Hot molecular emission in circumstellar disk gas as a diagnostic of radiative and mechanical heating

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Prebiotic Molecules in Space and Origins of Life on Earth
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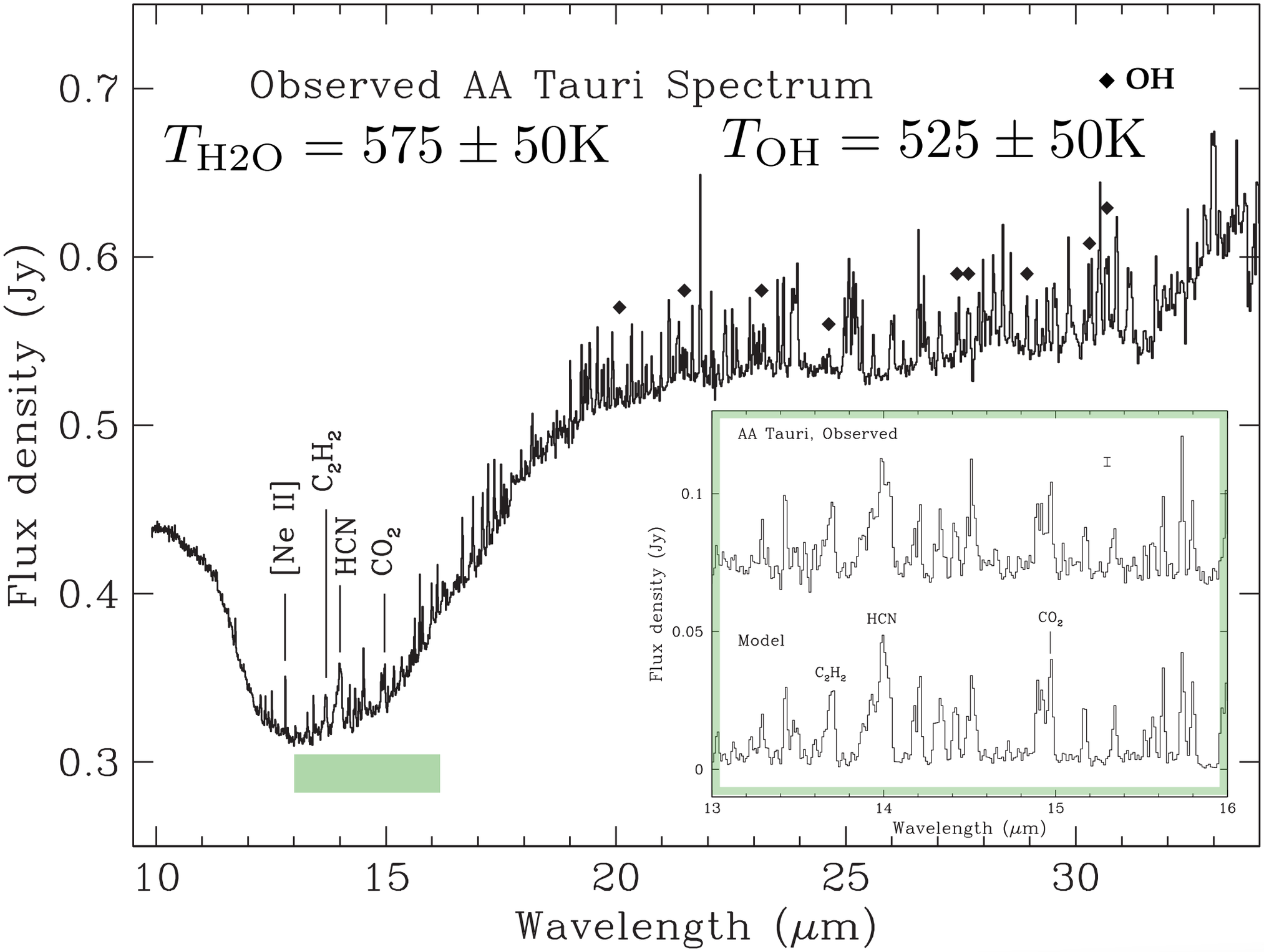
Warm molecular emission

Carr & Najita (2008)

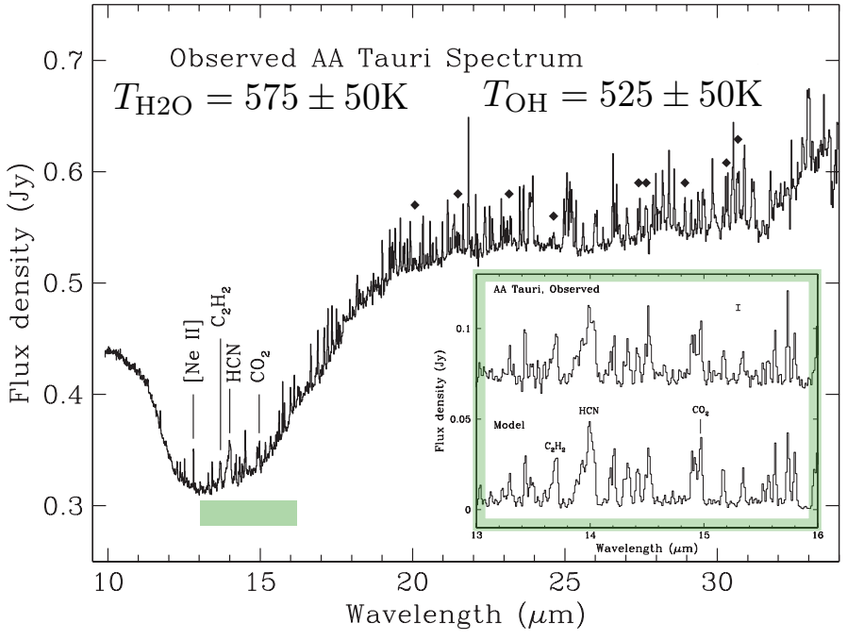


Warm molecular emission

Carr & Najita (2008)

Molecule	T (K)	N (10^{16} cm^{-2})	R* (AU)	Abundance to CO
H_2O	575 ± 50	65 ± 24	2.1 ± 0.1	1.3
OH	525 ± 50	8.1 ± 5.2	2.2 ± 0.1	0.18
HCN	650 ± 100	6.5 ± 3.3	0.60 ± 0.05	0.13
C_2H_2	650 ± 150	0.81 ± 0.32	0.60†	0.016
CO_2	350 ± 100	0.2 –13	1.2 ± 0.2	0.004 – 0.26
CO	900 ± 100	49 ± 16	0.7 ± 0.1	1.0

*The equivalent radius for the emitting area A ($R = [A/\pi]^{1/2}$). †Area was set to that derived for HCN.



Carr+ (2004)
Carr & Najita (2011)
Pascucci+ (2009)
Pontoppidan+ (2010a, 2010b)
Salyk+ (2011)
Najita+ (2013)

