THERMAL BALANCE

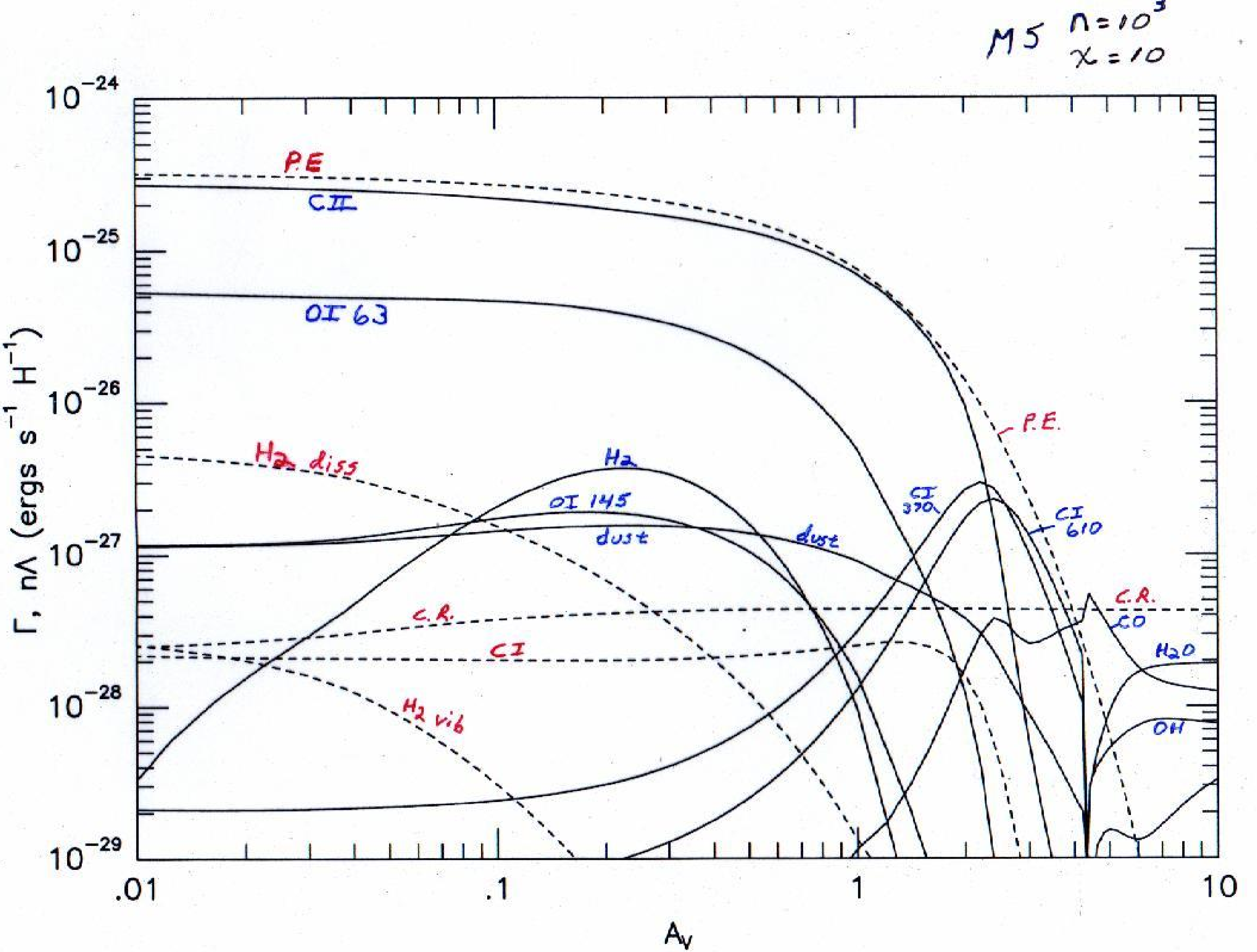
Heating Rates: Rate equations
Grain size distributions
H_2 treatment

