Command deck so far

- Blackbody 4.3e4 K
- Q(H) 49.34
- Radius 16
- Hden 4
- Abundances ISM
- Cosmic rays background
- stop zone 1
- set dr 0
- Save overview “HII.ovr” last no hash
- Save element hydrogen “HII.hyd” last no hash
- Save emitted continuum “HII.econ” units microns

The “main output”

- **The *.out file created when code is executed**
  - QSG 7.1 & Hazy 2 Chapter 1
- **Gas & grain composition**
- **Physical conditions in first and last zone**
- **Emission-line spectrum**
- **Mean quantities**

Run the model

- **Look at the HII.out file**

Results for one zone

```
   Carbonaceous: -9.811  Silicate: -9.748  PAH: -30.000          Carbonace
#### 1  Te:1.815E+04 Hden:1.000E+04 Ne:1.198E+04 R:1.000E+16 R-R0:5.000E-01
Hydrogen       5.78e-08 1.00e+00 H+o/Hden 1.00e+00 4.12e-18 H-     H2 1.05e-22
Helium         5.75e-10 3.69e-03 9.96e-01 HeI 2s3S 4.73e-11 Comp H C 2.53e-19
```

Gas kinetic temperature

Results for one zone

```
   Carbonaceous: -9.811  Silicate: -9.748  PAH: -30.000          Carbonace
#### 1  Te:1.815E+04 Hden:1.000E+04 Ne:1.198E+04 R:1.000E+16 R-R0:5.000E-01
Hydrogen       5.78e-08 1.00e+00 H+o/Hden 1.00e+00 4.12e-18 H-     H2 1.05e-22
Helium         5.75e-10 3.69e-03 9.96e-01 HeI 2s3S 4.73e-11 Comp H C 2.53e-19
```

H^0, H^+ ionization fractions
n(x)/n(H, all forms)

Results for one zone

```
   Carbonaceous: -9.811  Silicate: -9.748  PAH: -30.000          Carbonace
#### 1  Te:1.815E+04 Hden:1.000E+04 Ne:1.198E+04 R:1.000E+16 R-R0:5.000E-01
Hydrogen       5.78e-08 1.00e+00 H+o/Hden 1.00e+00 4.12e-18 H-     H2 1.05e-22
Helium         5.75e-10 3.69e-03 9.96e-01 HeI 2s3S 4.73e-11 Comp H C 2.53e-19
```

H_2 fraction
$2n(H_2)/n(H, \text{all forms})$

Warnings, cautions, notes

- **Cloudy is designed to be autonomous and self aware**
- **Generates notes, cautions, or warnings, if conditions are not appropriate.**

```
 Calculation stopped because NZONE reached. Iteration 1 of 1
 The geometry is plane-parallel.
 -Continuum zero at some energies.
 -The H Lyman continuum is thin, and I assumed that it was thick.  Use the ITERATE command to do more iterations.
 -The He II continuum is thin and I assumed that it was thick.  Use the ITERATE command to do more iterations.
 -The He I continuum is thin and I assumed that it was thick.  Use the ITERATE command to do more iterations.
 !Destruction of He 2TriS reached 32.0% of the total He0 dest rate at zone 1, 32.0% of that was photoionization.
 !Non-collisional excitation of [O III] 4363 reached 12.61% of the total.
 !AGE: Cloud age was not set.  Longest timescale was 5.40e+08 s = 1.71e+01 years.
 !Local grain-gas photoelectric heating rate reached  63.5% of the total.
 !Grain photoelectric heating is VERY important.
 !The CMB was not included.  This is added with the CMB command.
```

Check end of output

```
Cloudy ends: 1 zone, 1 iteration, 4 cautions. (single thread) ExecTime(s) 8.80
[Stop in cdMain at ../maincl.cpp:517, Cloudy exited OK]
```

Break into 6 groups, do 6 radii

- **Radius (log, cm)**
  - 13
  - 15
  - 17
  - 19
  - 21
  - 23
- **Find following in main output**
  - Temperature, H ionization,

