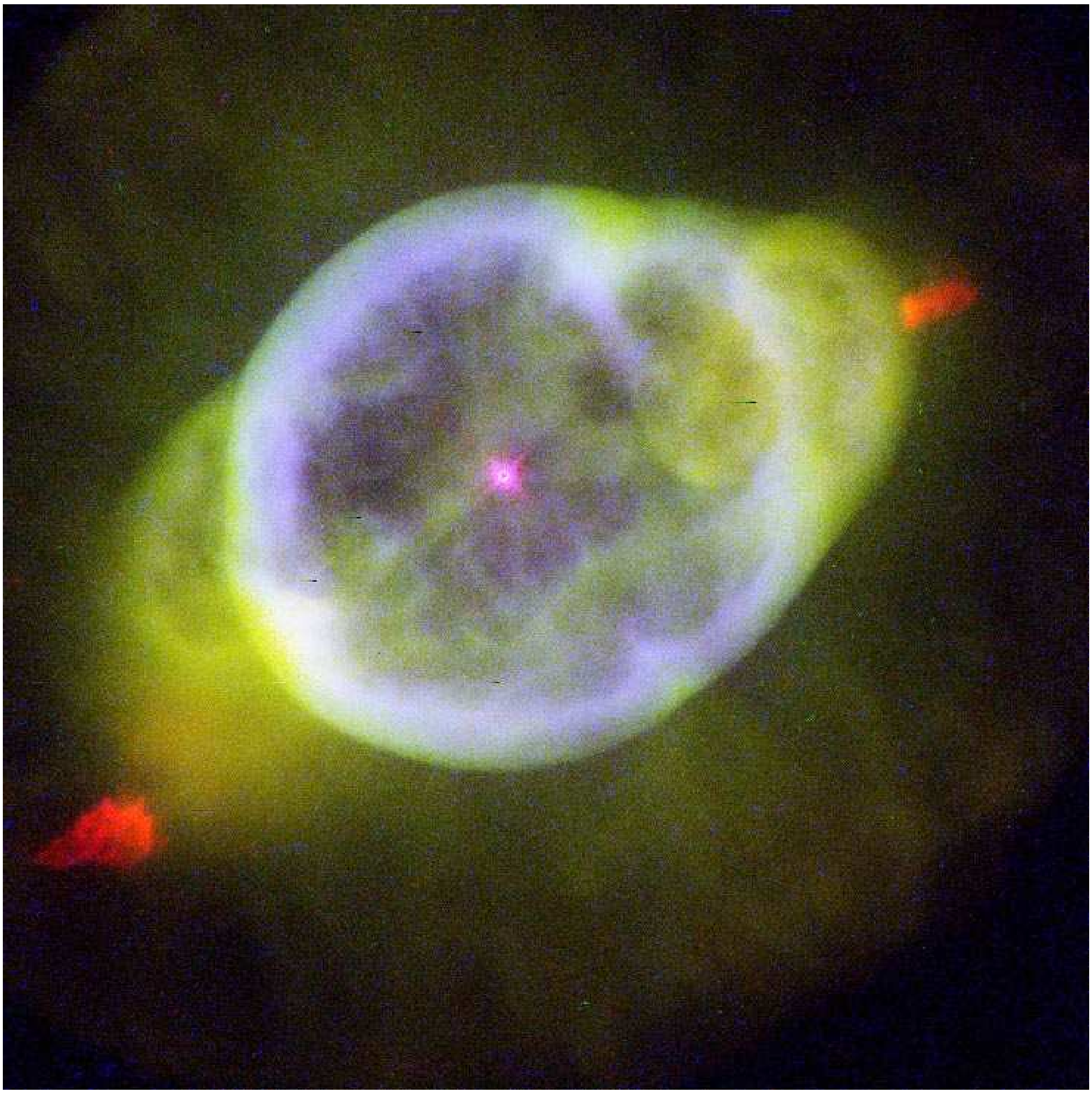
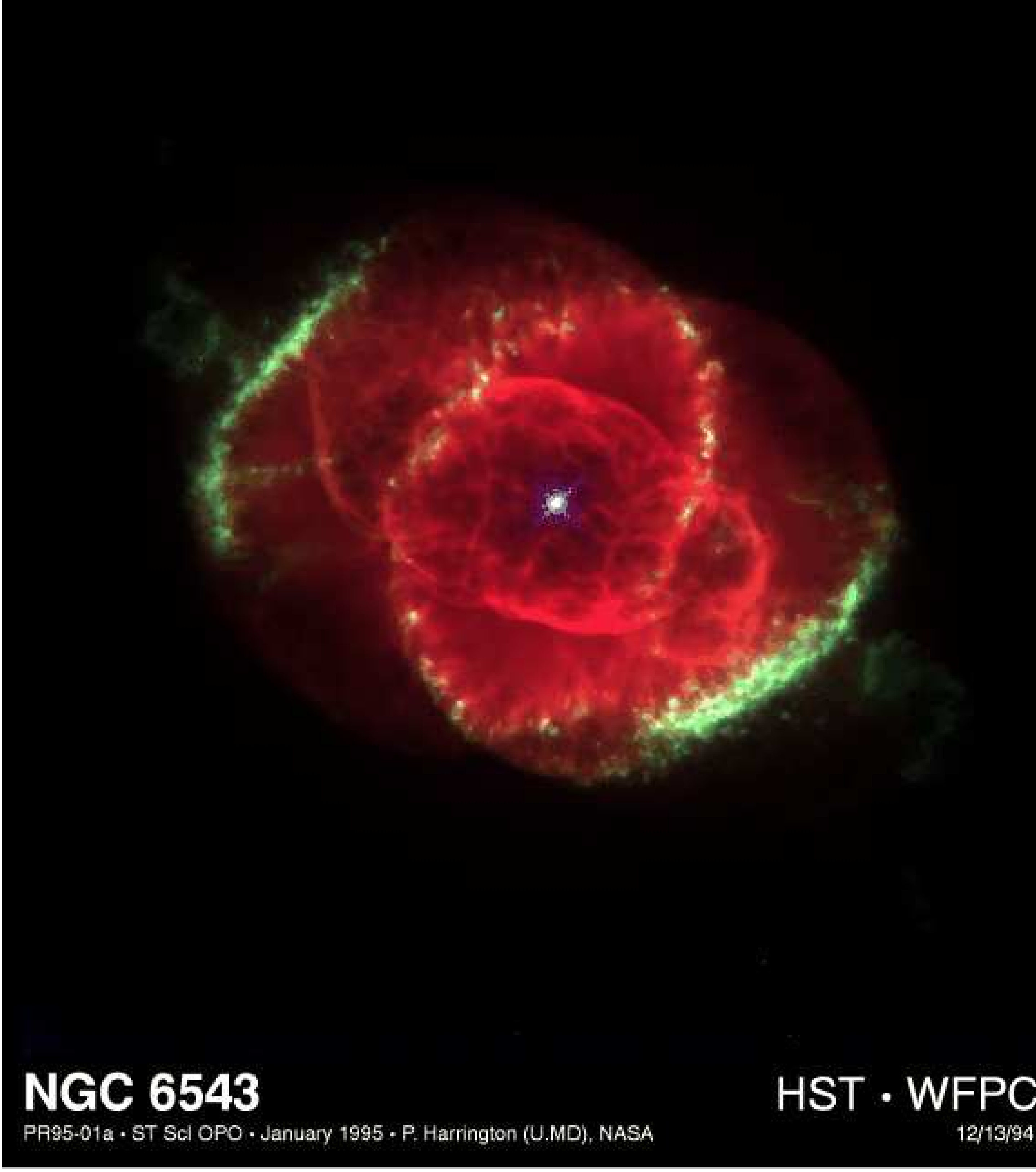
Line Diagnostics

