Flares

a complete dissipation of the sunspot in corona

$B \sim 1000\,G = 0{,}1\,T$

$V \sim (10 \times 10 \times 10)\ Mm^3 = 10^{18}\, m^3$

$\rightarrow E_m = \frac{B^2}{2\mu_0} V = \frac{0{,}01}{2\mu_0} 10^{18}\, J \sim 4 \times 10^{21}\, J$

$\rightarrow$ many orders less than observed $\Rightarrow$ a quiet dissipation can't be the source for flares

Time scales

in explosive: Joule heat

$$t_j = \frac{B^2/2\mu_0}{j^2/\sigma} = \left| j = \frac{1}{\mu_0} \nabla \times B \sim \frac{1}{\mu_0} \frac{B}{L} \right| =$$

$$= \frac{B^2/2\mu_0}{B^2/\mu_0^2 L^2 \sigma^2} = \frac{\mu_0 L^2 \sigma}{2}$$

comparable

field diffusion:

$$\frac{\partial B}{\partial t} = \frac{1}{\mu_0 \sigma} \Delta B \Rightarrow \frac{B}{t_{diff}} \sim \frac{1}{\mu_0 \sigma} \frac{B}{L^2}$$

$$\Rightarrow t_{diff} \sim \mu_0 \sigma L^2$$

diffusivity: $\eta = \frac{1}{\mu_0 \sigma} \Rightarrow t_{dif} \sim \frac{L^2}{\eta}$

η: chromosphere $\eta \sim 10^7\ \frac{cm^2}{s}$

corona: $\eta \sim 3 \times 10^3\ cm^2/s$

slow!

advection – dynamical phenomenon

$t_a \sim L/v$

to compare in equilibrium steady-state

$$t_j = \frac{L^2}{\eta} = \frac{Lv}{\eta} \cdot \frac{L}{v} = R_M\, t_a$$

magnetic Reynolds number

$\Rightarrow$ advection vs. diffusion

=I=

for $R_M \gg 1$ $\quad t_j \gg t_d$ ⇒ diffusion plays no role

for $v \equiv c_A \sim 10^6\,\mathrm{m/s}$

$$t_j = \frac{L^2}{\eta} = \frac{L c_A}{\eta}\,\frac{L}{c_A} = N_L\, t_A$$

t_A: alfvén time

N_L: Lundquist number

N_L large ⇒ highly conducting plasma

N_L small ⇒ resistive plasma

<u>example</u>

time it takes do dissipate dynamically with alfvén speed

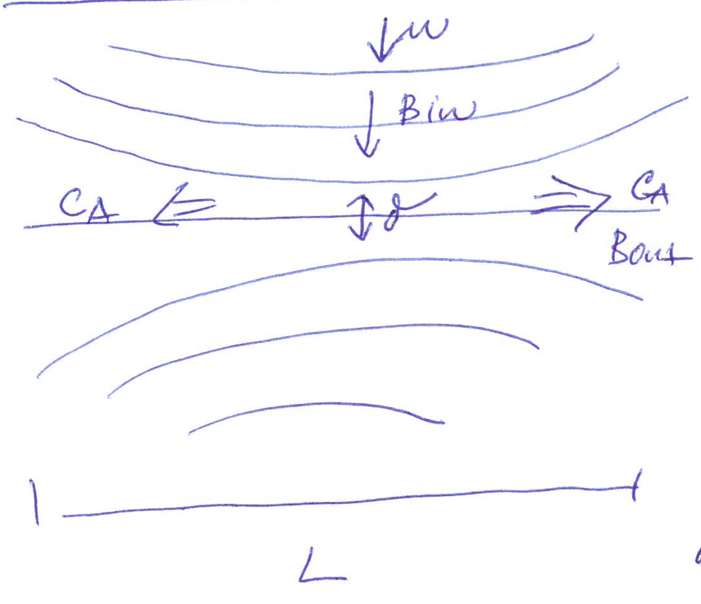
$$t_j = \frac{L N_L}{c_A}$$

corona: $L \sim 10^7\,\mathrm{m}$, $c_A \sim 10^6\,\mathrm{m/s}$, $\eta \sim 10^3\,\mathrm{cm^2/s}$,

$N_L \sim 10^{14}$, $\frac{L}{c_A} \sim 10\,\mathrm{s}$

⇒ $t_j \sim 10^{15}\,\mathrm{s}$ ⇒ slow!

