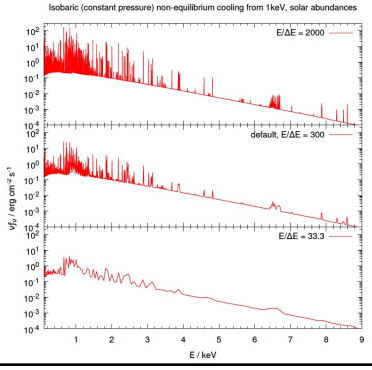
Running cloudy

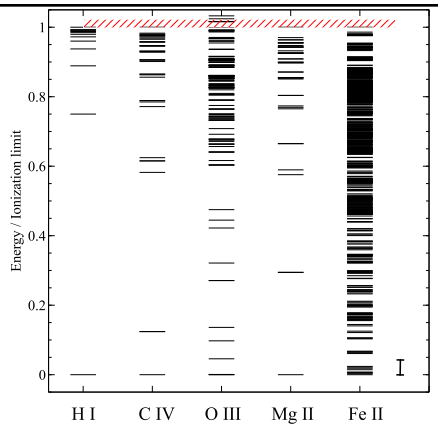
- "run" file contains /Users/gary/cloudy/trunk/source/sys_llvm/cloudy.exe -r $1 2> $1.err
- If file "model.in" contains input, then
- run model &
- Produces output "model.out"
- The model will run in the "background" when the line ends with &

Runtime options

- Appear after cloudy.exe
- Described here
- -r
  - I use this in my workflow
  - Required for grids to work
  - Study the options and consider what is best for your workflow

- How to make sense of all these lines



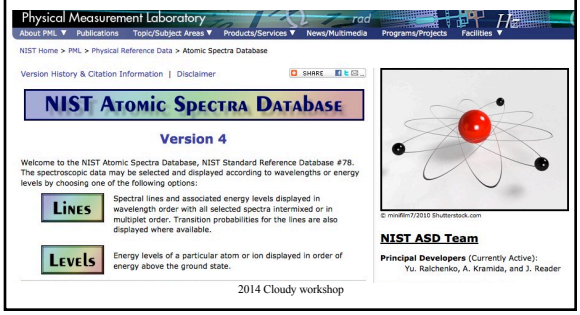


Peter's atomic line list

- http://www.pa.uky.edu/~peter/atomic/
- http://www.pa.uky.edu/~peter/newpage/
  - Beta version with new features
- Search wavelength range to find what lines are present

NIST

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



2014 Cloudy workshop

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

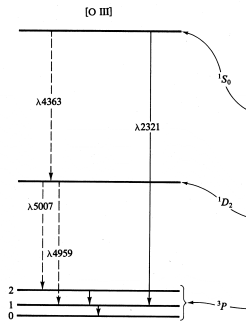
Default Values | Retrieve Data

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

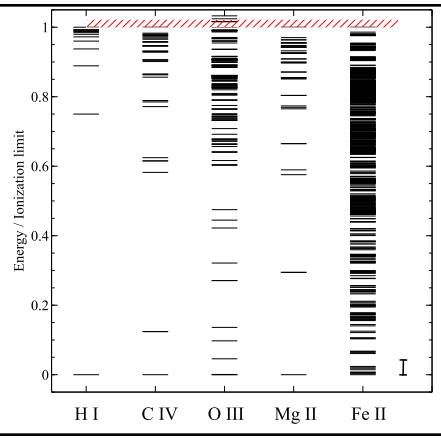
O III

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



Two types of lines

- **Recombination AGN3 sec 4.2**
  - e + p radiative recombination
  - Rate coefficient q~10^{-13} cm^3 s^{-1}
  - Mainly H, He
- **Collisionally excited AGN3 3.5**
  - Inelastic e + ion collision
  - q~10^{-9} cm^3 s^{-1}
  - Heavy elements