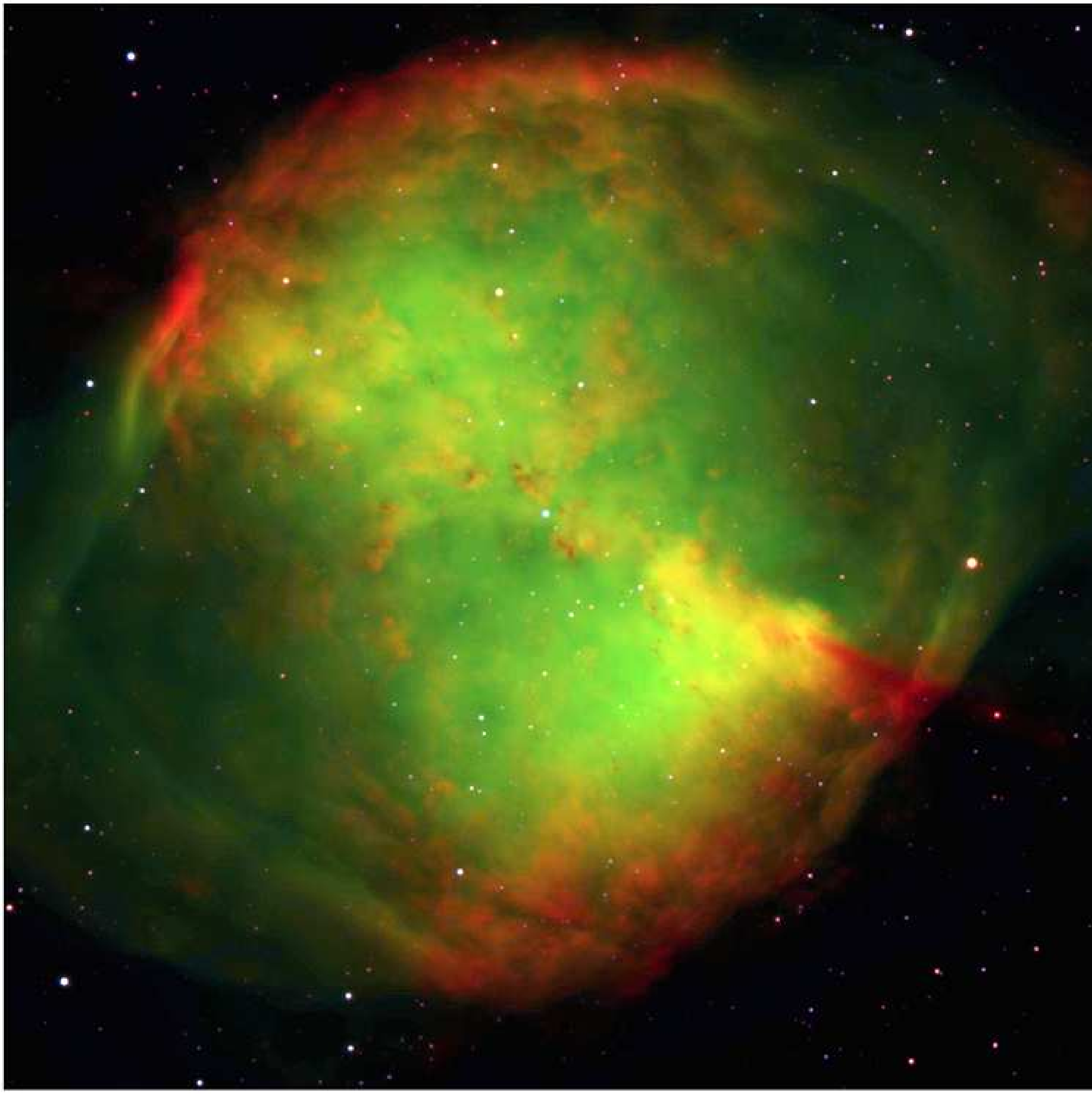
Planetary Nebulae, I



NGC 3242 with HST


NGC 6543
PR95-01a • ST ScI OPO • January 1995 • P. Harrington (U.MD), NASA
HST • WFPC
12/13/94


