

THERMAL BALANCE

Heating Rates: Rate equations
Grain size distributions
 H_2 treatment

Cooling Rates: Rate coefficients
Radiation transfer

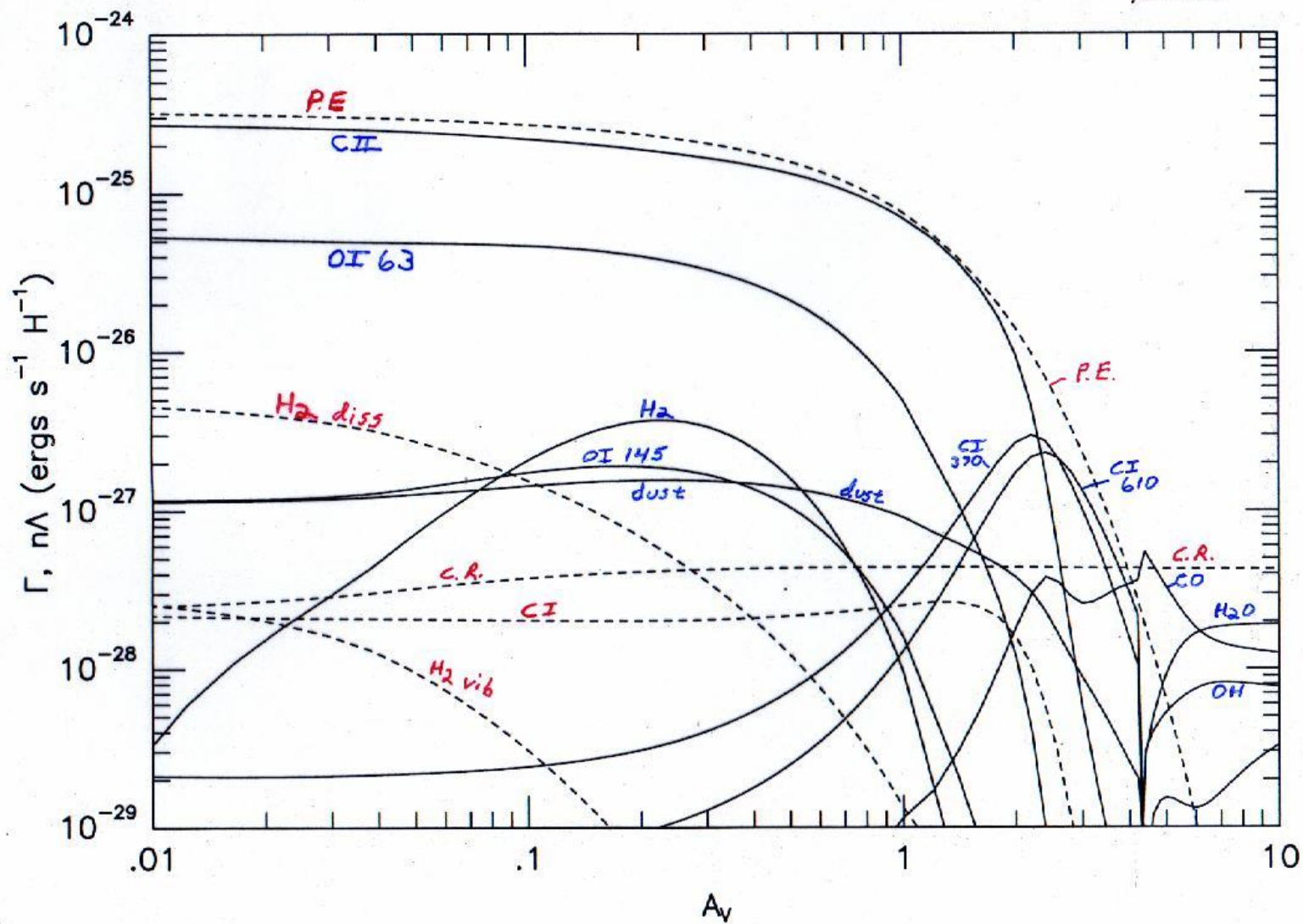
Temperature: Differences
Line Intensities

