Thermal dependency of CO_2 VUV absorption cross section: application to warm exoplanetary atmospheres

Olivia VENOT,

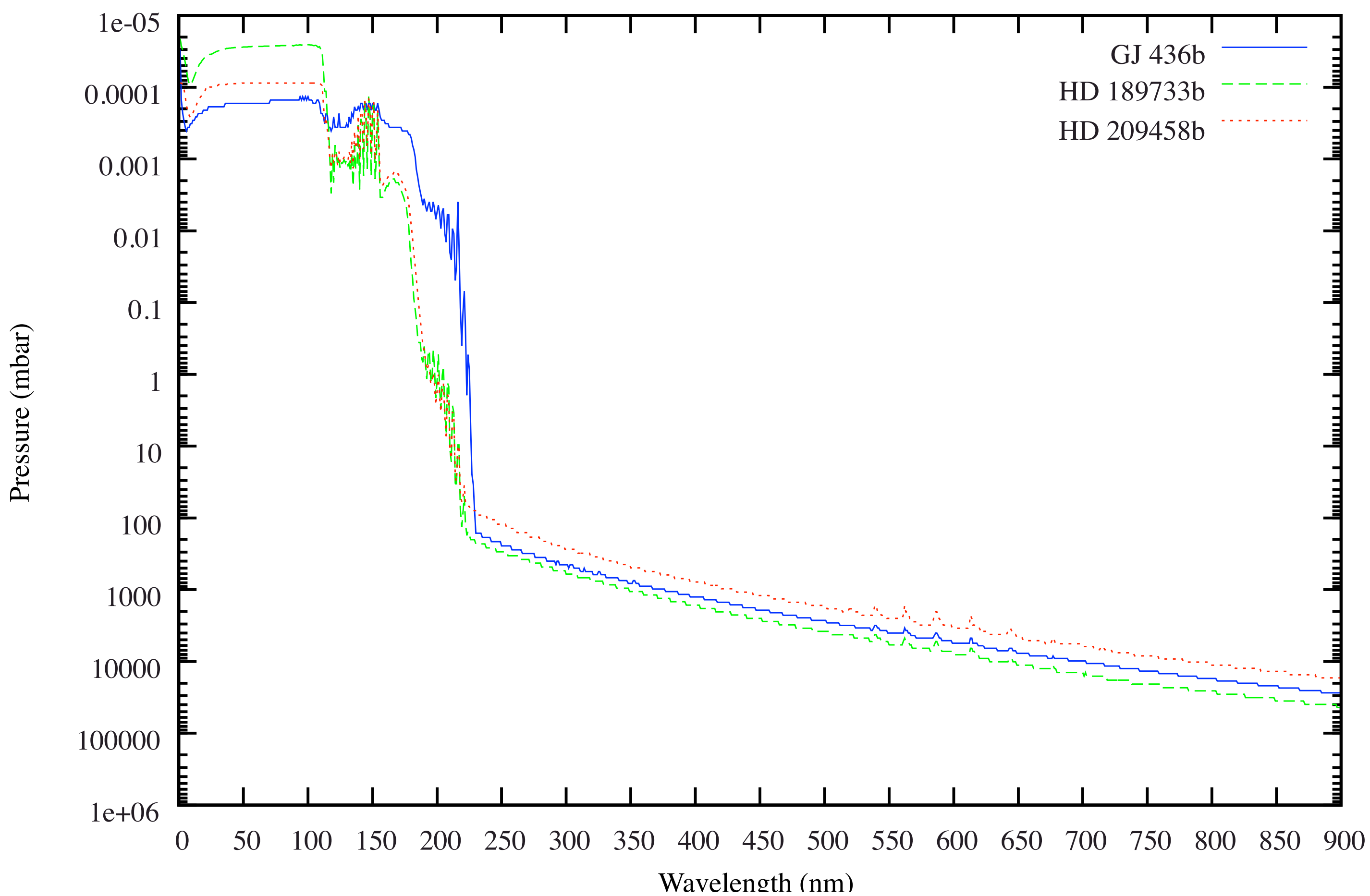
Y. Bénilan, N. Fray, M.-C. Gazeau, F. Montmessin, F. Lefèvre, C. Bahrini, Et. Es-Sebbar, M. Schwell, E. Hébrard, M. Lefèvre, I.P Waldmann

olivia.venot@lisa.u-pec.fr

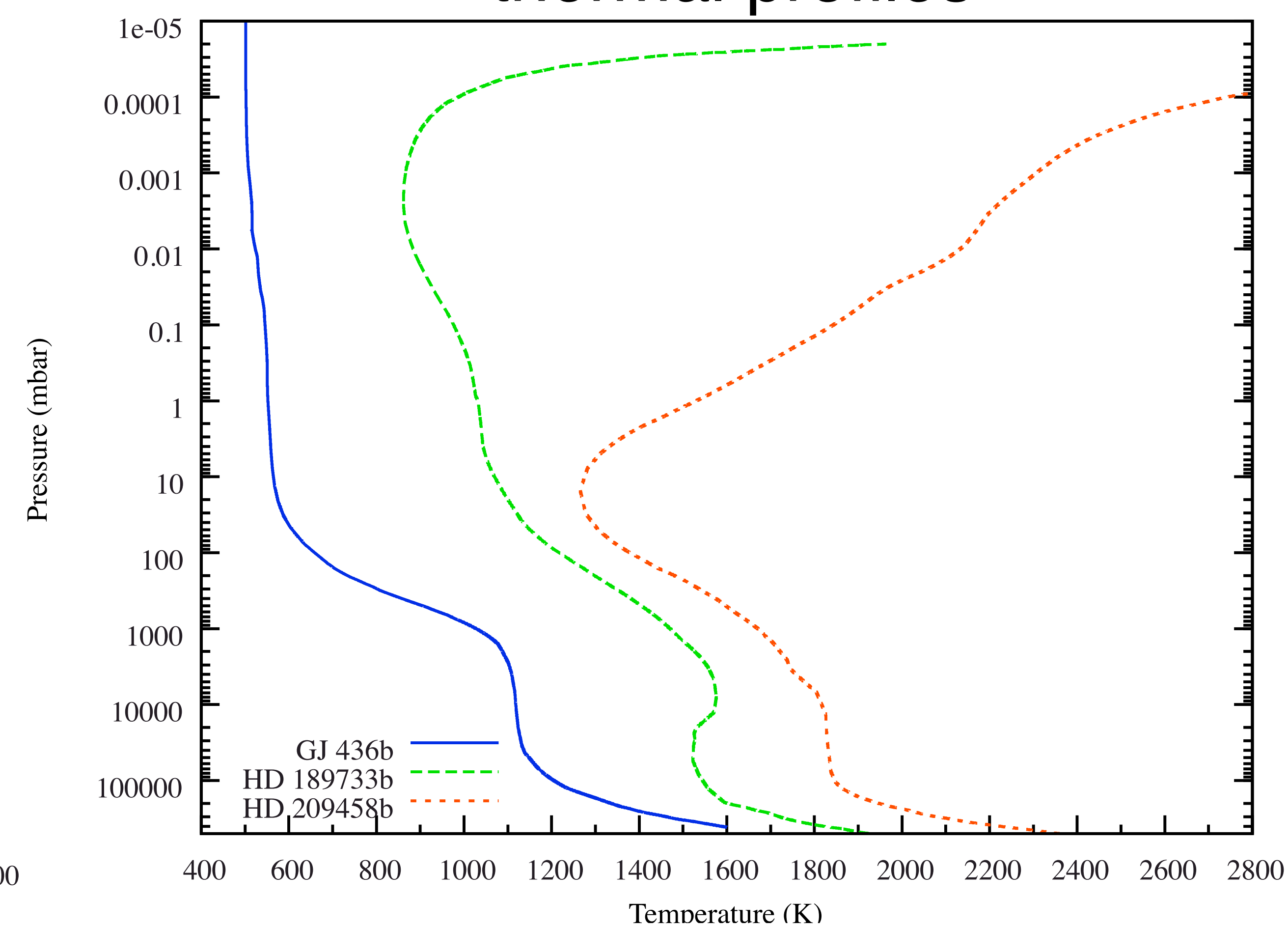
Where do photolysis take place in planetary atmospheres ?

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

penetration of stellar flux (level τ=1)



thermal profiles



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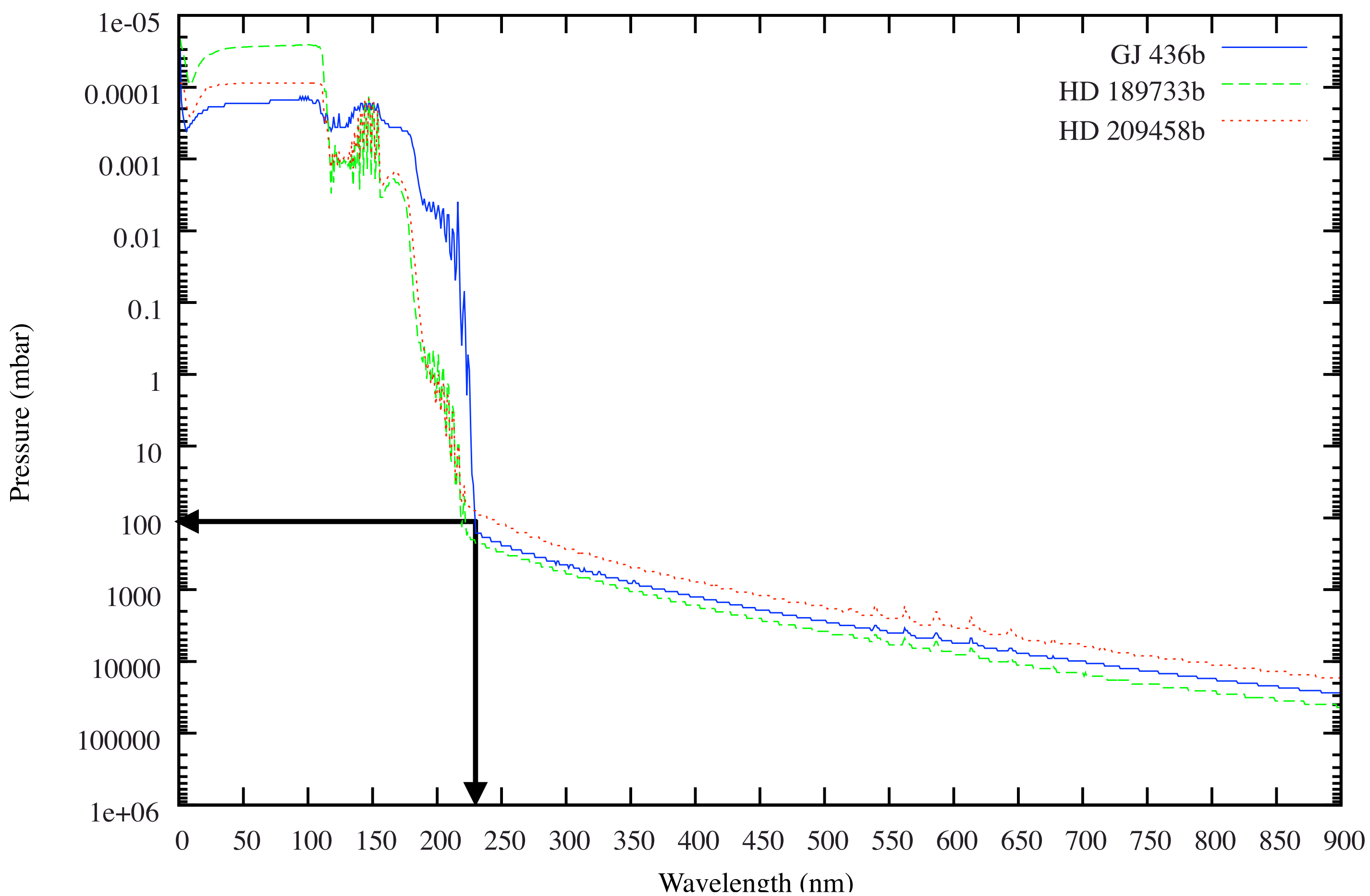

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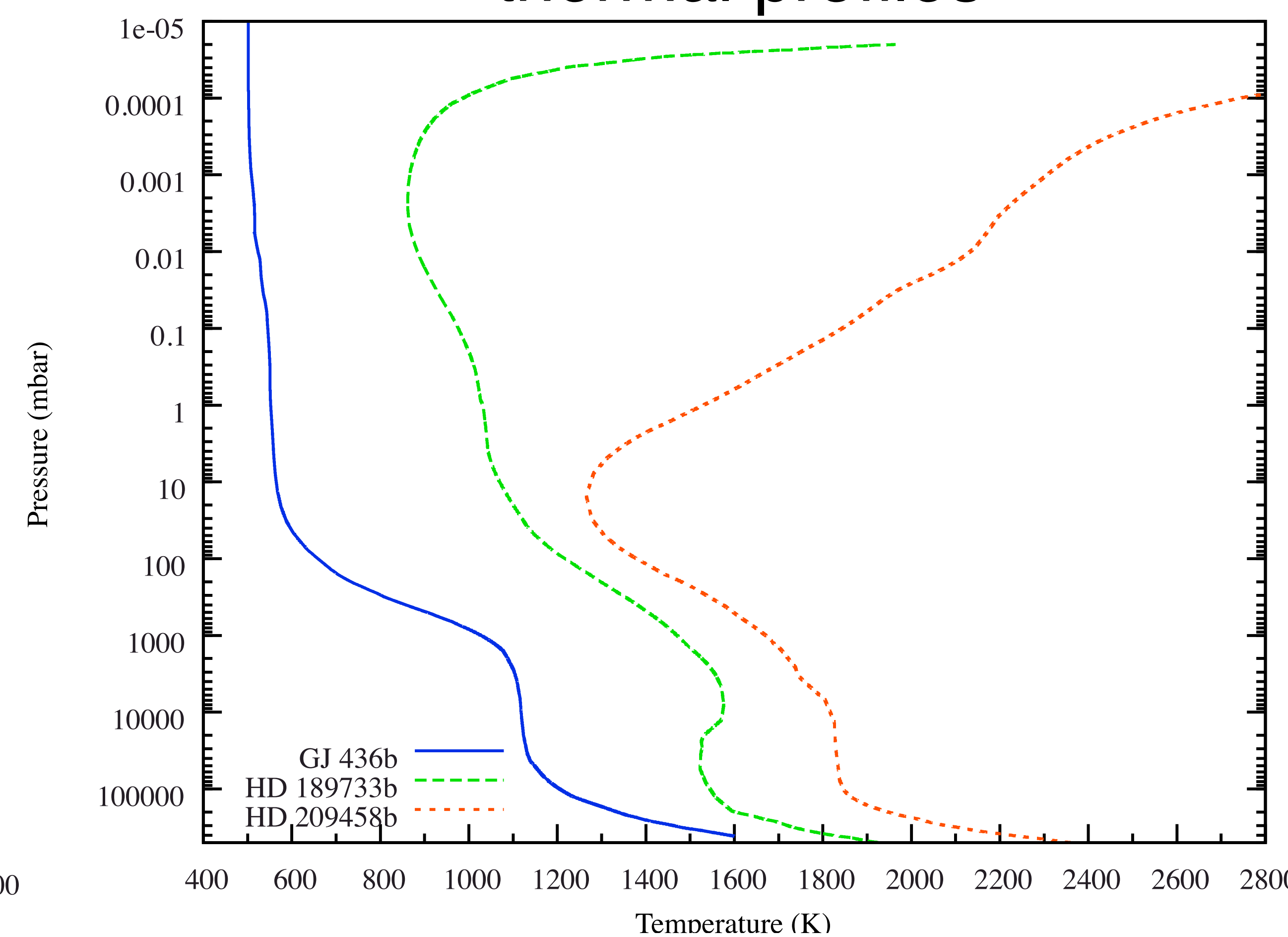

