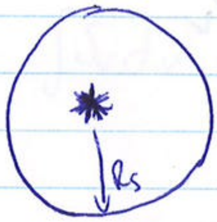
ISM 14-10-2019

HII regions

Recombination line spectrum : excited gas shows spectral lines. Ratios are near-constant. Depend little ~~a~~ of temperature, but mostly constant temperatures.

Rosette nebula



Strömgen spheres
Star produces ionizing photons. Hydrogen absorbs photons. At some extent there are no more photons.

Q_0 = # ~~photons~~ ~~pe~~ ionizing photons produced per second

$$\frac{4}{3} R_S^3 \pi \, n_e n_p \alpha_B$$

$$\rightarrow R_S = \left(\frac{3Q_0}{4 \pi n_e n_p \alpha_B} \right)^{1/3}$$

$$= 32\,\mathrm{pc} \left(\frac{Q_0}{10^{49}} \right)^{1/3} \left(\frac{n_e}{100\,\mathrm{cm}^{-3}} \right)^{-2/3}$$

Now use this to calculate Q_0. (and hereby the SFR)

In SF ~~co~~ clusters, also HeI

! Hydrogen / helium ~~is~~ are recombination line. Forbidden lines are not recombination lines. Lines come from ISM, not from stellar emission.

Problem with radio ~~emi~~ recombination lines : stimulated emission.

Rate at which recombination line photon is emitted

$$n_e n_p \, \gamma_{n\ell \to n'\ell'}(T)$$

need : energy s^{-1} cm^{-2} sr^{-1}

$$\hookrightarrow j_\nu = \frac{h\nu}{4\pi} n_e n_p \gamma_{n\ell \to n'\ell'}(T) \, \phi_\nu$$

(all hydrogen ionized)

$$= \frac{h\nu}{4\pi} n_H^2 \gamma(T) \phi_\nu$$

$$\int j_\nu \, d\nu = \frac{h\nu}{4\pi} n_H^2 \gamma(T)$$

$$I_\nu = \frac{j_\nu}{k_\nu}(1 - e^{-\tau_\nu})$$

$$\left.\begin{aligned} &= \tau_\nu \frac{j_\nu}{k_\nu} \\ S k_\nu &= \tau_\nu \end{aligned}\right\} I_\nu = j_\nu S$$

$$\int I_\nu \, d\nu = \frac{h\nu}{4\pi} \gamma(T) \underbrace{\int n_e n_p \, ds}_{\text{emission measure } [cm^{-6}\, pc]}$$

Signal is strongly dominated by denser material because of $n_e n_p \sim n^2$.

Radio continuum $\tau_\nu = 0.33\left(\frac{10^4}{T_e}\right)^{1.35}\left(\frac{1\,GHz}{\nu}\right)^2\left(\frac{EM}{cm^{-6}pc}\right)$

$$T_B = T_e\left(1-e^{-\tau_\nu}\right) \approx \tau_\nu T_e = 0.33\left(\frac{10^4}{T_e}\right)^{0.35}\left(\frac{1\,GHz}{\nu}\right)^2\left(\frac{EM}{10^{-6}pc}\right)$$

electron temperature (=kinetic temp of HII region).

Calculate integrated flux density by integrating intensity over solid angle

$$\int S_\nu d\nu = \iint I_\nu d\Omega d\nu$$

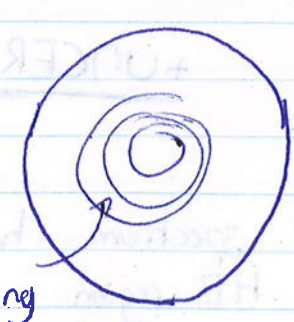
$$= \frac{h\nu}{4\pi}\gamma(T)\int EM\, d\Omega$$

$$d\Omega = \frac{A}{D^2} = \frac{\pi R_s^2}{D^2}$$

$\langle EM\rangle$

$$\to \int S_\nu d\nu = \frac{h\nu}{4D^2}\langle EM\rangle \gamma(T) R_s^2$$

$$\langle EM\rangle = \frac{1}{\pi R_s^2}\int_0^{R_s} \cancel{2\pi r}\, 2\pi r \int n_e n_p\, ds\, dr$$



integrating over rings dr.

$$\to \underbrace{\int S_\nu d\nu}_{\text{we measure this}} = \frac{h\nu}{4D^2}\frac{4}{3} n_e n_p R_s^3 \gamma(T)$$

$$L\,[\text{ergs s}^{-1}] = 4\pi D^2 \int S_\nu \, d\nu$$

$$= \frac{Q_0}{\alpha_B} h\nu \, \gamma(T)$$

observing freq

table

case B recombination rate

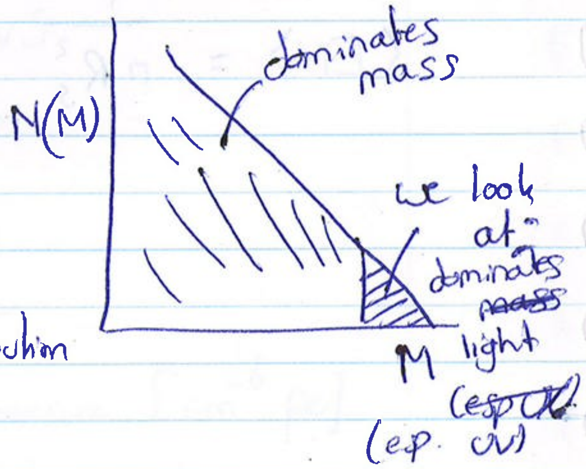
Recombination involves two particles ($p^+ + e^-$). 21 cm line only one particle

$n_e n_p$ cannot be turned into mass but can be turned into ionization rate Q_0.

$Q_0 \mapsto$ massive star formation rate. Only massive stars produce UV (ionizing photons) We ~~thus~~ need to keep forming stars since they only live shortly Need to assume star formation history. Hidden assumption when going from Q_0 to SFR (SFR = constant, standard conversion factors can be found in literature) To get complete SFR from massive SFR, we need to scale. Massive stars are rare, & low mass stars are common

MASSIVE ASSUMPTION

+ UNCERTAINTY



SN spectrum has same distribution as HII region

Only number of ionizing photons matter. Spectral details of stars do not matter.

→ Nebulea with H and He : inner and outer Strömgen sphere (He^+ and H^+)

If hydrogen densities become higher ; strömgen spheres become smaller. Therefore fraction of ionization goeos up and thus dust becomes more important in absorbing UV photons