Cooling Rates: Rate coefficients
Radiation transfer

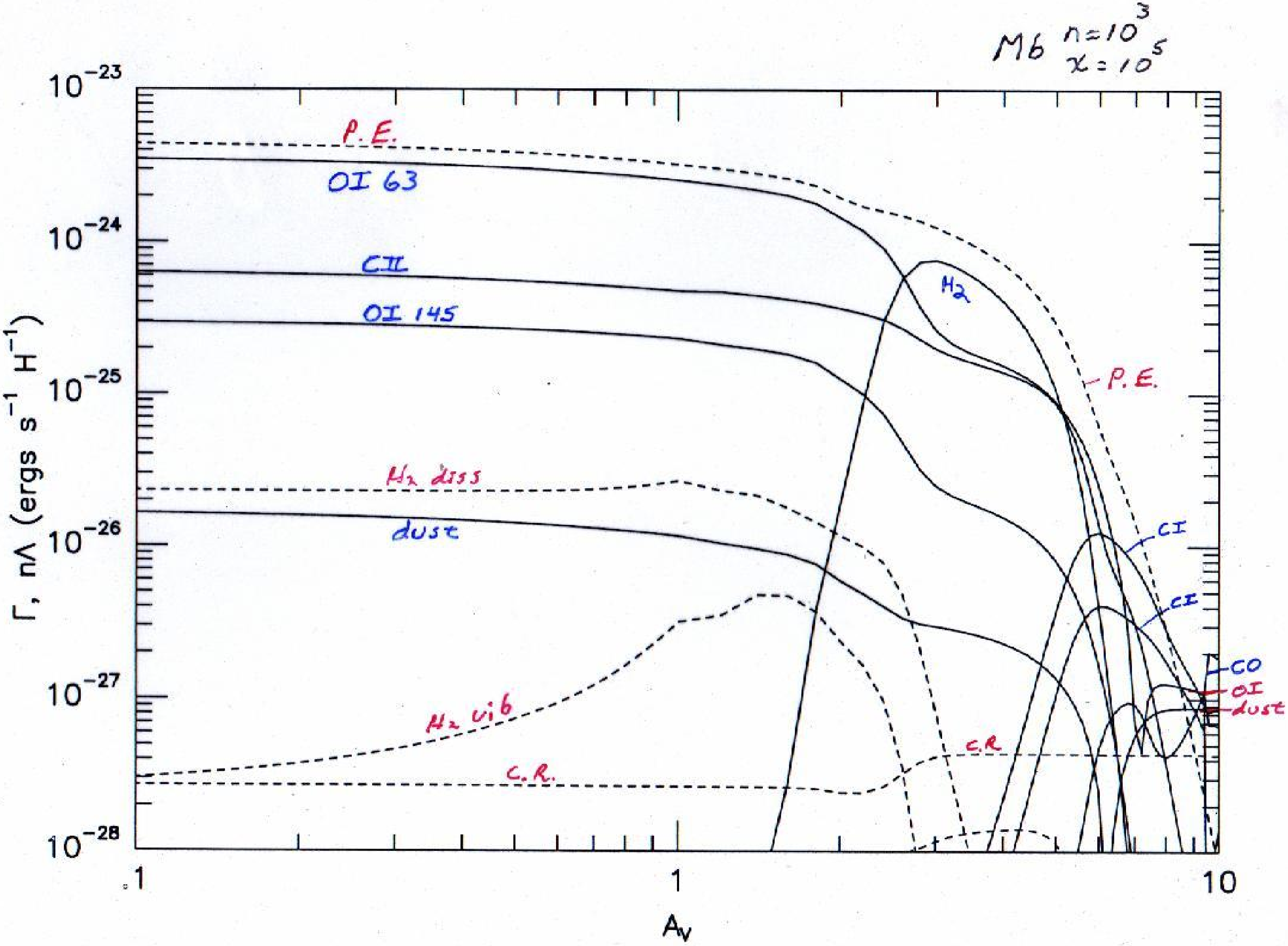
Temperature: Differences
Line Intensities