Selection rules for transitions

- **AGN3**
- **Appendix 4 Nebular quantum mechanics**
- **Appendix 6 Molecular quantum**

O III

Configuration	Term	J	Level (cm^{-1})
$2s^2 2p^2$	^{3}P	0	0
		1	113.178
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$2s^2 2p^2$	^{1}D	2	20 273.27
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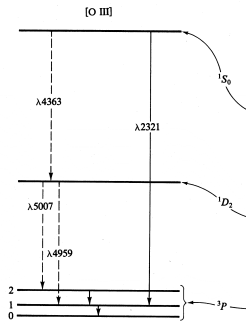
		1	120 058.2



Species vs spectra

- **H^0, C^{3+}, O^{2+}, H_2, CO are baryons**
- **H I, C IV, O III, H_2, and CO are the spectra they emit / absorb**
- **O III is a permitted line produced by O^{2+}, while [O III] is a forbidden line**
- **C III] is a semi-forbidden line, often an intercombination line**

Species vs spectra

- **H I Lyα *emission* can be produced by**
  - Recombination of H^+
  - Impact excitation of H^0
- **H I absorption can only be produced by H^0**
- **H I is not the same as H^0**
  - Ambiguous for emission lines

Baryons and spectra

- **Hazy 1 Section 2.5**
- **SpeciesLabels.txt in docs**
- **Molecules are not ambiguous**
  - H2
  - CO
  - O2
  - H2+
  - C2+
  - Their spectra have the same notation as the baryon

Baryons and spectra

- **Atomic spectra use number of spectra**
  - H 1
  - C 4
- **The baryon**
  - "H"
  - "He+"
  - "C+2"
  - (C2+ is C_2^+ in our notation)

Lines in the main output

- **Print lines column**
- **Print lines sort wavelength**
- **Print lines faint**

Finding lines in Cloudy

- **Run smoke test with commands**
- **Save line labels; save species labels**
- **Spectral label, wavelength, identifies a line**
- **Save output file has label, wavelength, comment about line**
- **Pick lines from this save file**

Other database reporting options

- See C17 review article, section 2
- Database print

Line blends

- Blnd 3727
- Blnd 2798
- Blnd 1549
- Two or more lines that appear as a single line in most spectra

Luminosity, relative intensity

- Intensity or luminosity of line
  - depending on case
- Intensity relative to normalization line, default Hβ
  - Change with *normalize* command

```
0  3 88.3323m   -5.577    1.5126
0  3 51.8004m   -5.106    4.4704
0  3 4931.23A   -8.339    0.0026
0  3 4958.91A   -4.876    7.5973
0  3 5006.84A   -4.401   22.6702
0  3 2320.95A   -7.193    0.0366
0  3 4363.21A   -6.593    0.1456
0  3 1660.81A   -7.187    0.0371
0  3 1666.15A   -6.720    0.1087
```

Why use the laser at all

- Cloudy has lots of lines and does many levels for many ions
- A single zone (which we do for speed) is optically thin
- So continuum fluorescent excitation can be important.
- But would not happen with a finite column density
- Show fig with energy levels for H, C IV etc and say continuum photons would excite to all upper levels

Two level atom AGN3 Sec 3.5

- Excitation, deexcitation rates
- Transition probabilities
- Critical density
- Two limits
  - Low densities, every excitation leads to emission of a photon
  - high densities, levels are n LTE, photon emission proportional to $n_u A_{ul}$