λ of interest for photochemistry: < 250 nm

penetrates down to P < 100 mbar

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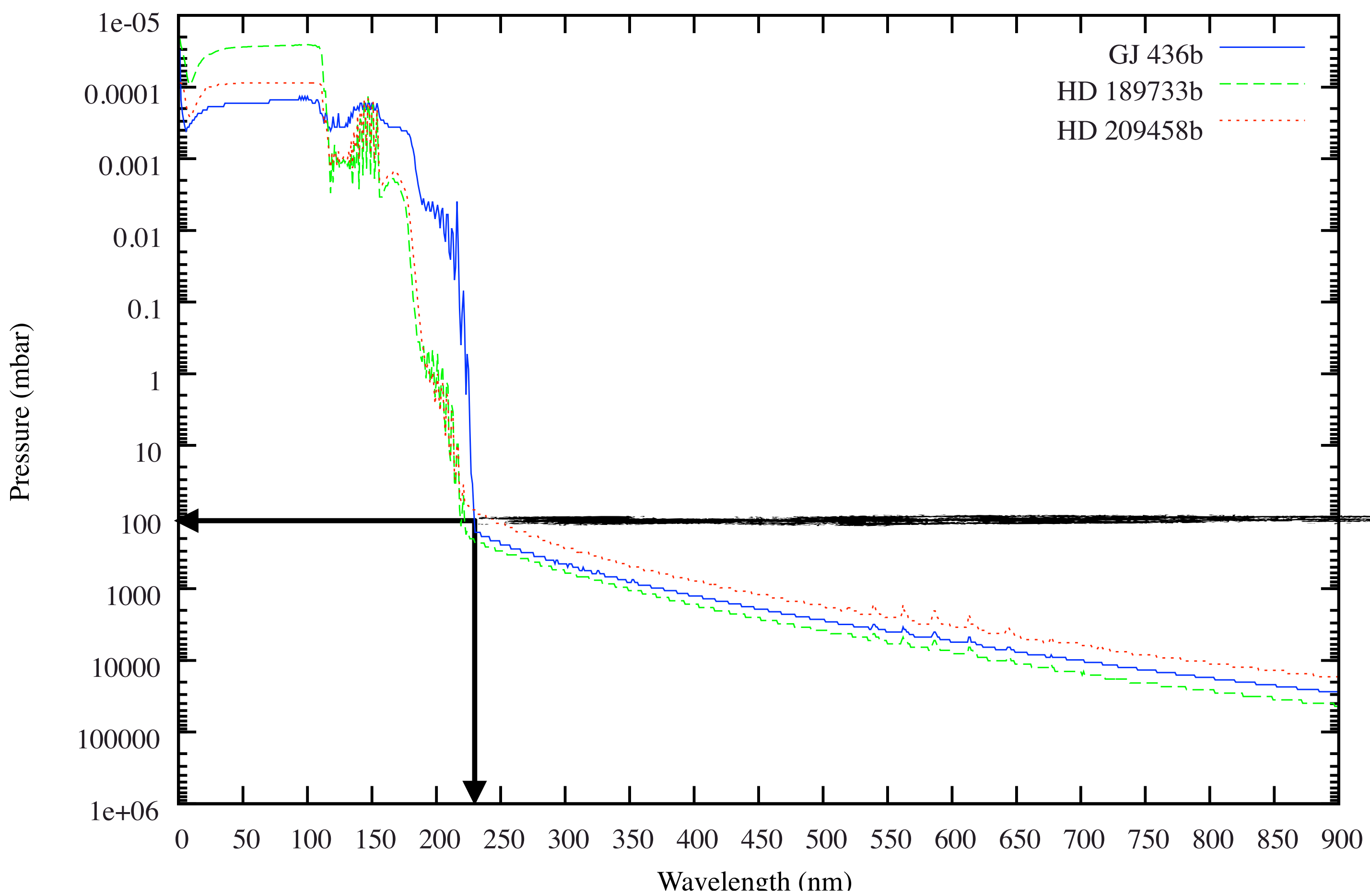

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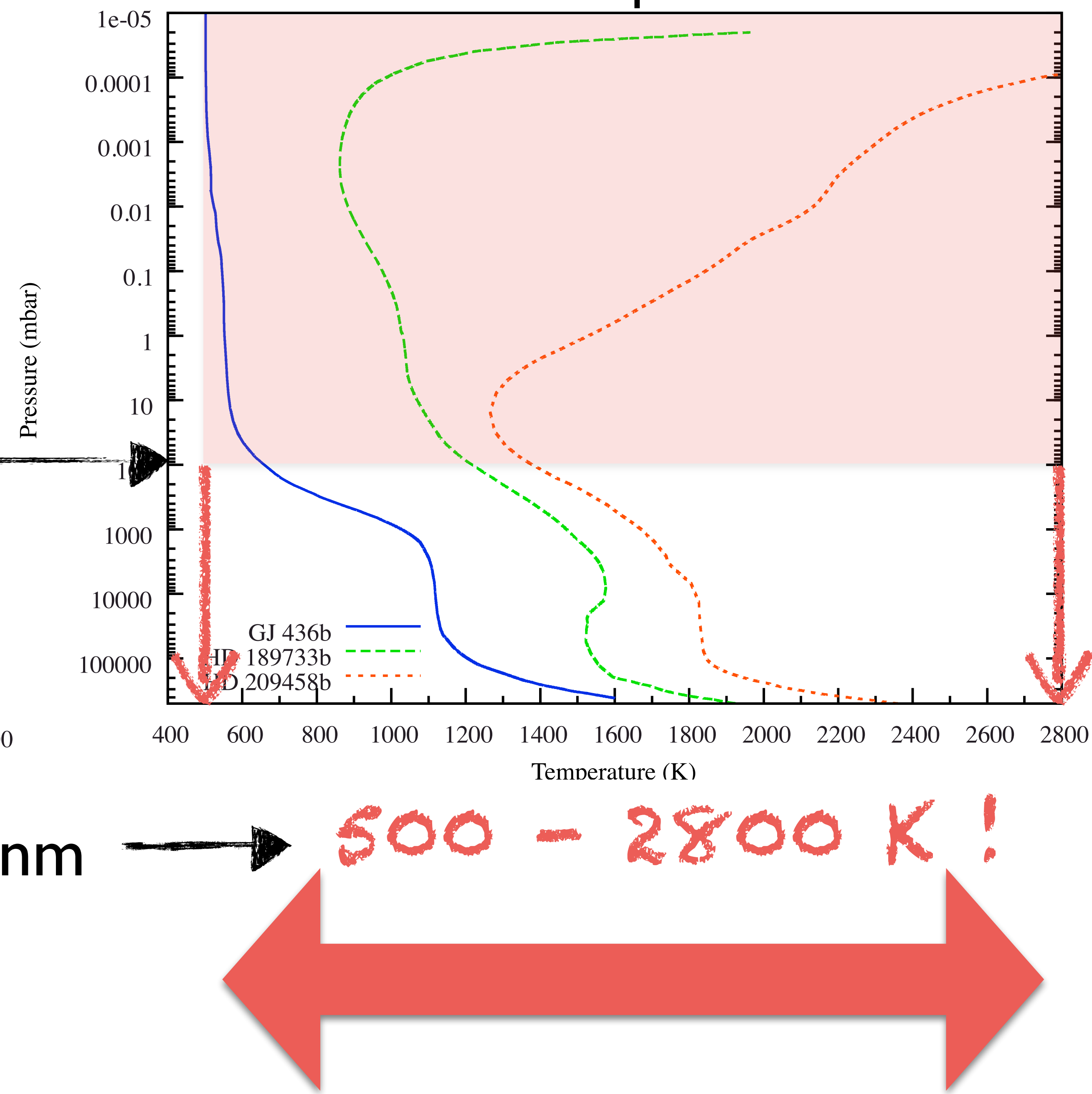

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VUV absorption cross section

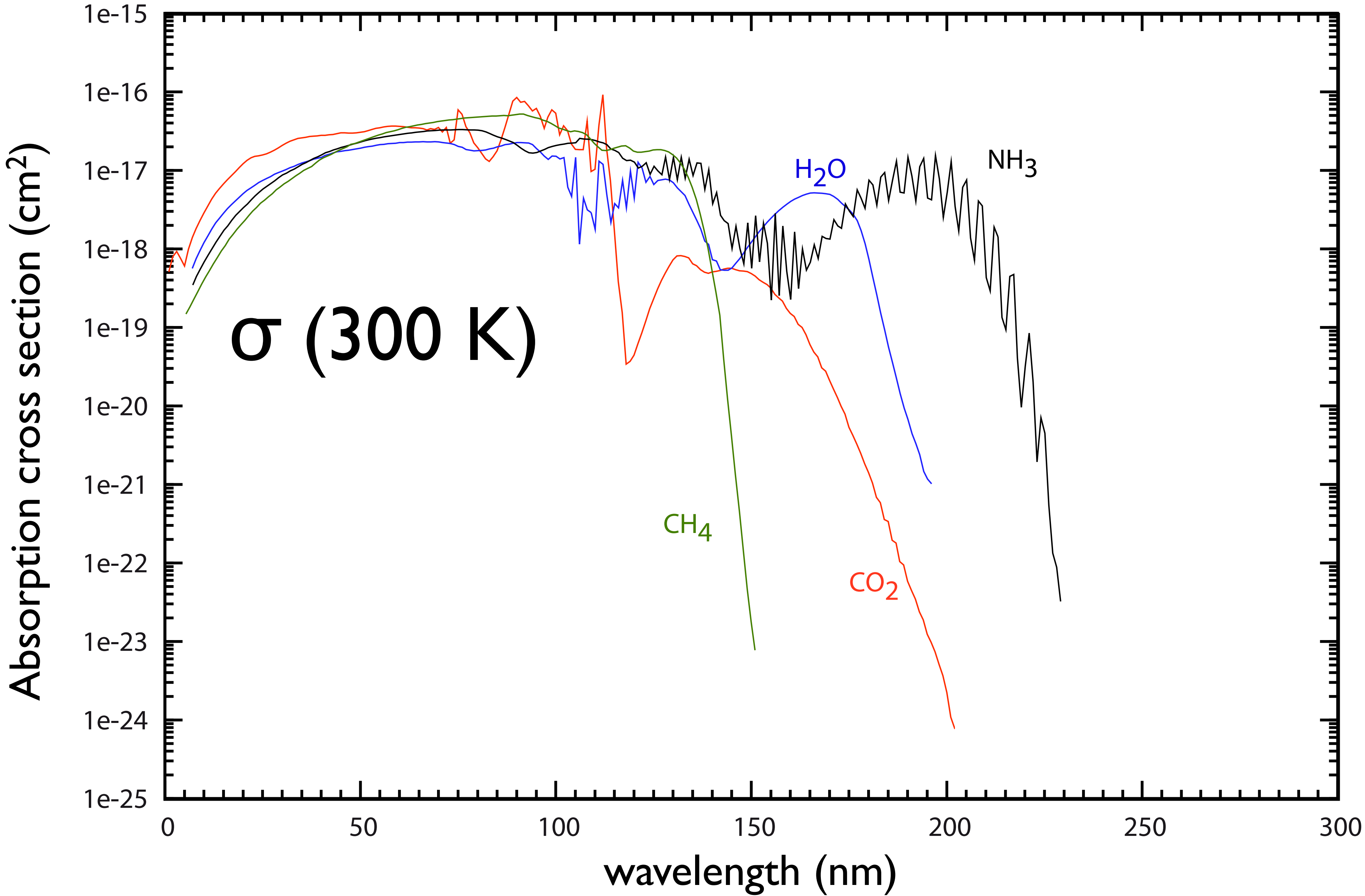
σ(λ,T) are crucial data for atmospheric modellers

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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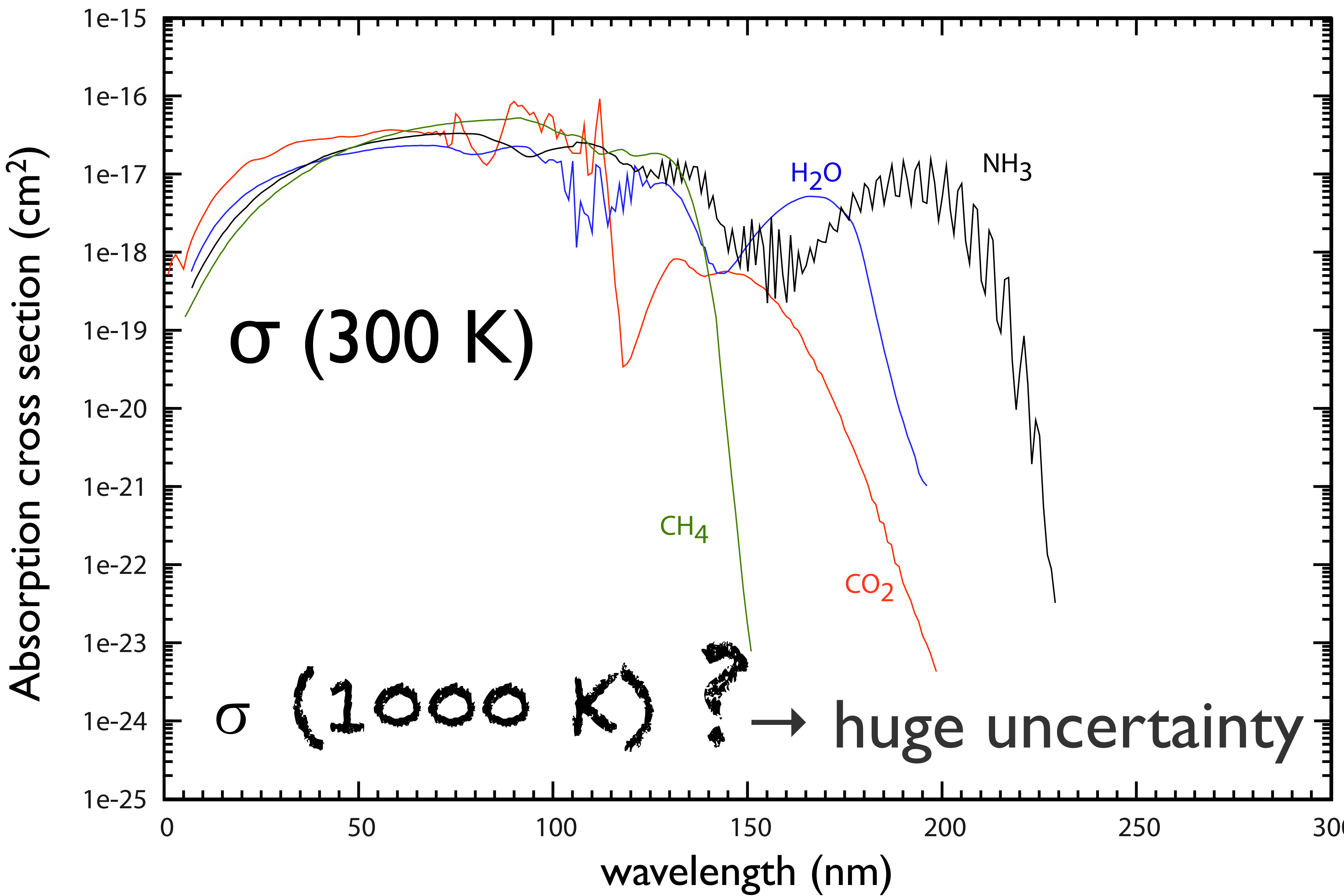