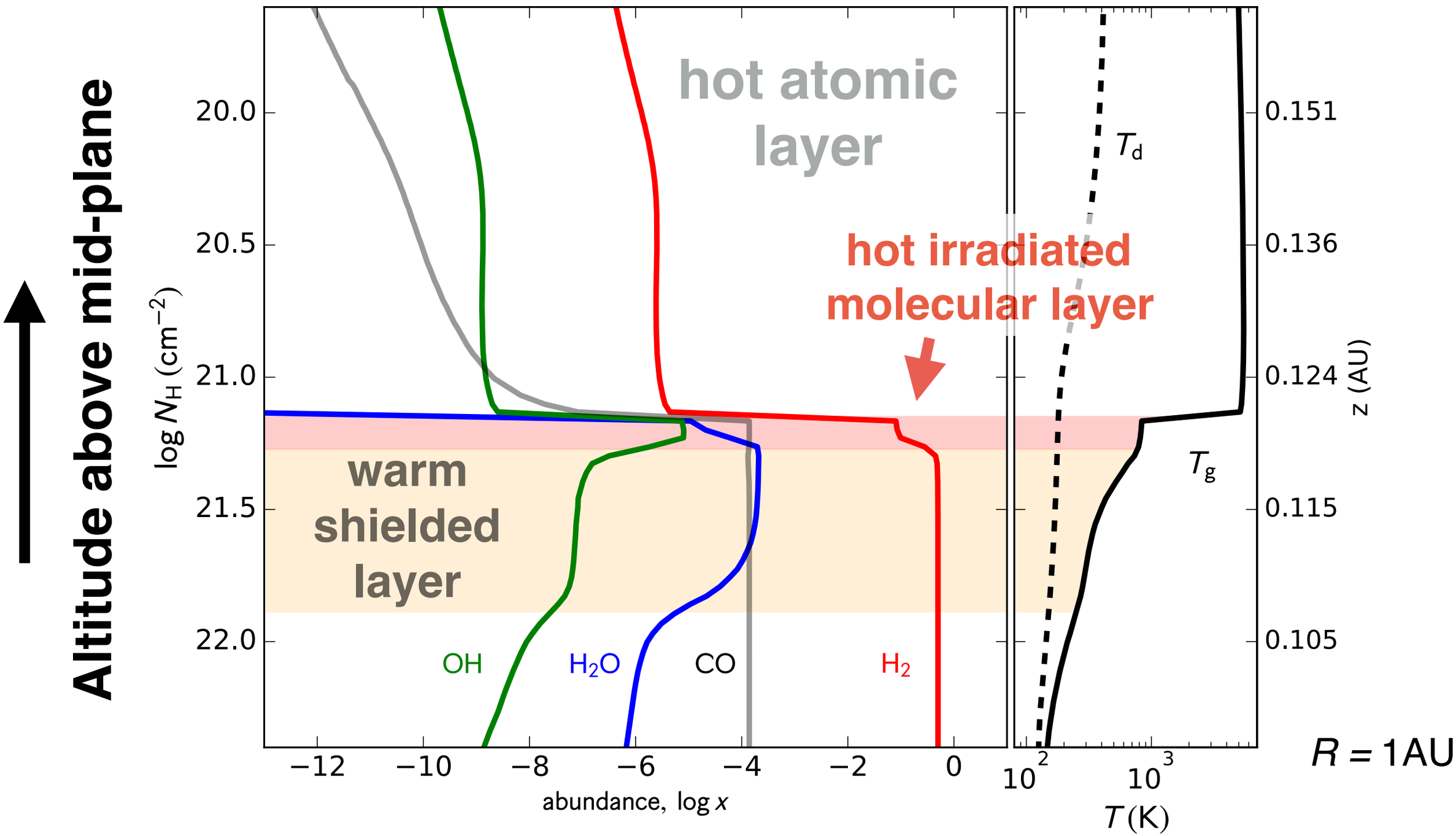
Thermal-chemical model of disk gas

- **X-ray, FUV & Ly-a irradiated gas in circumstellar disk**
- **Dust: H_2 formation, FUV opacity, and thermal accommodation**
- **~120 chemical species, ~1200 reactions**
- **Time-dependent, non-equilibrium chemical kinetics**
- **Detailed FUV photo-rates & heating ("radiation transfer")**
  - **local FUV field, molecular cross sections, treat self-shielding**
- **Python codebase:**
  - **Kinetics pre-processor of chemical rate equations**
  - **Modules for disk `structure`, `heating`, `cooling` & `FUV`**
  - **Wrapper to C-library for `LSODE` in `ODEPACK`**

Najita & Ádámkovics (2017)
Ádámkovics, Najita & Glassgold (2016)
Ádámkovics, Glassgold, & Najita (2014)
Ádámkovics, Glassgold, & Meijerink (2011)
Glassgold, Meijerink, & Najita (2009)
Glassgold, Najita, & Igea (2004)
Glassgold, Najita, & Igea (1997)

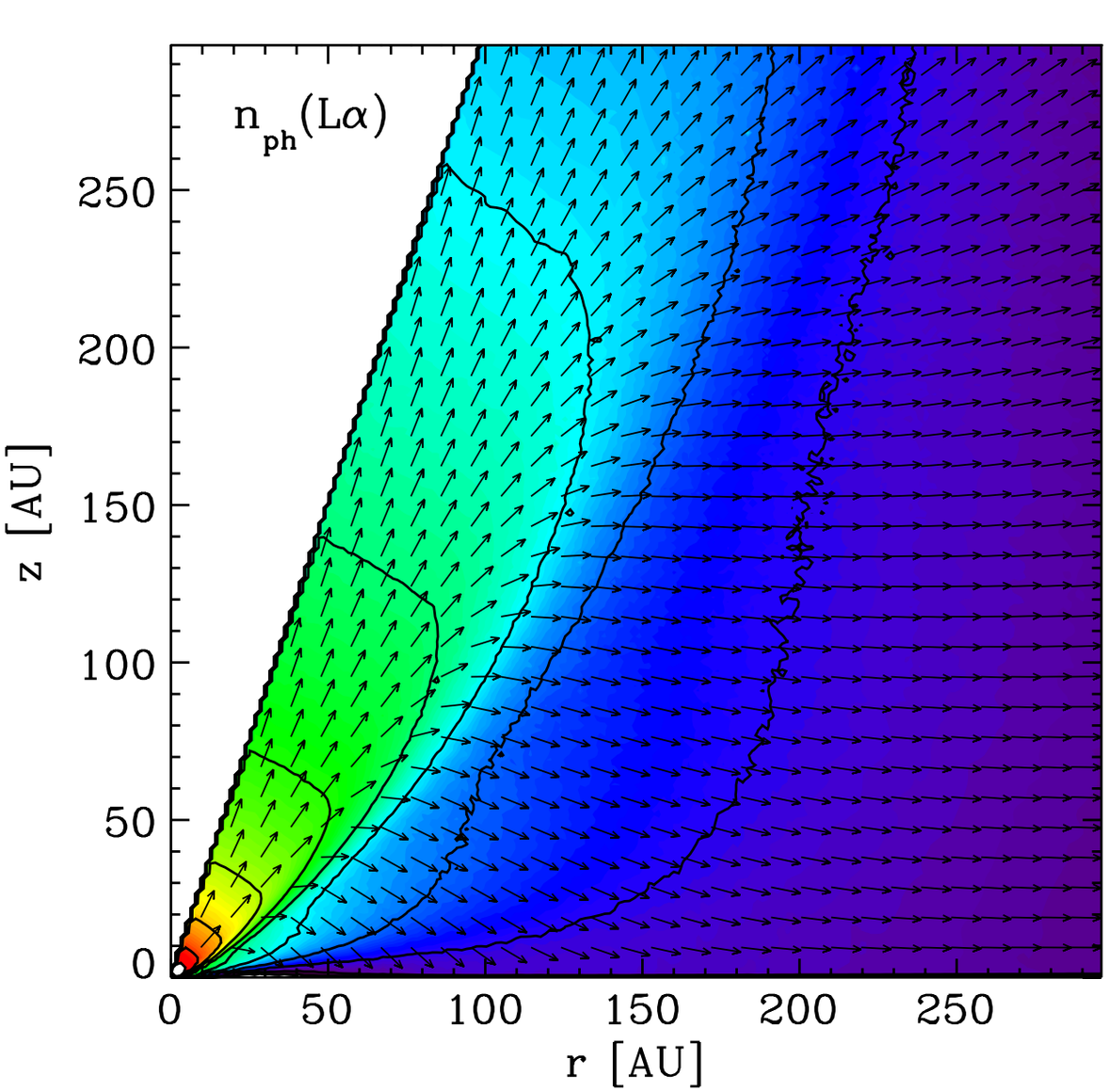
Layered disk gas

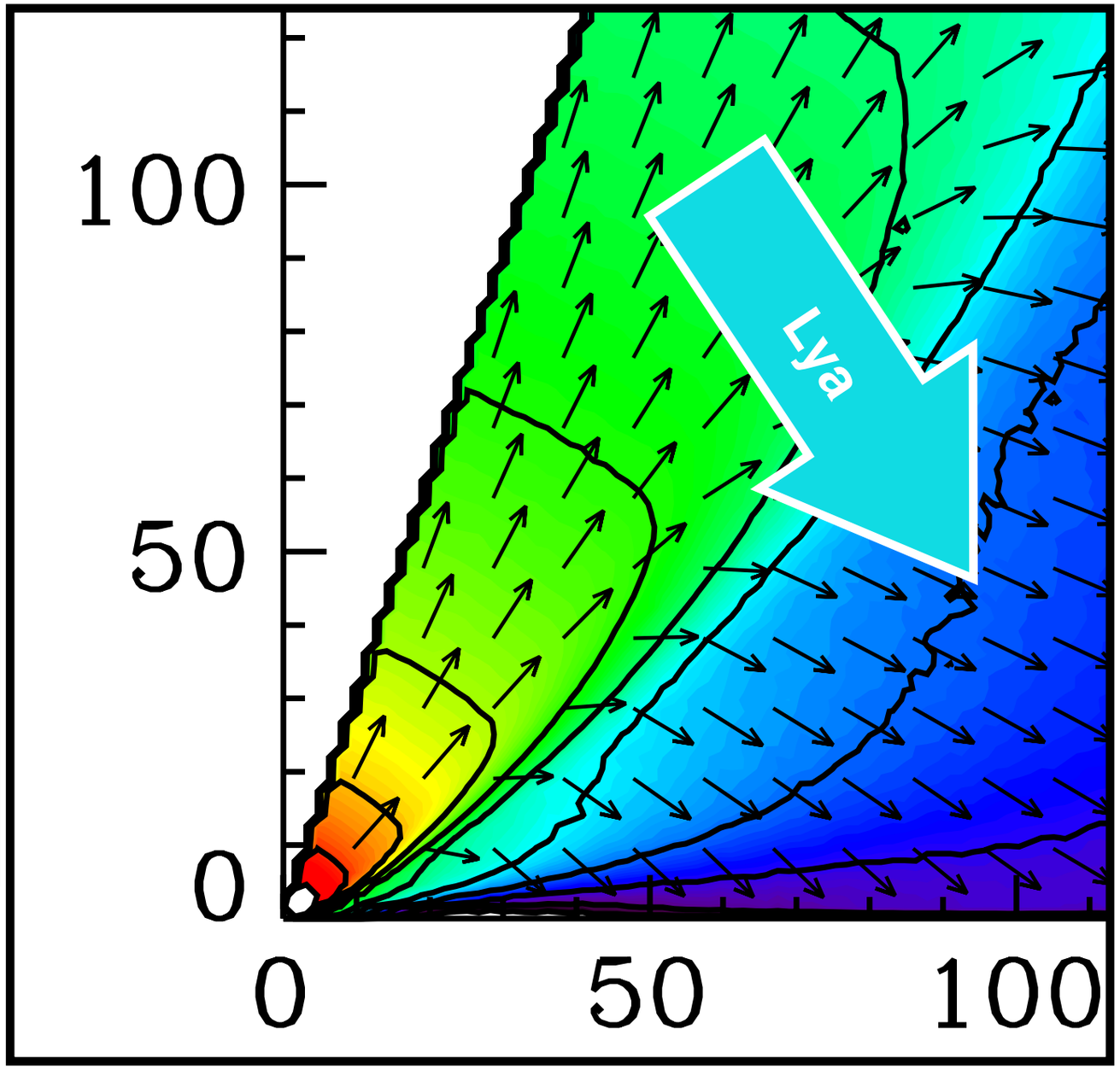
Ádámkovics, Glassgold, & Najita (2014)



