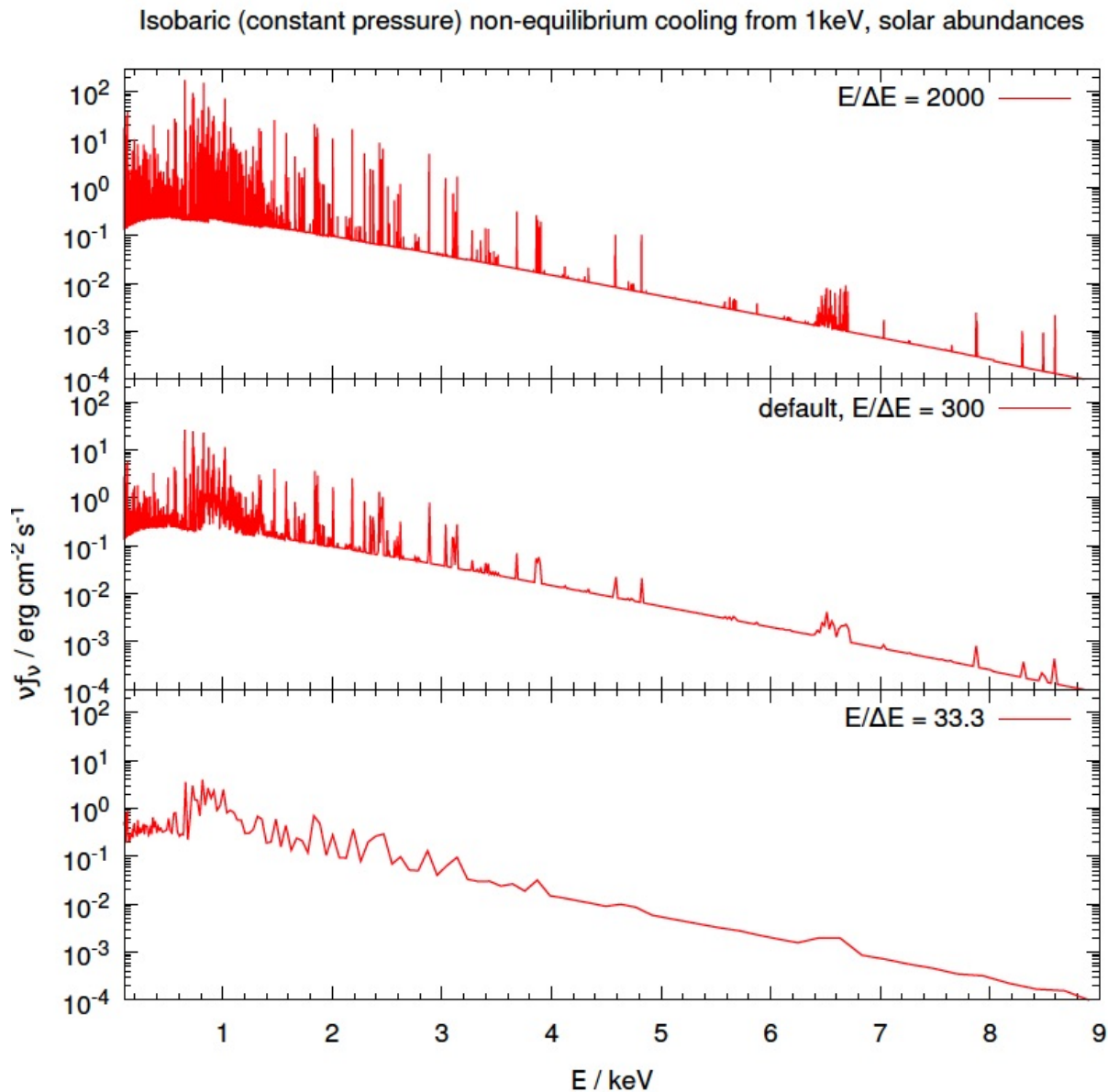
