Relativistic reconnection

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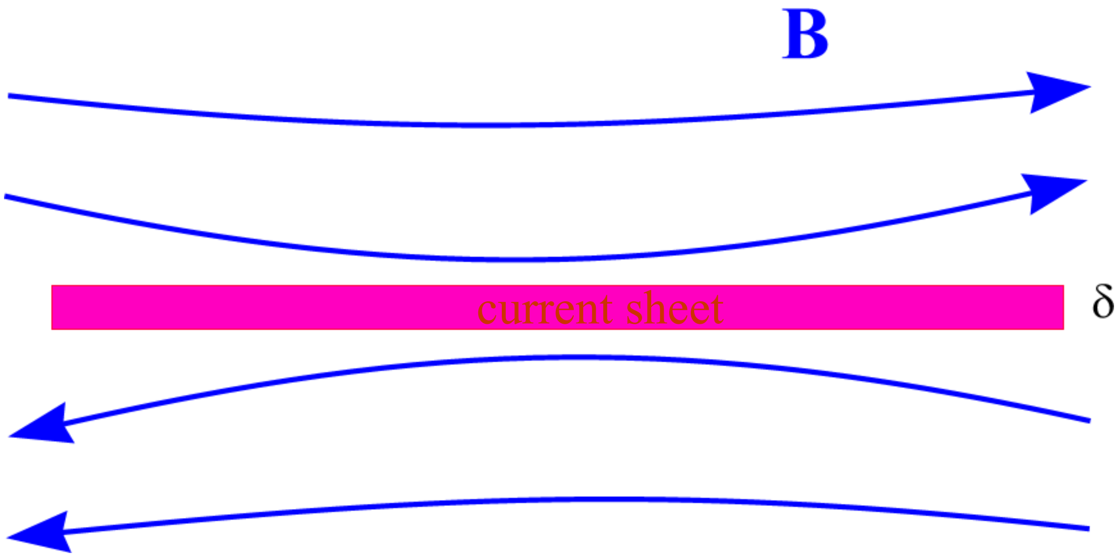
$$\sigma = \frac{B^2}{4\pi\rho c^2} >> 1$$



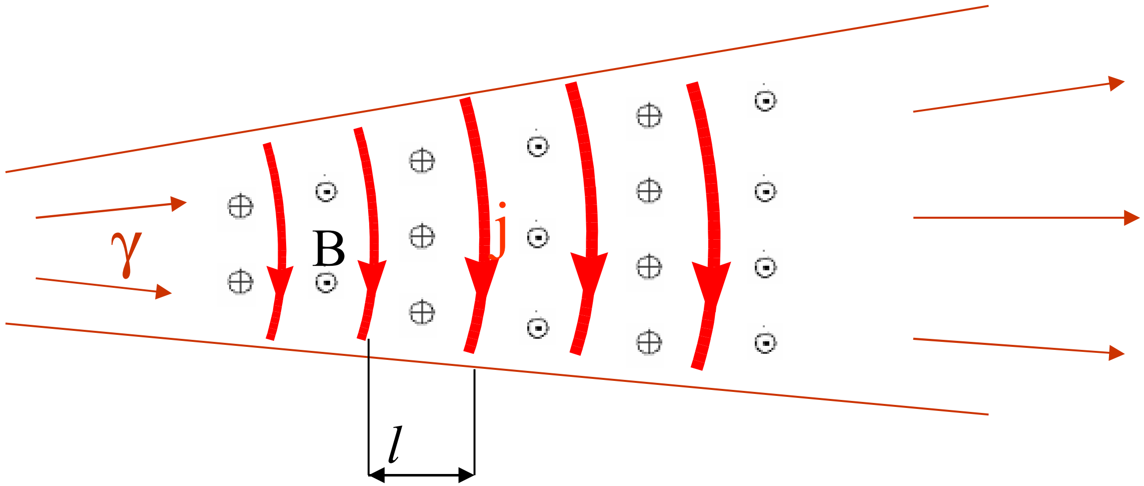
$$r_B = \frac{T}{eB} = \frac{B}{8\pi en} \qquad nT = \frac{B^2}{8\pi}$$

$$T = \frac{B^2 m}{8\pi\rho} = \frac{1}{2}\sigma mc^2$$

$$j = \frac{cB}{4\pi\delta} \qquad \delta = \frac{B}{8\pi en} \qquad \mathrm{v}_{\mathrm{current}} = \frac{j}{en} = 2c$$

