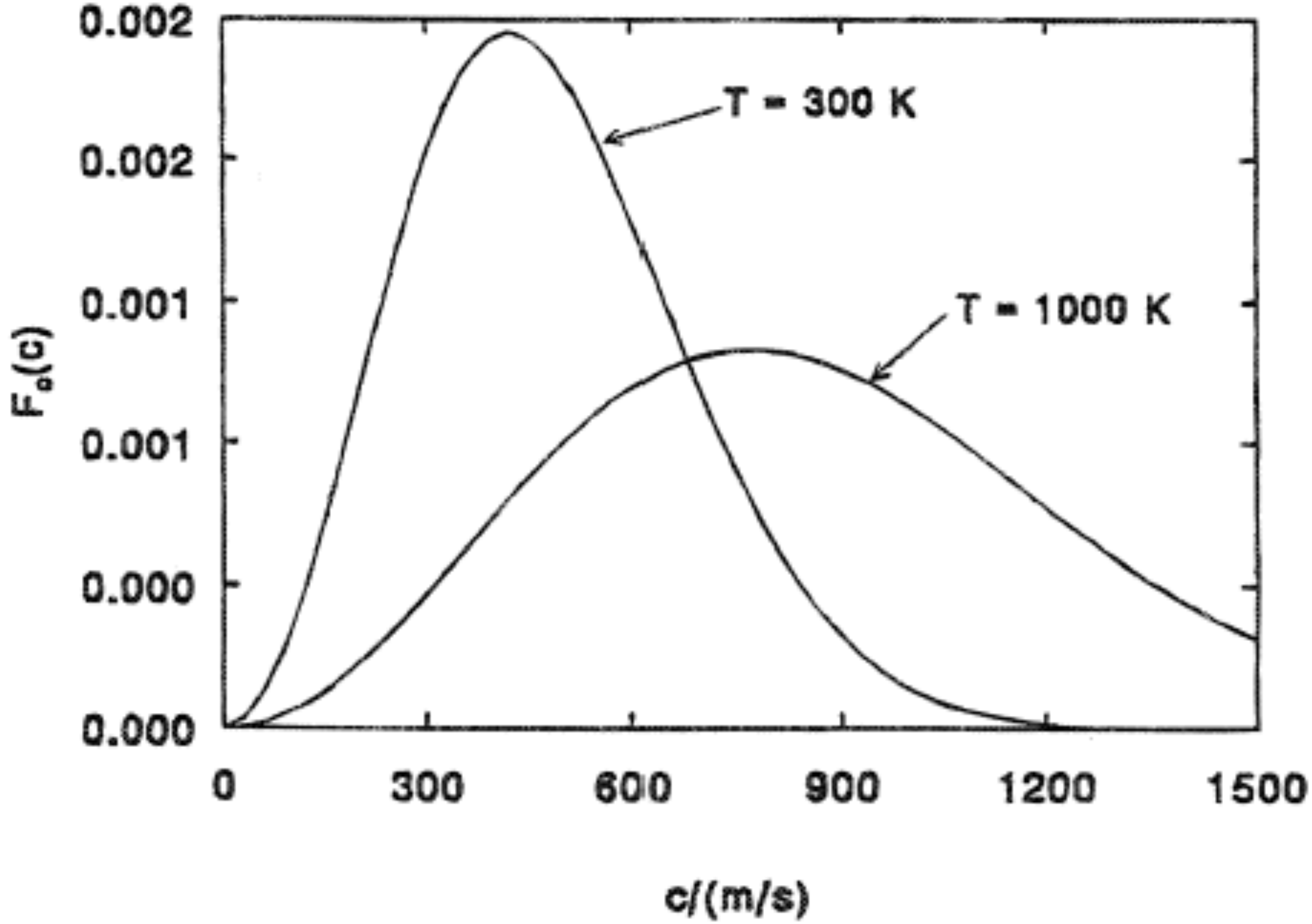
Chapt 3 Heating and cooling

- Free electrons have a kinetic temperature, the only real temperature in the gas
- Heating is any process that gives energy to the gas, increasing the temperature
- Cooling is any process that removes energy from the gas, lowering the temperature
- Thermal equilibrium is when heating and cooling rates match

