THERMAL RADIO EMISSION

Plank Function

$$B_\nu(T) = \frac{2h\nu^3/c^2}{exp(h\nu/kT) - 1}$$

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{exp(hc/\lambda kT) - 1}$$

Rayleigh-Jeans:

$$I_\nu(T) = \frac{2\nu^2}{c^2}kT = j_\nu/\kappa_\nu$$

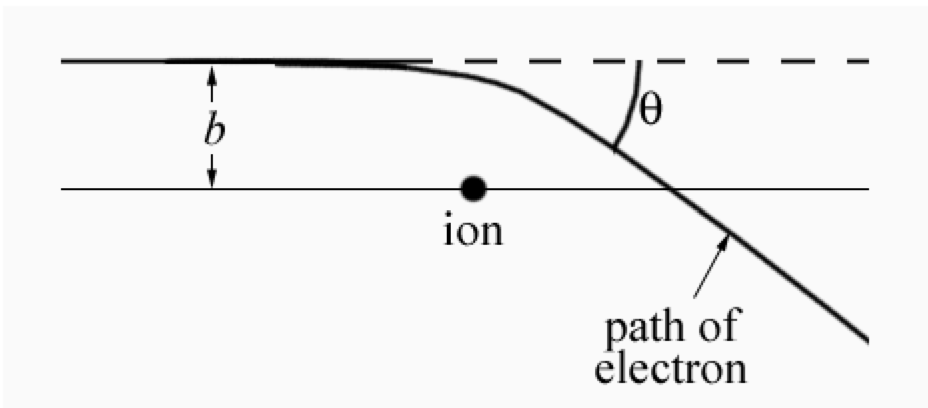
Optical Depth: $\tau = \int \kappa_\nu ds$

$$\Rightarrow I_\nu(T) = \frac{2\nu^2}{c^2}kT(1 - e^{-\tau})$$

$$\Rightarrow S_\nu(T) = \int \frac{2\nu^2}{c^2}kT(1 - e^{-\tau})d\Omega$$

Bremsstrahlung (free-free)

"Radiation due to the acceleration of a charged particle in the Coulomb field of another charge"



Classical Treatment:

$$\frac{dW}{dwdVdt} = \frac{16e^2}{3c^3m^2v} n_e n_i Z^2 ln(\frac{b_{max}}{b_{min}})$$

Quantum Treatment: $g_{ff} = \frac{\sqrt{3}}{\pi} ln(\frac{b_{max}}{b_{min}})$

$$\frac{dW}{dwdVdt} = \frac{16\pi e^2}{3\sqrt{3}c^3m^2v} n_e n_i Z^2 g_{ff}$$

Maxwellian Distribution:

Probability Distribution:

$$dP \propto exp(-\frac{mv^2}{2kT})d^3v \propto v^2 exp(-\frac{mv^2}{2kT})dv$$

$$h\nu \leq \tfrac{1}{2}mv^2$$

$$\frac{dW}{d\nu dV dt} = \frac{2^5\pi e^6}{3mc^3}(\frac{2\pi}{3km})^{1/2}T^{-1/2}n_e n_i Z^2 e^{-h\nu/kT}\bar{g_{ff}}$$

$$[\text{note } dw = 2\pi d\nu]$$

In cgs units,

$$\epsilon_\nu \equiv \frac{dW}{d\nu dV dt} = 6.8\times10^{-38}T^{-1/2}n_e n_i Z^2 e^{-h\nu/kT}\bar{g_{ff}}$$

Free-free Absorption coefficient:

$$\kappa_\nu = \epsilon_\nu / I_\nu = \frac{4e^6}{3kmc}(\frac{2\pi}{3km})^{1/2} T^{-3/2} n_e n_i Z^2 \nu^{-2} \bar{g_{ff}}$$

In cgs units,

$$\kappa_\nu = 0.018 T^{-3/2} n_e n_i Z^2 \nu^{-2} \bar{g_{ff}}$$

Emission Measure (EM):

$$\frac{EM}{\mathrm{pc\ cm^{-6}}} \equiv \int (\frac{n_e}{\mathrm{cm^{-3}}})^2 d(\frac{s}{\mathrm{pc}})$$

