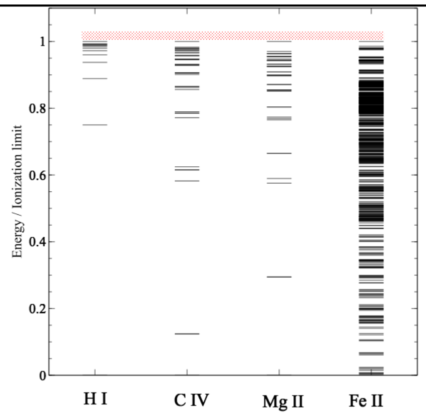
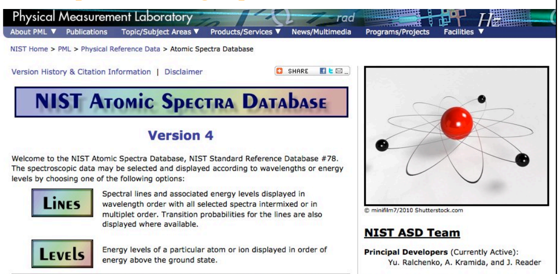


Peter's atomic line list

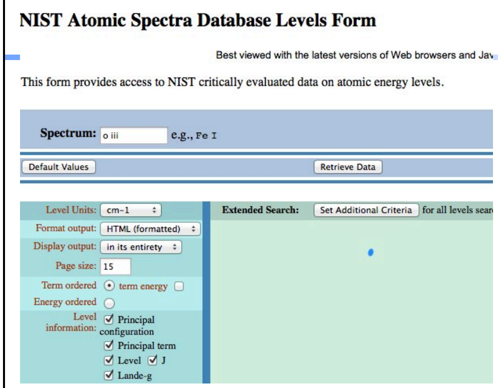
- http://www.pa.uky.edu/~peter/atomic/
- Search wavelength range to find what lines are present

NIST

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

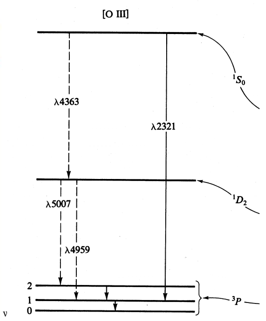


2014 Cloudy workshop



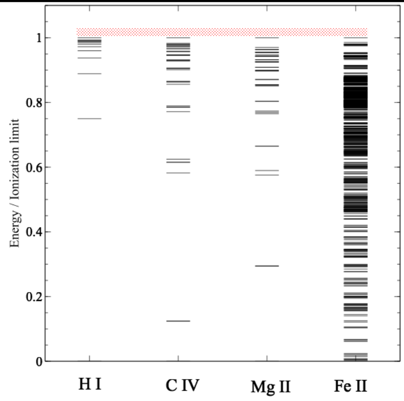
O III

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



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



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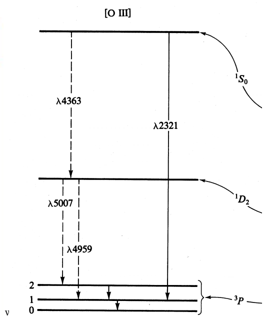


Species vs spectra

- **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 Lya *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

Lines in the main output

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

Finding lines in Cloudy

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

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

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

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**

Emissivity vs density, temperature

- **Recombination line, O III forbidden lines**

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 $n_u A_{ul}$

$$4\pi j = n_u A_{ul} h\nu$$
$[\mathrm{erg\ cm^{-3}\ s^{-1}}]$

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

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

$$n_u + n_l = n$$

critical density

$$A_{ul} = q_{ul} n_{crit}$$

$n_e \ll n_{crit}$

$$4\pi j = n_e n_l q_{lu} h\nu$$

$n_e \gg n_{crit}$

$$4\pi j = n_l \frac{q_{lu}}{q_{ul}} A_{ul} h\nu$$

Vary density over extreme range

- Plot emissivity vs density over wide range to see how emissivity changes

Recombination lines

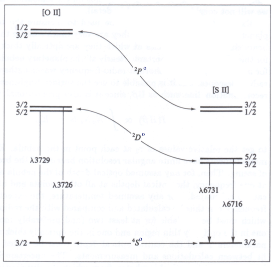
- $H^+ + e \rightarrow H^{0*} \rightarrow H^0$ + photons
- Critical densities of H I, He I, and He II optical lines are very high, n > 1e15 cm^{-3}, so they are usually in LDL
- Emissivity goes as n^2 for $n < 10^{20}$ cm^{-3}
- Case B predictions
- H I, He I, He II are the strongest in UV/ Opt/ IR
-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

Forbidden lines

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

Compute spectrum of clouds with two very different densities

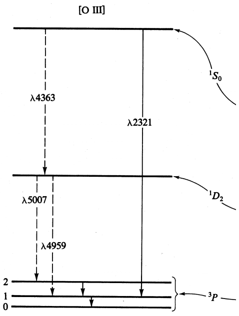
Density indicators



AGN3 Fig 5.7

Temperature indicators

- Lines from same species which have different excitation potentials

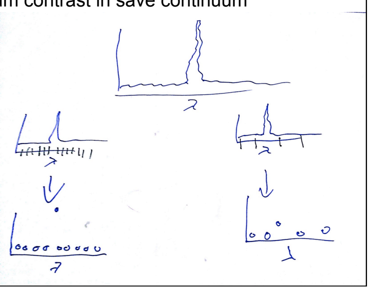


Inward vs total emission

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

Line to continuum contrast

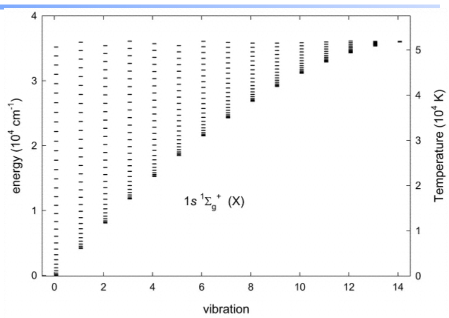
- Hazy 1, sec 16.43.2, 19.14.44
  - Line to continuum contrast in save continuum
  - Command SET SAVE LINE WIDTH



Databases in Cloudy

- Stout (atoms & low ionization)
- Chianti (higher ionization)
- LAMDA (heavy-element molecules)

H_2 (Shaw+05) “species H2”



Controlling model atoms

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