FUV radiative transfer: *scattered Lya*

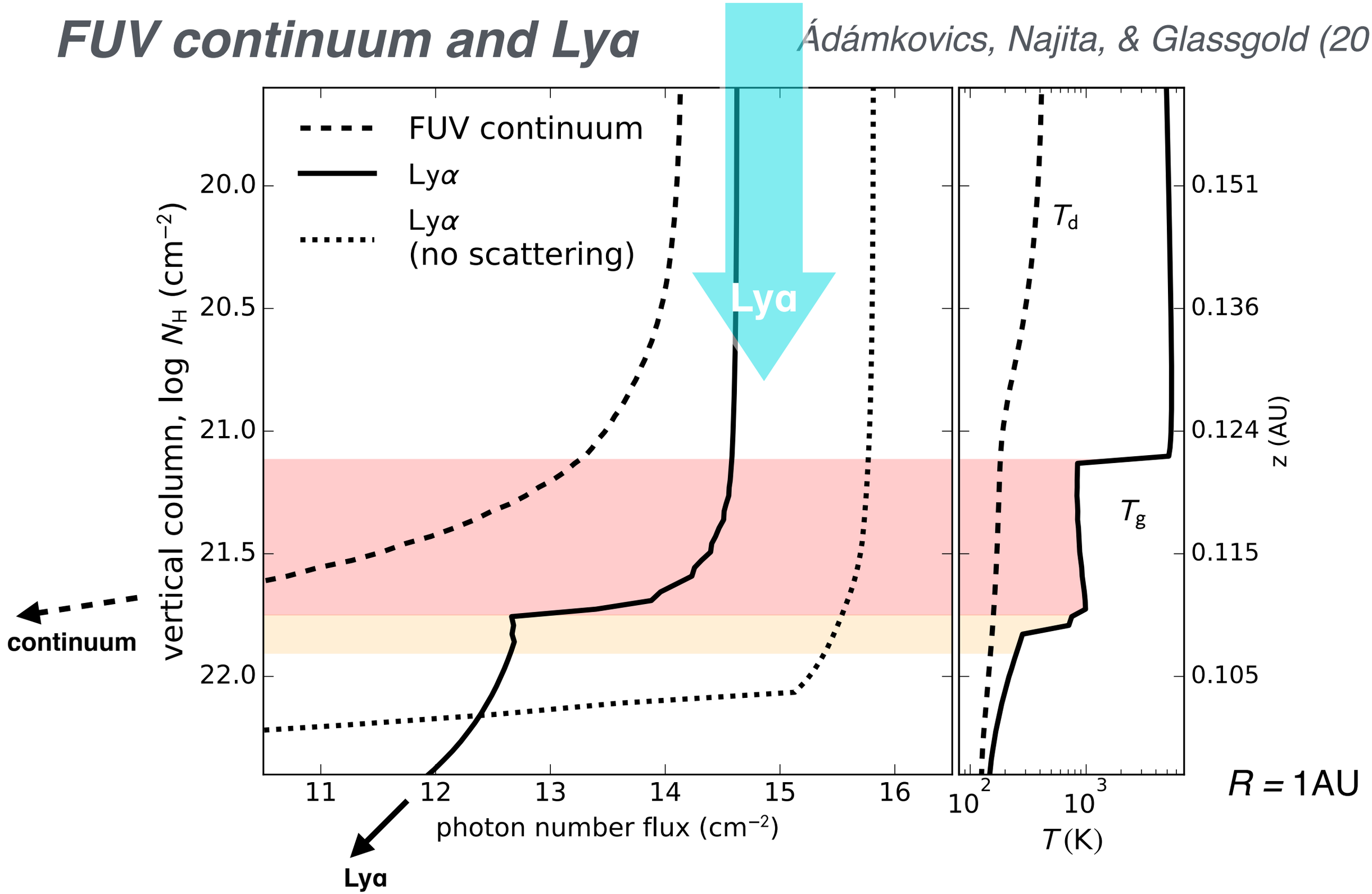
Bethell & Bergin (2011)





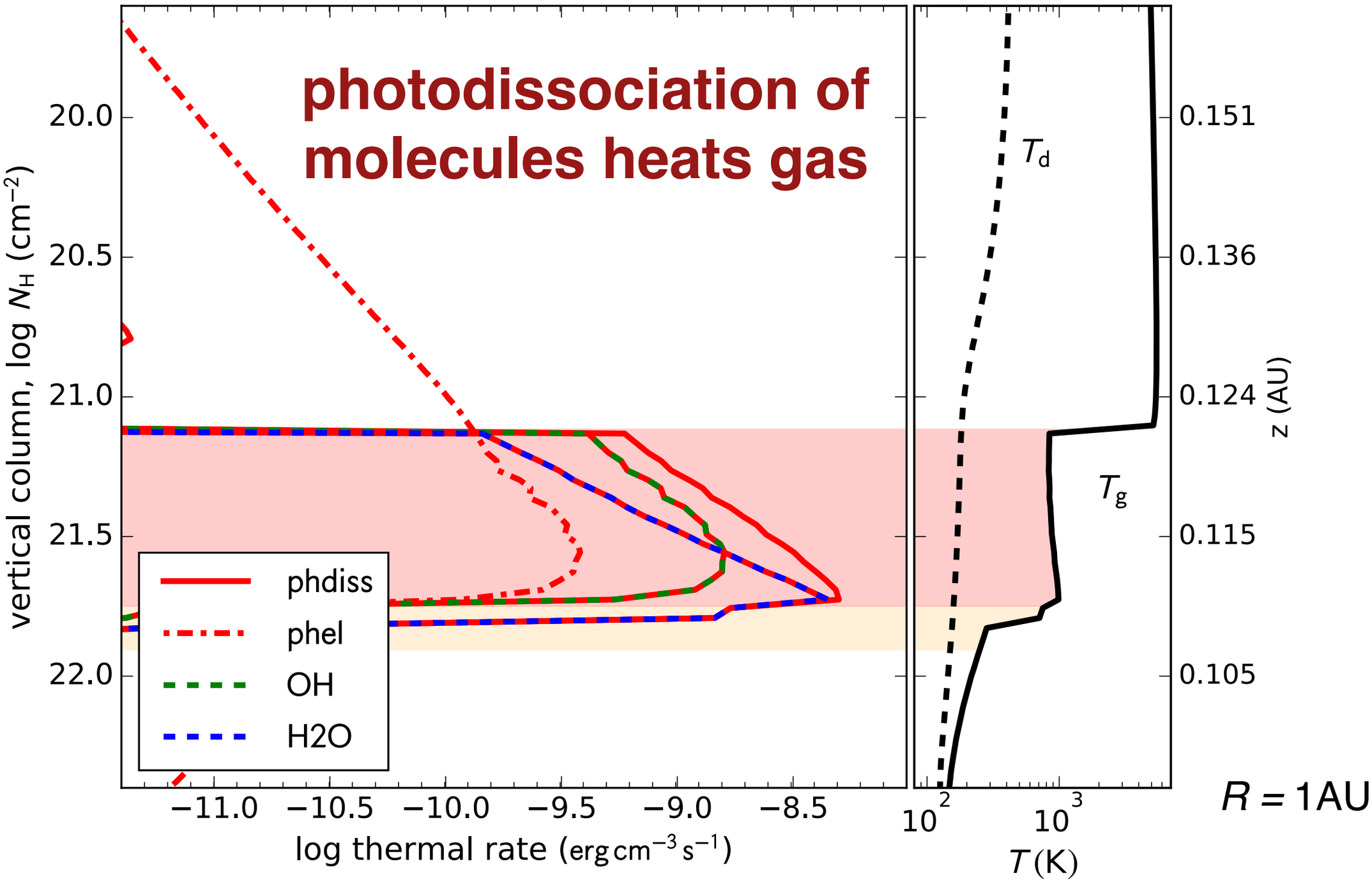
FUV continuum and Lyα

Ádámkovics, Najita, & Glassgold (2016)