Heating:	Cooling:
Grain Photoelectric	CII
Photoionization CI	OI 63 145
Cosmic Ray	CI 370 610
H_2 vib	SiII 35
H_2 diss	CO, H_2, OH, H_2O
	grains
	Lyα + OI, CI

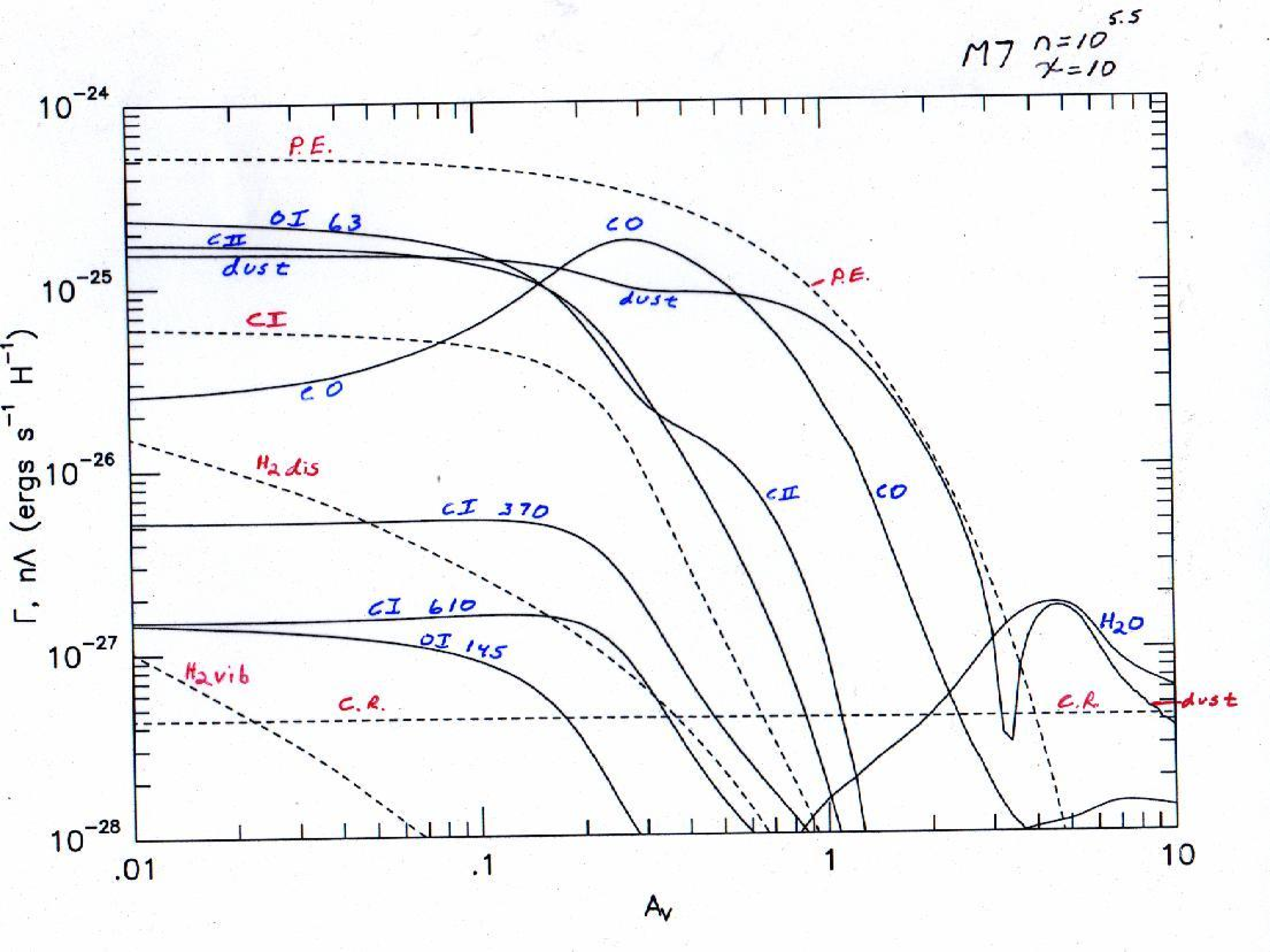
Plus minor process: S, FeI, FeII
Recombination



