Theoretical Models for Solar Flares

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(slow) energy build-up

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dynamical instability or loss of equilibrium

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magnetic reconnection driven by dynamical catastrop

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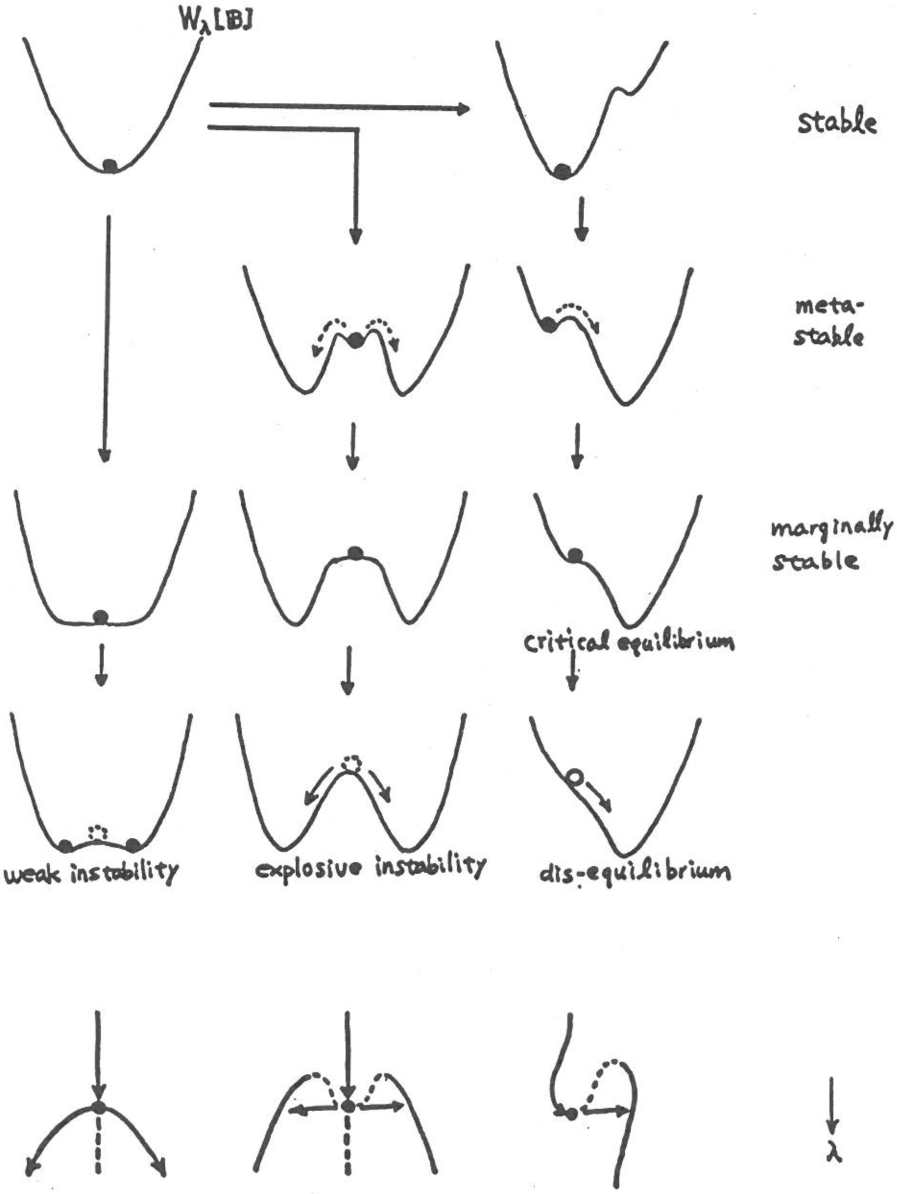
heating mass motion particle acceleratio