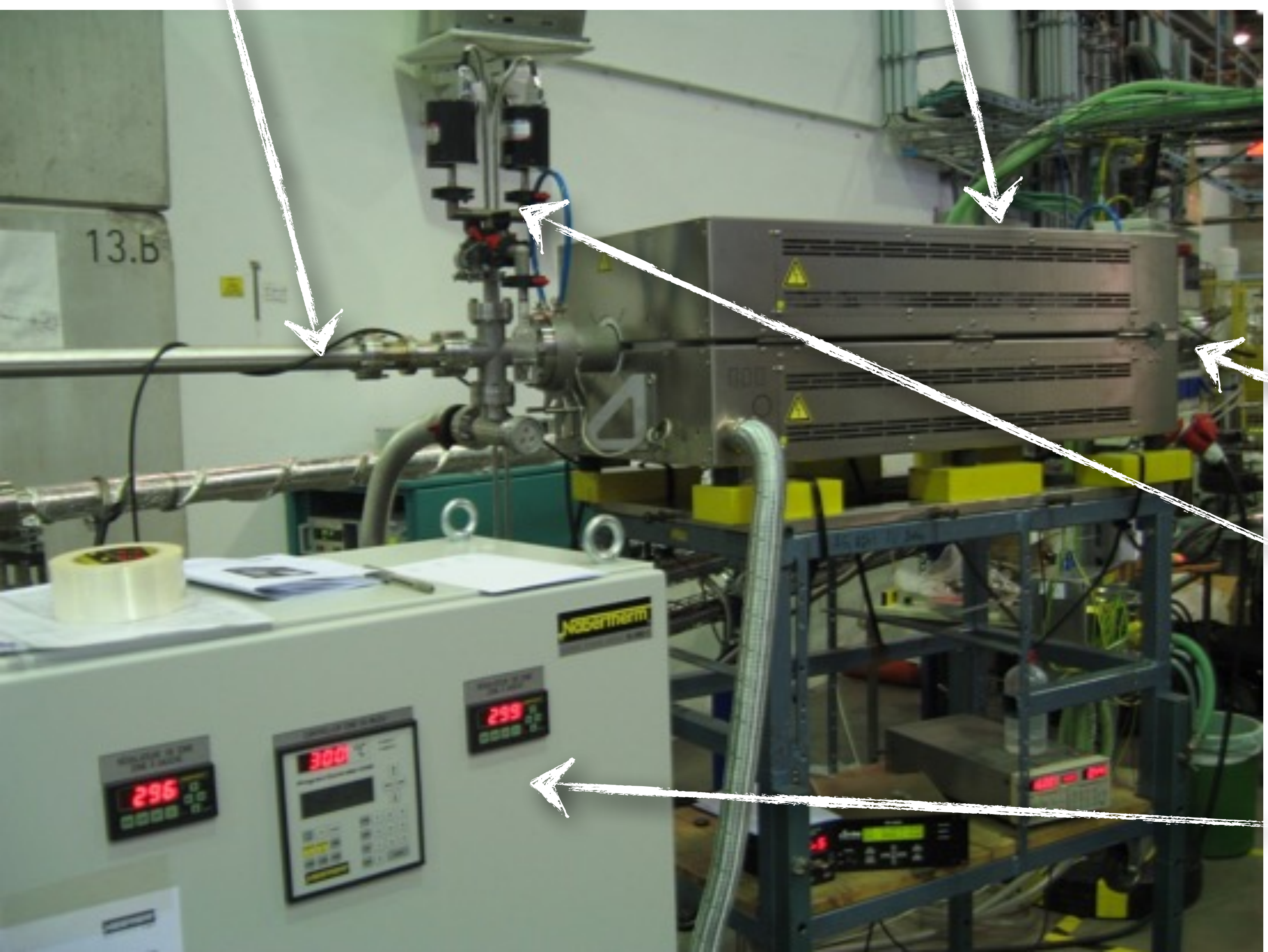
VUV absorption cross section

experimental setup :

T up to 1200K

incident monochromatic flux

oven + cell



photomultiplier

injection of gaz

temperature control

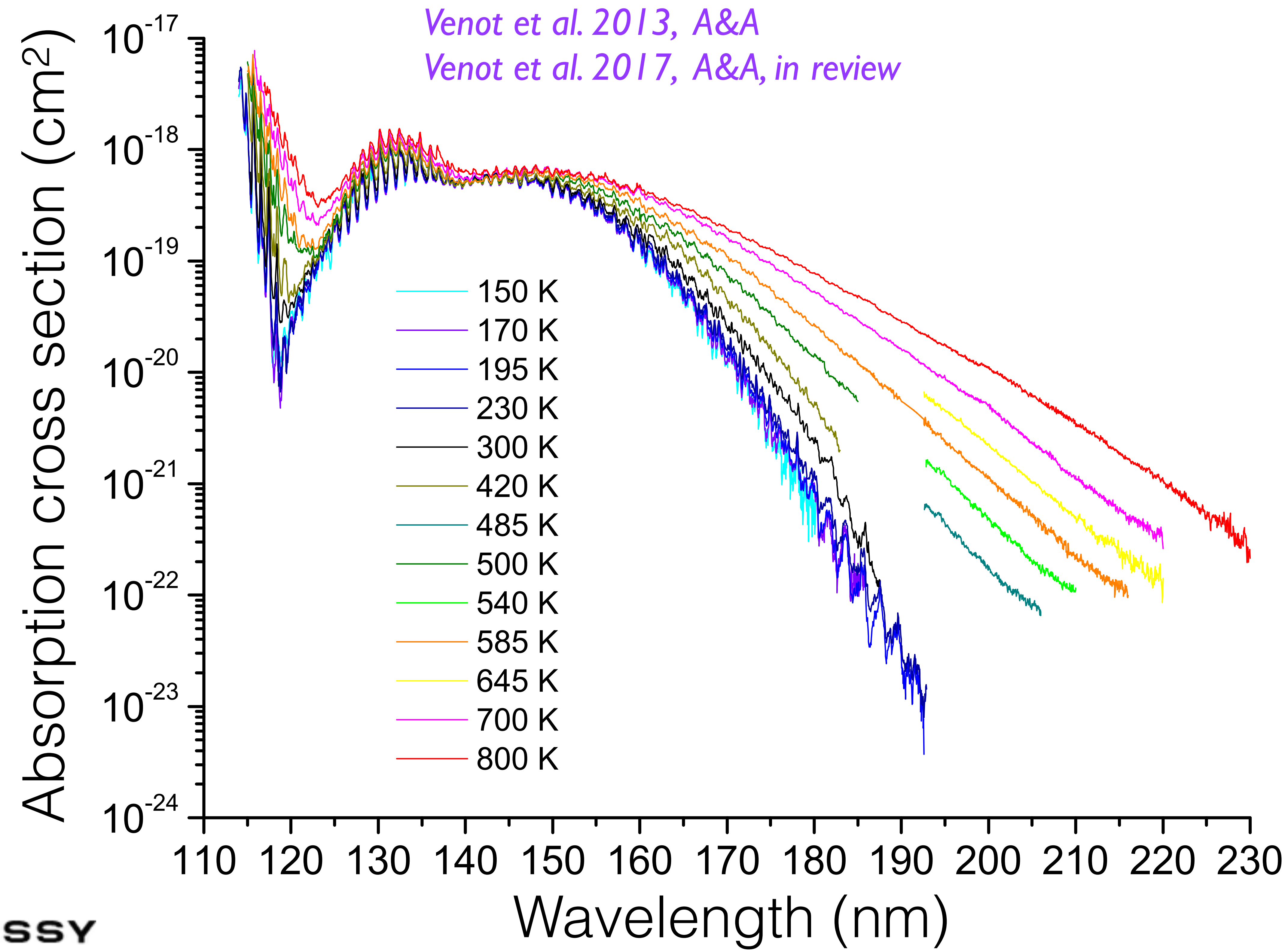
115-230 nm

synchrotron radiation facilities BESSY / SOLEIL
115 < λ < 190 nm

UV lamp at LISA
190 < λ < 230 nm

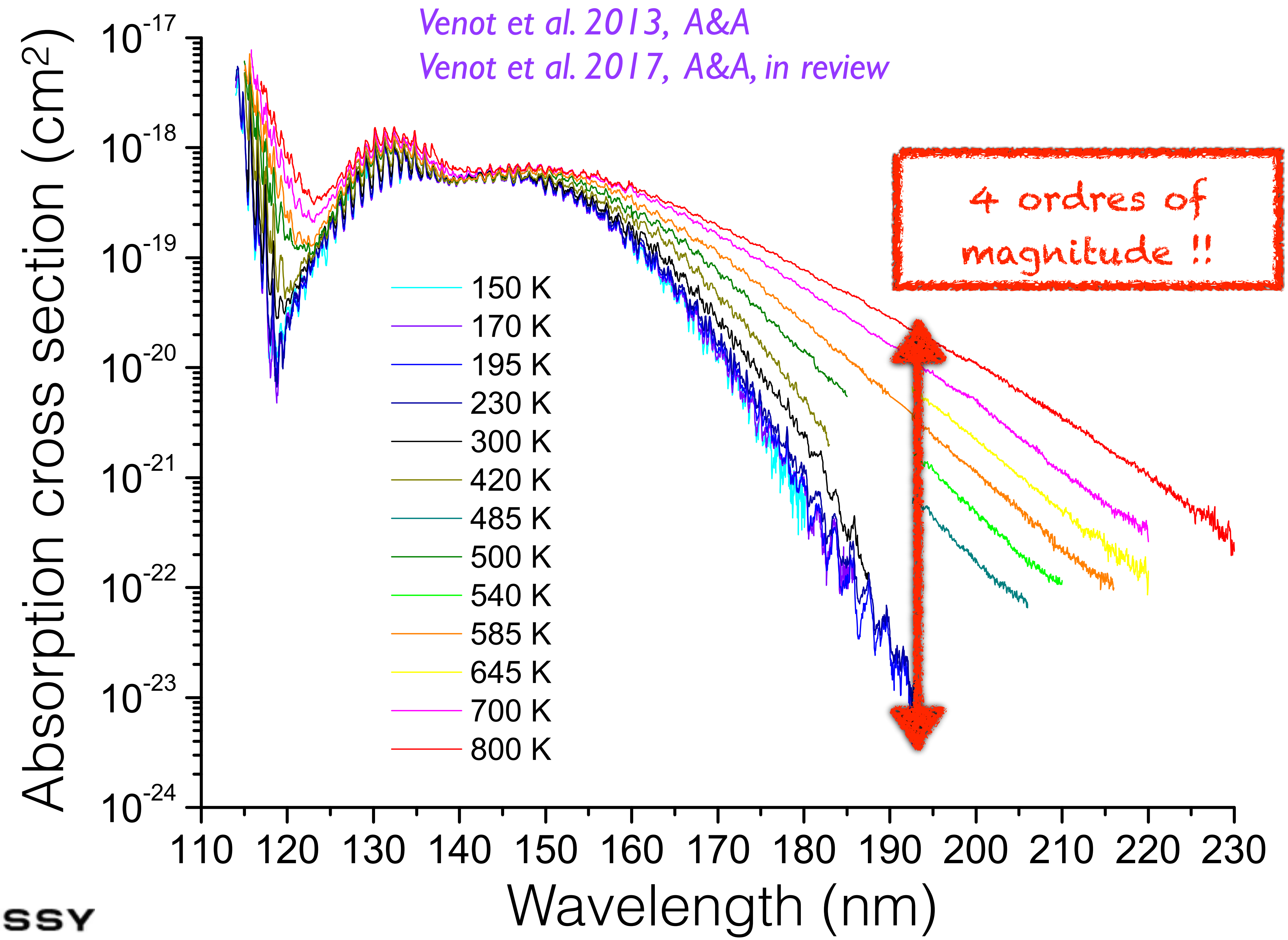
lisa

CO_2 VUV absorption cross section



BESSY

CO_2 VUV absorption cross section



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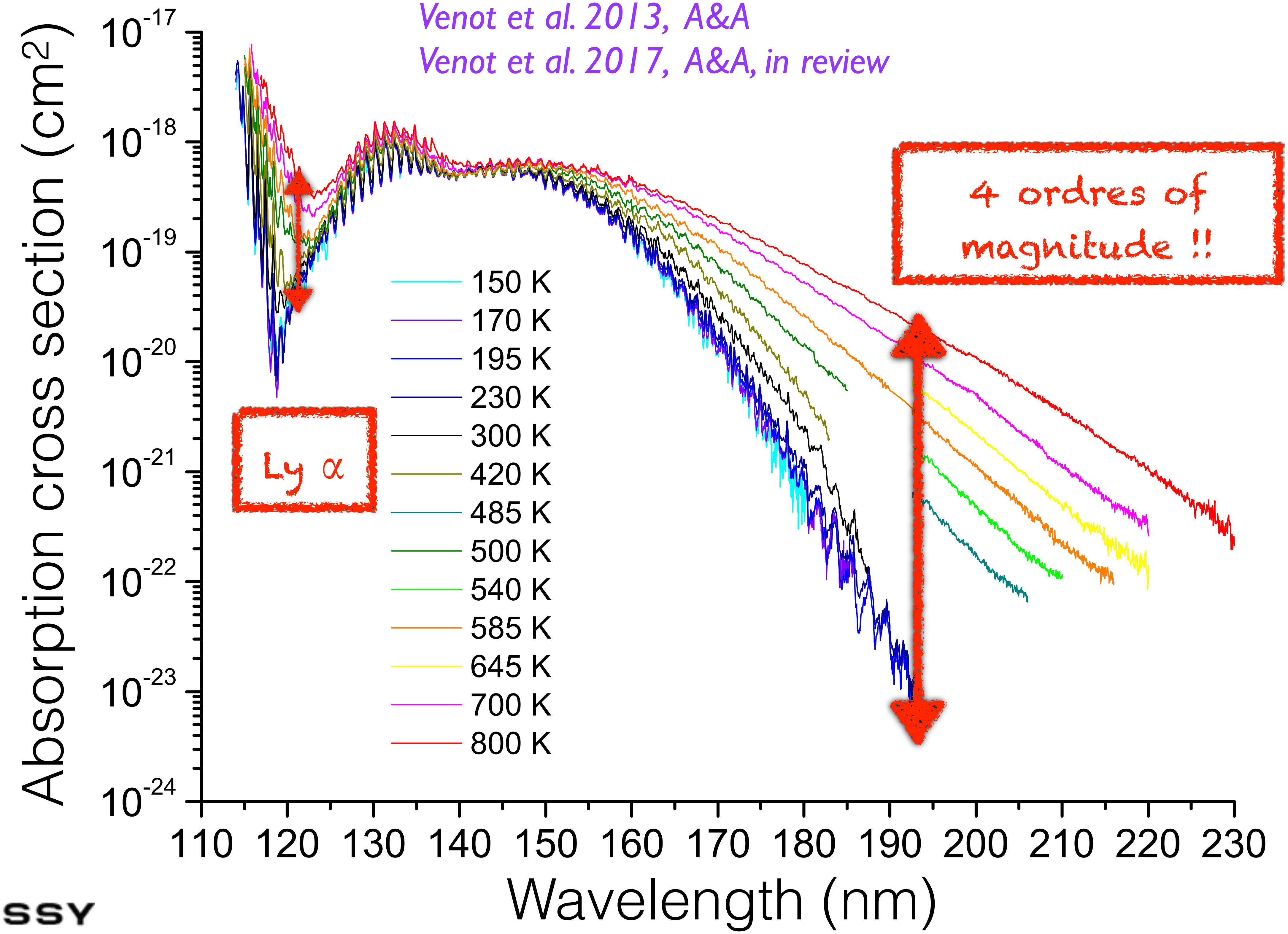