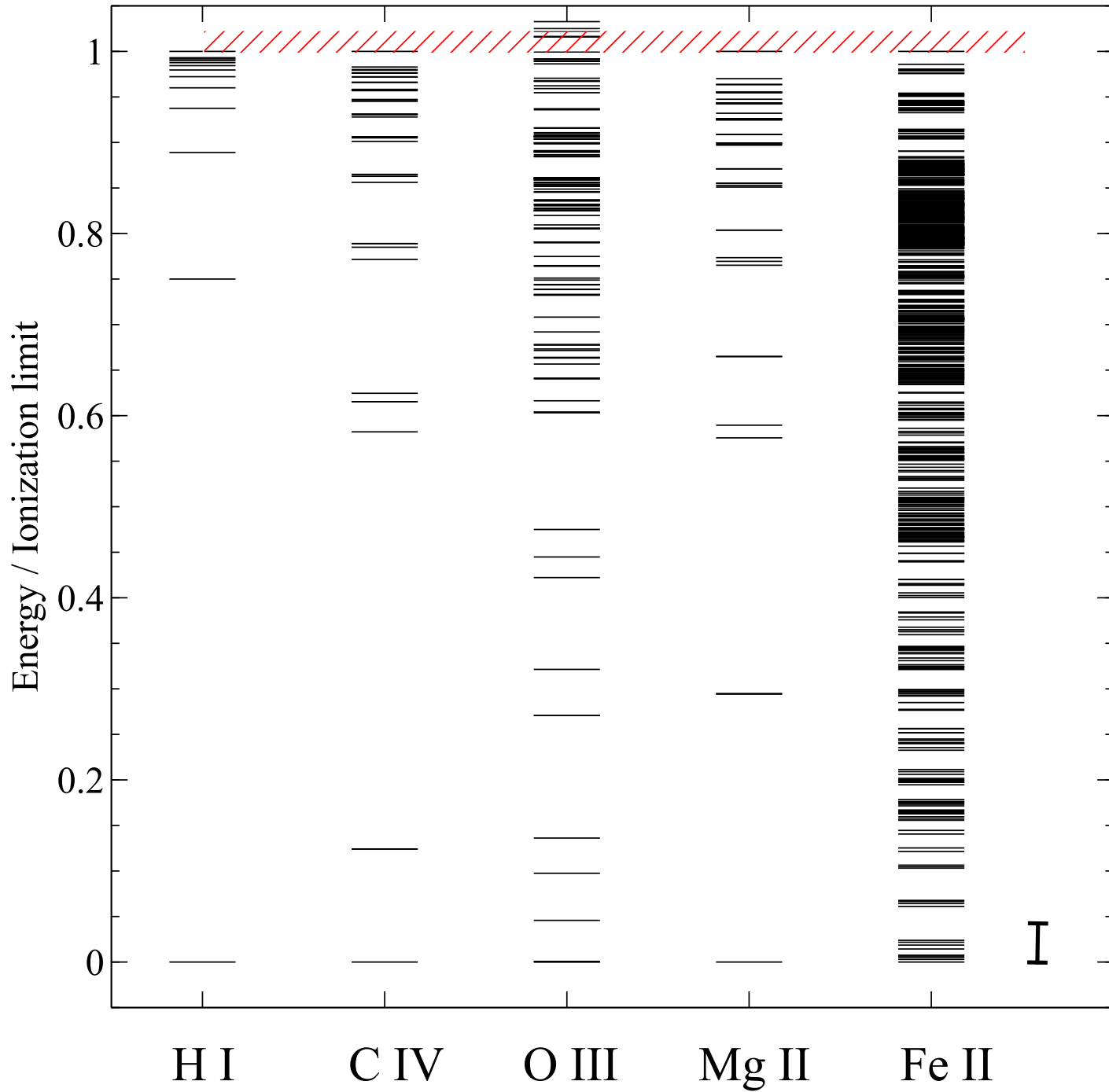