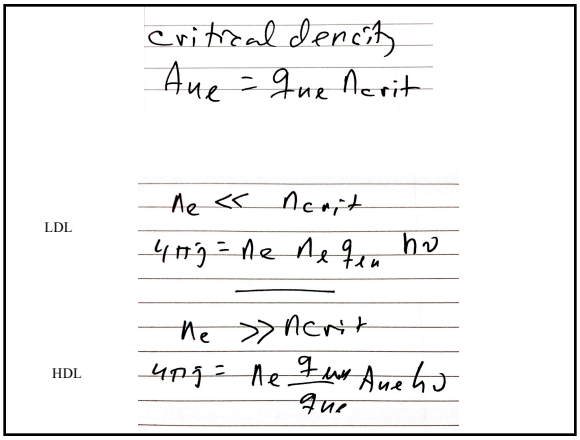
$4\pi j = n_u A_{ue} h\nu$

$[\text{erg cm}^{-3} \text{s}^{-1}]$

$n_l q_{lu} n_e = n_u [A_{ue} + q_{ue} n_e]$

$\frac{n_u}{n_l} = \frac{q_{lu} n_e}{A_{ue} + q_{ue} n_e}$

$n_u + n_l = n$



Why we set the ionization

- If most O were O3+ the process
- O3+ + e -> O2+ + hn
- Would be fast, and would make O III recombination lines
- This can happen in nature, but it would confuse our homework problem

Vary density over extreme range

- Plot emissivity vs density over wide range to see how emissivity changes
- Recombination line, [O III] forbidden lines

Recombination lines

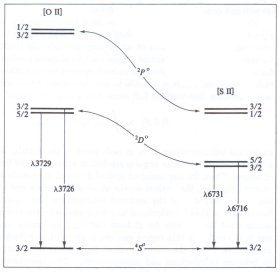
- $H^+ + e \rightarrow H^{0*} \rightarrow H^0$ + photons
- Critical densities of H I, He I, and He II optical lines are very high, n > 1e15 cm^{-3}, so they are usually in LDL
- Emissivity goes as n^2 for n < 10^{20} cm^{-3}
- Case B predictions
- H I, He I, He II are the strongest in UV/ Opt/ IR
- Second row (C,N, O, Ne) & Fe in X-ray

Forbidden lines

- [O III]
- $O^{++} + e \rightarrow O^{++*} + e \rightarrow O^{++} + e$ + photons
- Critical densities of many forbidden lines n ~ 1e3 cm^{-3}, so they can be in LDL or HDL
- Emissivity goes as n^2 or n

Compute spectrum of clouds with two very different densities

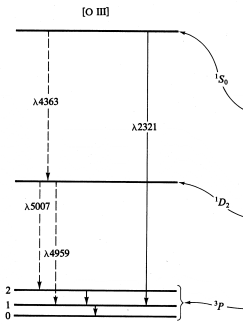
Density indicators



AGN3 Fig 5.7

Temperature indicators

- Lines from same species which have different excitation potentials



Ionization parameter indicators

- Lines from different ionization stages of the same element

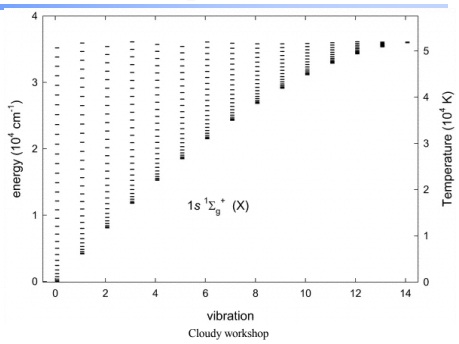
Databases in Cloudy

- Iso sequences (H and He like)
- H_2
- Stout (atoms & low ionization)
- Chianti (higher ionization)
- LAMDA (heavy-element molecules)

- Database print command
  - Reports all databases in us
  - The number of levels used

- Species "C+2" levels 40

H_2 (Shaw+05) "species H2"



Cloudy workshop

Controlling model atoms

- Series of SPECIES XXX commands
- Compare exec time species limit vs small

Inward vs total emission

- **"Inwd" label for line**
- **Inward/outward emission computed on second and later iterations**
  - Iterate to convergence
  - Print last

Line to continuum contrast

- **Hazy 1, sec 16.43.2, 19.14.44**
  - Line to continuum contrast in save continuum
  - Command SET SAVE LINE WIDTH