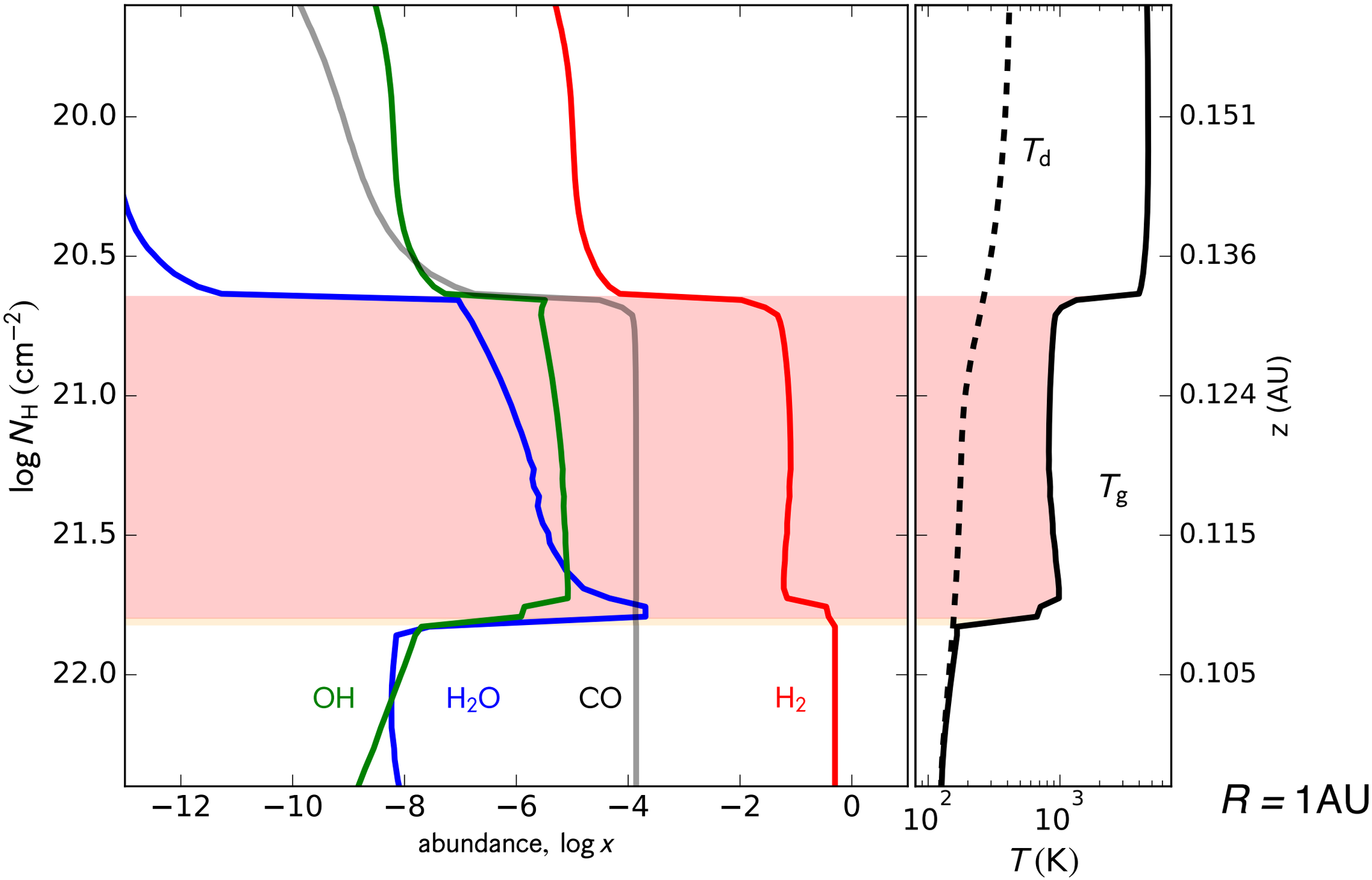
Photochemical heating

Glassgold & Najita (2015)



Hot molecular gas

Ádámkovics, Najita, & Glassgold (2016)

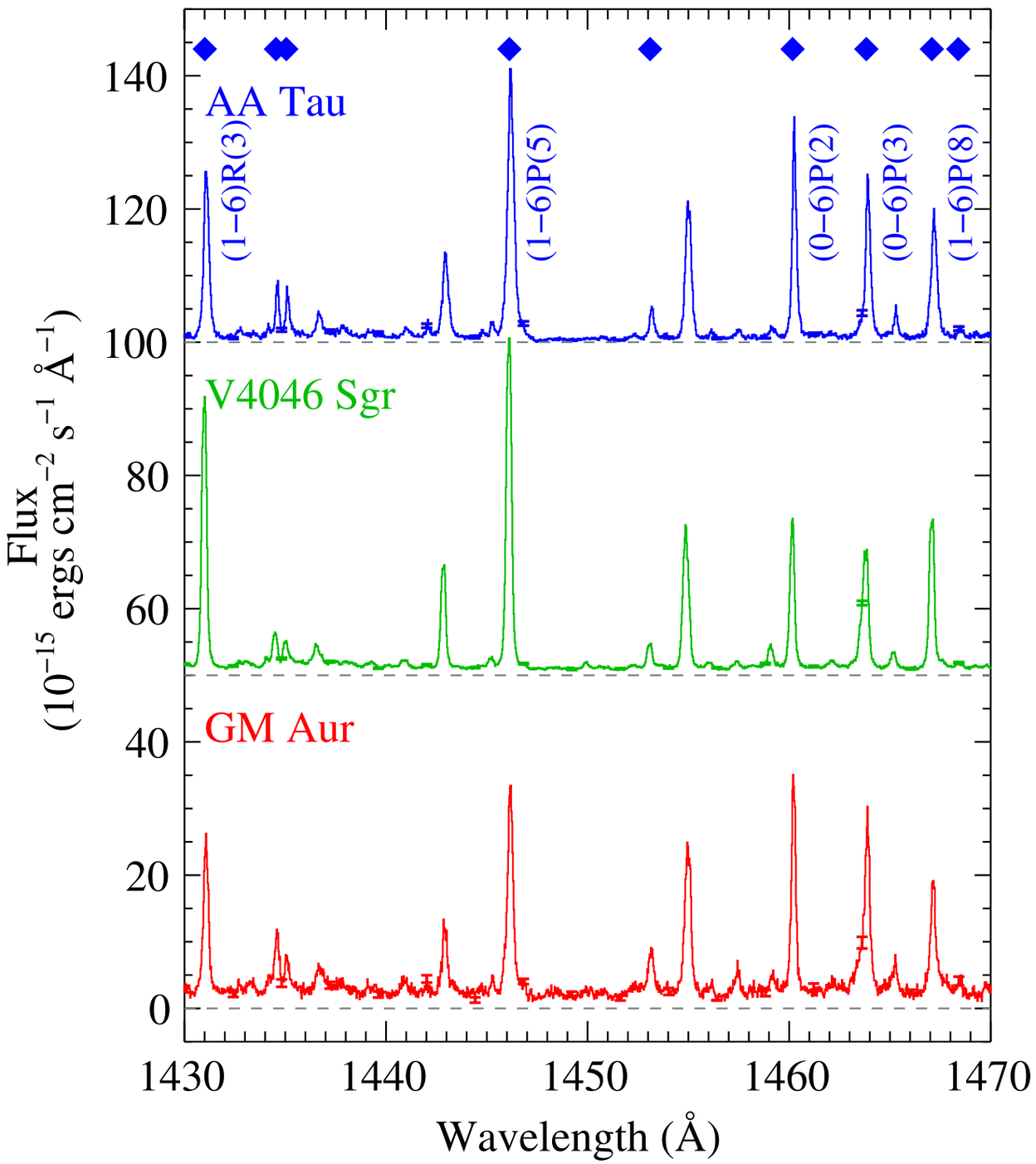


Fluorescent H_2 Emisssion

Ardila et al., 2002; Herczeg et al., 2002

France+ (2012)

- **H_2 excitation ~ 2500 K**
- **Hot H_2 pumped by Lyα**
- **emitting region < 0.5 AU**



