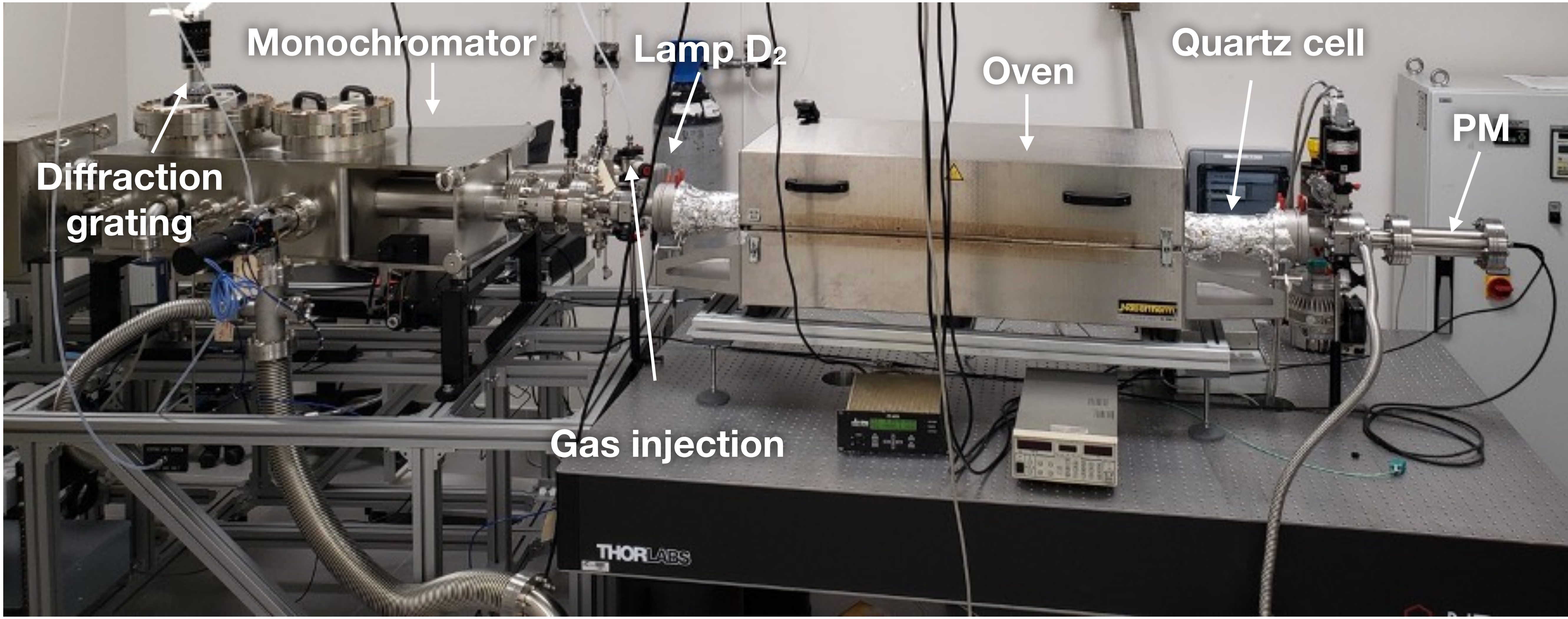
don't conclude too fast … only σ_{CO_2} has been changed in this study …

with the absorption cross section at high temperature of all species:

➡ more important changes of atmospheric composition

➡ more effect on the observables

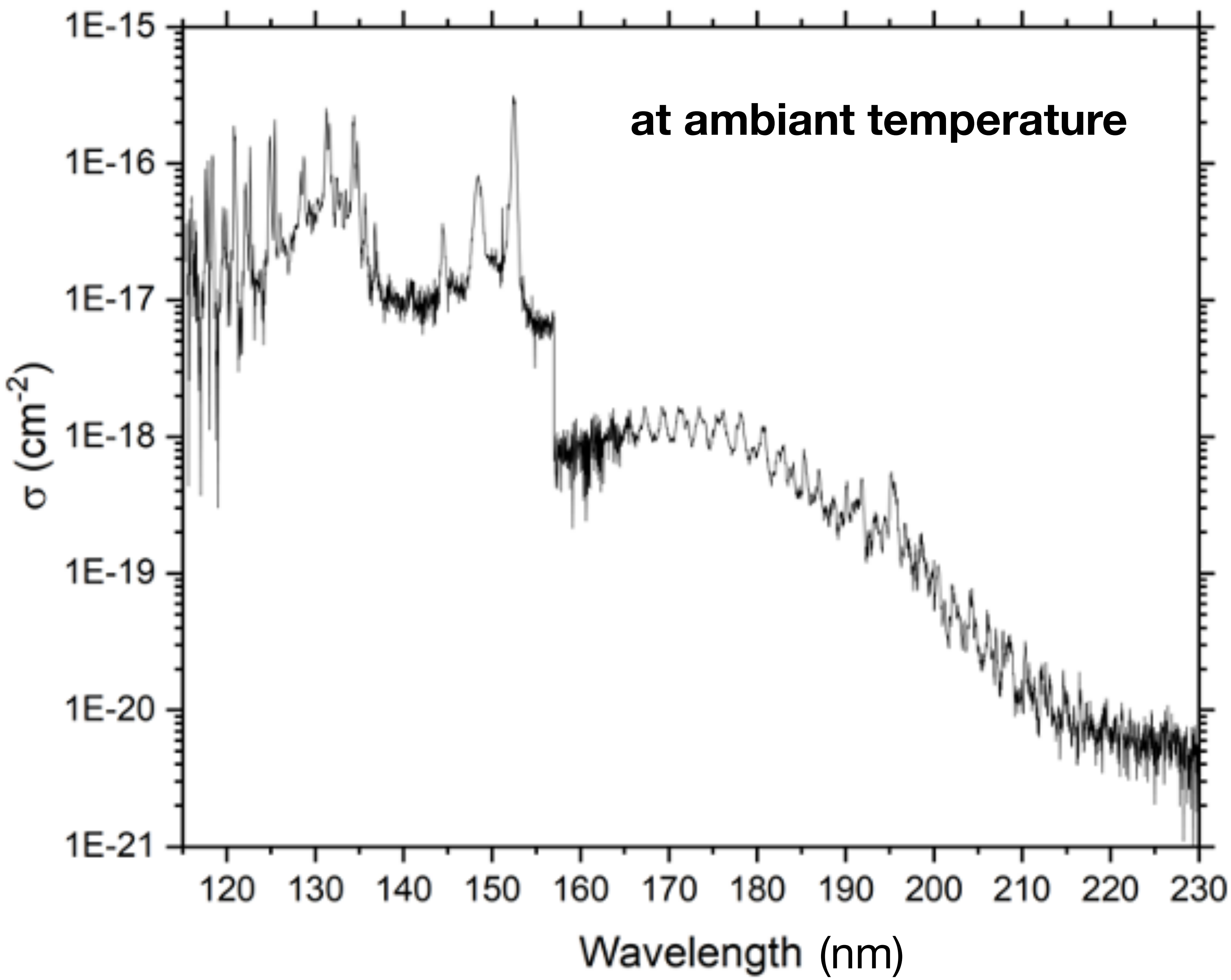
PLATFORM OF VUV SPECTROSCOPY AT lisa



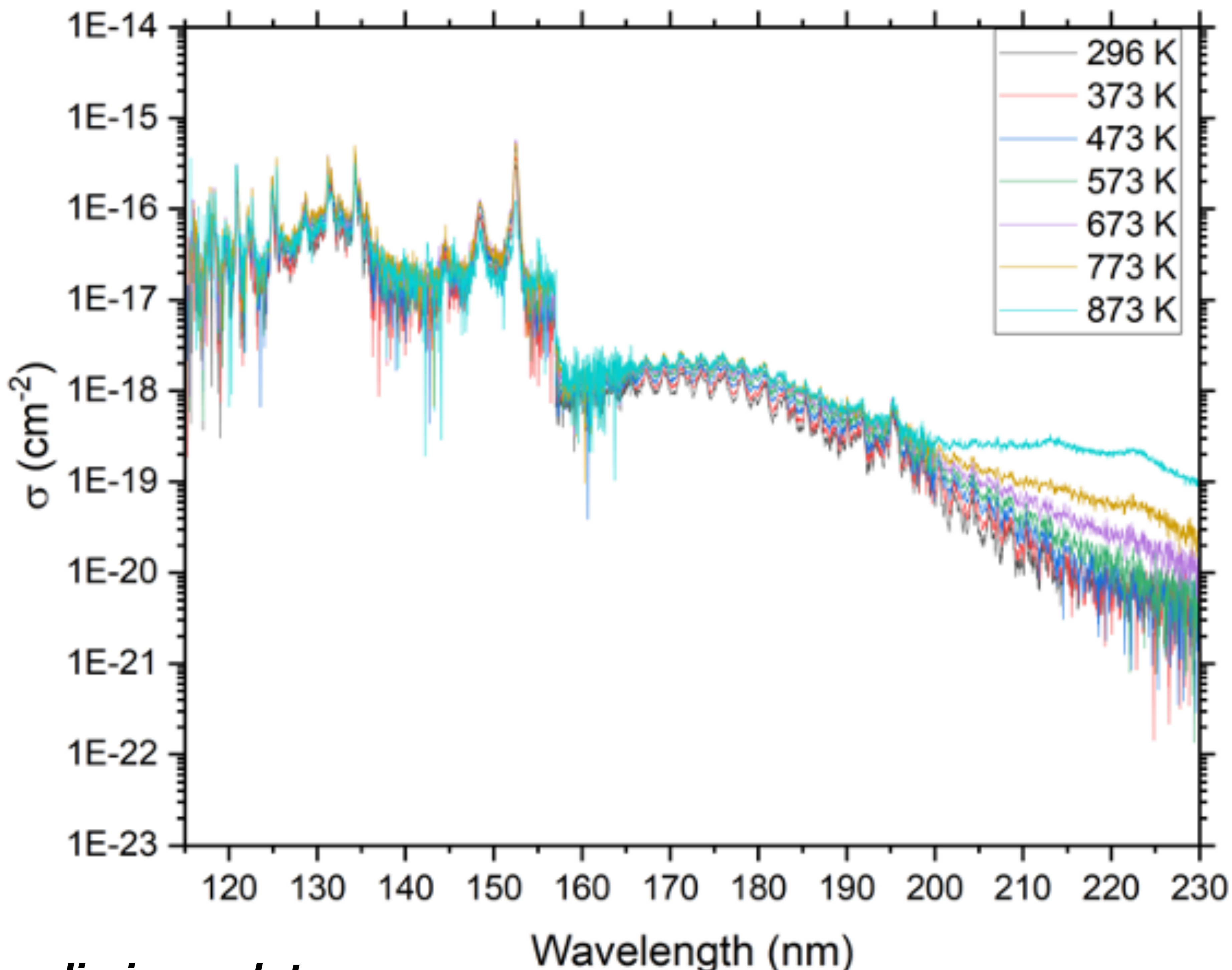
- future : study the thermal dependency of abs. cross section for all the molecules absorbing and abundant
- considerable increase of measurements in frequency and in quantity (limited currently by the short allocated time on synchrotron facilities)

- new VUV spectroscopy platform
  - λ range = [50-300] nm
  - resolution = 0.01 nm
- next targets : NH_3, C_2H_2, HCN….

