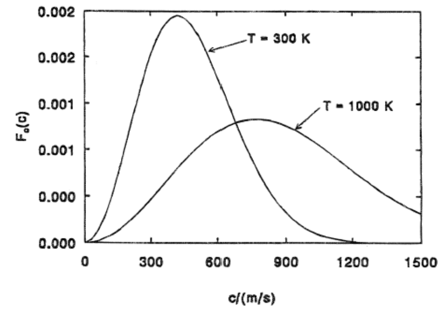
Chapt 3 Heating and cooling

- 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 gives kinetic energy to the gas
  - radiation field in photoionization case
  - by mechanical energy in shock
  - In coronal case an external process sets temperature

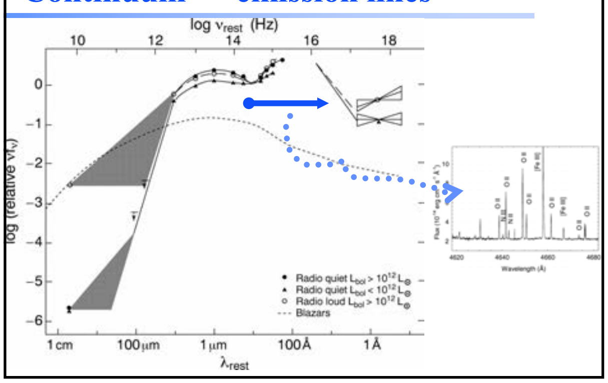
- Cooling is anything that converts kinetic energy into light that escapes

Photoelectric heating

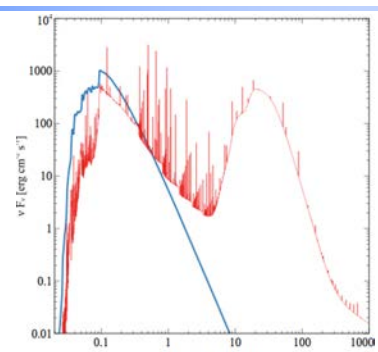
$$G(\mathrm{H}) = n(\mathrm{H}^0) \int_{\nu_0}^{\infty} \frac{4\pi J_\nu}{h\nu} h(\nu - \nu_0)\, a_\nu(\mathrm{H}^0)\, d\nu \ [\mathrm{erg\ cm^{-3} s^{-1}}]. \qquad (3.1)$$

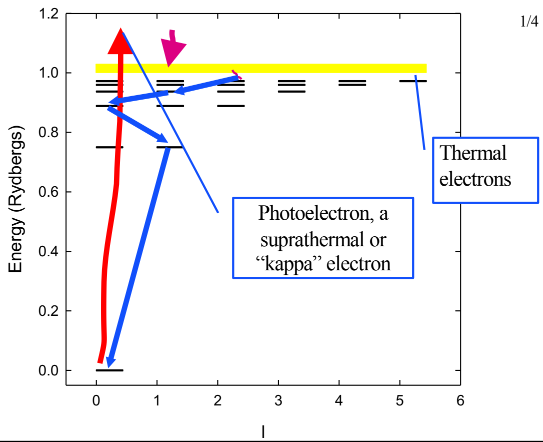
- Depends on SED shape

The "primary mechanism" Continuum → emission lines



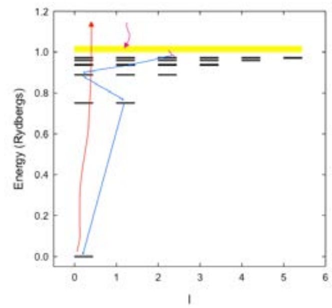
The "primary mechanism" Continuum → emission lines



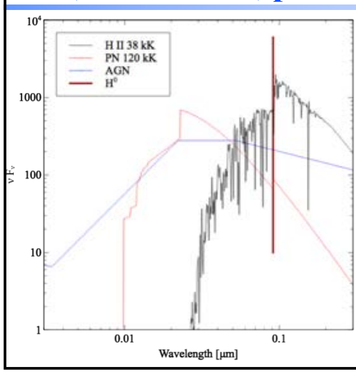


Life history of an Orion electron

- **H^0 ground state**
  - 1 day
- **Suprathermal**
  - 1 second
- **Thermal**
  - 1 yr
- **H^0 excited states**
  - 10^{-7} s
- **H^0 ground state**



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

Photoelectric heating

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

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

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

Vary blackbody temperature

- **Stoy or "energy balance" method of determining stellar temperatures**
- **AGN3 Section 5.10**

Cooling

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

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

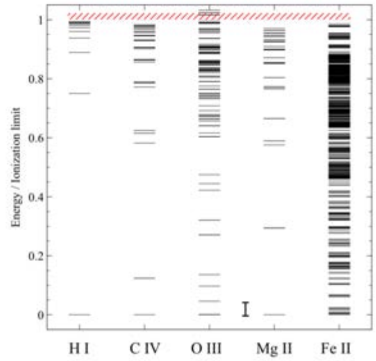
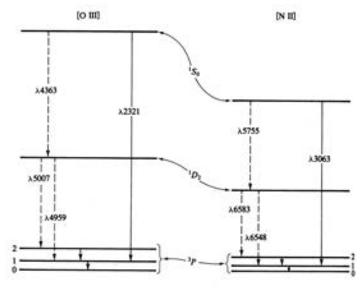


Figure 7.4: This shows energy levels for ions with increasing numbers of electrons. The level energies are relative to the ionization potential of the species so 1 indicates the ionization energy. The hashed band represents the ionization energy corresponding to a free electron.

