Gyrosynchrotron Radiation

→ Expressions for the emission and absorption coefficient are much more complicated than the nonrelativistic (thermal gyro-resonance) and ultra-relativistic (synchrotron) case, which are often solved numerically.

→ Gyrosynchrotron emission is typically produced by nonthermal electrons with energies of 100 keV~10 MeV.

→ Gyrosynchrotron emission is commonly observed as a broadband microwave spectrum in a typical frequency range of 2~20 GHz. Below 1 GHz it is self-absorbed and masked by free-free absorption from the overlying plasma.

→ The spectrum of gyrosynchrotron emission peaks typically around 5~10 GHz (3~6 cm), being optically thick at lower frequencies and optically thin at higher frequencies.

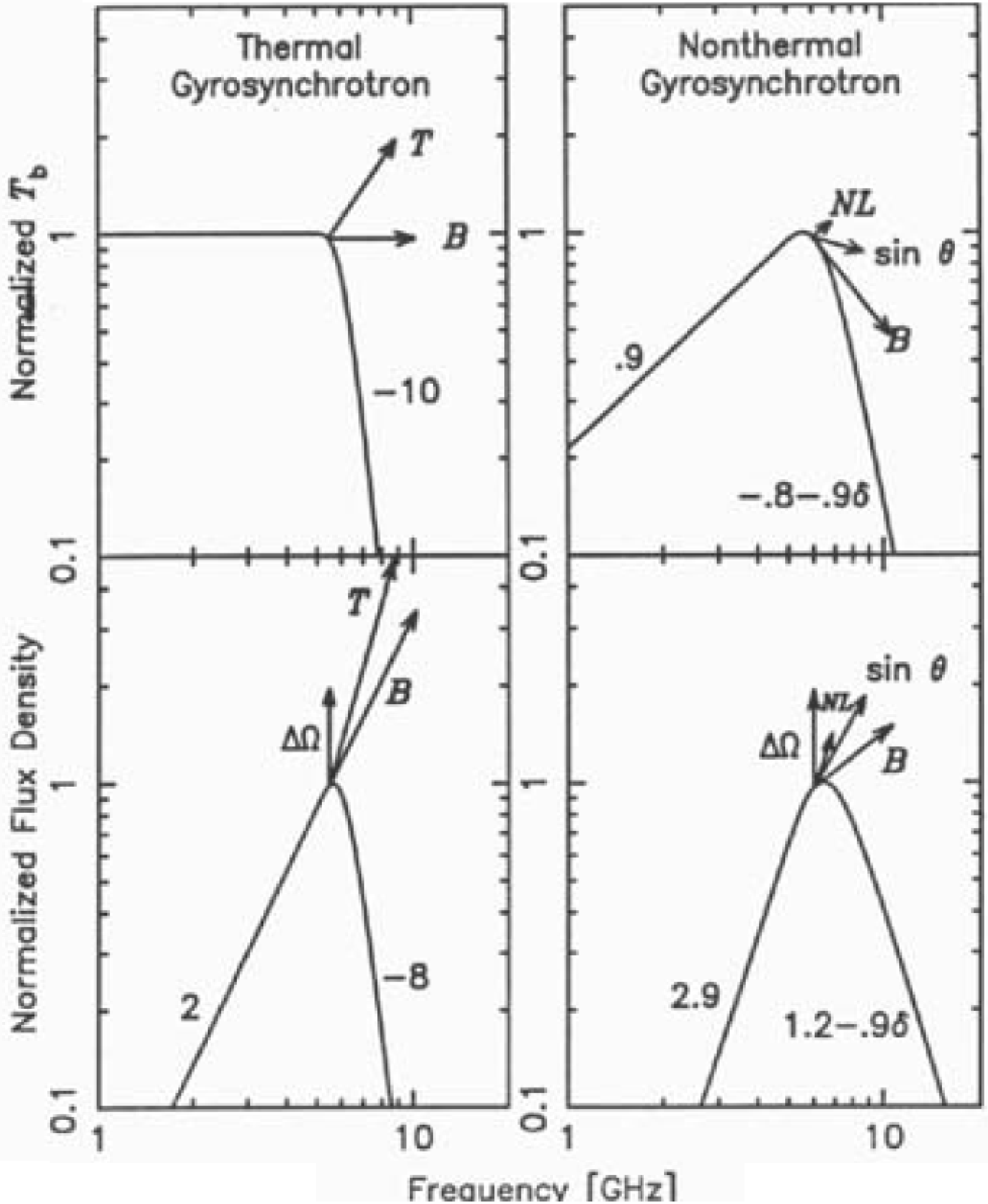


Figure 15.2 in Markus J. Aschwanden (2005)