◆ How to make sense of all these lines





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**

◆ <http://www.nist.gov/pml/data/asd.cfm>

Physical Measurement Laboratory

About PML ▾ Publications Topic/Subject Areas ▾ Products/Services ▾ News/Multimedia Programs/Projects Facilities ▾

NIST Home > PML > Physical Reference Data > Atomic Spectra Database

Version History & Citation Information | Disclaimer

SHARE    ...

NIST ATOMIC SPECTRA DATABASE

Version 4

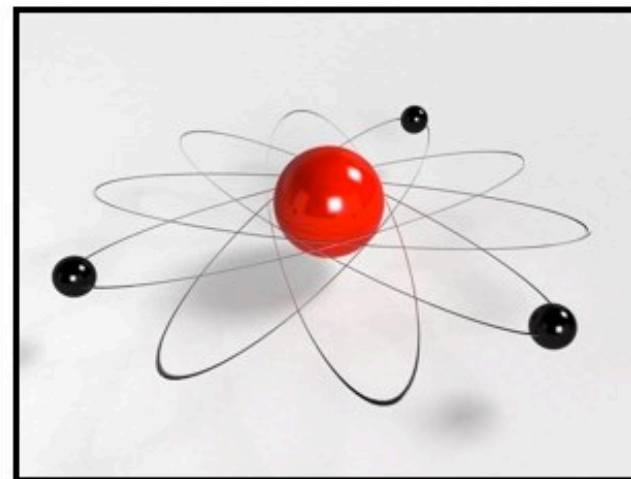
Welcome to the NIST Atomic Spectra Database, NIST Standard Reference Database #78. The spectroscopic data may be selected and displayed according to wavelengths or energy levels by choosing one of the following options:

LINES

Spectral lines and associated energy levels displayed in wavelength order with all selected spectra intermixed or in multiplet order. Transition probabilities for the lines are also displayed where available.

LEVELS

Energy levels of a particular atom or ion displayed in order of energy above the ground state.



© minifilm7/2010 Shutterstock.com

NIST ASD Team

Principal Developers (Currently Active):

Yu. Ralchenko, A. Kramida, and J. Reader

NIST Atomic Spectra Database Levels Form

Best viewed with the latest versions of Web browsers and Java

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

Spectrum: e.g., Fe I

Default Values

Retrieve Data

Level Units:

Format output:

Display output:

Page size:

Term ordered term energy

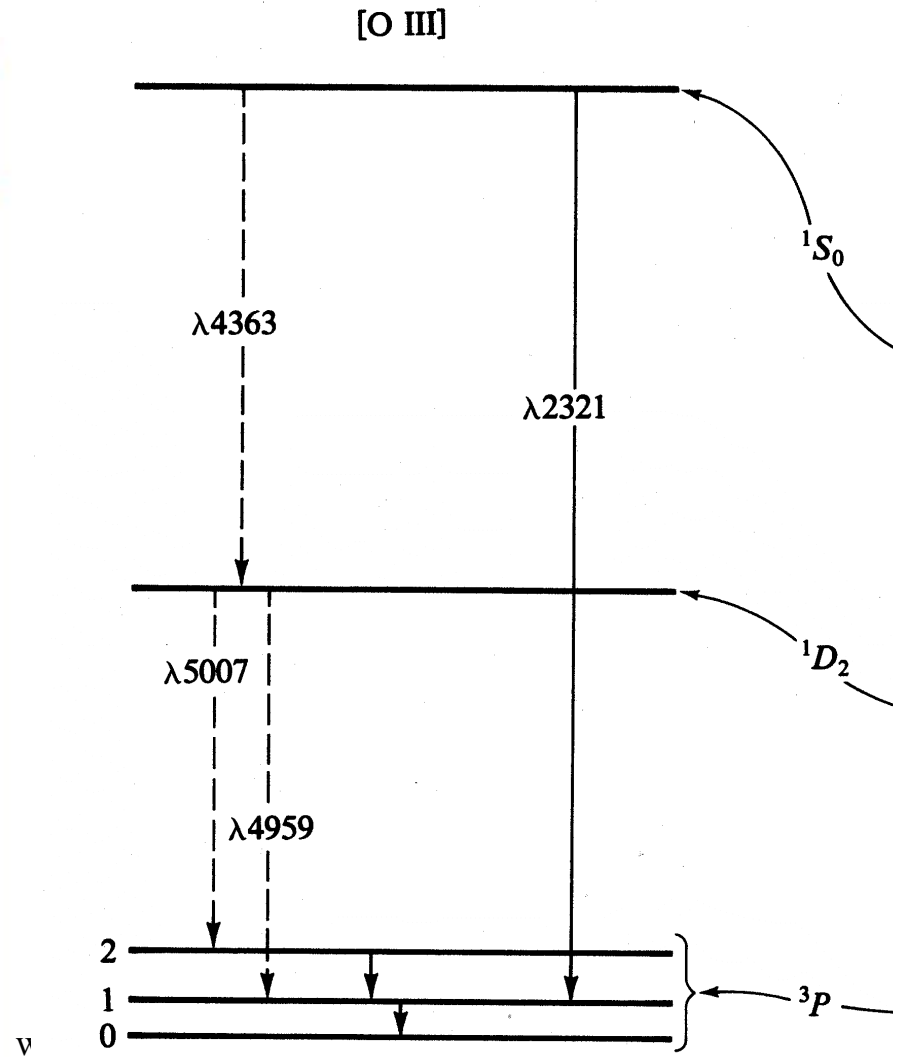
Energy ordered

Level information:
 Principal configuration
 Principal term
 Level J
 Lande-g

Extended Search: for all levels search

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 ^o	2	60 324.79
2s2p ³	3D ^o	3	120 025.2
		2	120 053.4
		1	120 058.2