Planetary Nebula IC 418
Hubble Heritage
PRC00-28 • NASA and The Hubble Heritage Team (STScI/AURA) • HST/WFPC2



Planetary Nebula NGC 6853 (M 27) - VLT UT1+FORS1

ESO PR Photo 38a/98 (7 October 1998)

Blue: broad band blue filter, green: O II, red: Hα

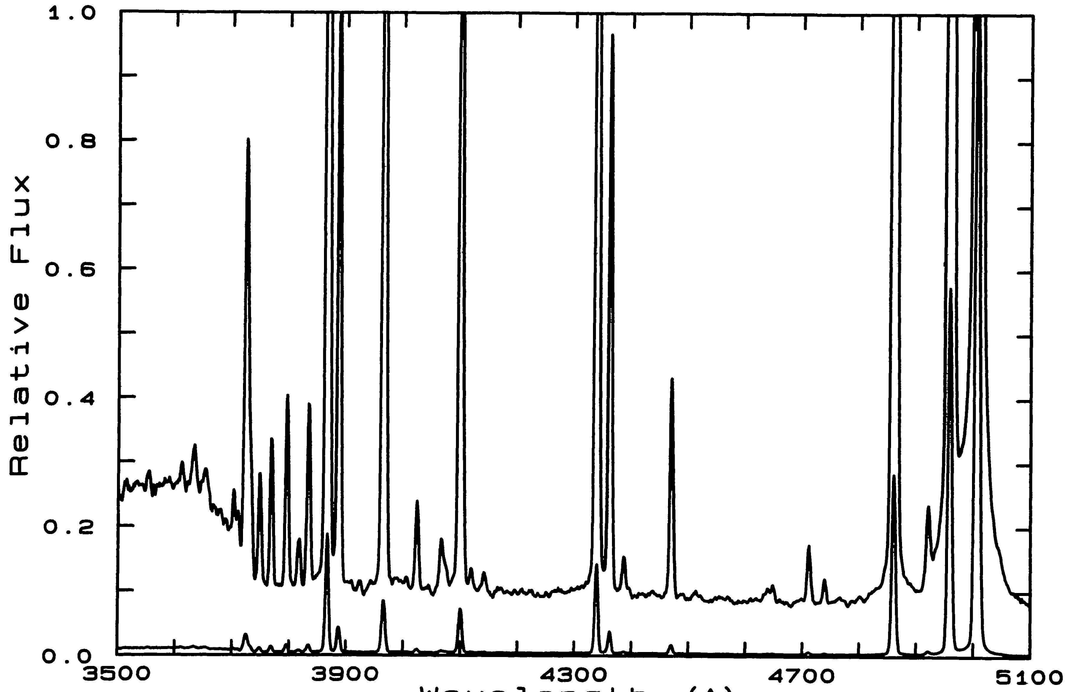


FIG. 1*a*

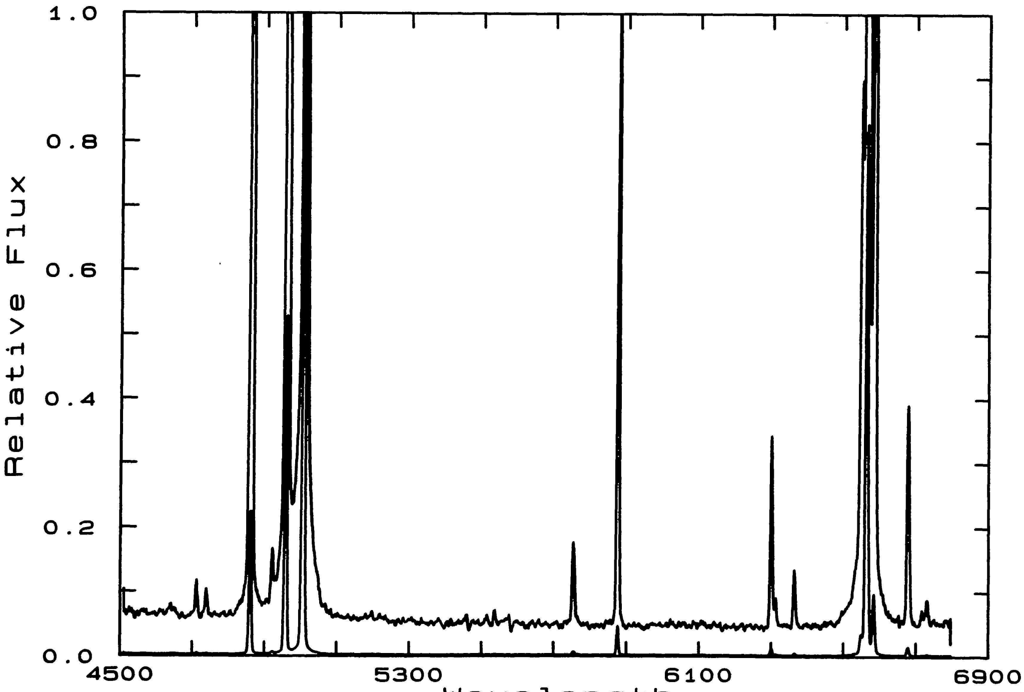
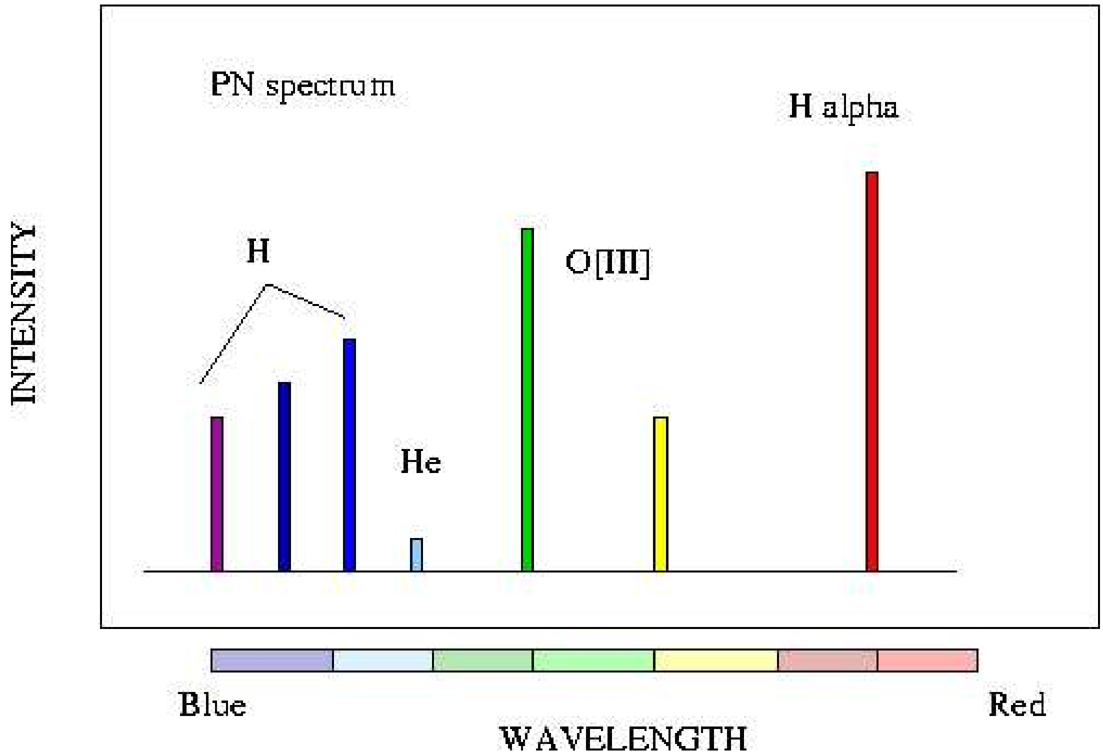


FIG. 1*b*

FIG. 1.—Spectral scans of the low-excitation planetary NGC 6833. All scans are corrected for effects of atmospheric extinction, response functions, and nonlinearity of dispersion. Nebular fluxes were measured in units of ergs cm^{-2} s^{-1} $Å^{-1}$. We give here relative fluxes. All data were secured with the 3 m Shane telescope and image-tube scanner on 1981 August 7. All scans of NGC 6833 have a resolution of 9 Å. (*a*) The regions 3500–5100 Å. The two magnifications are 1× (scaled to strongest line λ5007) and 25×. Note the strong background continuum. (*b*) The region 4500–6800 Å, magnifications 1× and 25×. (*c*) The region 6200 to 7800, magnifications 1× and 25×. Neither [N II] nor [S II] is prominent in this object, although the [S III] auroral-type transition λ6312 is fairly strong.

(Aller & Keyes, 1987, Fig. 1)