H2 Fluorescent Emission

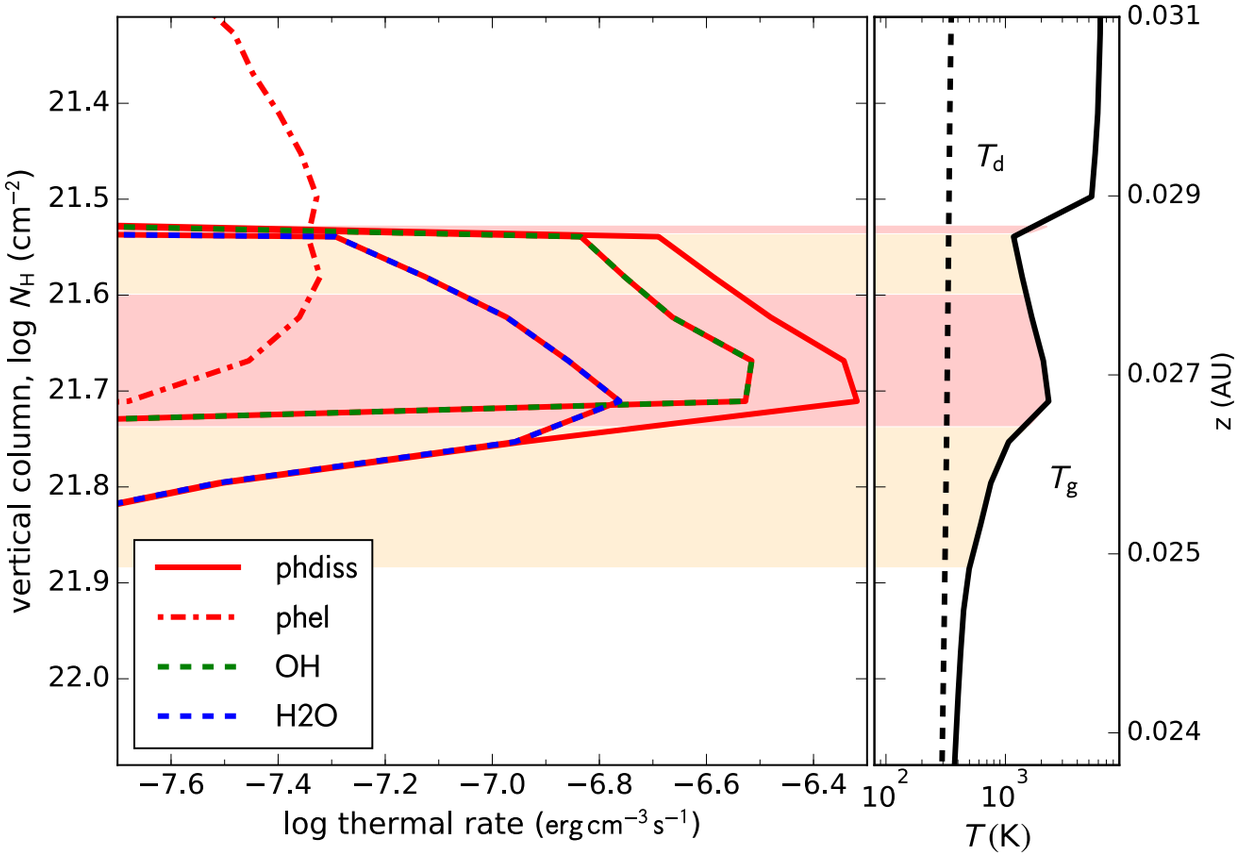
France+ (2012)

Target	$\mathrm{FWHM}_{[1,7]}$[a] ($\mathrm{km\,s^{-1}}$)	$\langle R_{\mathrm{H_2}} \rangle_{[1,7]}$[a] (AU)
AA Tau	62 ± 4	0.69 ± 0.08
AK Sco	57 ± 35	1.25 ± 0.77
BP Tau	70 ± 6	0.13 ± 0.02
CS Cha	18 ± 7	9.00 ± 4.55
CV Cha	22 ± 30	4.75 ± 3.88
DE Tau	55 ± 6	0.23 ± 0.04
DF Tau A[f]	64 ± 7	0.16 ± 0.03
DK Tau A[f]	55 ± 2	0.24 ± 0.02
DM Tau	27 ± 5	0.80 ± 0.24
DN Tau	71 ± 19	0.09 ± 0.04
DR Tau	35 ± 7	2.09 ± 0.62
GM Aur	41 ± 11	1.68 ± 0.65

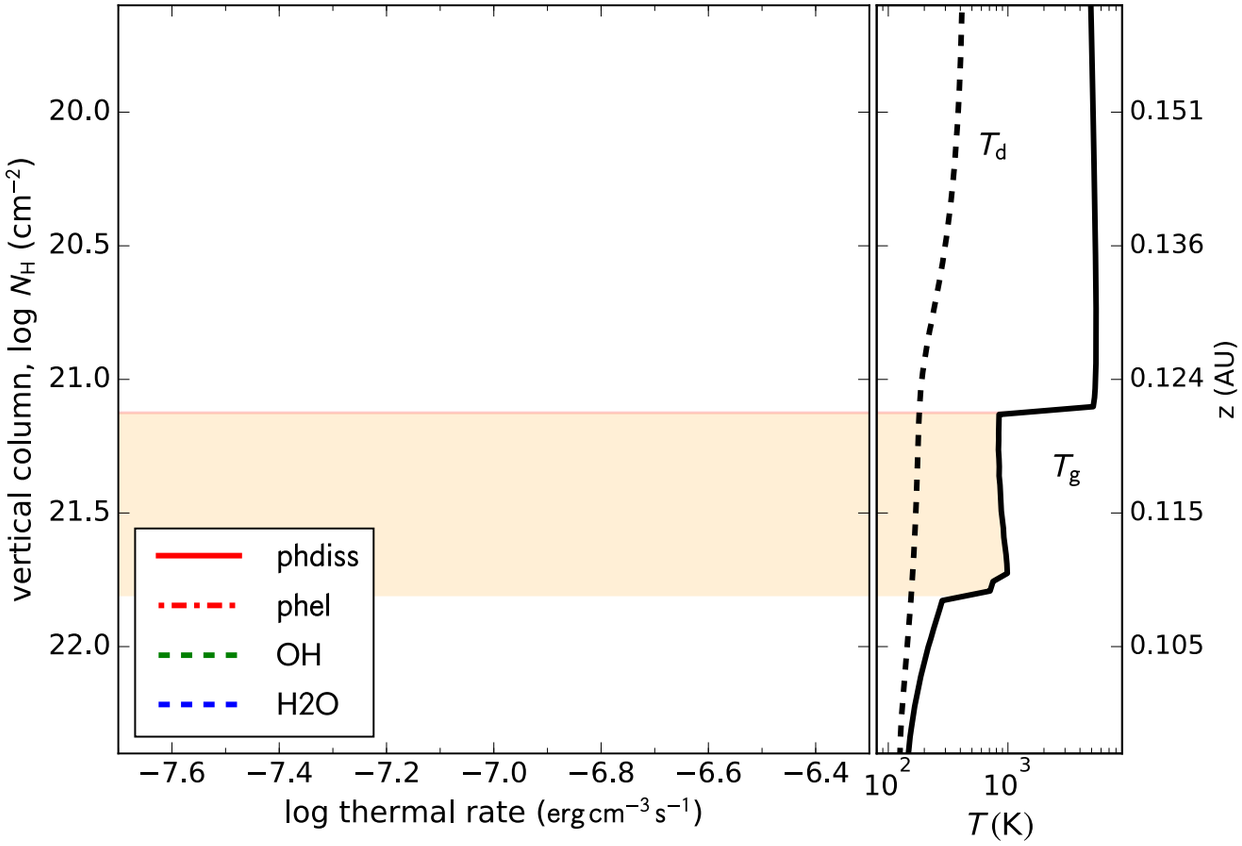
Fluorescent H_2 Emisssion

Ádámkovics, Najita, & Glassgold (2016)