$$l' = \gamma l$$

$$B' = B / \gamma$$



$$B = B_0 \frac{l}{R}$$

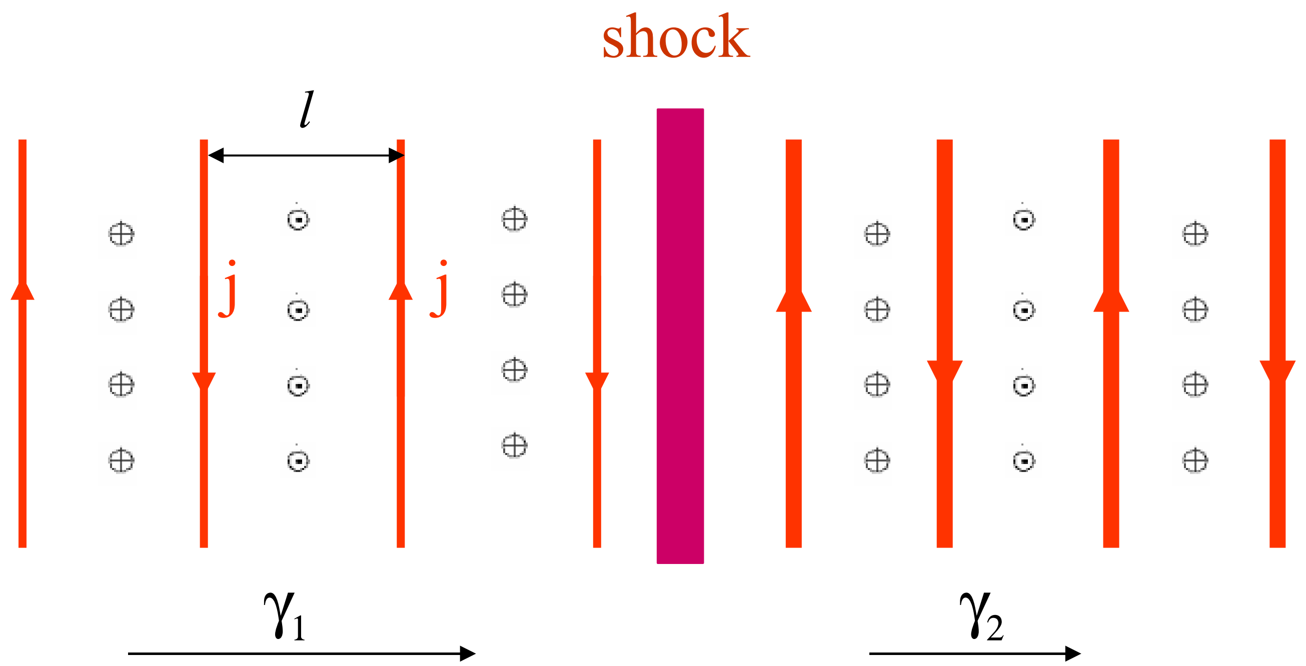
$$L = B_0^2 l^2 c$$

$$\frac{r'_B}{l'} = \frac{T}{eB'l'} = \frac{\sigma mc^2}{eB'l\gamma} = \frac{\sigma mc^2}{eBl} = \frac{\sigma mc^{2.5}}{eL^{1/2}} \frac{R}{l}$$

$$\frac{r'_B}{l'} = \frac{\sigma m c^{2.5}}{e L^{1/2}} \frac{R}{R_0}$$

$$\frac{r'_B}{l'} \to 1; \qquad \sigma \to 1$$

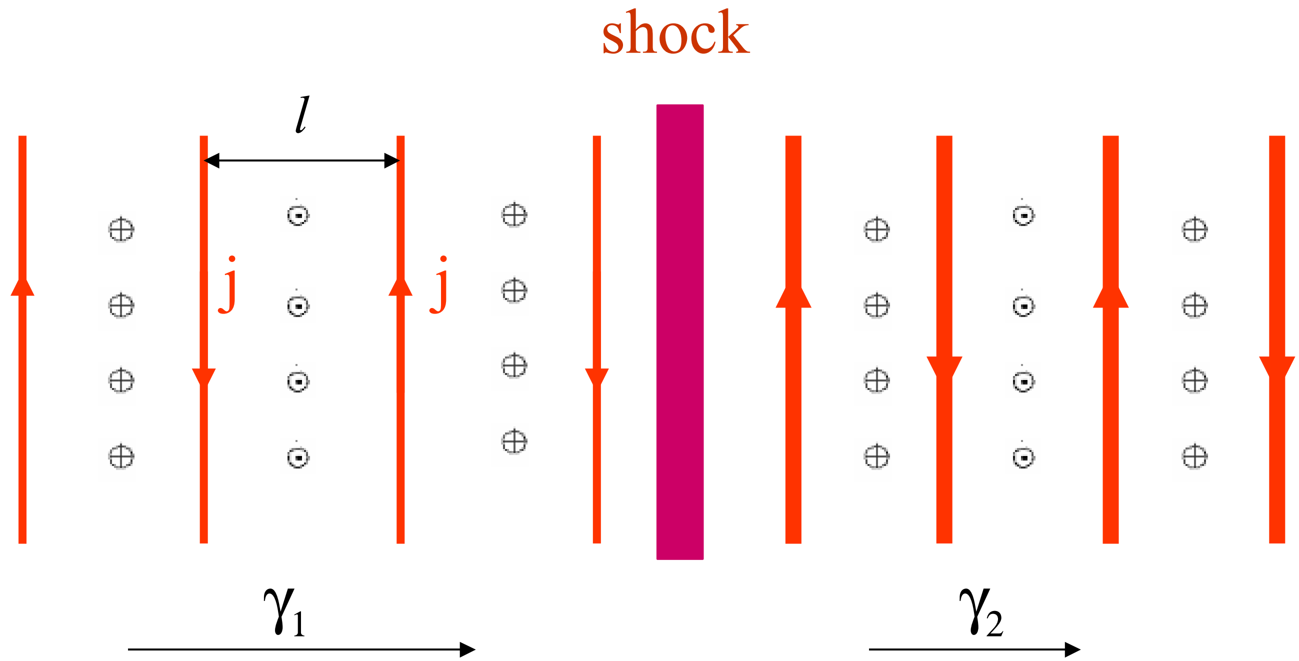
$$\frac{R}{l} = \frac{e}{m c^{2.5}} L^{1/2} = 3 \cdot 10^{10} \frac{m_e}{m} L_{38}^{1/2}$$



:no dissipation $\gamma_2 = \sqrt{\sigma}$

$$\frac{n'_2}{n'_1} = \frac{\gamma_1}{\gamma_2}$$

$$r'_B = \frac{B'}{8\pi e n'} = \frac{B}{8\pi e n} \qquad l' = \gamma l$$



$$\sigma < \left(\frac{l}{r_0}\right)^{2/3}; \qquad \gamma_2 = \sqrt{\sigma} \qquad \text{negligible dissipation}$$

$$\left(\frac{l}{r_0}\right)^{2/3} < \sigma < \frac{l}{r_0}; \qquad \gamma_2 = \frac{5}{4}\frac{l}{r_0\sigma} \qquad \text{partial dissipation}$$

$$\sigma > \frac{l}{r_0}; \qquad \mathrm{v}_2 = \frac{c}{3} \qquad \text{total dissipation}$$

$$r_0 = \frac{mc^2\gamma_1}{eB} \qquad B = B_0\,\frac{l}{R}$$

Total dissipation of alternating fields at the shock if

$$\frac{R}{l} > \frac{eB_0 l}{mc^2\Gamma} = \frac{eL^{1/2}}{mc^{2.5}\Gamma}; \qquad \Gamma = \sigma\gamma_1 = \frac{B^2}{4\pi\rho c^2}$$

