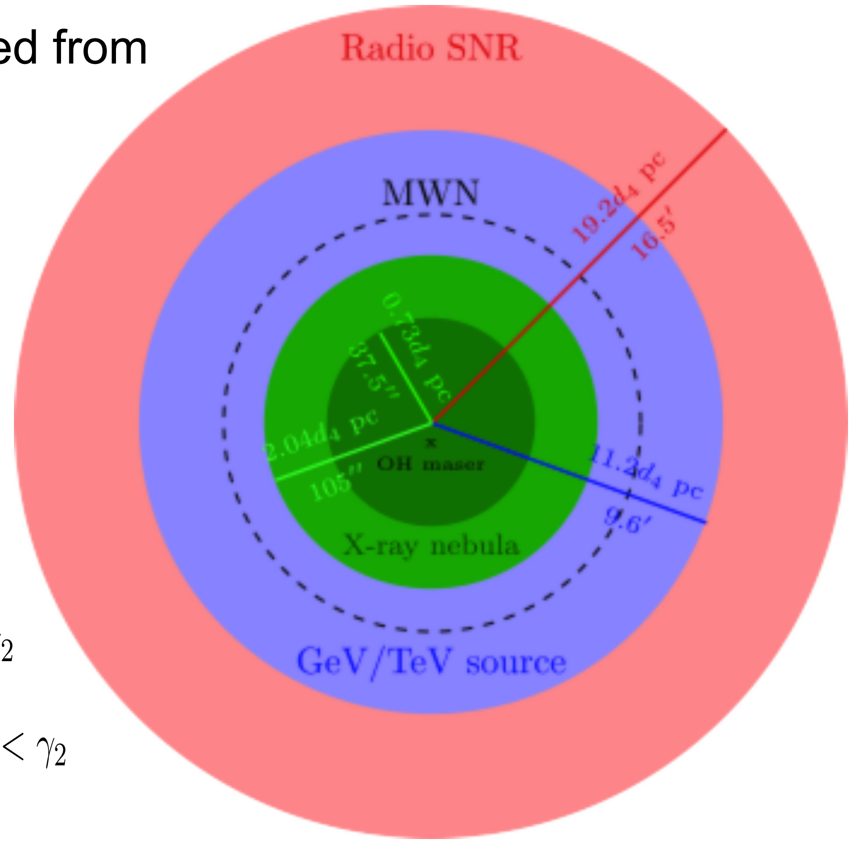
The Synchrotron X-Ray Nebula around Swift J1834.9–0846

- Magnetic field in the X-ray emitting region is obtained from



$$B = \left(\frac{L_X \sigma_e}{\mathcal{A}V} \frac{\Gamma - 2}{\Gamma - 1.5} \frac{\nu_1^{1.5-\Gamma} - \nu_2^{1.5-\Gamma}}{\nu_m^{2-\Gamma} - \nu_M^{2-\Gamma}} \right)^{2/7}$$

$$\simeq \begin{cases} 4.0\xi\sigma_e^{2/7} d_4^{-2/7}\ \mu\mathrm{G} & \text{(whole nebula)}\ , \\ 5.0\xi_{\rm in}\sigma_e^{2/7} d_4^{-2/7}\ \mu\mathrm{G} & \text{(inner nebula)}\ . \end{cases}$$

Assuming:

- Power-law electron distribution: $\frac{dN_e}{d\gamma_e} \propto \gamma_e^{-p}$ $\quad \gamma_1 < \gamma_e < \gamma_2$
- Electrons emitting in observed range: $\gamma_1 < \gamma_m < \gamma_e < \gamma_M < \gamma_2$
- Magnetization: $\sigma = \frac{B^2}{4\pi w} = \frac{3}{2}\frac{B^2}{8\pi e} = \frac{3}{2}\frac{E_B}{E_m} = \frac{3}{2}\sigma_e \epsilon_e$
- Emission volume: $V = \frac{4}{3}\pi R_x^3$

$\sigma_e \equiv E_B / E_e$

$E_e = \epsilon_e E_m$

(E_m = total energy in matter in the emission region)

$$\xi^{7/2}(\nu_1, \nu_2) = \left(\frac{\nu_2^{1.5-\Gamma} - \nu_1^{1.5-\Gamma}}{\nu_M^{1.5-\Gamma} - \nu_m^{1.5-\Gamma}} \right)$$

= ratio of energy in all electrons to that in those radiating in the observed frequency range

Total emitted power (0.5 – 30 keV)