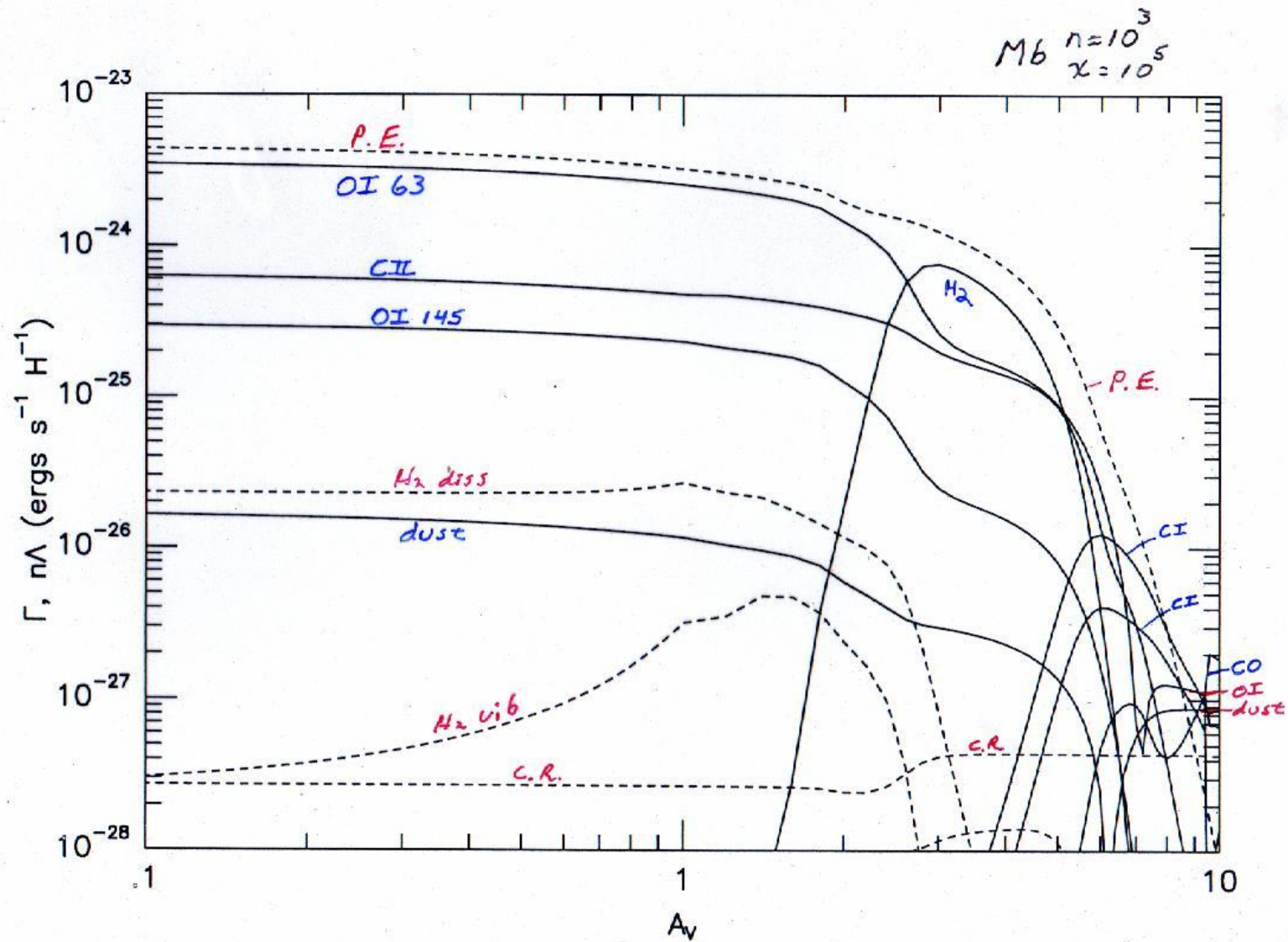
Heating:
Grain Photoelectric
Photo ionization CI
Cosmic Ray
 H_2 vib
 H_2 diss

Cooling:
CII
OI 63 145
CI 370 610
SiII 35
CO, H_2 , OH, H_2O
grains
Ly α + OI, CI