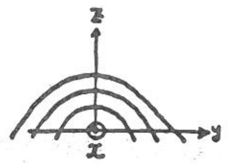


2-D equilibria

x = ignorable coordinate

$\mathbb{B} = \left(B_x,\ \frac{\partial A}{\partial z},\ -\frac{\partial A}{\partial y} \right)$

isothermal



$\Rightarrow$ $P = P_0(A)\, e^{-z/H}$, H = scale height

$B_x = B_x(A)$

$$\nabla^2 A + \underbrace{\frac{1}{2}\frac{\partial}{\partial A}\left(B_x^2 + 8\pi P_0\, e^{-z/H} \right)}_{\lambda F(A,\, z)} = 0$$

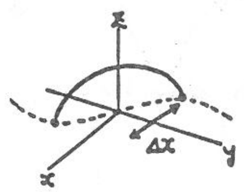
Grad-Shafranov eq.

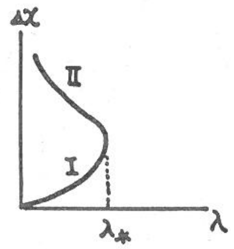
- $\lambda = 0$: current-free
- increase in λ .... energy storage
- loss of solution for $\lambda > \lambda_*$

$$\left(\begin{array}{c} \text{if} \quad F > 0,\ \frac{\partial F}{\partial A} > 0,\ \frac{\partial^2 F}{\partial A^2} > 0 \\ \text{or} \\ F < 0,\ \frac{\partial F}{\partial A} > 0,\ \frac{\partial^2 F}{\partial A^2} < 0 \end{array} \right)$$

loss of equilibrium by shear

$P = 0, \quad \lambda F = \frac{d}{dA}\frac{B_x^2}{2}$





take Δx (shear) as the control parameter

$\rightarrow$ no loss of equilibrium (Jockers, 1978)

$\Delta x \sim B_x \times L_F$ $\quad L_F$: length of field line

branch I : $B_x \sim \Delta x$, $L_F \sim$ const.

II : $B_x, \lambda \downarrow$ but $L_F \uparrow$ as Δx increase.

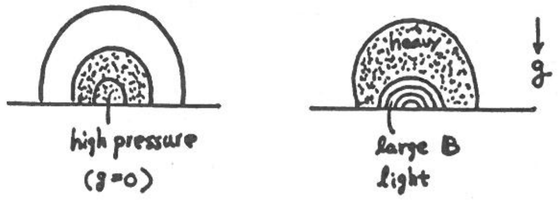
expansion of arcade (Klimchuk 1990)

loss of equilibrium by pressure

$B_z = 0$, $\lambda F = 4\pi \frac{dR}{dA} e^{-z/H}$

increase in pressure

$\longrightarrow$ loss of equilibrium (Low, 1981)



pressure too high to be magnetically confined

magnetic buoyancy

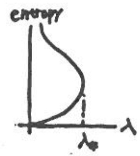
- $p \ll \frac{B^2}{8\pi}$ in active region corona (OK for CME ?)

- shear less ($B_z = 0$) $\longrightarrow$ interchange unstable

  even if $\lambda < \lambda_*$

  (Melville et al. 1987)

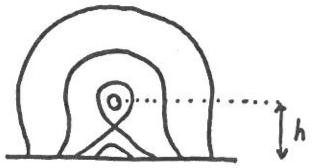
- no catastrophe if entropy (or $\int p\rho^{-\gamma} dV$) is specified (Finn & Chen 1990)



force-free arcade

no instability has been found so far

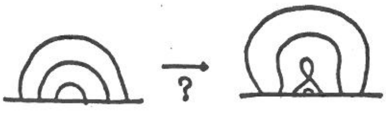
exception :