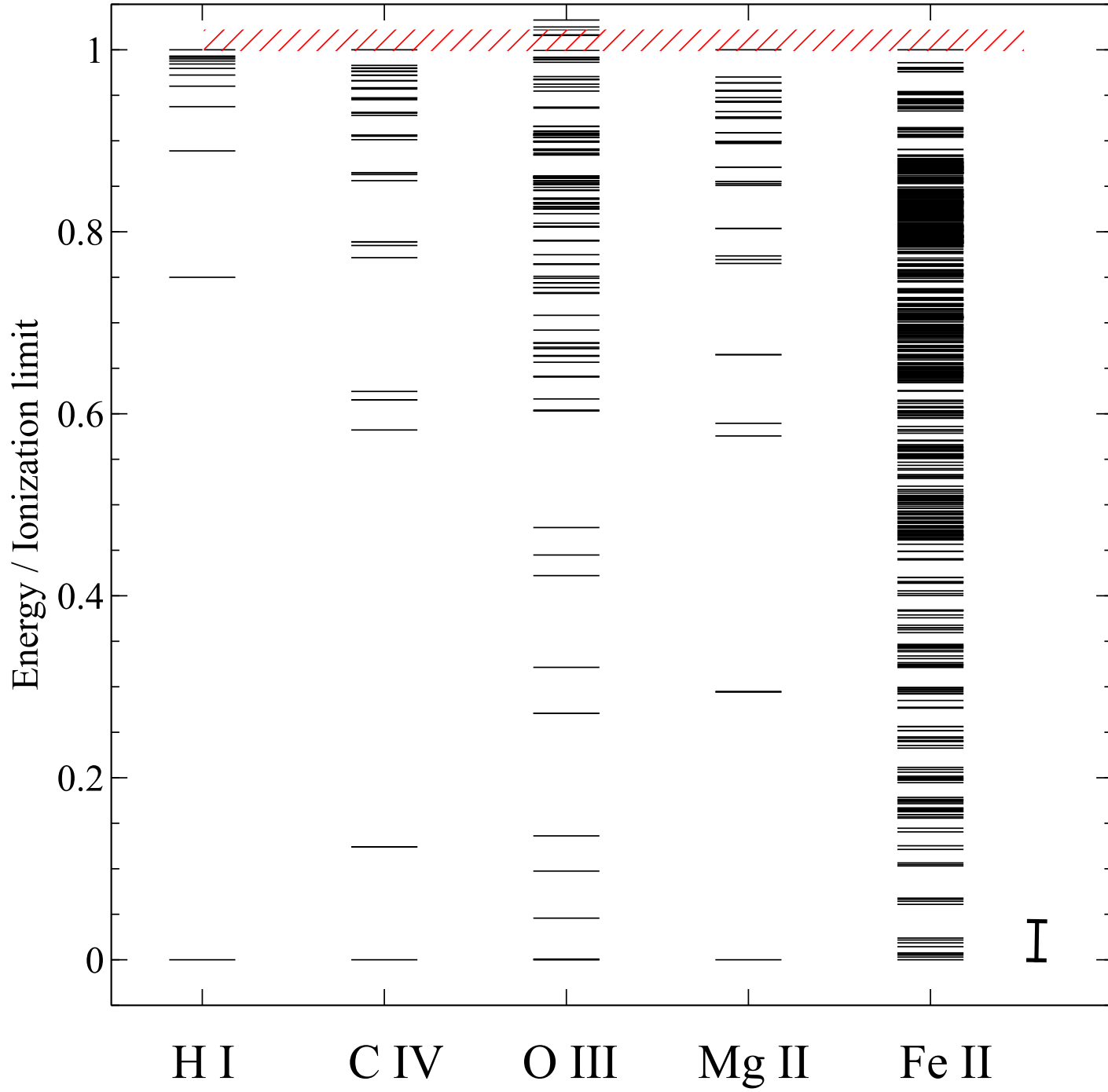
Two types of lines

- ◆ **Recombination AGN3 sec 4.2**

- e + p radiative recombination
- Rate coefficient $q \sim 10^{-13} \text{ cm}^3 \text{ s}^{-1}$
- Mainly H, He