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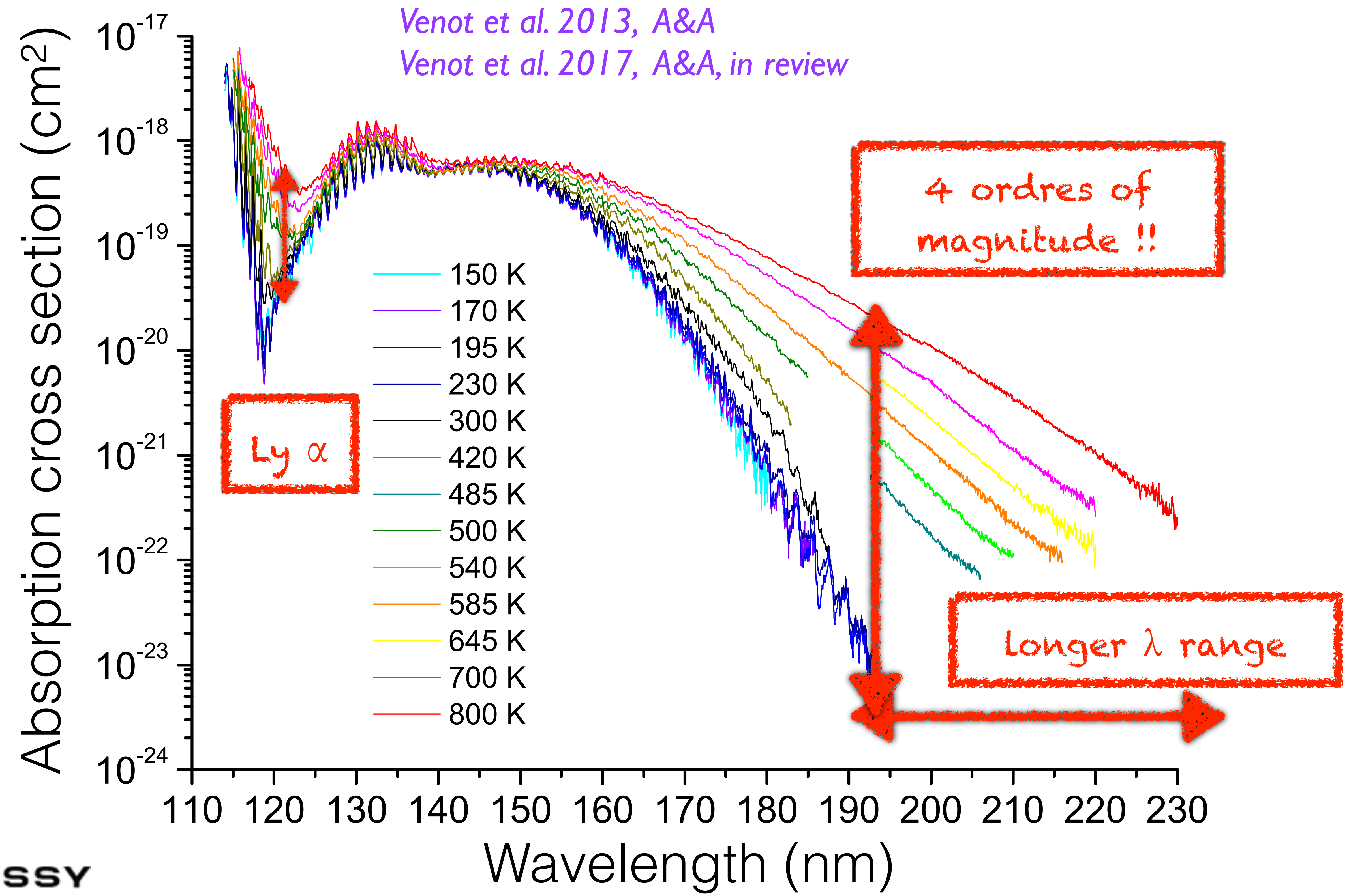
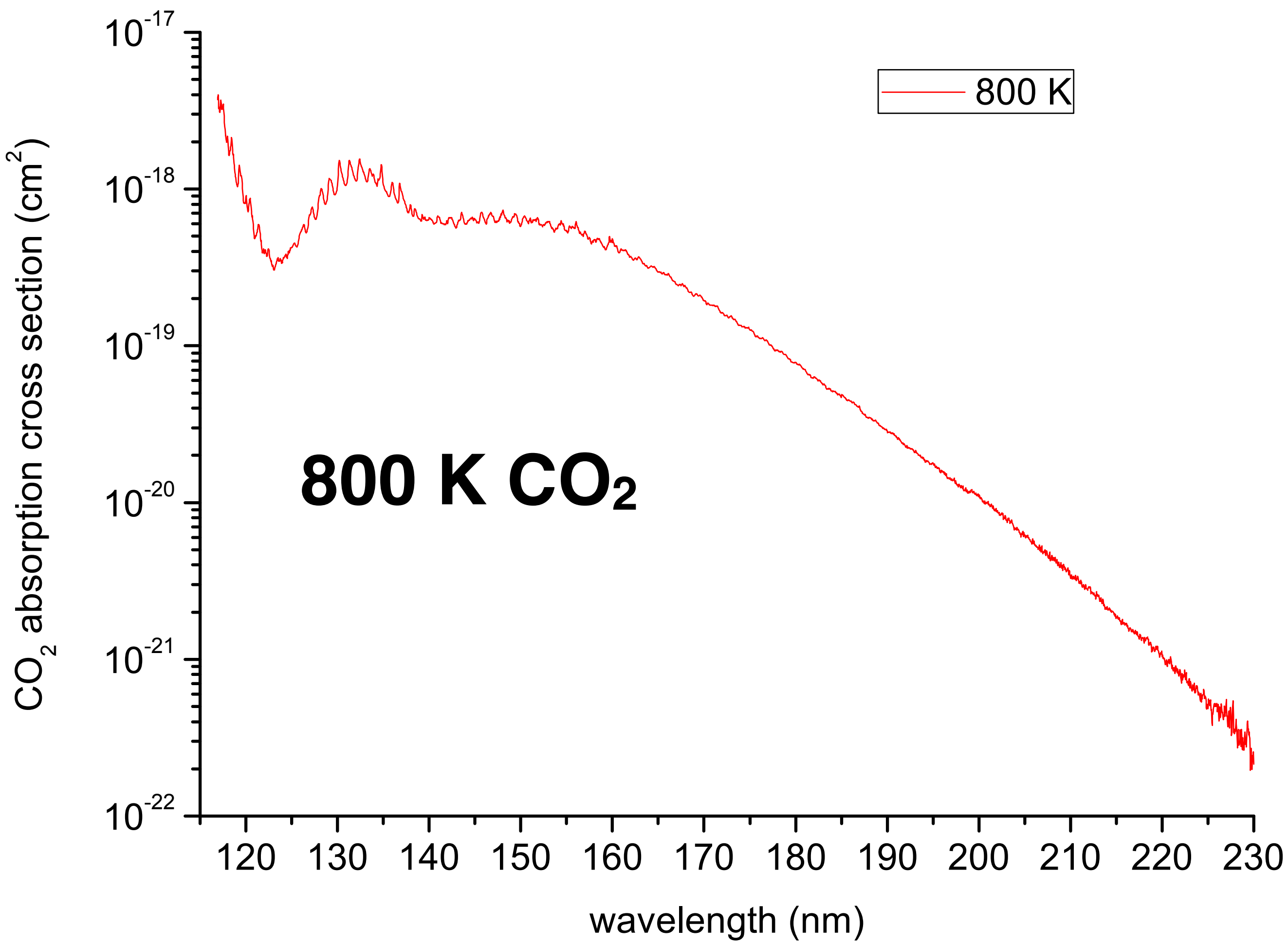


BESSY

Continuum and fine structure

separation of the absorption cross section in **2 parts**:

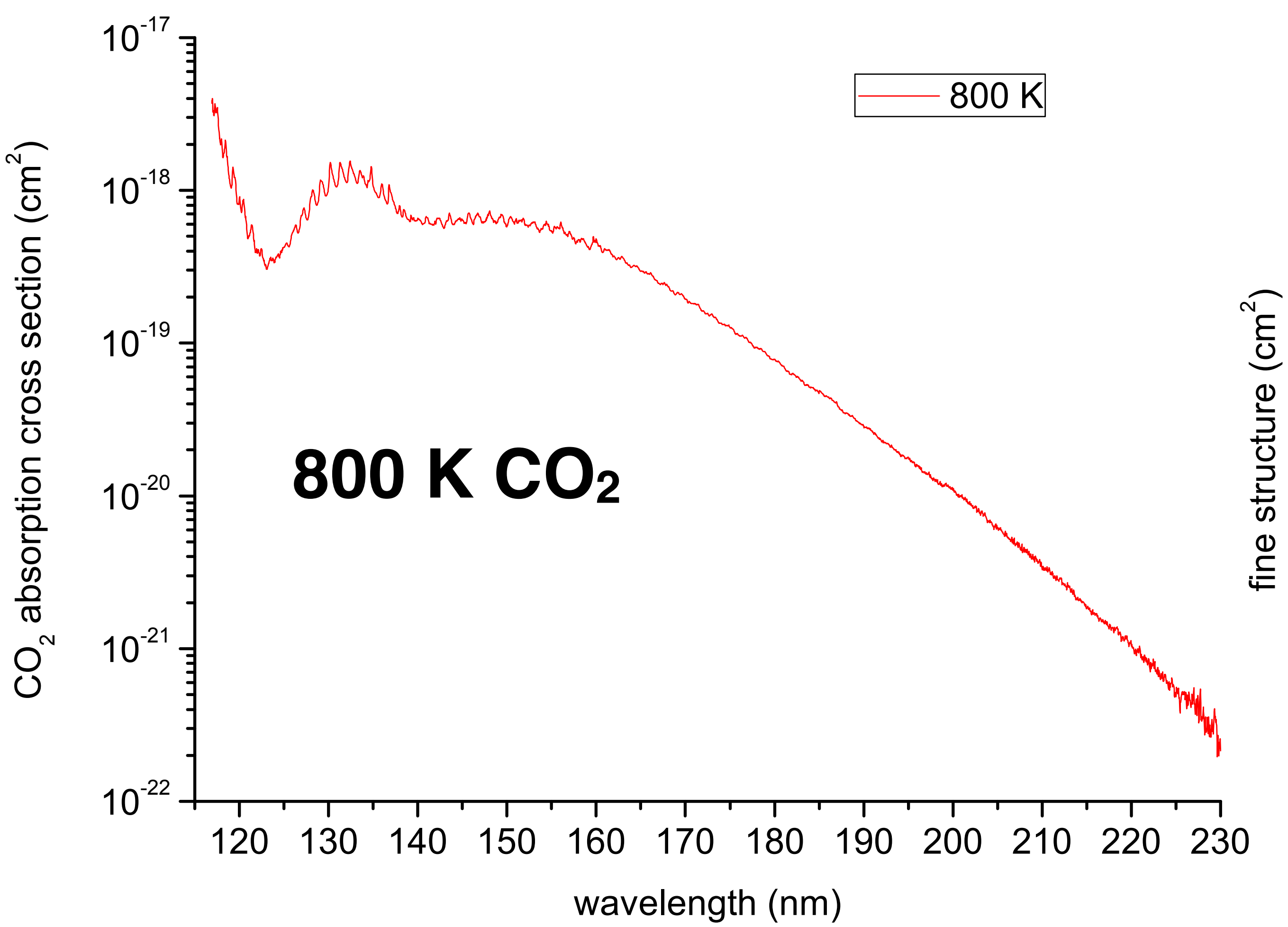
Venot et al. 2017, A&A, in review

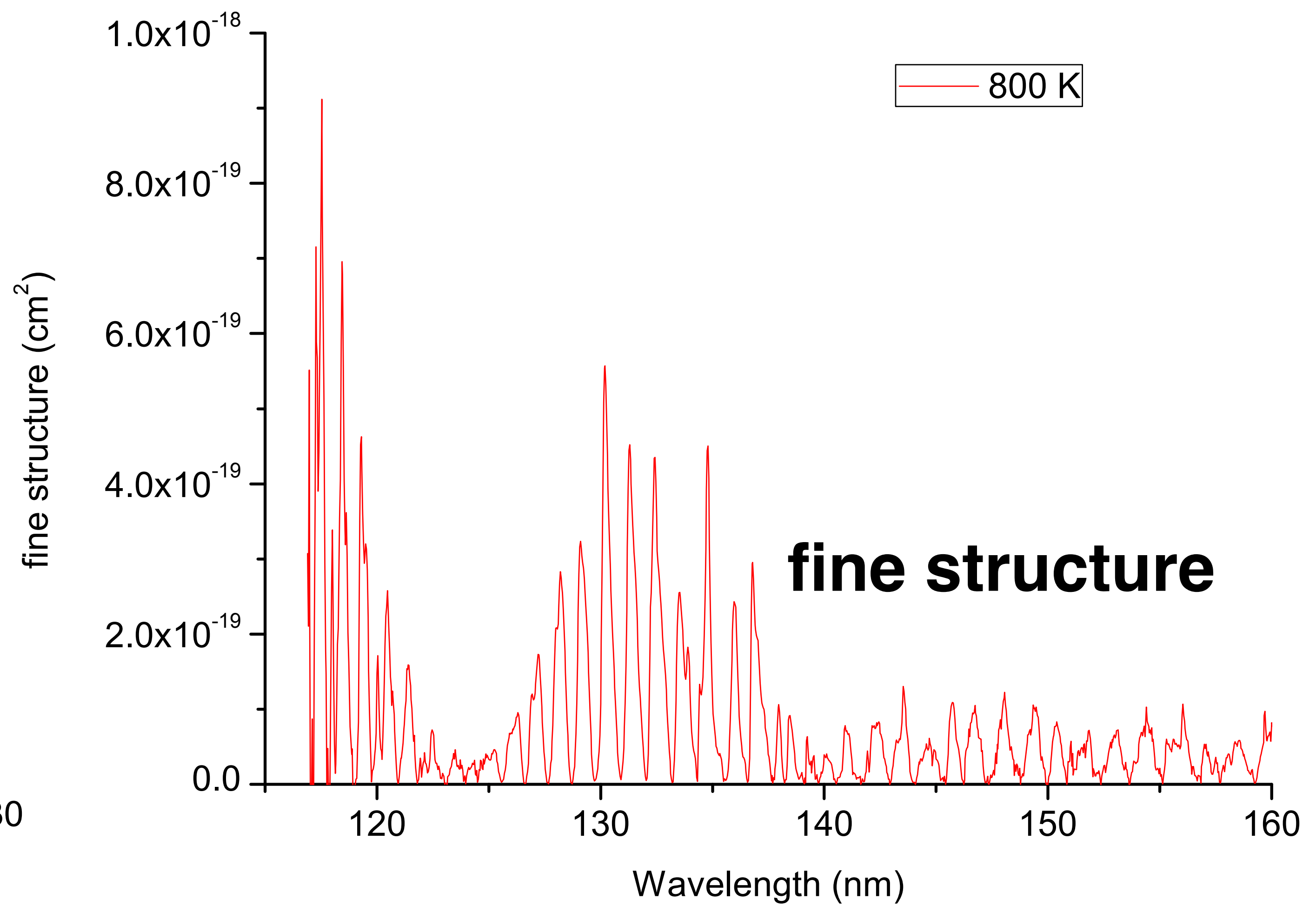


Continuum and fine structure

separation of the absorption cross section in **2 parts**:
- **the fine structure** : due to rovibrational energy transitions