- Often radiation is the only heating & cooling

A Maxwellian velocity distribution



For N_2, depends on mass http://www.thermopedia.com/content/942

Thermal equilibrium

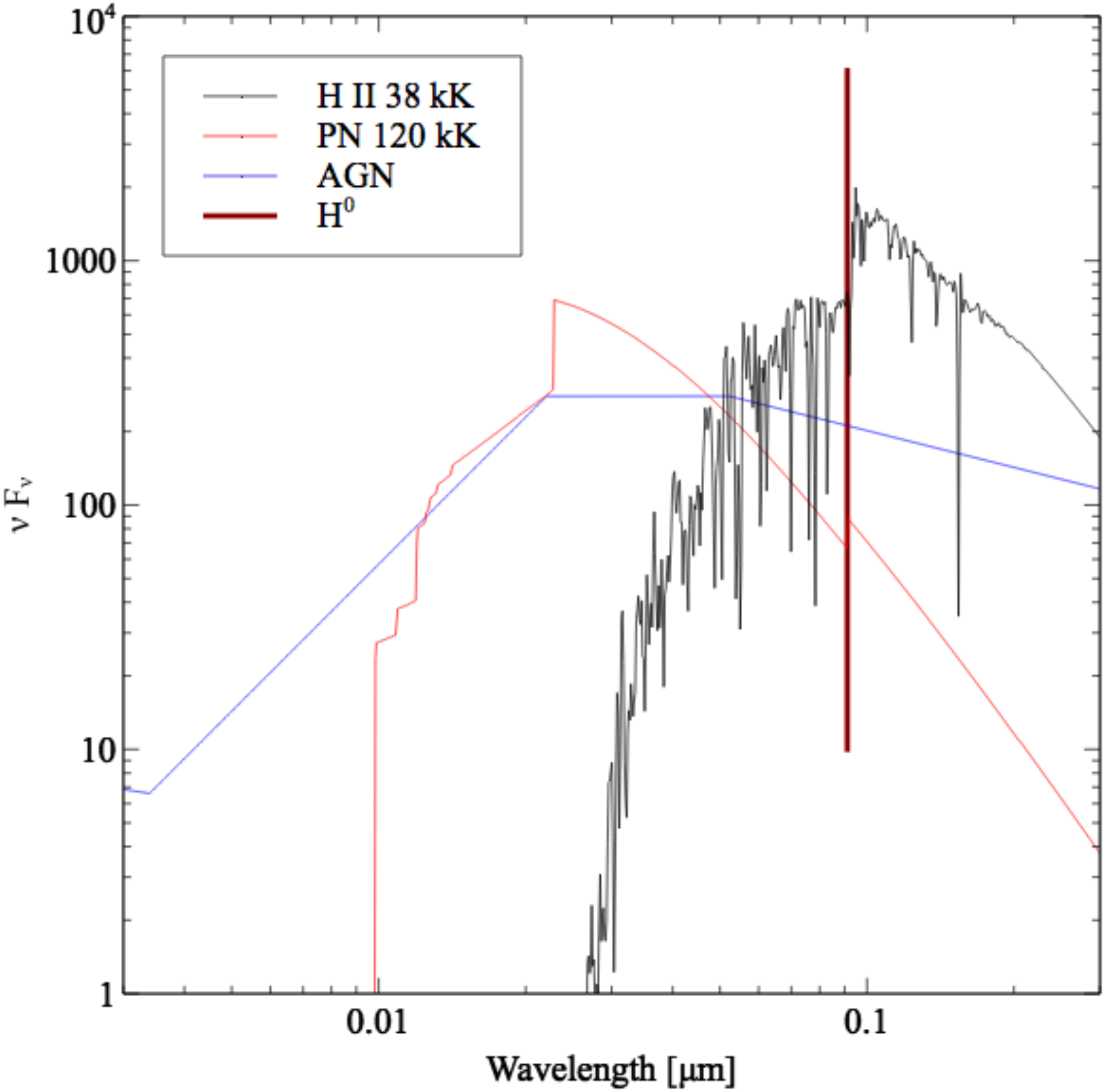
- **Heating by radiation field in photo case**
- **In coronal case external process sets temperature**
- **Cooling is anything that converts kinetic energy into light that escapes**

Photoelectric heating

$$G(\mathrm{H}) = n(\mathrm{H}^0) \int_{\nu_0}^{\infty} \frac{4\pi J_\nu}{h\nu} h\left(\nu - \nu_0\right)\ a_\nu(\mathrm{H}^0)\, d\nu\ [\mathrm{erg\ cm^{-3} s^{-1}}]. \qquad (3.1)$$

- **Depends on SED shape**

SED, H^0 ion limit, photoelectron energy



SED	<hν-13.6eV>
H II	52.7 kK
PN	266 kK
AGN	321 kK
Thermal	10 – 20 kK

Ionization parameter

- **Dimensionless ratio of hydrogen to ionizing photon densities**

$$U = \frac{1}{4\pi r^2 c n_{\rm H}} \int_{\nu_0}^{\infty} \frac{L_\nu}{h\nu} d\nu = \frac{Q\left(\mathrm{H}^0\right)}{4\pi r^2 c n_{\rm H}}, \tag{14.7}$$

$$\begin{aligned} n(X^{+i}) \int_{\nu_i}^{\infty} \frac{4\pi J_\nu}{h\nu} a_\nu(X^{+i}) d\nu &= n(X^{+i}) \Gamma(X^{+i}) \\ &= n(X^{+i+1}) n_e \alpha_G(X^{+i}, T), \end{aligned} \tag{2.30}$$

Xi – an x-ray ionization parameter

Hazy 1

5.16 xi -0.1

Tarter et al. (1969); Krolik et al. (1981); Kallman and Bautista (2001) define an ionization parameter ξ given by

$$\xi = (4\pi)^2 \int_{1R}^{1000R} J_\nu d\nu / n(\mathrm{H}) \approx \frac{L_{ion}}{n(\mathrm{H})\, r^2} [\mathrm{erg\ cm\ s^{-1}}] \quad (5.12)$$

Photoelectric heating

- **Heating proportional to photoionization rate, which is equal to n_e n_p α, the recombination rate**
- **Heating depends on density squared**

$$G(\mathrm{H}) = n_e n_p \alpha_A(\mathrm{H}^0, T) \frac{\displaystyle\int_{\nu_0}^{\infty} \frac{4\pi J_\nu}{h\nu} h(\nu - \nu_0) a_\nu(\mathrm{H}^0)\, d\nu}{\displaystyle\int_{\nu_0}^{\infty} \frac{4\pi J_\nu}{h\nu} a_\nu(\mathrm{H}^0)\, d\nu} \tag{3.2}$$

$$= n_e n_p \alpha_A(\mathrm{H}^0, T) \frac{3}{2} kT_i$$

Let’s try different SEDs

- Density 1 cm^{-3}, constant temperature, one zone, same ionization parameter
- Report “Average nu” and “Te” in main output