Total dissipation in a freely expanding flow at $\frac{R}{l_0} = \frac{eL^{1/2}}{mc^{2.5}}$

In pulsars $l = (1/2)cP; \qquad \kappa = \frac{eB_0 l}{mc^2\Gamma} = 1 \ldots 10^3 \ldots 10^6$

Termination shocks in PWNe at $R >> \kappa l$

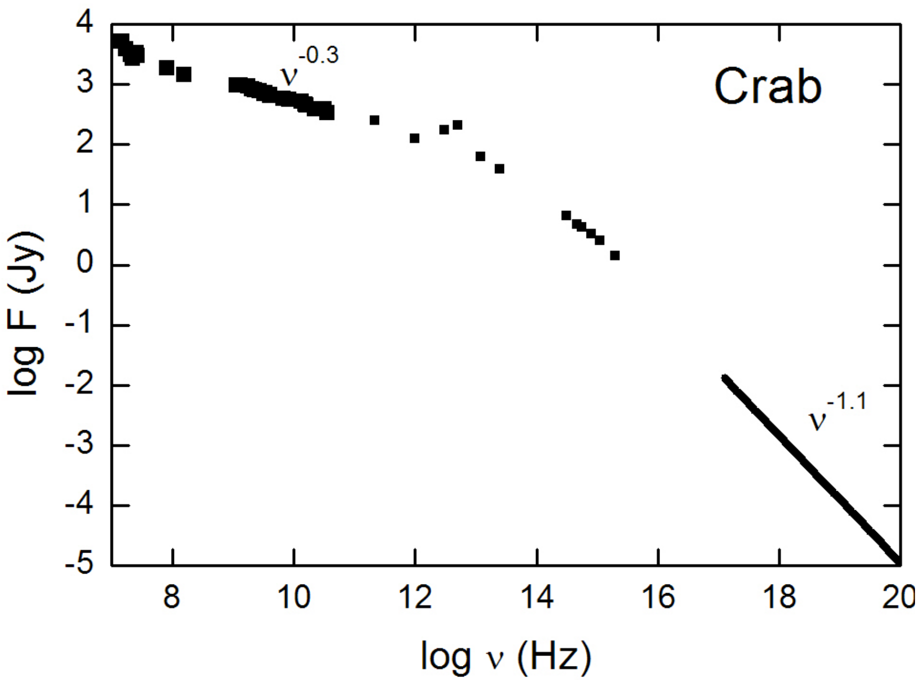
Bow shocks in binary pulsars at $R \approx 10^3 l$

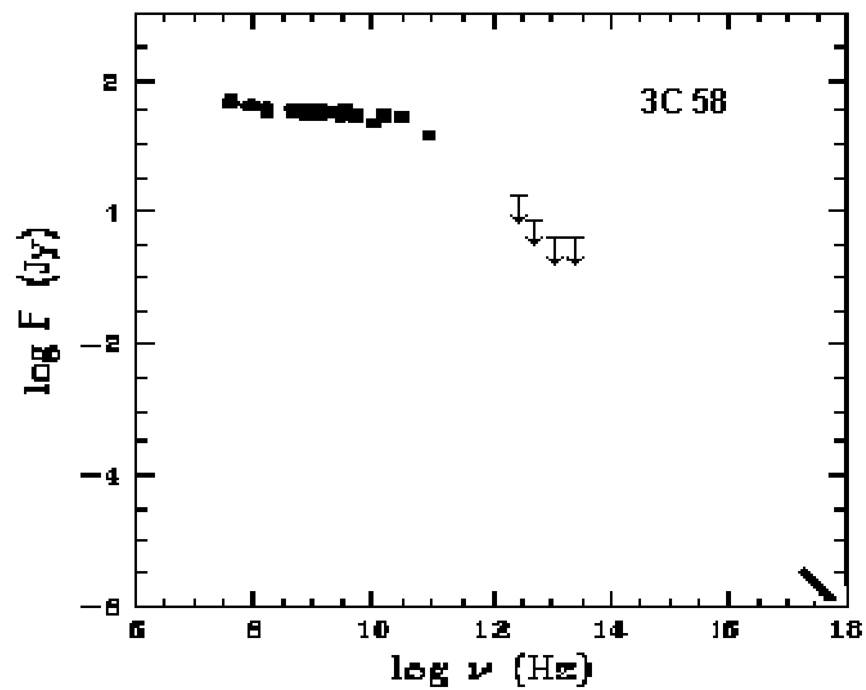
Dissipation at shocks in AGNs: Levinson & van Putten 1997

