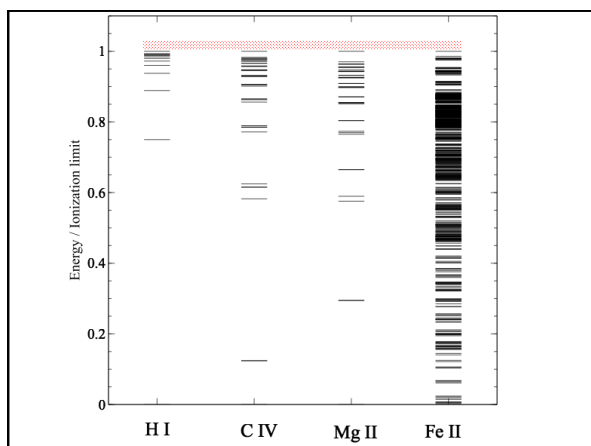## What happened with the laser?

- ◆ 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 heading (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 happenwith 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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Slide 1: NIST

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
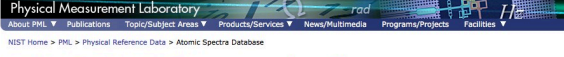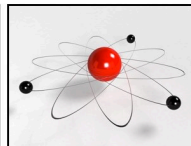
NIST Atomic Spectra Database

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. Ralchenko, A. Kramida, and J. Reader

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Slide 2: NIST Atomic Spectra Database Levels Form

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
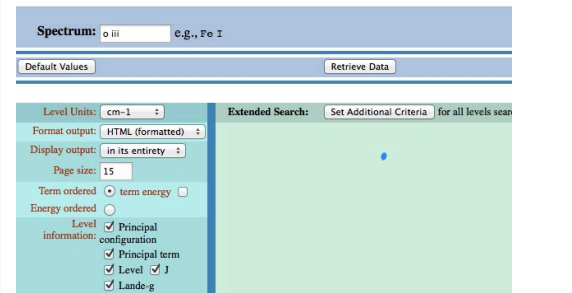Format output: HTML (formatted)
Display output: in its entirety
Page size: 15
Term ordered: ⦿ term energy ☐
Energy ordered: ◯
Level information:
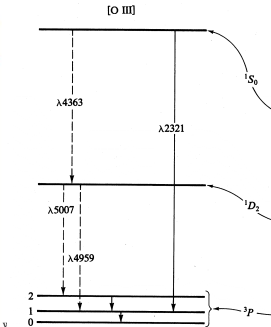☑ Principal configuration
☑ Principal term
☑ Level ☑ J
☑ Lande-g
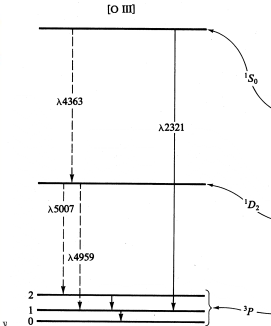
Extended Search: Set Additional Criteria for all levels sear

Slide 3: O III

O III

[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
$2s 2p^3$	$^5S°$	2	60 324.79
$2s 2p^3$	$^3D°$	3	120 025.2
		2	120 053.4
		1	120 058.2

λ4363
λ2321
λ5007
λ4959
$^1S_0$
$^1D_2$
^3P
2
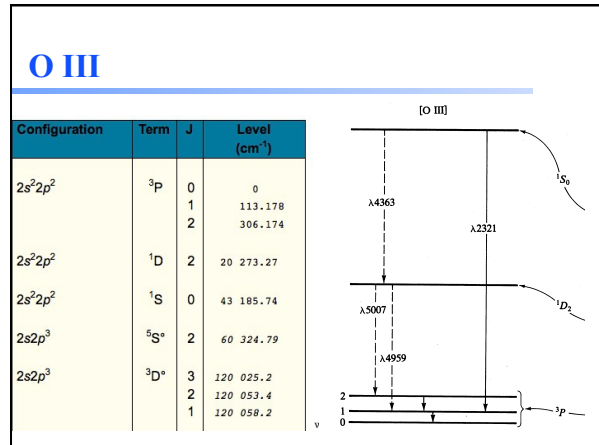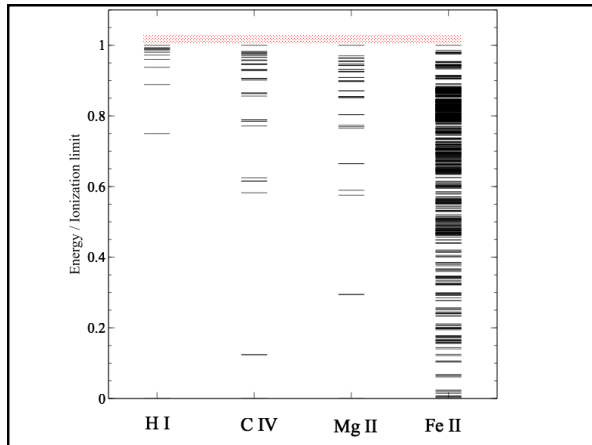1
0

Slide 4: Two types of lines

Two types of lines

◆ **Recombination AGN3 sec 4.2**
 – e + p radiative recombination
 – 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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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
$2s 2p^3$	$^5S°$	2	60 324.79
$2s 2p^3$	$^3D°$	3	120 025.2
		2	120 053.4
		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 forbidden

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 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 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
```

Emissivity vs density, temperature

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

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