HII regions

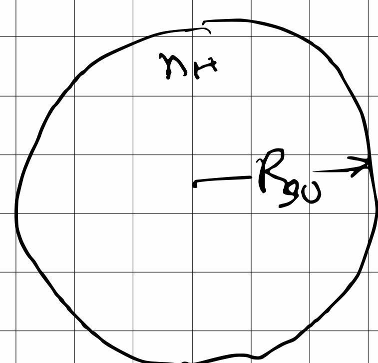
Chapter 27, 15

Stellar nurseries are marked by HII regions. The strong EUV light from stars photoionize and create Stromgren spheres of ionized gas.

HII regions have sharp boundaries.

The primary source of heating in HII regions is photoelectric heating by stellar UV light and cooling by optical fine structure lines of O^{++}, S^{++}, O^{+}, N^{+}. ~~and~~

Assume (for now) that the gas is fully ionized



Q_0 = rate of emission of ionizing photons (by star)

$$Q_0 = \frac{4\pi}{3} R_{S0}^3 \alpha_B n(H^+) n_e$$

Since $n(H^+) = n_e$ [Assume pure Hydrogen]

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

A typical ~~fo~~ value of Q_0 is 10^{49} phot/s

$$R_{SO} \simeq 3\,\text{parsec}\left(\frac{Q}{10^{49}}\right)^{1/3}\left(\frac{n_H}{100\,\text{cm}^{-3}}\right)^{-2/3}\left(\frac{T}{10^4 K}\right)^{0.28}$$

The Emission measure is

$$EM \simeq n_H^2 R_{SO} = 4.2\times10^4\, Q_{49}^{1/3}\, n_2^{4/3}\, T_4^{0.28}$$

$\text{cm}^{-3}\,\text{pc}$

For stellar temperatures $T < 50{,}000K$ the average energy of photons with $h\nu > 13.6\,eV$ is 18eV.

$$\sigma_{pi}(h\nu = 18eV) \simeq 3\times10^{-18}\,\text{cm}^2$$

$$\therefore \quad mfp = \frac{1}{n(H^0)\sigma_{pi}} = 3.4\times10^{17}\left(\frac{n(H^0)}{\text{cm}^{-3}}\right)^{-1}\text{cm}$$

Since $mfp \ll R_{SO}$ for $n(H^0) \gtrsim 1$ we can safely assume that HII regions have sharp boundaries (unless the region runs ~~of~~ out of gas)

Homework problem: show the neutral fraction is small throughout the HII region

Timescales:

The time to ionize an HII region is

$$\tau_{ionize} \times Q_0 = \left(\frac{4\pi}{3}\right) R_{S0}^3 n_H$$

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

$=$ time to recombine.

$$\tau \simeq \frac{1}{\alpha_B n_H} = \frac{1.2 \times 10^3 \text{ yr}}{(n_H / 100 \text{ cm}^{-3})}$$

Real-life complications in HII regions

DUST

- will absorb some of the EUV photons
- will absorb many of the Lyα photons
- will dynamically affect the HII region because of radiation pressure acting on dust

Heating of HII regions

$$H + h\nu \rightarrow H^+ + e^-$$

↑ Kinetic energy $= h\nu - I_p$

I_p = ionization potential

Γ_{pe} = photo-electric heating per unit volume per unit time

$$= n(HI) \int_{\nu_0}^{\infty} \sigma_{pe}(\nu) \left[\frac{U_\nu}{h\nu}\right] (h\nu - h\nu_0)\, d\nu$$

$$I_p = h\nu_0$$

Approximate FUV emission spectrum of stars by a color temperature, T_c

$$\psi = \frac{\langle E_{pe} \rangle}{kT_c}$$

Two approximations:

Near the star there is not much absorption and so the incident spectrum is that of the star

$$\psi_0 kT_c \equiv \frac{\int_{\nu_0}^{\infty} \frac{B_\nu(T_c)}{h\nu} \sigma_{pe}(\nu)(h\nu - h\nu_0)\, d\nu}{\int_{\nu_0}^{\infty} \frac{B_\nu(T_c)}{h\nu} \sigma_{pe}(\nu)\, d\nu}$$

Another approximation is that all Lyman continuum stellar photons ($h\nu > I_H$) will produce a photionization <u>somewhere</u> in the nebula.

$$\langle\psi\rangle kT_c = \frac{\int_{\nu_0}^{\infty} \left[\frac{B_\nu(T_c)}{h\nu}\right](h\nu - h\nu_0)\, d\nu}{\int_{\nu_0}^{\infty} \left[\frac{B_\nu(T_c)}{h\nu}\right] d\nu}$$

T_c	8000	16,000	32,000	64,000
ψ_0	.959	.922	.864	0.775
$\langle\psi\rangle$	1.1	1.2	1.4	1.6

The integral above is dominated by the rapid (exponential) drop of B_ν as you approach $h\nu_0$

In steady state the number of recombinations equals the number of ionizations

$$\Gamma_{pe} = \alpha_B n_e n_p \psi k T_c$$

Cooling of HII regions.

- free-free emission

$$\Lambda_{ff} = \alpha_B n_e n_p f(T)$$

- radiative recombination

$$\Lambda_{rr} = \alpha_B n_e n_p \langle E_{rr} \rangle$$

$\langle E_{rr} \rangle$ = mean kinetic energy of the recombining electrons

ads $H\alpha$
NGC
power-law