$R = 0.25$AU

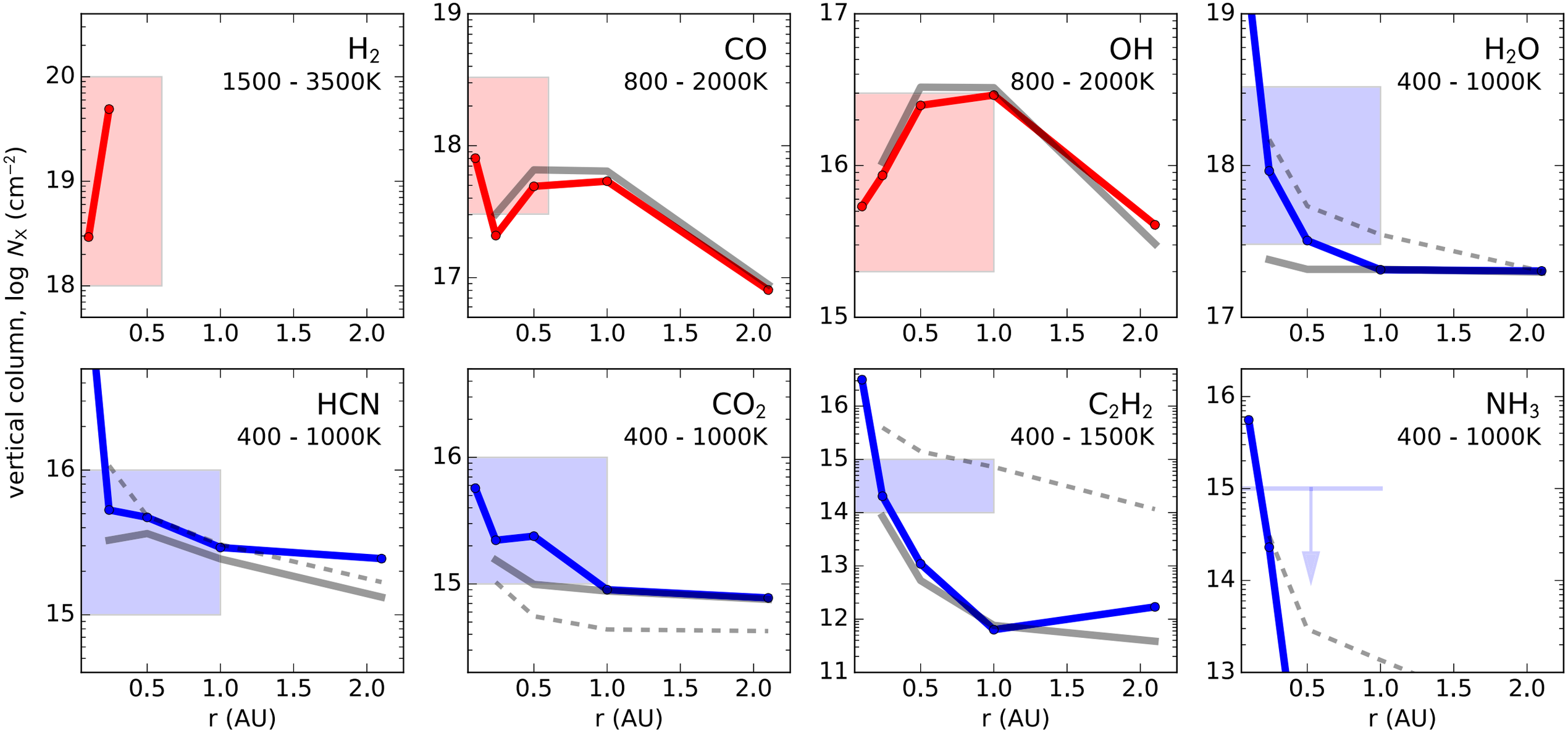


$R = 1$AU



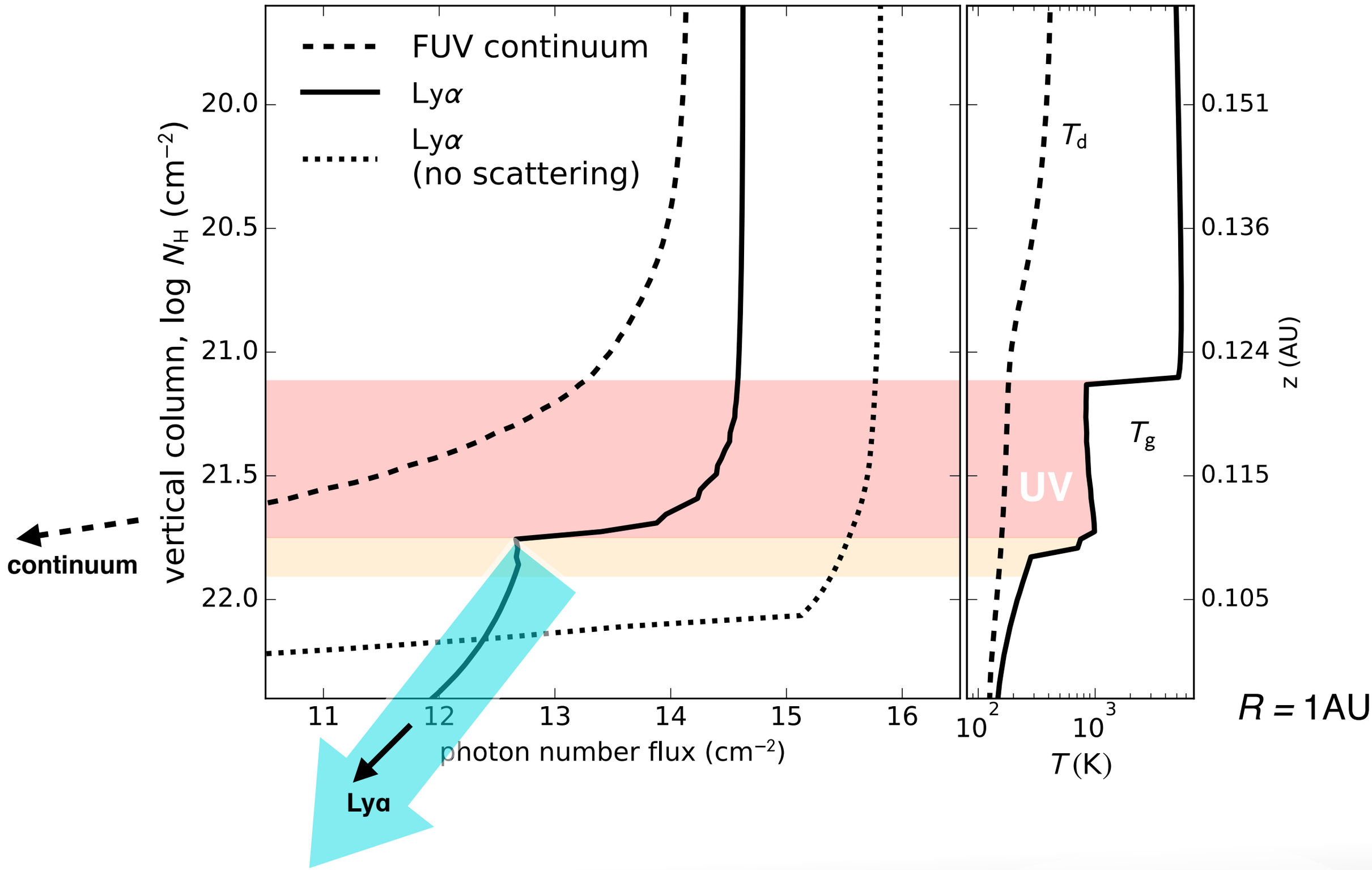
Dissociation of H_2O & OH by Lyα heats gas,
Hot H_2 for fluorescent emission can be thermally pumped

Najita & Ádámkovics (2017)



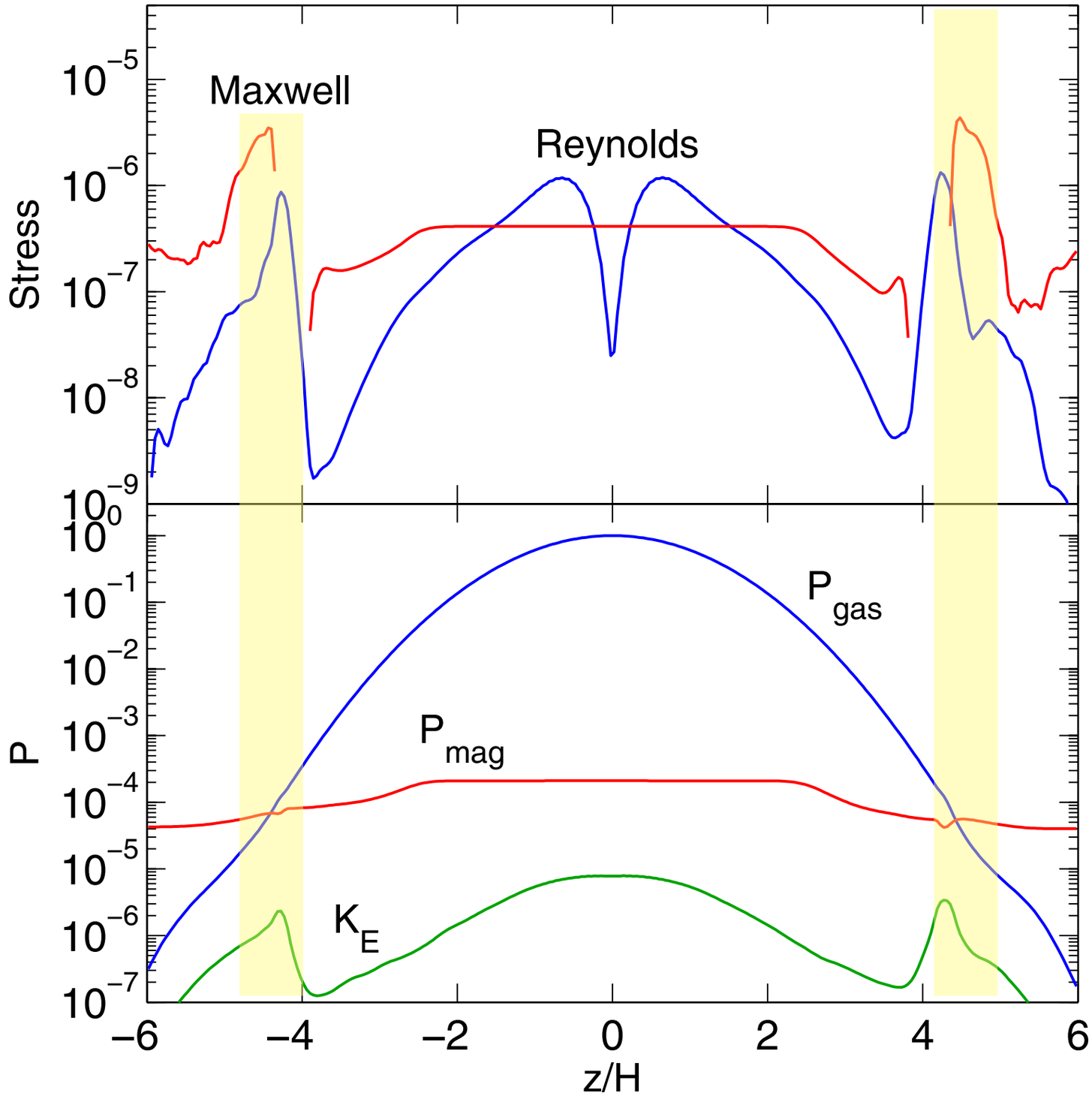
What is left after FUV?