in GRBs: Fan, Wei & Zhang 2004

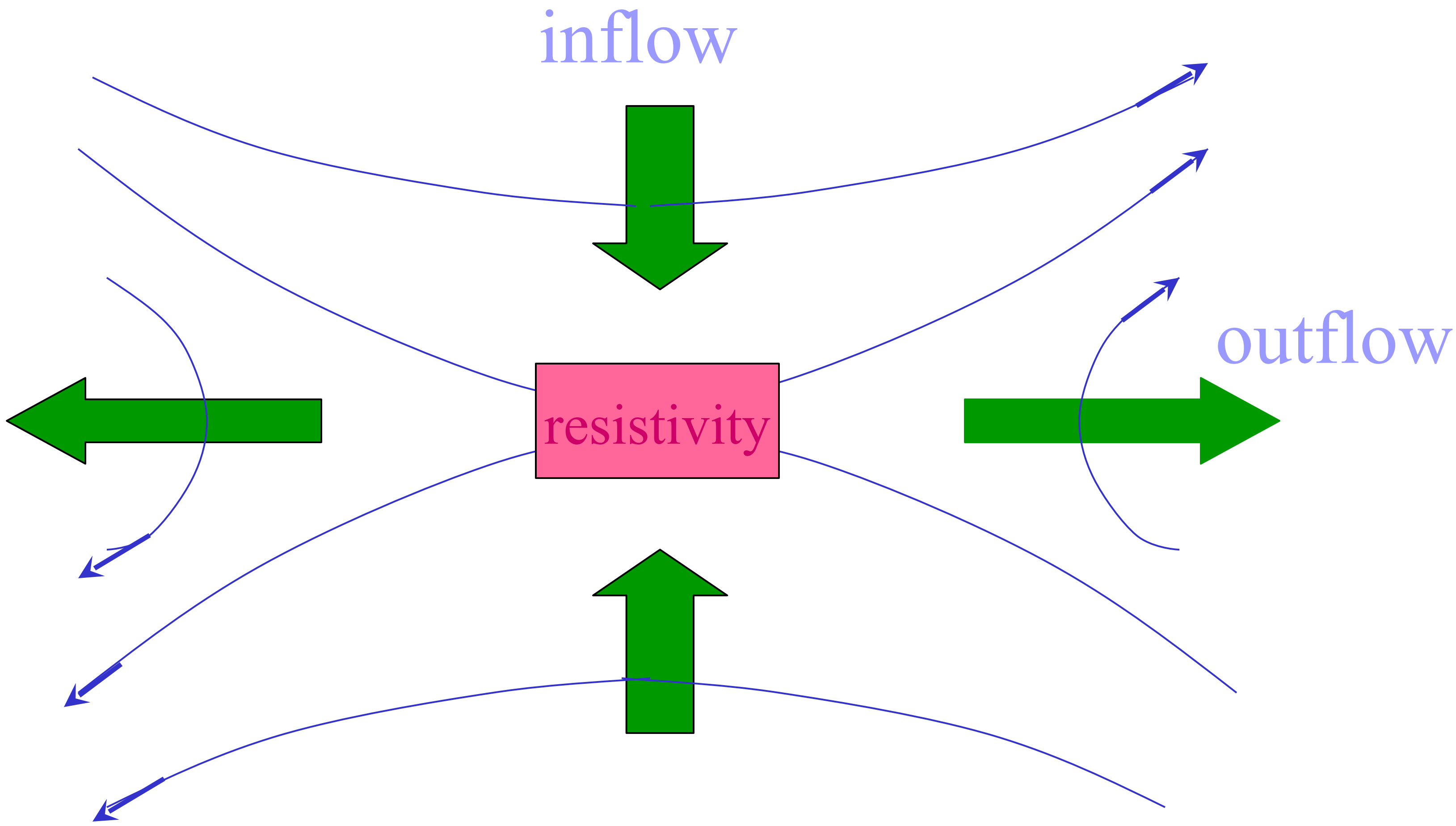
Particle acceleration: talks by Drake and Hoshino

$$N \propto \gamma^{-p}; \qquad p \approx 1 \qquad \alpha = \frac{p-1}{2} \approx 0$$