Venot et al. 2017, A&A, in review



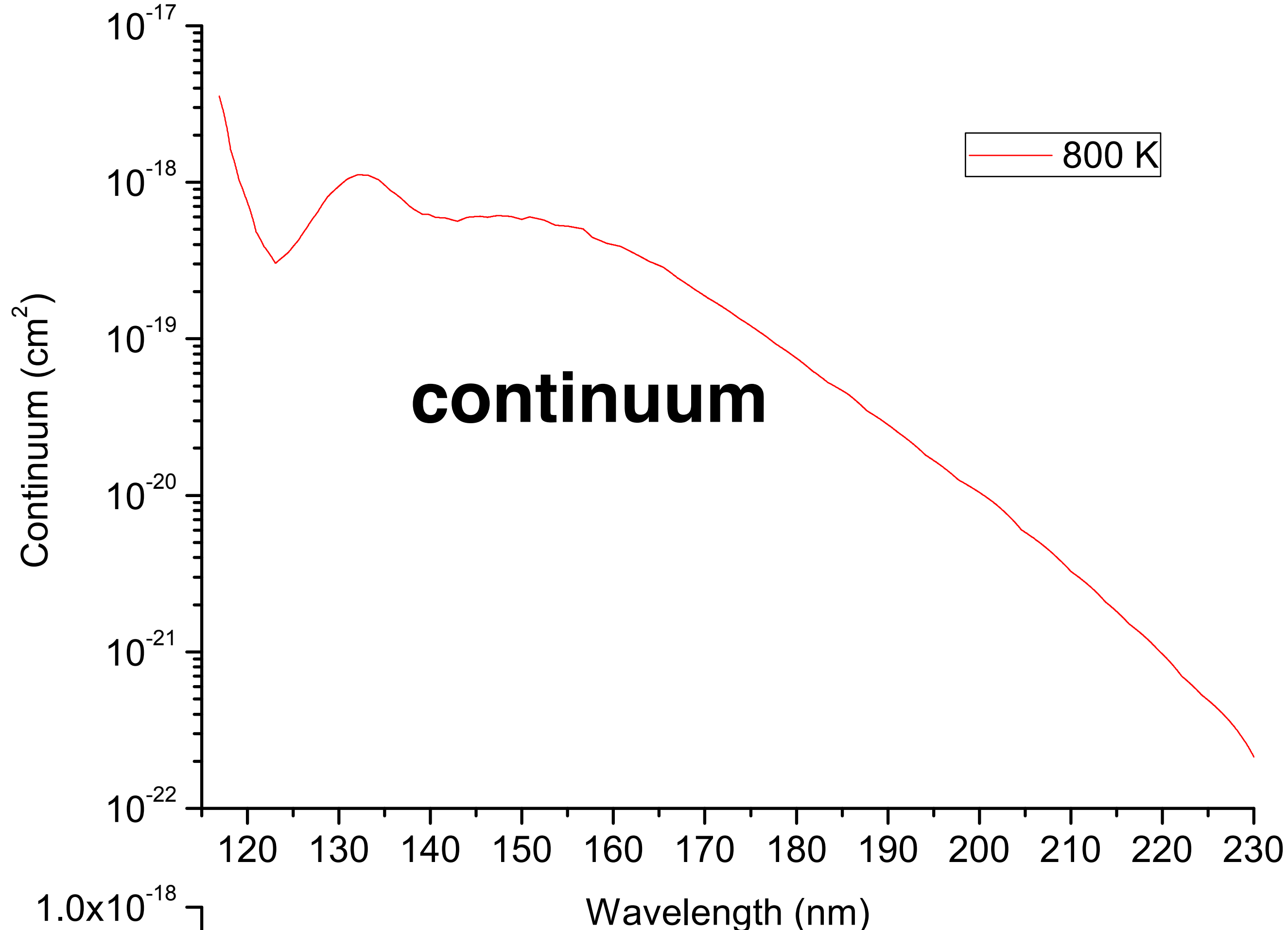


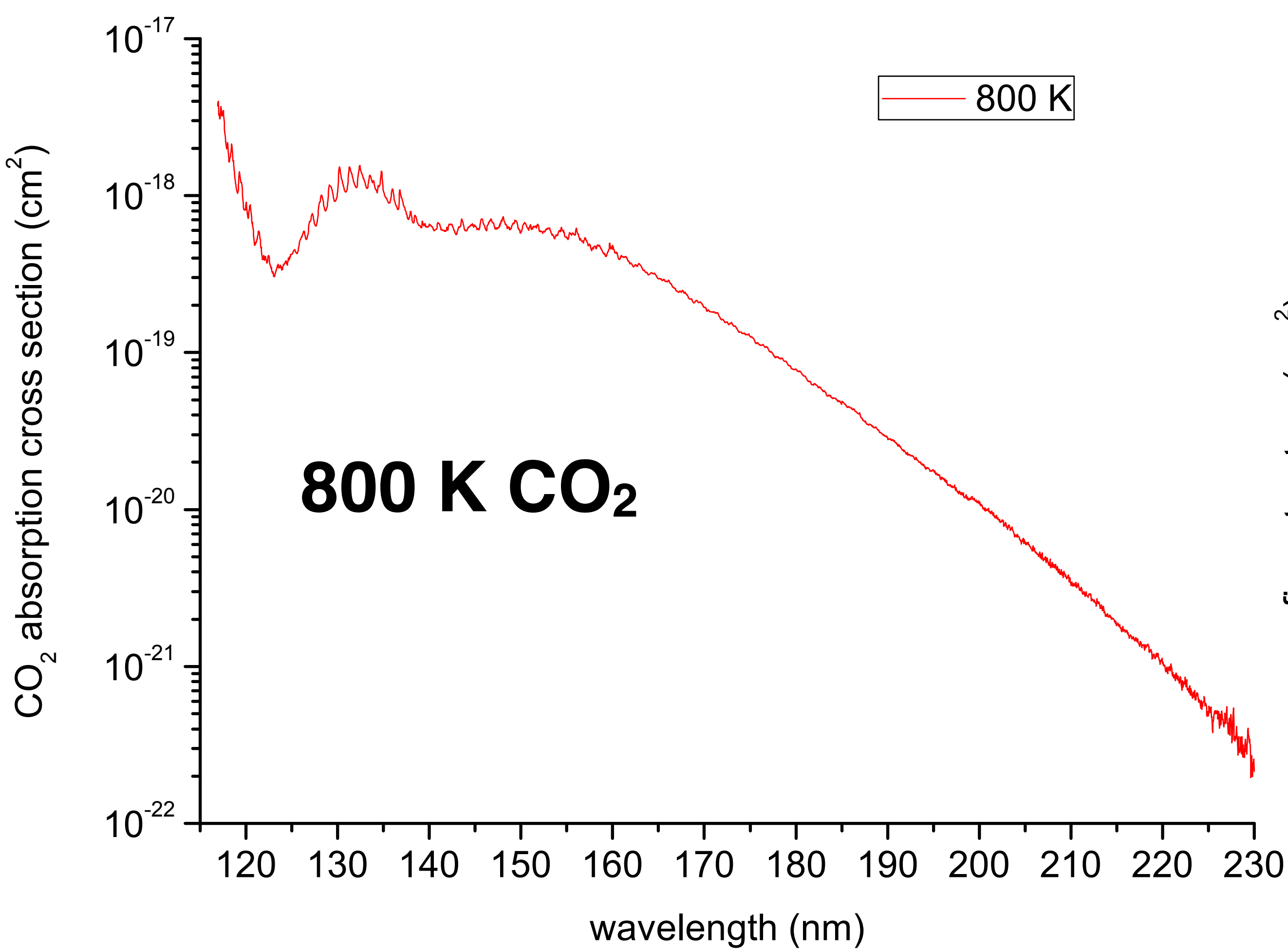
Continuum and fine structure

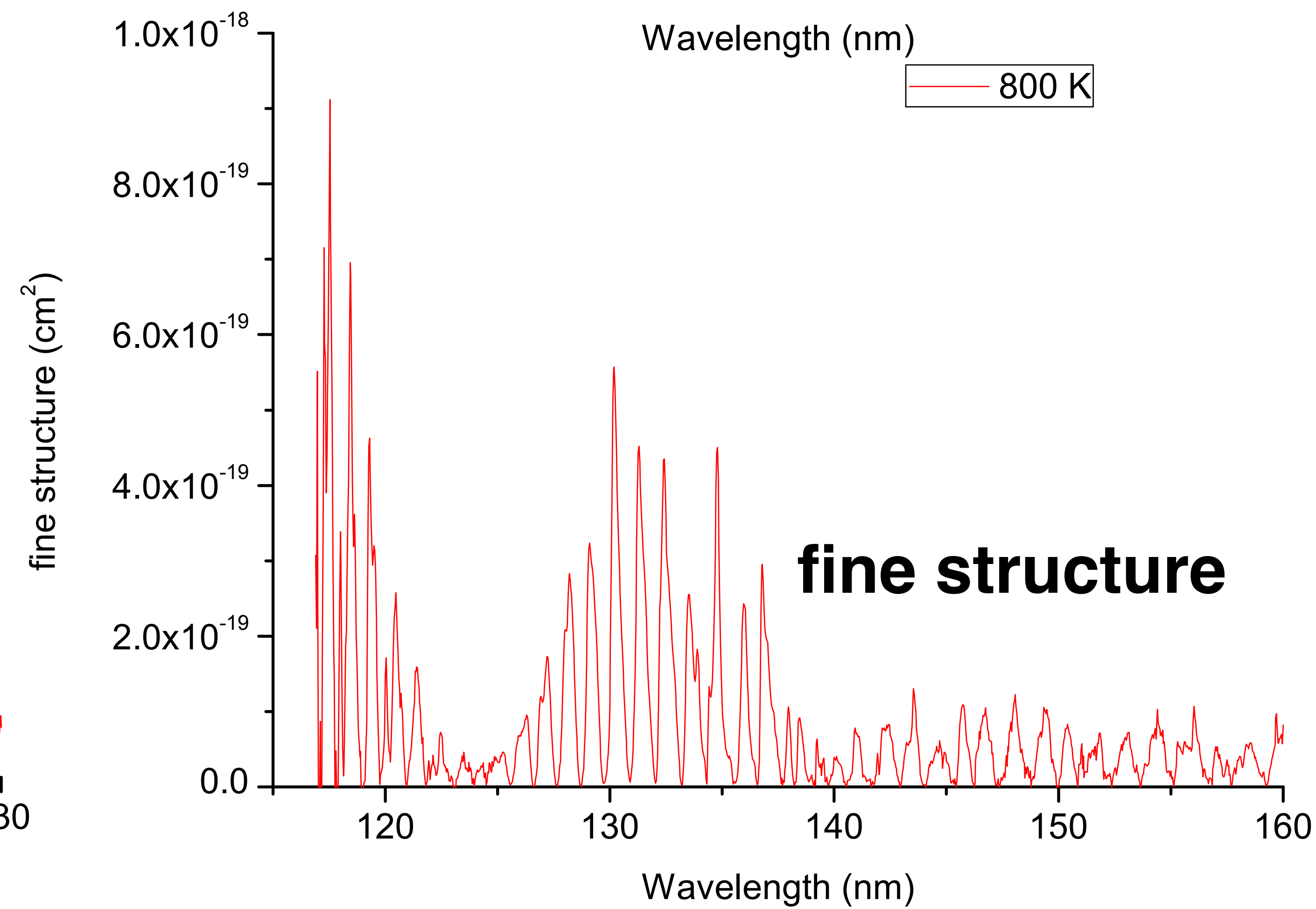
separation of the absorption cross section in **2 parts**:

- **the fine structure** : due to rovibrational energy transitions
- **the continuum** (the envelope) : also rovibrational transitions but of lower intensity and separated by very small energy gaps

Venot et al. 2017, A&A, in review





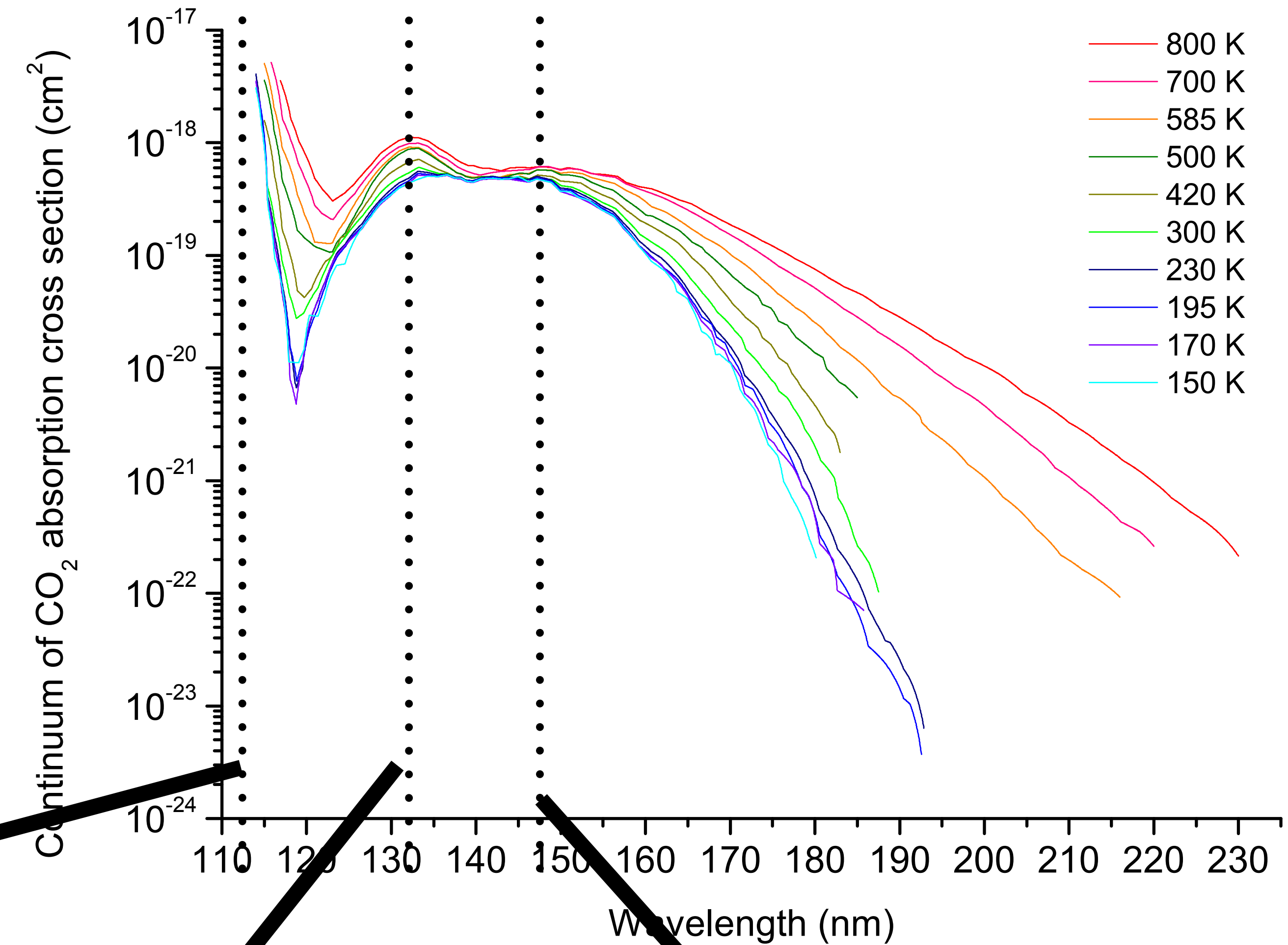


Thermal variation of the continuum

continuum represented by the sum of 3 gaussians

$$\sigma_{continuum}(\lambda,T) = \sigma_1(\lambda,T) + \sigma_2(\lambda,T) + \sigma_3(\lambda,T)$$

centers : ~113 nm, ~131 nm, ~147 nm



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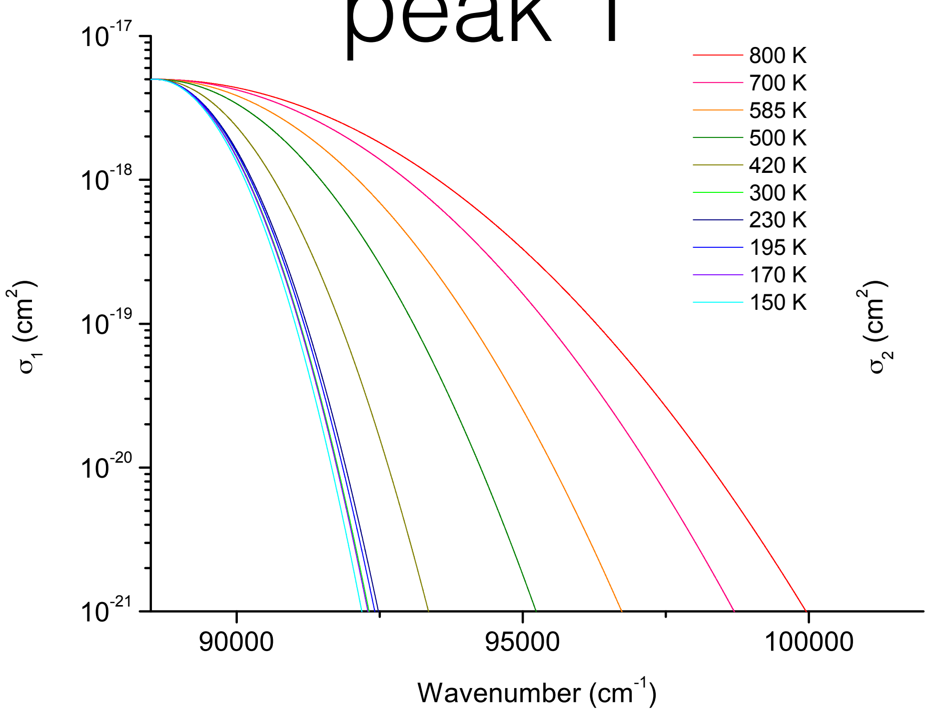
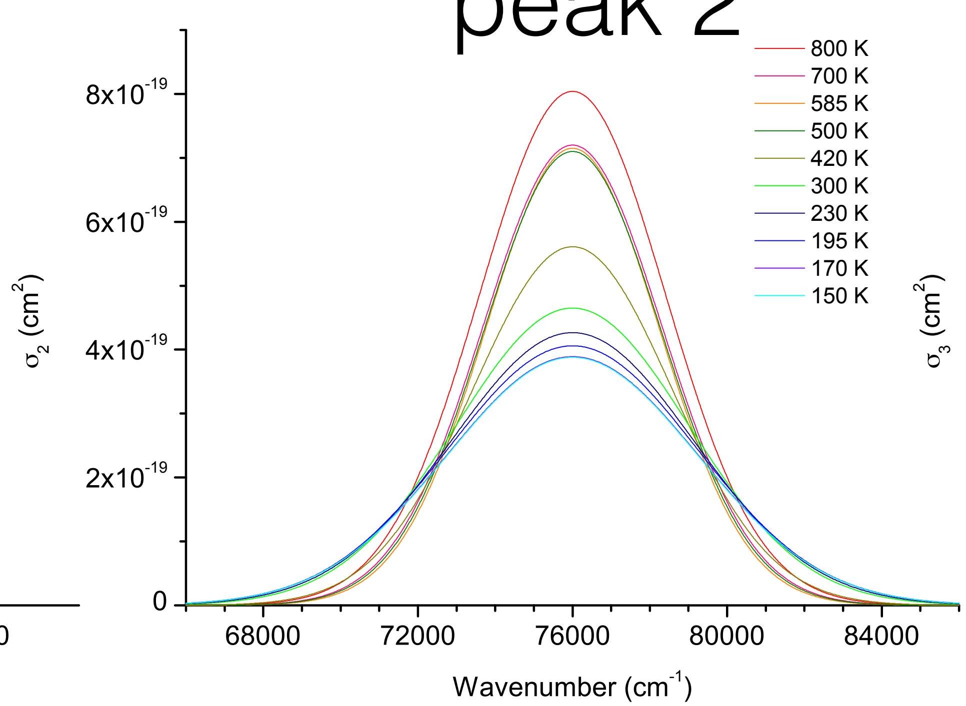
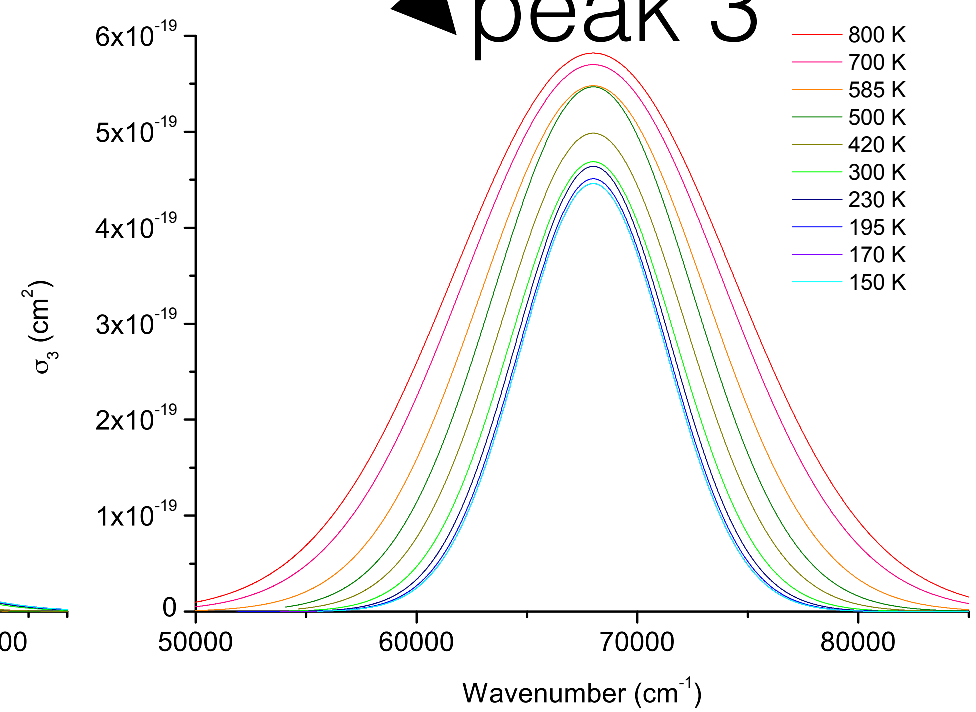
peak 1