C_2H_2 ABSORPTION CROSS-SECTION



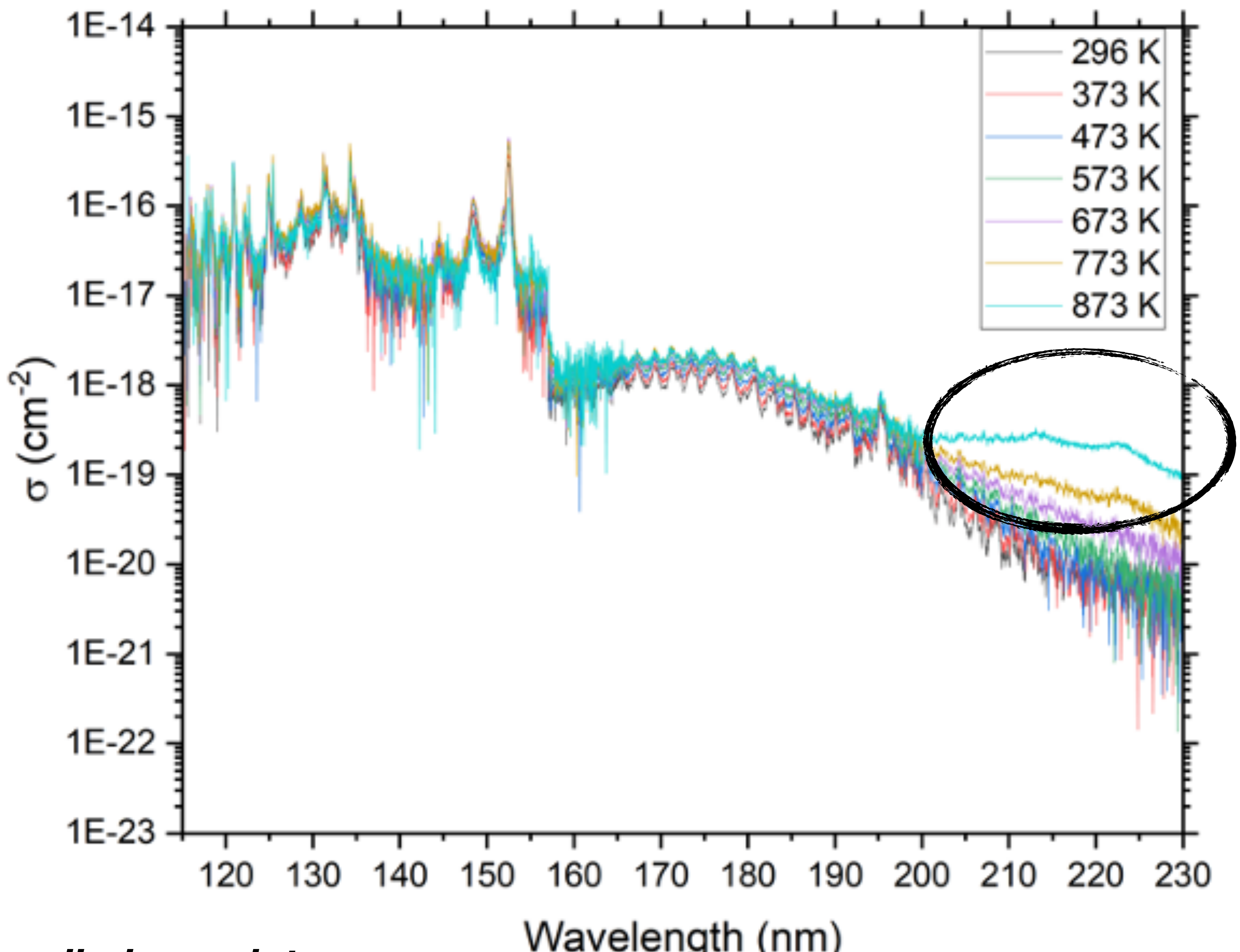
C_2H_2 ABSORPTION CROSS-SECTION



preliminary data