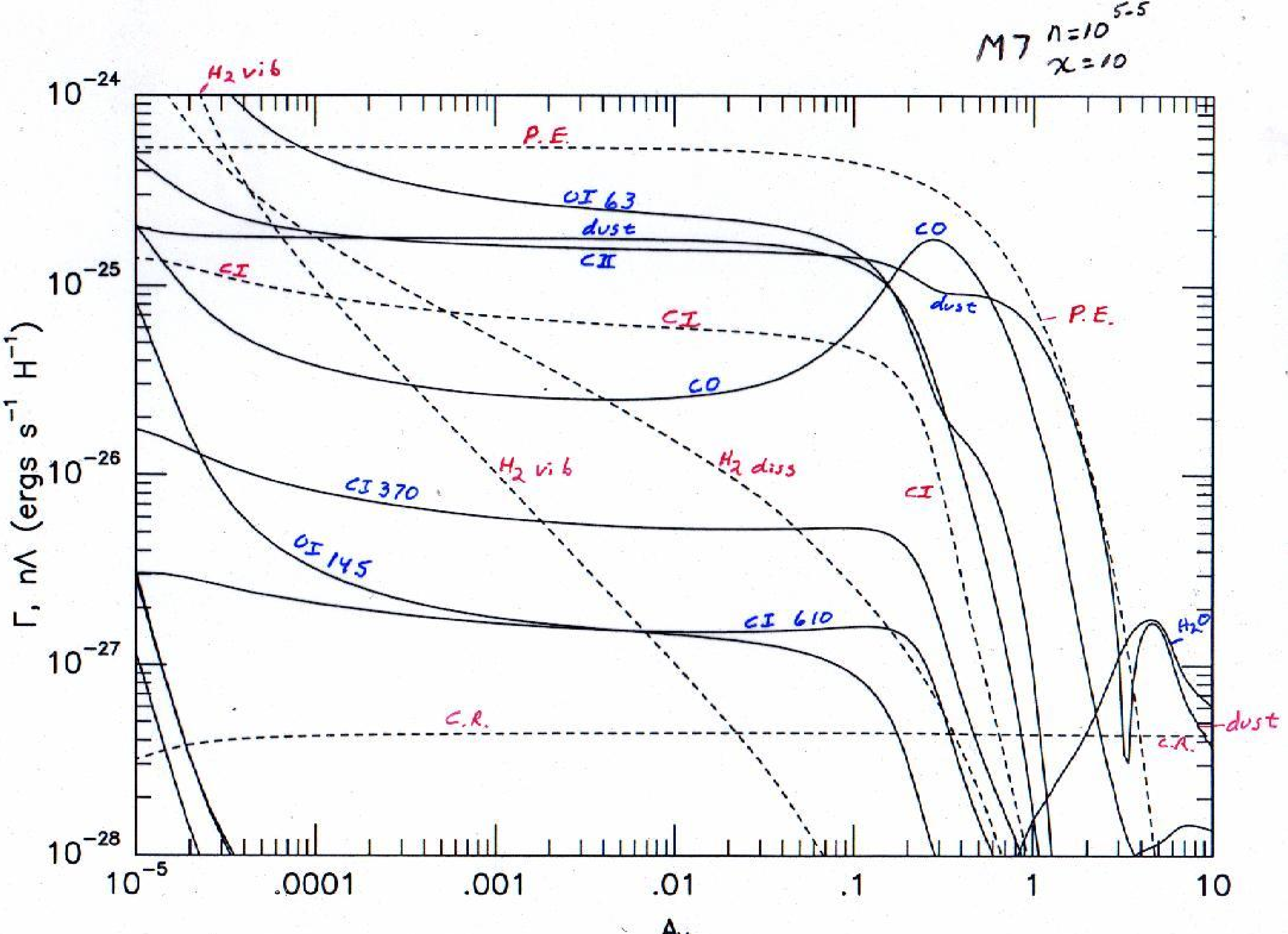
M5 n=10^3
χ=10
P.E
CII
OI 63
H2 diss
H2
OI 145
dust
dust
P.E.
CI 370
CI 610
C.R.
CI
H2 vib
C.R.
CO
H2O
OH
Γ, nΛ (ergs s^-1 H^-1)
A_V
10^-24
10^-25
10^-26
10^-27
10^-28
10^-29
.01
.1
1
10