peak 2

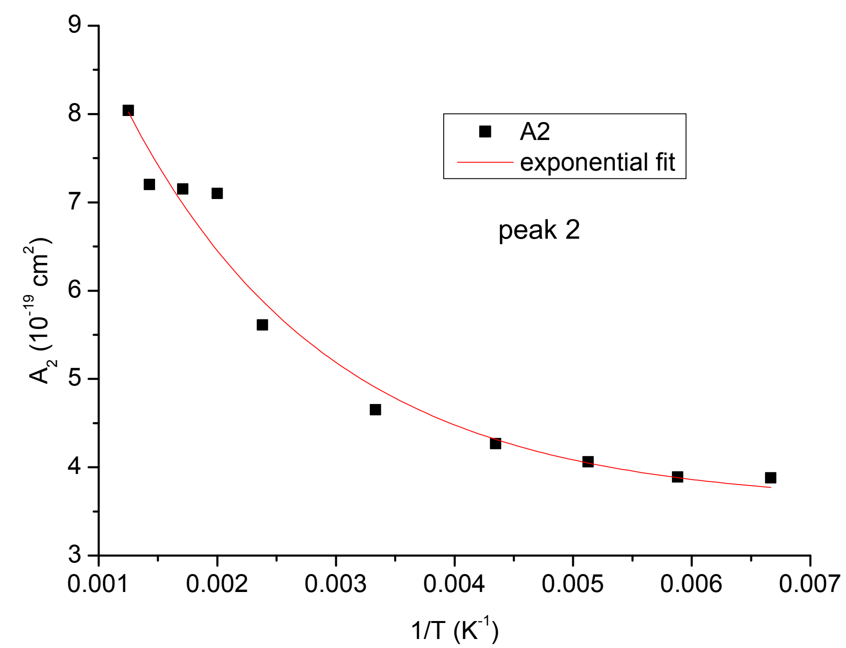


peak 3

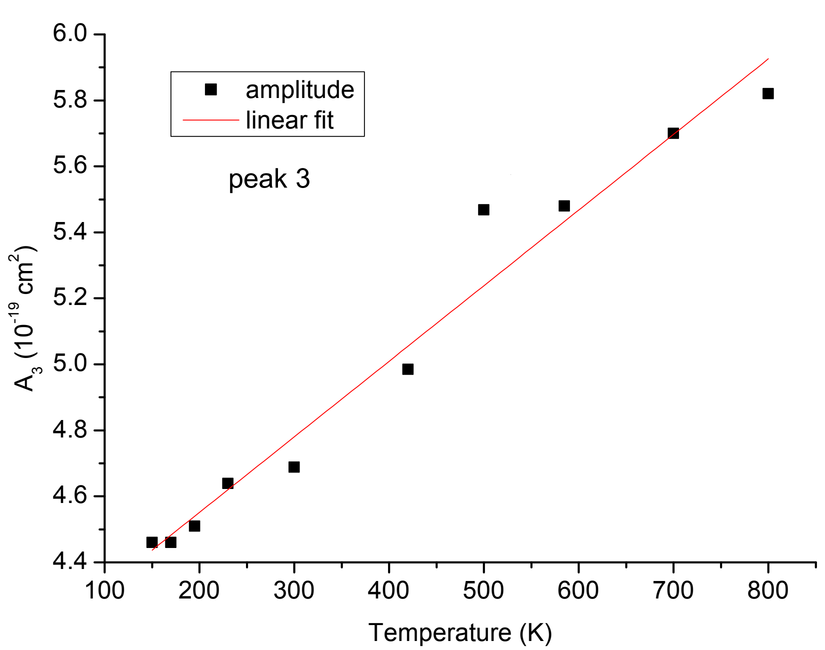


Thermal variation of the continuum

each gaussian function: $\sigma_i(\lambda, T) = \sigma_i(\nu, T) = A_i(T) \times \exp\left(-\frac{(\nu - \nu_{ci})^2}{2 \times s_i(T)^2}\right)$



variation of amplitude with T



amplitude : A_1, $A_2(T)$, $A_3(T)$

spectral width : $s_1(T)$, $s_2(T)$, $s_3(T)$

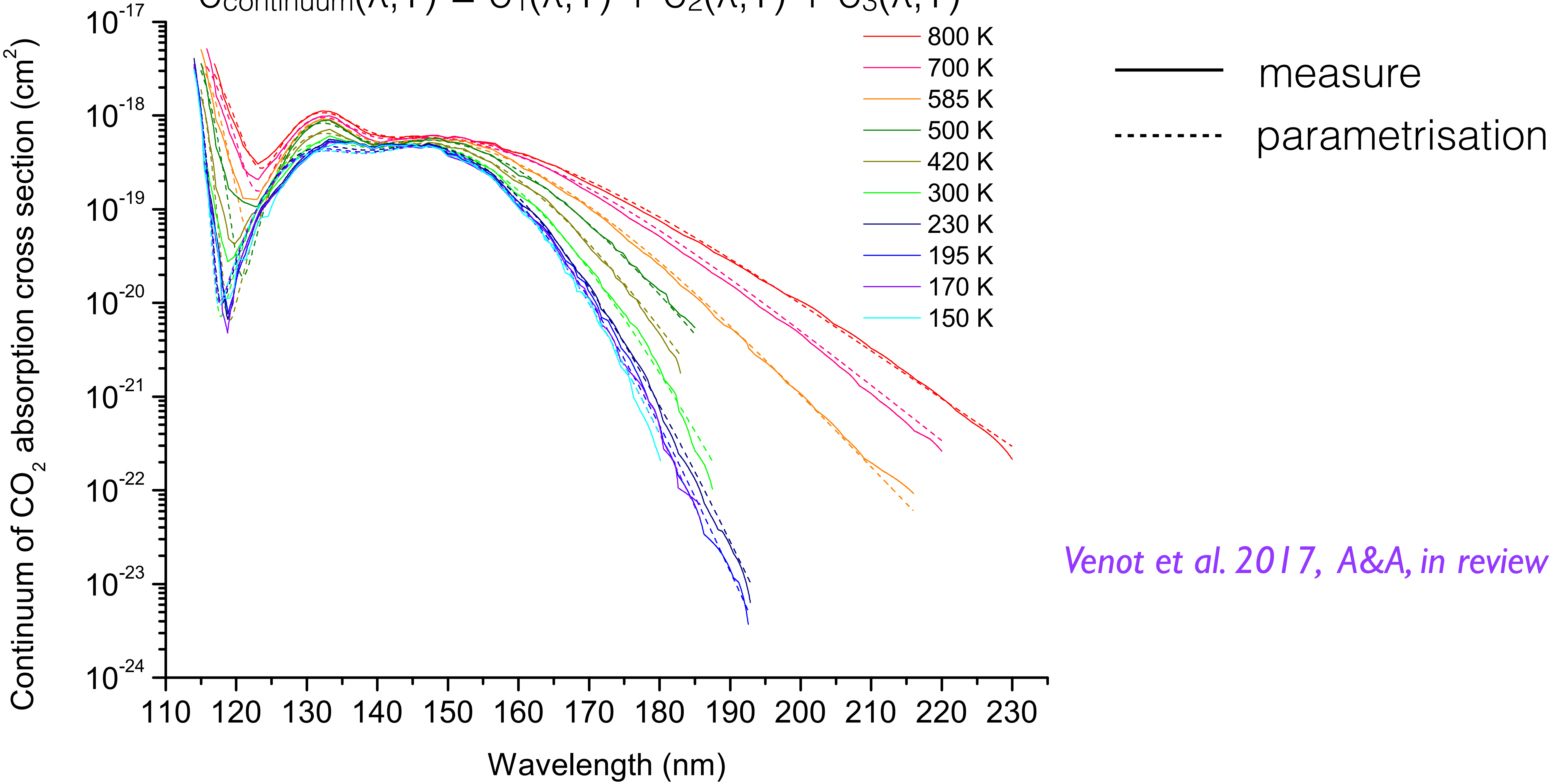
position of the centre (fix) : ν_{c1}, ν_{c2}, ν_{c3}

➡variations of the parameters with temperature fitted by exponential or linear functions

Venot et al. 2017, A&A, in review

Thermal variation of the continuum

$$\sigma_{continuum}(\lambda,T) = \sigma_1(\lambda,T) + \sigma_2(\lambda,T) + \sigma_3(\lambda,T)$$



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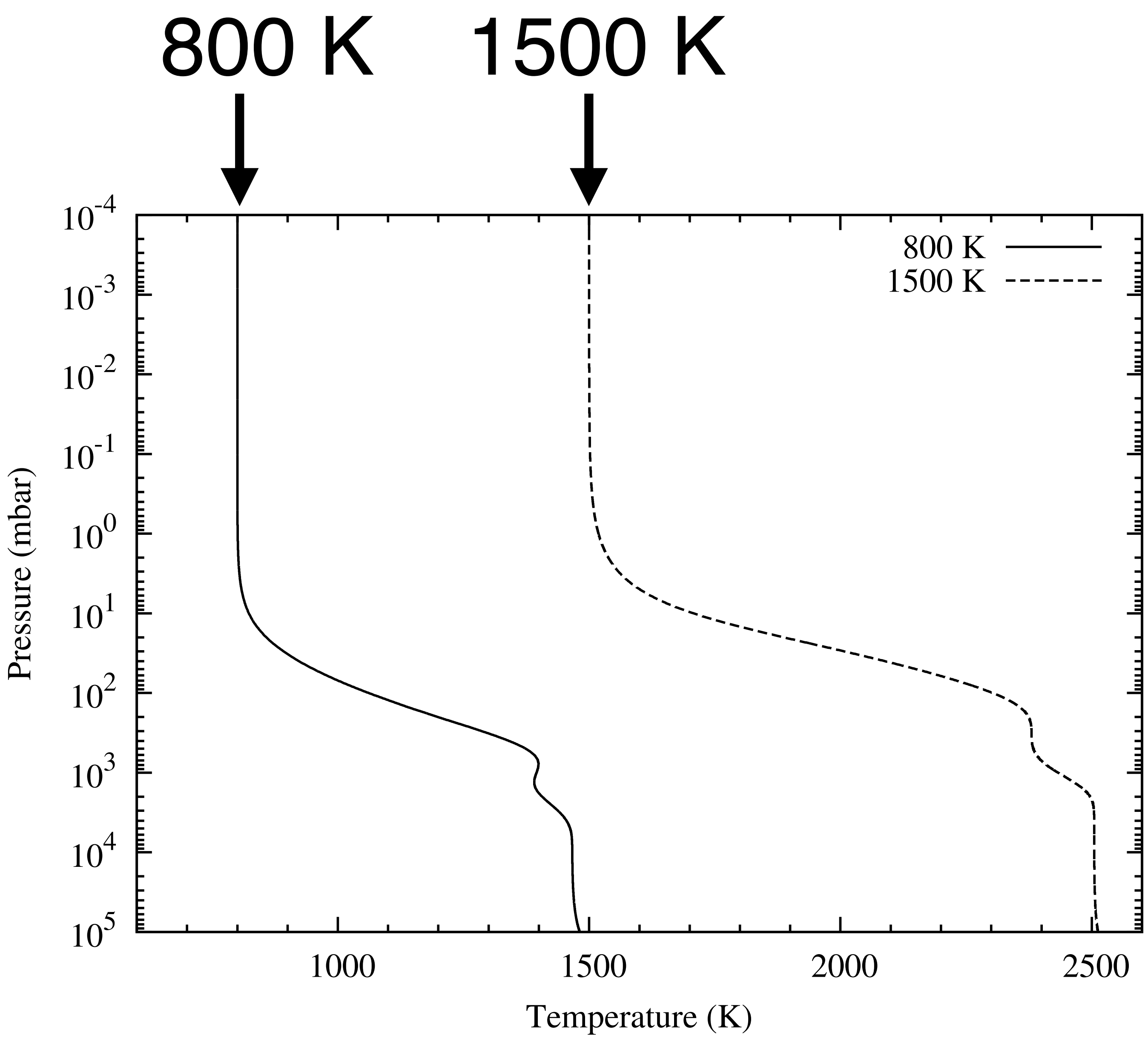
good agreement between experimental data and parametrisation (mean deviation ~15%)

advantage : the parametrisation can be extrapolated at higher temperature !