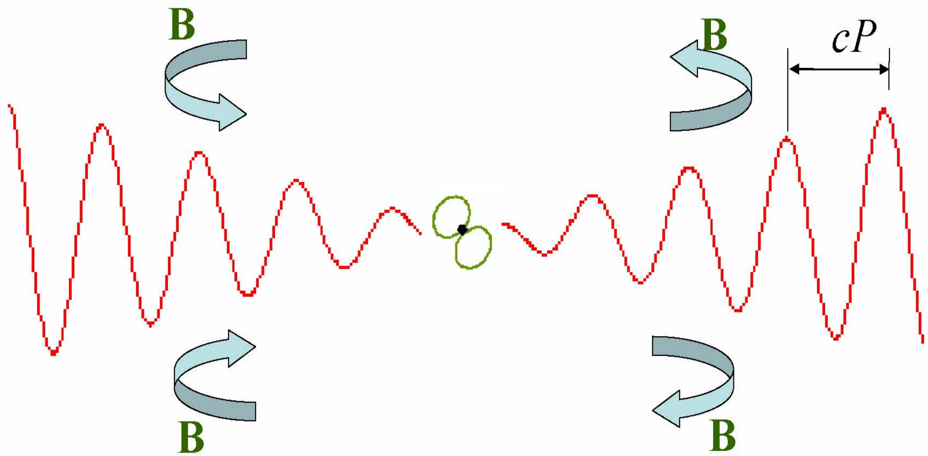


Reconnection at $r'_B << l'$

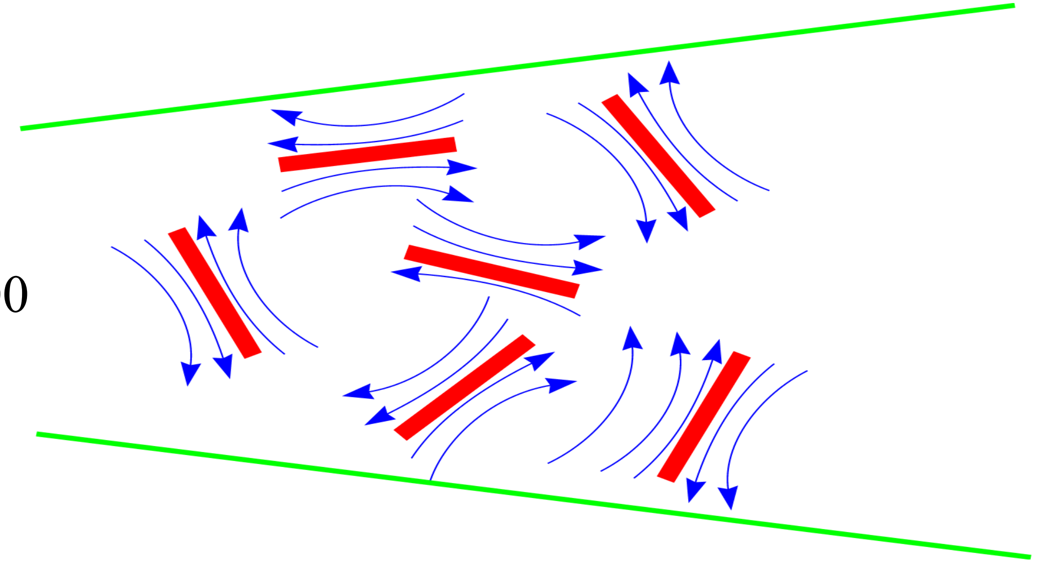


$$l' < \frac{R}{\gamma}$$

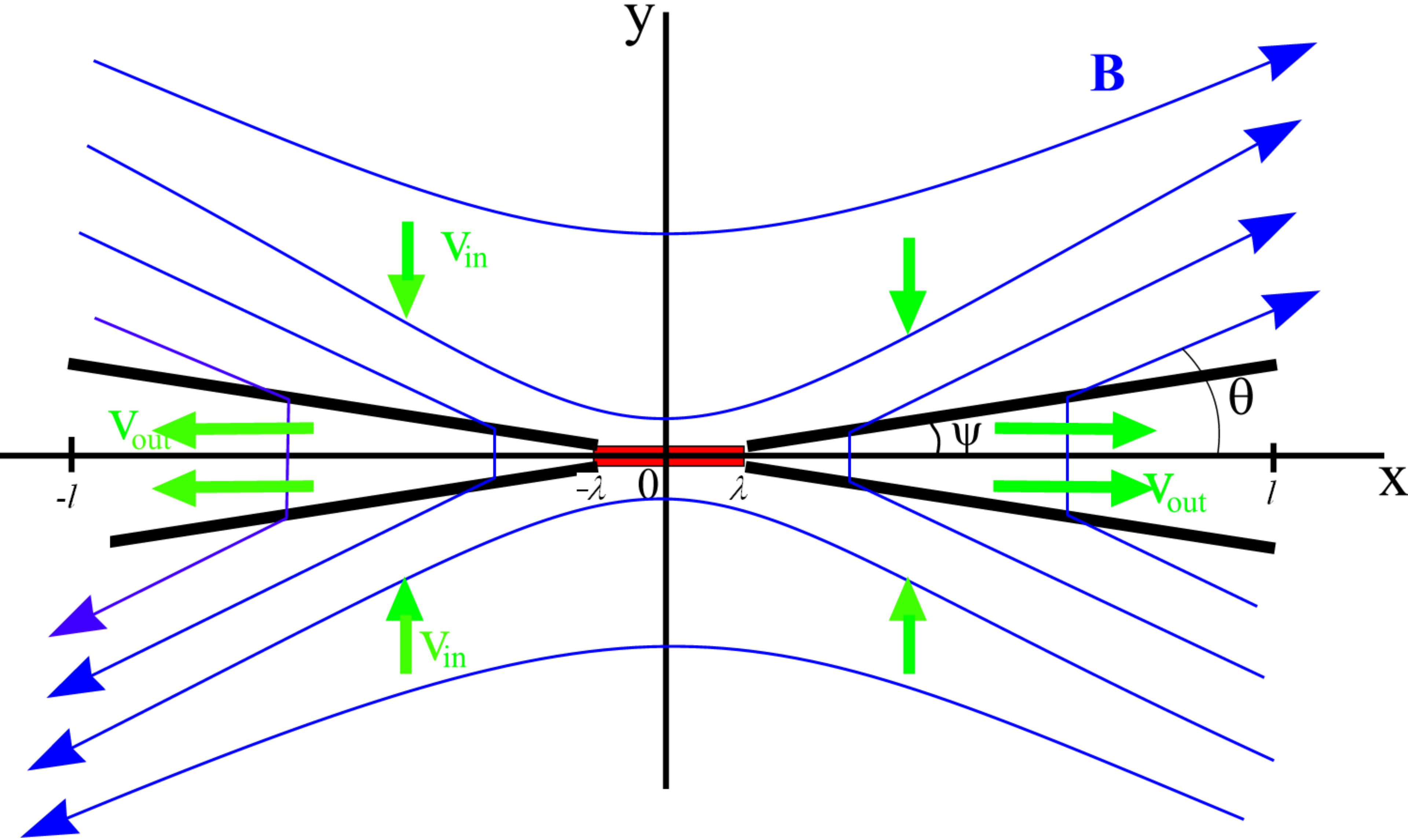
current sheet in the pulsar wind



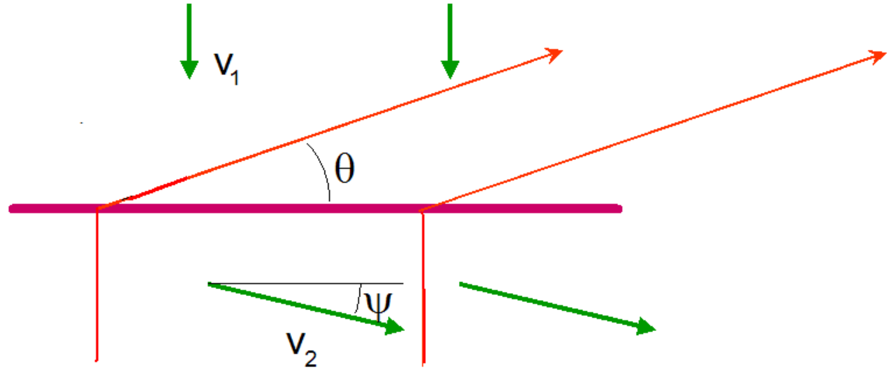
jet with tangled magnetic fields((Heinz & Begelman 2000