Fleury, Poveda, Venot et al. in prep

C_2H_2 ABSORPTION CROSS-SECTION



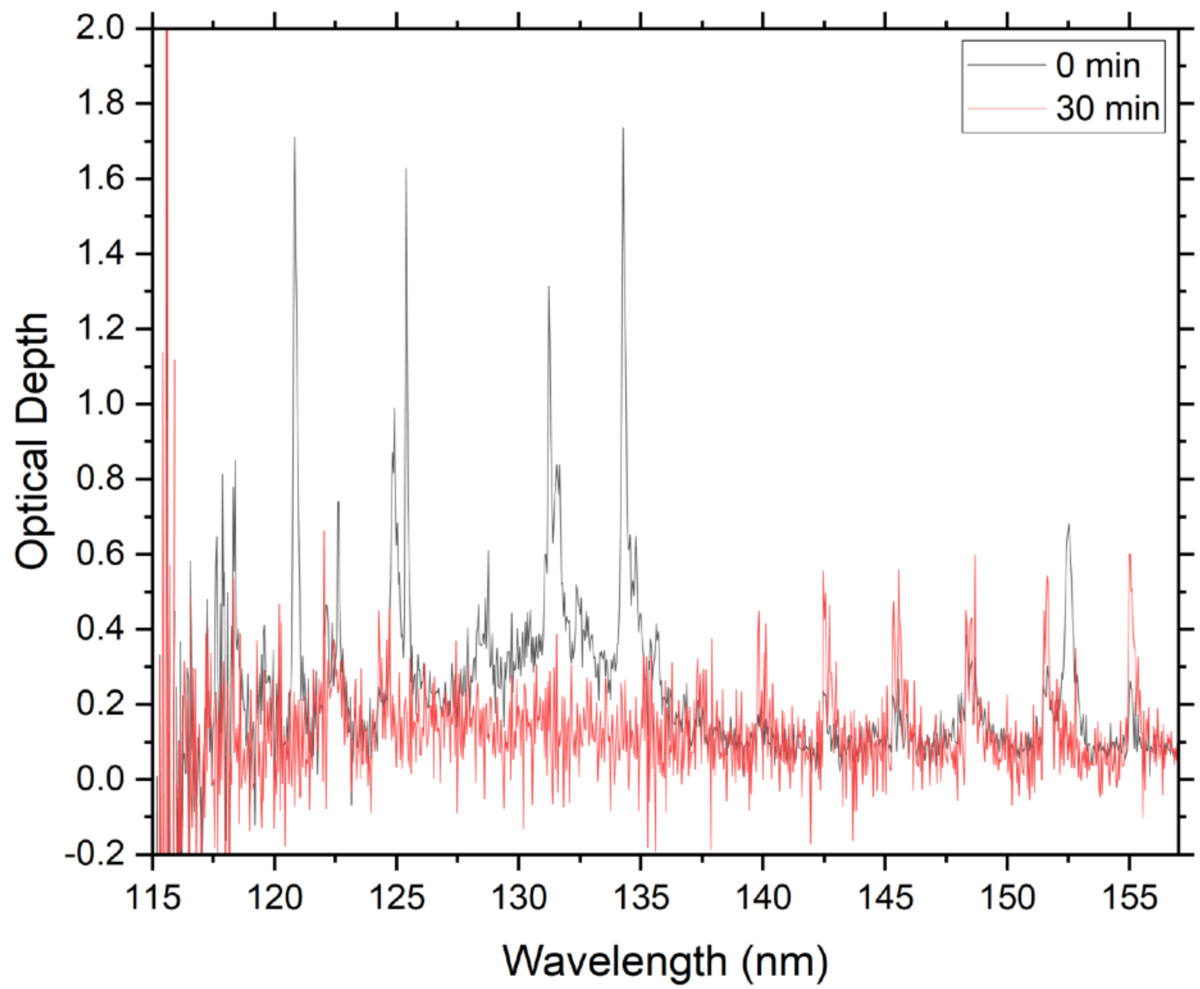
suspicious increase…. thermal dissociation ?