Effect on exoplanetary atmospheres



modelling using photochemical model
Venot et al. 2012: 105 C/H/O/N species, 1920 reactions + 55 photolysis

2 hot Jupiters with upper atmospheres at 800 K and 1500 K

different CO_2 abs. cross sections :

- σ(300 K), σ(800 K), $\sigma_{continuum}$(800 K)

- σ(300 K), $\sigma_{continuum}$(1500 K)

abs. cross sections of all other species remain unchanged (data available in literature between 300 and 400 K)

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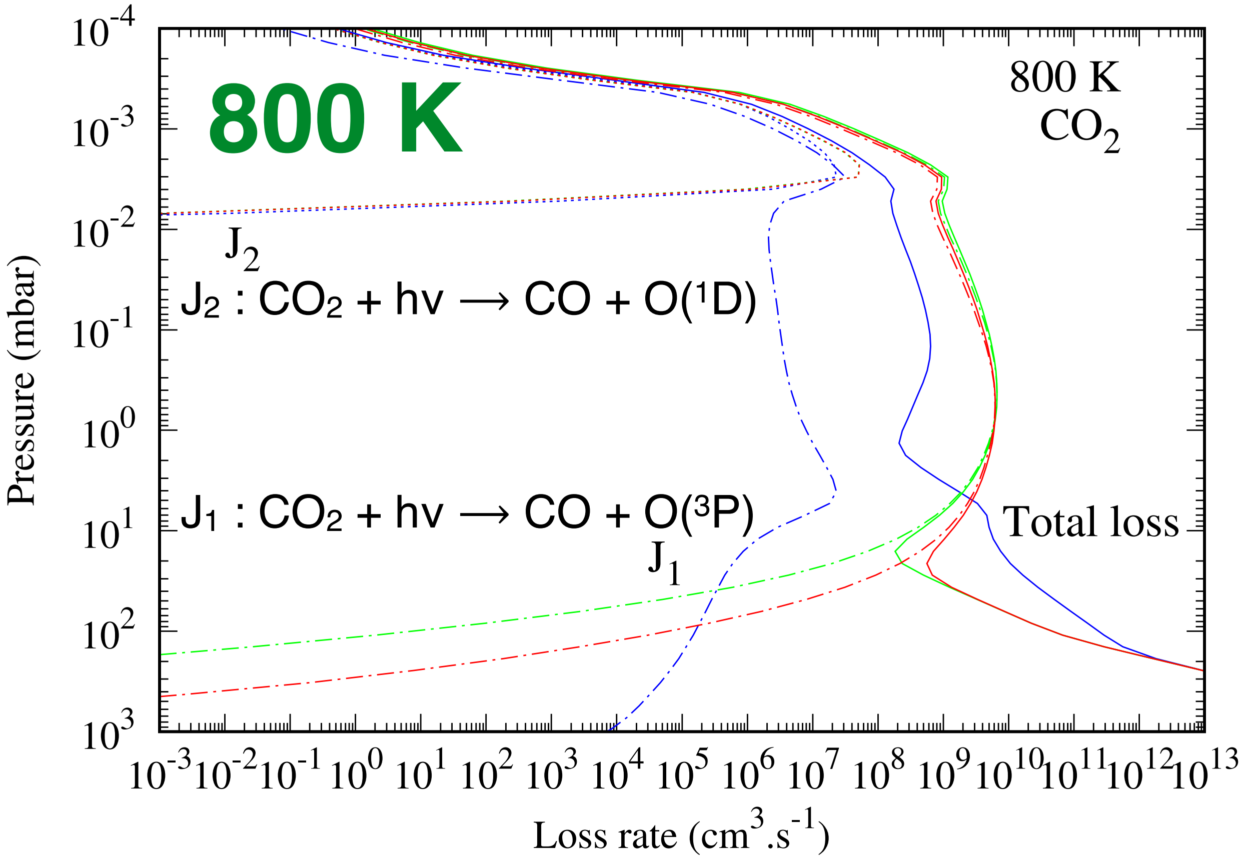
Effect on exoplanetary atmospheres



σ(300 K) σ(800 K) $\sigma_{continuum}$(800 K)

- total loss rate of CO_2 + loss rates due to each photolysis (mainly J_1 x1200 at 0.1mbar)
- J_1 becomes the dominant loss process for P<20mbar: @0.5 mb: 90% vs 0.5%
- quite small difference between σ(800 K) and $\sigma_{continuum}$(800 K)

Venot et al. 2017, A&A, in review

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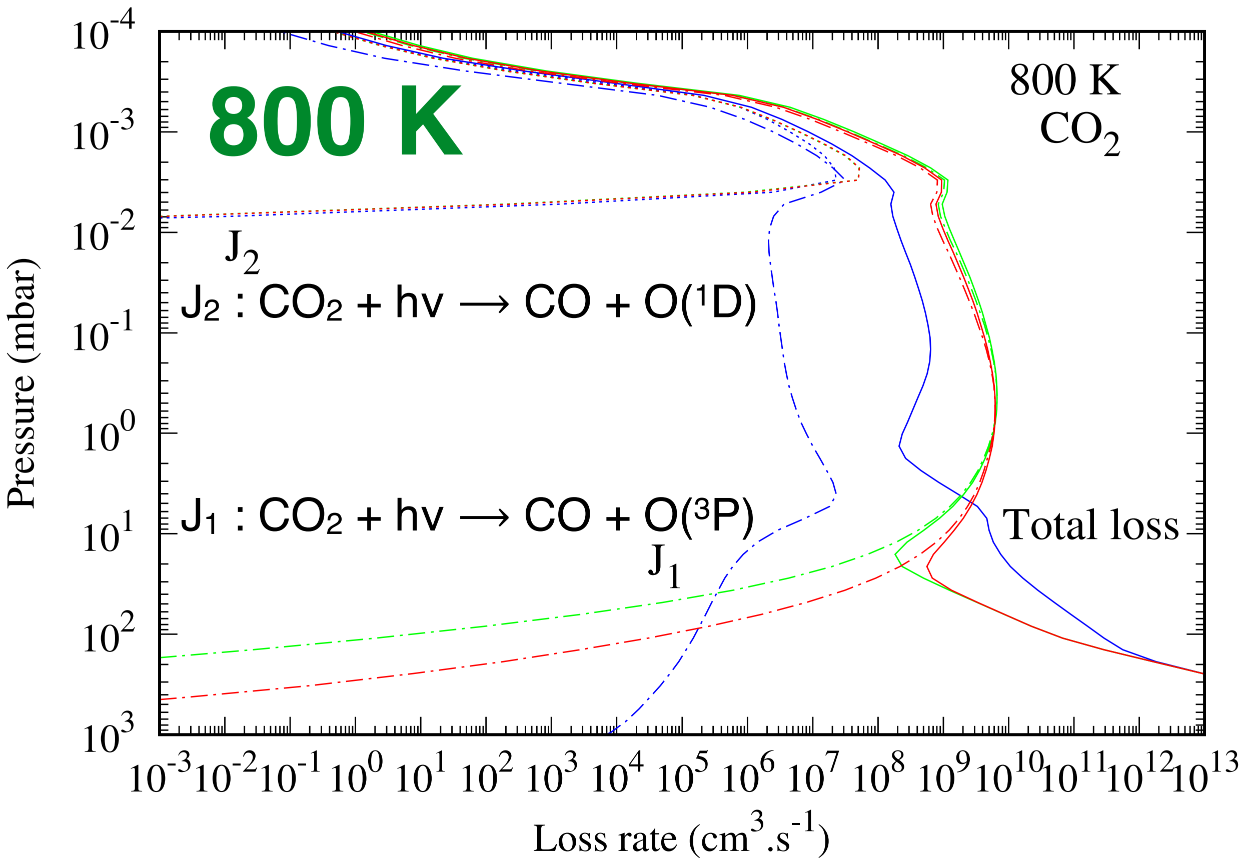

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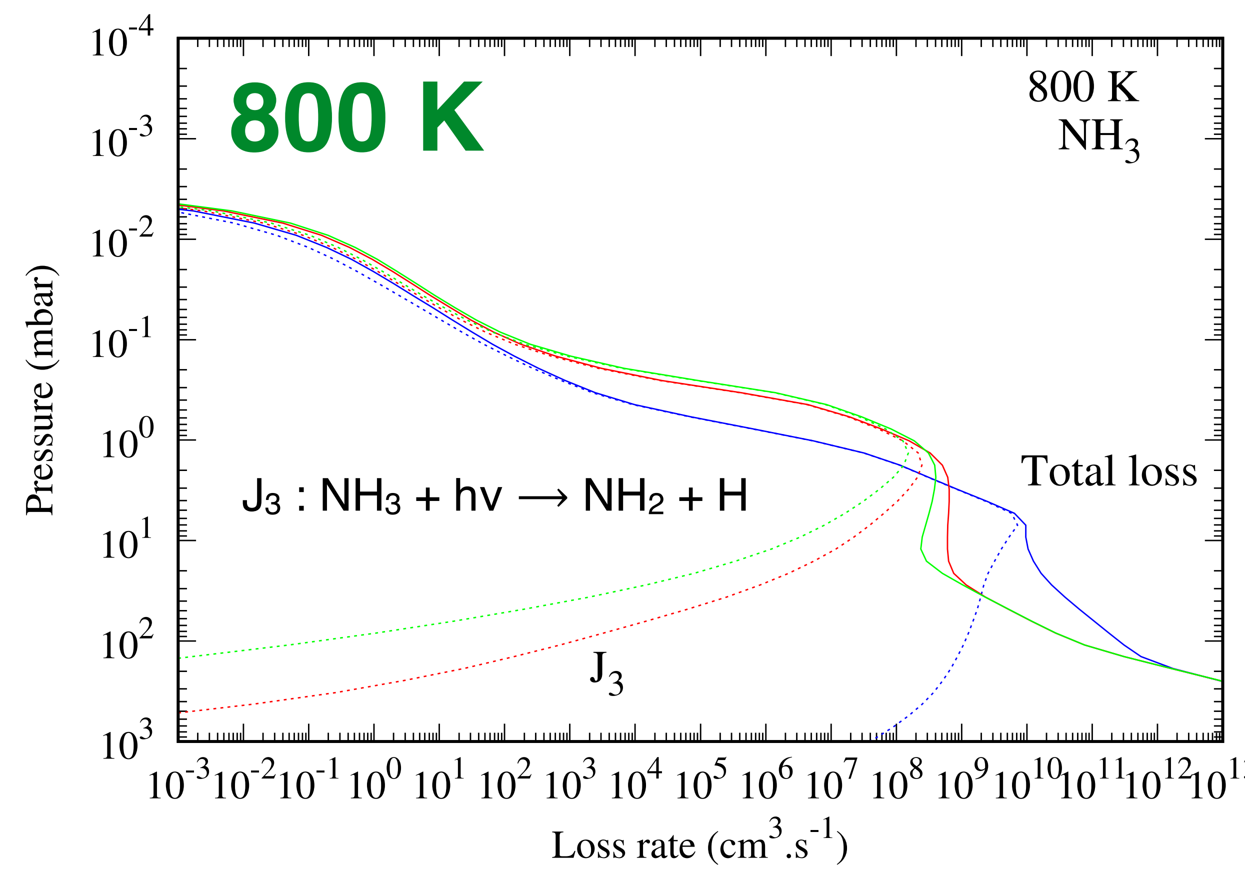
➡ actinic flux is modified

➡ loss rates of other species are affected such as NH_3 (phenomenon of shielding)

➡ maximum of J_3 loss rate lowered and shifted at upper altitude



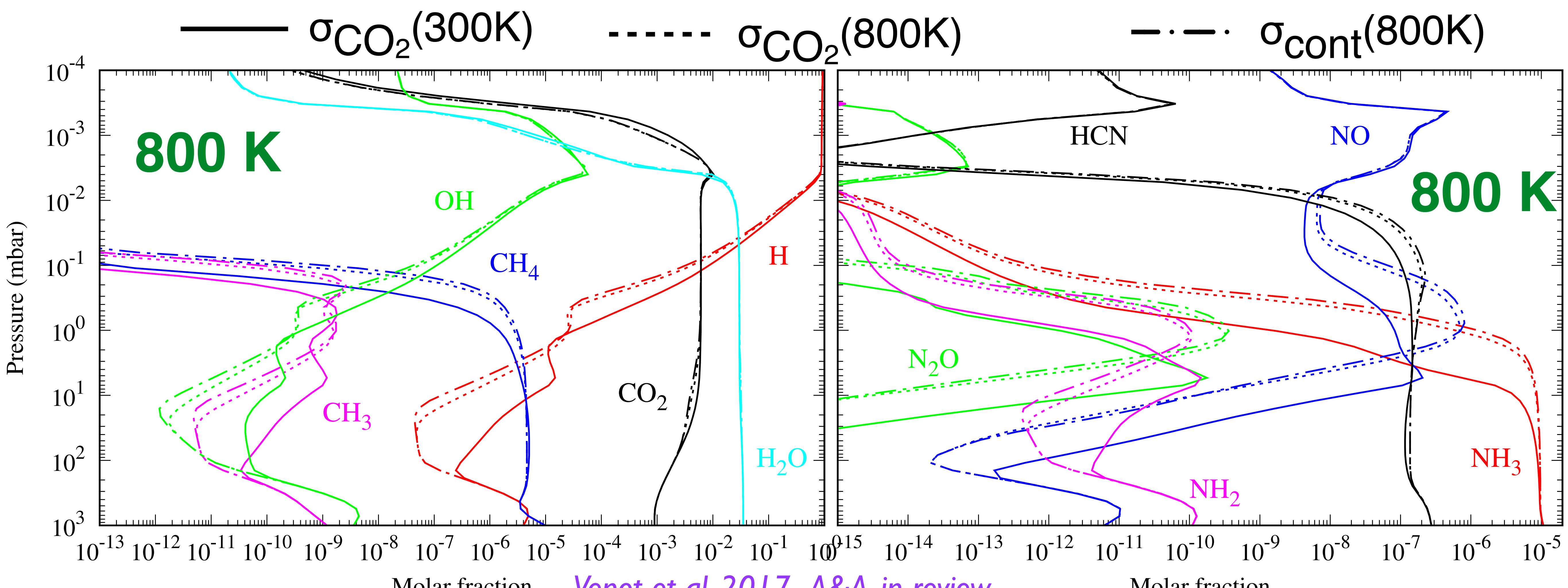
Venot et al. 2017, A&A, in review

Effect on exoplanetary atmospheres

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

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

➡ change of σ_{CO_2} affects many species. Some species see their abundances more modified than the one of CO_2 !



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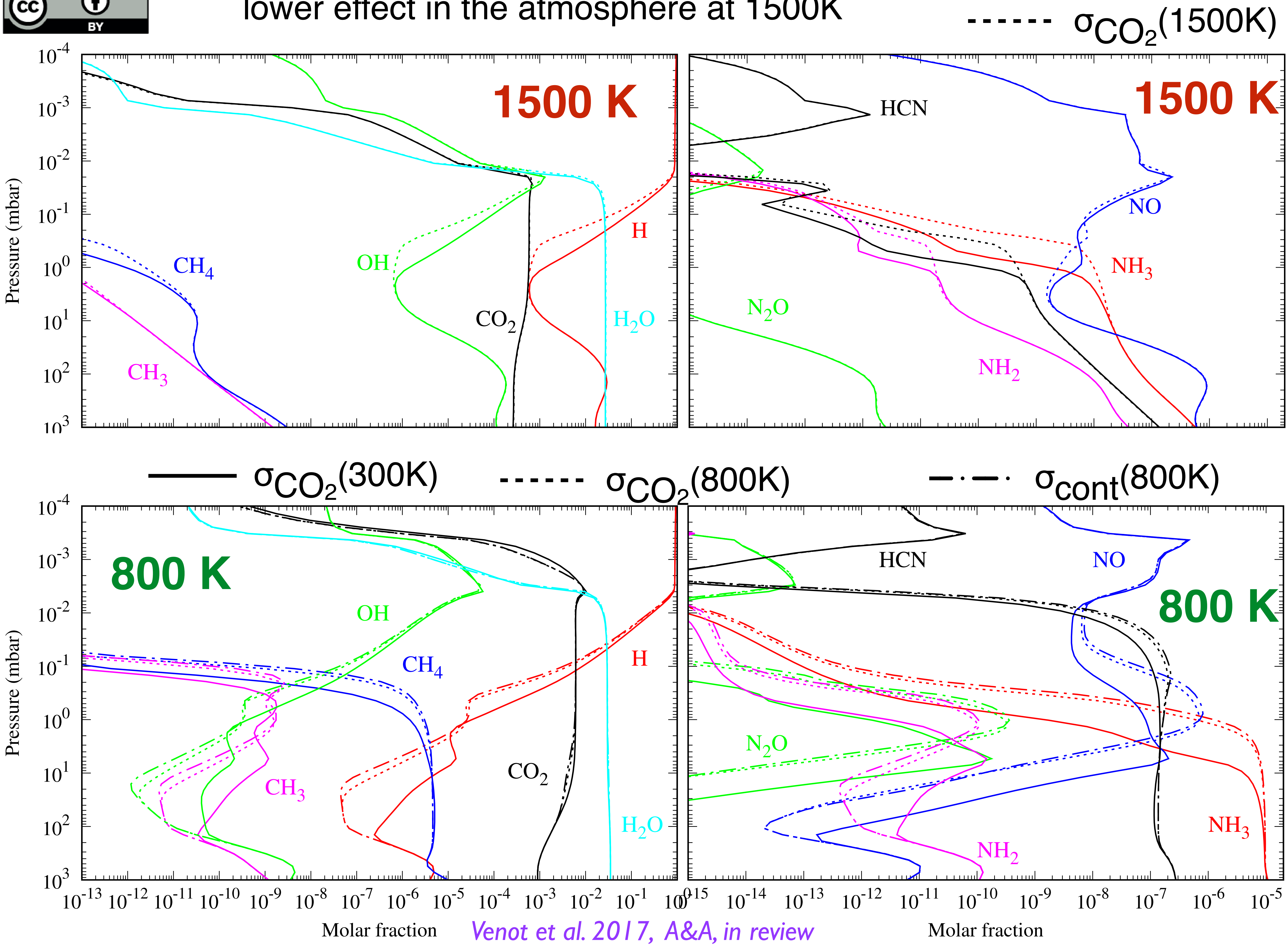
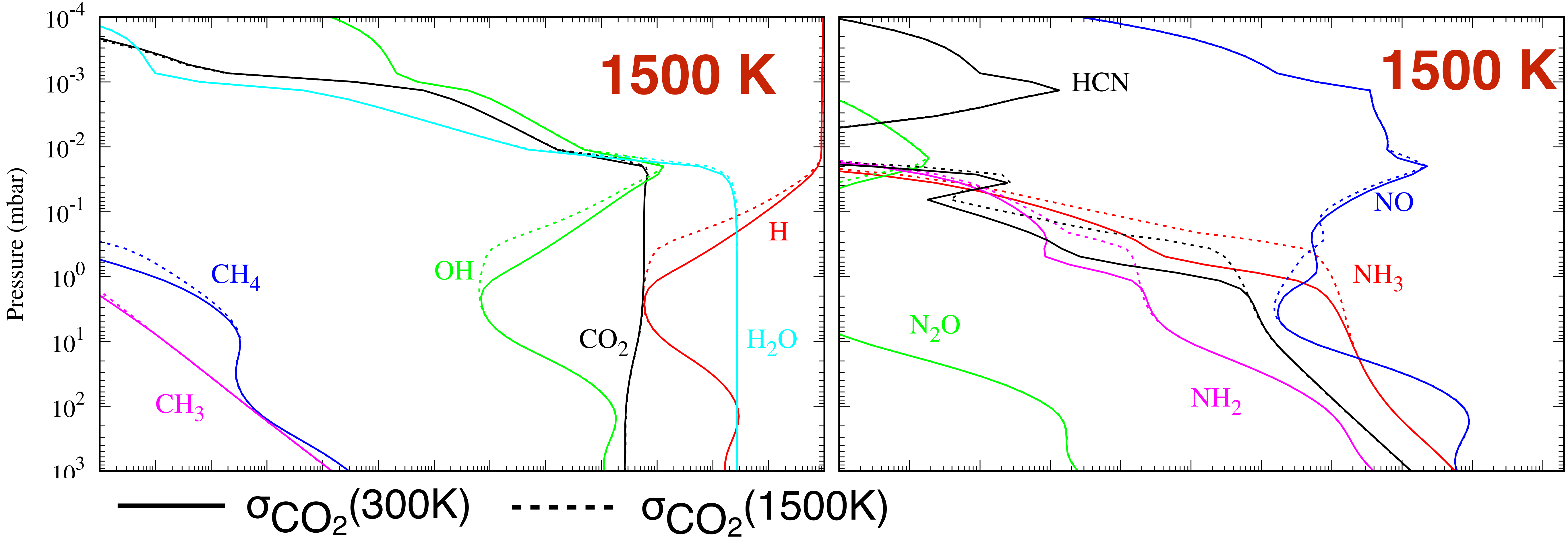
lower effect in the atmosphere at 1500K