$L_{\rm x,tot} = 2.74 \times 10^{33} d_4^2$ erg s^{-1}

The spin-down power

$L_{\rm sd} = 2.05 \times 10^{34}$ erg s^{-1} ⟶

X-ray efficiency of MWN

$\eta_X = \frac{L_{\rm X,tot}}{L_{\rm sd}} = 0.13 d_4^2$

Constraints From Maximum Electron Lorentz Factor

Maximum injected L.F.: (corresponding to acc. in the potential difference across the open field lines)

$$\gamma_{\max} = \frac{eR_{\rm NS}^3\Omega^2 B_s}{m_e c^4} = \frac{e}{m_e c^2}\sqrt{\frac{L_{\rm sd}}{fc}} = 4.9\times 10^8 f^{-1/2}$$

How robust is this limit?

since $\gamma_{\max} > \gamma_M$

Max. obs. energy: $E_X = 30 E_{M,30}$ keV

$$B > B_{\min} \equiv \frac{m_e^3 c^6 f E_X}{\hbar e^3 L_{\rm sd}} \simeq 11.0 f E_{M,30}\ \mu{\rm G}$$

which further yields

$$\sigma_e > 0.043\, d_4 \left(\frac{f E_{M,30}}{\xi_7}\right)^{\frac{7}{2}},$$

$$\sigma_{e,{\rm in}} > 0.055\, d_4 \left(\frac{f E_{M,30}}{\xi_{\rm in}/5}\right)^{\frac{7}{2}}.$$

$$\xi > 16.1\, f E_{M,30} \left(\frac{\epsilon_e d_4}{\sigma_{-2.5}}\right)^{\frac{2}{7}},$$

$$\xi_{\rm in} > 12.7\, f E_{M,30} \left(\frac{\epsilon_e d_4}{\sigma_{{\rm in},-2.5}}\right)^{\frac{2}{7}},$$

Synchrotron **cooling time** of X-ray emitting electrons: $t_{\rm syn} = \frac{6\pi m_e c}{\sigma_T B^2 \gamma_e} \simeq 1.02 B_{15\mu{\rm G}}^{-3/2} E_2^{-1/2}$ kyr .
(at $2E_2$ keV) is << system's age → quasi-steady state

Electron energy balance: $\langle \dot{E} \rangle = g L_{\rm sd} = \frac{(1+\sigma)}{\epsilon_e \epsilon_X} L_{X,{\rm tot}}$

In terms of the observed X-ray efficiency:

$$g = \frac{L_{X,{\rm tot}}}{L_{\rm sd}} \frac{(1+\sigma)\xi^{7/2}}{\epsilon_e} = \frac{\eta_X (1+\sigma)\xi^{7/2}}{\epsilon_e}$$

Estimate of $\xi_{\rm in}$ from the inner nebula yields: $\frac{g\sigma}{1+\sigma} > 3.07 d_4^3 E_{M,30}^{7/2} f^{7/2}$

$(1+\sigma)^{-1}$ = fraction of the total energy injected into the nebula going to particles (the rest goes into the B-field)

ϵ_e = fraction of that going into power-law energy distribution of electrons

$\epsilon_X = \xi^{-7/2}$ = fraction of that going into electrons radiating observed X-rays