For a power-law electron spectrum (with slope δ and electron number density N) which is isotropic in pitch angle,

gyrosynchrotron emissivity (or emission coefficient)

$$\frac{\eta_\nu}{BN} \approx 3.3 \times 10^{-24} 10^{-0.52\delta} (\sin\theta)^{-0.43+0.65\delta} \left(\frac{\nu}{\nu_B}\right)^{1.22-0.90\delta},$$

absorption coefficient

$$\frac{\kappa_\nu B}{N} \approx 1.4 \times 10^{-9} 10^{-0.22\delta} (\sin\theta)^{-0.09+0.72\delta} \left(\frac{\nu}{\nu_B}\right)^{-1.30-0.98\delta},$$

effective temperature

$$T_{\mathrm{eff}} \approx 2.2 \times 10^{9} 10^{-0.31\delta} (\sin\theta)^{-0.36-0.06\delta} \left(\frac{\nu}{\nu_B}\right)^{0.50+0.085\delta},$$

peak frequency

$$\nu_{\mathrm{peak}} \approx 2.72 \times 10^{3} 10^{0.27\delta} (\sin\theta)^{0.41+0.03\delta} (NL)^{0.32-0.03\delta} B^{0.68+0.03\delta}.$$

brightness temperature $T_b = T_{eff}(1 - e^{-\tau})$

θ: angle between magnetic field and line-of-sight

ν_B: electron gyrofrequency

valid over the range $2 \lesssim \delta \lesssim 7$, $\theta \gtrsim 20°$, and $10 \lesssim \nu/\nu_B \lesssim 100$

Dulk (1985)

For thermal electrons (valid for all s > 5)

$$\frac{\kappa_\nu B}{N_-} \approx 2.67\times 10^{-9}\,\frac{\mu^2(1-15/8\mu)}{n_\sigma^2\sin^3\theta}\,\frac{\gamma_o^{3/2}(\gamma_o^2-1)^{1/2}}{1+T_\sigma^2}\,\frac{\xi_o^2(\xi_o^2-1)}{s_o^{3/2}x^{1/2}}$$

$$\times\Bigg[\{c_2(1+0.85s_c/s_o)^{-1/3}+(1-n_\sigma^2\beta_o^2)^{1/2}(1-n_\sigma^2\beta_o^2\cos^2\theta)^{1/2}\}^2$$

$$+\frac{n_\sigma^2\beta_o^2T_\sigma^2\xi_o\sin^4\theta}{2(s_o+s_c)}\Bigg](1-n_\sigma^2\beta_o^2\cos^2\theta)\left(1+\frac{a_3s_c}{3s_o}\right)^{1/6}Z^{2s_o}$$

$$\times\exp[-\mu(\gamma_o-1)],$$

where

$$\mu=\frac{mc^2}{k_BT},\qquad \gamma_o=\left[1+\frac{2\nu}{\mu\nu_B}\left(1+\frac{9x}{2}\right)^{-1/3}\right]^{1/2},$$

$$\beta_o=\left(1-\frac{1}{\gamma_o^2}\right)^{1/2},\qquad x=\frac{\nu}{\nu_B}\,\frac{\sin^2\theta}{\mu},\qquad n_\sigma\approx 1-\frac{\nu_p^2}{\nu^2},$$

$$T_o=-T_x^{-1}=-[a+(1+a^2)^{1/2}],\qquad a=\frac{\nu_B}{\nu}\,\frac{\sin^2\theta}{2\cos\theta},$$

$$s_o=\gamma_o\frac{\nu}{\nu_B}(1-n_\sigma^2\beta_o^2\cos^2\theta),\qquad a_3=13.589,$$

$$\xi_o=(1-\beta'^2)^{-1/2},\qquad \beta'=\frac{n_\sigma\beta_o\sin\theta}{(1-n_\sigma^2\beta_o^2\cos^2\theta)^{1/2}},$$

$$s_c=\frac{3}{2}\xi_o^3,\qquad c_2=T_\sigma\cos\theta(1-n_\sigma^2\beta_o^2),\qquad Z=\frac{\beta' e^{1/\xi_o}}{1+1/\xi_o},$$

Robinson & Melrose (1984)