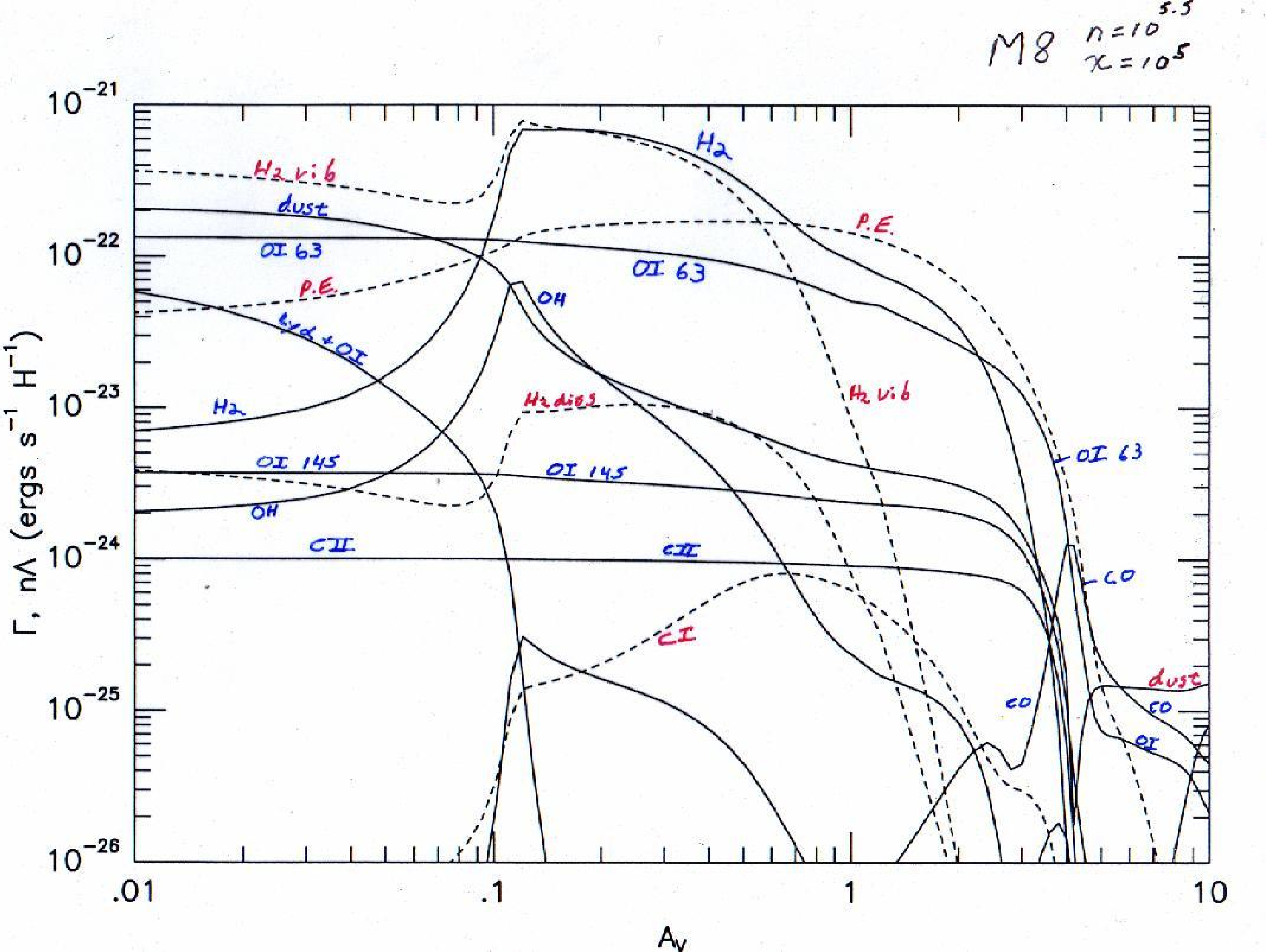


Mb n=10^3 χ=10^5
10^-23
10^-24
10^-25
10^-26
10^-27
10^-28
Γ, nΛ (ergs s^-1 H^-1)
.1
1
10
A_V
P.E.
OI 63
CII
H2
OI 145
P.E.
H2 diss
dust
CI
CI
CO
OI
dust
H2 vib
C.R
C.R.



M7 n=10^5.5
χ=10
P.E.
OI 63
CII
dust
CO
P.E.
dust
CI
CO
H2 dis
CI 370
CII
CO
CI 610
OI 145
H2O
H2 vib
C.R.
C.R.
dust
Γ, nΛ (ergs s⁻¹ H⁻¹)
A_V
10⁻²⁴
10⁻²⁵
10⁻²⁶
10⁻²⁷
10⁻²⁸
.01
.1
1
10


M7 $n=10^{5.5}$ $\chi=10$
H_2 vib
P.E.
OI 63
dust
CII
CO
CI
dust
P.E.
CO
H_2 vib
H_2 diss
CI 370
CI
OI 145
CI 610
H_2O
C.R.
dust
C.R.
Γ, nΛ (ergs s⁻¹ H⁻¹)
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-5}
.0001
.001
.01
.1
1
10
A_V