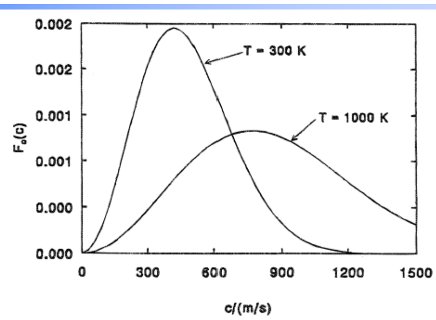
The grid command – Hazy1 Chap 18

- **Grid command compute a grid of models in parallel**
- **Include "vary" keyword on commands with variable parameters (Chapter 17.4)**
- **"grid" command specifies lower, upper bounds, and step size**
  - Radius 13 vary
  - grid 13 23 2
  - Hazy 1 sec 18.5
- **"Save grid" command saves step parameters**
- **"no hash", "last", options on other save commands**
- **(See this page for description of –a runtime)**

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

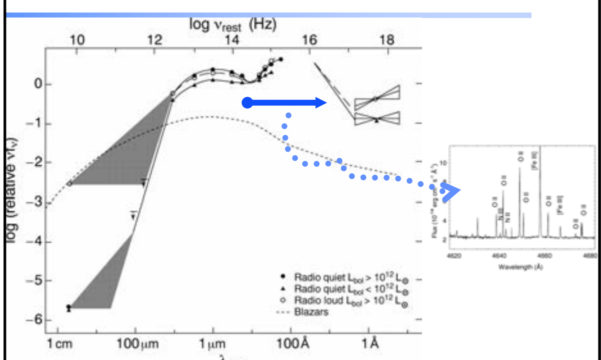
- **Heating gives kinetic energy to the gas**
  - radiation field in photoionization case
  - by mechanical energy in shock
  - In coronal case an external process sets temperature
- **Cooling is anything that converts kinetic energy into light that escapes**

Photoelectric heating

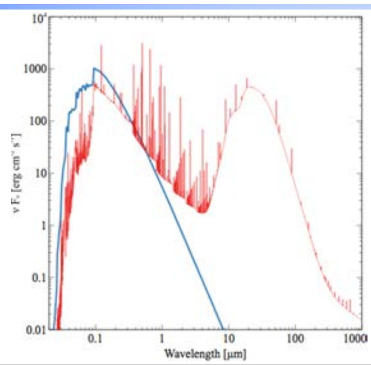
$$G(\mathrm{H}) = n(\mathrm{H}^0) \int_{\nu_0}^{\infty} \frac{4\pi J_\nu}{h\nu} h(\nu - \nu_0)\ a_\nu(\mathrm{H}^0)\, d\nu\ [\mathrm{erg\ cm^{-3} s^{-1}}]. \qquad (3.1)$$

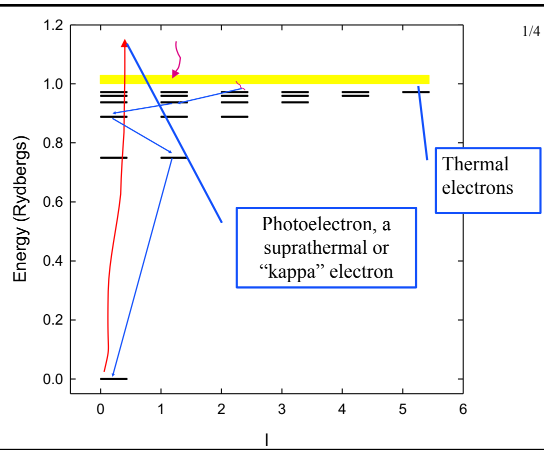
- **Depends on SED shape**

The "primary mechanism" Continuum → emission lines



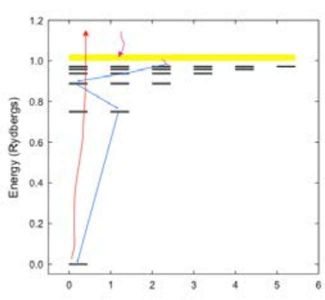
The "primary mechanism" Continuum → emission lines



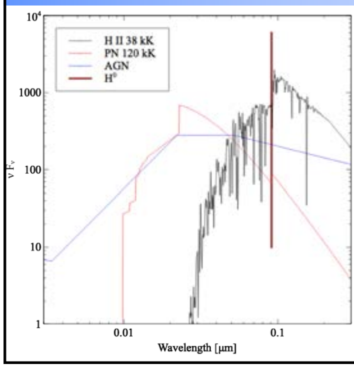


Life history of an Orion electron

- **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 $n_e\, n_p\, \alpha$, the recombination rate
- Heating depends on density squared

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

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

Let's try different SEDs

- Change "blackbody" command in yesterday's version of HII.in,
  - with "radius 18"
- Report "Average nu" and "Te" in main output

