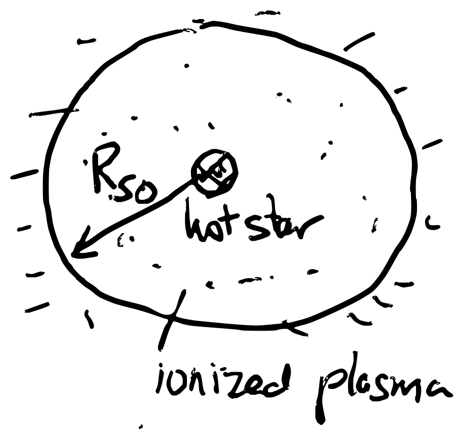
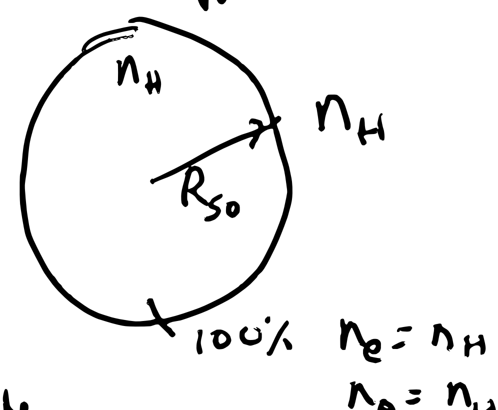
HII Regions

Classical HII regions : sharp boundaries



STROMGREN approximation



Q_0 = rate of photoionizing photons

$$Q_0 = n_e n_p \alpha \frac{4\pi}{3} R_{SO}^3$$

(s^{-1}) $(cm^{-3} s^{-1})$

$n_e \approx n_p \approx n_H$

$$R_{S0} = \left(\frac{3 Q_0}{4\pi n_H^2 \alpha} \right)^{1/3}$$

$Q_0 \simeq 10^{49}$ phot/s

$$R_{S0} = 3 \text{ pc } Q_{49}^{1/3} n_2^{-2/3} T_4^{0.28}$$

$Q_{49} = \left(\frac{Q}{10^{49}}\right)$ $n_2 = \frac{n_H}{10^2 \text{ cm}^{-3}}$ $T_4 = \frac{T}{10^4 K}$

Hot white dwarf: 2×10^4 K

WNM: $n_H = 1$ cm^{-3}

CNM: $n_H = 50$ cm^{-3}

EM = column of $n_e n_p$

$$= \int n_e n_p \, dl \simeq n_e^2 L$$

$$\simeq n_H^2 \, 2 R_{S0}$$

$$EM = n_H^2 R_{S0}$$

$$= 4.2 \times 10^4 \, Q_{49}^{1/3} \, n_2^{4/3} \, T_4^{0.28} \text{ cm}^{-6} \text{ pc}$$

$T \lesssim 50{,}000\,K$

$h\nu \simeq 18\,eV$

Mean-free path in ISM

$\sigma_{pi}(h\nu = 18\,eV) \simeq 3 \times 10^{-18}\,cm^2$

$mfp = \frac{1}{n_{H^0}\,\sigma_{pi}} \simeq 3.4 \times 10^{17}\,n^{-1}\,cm$

~~pc~~

$\simeq 0.1\,n^{-1}\,pc$

$\simeq 10^{-3}$

$R_{50} \simeq 3\,pc$

$mfp \simeq \underline{\underline{10^{-3}}}\,pc$

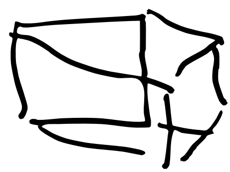
Time to Ionize an HII region?

$$t_{ionization} \times Q_0 = \frac{4\pi}{3} R_{S}^3 n_H$$

$$t_{ion} \propto \frac{1}{\alpha_B n_H}$$

α_B (α "case B")

Timescale for recombination



$$n_e n_p \alpha_B$$

$$t_{recomb} \times n_e n_p \alpha_B = n_H$$

$$n_e = n_p = n_H$$

$$t_{recomb} = \frac{1}{\alpha_B n_H}$$

$$t_{rec} \simeq \frac{1.2 \times 10^3\,\mathrm{yr}}{(n_H / 100\,\mathrm{cm}^{-3})}$$

