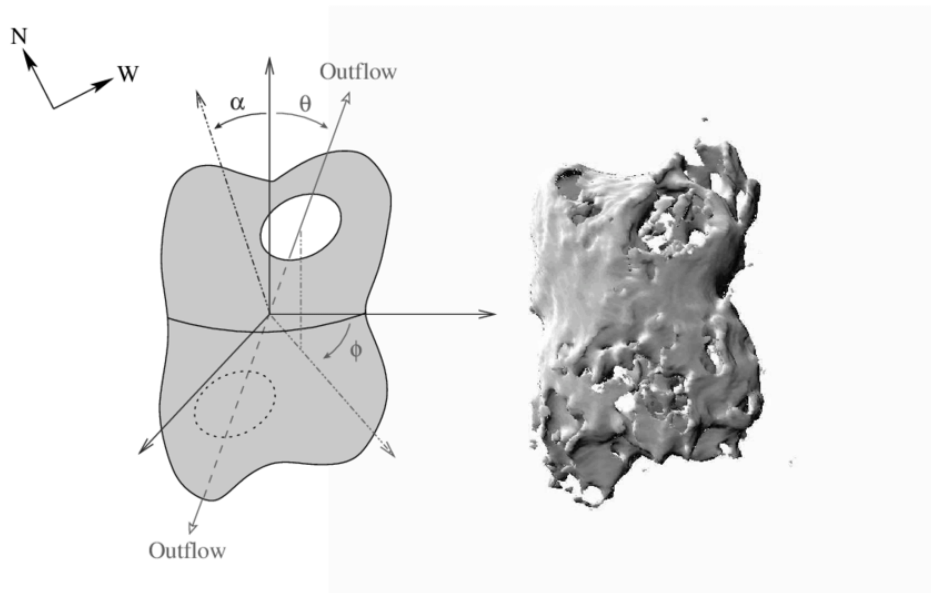
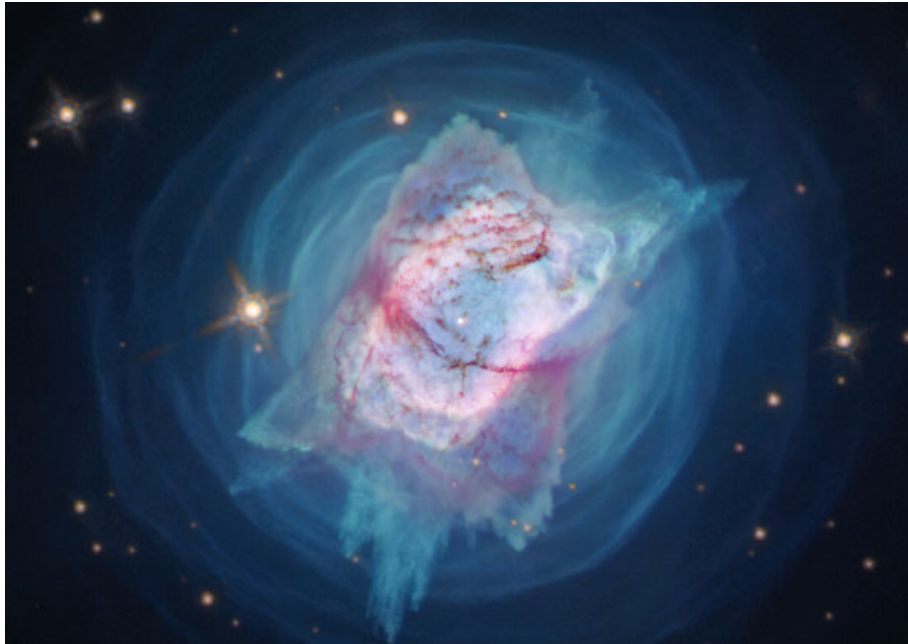


# Vibrational emission of CH<sup>+</sup> in the planetary nebula NGC 7027

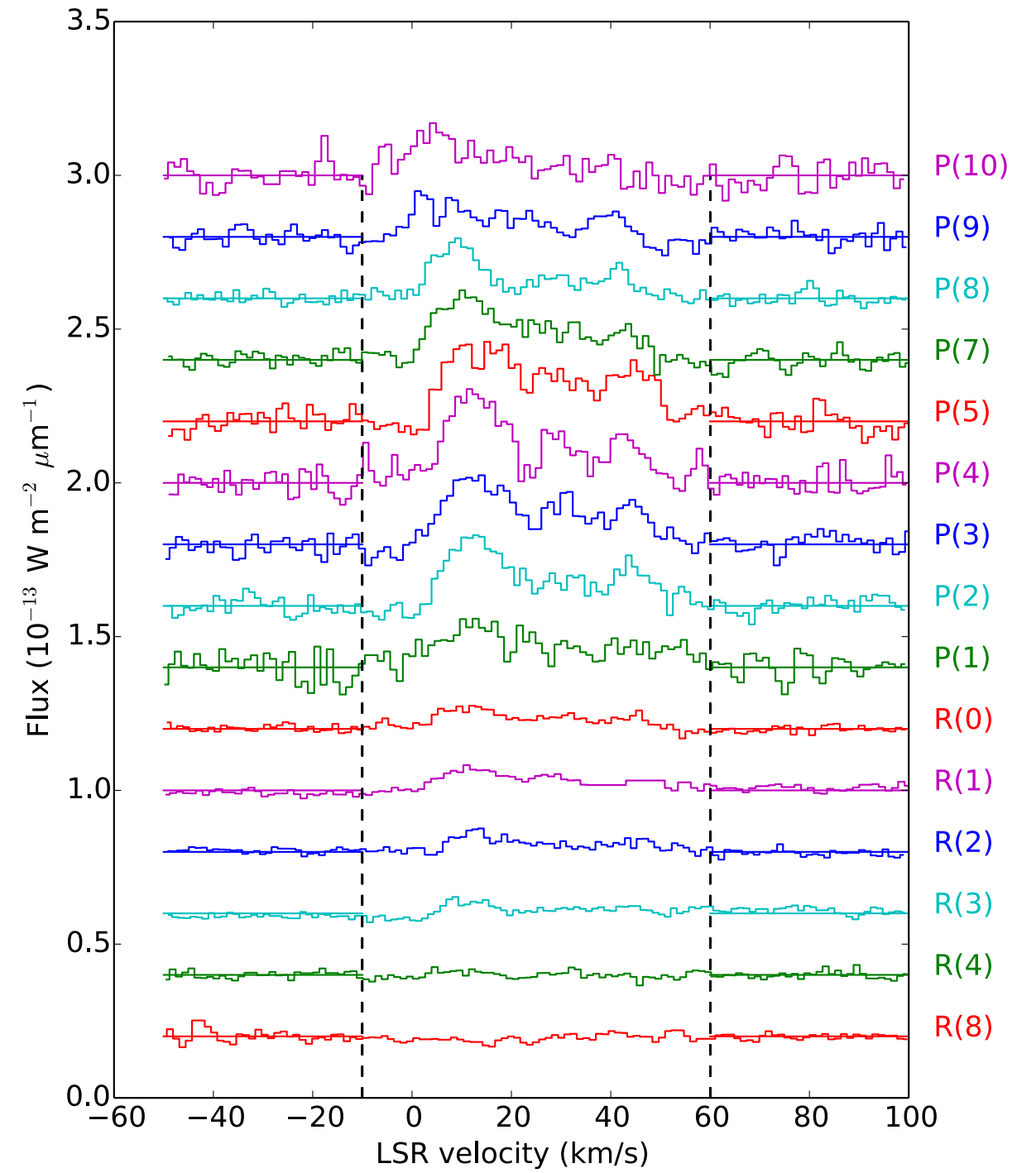
D. Neufeld, B. Godard, B. Changala, A. Faure

# NGC 7027



Cox et al. (2002)  
Mékarnia et al. (2005)

# Vibrational bands of CH<sup>+</sup>



Neufeld et al. (in prep.)