Petschek reconnection



slow shock

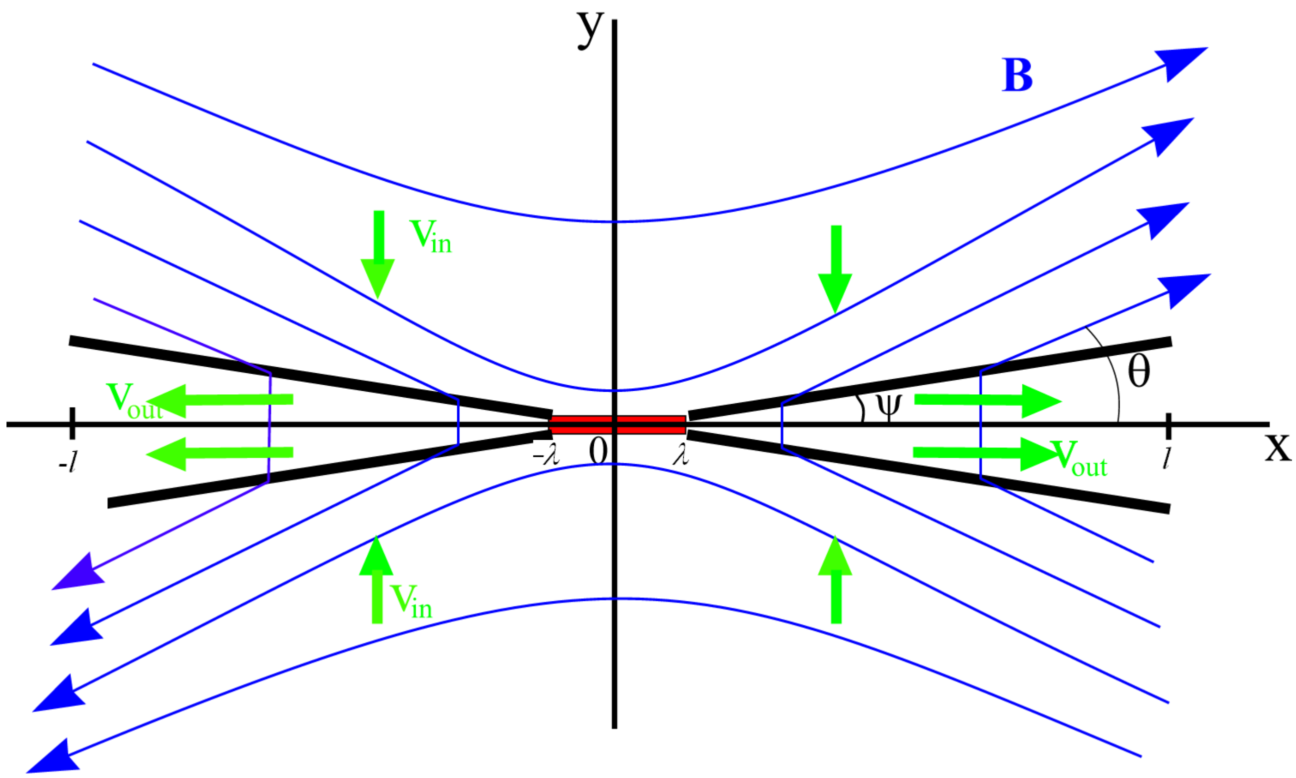


$$\sigma = \frac{B_1^2}{4\pi\rho_1\gamma_1^2} >> 1 \qquad v_1 = \tan\theta \qquad \theta < \pi/2$$

$$p_2 = \frac{B_1^2\cos^2\theta}{8\pi} \qquad T = \frac{\cos^2\theta}{4}\sqrt{\frac{\sigma}{\cos 2\theta}}$$

