The Role of Flux Emergence in Triggering Solar Eruptive Events

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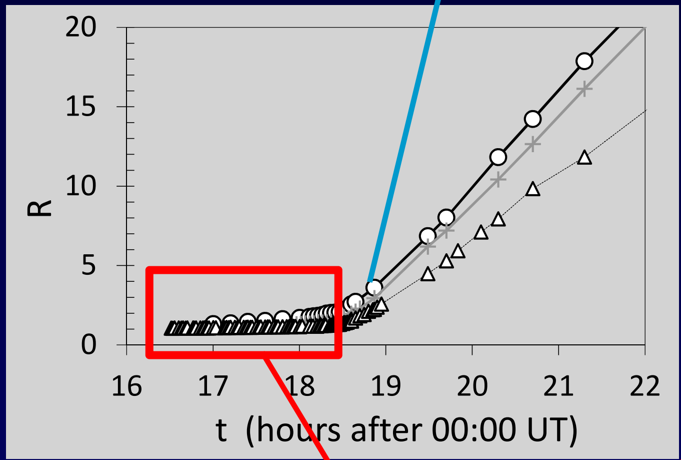
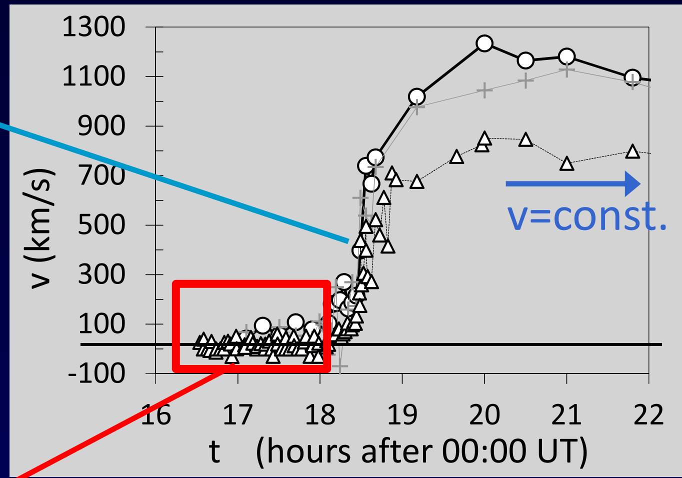
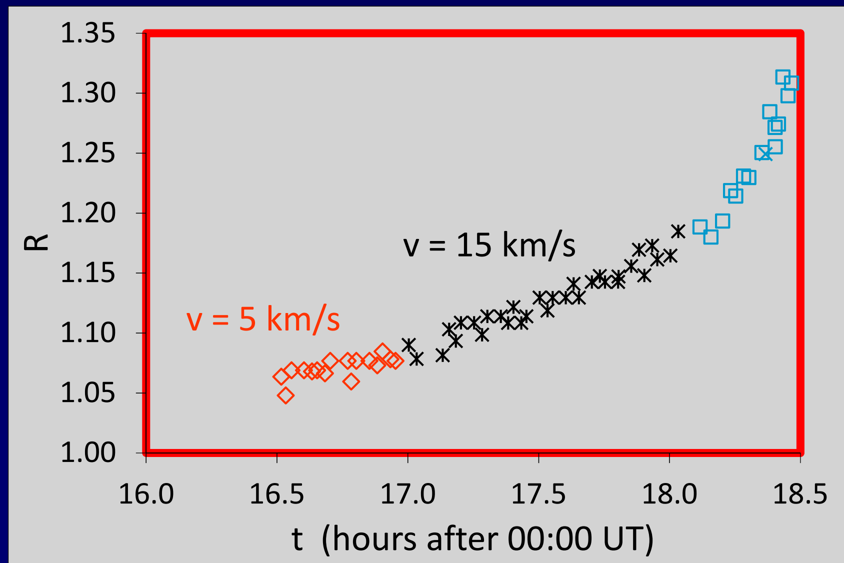
CME Kinematics