SED	Average nu	T(e)
BB 2.5e4 K		
BB 3e4 K		
BB 5e4 K		
BB 1e5 K		
BB 1.5e5 K		
Table agn		
Table power law		

Photoelectric heating vs depth

- **Dependence on depth**
  - Spectrum, heating, across H^+ region
  - Yesterday's hiis.in
  - Save continuum output
- **Save heating**

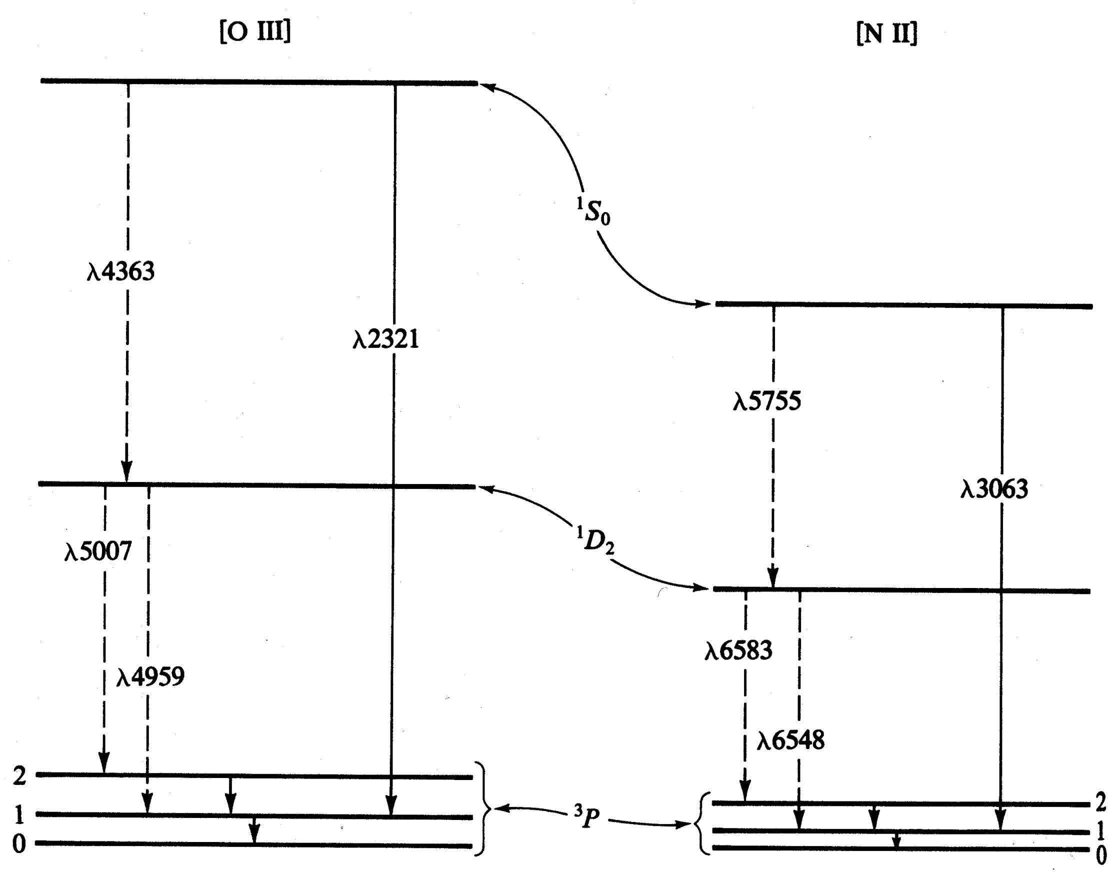
Cooling

- Anything that converts kinetic energy (heat) into light (which escapes)
- AGN3 Chap 3 lists a number of processes
- Collisional excitation of lines is normally the most important cooling process

$$L_C = n_e n_1 q_{12} h\nu_{21}. \tag{3.22}$$

[O III]