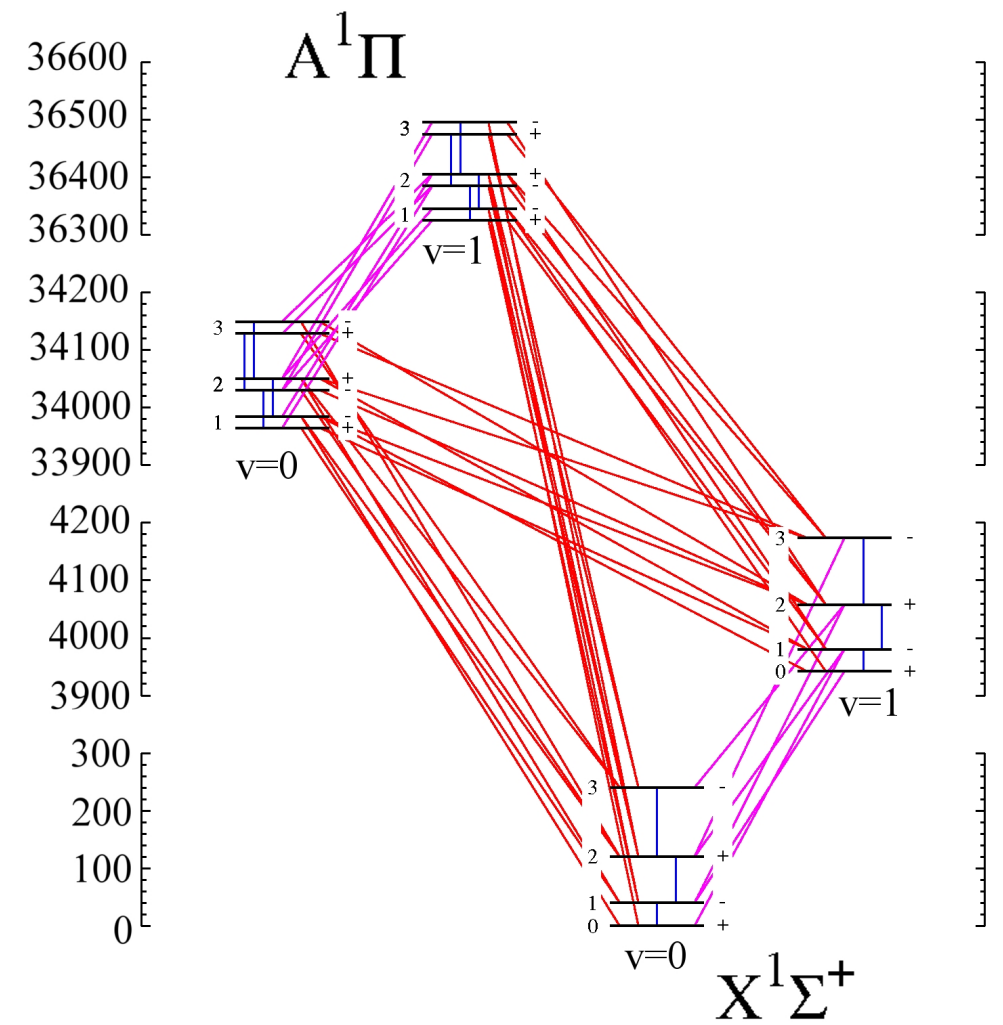
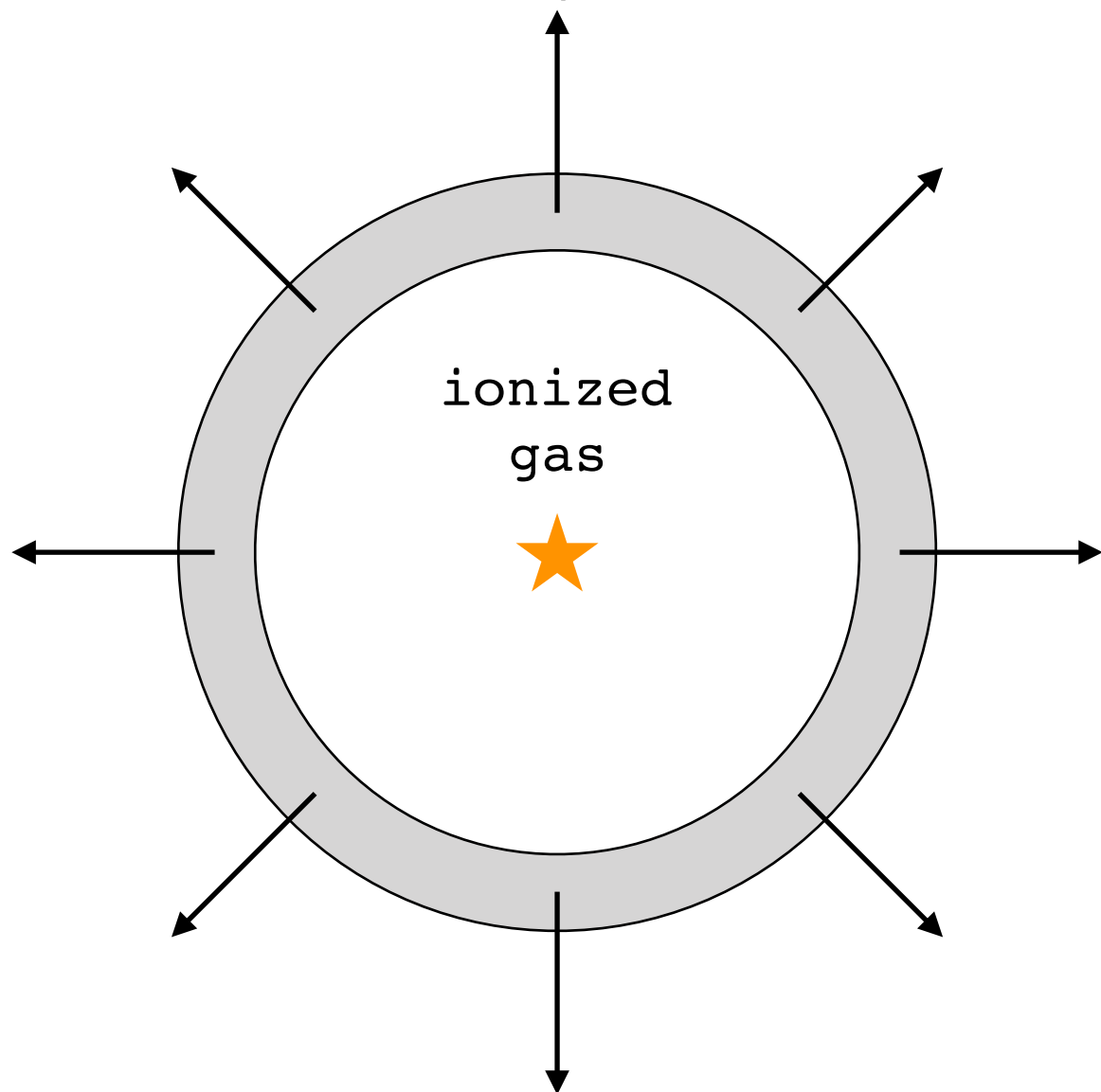
*Are we able to explain such emission ?*

*What does it tell us regarding microphysical processes ?*

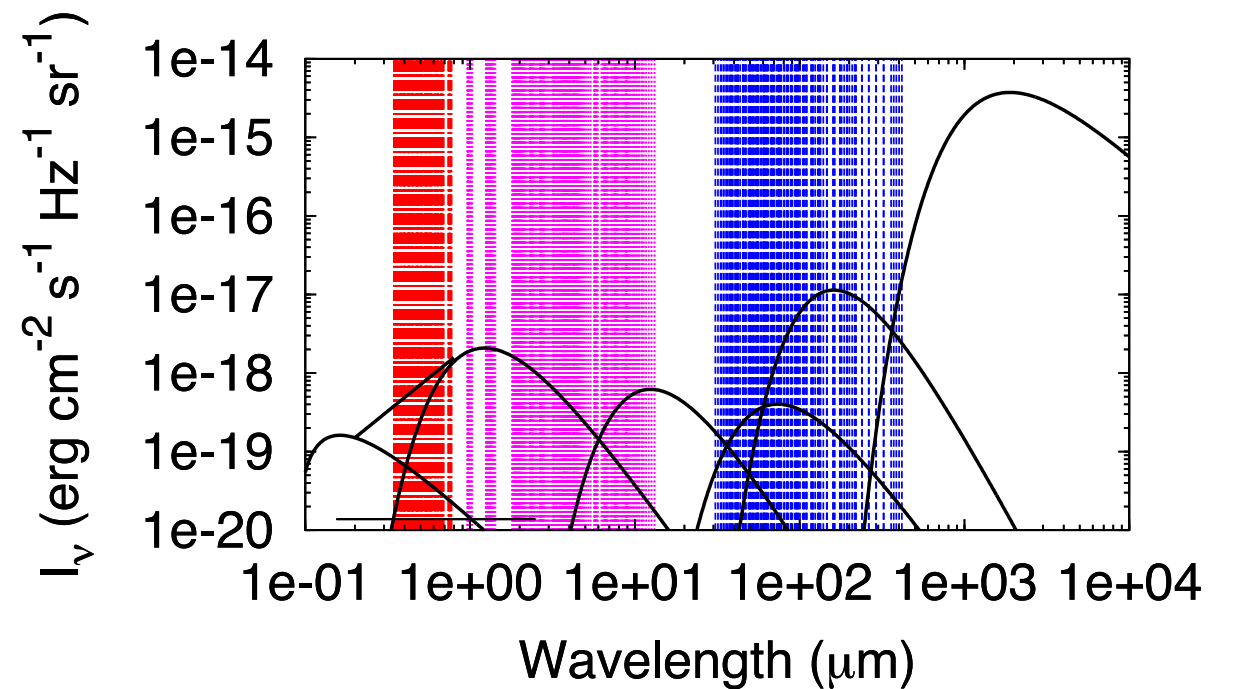
*What information can we derive on the source itself ?*