acceleration phase





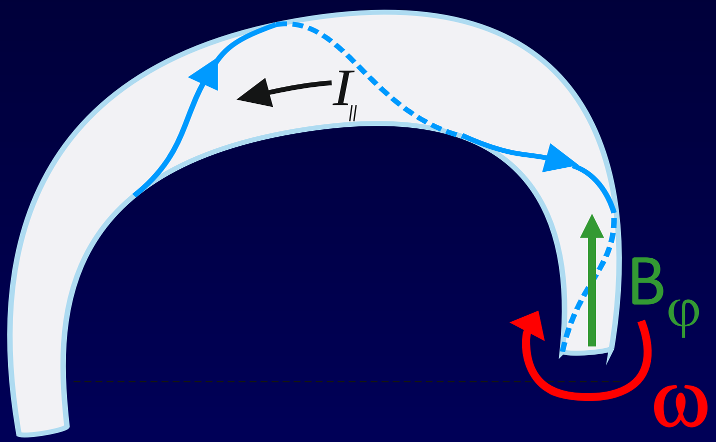
gradual rise



(May 15, 2001)

Emerging-Flux Effects

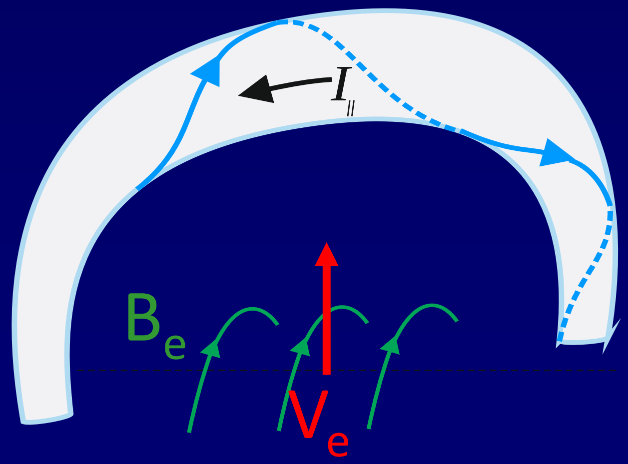
Poloidal flux injection



footpoint rotation (ω)