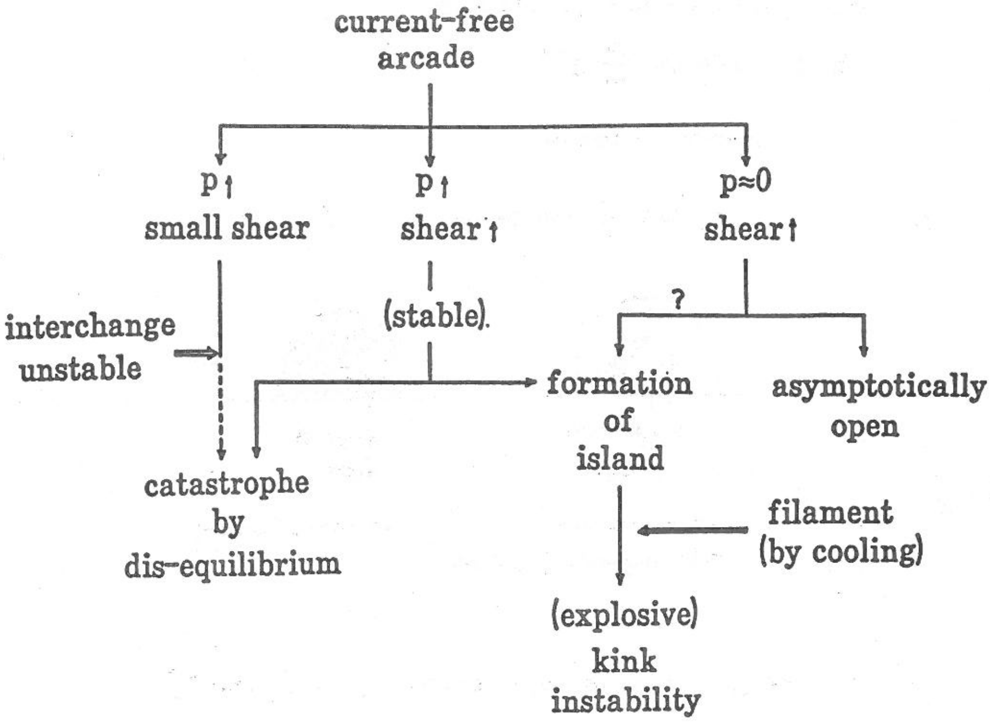


instability for large h (kink instability)

detached field lines = filament ?

equilibrium sequence



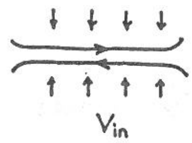


Magnetic Field Reconnection

$$R_m = \frac{\tau_r}{\tau_A} \quad \text{magnetic Reynolds number} \quad (\gg 1)$$

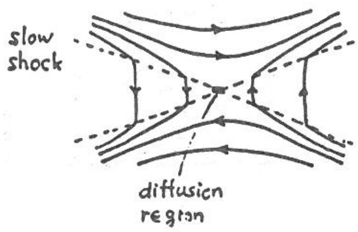
Sweet (1958) - Parker (1957) annihilation

$$V_{in} = R_m^{-\frac{1}{2}} V_A$$

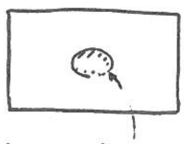


Petschek (1964) : (fast) reconnection

$$V_{in} \lesssim \frac{\pi}{8} \frac{1}{\ln R_m} V_A \sim 0.1\, V_A$$



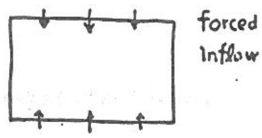
Ugai & Tsuda (1977)



enhanced η

spontaneous reconnection

Sato & Hayashi (1978)



$\eta \sim (j - j_c)^2$

forced reconnection

Tajima et al (1982)

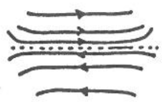
coalescence instability

Biskamp (1986)

forced reconnection $(\eta = \text{const})$

$V_{in} > R_m^{-\frac{1}{2}} V_A \longrightarrow$ flux pile up

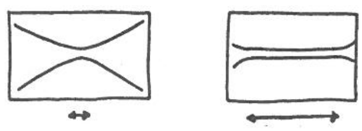
"fast reconnection is impossible"