Effect on exoplanetary atmospheres



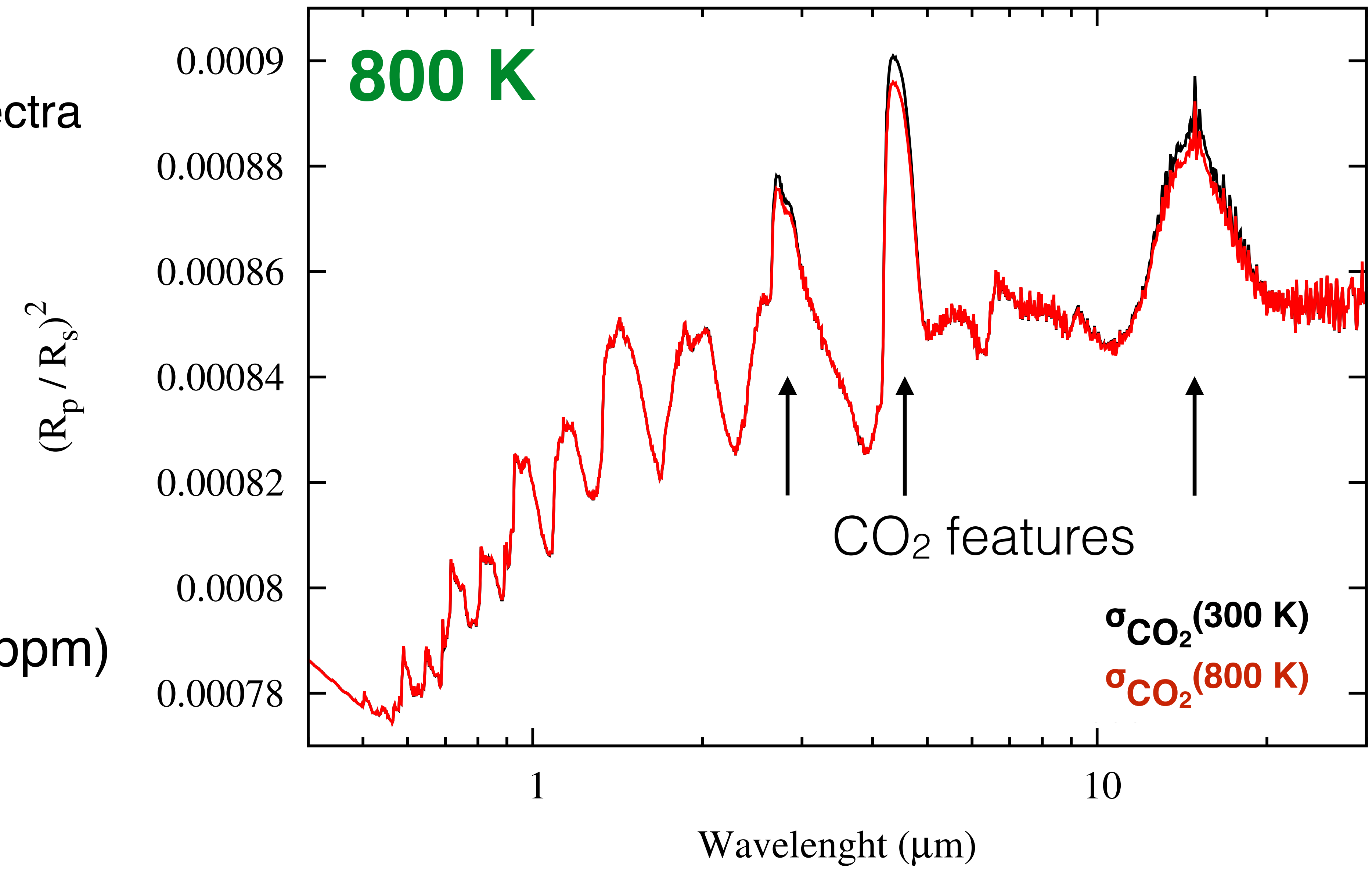
at this high temperature, photodissociation is NOT the dominant destruction process

for CO_2: at 800K : 90% of total loss rate due to photodissociations
at 1500K : 32% (@0.1mbar)

Venot et al. 2017, A&A, in review

Effect on observations

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



differences only in CO_2 absorption bands

moderate deviations (< 5 ppm)
-> not detectable !

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

with hot abs. cross-sections for all species: more deviations on the atmospheric composition and larger effect on observable are expected

Venot et al. 2017, A&A, in review

Key ideas

- UV absorption cross sections at high temperature are lacking

➡ important uncertainty on atmospheric modelling of exoplanets

- experimental setup to perform measurements up to 1200K

- study CO_2 from 115 to 800 K on [115-230] nm - Venot+ 2013, 2017 (in review)

➡ important thermal variations

➡ parametrisation to calculate the continuum at any temperature

➡ analyse of the fine structure in progress

- effect on photodissociation rates and abundances of many molecules (CO_2, NH_3, CH_4, …)

- moderate effect on synthetic IR transmission spectra (< 5 ppm)

- BUT using hot absorption cross section for all species could have more spectacular effect on atmospheric composition and observable…
- a lot of measurements needs to be done and is in progress (NH_3, HCN, C_2H_2)

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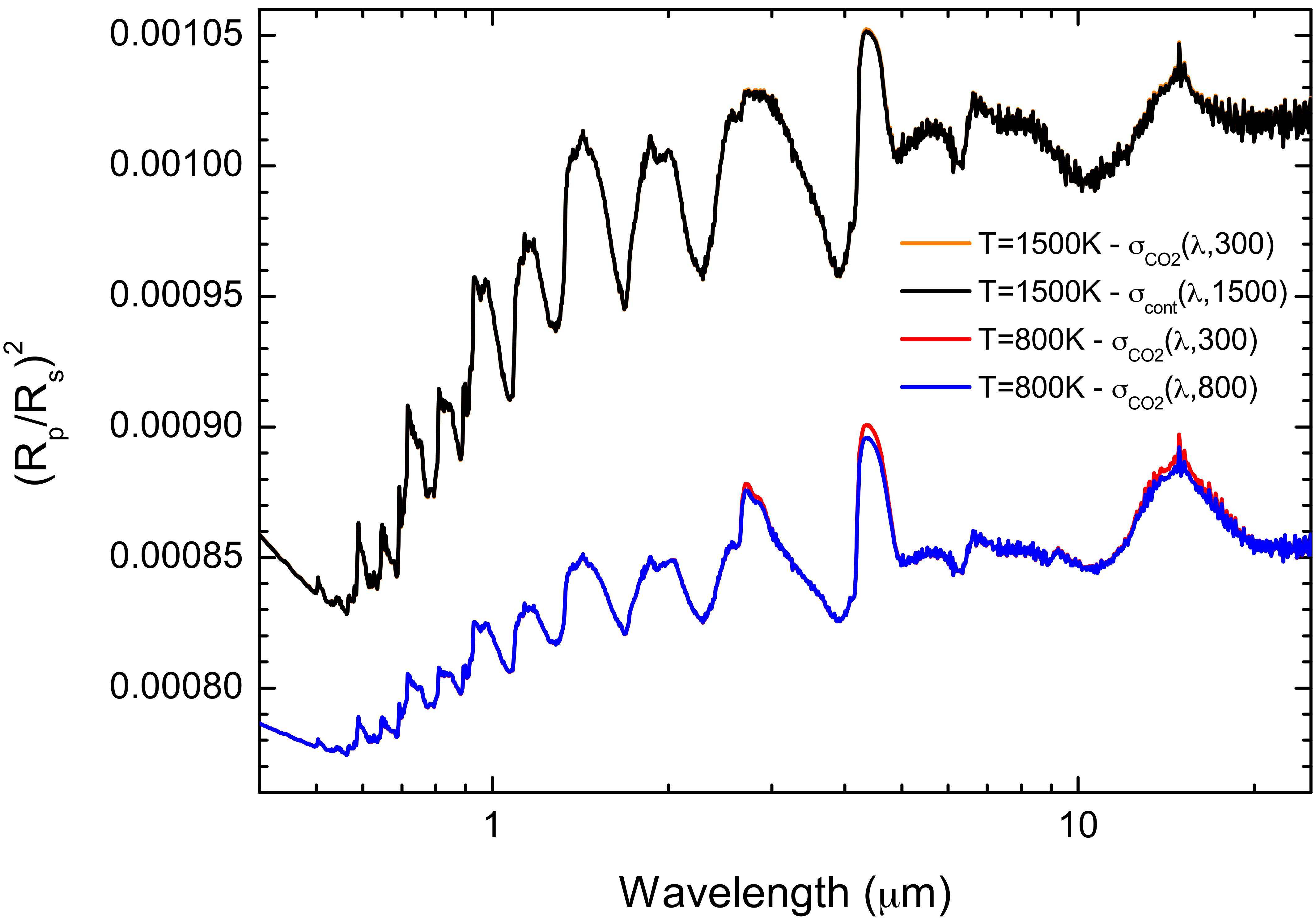
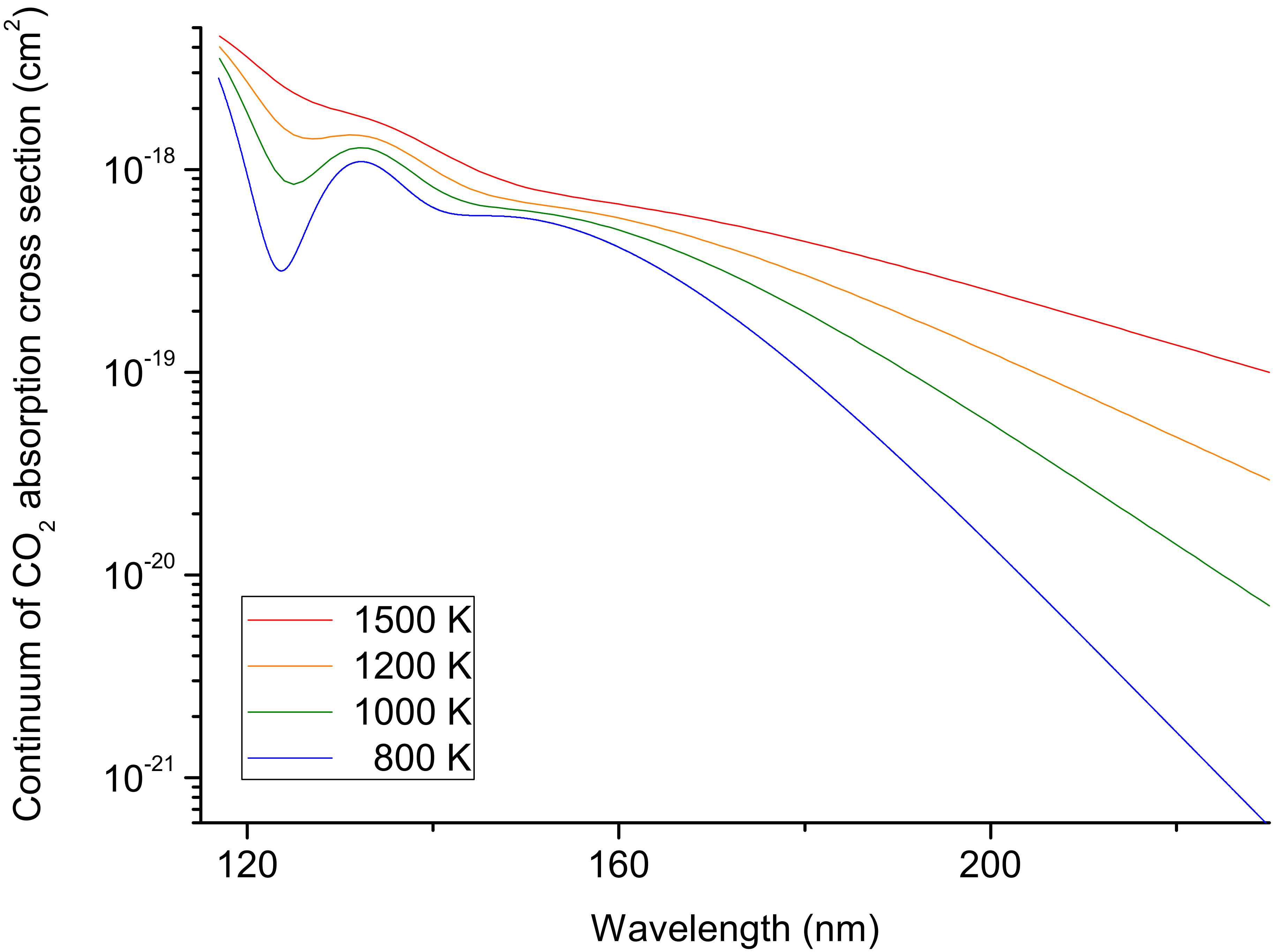
…Thank you for your attention …



0.00105
0.00100
0.00095
0.00090
0.00085
0.00080
$(R_p/R_s)^2$
1
10
Wavelength (μm)
T=1500K - $\sigma_{CO2}(\lambda,300)$
T=1500K - $\sigma_{cont}(\lambda,1500)$
T=800K - $\sigma_{CO2}(\lambda,300)$
T=800K - $\sigma_{CO2}(\lambda,800)$

Extrapolation at higher temperature



Penetration of stellar flux