# astrochemical model

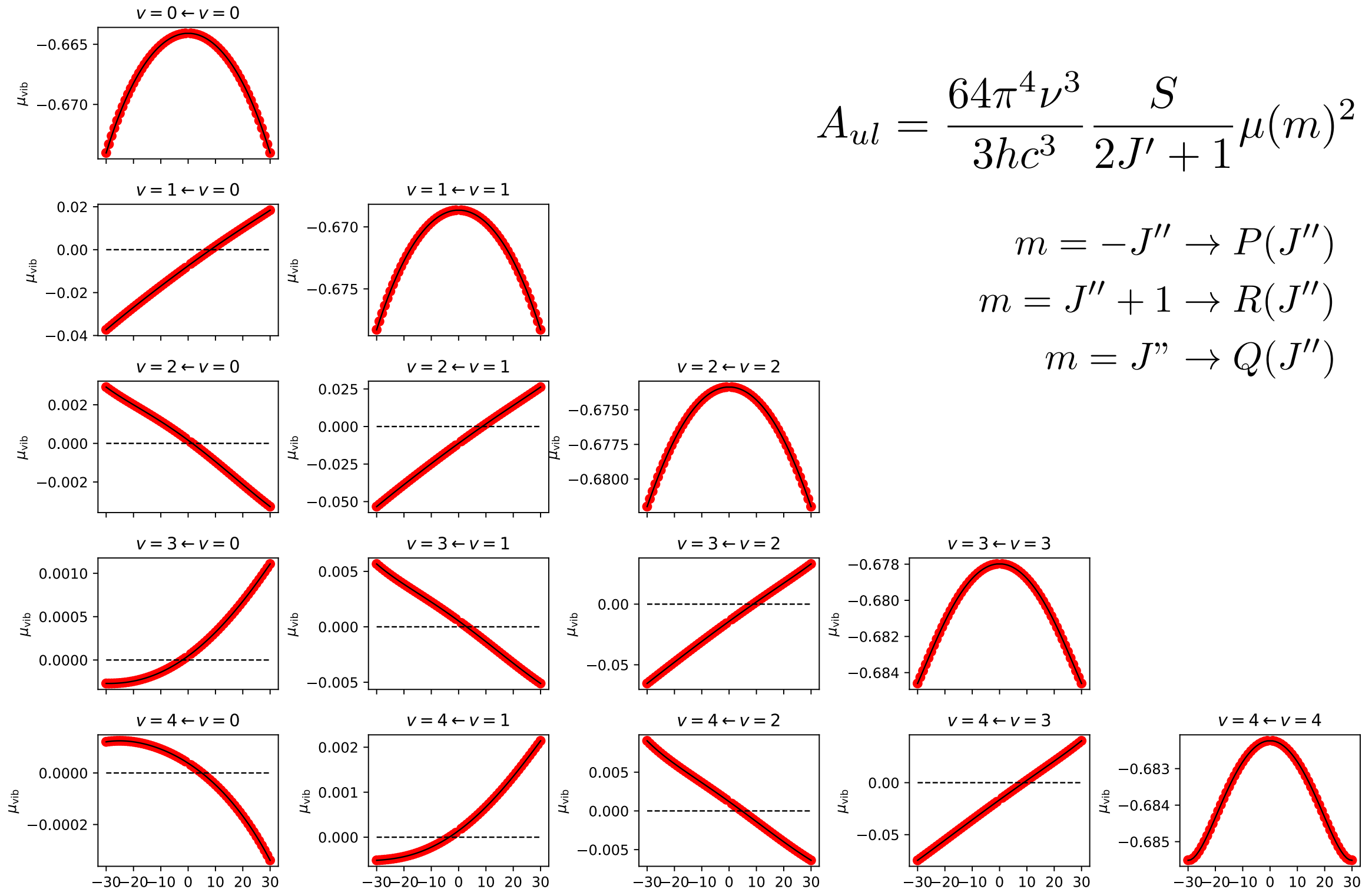
- spherical PDR cloud
- Meudon PDR Le Petit et al. (2006)
- entire energetic structure of CH<sup>+</sup>
- all excitation processes



Godard & Cernicharo (2013)



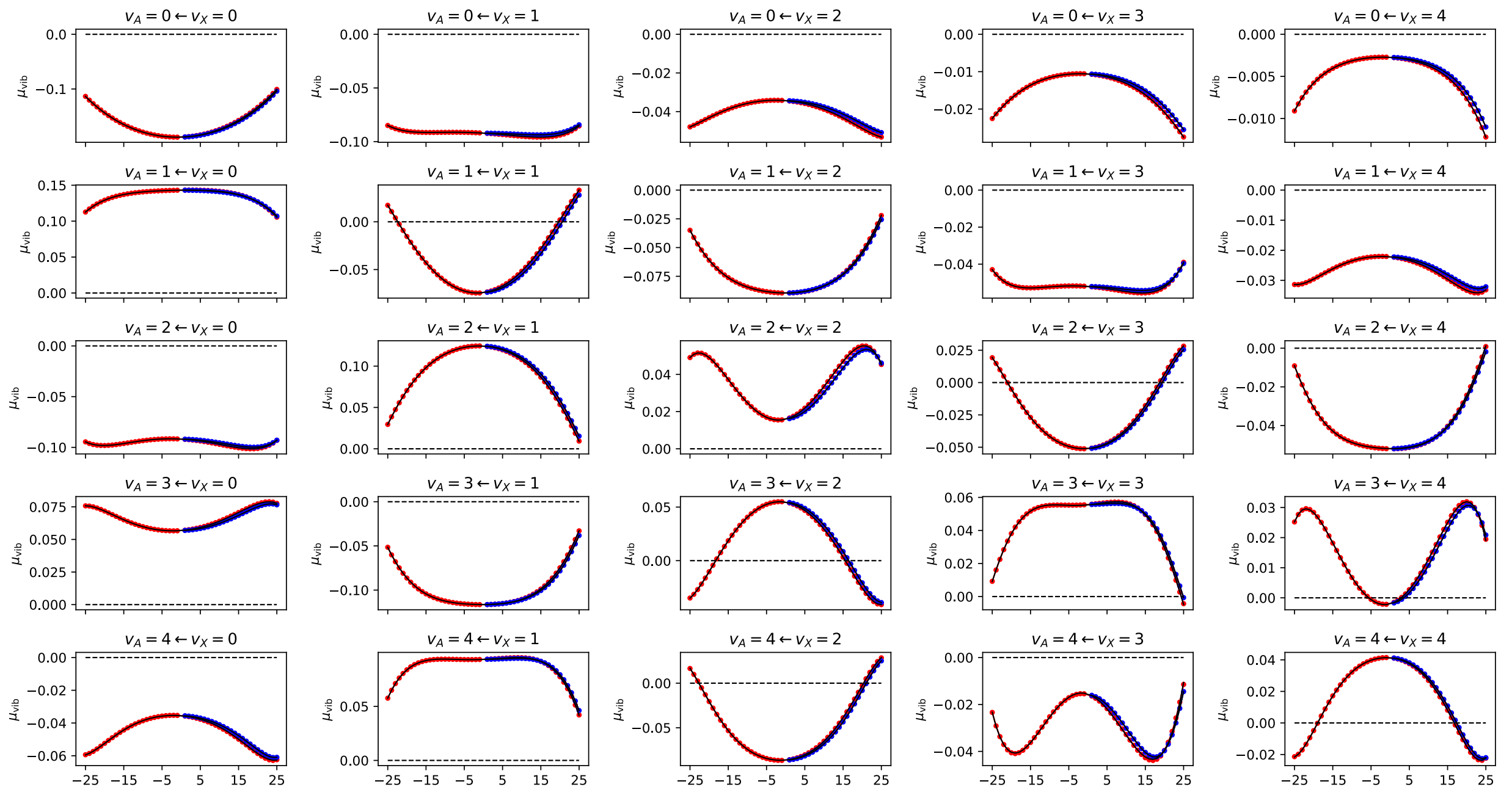
# radiative (de)excitation inclusion of dipole moment functions