Najita & Ádámkovics (2017)



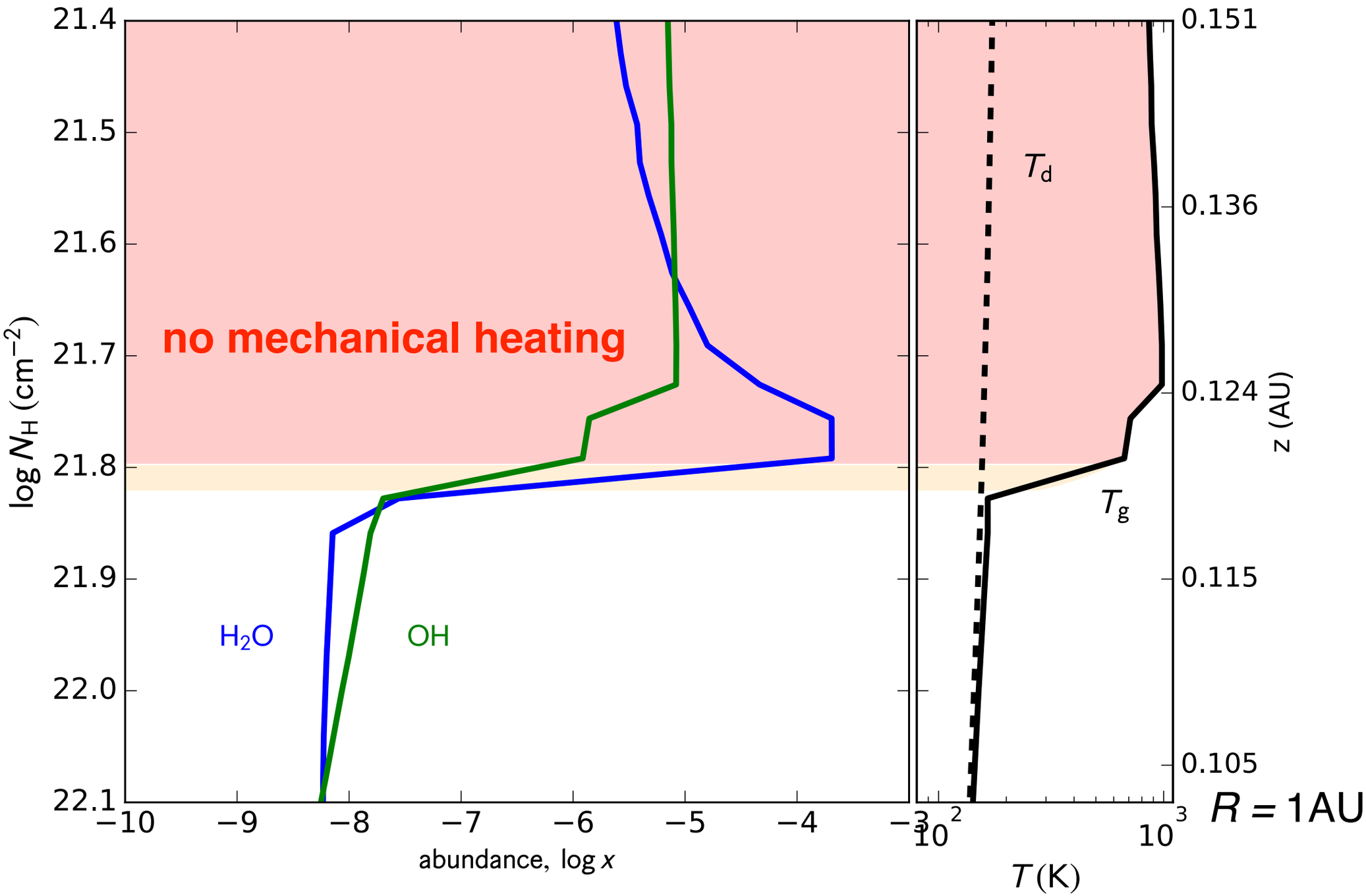
Turbulent / viscous / mechanical heating

Bai & Stone (2013)