Free-free Opacity:

In fully ionized medium, $n_e \sim n_i$ and $Z \sim 1$,

$$\tau_\nu = \int \kappa_\nu ds = 0.030\, (\frac{T_e}{\mathrm{K}})^{-3/2} (\frac{\nu}{\mathrm{GHz}})^{-2} (\frac{EM}{\mathrm{pc\ cm^{-6}}}) \bar{g_{ff}}$$

Altenhoff et al. (1960): $\bar{g_{ff}} \propto T^{0.15} \nu^{-0.1}$

$$\Rightarrow \tau_\nu = 0.082\, (\frac{T_e}{\mathrm{K}})^{-1.35} (\frac{\nu}{\mathrm{GHz}})^{-2.1} (\frac{EM}{\mathrm{pc\ cm^{-6}}})$$

What can we learn about HII regions?

1. Temperature: at ν where $\tau \gg 1$

$$S_\nu(T) = \frac{2\nu^2}{c^2} kT\Omega_s$$

2. EM: at ν where $\tau \ll 1$

$$S_\nu(T) = \tau \frac{2\nu^2}{c^2} kT\Omega_s$$

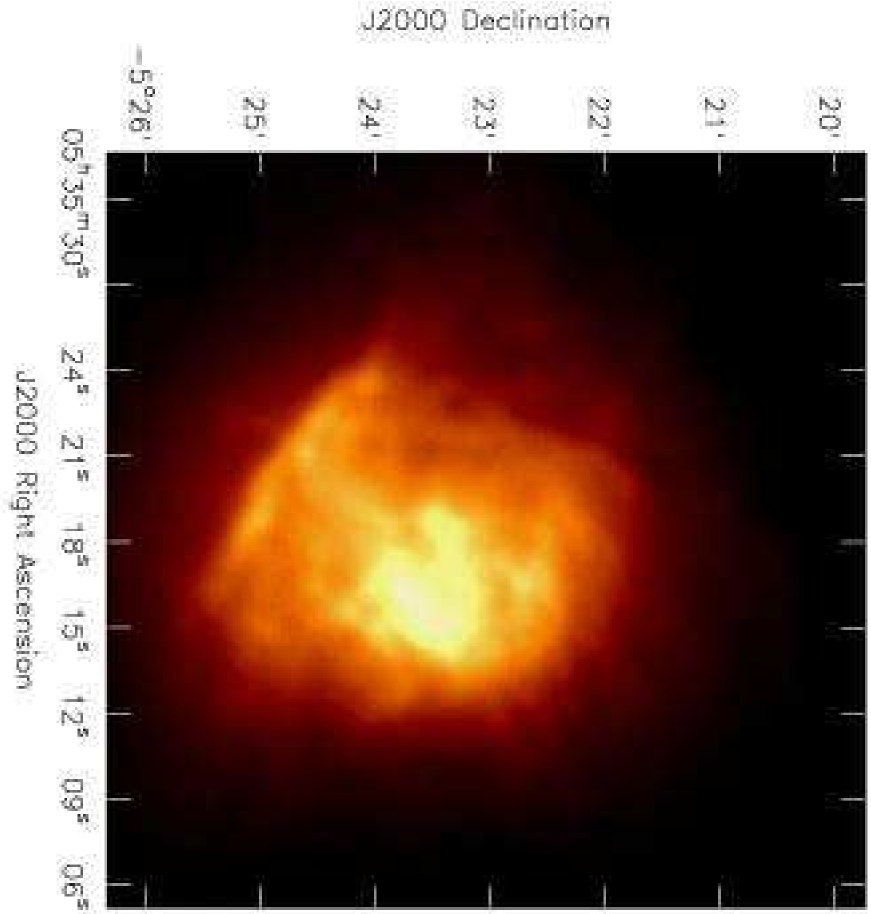
Since $\tau \propto EM$, EM can be derived from S_ν and T_e!