# radiative excitation

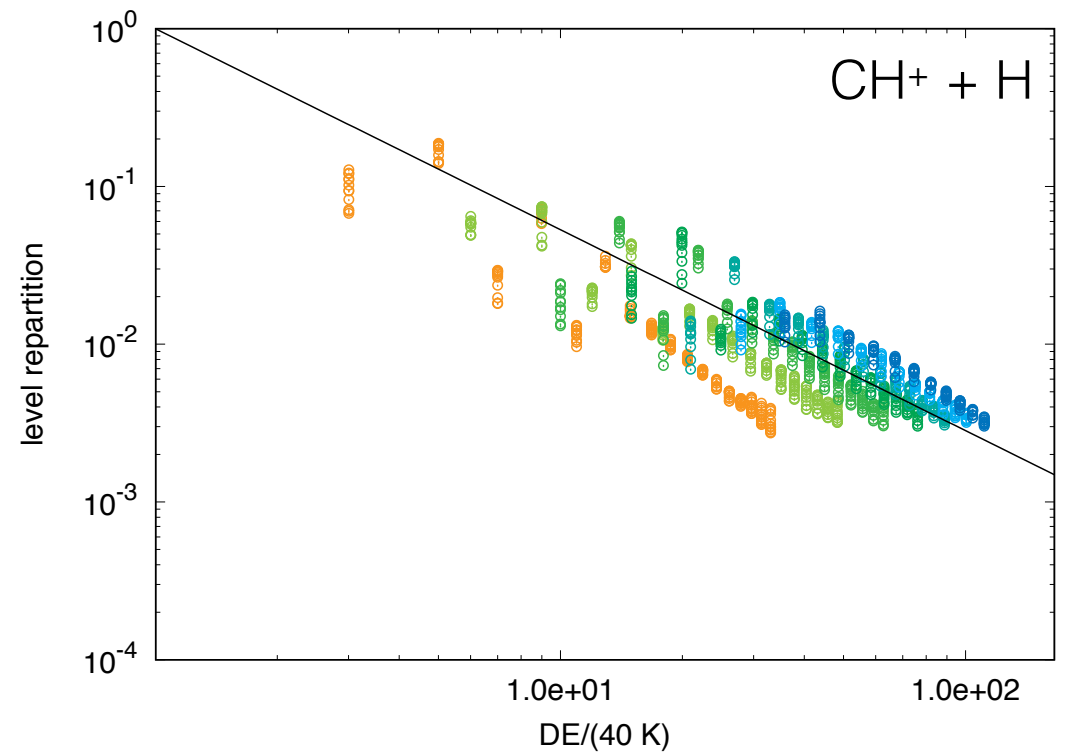
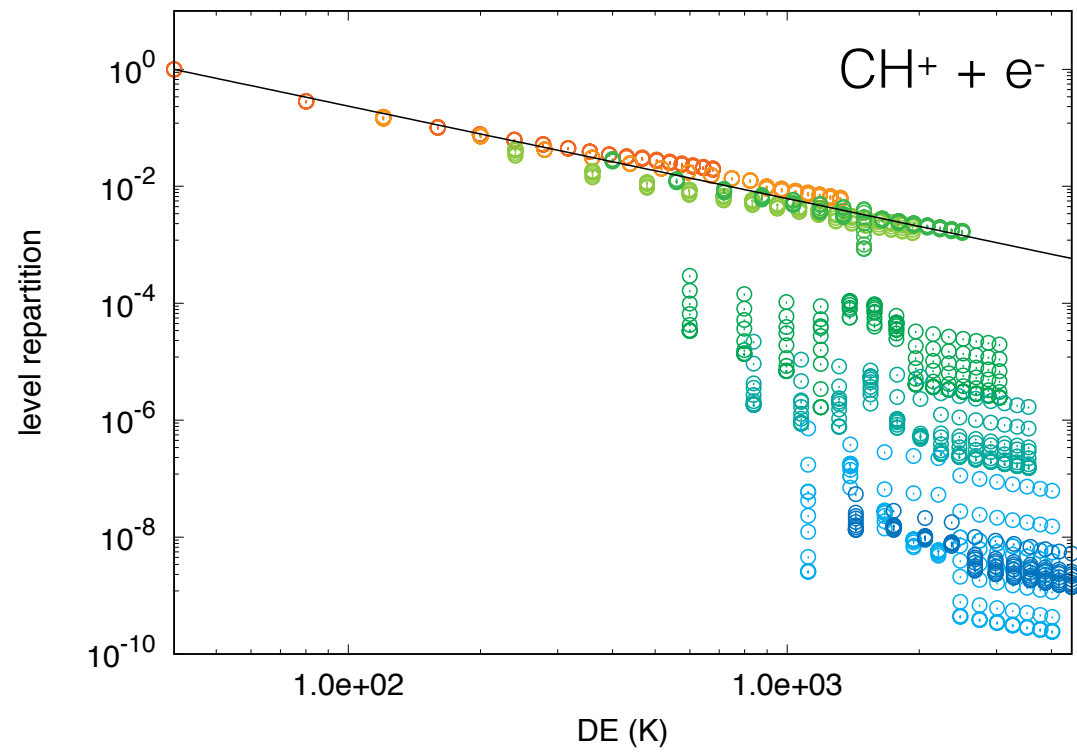
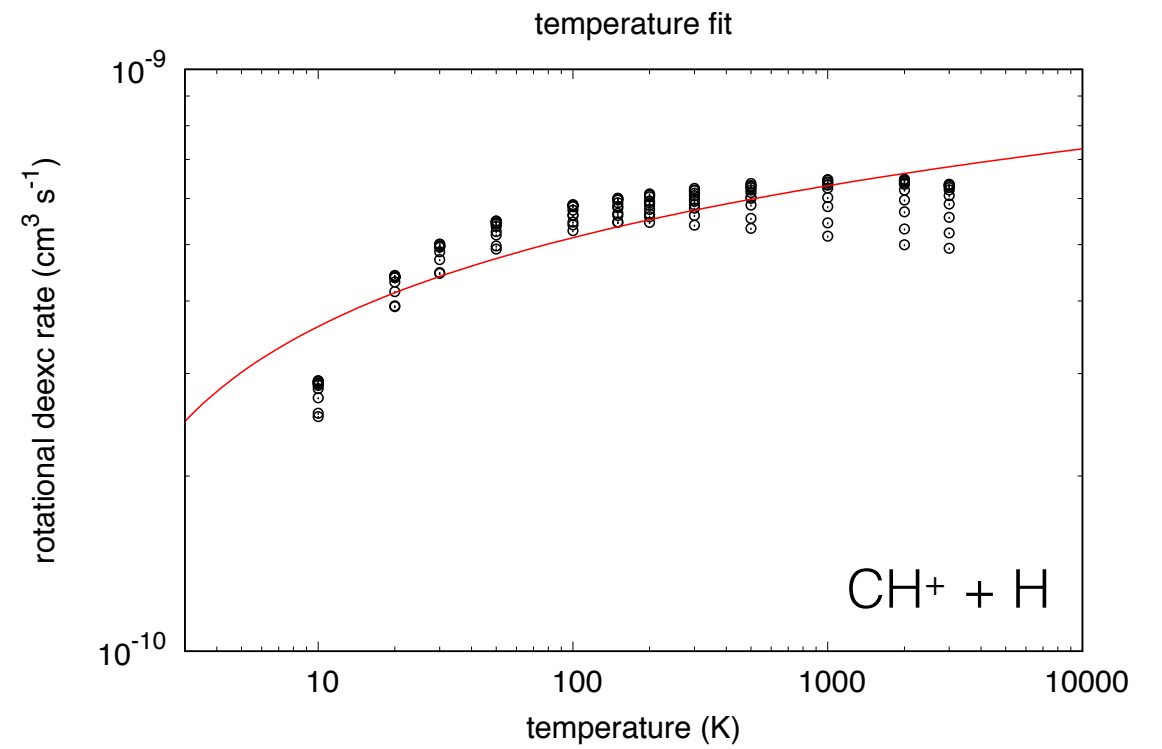
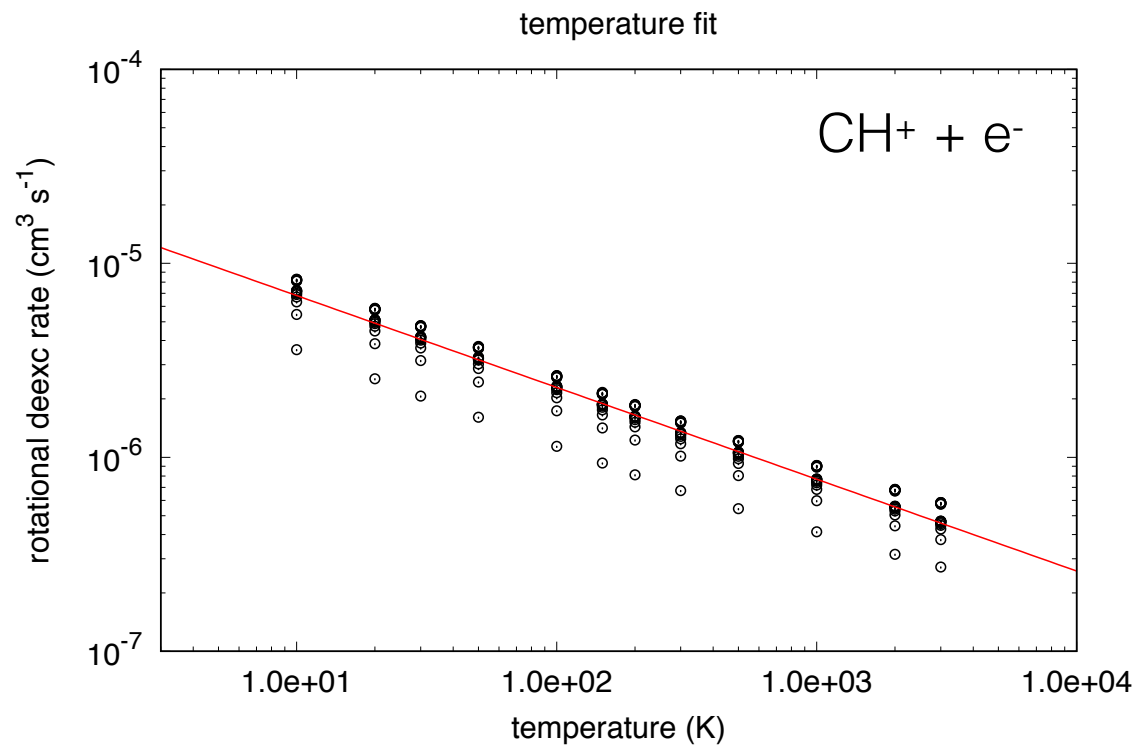
## inclusion of dipole moment functions

A(e,f)-X rovibronic transitions



Changala et al. (in prep.)