- **AGN3 Fig 3.1**

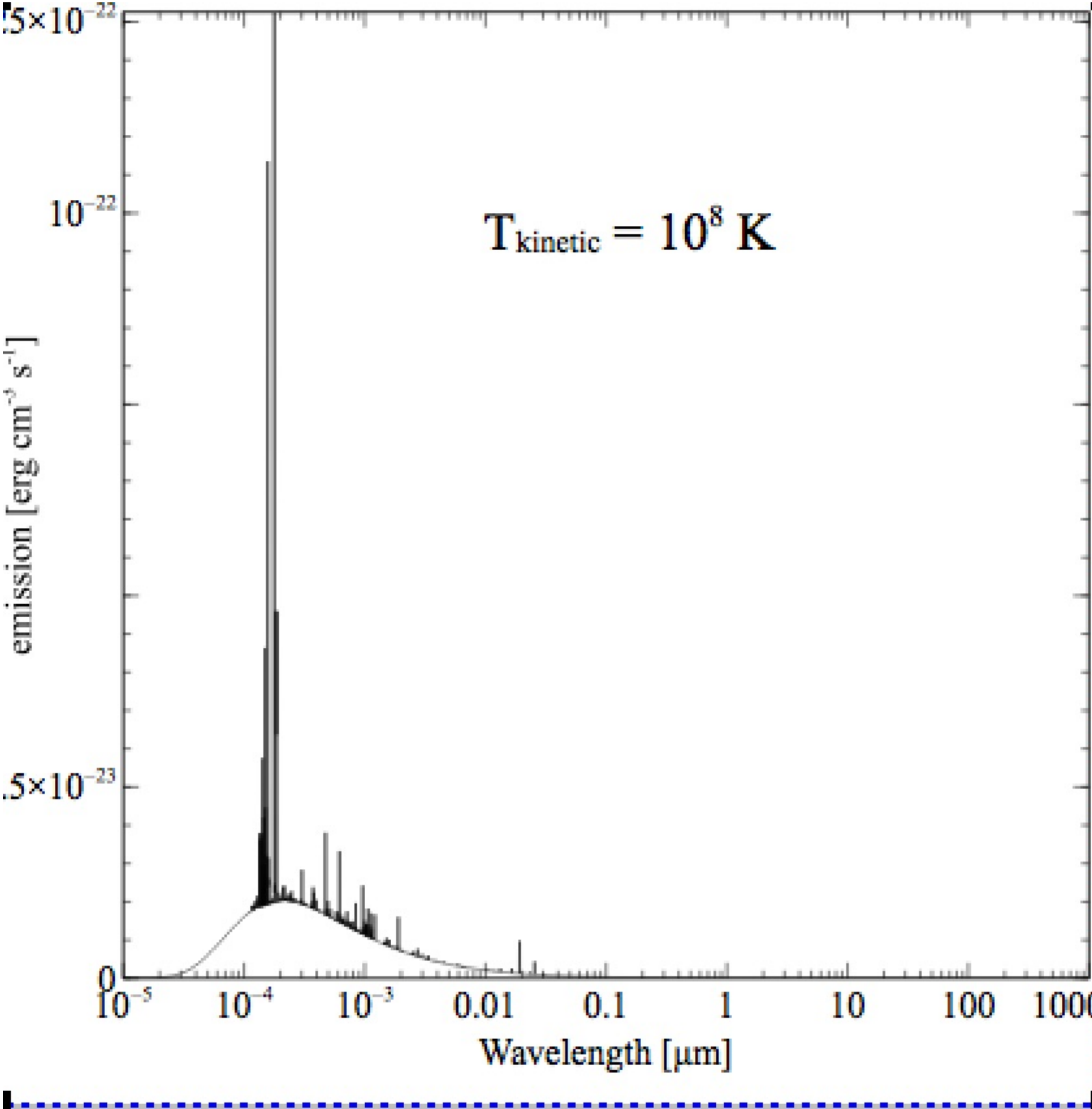


Coronal equilibrium

- Mechanical energy sets kinetic temperature
- "Coronal" command in Cloudy
- No ionizing radiation
- Collisional ionization, due to collision by thermal electrons

Try different temperatures

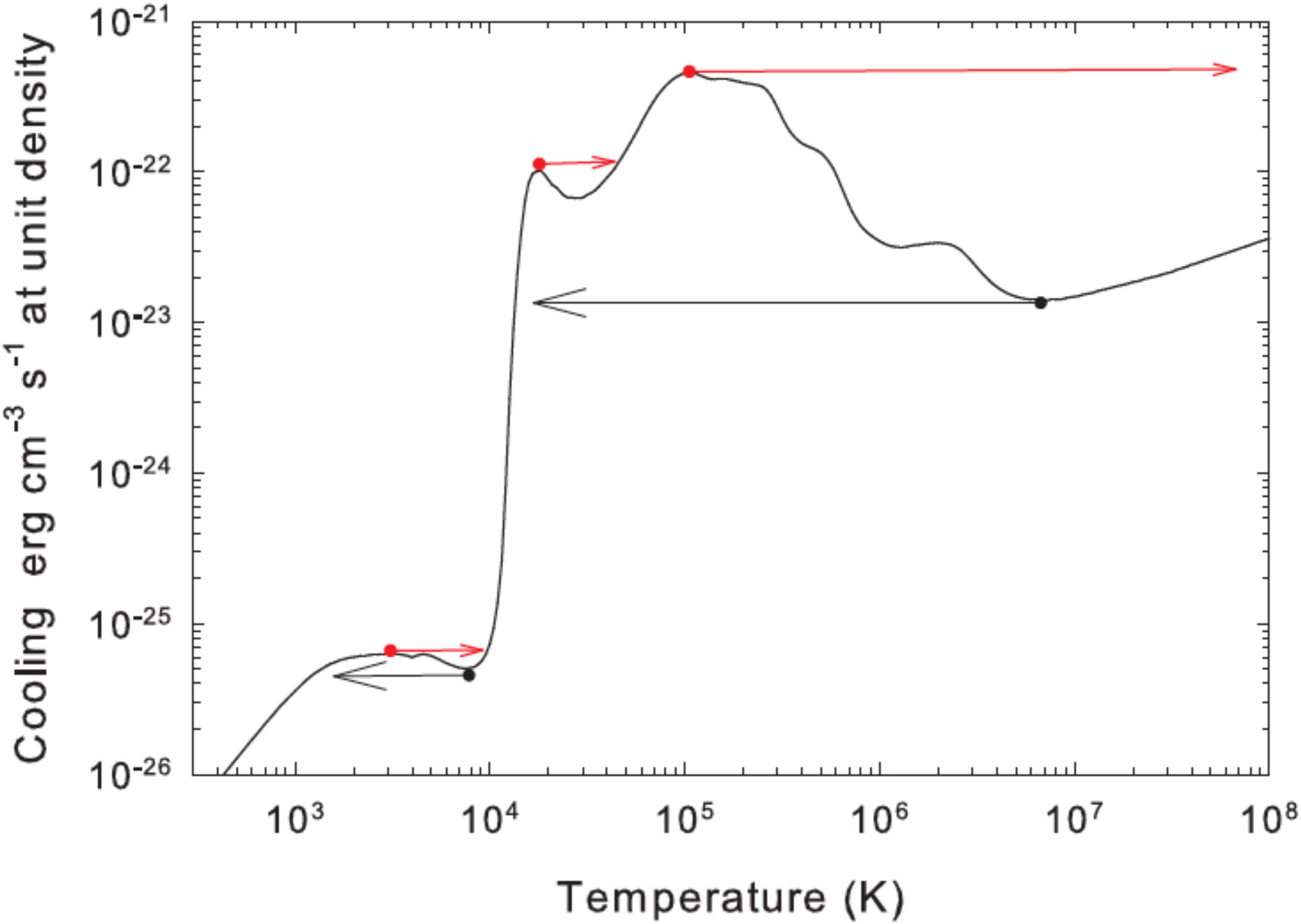
- **Coronal command**
  - Log T=2, 3, 4, 5, 6, 7, 8
- **Unit cell**
- **Must include "cosmic ray background" and grains when molecules are significant**
- **Plot spectrum**
  - X-axis log wavelength from 1e-4 to 1e3 microns
  - Y-axis linear intensity, with strongest line at the top