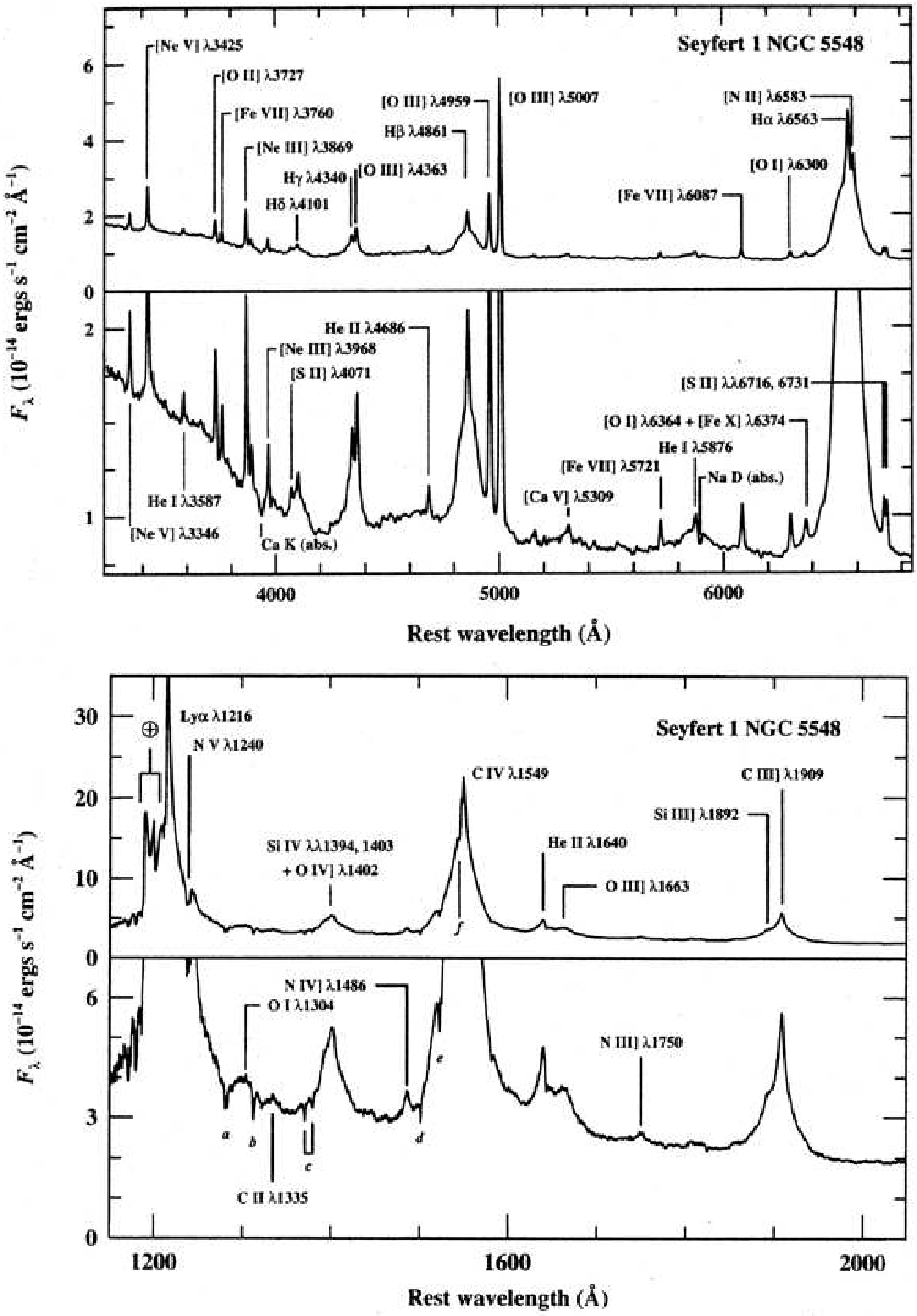
Planetary Nebulae, VI



www.ucolick.org/~bolte/AY4/notes10/node3.html

Typical spectra of planetary nebulae are dominated by Hydrogen lines, plus emission from O III at 5007 Å ("nebulium").

Seyfert Galaxies



Peterson (1997)

Optical/UV spectrum of NGC 5548: a typical Seyfert 1 Galaxy.

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Photoionization, I

Assume: cloud irradiated by photons

Goal: only source for ionization: photoionization

Equilibrium: number ionizations $=$ number of recombinations

$$\int_{\nu_{\text{ion}}}^{\infty} a(\nu)\frac{F_\nu}{h\nu} n(X^r)\text{d}\nu = \alpha(T) n_{\text{e}} n(X^{r+1}) \tag{7.1}$$

where

$a(\nu)$: photoionization cross section (cm^2; $\propto E^{-3}$)

$\alpha(T_{\text{e}})$: Recombination coefficent (cm^3 s^{-1})

n_i: particle density (cm^{-3})

F_ν: local photon flux, erg cm^{-2} s^{-1} keV^{-1},

$$F_\nu = \frac{L_\nu}{4\pi D^2} \tag{7.2}$$

Since $a(\nu)$ quickly decreasing function:

$$\frac{n(X^r)}{n(X^{r+1})} \sim \frac{a(\nu_{\text{ion}})}{\alpha(T)} \frac{L}{4\pi D^2 n_{\text{e}}} \frac{1}{h\nu_{\text{ion}}} \tag{7.3}$$

i.e., ionization equilibrium mainly depends on

$$U = \frac{L/4\pi D^2 h\nu_{\text{ion}}}{n_{\text{e}}} \frac{1}{c} = \frac{\text{\# ionizing photons/cm}^3}{\text{\# electrons/cm}^3} \tag{7.4}$$

the ionization parameter

many other definitions available!

Photoionization, II

In reality, other physical processes need to be considered:

Ionization:

- Photoionization
- collisional Ionization
- Auger-Ionization

Recombination:

- radiative recombination
- dielectric recombination

Continuum Processes:

- Bremsstrahlung
- Compton-Scattering

Real life: Solution of RT problem using advanced radiation codes such as Cloudy or XSTAR (*not* worthwhile to develop your own code...).