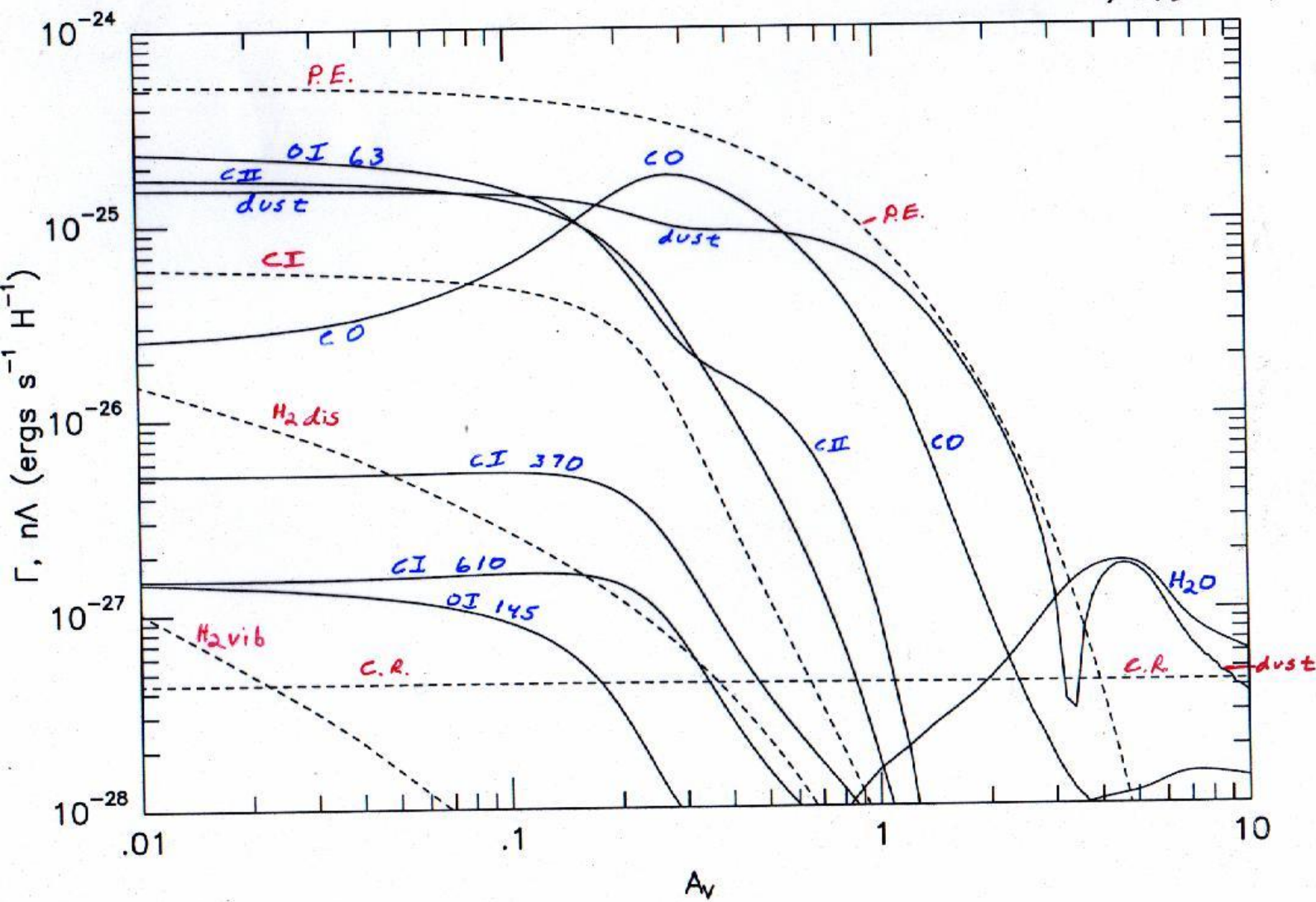
Plus minor process: S, FeI, FeII
Recombination