SED	Average nu	T(e) K
BB 2.5e4 K		7600
BB 3e4 K		8050
BB 5e4 K		9130
BB 1e5 K		14000
BB 1.5e5 K		16000
Table agn		15100
Table power law		17900

In HII.in

- Copy HII.in to HIIt.in
- Change "set save prefix" name
- Set radius to 10^18 cm
  - Radius 18
- Change "blackbody" value

Photoelectric heating vs depth

- In homework H II region, why did temperature fall, increase, then fall catastrophically?
- Dependence on depth
  - Spectrum, heating, across H^+ region
  - Homework problem
  - Save continuum output
- Save heating

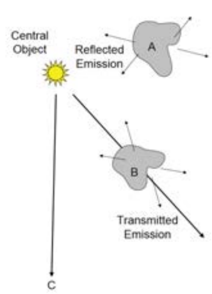


Figure 16.2: This figure illustrates several components of the radiation field that enter in the calculations.

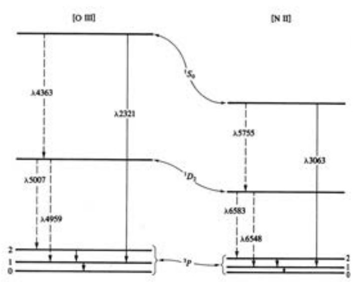
Cooling

- 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

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

[O III]

- AGN3 Fig 3.1

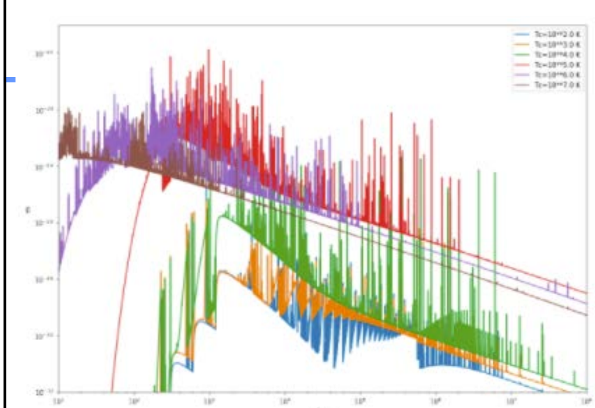


Coronal equilibrium

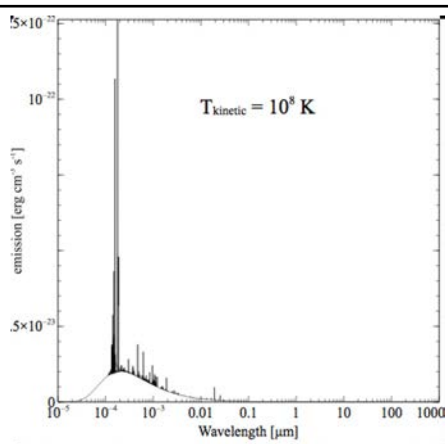
- Mechanical energy sets kinetic temperature
- “Coronal” command in Cloudy
- No ionizing radiation
- Collisional ionization, due to collision by thermal electrons

