Outline

- Go to colloquium on Monday:

The Death of Stars Like the Sun (what we know and don't know)

by Lee Anne Willson (Iowa State)

- Go over problem 5-1, exam problem #5

- H II regions
- Stromgren radius
- Ionization fraction

H II regions

- Star-forming regions contain young, massive stars that radiation strongly in the UV.
- UV ionizes gas. Ionized gas recombines and emits line emission.
  - Gas is mostly H. Strongest line is H at 6563 Å.

- Roman numeral = # ionizations – 1.
  - H I = neutral, H II = single ionized (= proton)
  - He I = neutral, He II = single ionized, He III = doubly ionized
  - e.g. O III = oxygen with two missing electrons

Strömgren Radius

- Gas is in equilibrium between photoionization and recombination.
- Size of H II region, r, set by rate of emission of ionizing photons, Q.

$$Q = \frac{4}{3}\pi r^3 R$$

  - where R is the recombination rate (per unit time per unit volume).
- R depends on cross section for recombination, σ, relative velocity, v, and number densities of protons and electrons, $n_\mathrm{p} = n_\mathrm{e} = xn$, where n is number density of all H (ionized or not) and x is ionized fraction.

$$R = n_p n_e \langle \sigma v \rangle = x^2 n^2 \alpha(T)$$

  - where $\alpha(T) = \langle\sigma v\rangle$ = "recombination coefficient", units = $\mathrm{cm}^3\ \mathrm{s}^{-1}$.
- "Strömgren radius" is defined with $x = 1$, then $r_\mathrm{strom} = \left(\frac{3Q}{4\pi\alpha n^2}\right)^{1/3}$

Strömgren Sphere

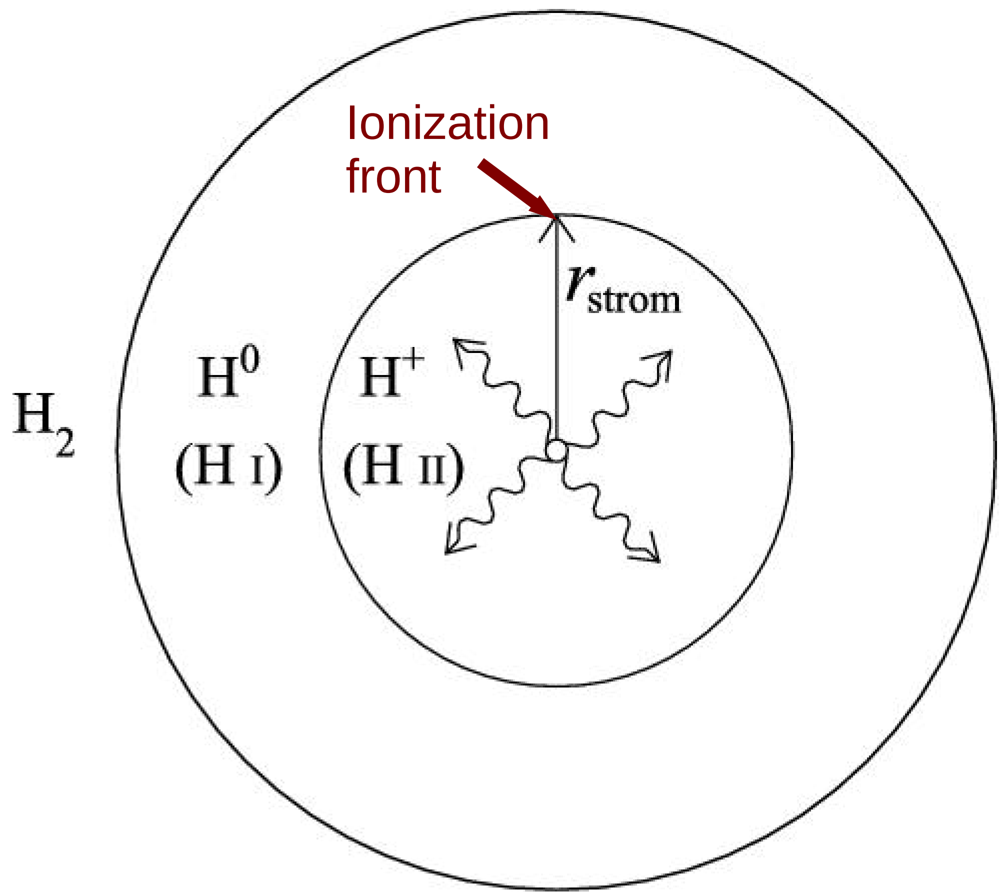
- Need 13.6 eV to ionize H, so

$$Q = \int_{h\nu=13.6\,\mathrm{eV}}^{\infty} \frac{L_\nu}{h\nu}\,d\nu$$

- For an 05V star, $Q = 3\times10^{49}$ s^{-1}.
- Temperature ~ 10^4 K,
  - so $\alpha = 2.6\times10^{-13}$ cm^3 s^{-1}.
- Typically $n = 10\text{-}10^4$ cm^{-3}, then

$$r_{\mathrm{strom}} = 0.2\ \mathrm{pc}\left(\frac{n}{10^4\,\mathrm{cm}^{-3}}\right)^{-2/3}$$

$$r_{\mathrm{strom}} = 0.2\ \mathrm{pc}\ n_4^{-2/3}$$



Note that α includes recombinations to all excited states, but not to the ground state. Why?

