

Thoughts from yesterday

- ◆ **The CMB**

- Radio telescopes automatically subtract off the CMB when the observation is made
- So faint lines, much fainter than the CMB in the total Cloudy prediction, are easily observed

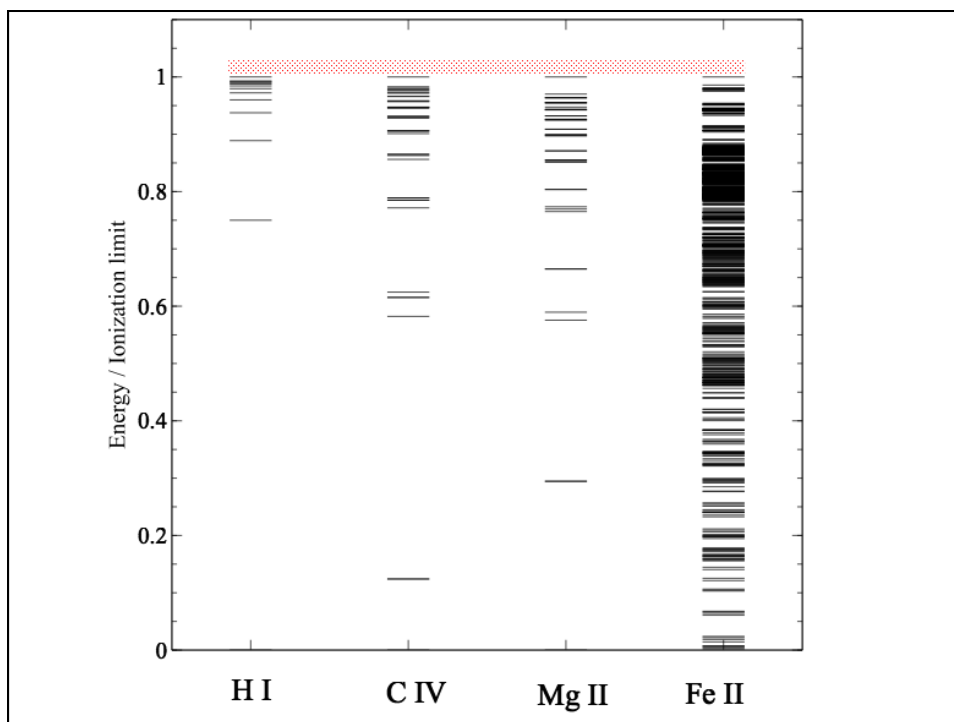
- ◆ **Beam switching, frequency switching**

What happened with the laser?

- ◆ **The sum of the cooling lines matches the heating**
- ◆ **So that sum can't change (energy balance)**
- ◆ **The [O III] lines are normally the strongest single coolants for an H II region, so they can't change unless the heating (set by the SED) changes**
- ◆ **The [O III] lines were not the strongest coolant's with the laser. They were with the star.**

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 be with a finite column density



Peter's atomic line list

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

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NIST

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

Physical Measurement Laboratory

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

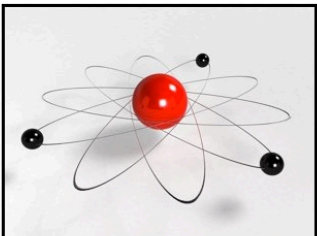
Version History & Citation Information | Disclaimer SHARE

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.



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NIST ASD Team

Principal Developers (Currently Active):
Yu. Raichenko, A. Kramida, and J. Reader

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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.