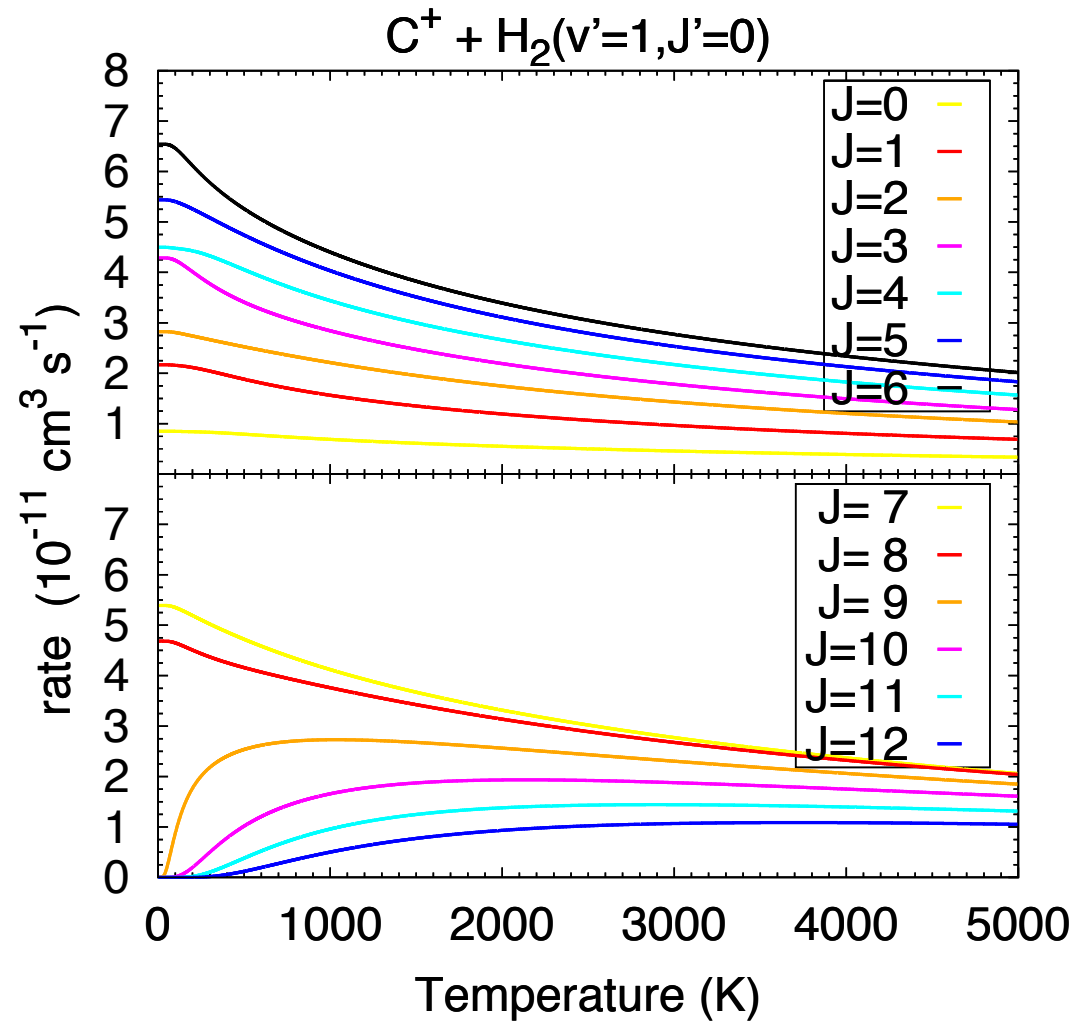
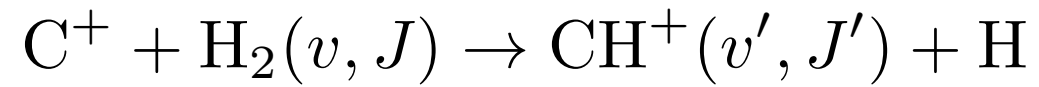
# collisional (de)excitation



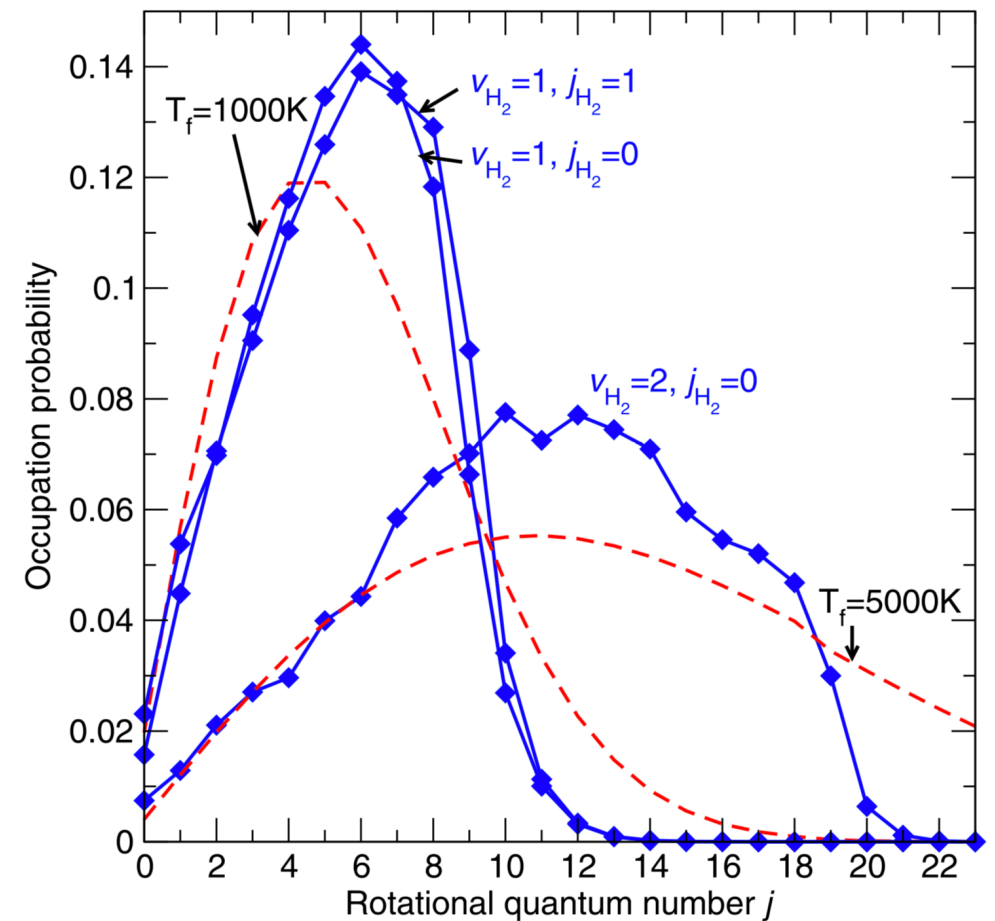
Hamilton et al. (2016)

Faure et al. (2017)

# chemical pumping



Zanchet et al. (2013)



Faure et al. (2017)