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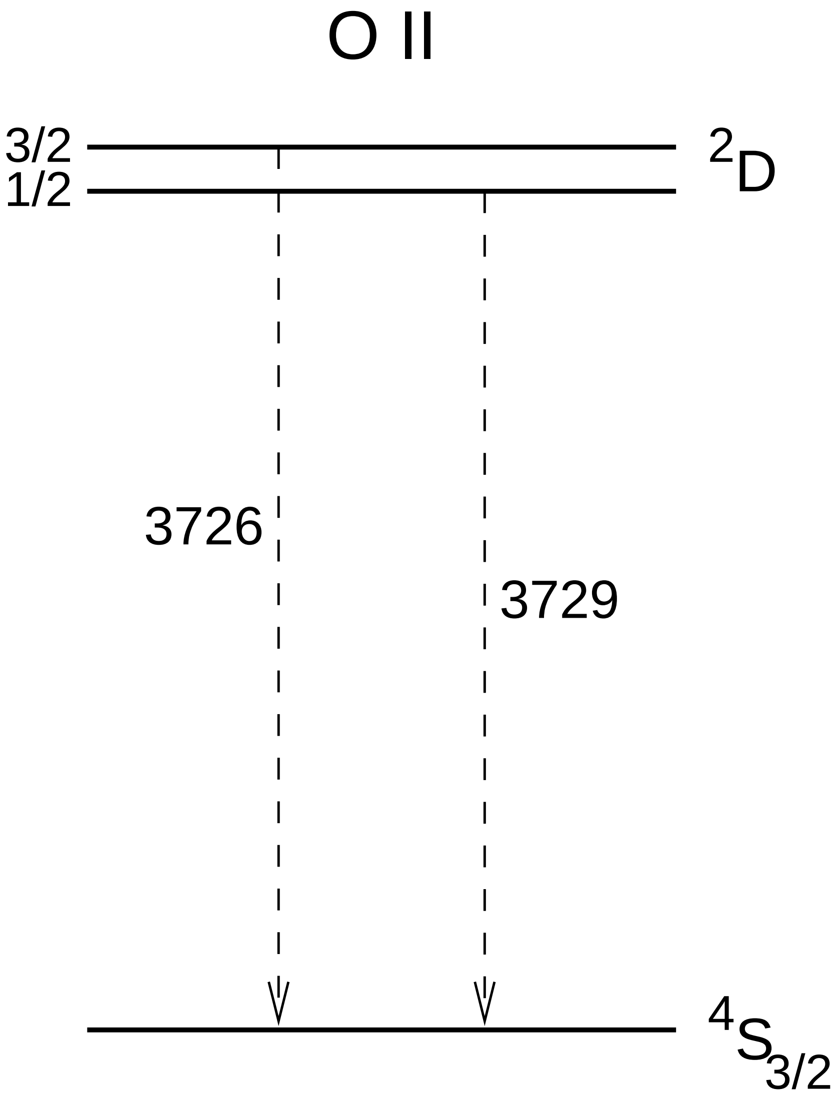
Line Diagnostics: Density, I

Choose atom with two levels with almost same excitation energy. Either radiative or collisional deexcitation.



For $N_\mathrm{e} \approx 1000\,\mathrm{cm}^{-3}$ use [O II] 3729/3726, for higher densities: C II

Line Diagnostics: Density, II

Rate equations in equilibrium:

$$n_1 n_\mathrm{e} C_{12} = n_2 A_{21} + n_2 n_\mathrm{e} C_{21} \quad (7.5)$$

$$n_1 n_\mathrm{e} C_{13} = n_3 A_{31} + n_3 n_\mathrm{e} C_{31} \quad (7.6)$$

where A_{ij} Einstein-Coefficient, C_{ij} coefficient for collisional (de)excitation.

Computation of C_{ij}:

For de-excitation:

$$C_{21} = \int_0^\infty \sigma_{21}(v) v f(v) \mathrm{d}^3 v \quad (7.7)$$

where σ: cross section, $f(v)$ Maxwell.

One can show that

$$\sigma_{21}(v) = \frac{\pi \hbar^2}{m^2 v^2} \frac{\Omega_{21}}{g_2} \quad (7.8)$$

where Ω_{21}: collision strength.

Therefore

$$C_{21} = \frac{\hbar^2}{m^{3/2}} \frac{\Omega_{21}}{g_2} \left(\frac{2\pi}{kT}\right)^{1/2} \sim \frac{8.616 \times 10^{-6}}{T^{1/2}} \frac{\Omega_{21}}{g_2} \mathrm{cm}^3\,\mathrm{s}^{-1} \quad (7.9)$$

Because of Microreversibility

$$C_{12} = \frac{g_2}{g_1} C_{21} \exp(-E_{12}/kT) \quad (7.10)$$

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Line Diagnostics: Density, III

Solve rate equations

$$\frac{n_2}{n_1} = \frac{n_e C_{12}}{A_{21} + n_e C_{21}} \tag{7.11}$$

$$= \frac{n_e}{A_{21} + n_e C_{21}} \frac{g_2}{g_1} C_{21} \exp(-E_{12}/kT) \tag{7.12}$$

and a similar equation for n_3/n_1.

Intensity of the line (assuming cloud is optically thin)

$$I_{21} = \frac{A_{21} n_2 h\nu_{21}}{4\pi} \tag{7.13}$$

Therefore

$$\frac{I_{21}}{I_{31}} = \frac{A_{21} n_2 h\nu_{21}/4\pi}{A_{31} n_3 h\nu_{31}/4\pi} \tag{7.14}$$

since $\nu_{21} \sim \nu_{31}\dots$

$$= \frac{A_{21} n_2}{A_{31} n_3} \tag{7.15}$$

$$= \frac{C_{21}}{C_{31}} \frac{g_2}{g_3} \frac{A_{21}}{A_{31}} \frac{A_{31} + n_e C_{31}}{A_{21} + n_e C_{21}} \exp(-E_{32}/kT) \tag{7.16}$$

$$= \frac{g_2 C_{21}}{g_3 C_{31}} \frac{1 + n_e/n_{\mathrm{cr},3}}{1 + n_e/n_{\mathrm{cr},2}} \exp(-E_{32}/kT) \tag{7.17}$$