3. Electron Density: if the HII region has a uniform density over a roughly spherical volume with a radius r,

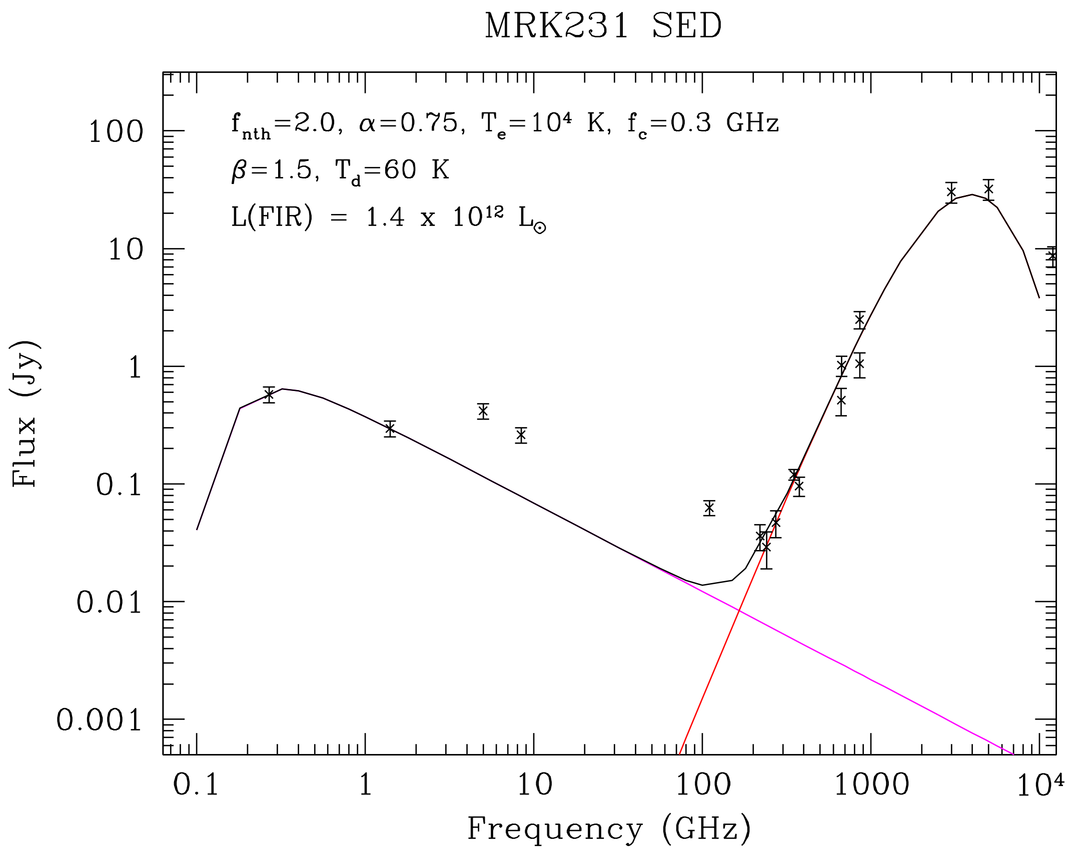
$$n_e = (EM/2r)^{1/2}$$

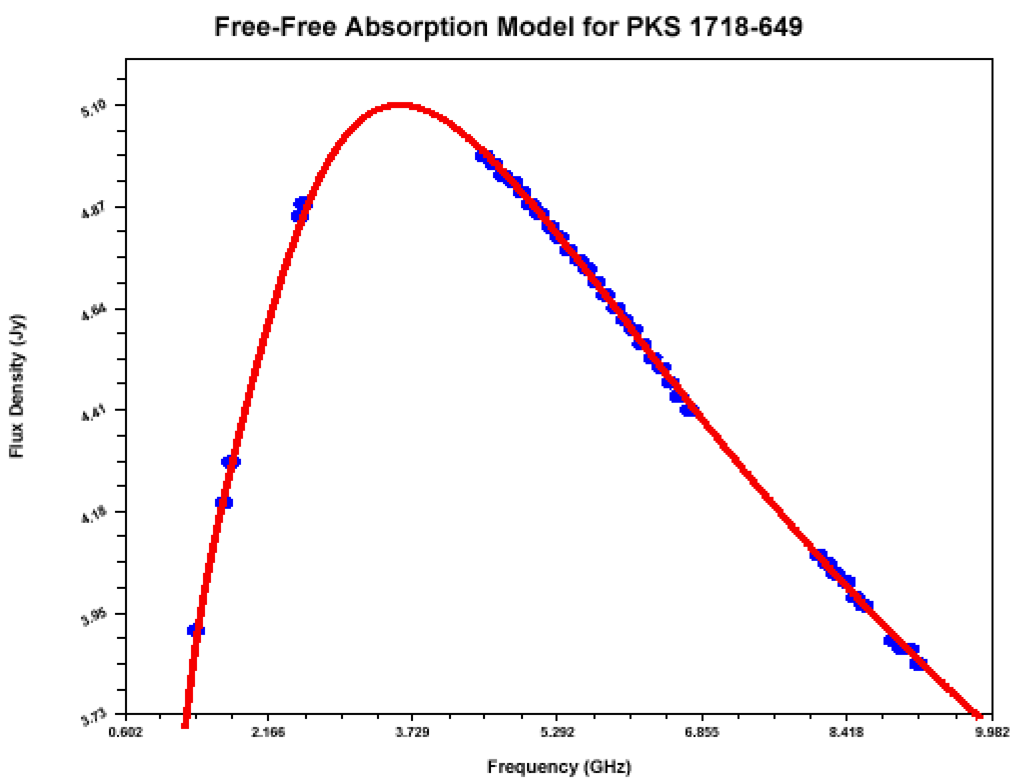
4. Mass: if the HII region is primarily of ionized hydrogen,

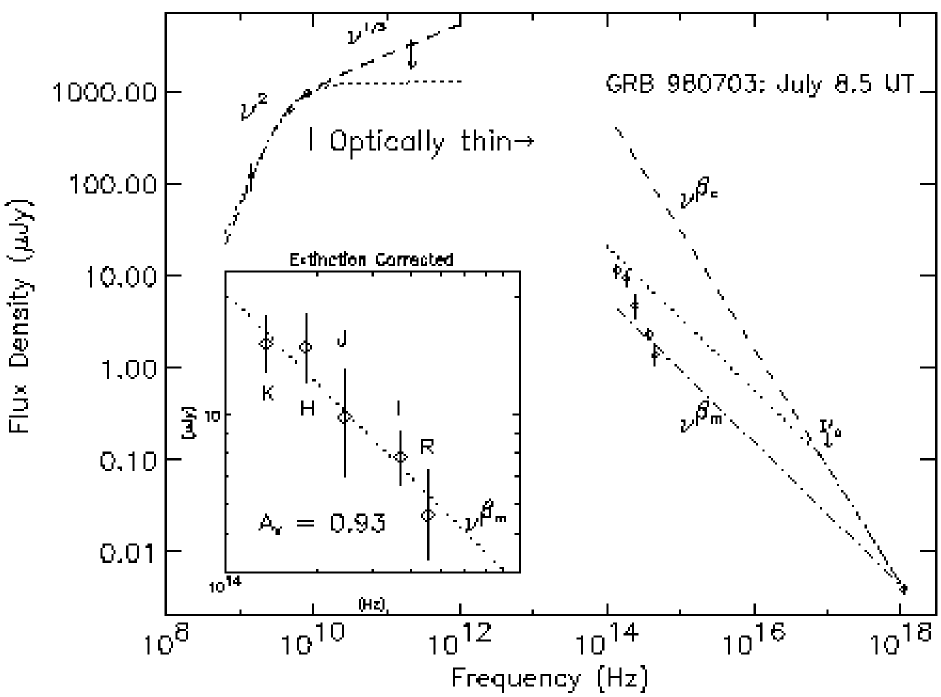
$$M = n_e \times (\frac{4}{3}\pi r^3) \times m(H)$$


J2000 Declination
−5°26'
25'
24'
23'
22'
21'
20'
05h35m30s
24s
21s
18s
15s
12s
09s
06s
J2000 Right Ascension

Examples of free-free Absorption:







GRB 980703: July 8.5 UT
Optically thin→
Flux Density (μJy)
Frequency (Hz)
Extinction Corrected
A_v = 0.93
K
H
J
I
R