M5 $n=10^3$
 $\chi=10$

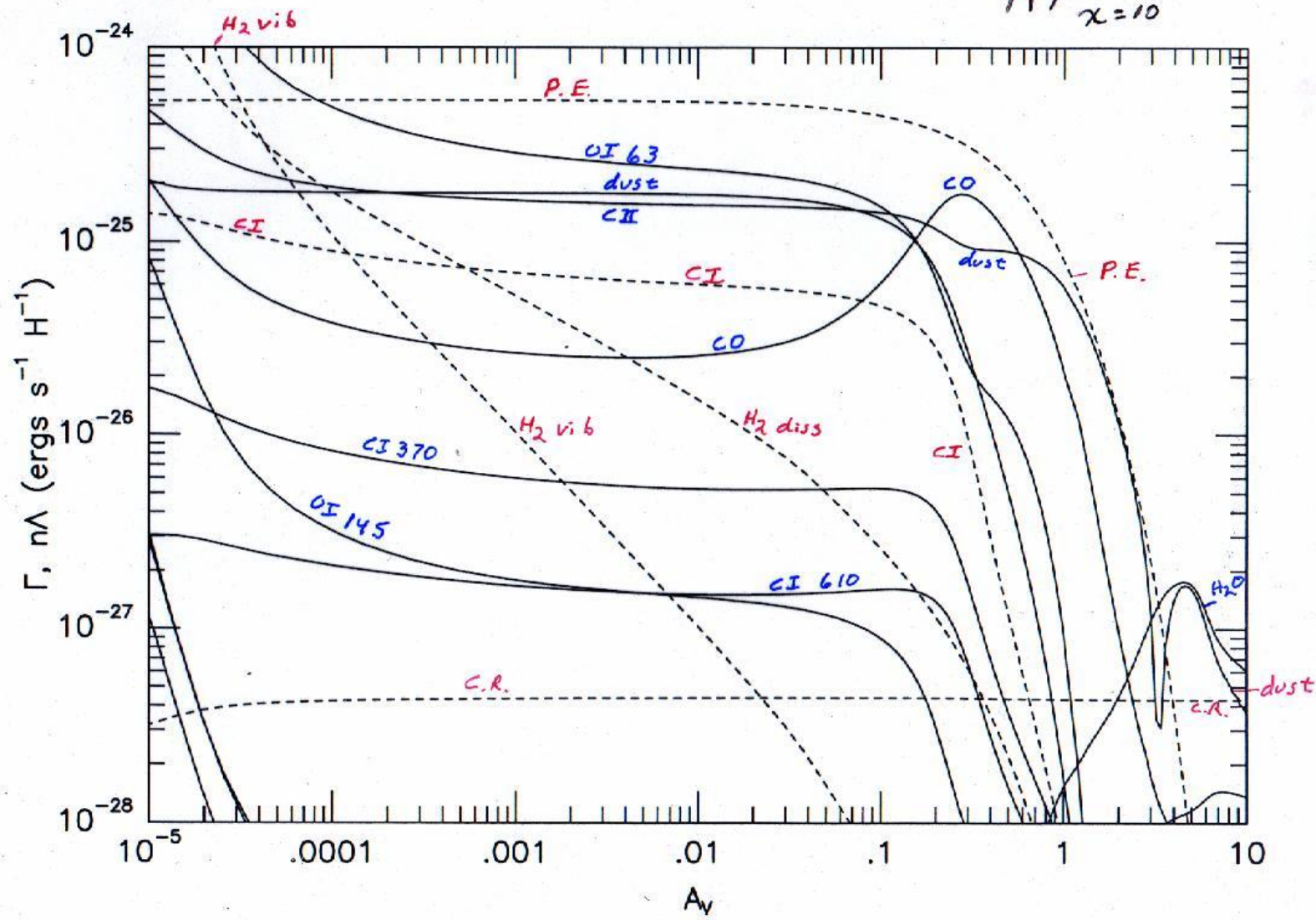