=> $\Delta\Phi$ => ΔB_{φ} => ΔI

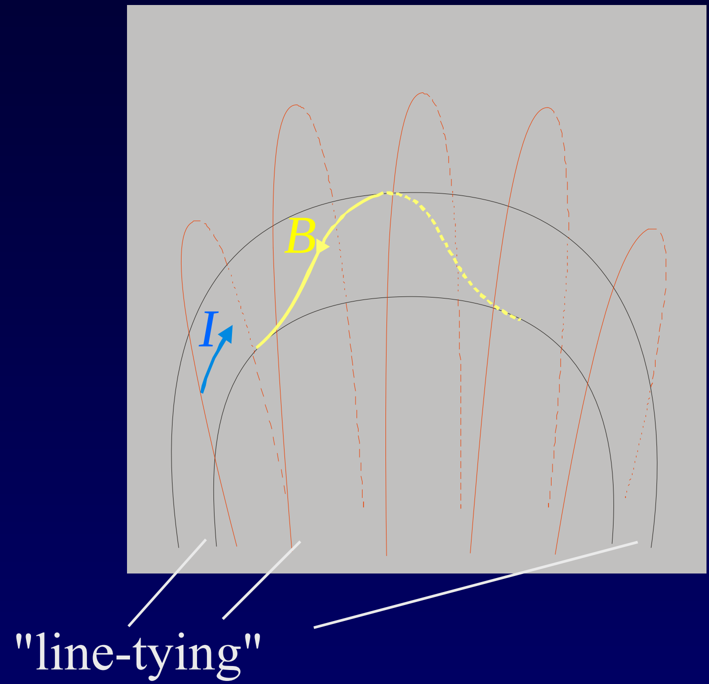
Background field emergence

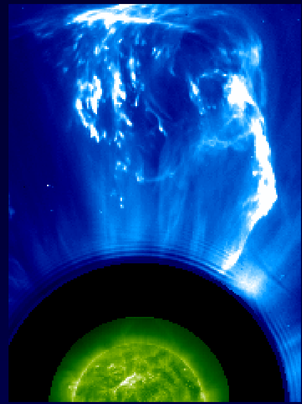


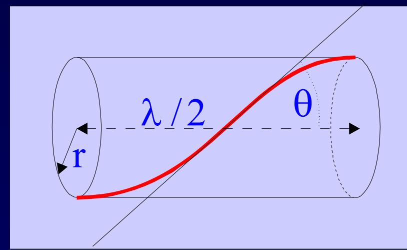
Emergence V_e x B_e

=> $\Delta\Psi_e$ => ΔI

Physical Background







$$X = \mathrm{tg}\ \theta = B_\phi / B_{//}$$

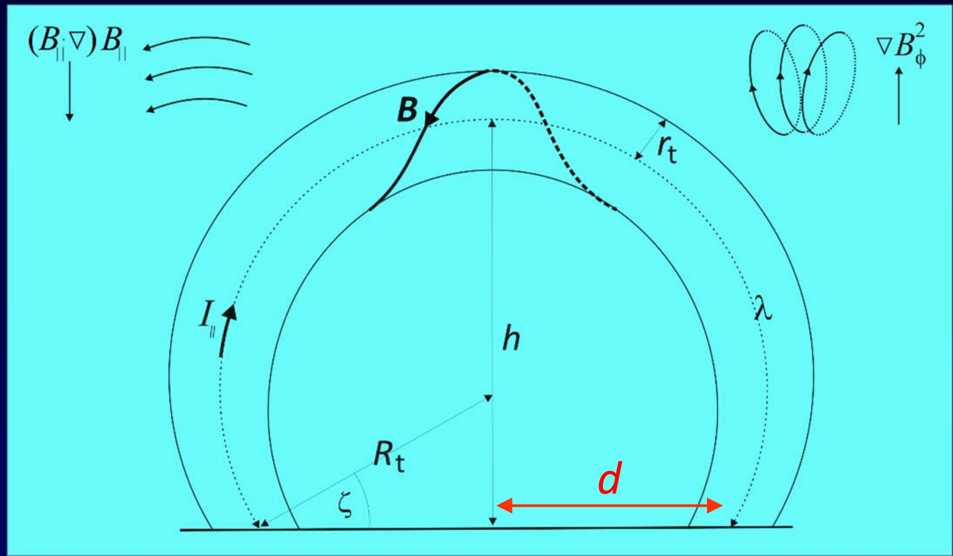
$$\Phi = l\ X/r, \quad N = \Phi/2\pi$$

$$N = l/\lambda, \quad \cancel{N = const.}$$

$$a = a_L - \cancel{g} - \cancel{a_d}$$

Mouschovias & Poland, 1978, ApJ 220, 675
Anzer & Pneuman, 1982, SPh 79, 1
Chen, J. 1989, ApJ 338, 453
Vrsnak, B. 1990, SPh 129, 295
Chen, J., Krall, J.: 2003, JGR 108, 1410
....
TDm 1999 A&A

Semitoroidal Flux Rope



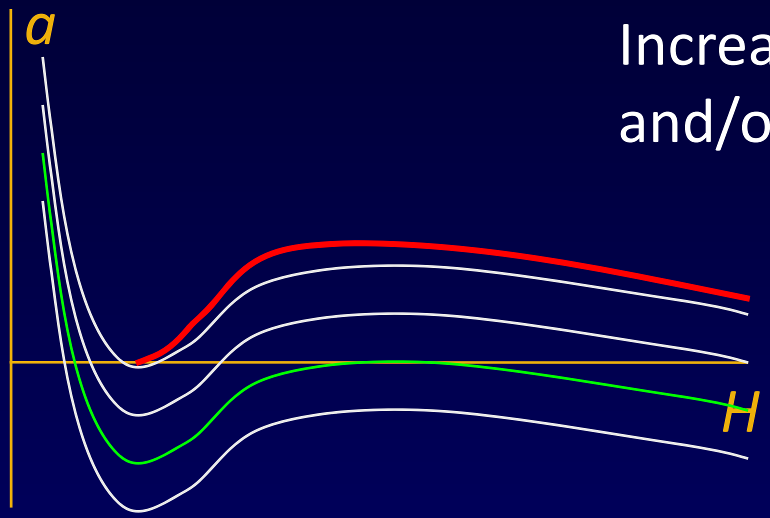
$a = f/\rho$

$$a = (1/2R - 1/RX^2 + 1/H)\, C_L/\Lambda \;\cancel{-\, C_C/\Lambda^2 R}\; \cancel{-\, C_g\, g}$$