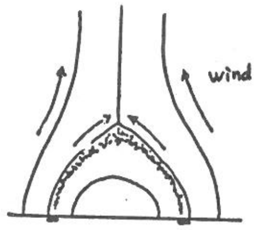
Scholer (1989)

spontaneous reconnection

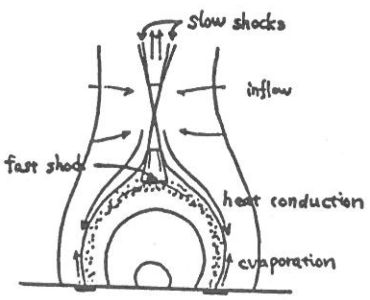
area of enhanced η ↔ diffusion region



Two-Ribbon Flares by Reconnection



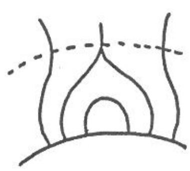
Kopp & Pneuman (1976)



"line-tied reconnection"

Forbes & Priest (1982)

Poletto & Kopp (1988)



← source surface height

↕

magnetogram
+
loop geometry

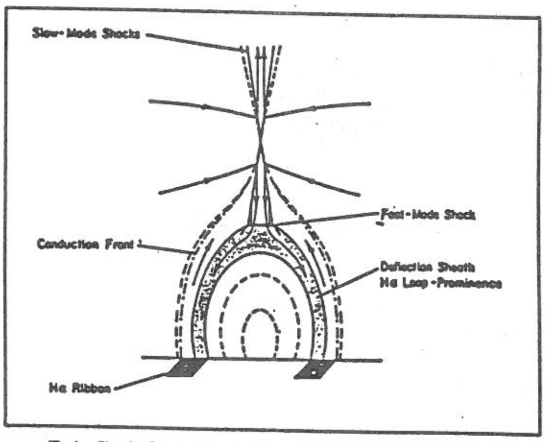
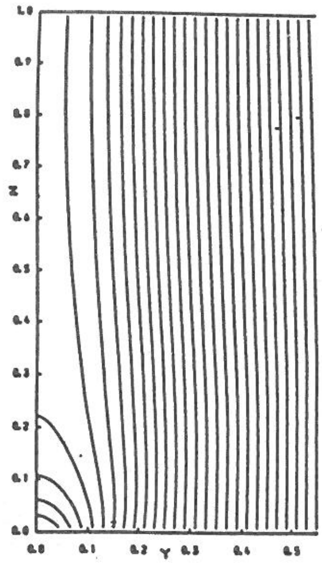


Fig. 1. Sketch of the model of line-tied reconnection of Forbes and Priest.

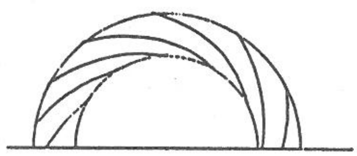


Robertson & Priest 1987

flare models

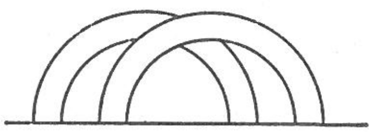
(a)

discrete loop(s) ?



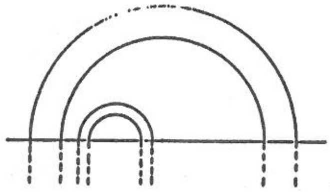
single loop
(tearing instability)
[spatial resolution]

(b)



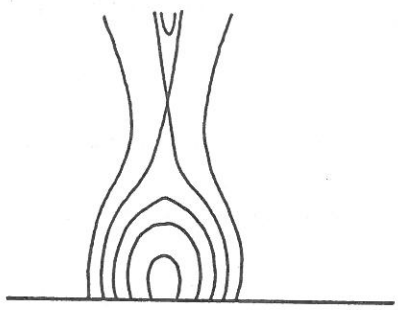
interacting loop
(coalescence instability)

(c)



emerging flux
(reconnection)

(d)



reconnection
in arcade

Fig 4