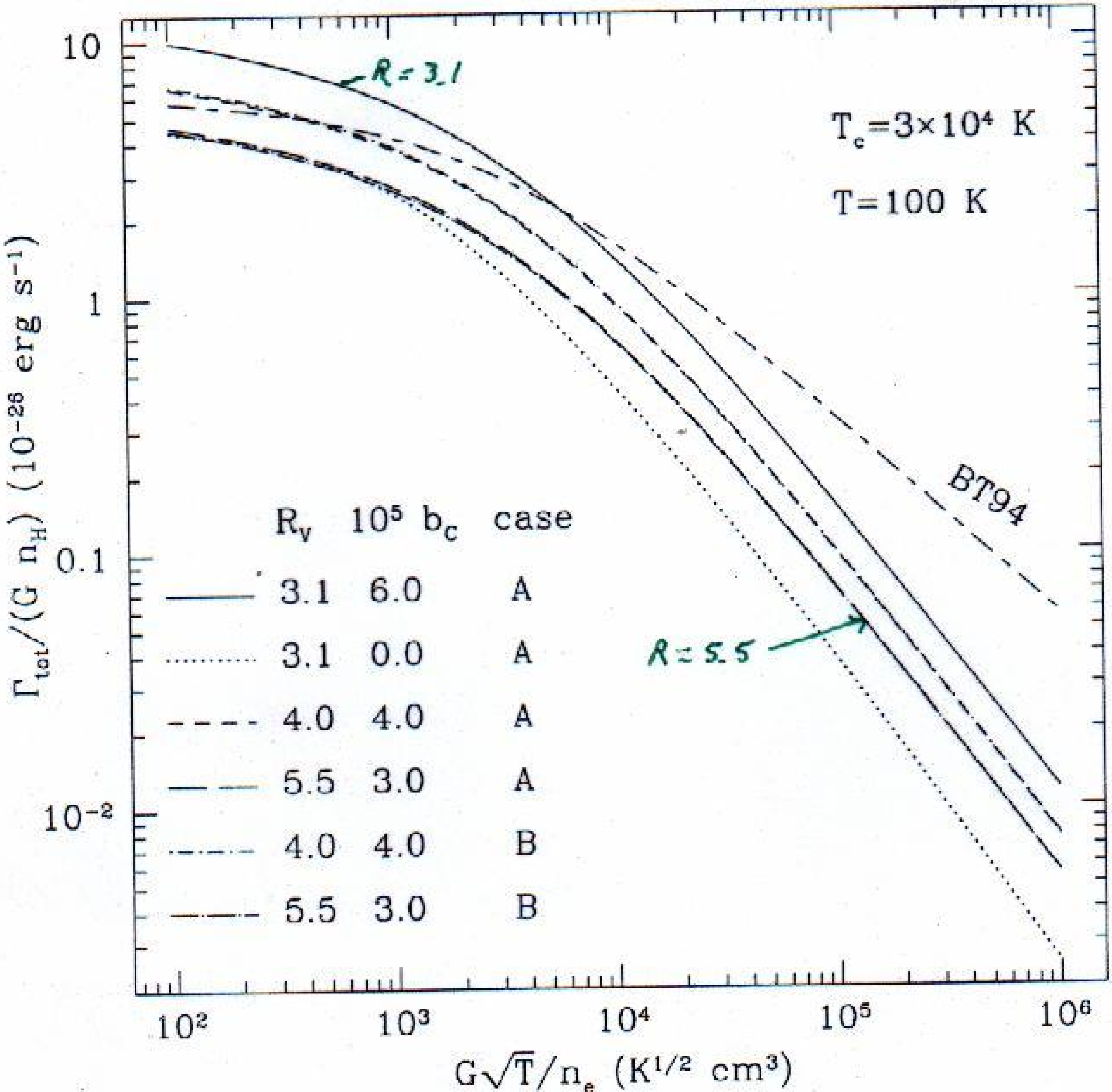
M8 $n=10^{5.5}$ $\chi=10^5$
Γ, $n\Lambda$ (ergs s^{-1} H^{-1})
A_V
H2 vib
dust
OI 63
P.E.
H2
OH
Lyα + OI
H2 diss
OI 145
CII
CI
CO
OI