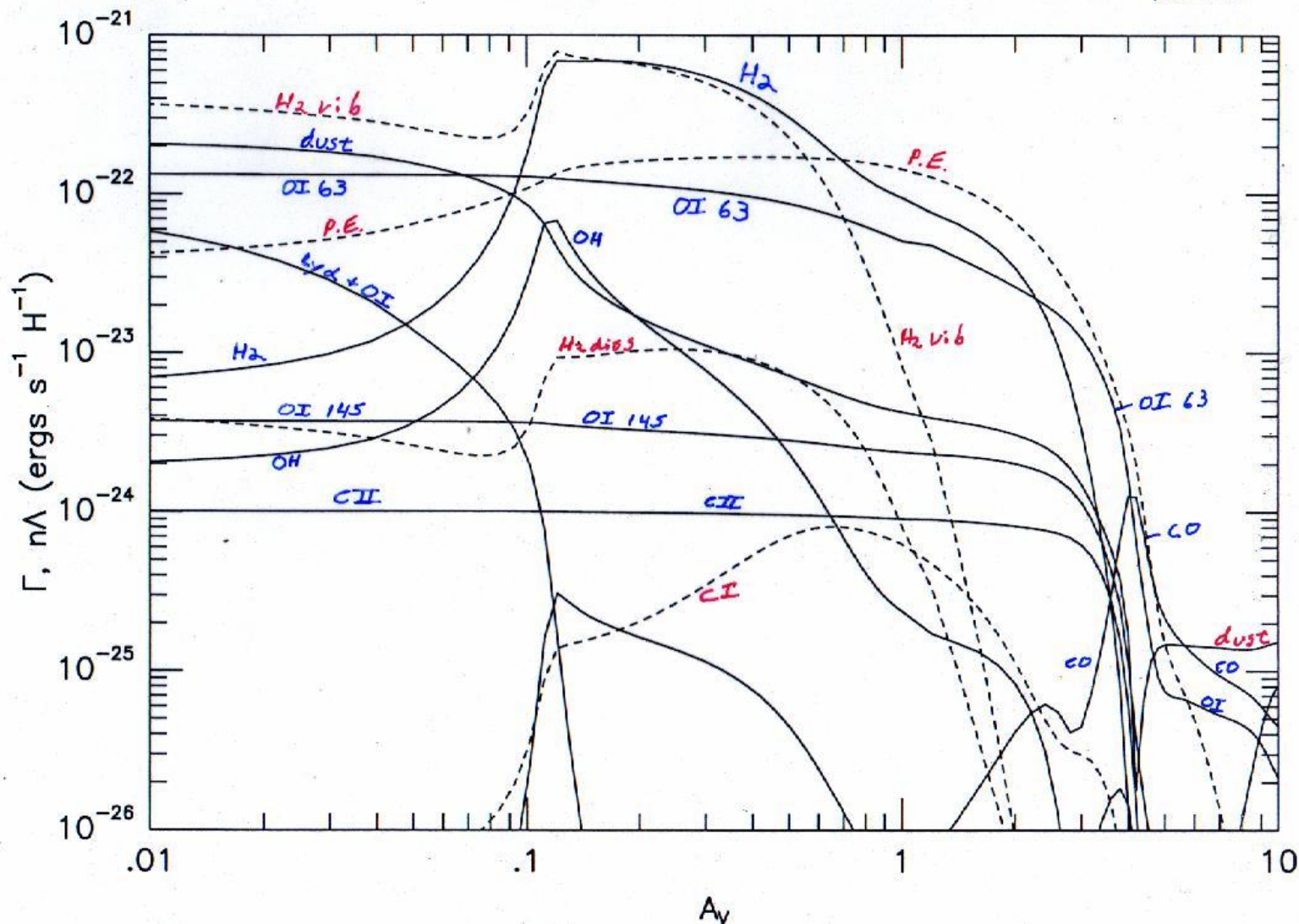
M7 $n=10$ ^{5.5}
 $\chi=10$



M7 $n=10^{5.5}$