repartition

$$\propto (2J' + 1) \exp(-E/T)$$

$$\propto (2J' + 1)$$

if  $E = E_r + E_{\text{CH}^+(v', J')} - E_{\text{H}_2(v, J)} < 0$   
otherwise



# main excitation pathways

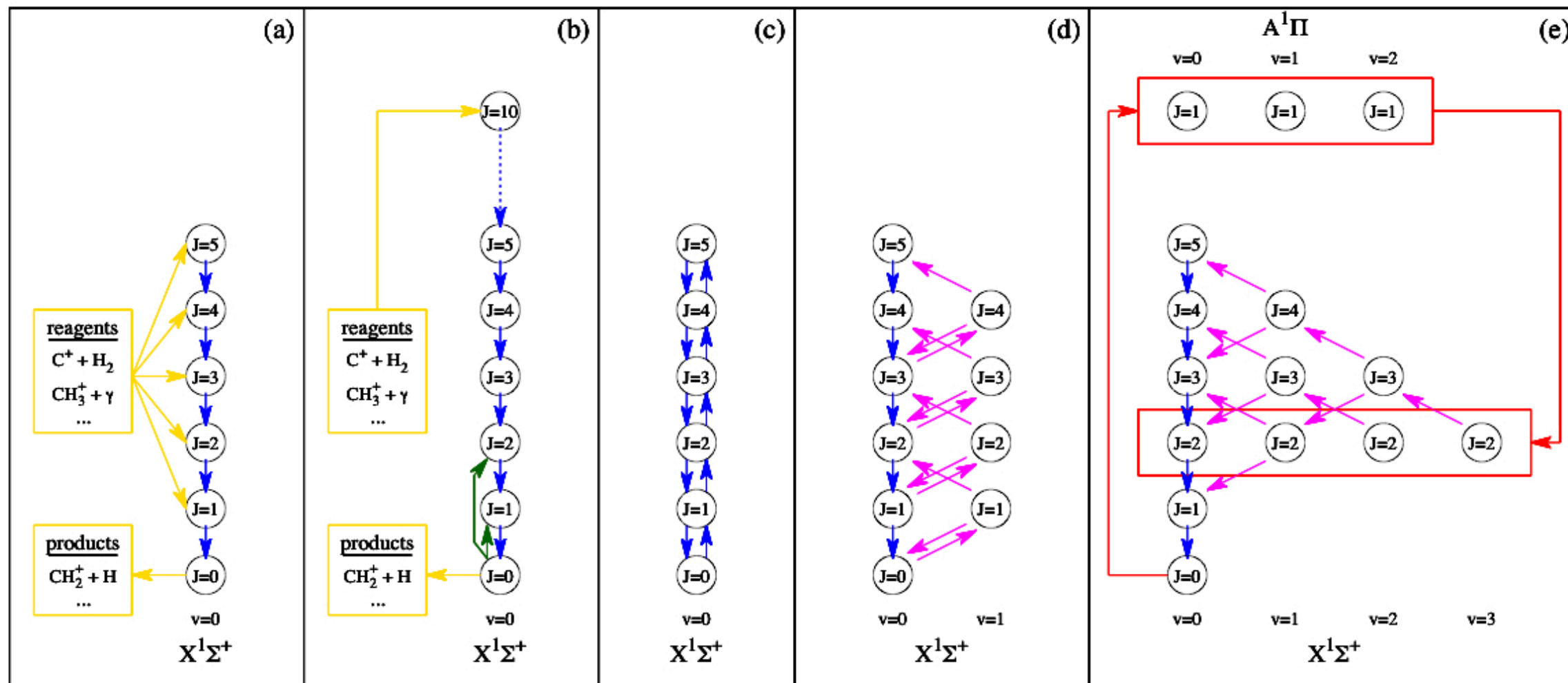
$T_K = 100 \text{ K}$

$T_K = 1000 \text{ K}$

$\chi_{\text{fir}} = 10^6$

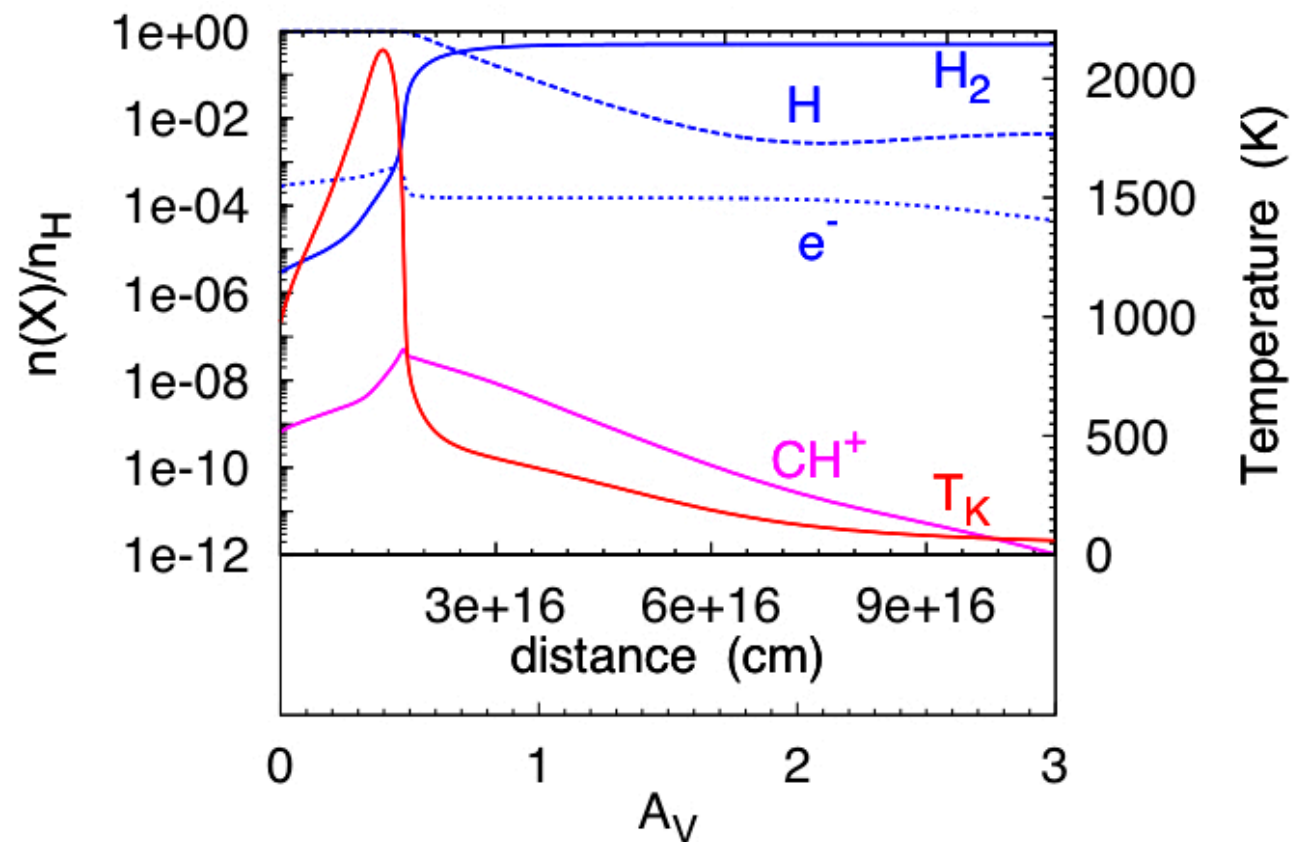
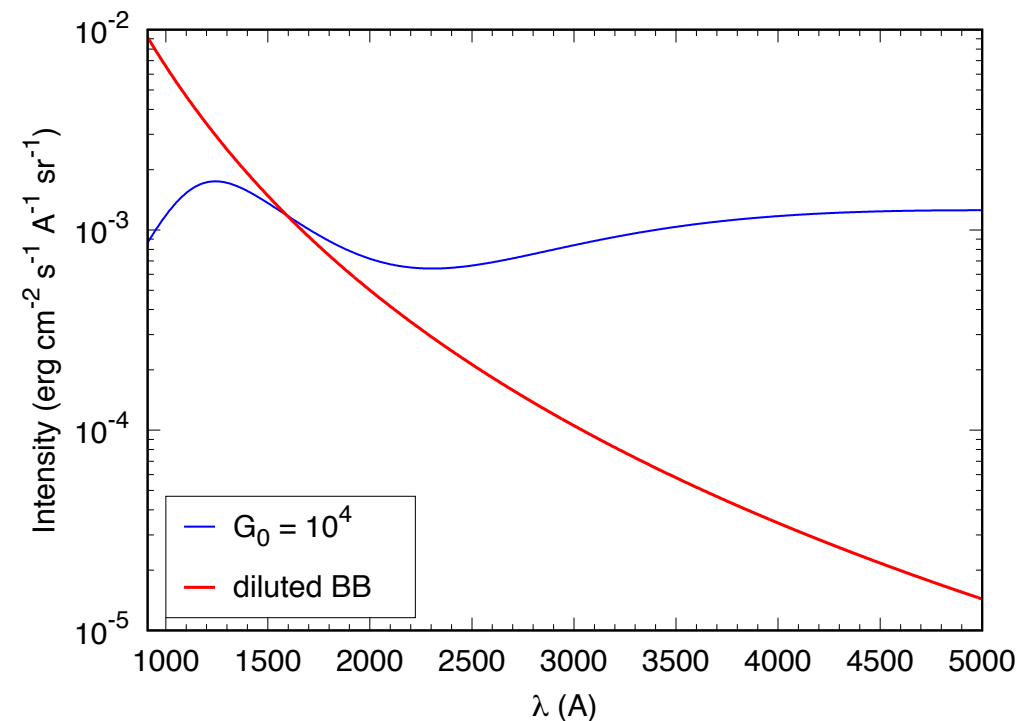
$\chi_{\text{nir}} = 10^{10}$