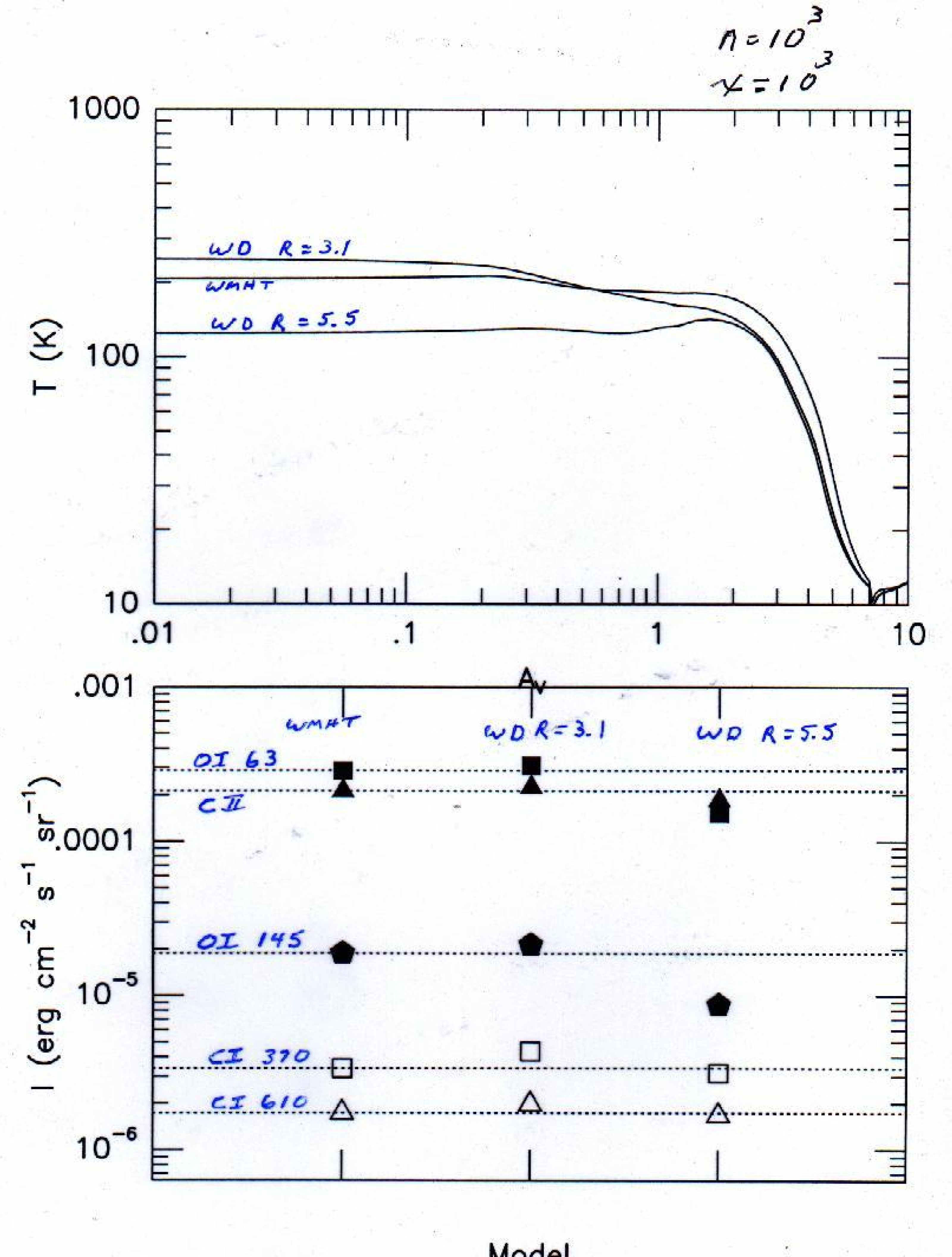
$$n\Gamma_{\rm pe} = 1.3 \times 10^{-24} n\epsilon G \quad {\rm erg\ cm^{-3}\ s^{-1}}$$

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

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

Weingartner + Draine (01)





n = 10^3
χ = 10^3
1000
100
10
T (K)
.01
.1
1
10
A_V
WD R = 3.1
WMAT
WD R = 5.5
.001
.0001
10^-5
10^-6
I (erg cm^-2 s^-1 sr^-1)
WMAT
WD R = 3.1
WD R = 5.5
OI 63
CII
OI 145
CI 370
CI 610
Model

H_2 Vibration Heating

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

(Burton, Hollenbach, & Tielens 1990)

Cosmic-Ray Heating

Molecular gas:

$n\Gamma = 10$ eV per H_2 ionization
(Maloney, Hollenbach, & Tielens 1996)

Atomic gas:

$n\Gamma < 10$ eV per H ionization (function of e/n)
(van Steenberg & Shull 1988)

Dominant Cooling Rates

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

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

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

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

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

[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).

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

Plus collisions with H_2, e as in summary

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

Dust-Gas: Hollenbach & McKee (1989)

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

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

H_2O: Fits by Uma Gorti and Michael Kaufman from Phillips, Maluendes, & Green (1996)