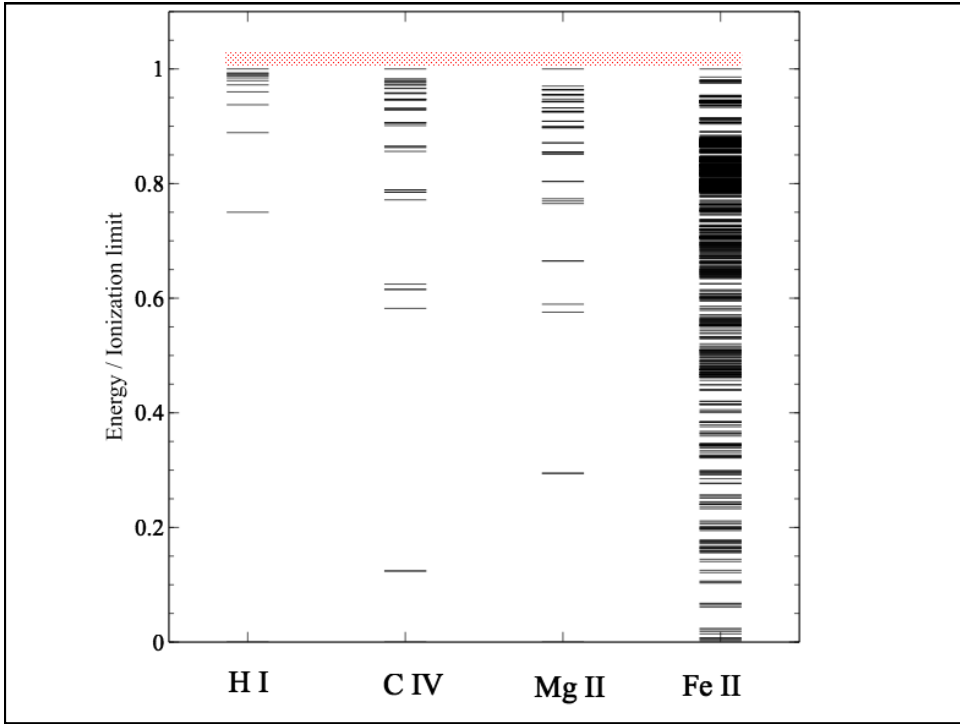
Spectrum: e.g., Fe I

<p>Level Units: <input type="text" value="cm-1"/></p> <p>Format output: <input type="text" value="HTML (formatted)"/></p> <p>Display output: <input type="text" value="in its entirety"/></p> <p>Page size: <input type="text" value="15"/></p> <p>Term ordered <input checked="" type="radio"/> term energy <input type="checkbox"/></p> <p>Energy ordered <input type="radio"/></p> <p>Level information: <input checked="" type="checkbox"/> Principal configuration <input checked="" type="checkbox"/> Principal term <input checked="" type="checkbox"/> Level <input checked="" type="checkbox"/> J <input checked="" type="checkbox"/> Lande-g</p>	<p>Extended Search: <input type="button" value="Set Additional Criteria"/> for all levels search</p>
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Two types of lines

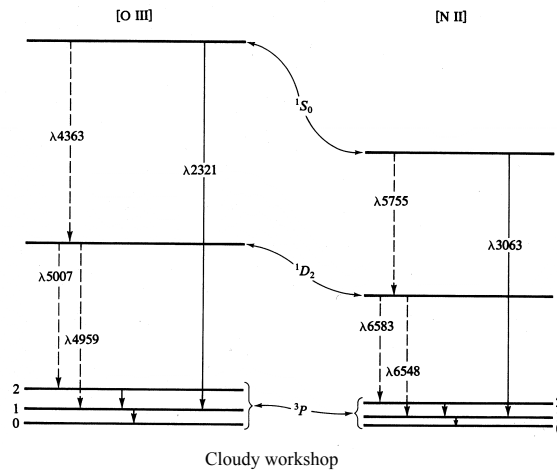
- ◆ **Recombination AGN3 sec 4.2**
 - e + p radiative recombination
 - $q \sim 10^{-13} \text{ cm}^3 \text{ s}^{-1}$
 - Mainly H, He
- ◆ **Collisionally excited AGN3 3.5**
 - Inelastic e + ion collision
 - $q \sim 10^{-9} \text{ cm}^3 \text{ s}^{-1}$
 - Heavy elements

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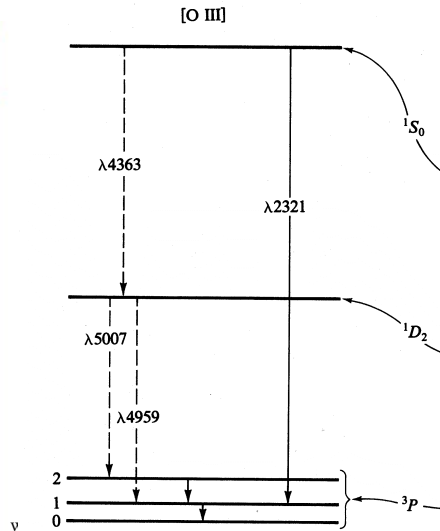
[O III]

◆ AGN3 Fig 3.1



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°	2	60 324.79
2s2p ³	3D°	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 forbidden

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

Finding lines in Cloudy

- ◆ **Run smoke test with command**
- ◆ **Save line labels**

- ◆ **Spectral label, wavelength, identifies a line**

- ◆ **Save file has label, wavelength, comment about line**

- ◆ **Pick lines from this save file**

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

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

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Recombination lines

- ◆ $H^+ + e \rightarrow H^{0*} \rightarrow H^0 + \text{photons}$
- ◆ **Critical densities of H I, He I, and He II optical lines are very high, $n > 1e15 \text{ cm}^{-3}$, so they are usually in LDL**
- ◆ **Emissivity goes as n^2**

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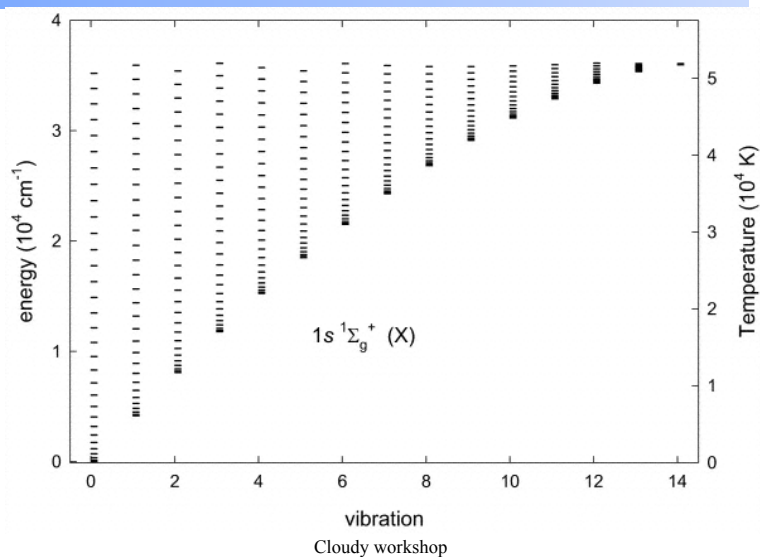
Forbidden lines

- ◆ [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

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Inward vs total emission

H₂ (Shaw+05) “species H2”



Controlling model atoms

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