$\chi_{\text{opt}} = 10^6$



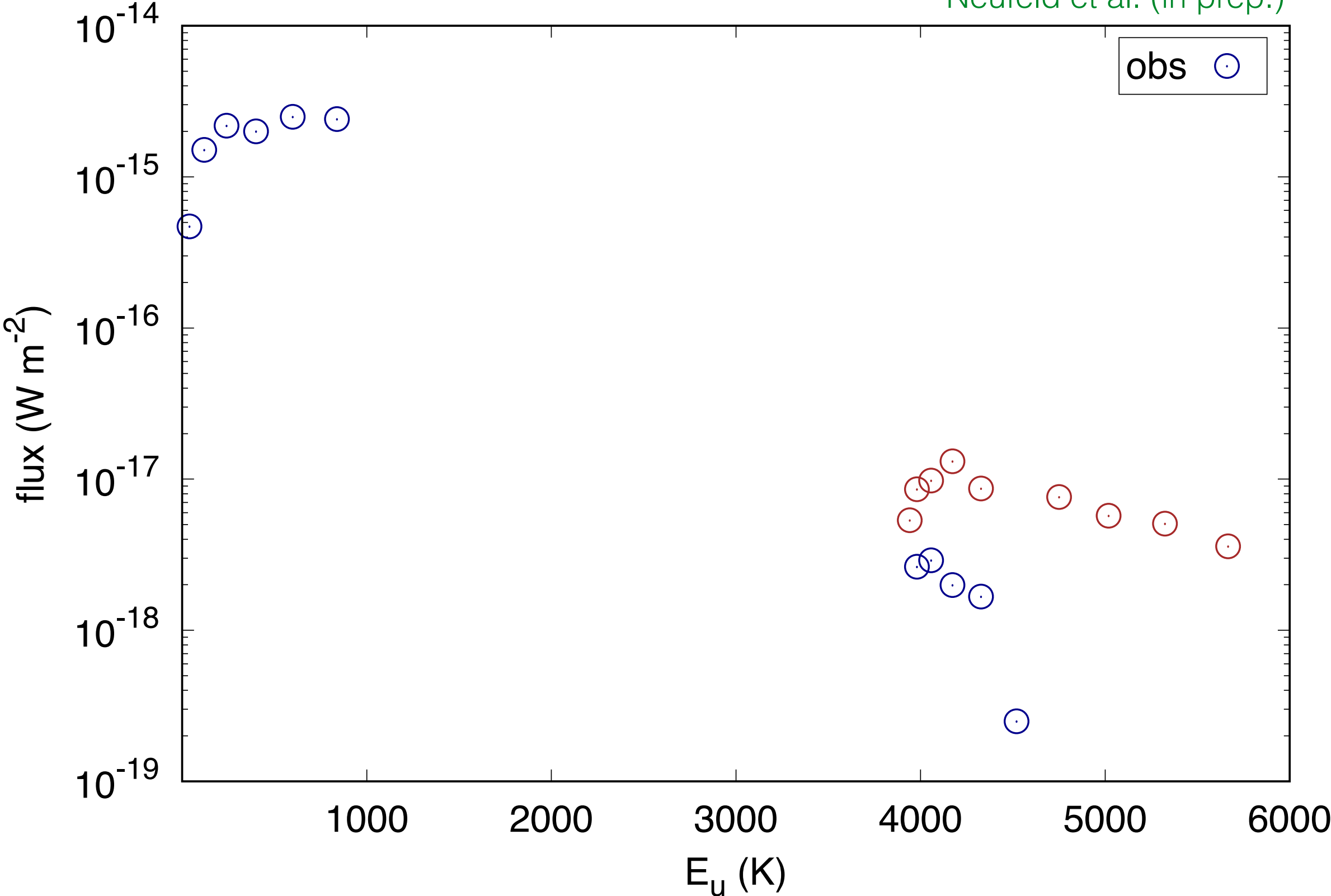
## model parameters

- source distance = 980 pc
- spherical shell
- ionization front = 0.022 pc
- $V_{\text{exp}} = 20 \text{ km s}^{-1}$
- $T_{\text{S}} = 198\,000 \text{ K}$   
in practice, parametrized by  $G_0$
- $n_{\text{H}} = 10^5 - 10^7 \text{ cm}^{-3}$
- $[\text{C}] = \text{solar to } 10 \times \text{solar}$



comparison with observations

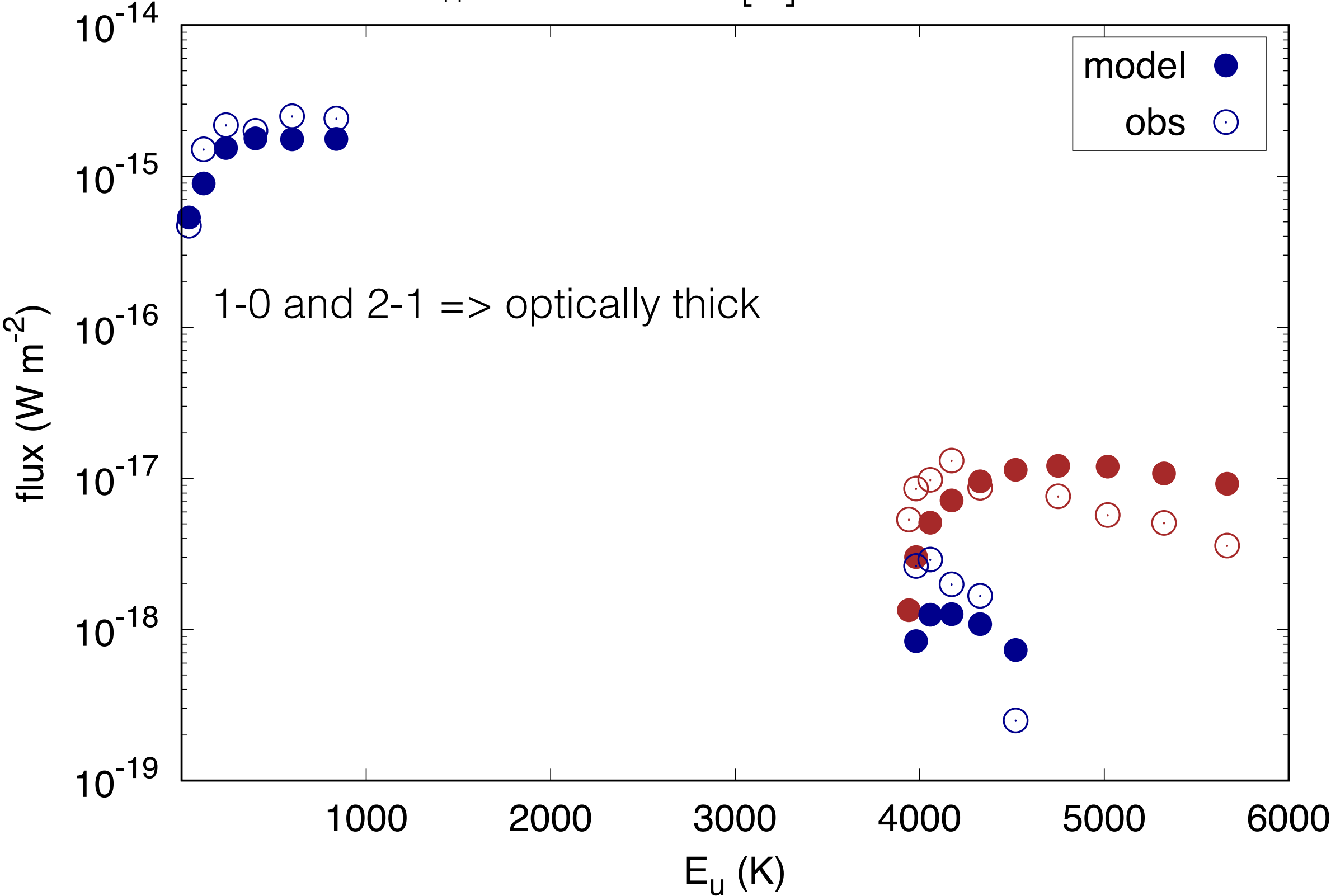
Cernicharo et al. (1997)  
Neufeld et al. (in prep.)