 $\chi=10$



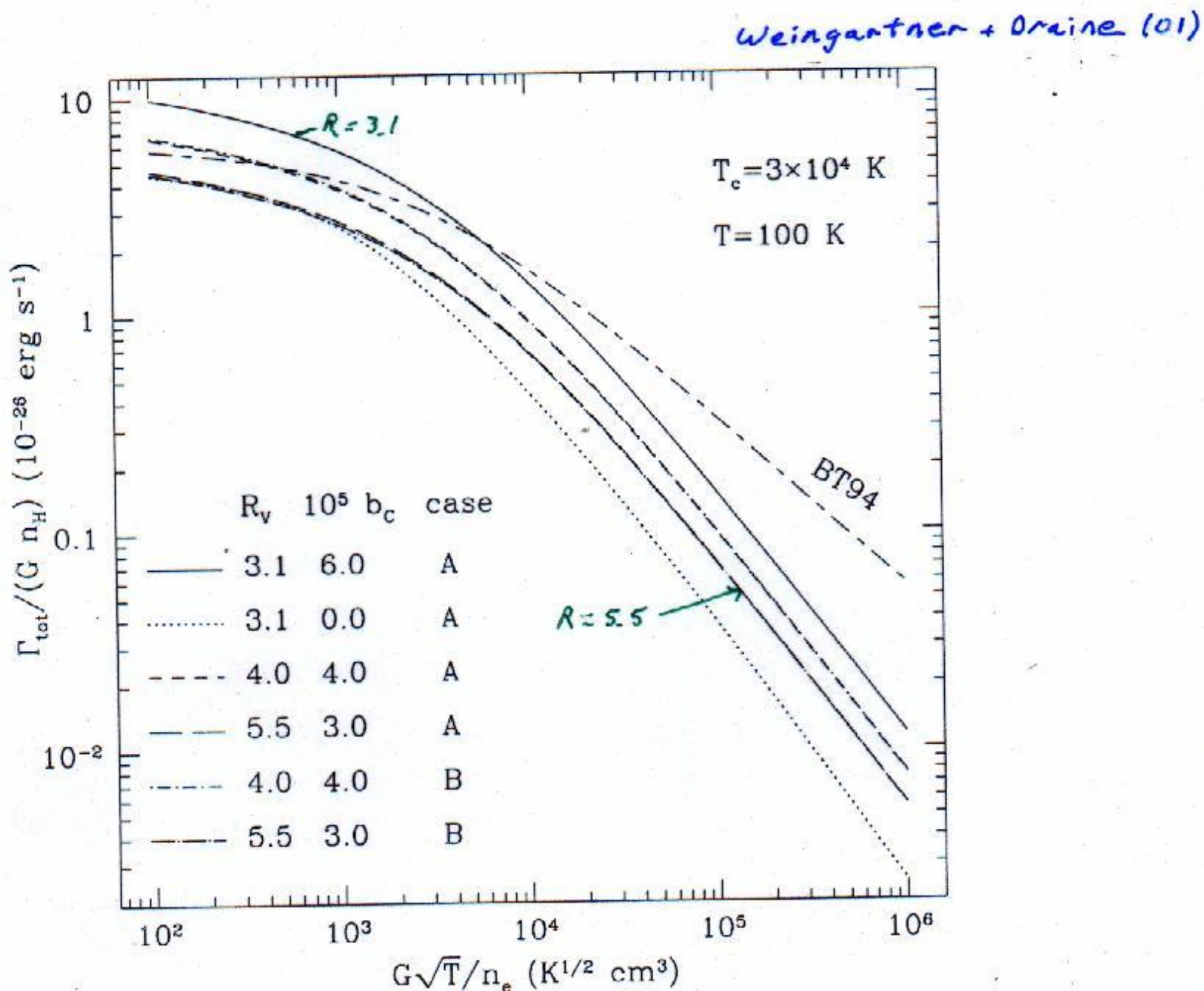
M8 $n=10$
 $\chi=10^5$ 5.5