[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

Coronal equilibrium

- Electron collisions cause ionization from ground state
- Balanced with all recombinations to all states
  - Which decay down to ground
- $n(H^0) n_e c_{ion} = n_e n_p \alpha_{rec}(T)$
- $\frac{n_p}{n(H^0)} = \frac{c_{ion}}{\alpha_{rec}(T)}$ (no density dependence)

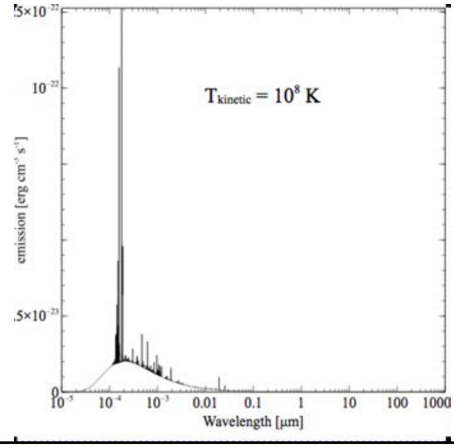
Coronal model with Cloudy

- Unit cell
- In coronal equilibrium (unit volume)
- Unit density (n=1 cm^{-3})

```
set save prefix "T7"
set dr 0
stop zone 2
coronal 4
hden 0 % this is not a realistic density for sun, 1e10 cm-3 more typical
iterate
print last iteration
save continuum last units microns ".con"
save cooling ".col"
```

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

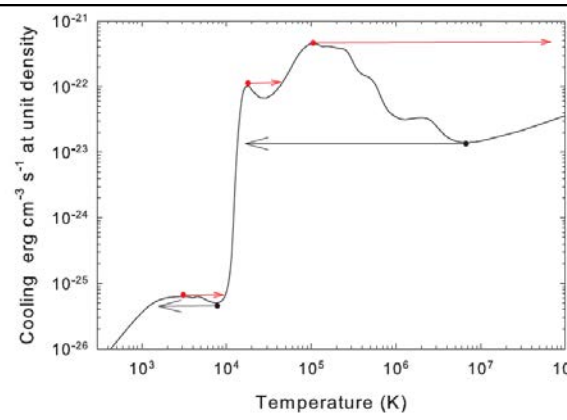


Coronal equilibrium

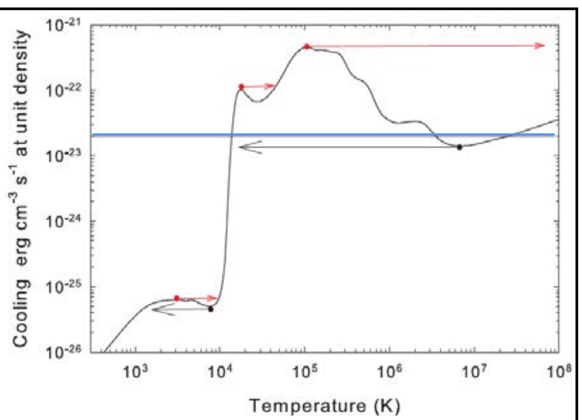
- What is spectrum, cooling, at each temperature

Vary low temperature care

- **Add grains**
  - H_2 forms on grain surfaces
- **Add cosmic rays**
- $n(H^0)n_e c_{ion} = n_e n_p \alpha_{rec}(T)$ **(no CRs)**
- $n(H^0)(n_e c_{ion} + c_{CR}) = n_e n_p \alpha_{rec}(T)$
- $\frac{n_p}{n(H^0)} = \frac{(n_e c_{ion} + c_{cr})}{n_e \alpha_{rec}(T)}$
- $n_e \rightarrow 0, \quad \frac{n_p}{n(H^0)} \rightarrow \infty$



Dalgarno&McCray 1972 ARAA 10, 375 Ferland+09 MNRAS, 392, 1475



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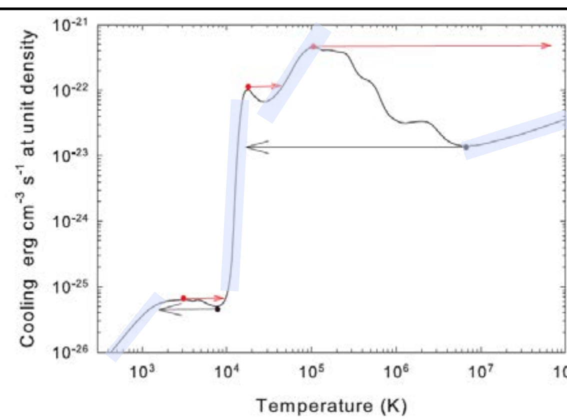