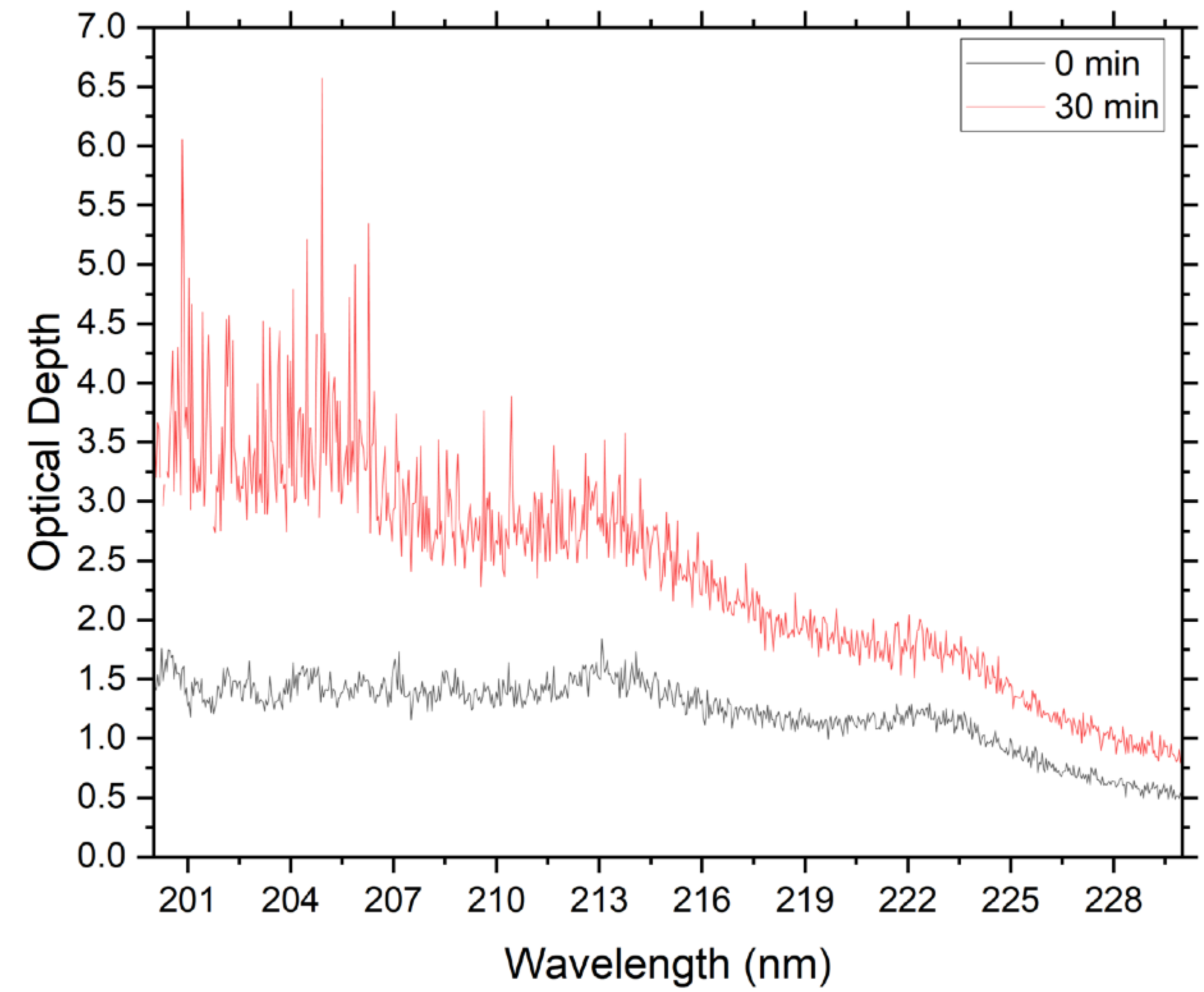
preliminary data
Fleury, Poveda, Venot et al. in prep

EXPERIMENTAL ISSUES

THERMAL DISSOCIATION

- above ~700 K : thermal dissociation of molecules
- Pressure in the cell increases, C_2H_2 absorption features decrease, but new features… = new compound ?