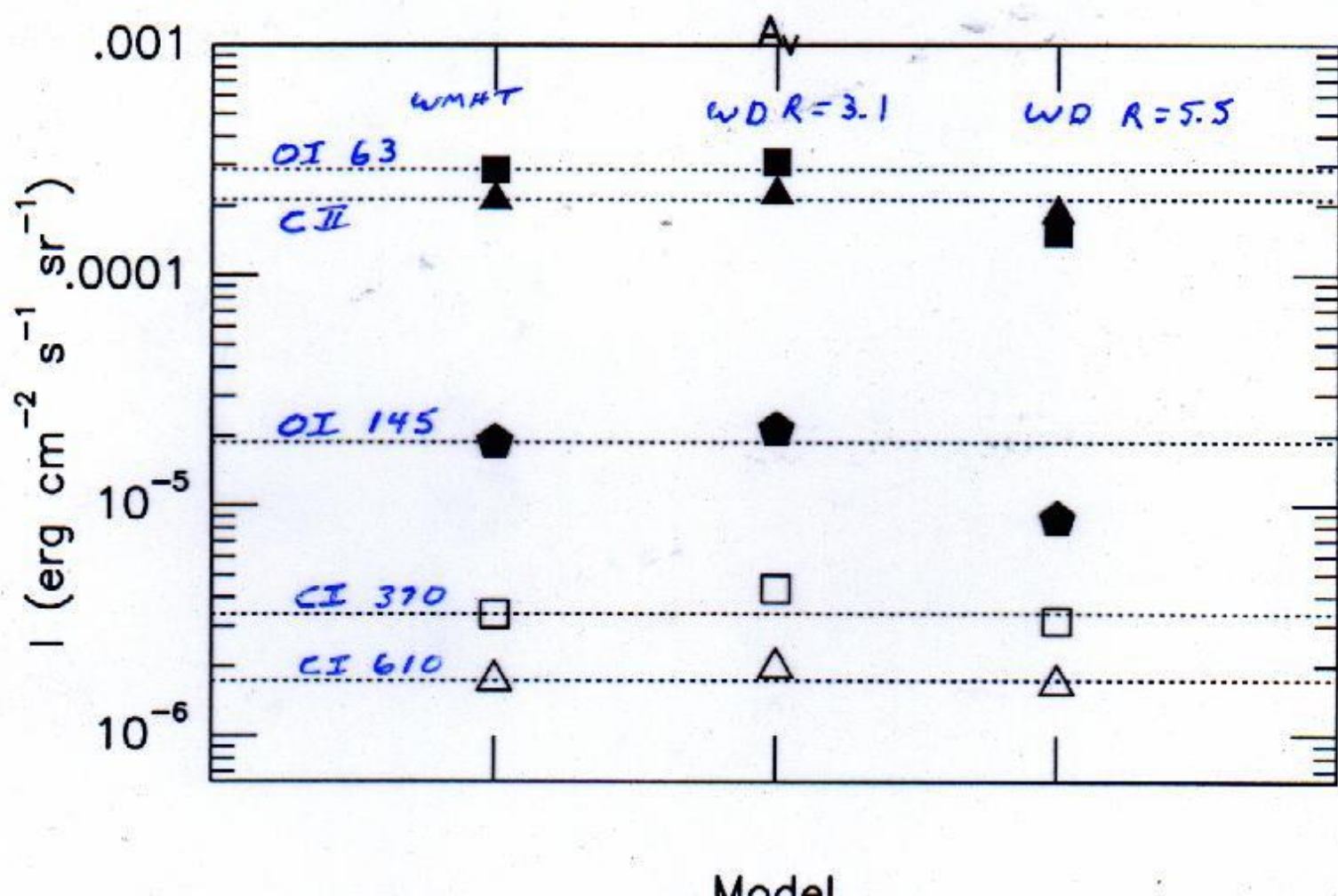
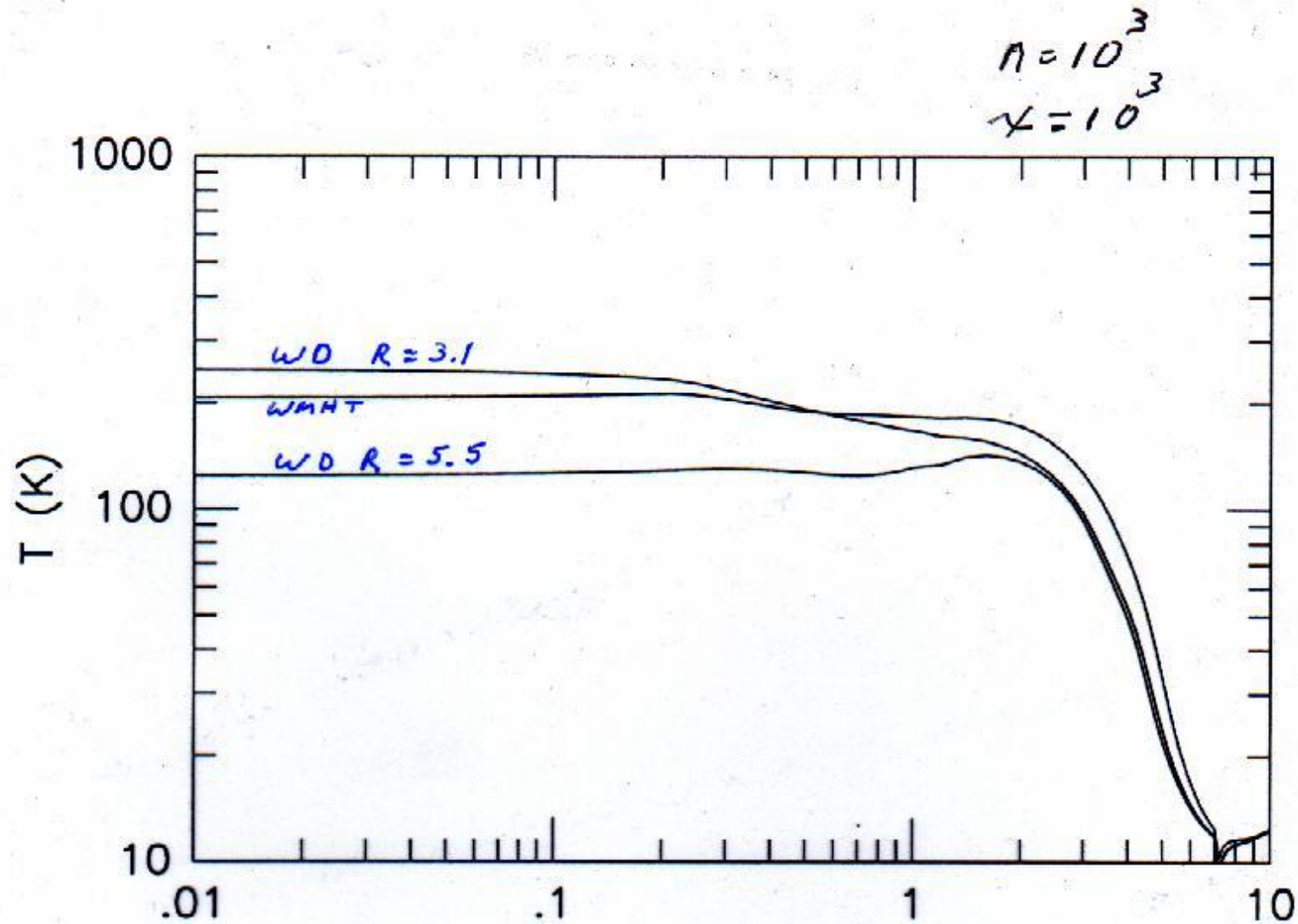