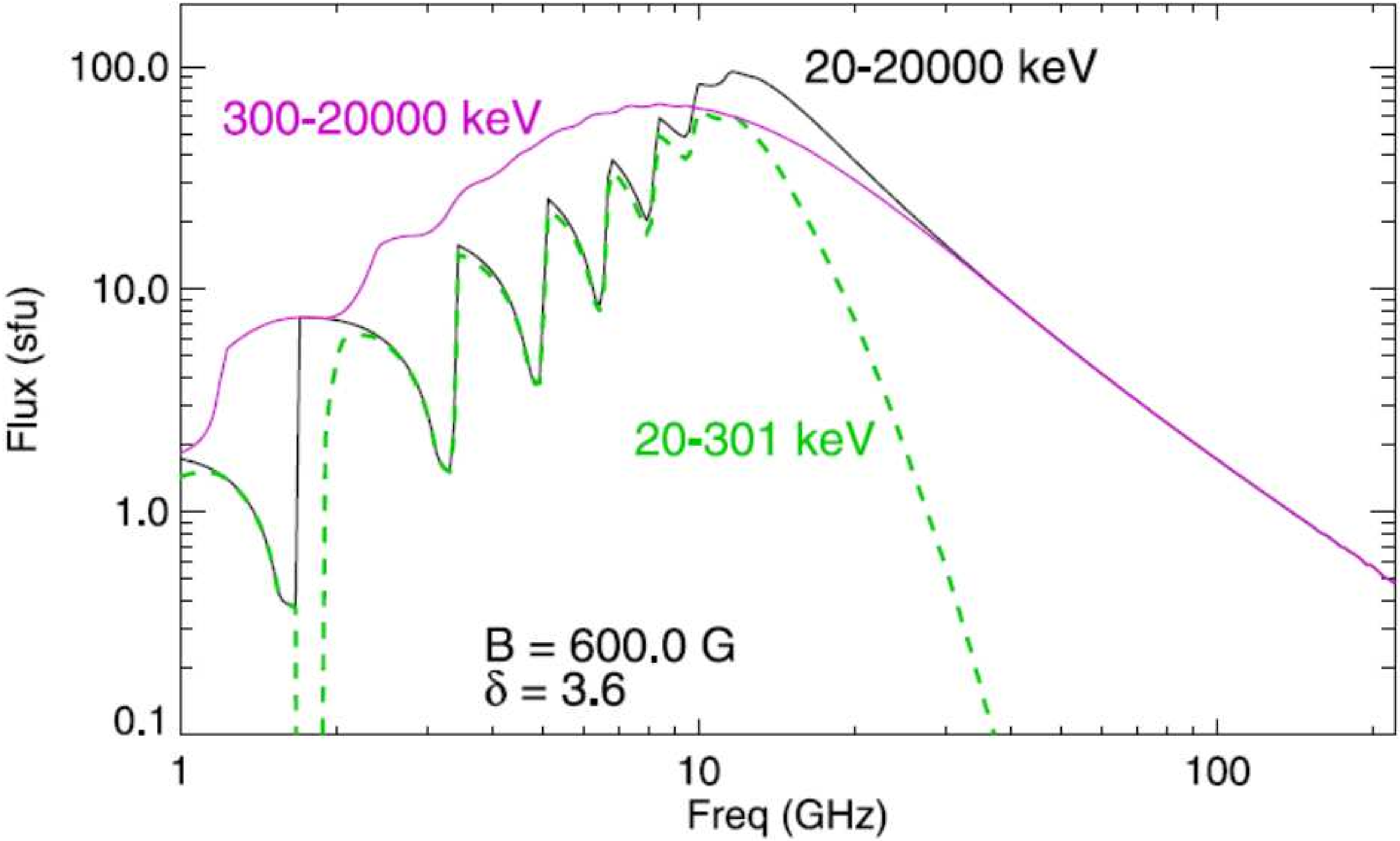
For thermal electrons (valid for $10^8 \leq T \leq 10^9$ K and $10 \leq s \leq 100$)

$$\frac{\kappa_\nu B}{N} \approx 50 T^7 \sin^6 \theta B^{10} \nu^{-10},$$

$$\frac{\eta_\nu}{BN} \approx 1.2 \times 10^{-24}\, T \left(\frac{\nu}{\nu_B}\right)^2 \frac{\kappa_\nu B}{N},$$

$$\nu_{\rm peak} \approx \begin{cases} 1.4 \left(\dfrac{NL}{B}\right)^{0.1} (\sin\theta)^{0.6} T^{0.7} B & (10^8 < T < 10^9 \text{ K}), \\ 475 \left(\dfrac{NL}{B}\right)^{0.05} (\sin\theta)^{0.6} T^{0.5} B & (10^7 < T < 10^8 \text{ K}). \end{cases}$$

Dulk et al. (1979)



The optically-thin microwaves are more sensitive to electrons above 300 keV, while hard X-rays are usually dominated by electrons below 300 keV.

White et al. (2011)