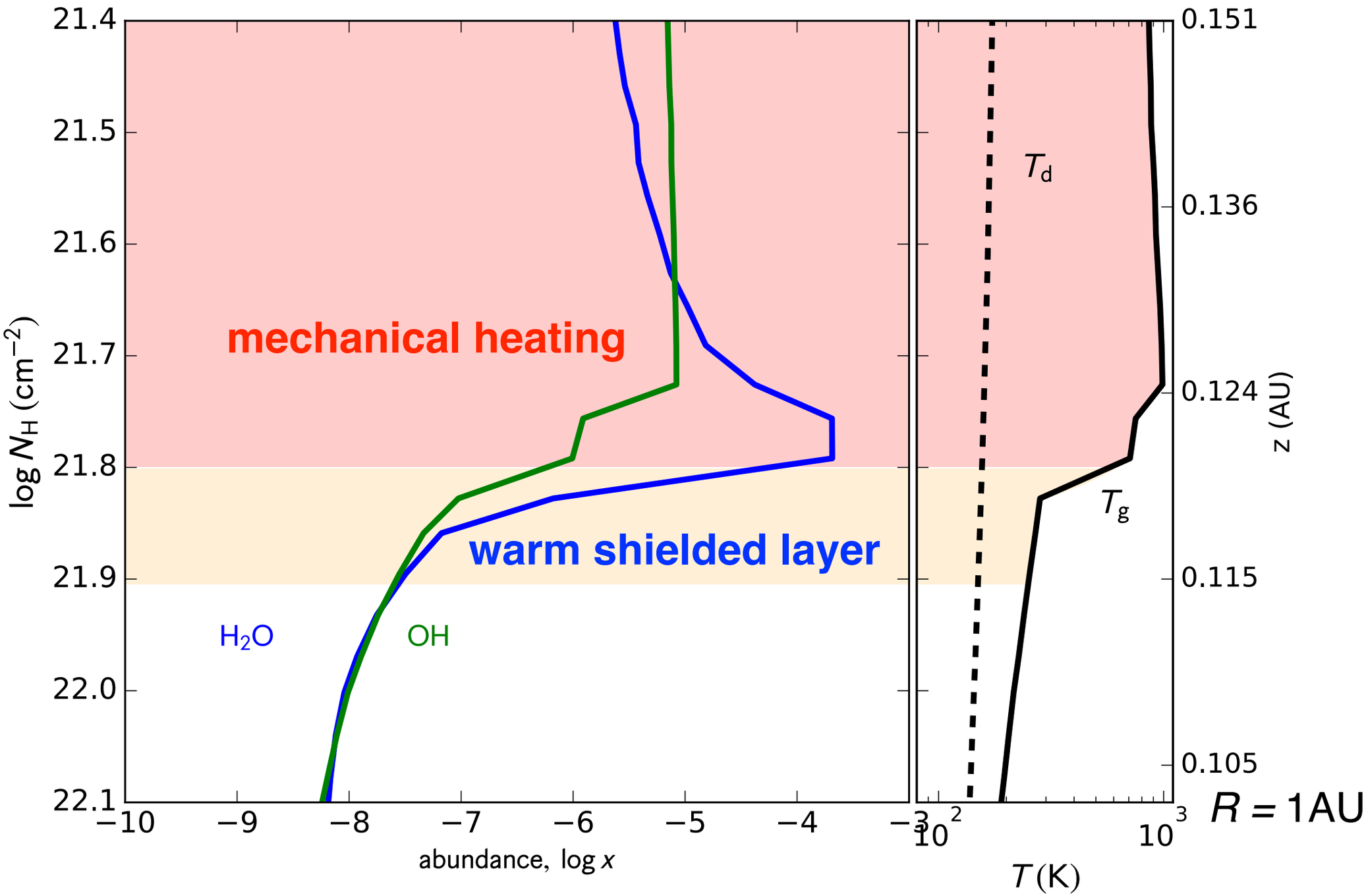


$R = 1\text{AU}$

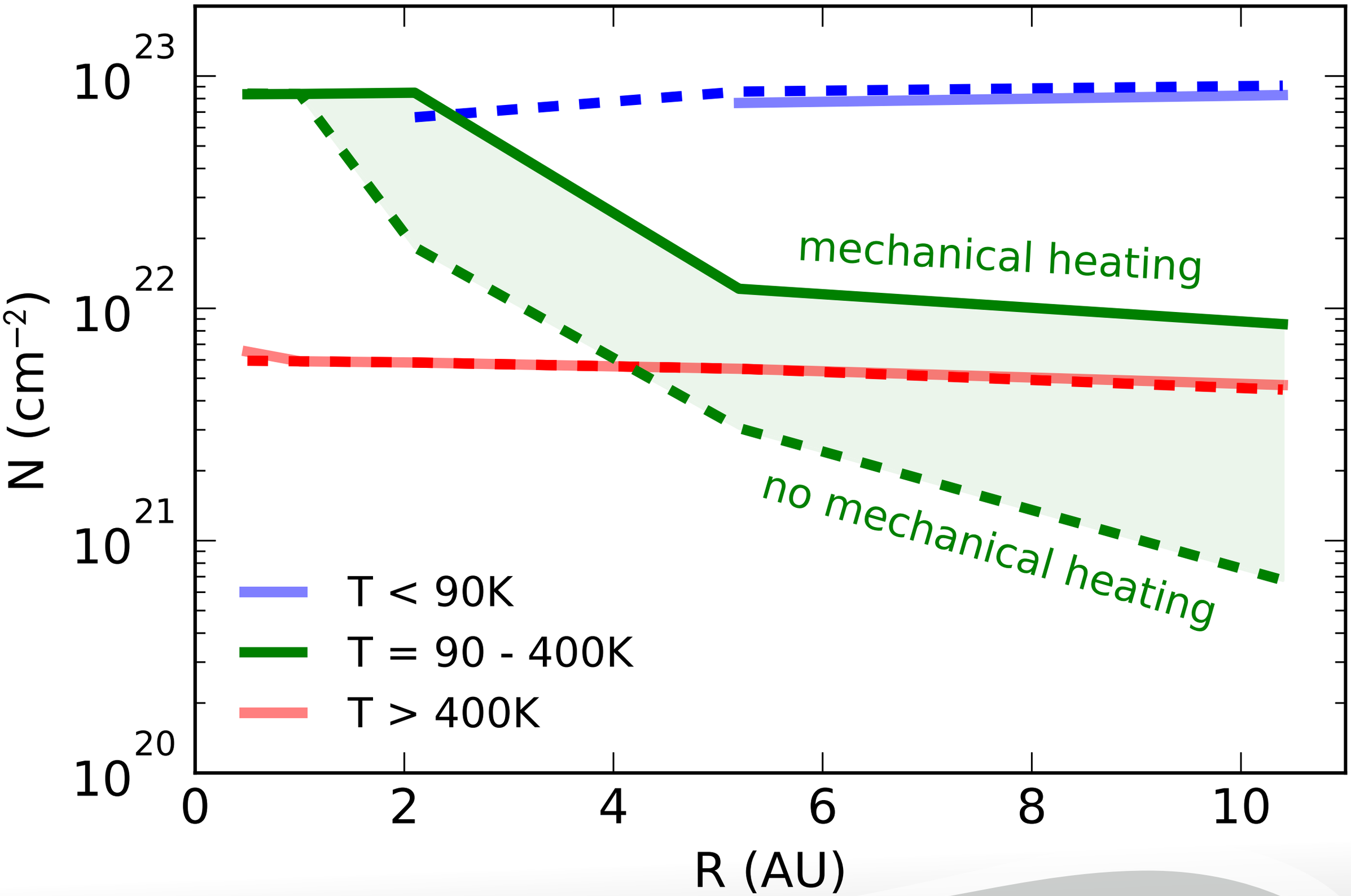
Role of mechanical heating: warm shielded layer

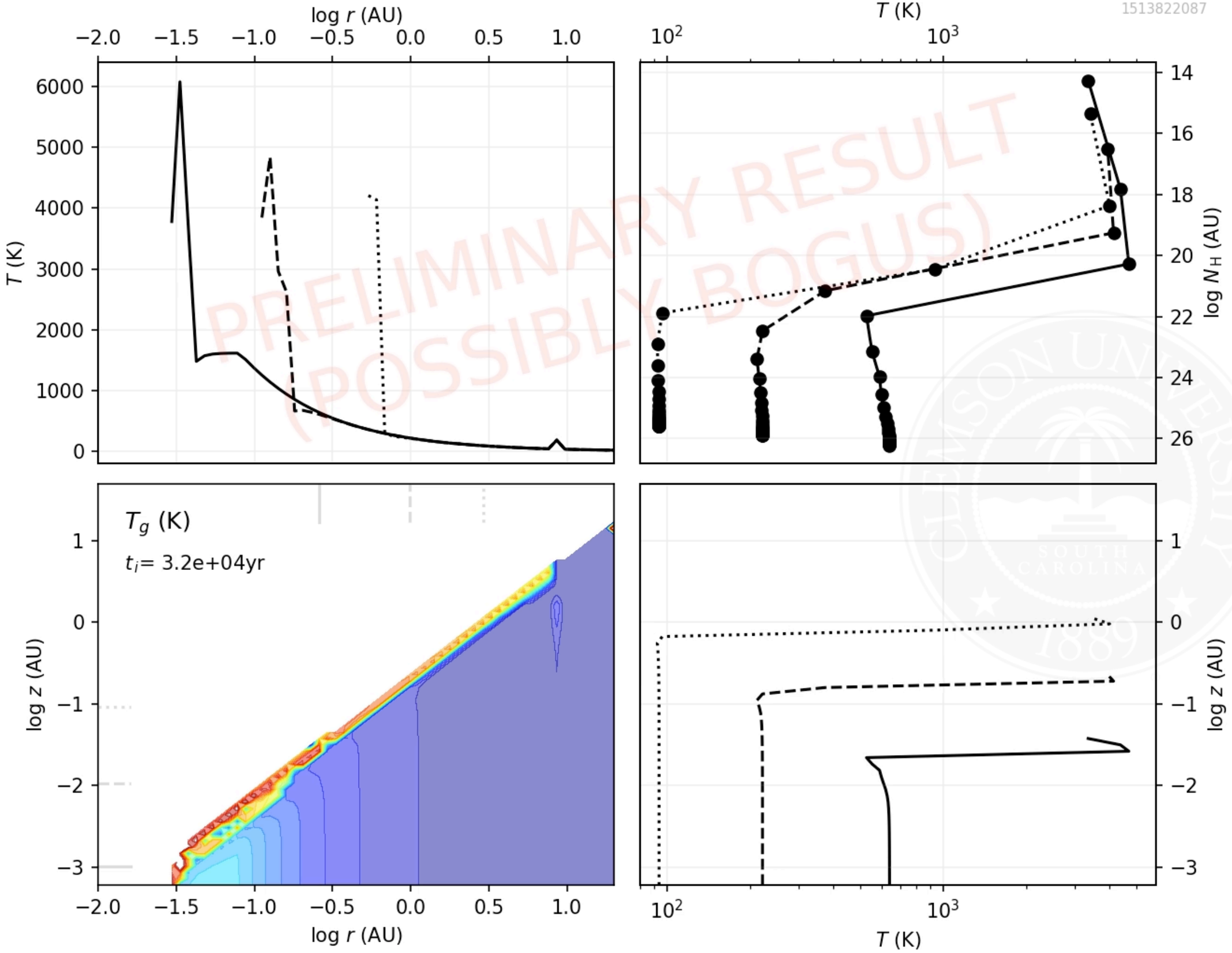


Role of mechanical heating: warm shielded layer



Najita & Ádámkovics (2017)




log r (AU)
T (K)
log N_H (AU)
T_g (K)
t_i= 3.2e+04yr
log z (AU)
PRELIMINARY RESULT
(POSSIBLY BOGUS)