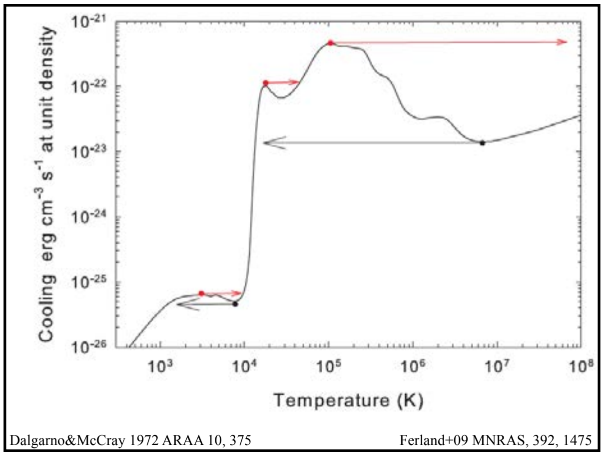
Try different temperatures

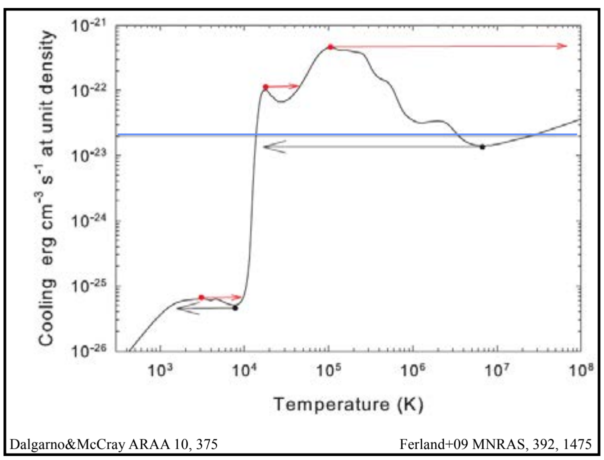
- **Coronal command**
  - Log T=2, 3, 4, 5, 6, 7, 8
- **Unit cell**
- **Must include "cosmic ray background" and grains when molecules are significant**
- **Plot spectrum**
  - X-axis log wavelength from 1e-4 to 1e3 microns
  - Y-axis linear intensity, with strongest line at the top

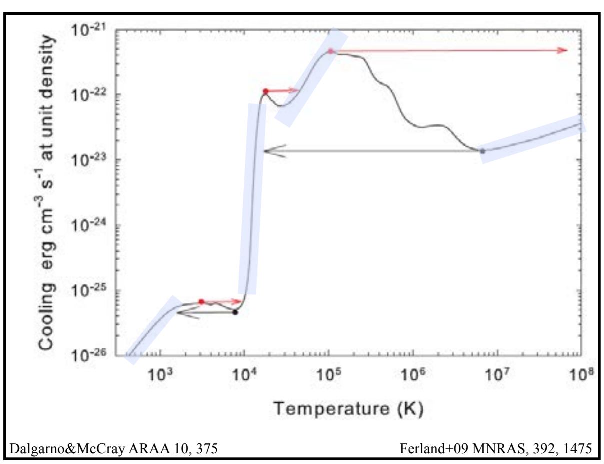


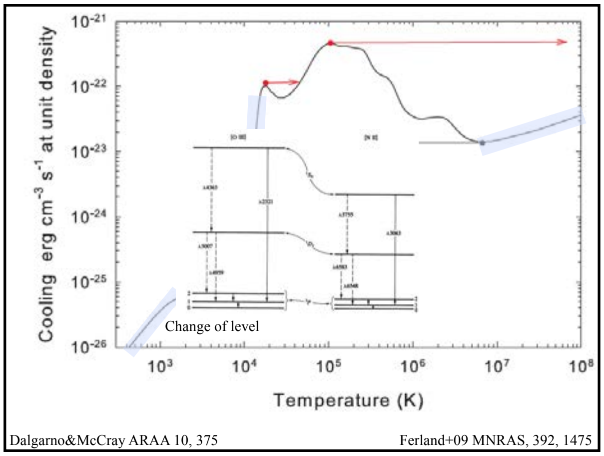
2014 Cloudy workshop

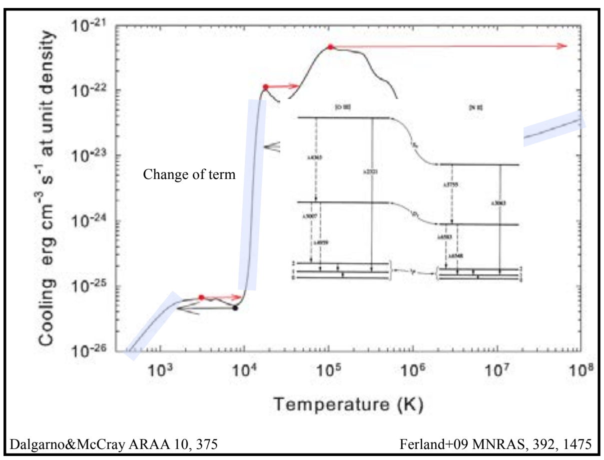


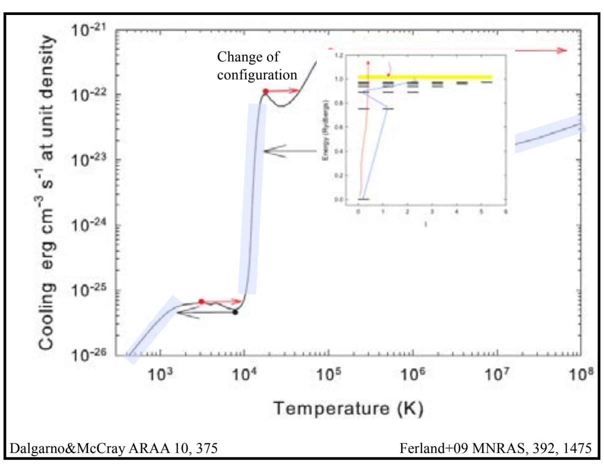

Cooling erg cm^{-3} s^{-1} at unit density
Temperature (K)
Dalgarno&McCray 1972 ARAA 10, 375
Ferland+09 MNRAS, 392, 1475


