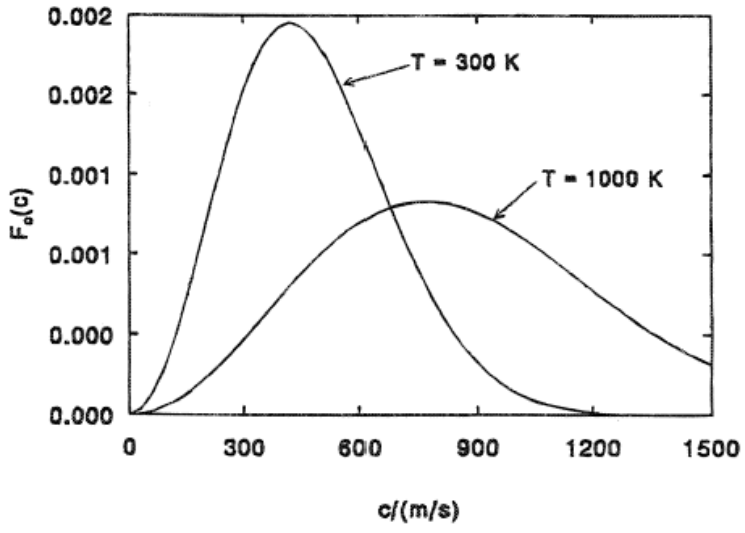
Heating and cooling

- 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

A Maxwellian velocity distribution



Thermal equilibrium

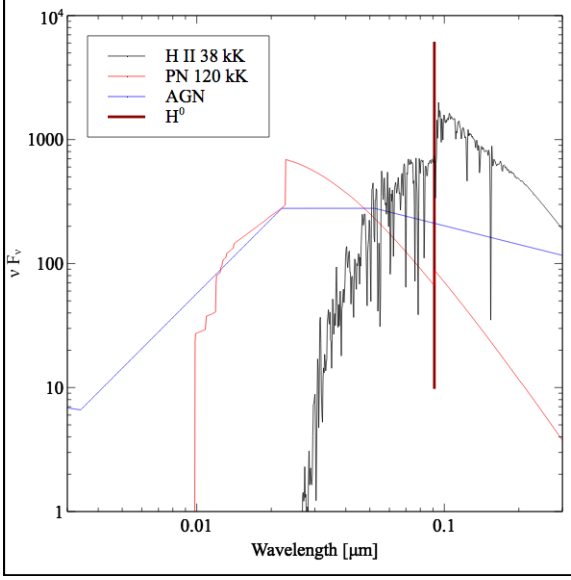
- Heating by radiation field in photo case
- In coronal case external process sets temperature
- Cooling is anything that converts kinetic energy into light that escapes

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

Let's try different SEDs

- **Density 4, constant temperature, one zone, ionization parameter**

Photoelectric heating vs depth

- **Dependence on depth**
  - Spectrum, heating, across H+ region
  - Hii_paris
  - Save continuum output
- **Save heating**

Photoelectric heating

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

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

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

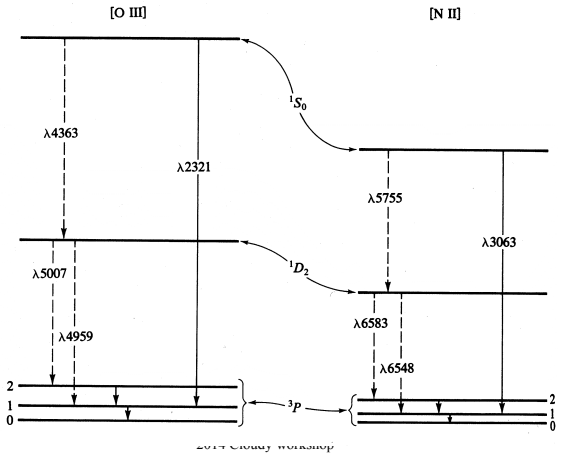
Cooling

- Anything that converts kinetic energy (heat) into light (which escapes)
- Collisional excitation of normally most important cooling process

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

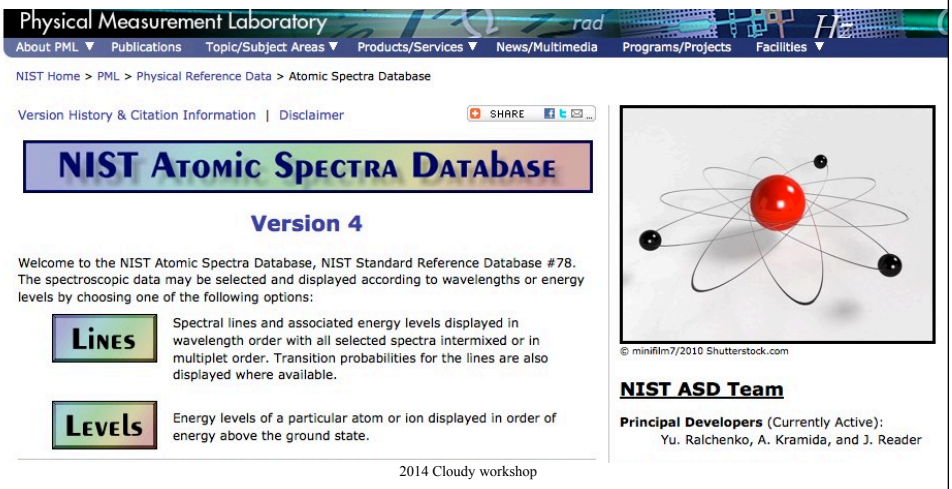
[O III]

- AGN3 Fig 3.1



NIST

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



NIST Atomic Spectra Database Levels Form

Best viewed with the latest versions of Web browsers and Jav

This form provides access to NIST critically evaluated data on atomic energy levels.

Spectrum: o iii e.g., Fe I

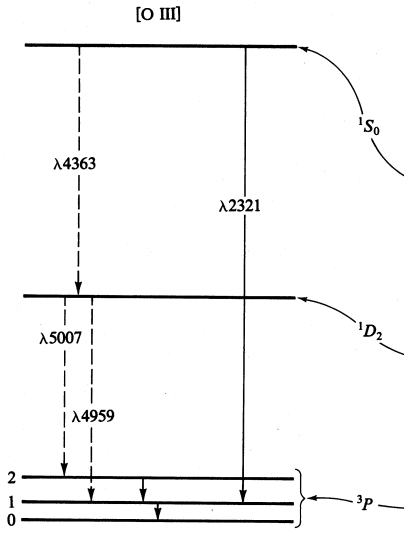
Default Values | Retrieve Data

Level Units: cm-1
Format output: HTML (formatted)
Display output: in its entirety
Page size: 15
Term ordered: term energy
Energy ordered
Level information: Principal configuration, Principal term, Level, J, Lande-g

Extended Search: Set Additional Criteria for all levels sear

O III

Configuration	Term	J	Level (cm^{-1})
$2s^2 2p^2$	^3P	0	0
		1	113.178
		2	306.174
$2s^2 2p^2$	^1D	2	20 273.27
$2s^2 2p^2$	^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