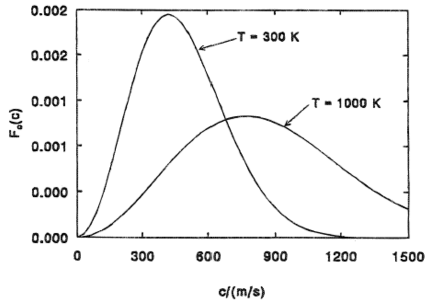
Chapt 3 Heating and cooling

- **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

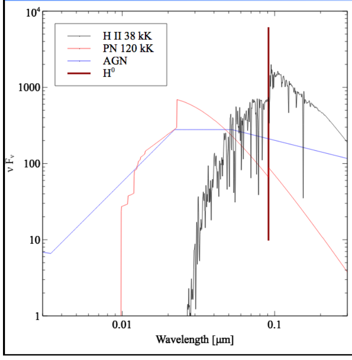
- **Heating by radiation field in photo case**
- **In coronal case external process sets temperature**
- **Cooling is anything that converts kinetic energy into light that escapes**

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**

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

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

Photoelectric heating

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

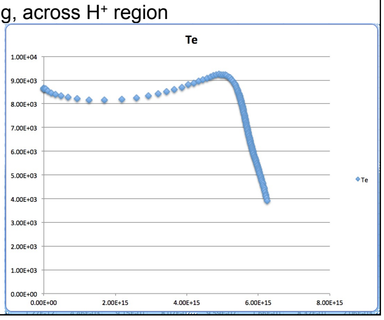
$$G({\rm H}) = n_e n_p \alpha_{\rm A}({\rm H}^0, T) \frac{\displaystyle\int_{\nu_0}^{\infty} \frac{4\pi J_\nu}{h\nu} h(\nu - \nu_0) a_\nu({\rm H}^0)\, d\nu}{\displaystyle\int_{\nu_0}^{\infty} \frac{4\pi J_\nu}{h\nu} a_\nu({\rm H}^0)\, d\nu} = n_e n_p \alpha_A({\rm H}^0, T) \frac{3}{2} kT_i \qquad (3.2)$$

Let's try different SEDs

- **Density 1 cm^{-3}, constant temperature, one zone, same ionization parameter**

Photoelectric heating vs depth

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



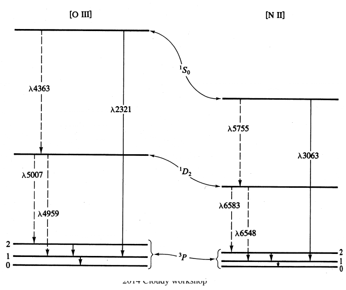
Cooling

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

$$L_C = n_e \, n_1 \, q_{12} \, h\nu_{21}. \qquad (3.22)$$

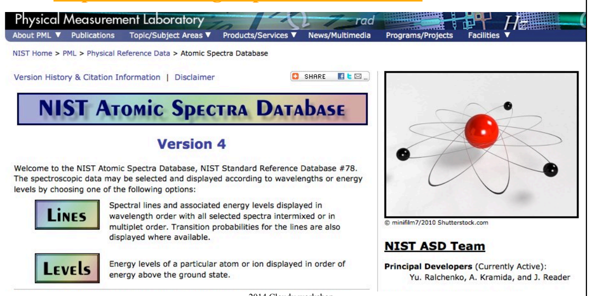
[O III]

- **AGN3 Fig 3.1**



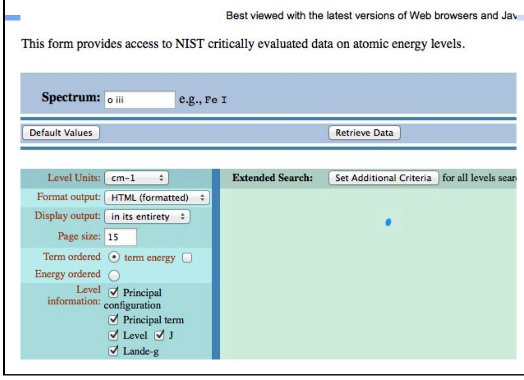
NIST

- http://www.nist.gov/pml/data/asd.cfm



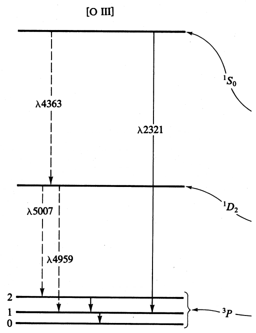
2014 Cloudy workshop

NIST Atomic Spectra Database Levels Form



O III

Configuration	Term	J	Level (cm^{-1})
$2s^22p^2$	^3P	0	0
		1	113.178
		2	306.174
$2s^22p^2$	^1D	2	20 273.27
$2s^22p^2$	^1S	0	43 185.74
$2s2p^3$	$^5S°$	2	60 324.79
$2s2p^3$	$^3D°$	3	120 025.2
		2	120 053.4
		1	120 058.2



Heating – cooling balance

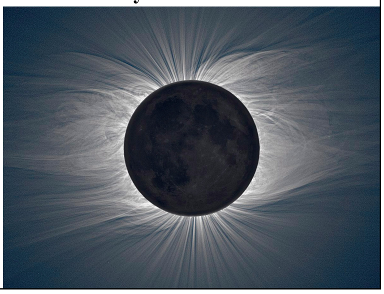
- Both heating and cooling depend on square of density
- So no density dependence
- Try it! Remove constant temperature command, compare temperatures at two densities