Cooling erg cm^{-3} s^{-1} at unit density
Temperature (K)
Dalgarno&McCray ARAA 10, 375
Ferland+09 MNRAS, 392, 1475


Cooling erg cm^{-3} s^{-1} at unit density
Temperature (K)
Dalgarno&McCray ARAA 10, 375
Ferland+09 MNRAS, 392, 1475


Cooling erg cm^{-3} s^{-1} at unit density
Temperature (K)
Change of level
Dalgarno&McCray ARAA 10, 375
Ferland+09 MNRAS, 392, 1475


Cooling erg cm^{-3} s^{-1} at unit density
Temperature (K)
Change of term
Dalgarno&McCray ARAA 10, 375
Ferland+09 MNRAS, 392, 1475


Cooling erg cm^{-3} s^{-1} at unit density
Temperature (K)
Change of configuration
Dalgarno&McCray ARAA 10, 375
Ferland+09 MNRAS, 392, 1475

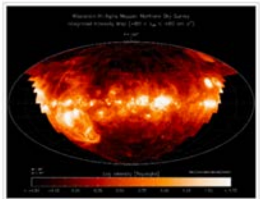
http://en.wikipedia.org/wiki/Interstellar_medium

Interstellar medium

From Wikipedia, the free encyclopedia

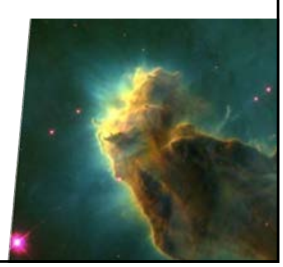
For other uses, see Interstellar (disambiguation).

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**.

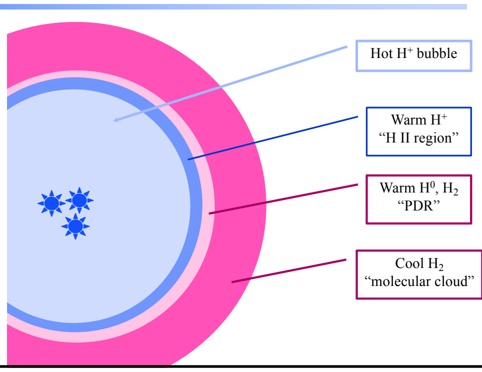


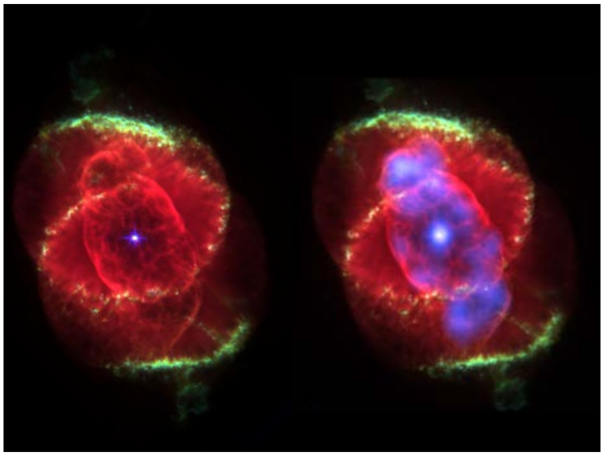
Star forming H II regions

- **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

Vary Metals –temperature balance

- Then energy balance
  - varyZ

Thermostat effect AN3 S9.5

- Vary metals with temperature balance
  - varyZ.in
- Look at line ratios, temperature vs Z
- Cooling and heating vs Z
- Thermostat effect – line spectrum does not change dramatically when Z changes
  - Heating and cooling are equal
  - Cooling is mainly O III lines
  - So they are constant when they are the main coolant

Vary blackbody temperature

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

Three cases

- **hiis.in – set radiation field, properties of cloud determined self consistently**
  - This is how we usually use Cloudy
- **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