Ionization Fraction

- Calculate dependence of ionization on radius.
- Rates for photoionization and recombination should be equal at all radii.
- Ionization rate $R_{\mathrm{ion}} = n_\gamma\, n_{\mathrm{HI}}\, \sigma_{\mathrm{ion}}\, c = n_\gamma\, n(1\text{-}x)\, \sigma_{\mathrm{ion}}\, c$.
- Photon number density $n_\gamma = Q/(4\pi r^2 c)$.
- Cross section for photoionization of H atom by photon $E = h\nu$ is

$$\sigma_{\mathrm{ion}} \approx \sigma_0 \left(\frac{\nu}{\nu_0}\right)^{-3} \text{ for } h\nu \geq h\nu_0 = 13.6 \text{ eV}$$

  - approximate $\sigma = \sigma_0 = 6.3\times10^{-18}$ cm^2. (Note $\sigma_0/\sigma_T \sim 10^7$.)
- Ionization rate:

$$R_{\mathrm{ion}} = \frac{Q}{4\pi r^2} n(1-x)\sigma_0$$

Ionization Fraction

- Recombination rate $R_{\mathrm{rec}} = \alpha\, x^2 n^2$, equate to ionization rate:

$$\alpha\, x^2 n^2 = \frac{Q}{4\pi r^2} n(1-x)\sigma_0$$

- Separate out x:

$$\frac{x^2}{1-x} = \frac{Q\sigma_0}{4\pi r^2 \alpha n} = b$$

- Quadratic equation for x: $x^2 + bx - b = 0$

- Solution: $x = \left(-b + \sqrt{b^2 + 4b}\right)/2 \text{ since } x > 0$

- Find $x = 1 - 2\times10^{-5}$ for r = 0.1 pc (half of r_{strom}) in previous example.

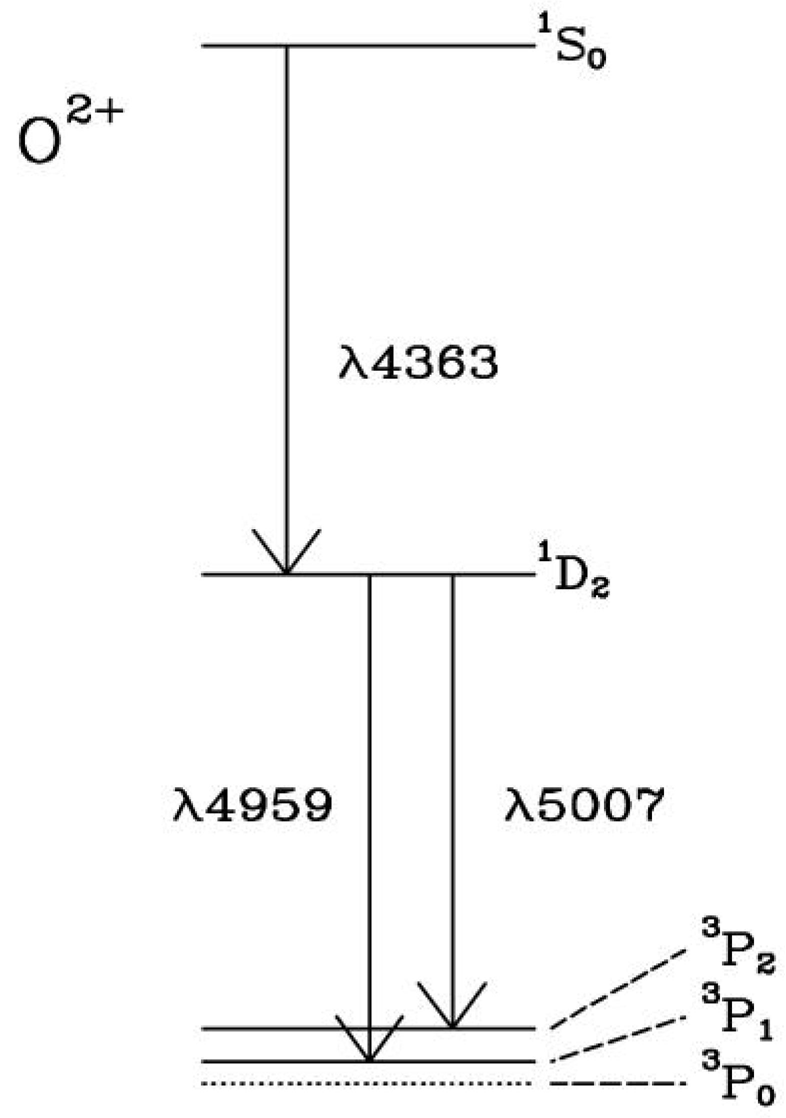
- Note that this derivation is only valid for $r < r_{\mathrm{strom}}$ since we don't account for the decrease in ionizing flux due to absorption.

Spectral Line Notation

- Spectral lines specified by ionization state of atom (H I , O III, etc.)

  Does line emission change ionization?

- Specify wavelength (in Å), e.g. λ4363.
- If the transition is "forbidden", meaning it does not occur via electric dipole radiation, then add [] around the ionization state, e.g. [O III].
- If the transition is a "doublet", two lines from the same excited state, then specify both wavelengths, e.g. λλ 4959, 5007.
- E.g.: [O III] λ4363; [O III] λλ 4959, 5007
- Note that lines from H do not follow this pattern (see lecture 2, Hα, Hβ, etc.).



Homework

- For next class:
  - Problem 5-2