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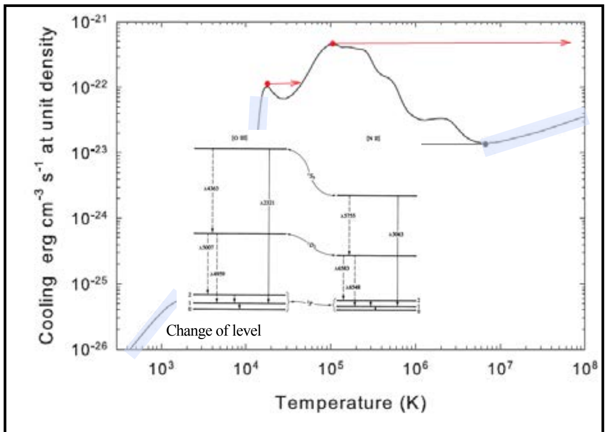

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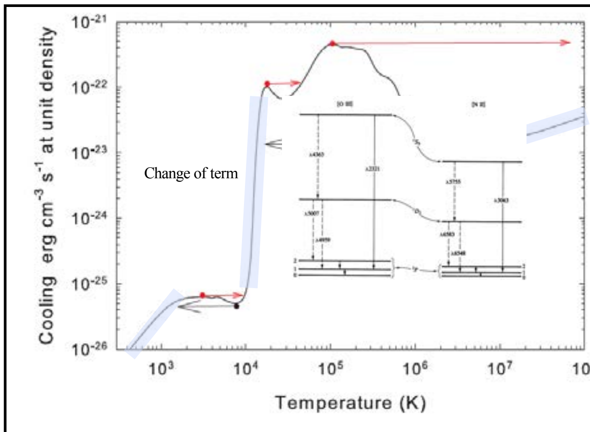

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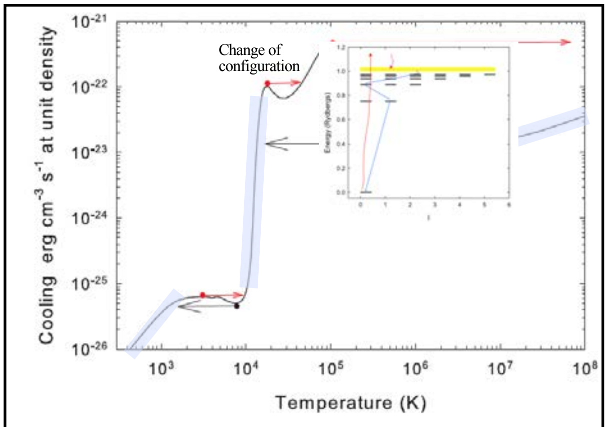


Dalgarno&McCray ARAA 10, 375 Ferland+09 MNRAS, 392, 1475

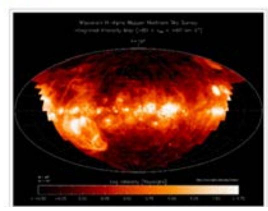
http://en.wikipedia.org/wiki/Interstellar_medium

Interstellar medium

From Wikipedia, the free encyclopedia

For other uses, see Interstellar (disambiguation).

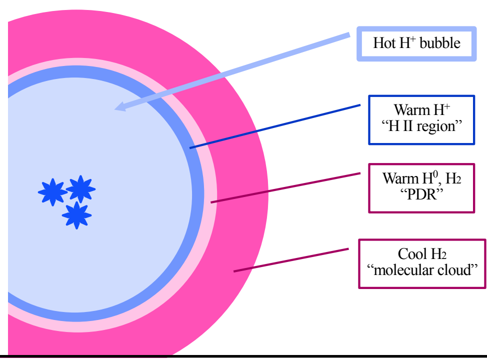
In astronomy, the **interstellar medium** (or **ISM**) is the matter that exists in the space between the star systems in a galaxy. This matter includes gas in ionic, atomic, and molecular form, dust, and cosmic rays. It fills interstellar space and blends smoothly into the surrounding intergalactic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

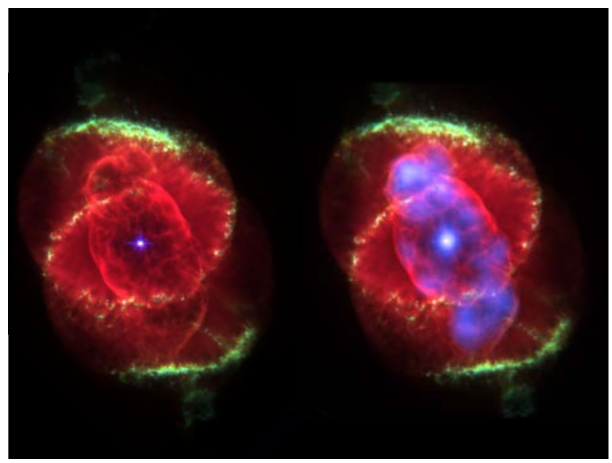


Star forming H II regions

- 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





Three-phase pressure stability

- **tsuite / auto / ism_grid**

Heating – cooling balance

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