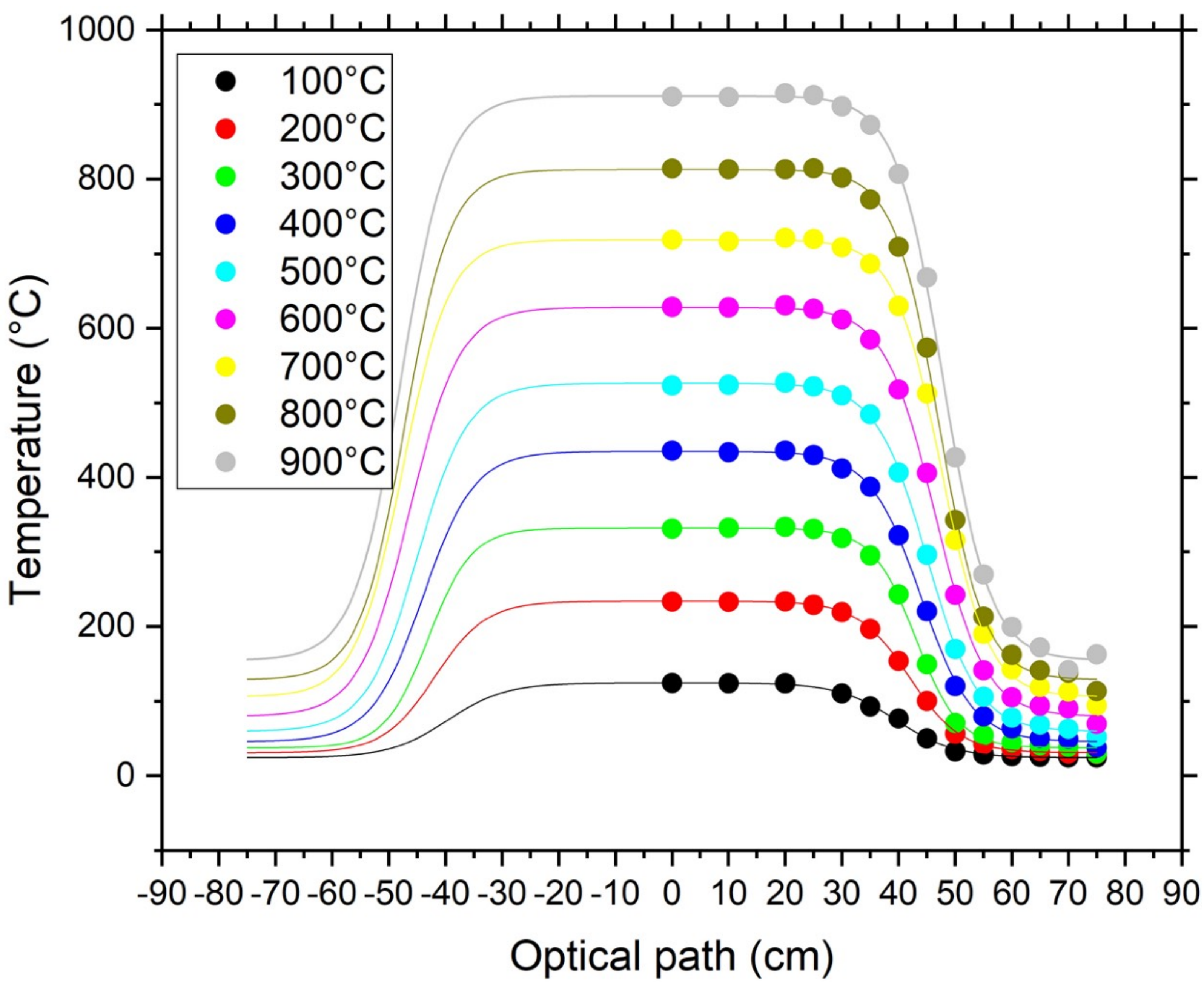




- difficult to monitor acquisition of 20 minutes…
- change from the previous Kantal cell to Quartz: reduces the issue but does not remove it

EXPERIMENTAL ISSUES

TEMPERATURE INSIDE THE CELL



- thermal gradient: uncertainty on the T corresponding to the absorption measured (combination of parcels of gas at different T)
- data processing in Venot+2018: all the gas is at Tmax
- from now (data on new UV platform): modelling of the thermal gradient

Photochemistry in Laboratory

Olivia Venot
olivia.venot@lisa.ipsl.fr

Exo-Atmospheres, Ecole de Physique des Houches, September, 19th 2022