$$n\Gamma_{pe} = 1.3 \times 10^{-24} n\epsilon G \quad \text{erg cm}^{-3} \text{ s}^{-1}$$

$$\epsilon = \frac{4.9 \times 10^{-2}}{1 + 4.0 \times 10^{-3} \left(\frac{GT^{1/2}}{n_e \phi_{PAH}} \right)^{0.73}} + \frac{3.7 \times 10^{-2} (T/10^4)^{0.7}}{1 + 2.0 \times 10^{-4} \left(\frac{GT^{1/2}}{n_e \phi_{PAH}} \right)}$$

(Bakes & Tielens 1994) with $G = 1.7G_0 e^{-1.8A_V}$ and $\phi_{PAH} \simeq 0.5$ (Wolfire et al. 2003).





H₂ Vibration Heating

$$n\Gamma = 2 \text{ eV} \times 1.6 \times 10^{-12} \gamma_{1-0} n_{\text{H}} n_{\text{H}_2^*} \text{ (erg cm}^{-3} \text{ s}^{-1}\text{)}$$

(Burton, Hollenbach, & Tielens 1990)

Cosmic-Ray Heating

Molecular gas:

$$n\Gamma = 10 \text{ eV per H}_2 \text{ ionization}$$

(Maloney, Hollenbach, & Tielens 1996)

Atomic gas:

$$n\Gamma < 10 \text{ eV per H ionization (function of } e/n\text{)}$$

(van Steenberg & Shull 1988)

Dominant Cooling Rates

[C II] 158 μm : H - Flower 1990 fit to Launay & Roueff (1977)

$$\gamma = 8.86 \times 10^{-10} \text{ cm}^{-3} \text{ s}^{-1}$$

[O I] 63 μm , 145 μm : Rates from Péquignot (1990) (H, H^+ , and e from $40 \text{ K} < 2 \times 10^4 \text{ K}$. Low temperature rates are from Launay & Roueff 1977).

$$\Omega = 9.18 \times 10^{-3} (T/10^3)^{0.9} \quad 65.6 \text{ K} < T < 989 \text{ K}$$

$$\gamma = 8.63 \times 10^{-6} \Omega T^{-0.5} / 3$$

[C I] 370 μm , 610 μm : H - Launay & Roueff (1977) fit by Hollenbach & McKee (1989)

$$\gamma = 1.6 \times 10^{-10} (T/100)^{0.14}$$

H_2 Vibration and Rotation: Fit by Hollenbach & McKee (1979) with updated rates from Burton, Hollenbach, & Tielens (1990).

$$\Lambda = \frac{\Lambda_r(LTE)}{1+(n_{\text{cr},r}/n)} + \frac{\Lambda_v(LTE)}{1+(n_{\text{cr},v}/n)}$$

Plus collisions with H_2 , e as in summary

CO: Tielens & Hollenbach 1985, de Jong, Chu, & Dalgarno 1975

Dust-Gas: Hollenbach & McKee (1989)

$$\Lambda = 1.2 \times 10^{-31} \left(\frac{T}{1000} \right)^{1/2} + [1.0 - 0.8 \exp(-75/T)](T_{\text{grain}} - T)$$

OH: Fits by Uma Gorti and Michael Kaufman from Offer & van Dishoeck (1992)

H₂O: Fits by Uma Gorti and Michael Kaufman from Phillips, Maluendes, & Green (1996)