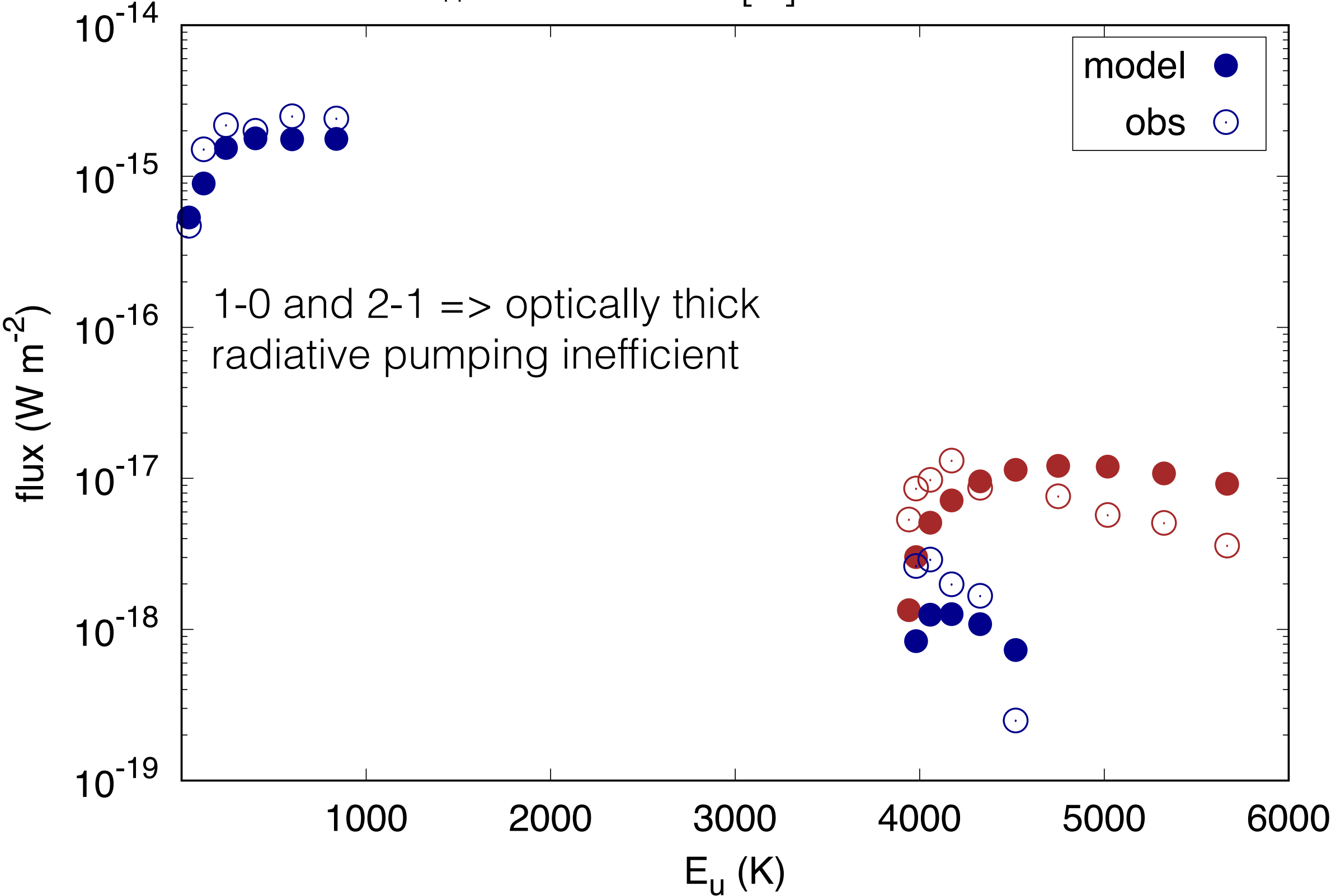
comparison with observations

$n_H = 3 \cdot 10^5 \text{cm}^{-3}$  [C]=3 x solar



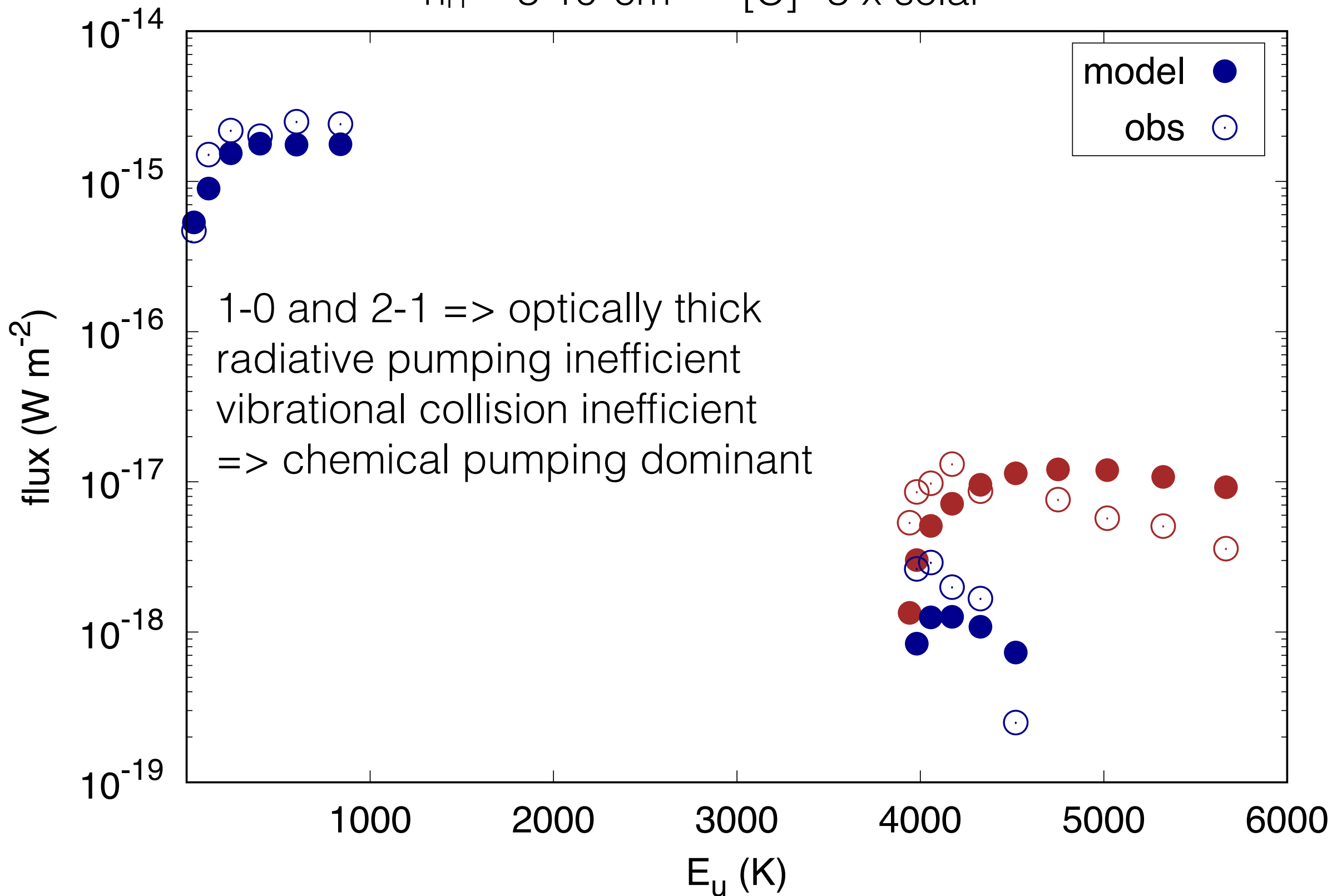
comparison with observations

$n_H = 3 \cdot 10^5 \text{cm}^{-3}$  [C]=3 x solar

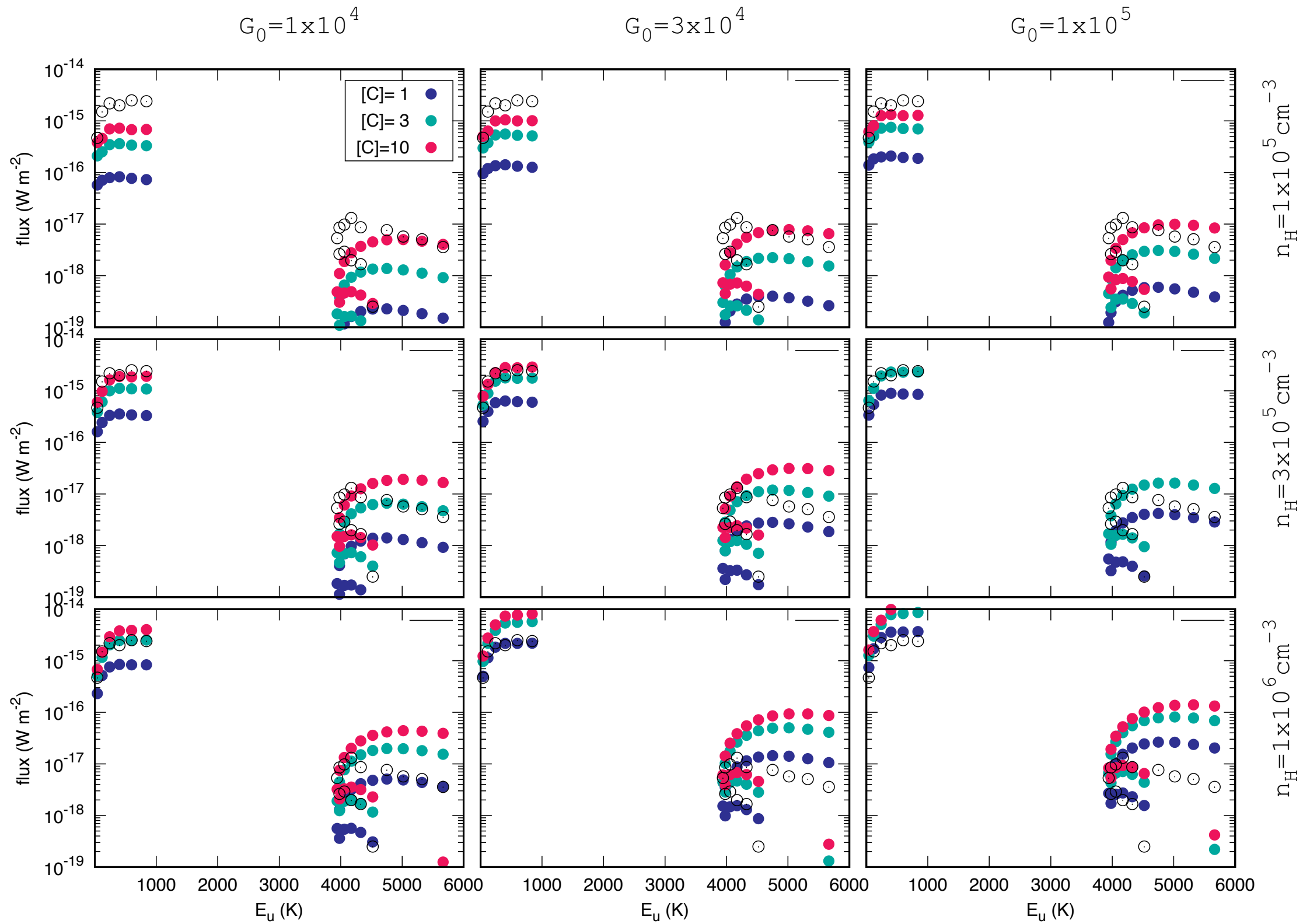


# comparison with observations

$n_H = 3 \cdot 10^5 \text{cm}^{-3}$  [C]=3 x solar



# exploration of parameters



$q_{\text{PAH}} = 5 \times 10^{-2}$  ,  $\text{H}_2$  formation = simple



## conclusions

### source NGC 7027

- 1-0 and 2-1 => optically thick  
=> need turbulent velocity
- rovibrational emission  
explained for high density or  
carbon rich environments
- excitation temperature of  
vibrational levels > observed

### microphysical processes

- radiative pumping and  
collisions inefficient
- chemical pumping dominant

### discrepancies

chemical pumping formalism ?  
form of the UV spectrum ?  
mistake in implementation of  
spectroscopic data ?