.5×10⁻²²
10⁻²²
.5×10⁻²³
0
emission [erg cm⁻³ s⁻¹]
T_kinetic = 10⁸ K
10⁻⁵
10⁻⁴
10⁻³
0.01
0.1
1
10
100
1000
Wavelength [μm]

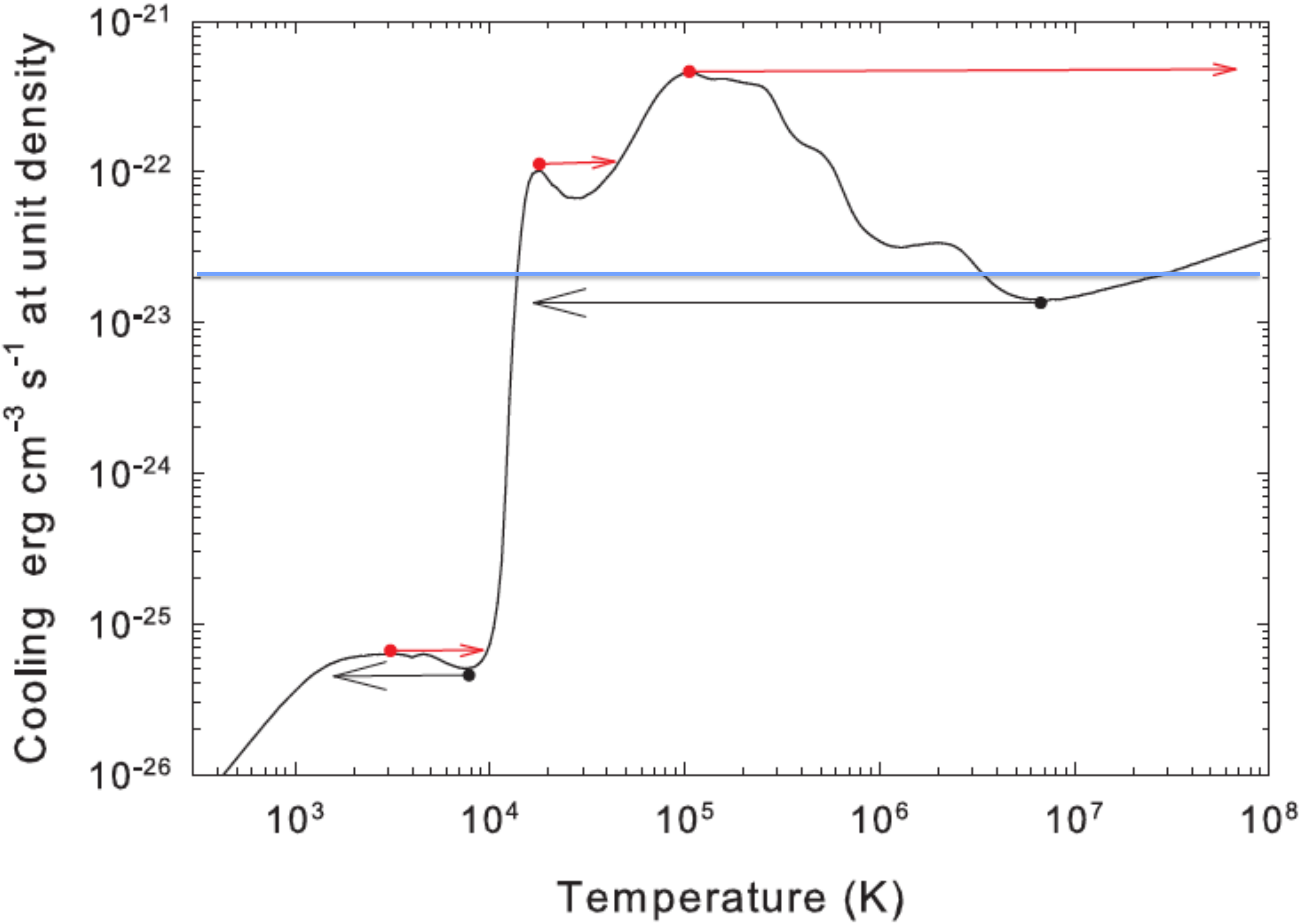
The grid command – Hazy1 Chap 18

- **Grid command allows a number of models to be computed in parallel**
- **Include “vary” keyword on commands with variable parameters**
- **“grid” command specifies lower, upper bounds, and step size**
  - coronal 8 vary
  - grid 2 8 0.25 log
  - Hazy 1 sec 18.5
- **“Save grid” command saves step parameters**
- **“No hash”, “last”, options on other save commands**