- ◆ **Collisionally excited AGN3 3.5**

- Inelastic e + ion collision
- $q \sim 10^{-9} \text{ cm}^3 \text{ s}^{-1}$
- Heavy elements

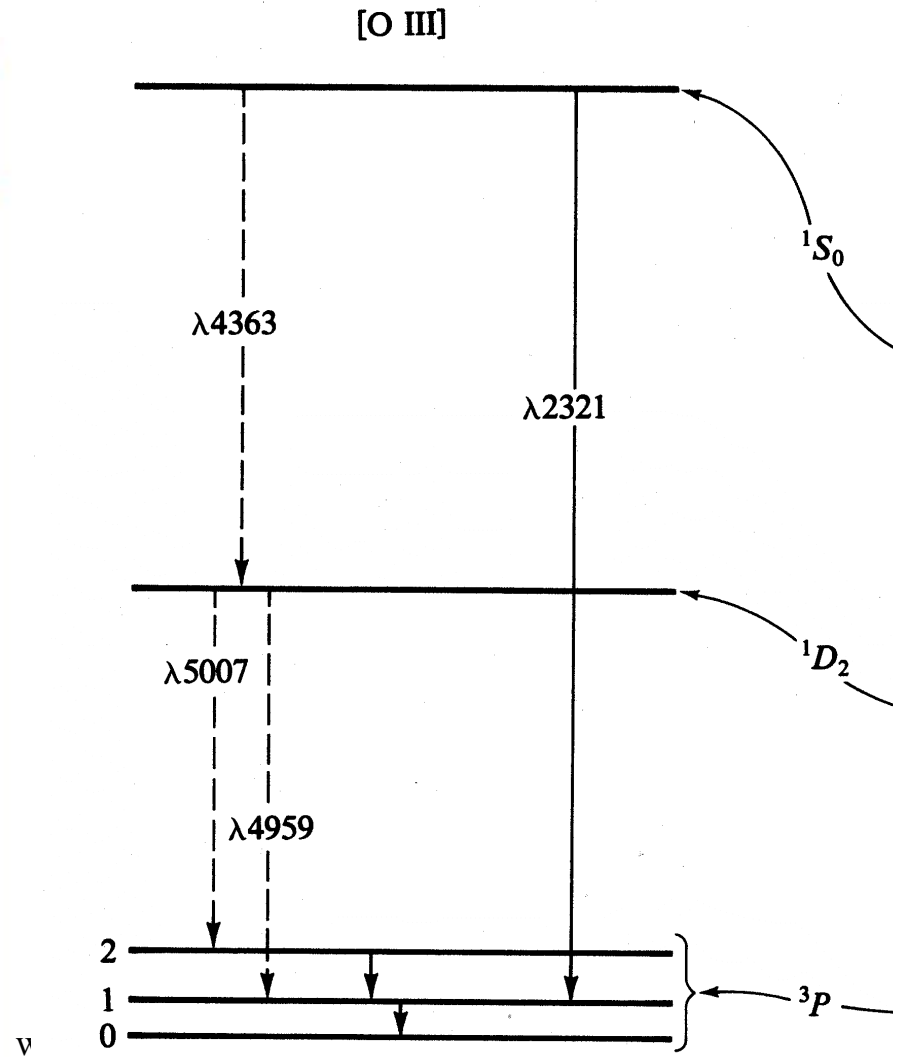


Selection rules for transitions

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

O III

Configuration	Term	J	Level (cm ⁻¹)
2s ² 2p ²	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 ^o	2	60 324.79
2s2p ³	3D ^o	3	120 025.2
		2	120 053.4
		1	120 058.2



Species vs spectra

- ◆ **H⁰, C³⁺, O²⁺, H₂, CO are baryons**
- ◆ **H I, C IV, O III, H₂, and CO are the spectra they emit / absorb**
- ◆ **O III is a permitted line produced by O²⁺, while [O III] is a forbidden line**
- ◆ **C III] is a semi-forbidden line, often an intercombination line**

Species vs spectra

- ◆ **H I Ly α *emission* can be produced by**
 - Recombination of H⁺
 - Impact excitation of H⁰
- ◆ **H I absorption can only be produced by H⁰**
- ◆ **H I is not the same as H⁰**
 - 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 H β**

– 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
6	4	10.5076	-4.004	5.0157

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 in LTE, photon emission proportional to $n_u A_{ul}$