where the critical density is defined by

$$n_{\mathrm{cr},2} = \frac{A_{21}}{C_{21}} \tag{7.18}$$

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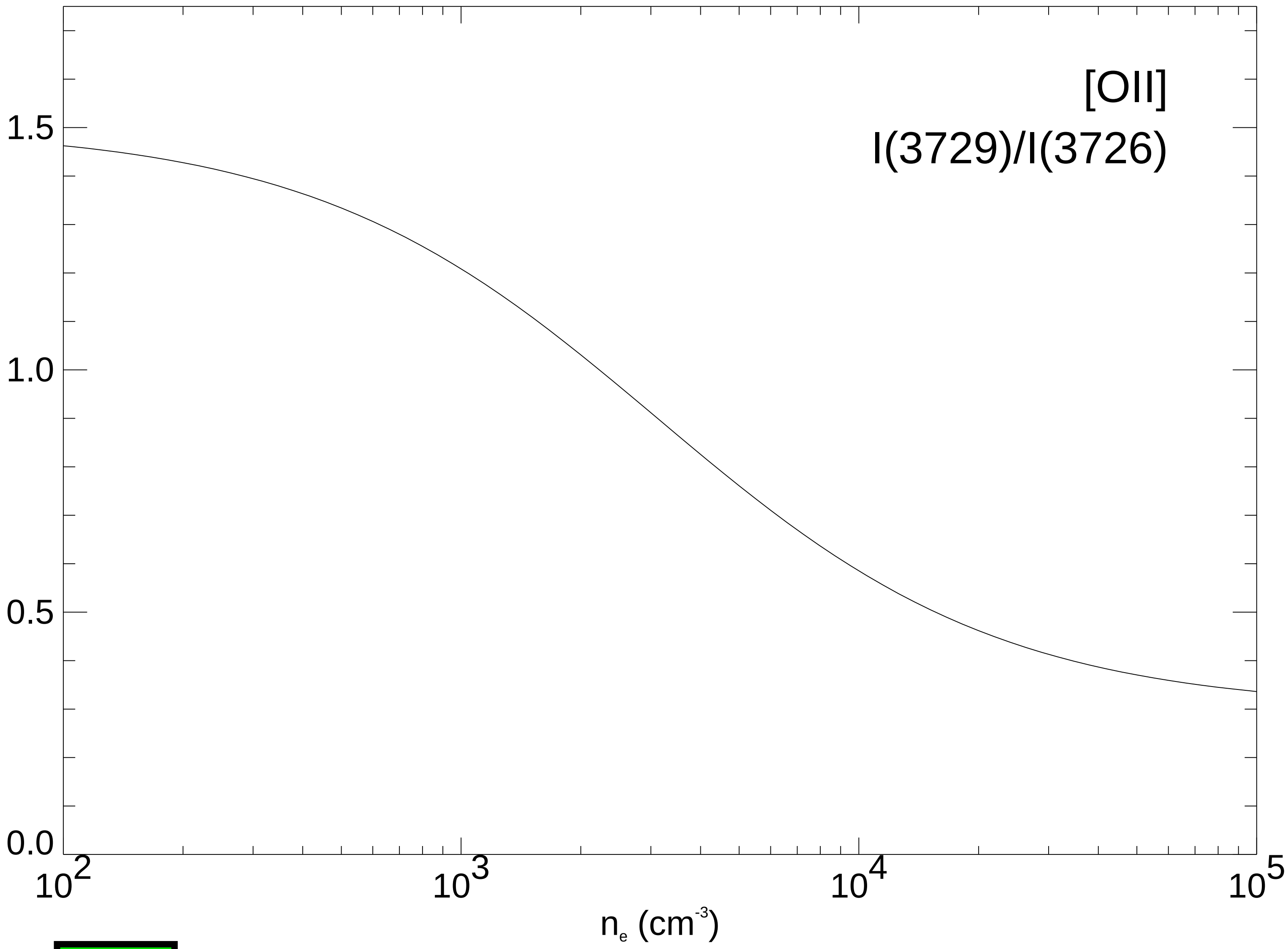
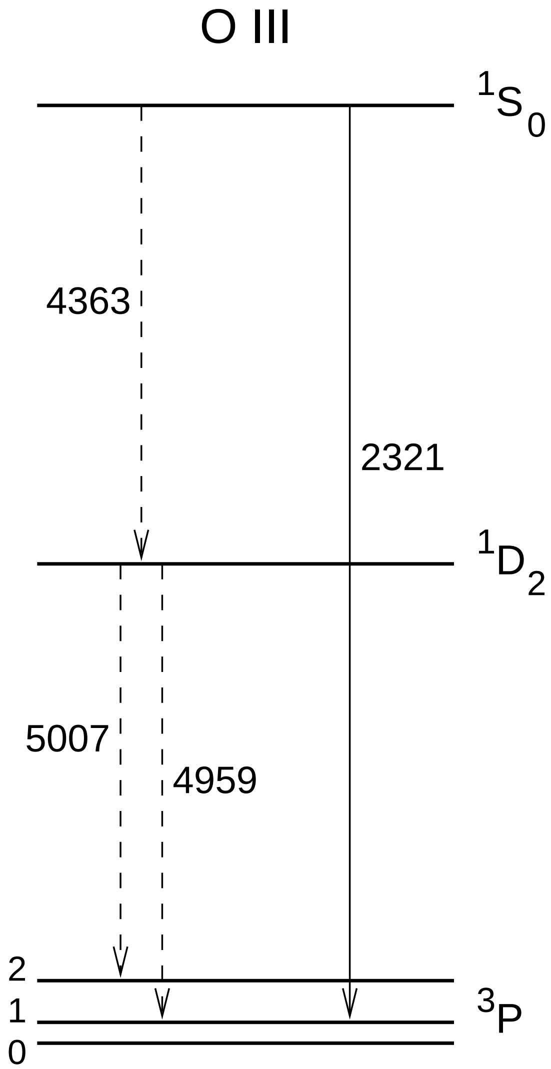
Line Diagnostics: Density, IV