$$\gamma_2 = \sqrt{\sigma}\cos\theta \qquad \rho_2 = 2\rho_1\sigma\cos^2\theta$$

$$\psi = \frac{\sin\theta}{2\sigma\cos^3\theta}$$

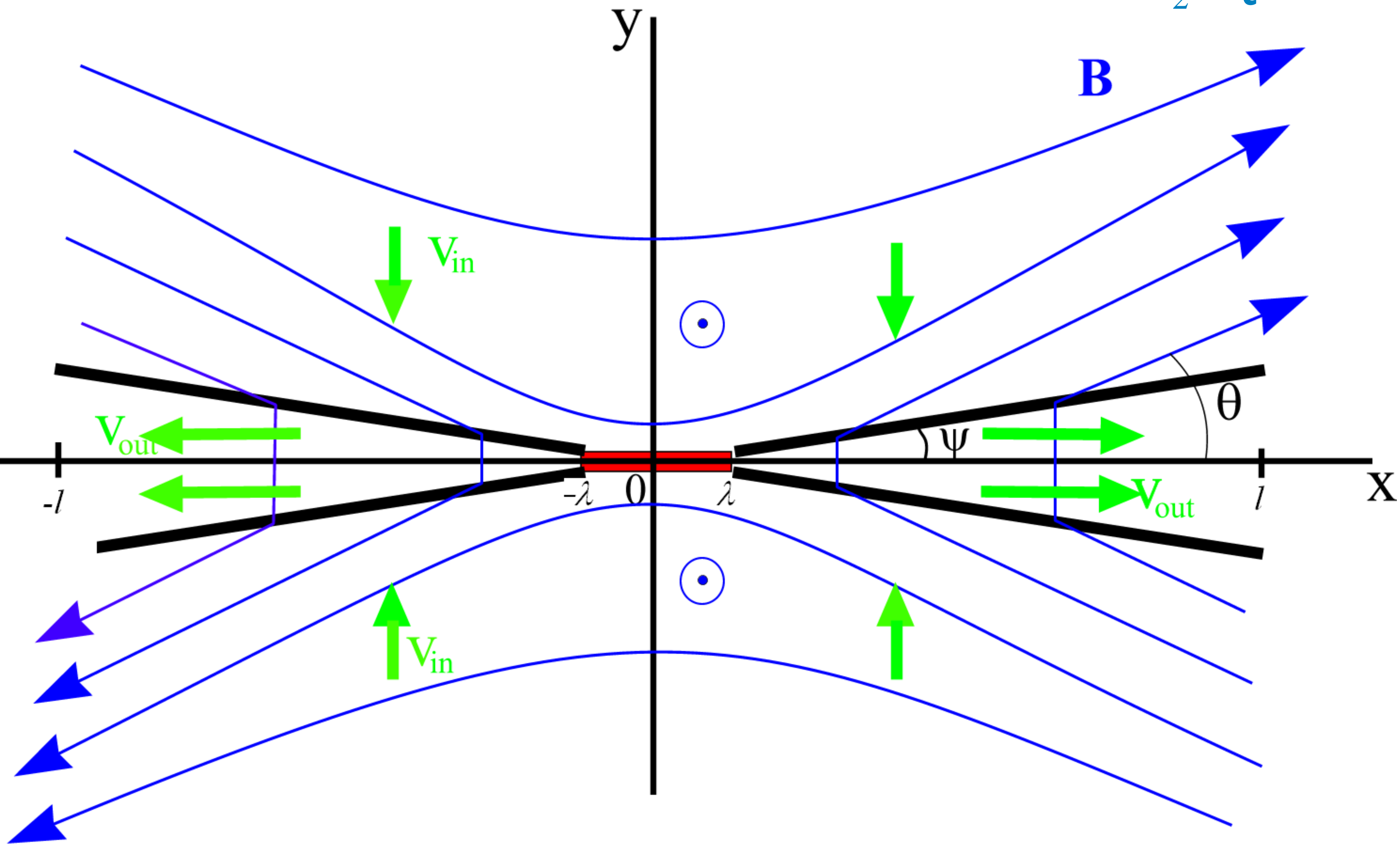


$$B_x(0,0) = B_0\left(1 - \frac{2\tan\theta}{\pi}\ln\frac{l}{\lambda}\right); \qquad \mathrm{v}_{in} = c\tan\theta$$

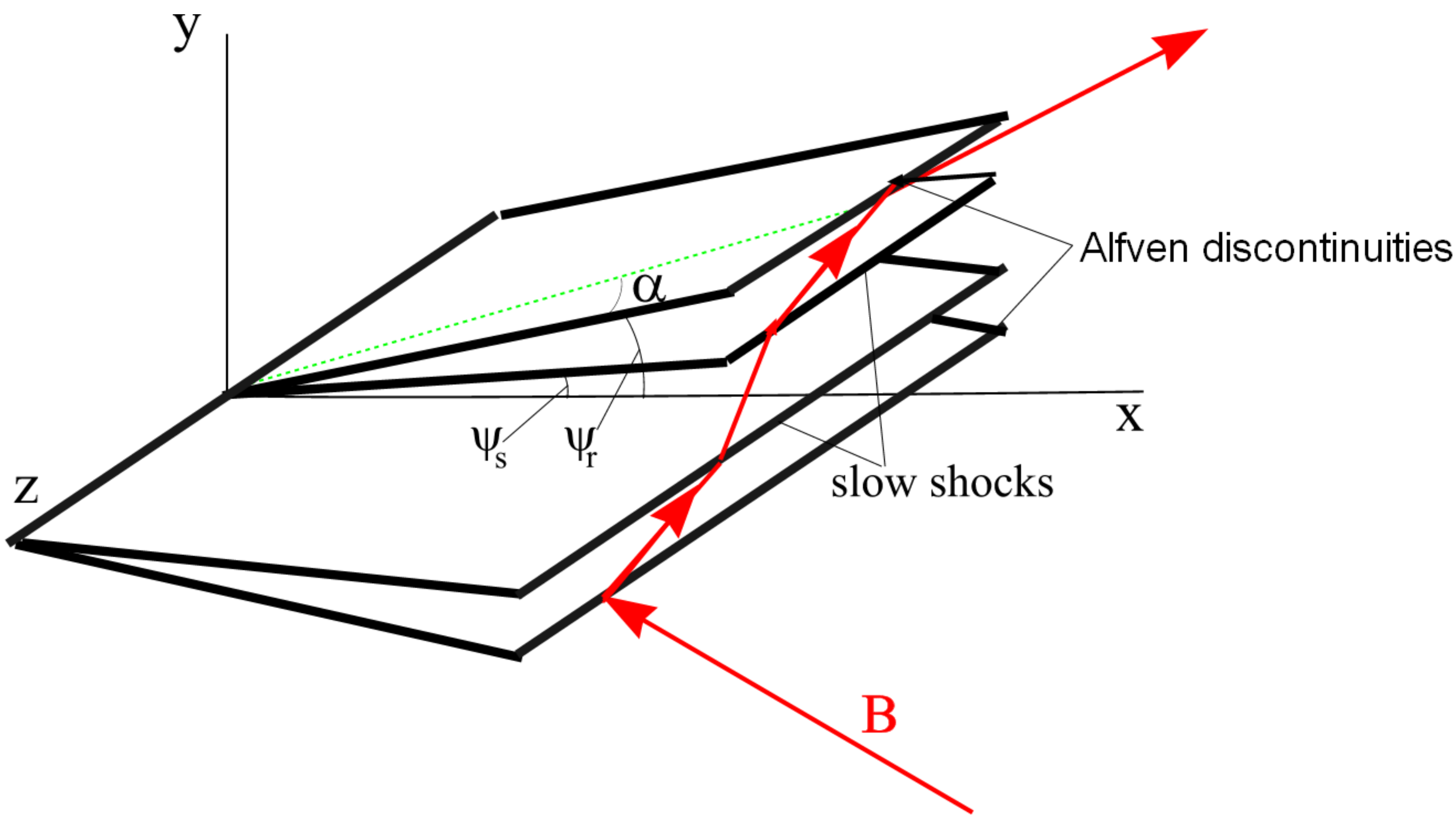
$$\mathrm{v}_{in} = \frac{\pi c}{4\ln(l/\lambda)} \approx 0.1c$$