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

$$n_e g_{lu} n_e =$$

$$n_u [A_{ul} + g_{ue} n_e]$$

$$\frac{n_u}{n_e} = \frac{g_{lu} n_e}{A_{ul} + g_{ue} n_e}$$

$$n_u + n_e = n$$

critical density

$$A_{ue} = g_{ue} n_{crit}$$

$$n_e \ll n_{crit}$$

$$4\pi j = n_e n_e g_{ue} h\nu$$

$$n_e \gg n_{crit}$$

$$4\pi j = n_e \frac{g_{ue}}{g_{ue}} A_{ue} h\nu$$

Why we set the ionization

- ◆ If most O were O³⁺ the process
- ◆ $O^{3+} + e \rightarrow O^{2+} + h\nu$
- ◆ 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**

Vary density over extreme range

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

Recombination lines

- ◆ $\text{H}^+ + \text{e} \rightarrow \text{H}^{0*} \rightarrow \text{H}^0 + \text{photons}$
- ◆ Critical densities of H I, He I, and He II optical lines are very high, $n > 1\text{e}15 \text{ cm}^{-3}$, so they are usually in LDL
- ◆ Emissivity goes as n^2 for $n < 10^{20} \text{ cm}^{-3}$
- ◆ Case B predictions

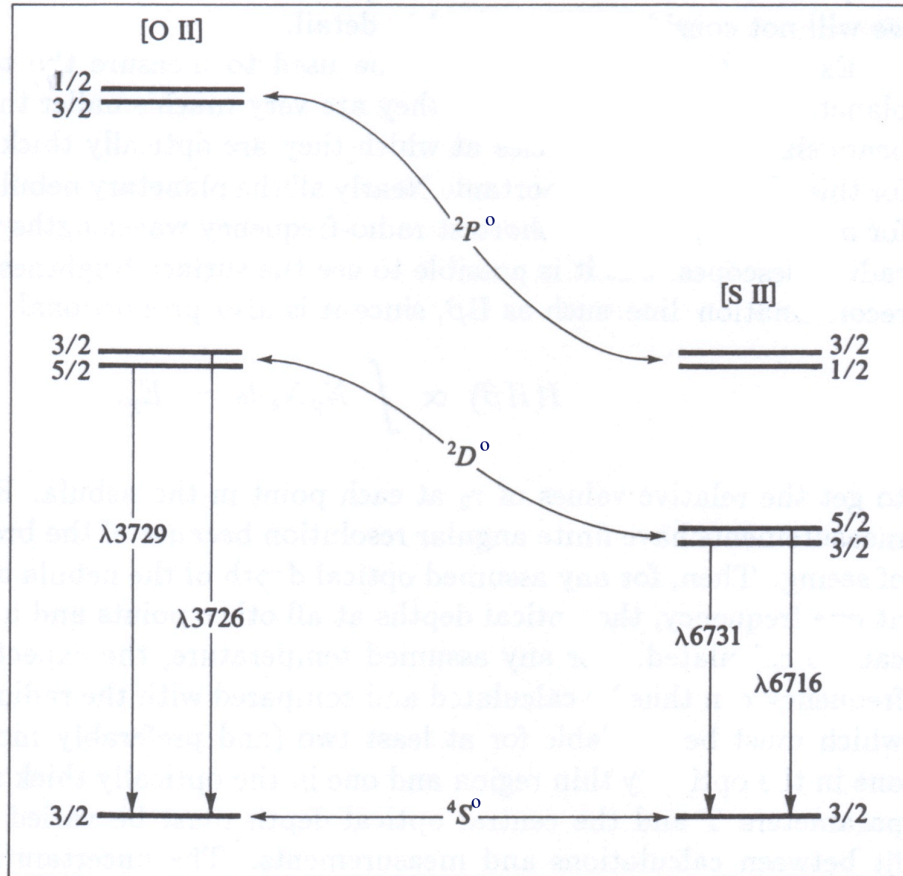
- ◆ H I, He I, He II are the strongest in UV/ Opt/ IR
- ◆ Second row (C,N, O, Ne) & Fe in X-ray