The g-sigma parameter space & Implications

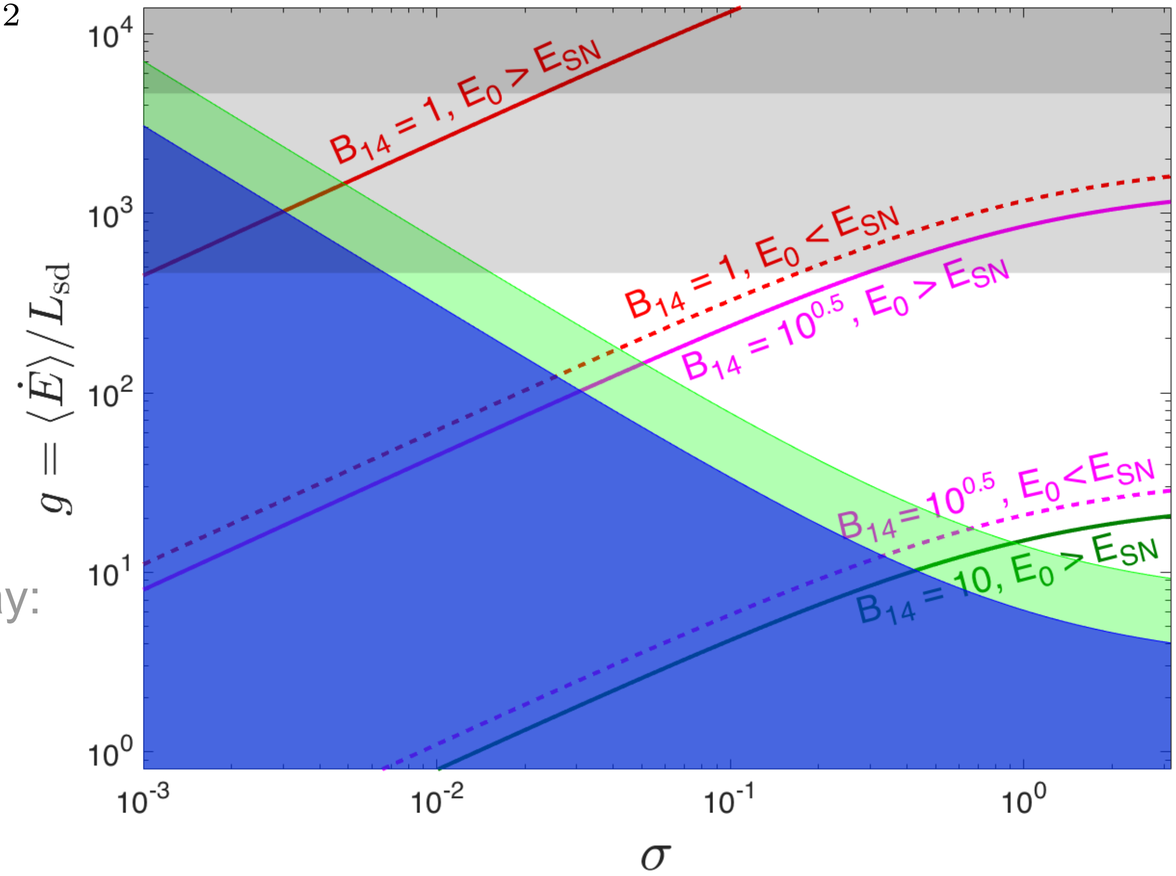
Electron energy balance: $$\frac{g\sigma}{1+\sigma} > 3.07 d_4^3 E_{M,30}^{7/2} f^{7/2}$$

Equating $B_{in}(L_X) = B_{in}$(dynamics) yields:

$$g = \begin{cases} \dfrac{1422\, E_{\mathrm{tot},52.3}^{\frac{7}{8}} \left(\frac{\kappa_1}{6.0f}\right)^{\frac{7}{4}}}{B_{14.5}^{\frac{7}{2}} d_4^4 M_3^{\frac{7}{8}}} \left(\dfrac{\sigma}{1+\sigma}\right)^{\frac{3}{4}}, & E_0 > E_{\mathrm{SN}} \\ \dfrac{35.03\, E_{\mathrm{tot},51}^{\frac{7}{8}} \left(\frac{\kappa_2}{4.47f}\right)^{\frac{7}{4}}}{B_{14.5}^{\frac{7}{2}} E_{\mathrm{SN},51}^{\frac{7}{20}} d_4^4 M_3^{\frac{7}{8}} M_3^{\frac{7}{8}} P_{0,-2}^{\frac{7}{10}}} \left(\dfrac{\sigma}{1+\sigma}\right)^{\frac{3}{4}}, & E_0 < E_{\mathrm{SN}} \end{cases}$$

Limit on energy source: internal field decay:

$$g < \frac{2}{2+\alpha}\frac{R_{\mathrm{NS}}^3 B_{\mathrm{int,max}}^2}{6 L_{\mathrm{sd}} t} \simeq 4.65 \times 10^2 B_{M,16}^2 t_{4.5}^{-1} \simeq 4.65 \times 10^3 B_{M,16.5}^2 t_{4.5}^{-1}$$



Dipole field decay isn't enough ⇒ another energy source is required – likely internal-field decay

Quiescent steady particle wind? What would drive it? Seems unlikely

Outflows associated to magnetar bursts – known to occur in giant flares (SGR 1806–20, 1900+14)

Burst distribution: $dN/dE \propto E^{-5/3}$ (self-organized criticality)? giant flares dominate for rising $E^2 dN/dE$

$$\Longrightarrow \Delta t_{\mathrm{GF}} = \frac{E}{\langle \dot{E} \rangle} = 100 \left(\frac{g}{50}\right)^{-1} \left(\frac{E}{10^{45.5}\,\mathrm{erg}}\right) \mathrm{yr} \quad \text{since} \quad \langle \dot{\mathrm{E}} \rangle \approx \left(\frac{\mathrm{g}}{50}\right) \times 10^{36}\,\mathrm{erg\,s^{-1}}$$