Other cooling processes

- Save cooling command
- Look at various output

Coronal equilibrium

- Mechanical energy sets kinetic temperature
- "Coronal" command in Cloudy
- Try several T, plot SAVE CONTINUUM output

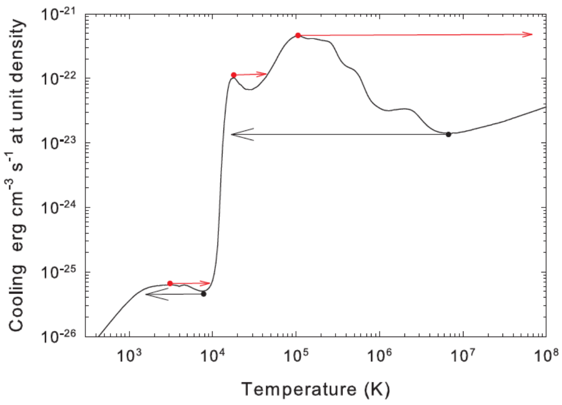


Try different temperatures

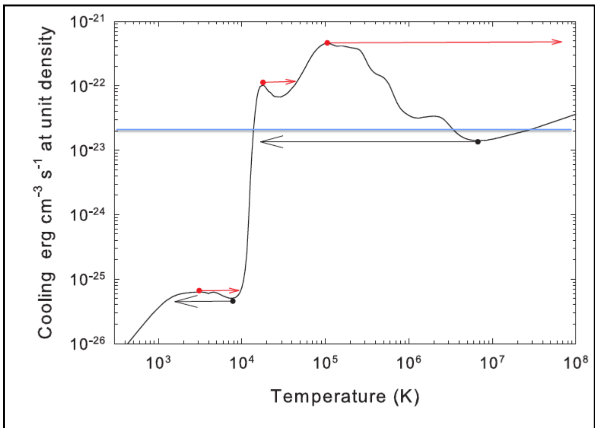
- Coronal command
- Unit cell
- Plot spectrum
- Must include "cosmic ray background"

Grid command – cooling function

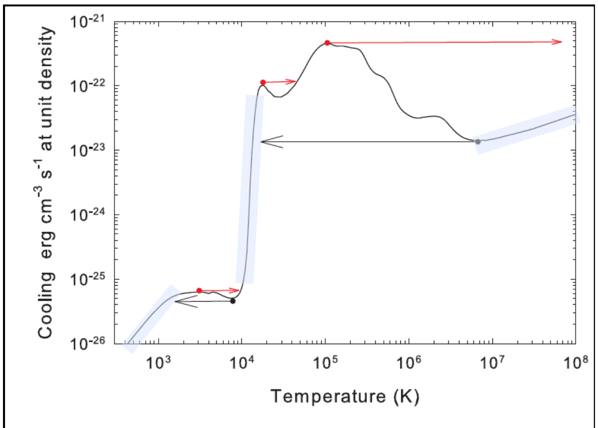
- Grid command Hazy 1 Chapter 18
  - Carefully study temperature log rules, Sec 18.5
- Coronal equilibrium command
- Save cooling output
- Plot cooling vs temperature



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

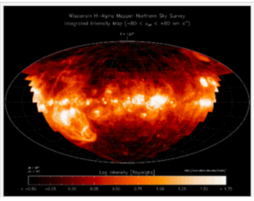
http://en.wikipedia.org/wiki/Interstellar_medium

Interstellar medium

From Wikipedia, the free encyclopedia

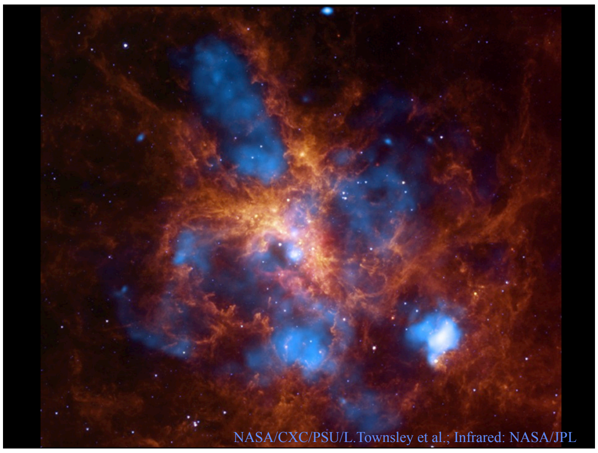
For other uses, see Interstellar (disambiguation).

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**.

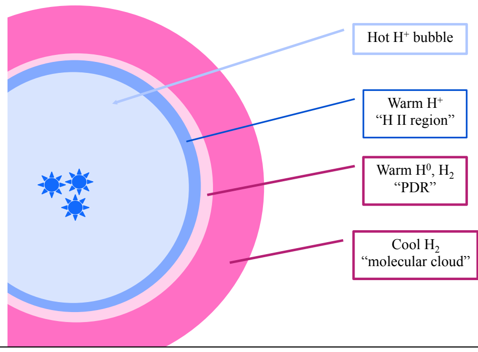


Star forming H II regions

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



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**

"make" parallel

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

Vary Metals – constant temperature

Vary Metals –temperature balance

Three-phase pressure stability

- tsuite / auto / ism_grid

Vary blackbody temperature