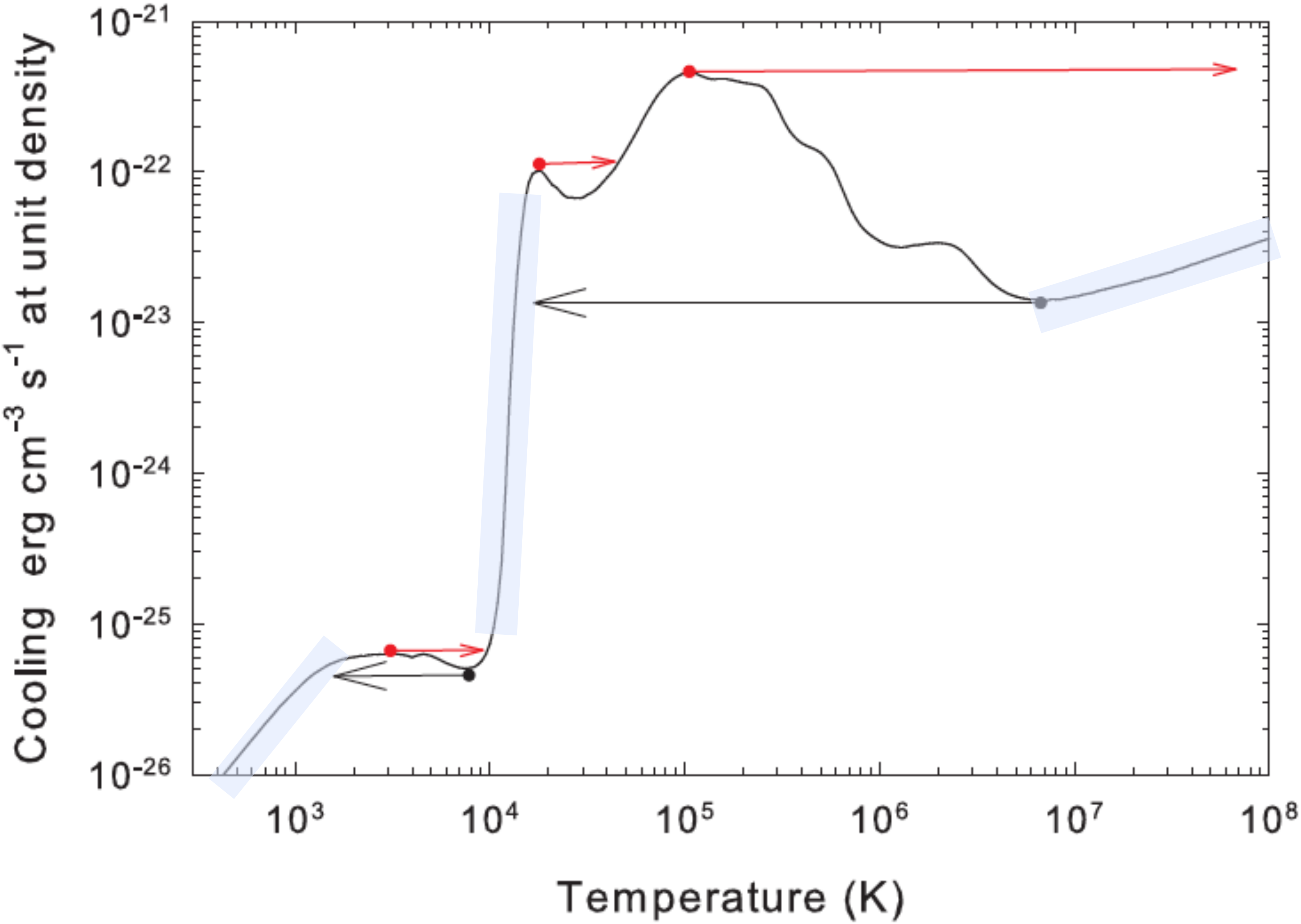
Dalgarno&McCray 1972 ARAA 10, 375

Ferland+09 MNRAS, 392, 1475



Dalgarno&McCray ARAA 10, 375

Ferland+09 MNRAS, 392, 1475



Dalgarno&McCray ARAA 10, 375

Ferland+09 MNRAS, 392, 1475

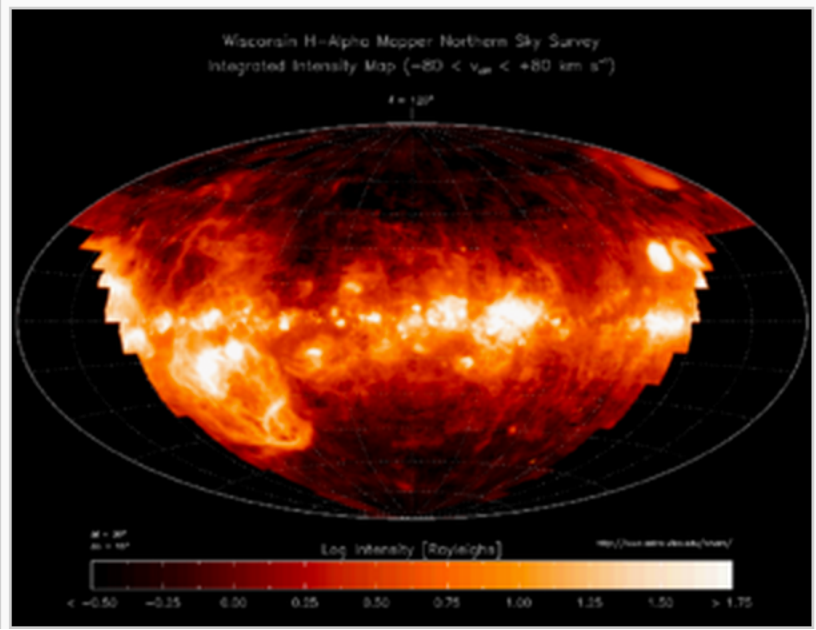
http://en.wikipedia.org/wiki/Interstellar_medium