Line Diagnostics: Temperature, I

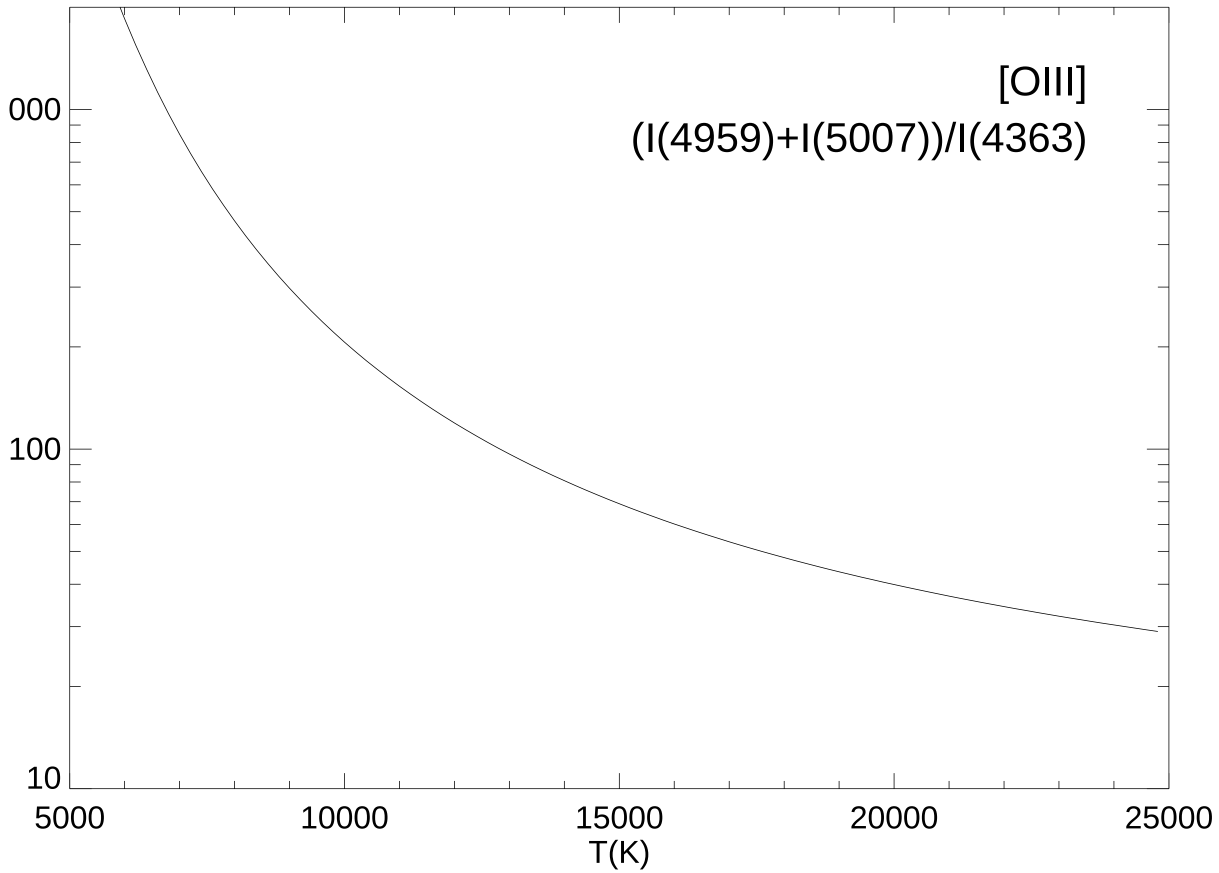
To obtain temperature use similar ideas. This time, use two levels with different excitation energy

$\Longrightarrow$ Use different excitation probability of collisionial excitation



For $T \sim 10000\,\mathrm{K}$, mainly O III and N II

Line Diagnostics: Temperature, II



$$\frac{I(4959+5007)}{4363} = \frac{7.7\exp(3.29\times 10^4/T)}{1+4.5\times 10^{-4} n_\mathrm{e} T^{-1/2}}$$

Line Diagnostics: Mass

Mass determination: Determine number of emitting atoms from line strength.
Hydrogen: Hβ (less influenced by radiative transfer effects)

$$j_{\mathrm{H}\beta} = n_{\mathrm{e}} n_{\mathrm{p}} \alpha_{\mathrm{H}\beta} \frac{h\nu_{\mathrm{H}\beta}}{4\pi} \tag{7.19}$$

$$= \frac{n_{\mathrm{e}}^2}{4\pi} \alpha_{\mathrm{H}\beta}^{\mathrm{eff}} \frac{h\nu_{\mathrm{H}\beta}}{4\pi} \tag{7.20}$$

$$= 1.24 \times 10^{-25}\,\mathrm{erg\,s^{-1}\,cm^{-3}\,sr^{-1}} \frac{n_{\mathrm{e}}^2}{4\pi} \tag{7.21}$$

where $\alpha_{\mathrm{H}\beta}^{\mathrm{eff}}$: effective recombination coefficient for $n = 4 \rightarrow n = 2$ transition (weakly temperature dependent).
Total emissivity

$$L_{\mathrm{H}\beta} = \int\int j_{\mathrm{H}\beta}\,\mathrm{d}\Omega\,\mathrm{d}V \tag{7.22}$$

$$= \frac{4\pi n_{\mathrm{e}}^2}{3} \cdot 1.24 \times 10^{-25} r^3 f\,\mathrm{erg\,s^{-1}} \propto \int n_{\mathrm{e}}^2 \mathrm{d}V \tag{7.23}$$

where $\int n_{\mathrm{e}}^2 \mathrm{d}V$: emission measure, and f: filling factor.

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