Case A, case B:

The photo-electron ionization cross-section is

$$\sigma_{pi} \simeq \sigma_0 \left(\frac{\nu}{\nu_0}\right)^{-3}$$

$\sigma_0 = 6\times10^{-18}\ cm^{-2}$, $h\nu_0 = 13.6\ eV$

Consider a typical HII region,

$$n_H \simeq 10^2\ cm^{-3}, \quad L \simeq 1\ pc.$$

The $\tau_{pi} = n_H L \sigma_{pi} \gg 1$

Any recombination to $n=1$ results in $h\nu > 13.6\ eV$ photon. It will get absorbed in the vicinity of emission

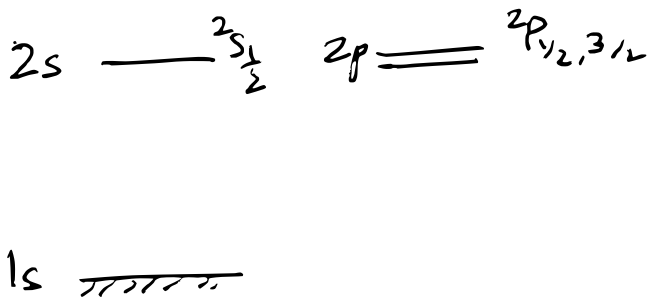
$\Rightarrow$ "on the spot absorption"

Case B: Do not include recombination to $n=1$

Case A: Include all recombinations

Lyman-α & Two-photon continuum:

Consider recombination to $n=2$.



About 1/3 will be to 2s $^2S_{\frac{1}{2}}$ and $\frac{2}{3}$ to 2p ^2P

- The latter decay rapidly to produce Lyα.
- The former decay ~~to~~ via 2-photon continuum.

However, if the density of protons is high the $2s \rightarrow 2p$ transition can take place $\Rightarrow$ Lyα.

Ly-series has large cross-section

	λ(Å)	A(s^{-1})	f_{lu}
Ly α	1216	6.2×10^{8}	0.4164
Ly β	10256	1.6×10^{8}	0.0791
Ly γ	972	6.8×10^{7}	0.0290
Ly δ	950	3.4×10^{7}	0.0139

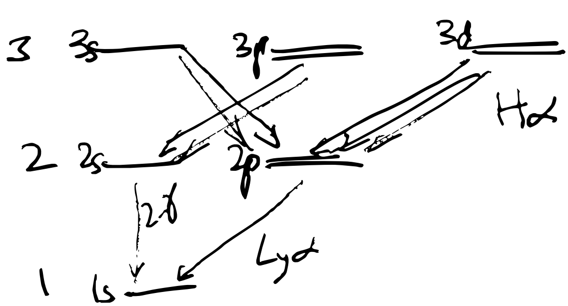
Lyα: $$\tau_0(\text{Ly}\alpha) = 0.758\left(\frac{N_e}{10^{13}\,cm^{-2}}\right)\left(\frac{f_{lu}}{0.4164}\right)\left(\frac{\lambda}{1216Å}\right)\left(\frac{b}{10\,km/s}\right)$$

So Ly-α will rattle around the HII region.

It will

- be destroyed by dust (if present in sufficient qty)
- "random walk" out of the HII region.

Lyβ: Consider recomb to $n=3$



Real-life complications:

- Dynamics.

$h\nu = 18\,eV$

$\Delta E = h\nu - IP = 18 - 13.6\,eV$

$= 4.4\,eV$

$\downarrow$ $4.4 \times 10^4\,K$

$1\,eV - 10^4\,K$

$T \simeq 8000\,K$

$$V_{rms} = \sqrt{\frac{T}{121}}\ km\,s^{-1}$$

$V_{rms} = 10\,km/s$

$$V_{ion} = \frac{3 \times 3 \times 10^{18}\,cm}{10^3 \times 3 \times 10^7\,s}$$

$$= 3 \times 10^8\,cm/s \simeq 0.01c$$

- DUST!