Forbidden lines

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

Compute spectrum of clouds with two very different densities

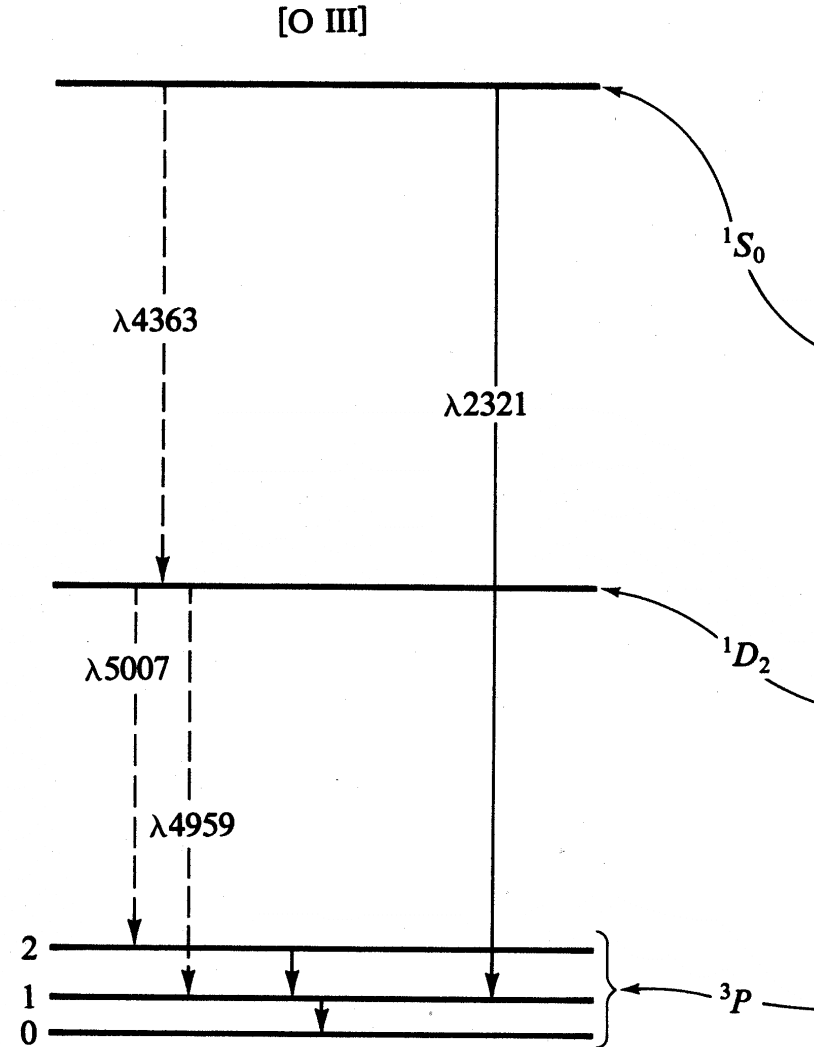
Density indicators



AGN3 Fig 5.7

Temperature indicators

- ◆ Lines from same species which have different excitation potentials



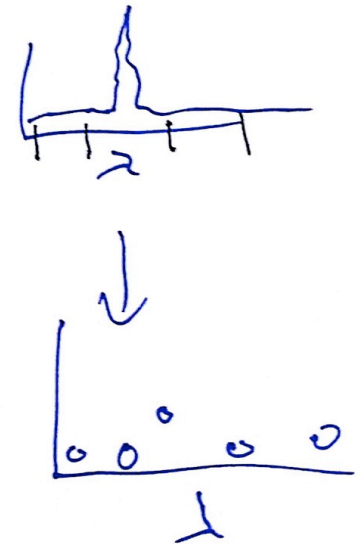
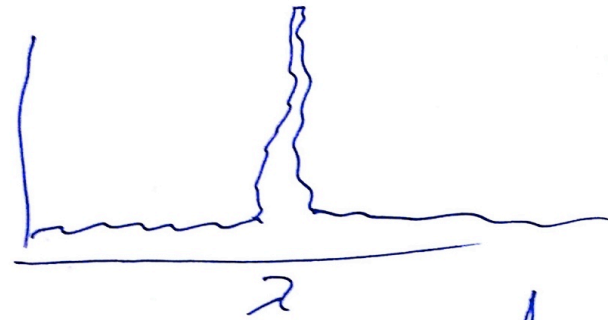
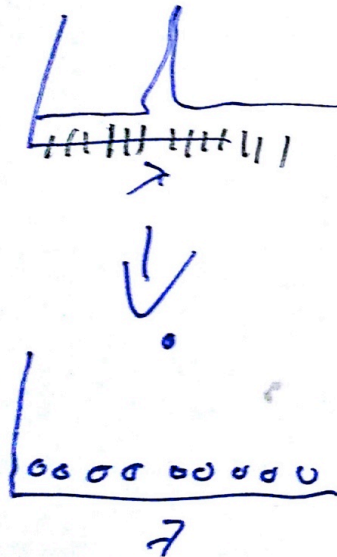
Inward vs total emission