$\boxed{\text{Explosive dissipation}}$



$\boxed{\text{Sweet-Parker}}$

antiparallel fields pushed together at length L, plasma pushed away in between of the anti parallel field by alfvén speed

∇B grows up until the steady state (*) →

δ – thickness of the current sheet

current sheet: $j = \frac{1}{\mu}\nabla \times B \sim \frac{B}{\mu\delta}$

energy: $\dot{U} = \eta j^2 = \eta \frac{B^2}{\mu^2 \delta^2}$

(*) a the axis - overpressure (thermal scale of $t_{HW} = L/c_A$), which is ballanced by the mg. field pressure (the thermal energy is removed from the mg. field)

$$U \sim \dot{U} t_{HW} \Rightarrow \frac{B^2}{2\mu} = \xi \frac{B^2}{\mu \delta^2} \frac{L}{c_A}$$

$$\Rightarrow \delta = \sqrt{\frac{2\xi L}{\mu c_A}} \propto \sqrt{\frac{\xi L}{c_A}}$$

continuity equation:

$$\rho w L = \rho \delta c_A \Rightarrow w = \frac{\delta}{L} c_A = \frac{\sqrt{\frac{\varepsilon L}{c_A}}}{L} c_A = \sqrt{\frac{\frac{\varepsilon L c_A^2}{c_A}}{L^2}} =$$

$$= \sqrt{\frac{\varepsilon c_A}{L}}$$

using $N_L = \frac{L c_A}{\varepsilon}$

$$w = \sqrt{\frac{\varepsilon c_A}{L}} = \sqrt{\frac{\varepsilon}{L c_A} c_A^2} = \frac{c_A}{\sqrt{N_L}}$$

reconnection speed

→ characteristic time:

$$t_{sp} = \frac{L}{w} = \frac{L\sqrt{N_L}}{c_A}$$

for the coronal conditions $t_s \sim 10^8 s$ slow

<u>Energetics</u>

$\delta \ll L \Rightarrow w \ll c_A$

inflow speed (rate) of elmag. energy → Poynting flux

$$(E \times H) L \sim EHL = \left| \begin{matrix} E_{induced} \\ \Rightarrow E = u \times B \end{matrix} \right| =$$

$$= E \frac{B_{in}}{\mu} L = w \frac{B_{in}^2}{\mu} L$$

ratio of kinetic & magnetic fluxes:

$$\frac{E_{k,in}}{E_{m,in}} = \frac{w \frac{1}{2} \rho w^2 L}{w \frac{B_{in}^2}{\mu} L} = \frac{w^2}{2 \frac{B_{in}^2}{\mu \rho}} = \frac{w^2}{2 c_A^2} \ll 1$$

⇒ most of the energy influx is magnetic

<u>outflow:</u>

mg. flux conservation: $c_A B_0 = w B_{in}$

$$\nabla \cdot B = 0 \Rightarrow \frac{B_{out}}{\delta} \sim \frac{B_{in}}{L} \Rightarrow B_{out} \ll B_{in}$$

elmag energy outflow:

$$E B_{out}\, \delta/\mu_0 \ll E_{m,in}, \quad \text{because } B_{out} \ll B_{in} \text{ and } \delta \ll L$$

where is the rest of the energy?

$$\frac{E_{k,out}}{E_{m,in}} = \frac{c_A \frac{1}{2} \rho c_A^2 \delta}{v B_i^2 L/\mu_0} = \frac{\frac{1}{2} c_A^2}{c_A^2} = 1/2$$

$\Rightarrow$ 1/2 of the inflowing energy converted to the kinetic energy of particles, the second 1/2 to heat. The mg. field energy is negligible

$\boxed{\text{Petschek model}}$

$t_s \sim L \Rightarrow$ shorten the L and the speed increases

after "some algebra"

$$t_p \sim \frac{L \ln N_L}{c_A}$$

for the corona: $t_p \sim 300\,s$

$\Rightarrow$ explosive dissipation in thin current sheets

Deformation of mg. fields brings free energy $\Rightarrow \Delta B \rightarrow$ current sheets

<u>anomalous resistivity</u> – speed of electrons (drift speed) comparable to the speed of plasma waves $\Rightarrow$ increase of the resistivity $\Rightarrow$ shortening the time

$$N_L \propto \frac{1}{\eta}$$