Interstellar medium

From Wikipedia, the free encyclopedia

For other uses, see Interstellar (disambiguation).

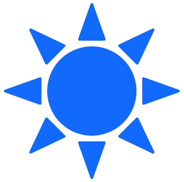
In astronomy, the **interstellar medium** (or **ISM**) is the matter that exists in the space between the star systems in a galaxy. This matter includes gas in ionic, atomic, and molecular form, dust, and cosmic rays. It fills interstellar space and blends smoothly into the surrounding intergalactic space. The energy that occupies the same volume, in the form of electromagnetic radiation, is the **interstellar radiation field**.



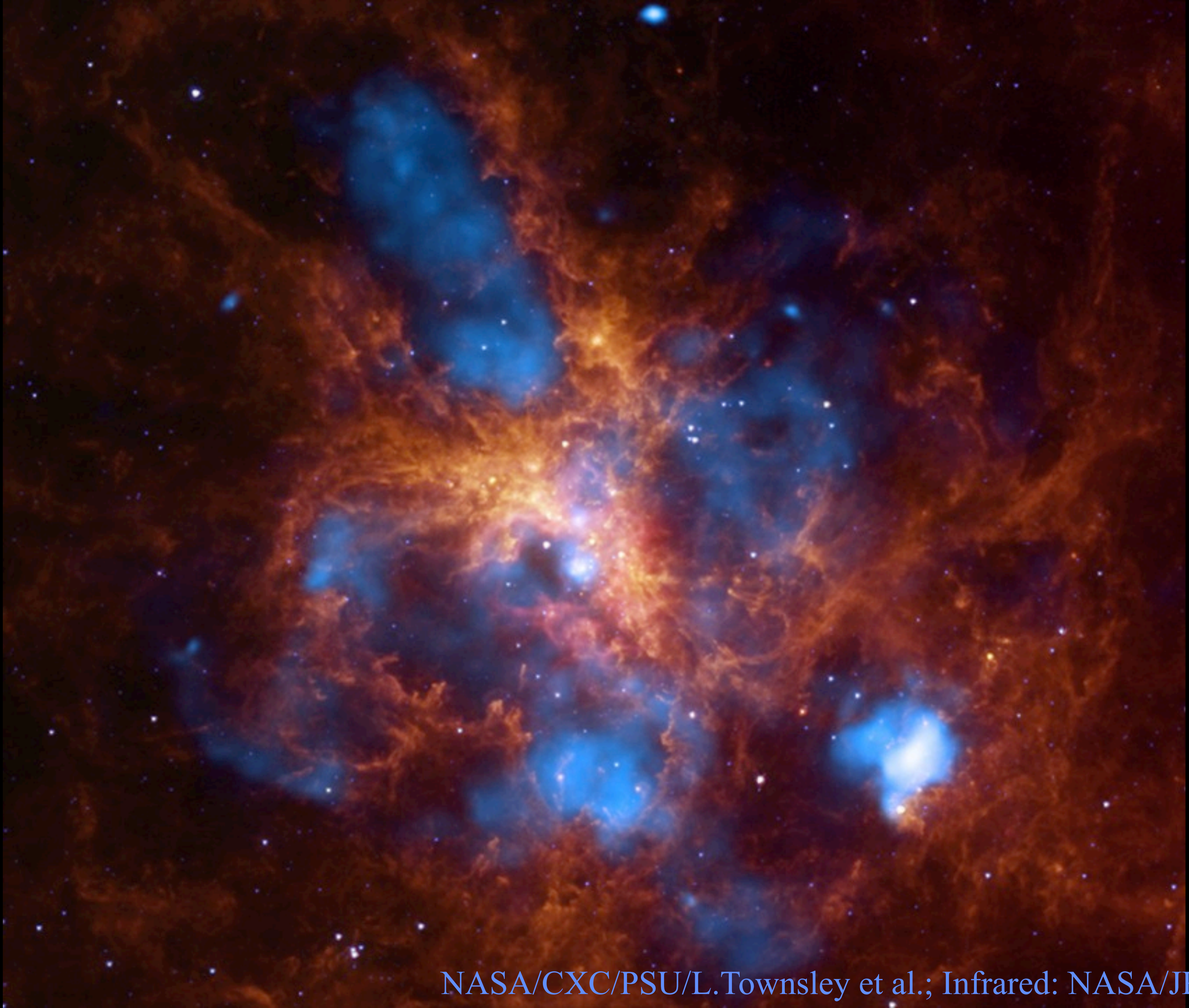

California Nebula APOD
Xi Persei

Star forming H II regions

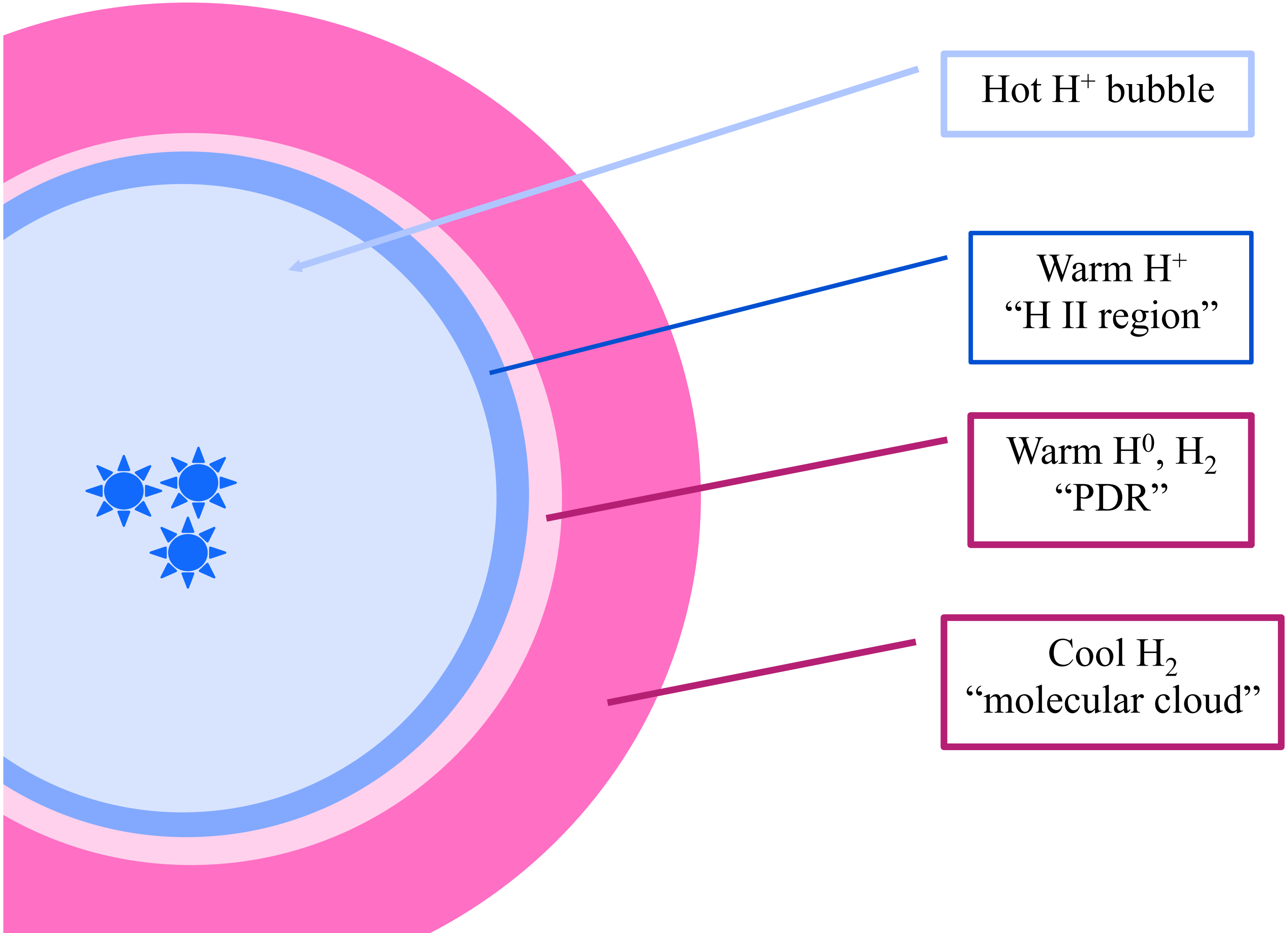
- Hot young stars very close to the molecular cloud that formed it
- Ionizing radiation and stellar winds strike nearby molecular cloud




ESO


NASA/CXC/PSU/L.Townsley et al.; Infrared: NASA/JPL

Idealized structure of an H II region



Make spectra of stable phases

- **Cold, warm, hot stable phases**
- **Ccurve.in**
  - Remove grid, vary option
  - Leave ISM abundances
  - Save continuum (units microns), cooling
- **Compute stable points**
  - T=5e2K 2e4K, 8e4K, 1.5e6K, 2e7K

Effects of U on ionization, temperature, & spectrum

- **Let's use**
  - A) an AGN SED
  - B) a low density, hden 0
  - C) unit volume
  - D) solar abundances
  - E) save the emitted continuum
  - F) and vary U; -5 <= U <= 3
- **Plot emitted continuum, 1e-4 to 1e3 microns, y axis 1e-20 down to 1e-26**
- **Temperature, peak ionization of Fe**

Heating – cooling balance

- Both heating and cooling depend on square of density
- So no density dependence
- Try it! compare temperatures at two densities

“make” parallel

- https://trac.nublado.org/wiki/MpiParallel

Vary Metals – constant temperature

- **Set constant temperature, look at [O III] lines relative to Hβ as metallicity varies**

Vary Metals –temperature balance

Three-phase pressure stability

- tsuite / auto / ism_grid

Vary blackbody temperature

Three cases

- **hiis.in – set radiation field, all gas parameters determined self consistently**
- **coronal.in – no radiation, but gas kinetic temperature set by external physics. Ionization and emission set by gas kinetic temperature**
- **constant temperature models – may include radiation but kinetic temperature set by external physics. Ionization determined by both radiation field and gas temperature**
  - Hazy1 Chap 11