- ◆ **“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

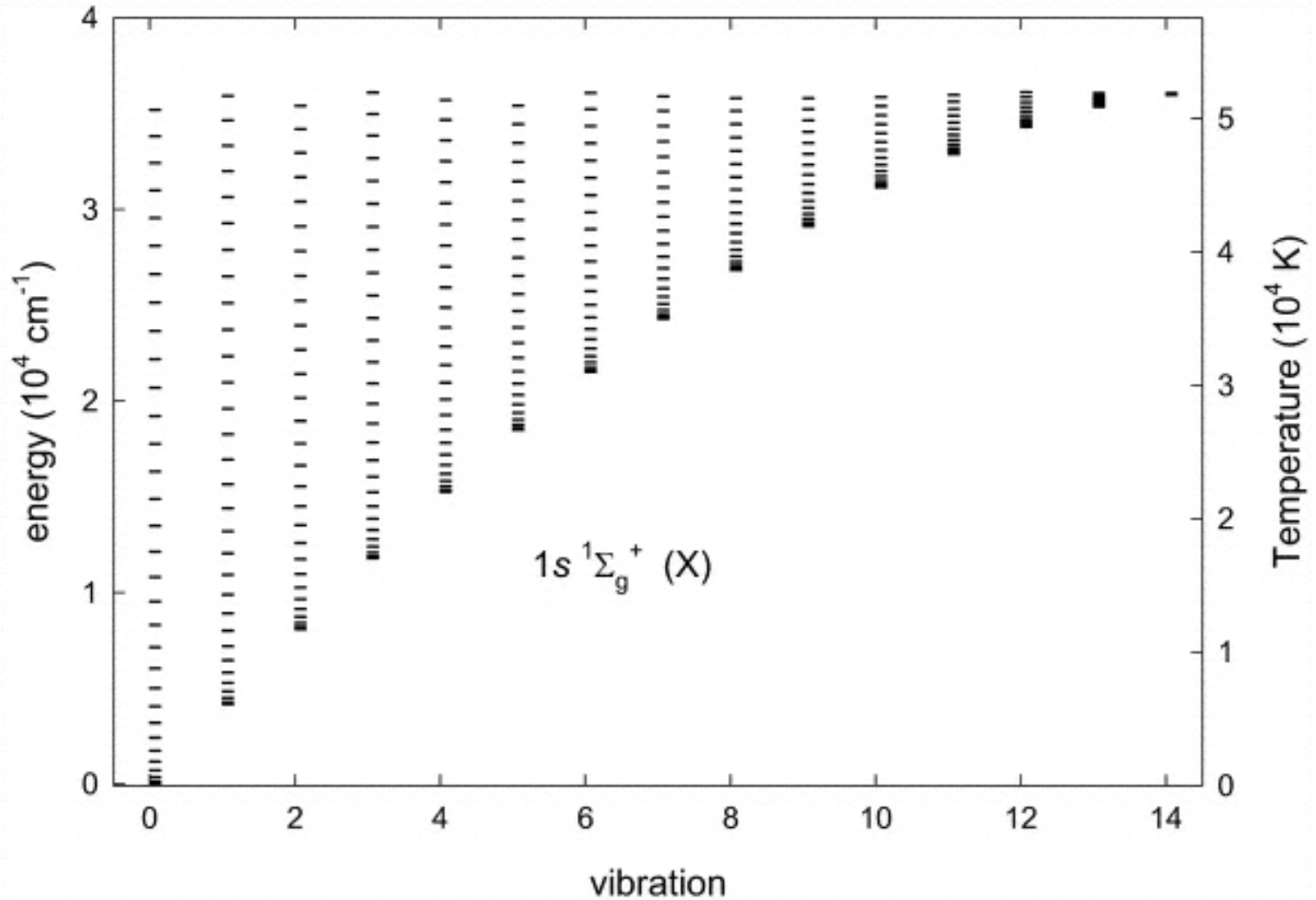
- Line to continuum contrast in save continuum
- Command SET
SAVE LINE
WIDTH



Databases in Cloudy

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

H₂ (Shaw+05) “species H2”



Controlling model atoms

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