Time dependent reconnection: Tolstykh, Semenov & Heyn, poster 48

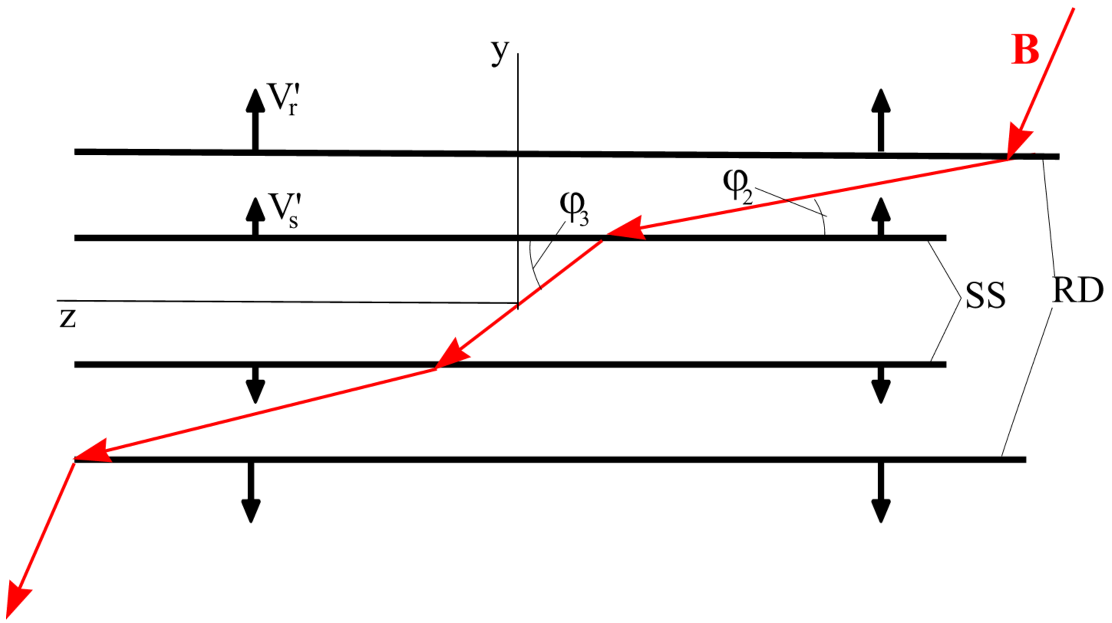
Relativistic Petschek reconnection in case B_z ą 0



$$B_{z,in} = \alpha B_0$$



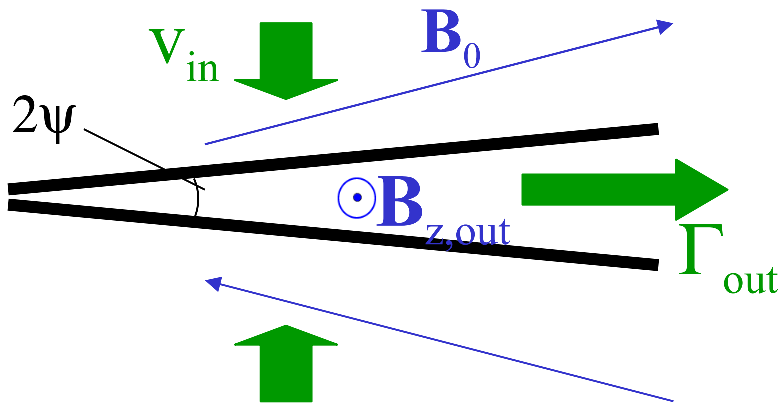
y
α
Alfven discontinuities
x
ψ_s
ψ_r
z
slow shocks
B



$$B_{z,out} = \frac{\alpha}{\psi} B_y = \frac{\alpha}{\psi} \mathrm{v}_{\mathrm{in}} B_0$$

$$\alpha = \frac{B_{z,in}}{B_0} << 1$$

$$B_{z,out} = \frac{\alpha}{\psi} \mathrm{v}_{\mathrm{in}} B_0$$



$$B_0 = \frac{B_{z,out}}{\Gamma_{out}}$$ pressure balance

$$v_{in} B_0^2 = B_{z,out}^2 \psi$$ energy balance

$$\psi = \mathrm{v}_{\mathrm{in}} \alpha^2 \qquad \Gamma_{out} = 1/\alpha \qquad \alpha = \frac{B_{z,in}}{B_0} << 1$$

$$\alpha_0 = \left(2\sqrt{\sigma}\right)^{-1}$$

$$\alpha > \alpha_0 \quad \Rightarrow \quad \frac{B_{z.out}^2 \psi_r}{4\pi h \gamma_{out}^2 \psi_s} = 3\alpha^2 \sigma$$

reconnection → force-free MHD turbulence →

→ cascade → dissipation

;Thompson & Blaes 1998; Troischt & Thompson 2004
Cho 2005; Luo & Melrose 2006

Conclusions

In freely expanding outflows, $r'_B/l;'$ grows with the distance .1 however total dissipation of alternating field generally occurs at too large distance

Dissipation at the termination shock is a plausible .2 mechanism, at least in pulsar winds

Fast reconnection of tangled field is possible if .3 $l' < R/\gamma$. At σ >>1, magnetic energy is generally not transferred ?to the plasma. Dissipation via turbulent MHD cascade