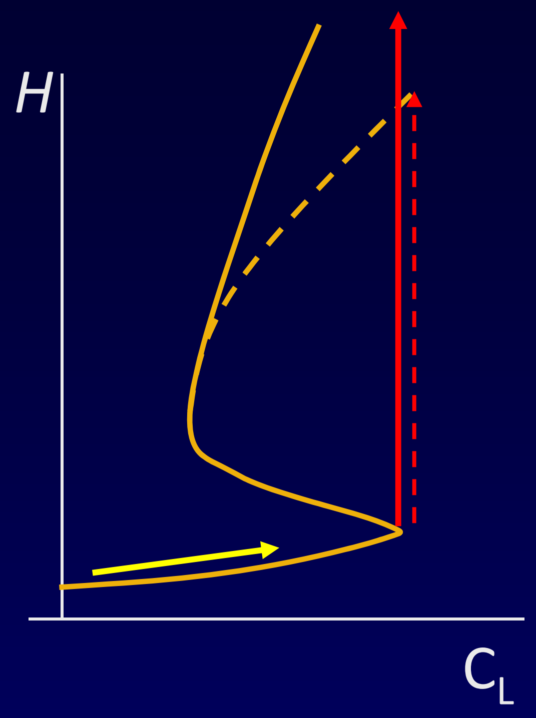
$$C_L = \mu I_0^2 \pi/4M$$

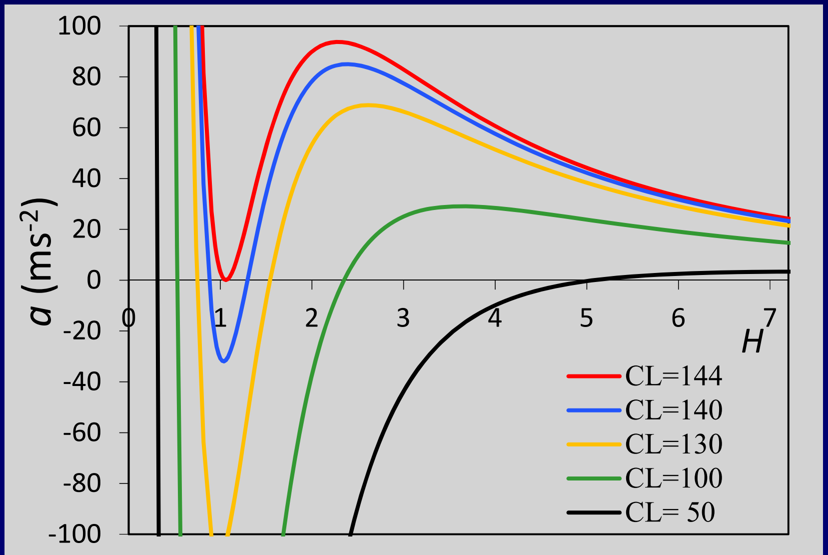
Equilibrium $a = 0$

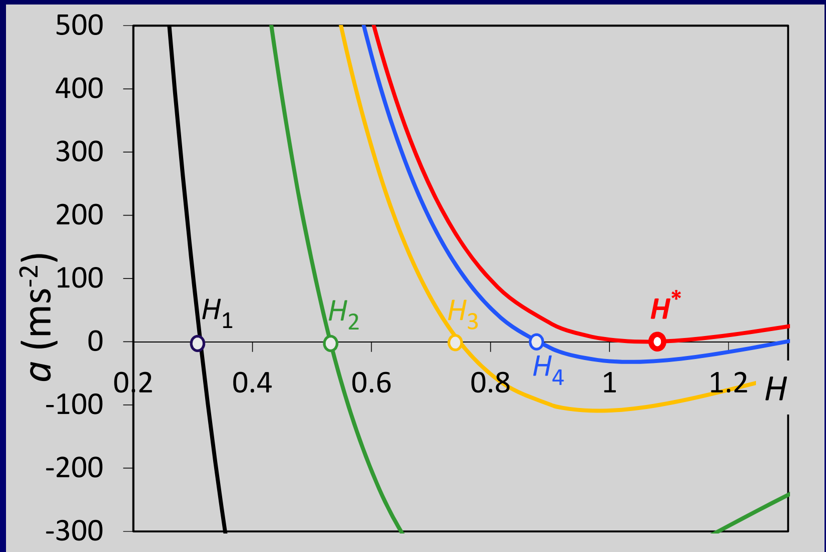
Loss of equilibrium



Increase of C_L
and/or X



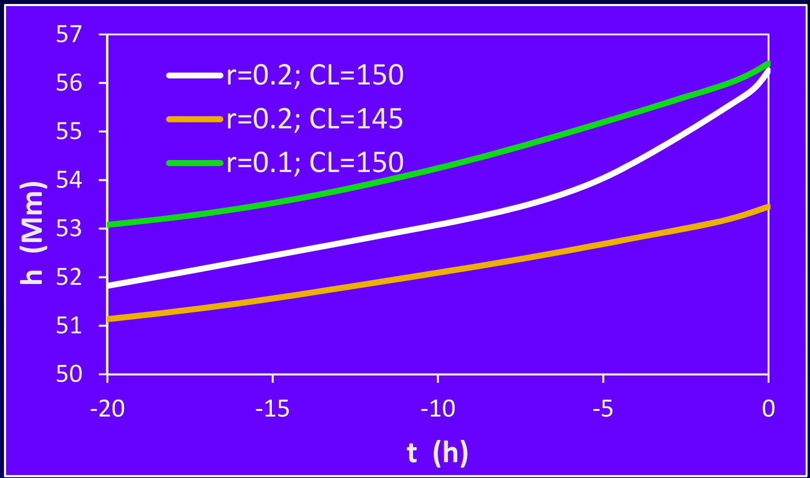


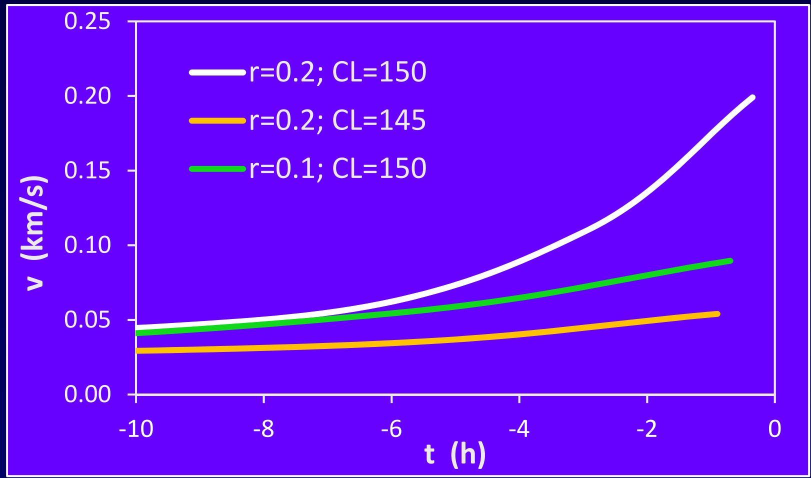


Poloidal flux injection

$d = 50$ Mm; $\omega = 100$ deg/day

$dX/dt = \omega r/\lambda$; $\Delta X = \Delta\Phi\, r/\lambda$; $\Psi_\varphi = \Psi_{//}\, \lambda X/2r\pi$





$X = 3.3$; 4.5; 3.3

$\Psi_{//} = 3$; 3; 0.8 $\times 10^{20}$ Mx ($B_{//} = 100$ G)

=> $d\Psi_\varphi/dt = 1$; 1; 0.3 $\times 10^{15}$ Mx/s (~10^{18} Mx/h)

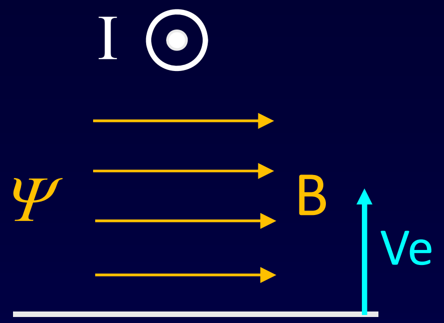
$P_z = E_r B_\varphi = V_\varphi B_z B_\varphi = \omega r\, B_z B_\varphi$

Emerging flux

$d = 50$ Mm;

$Be = 100$ G

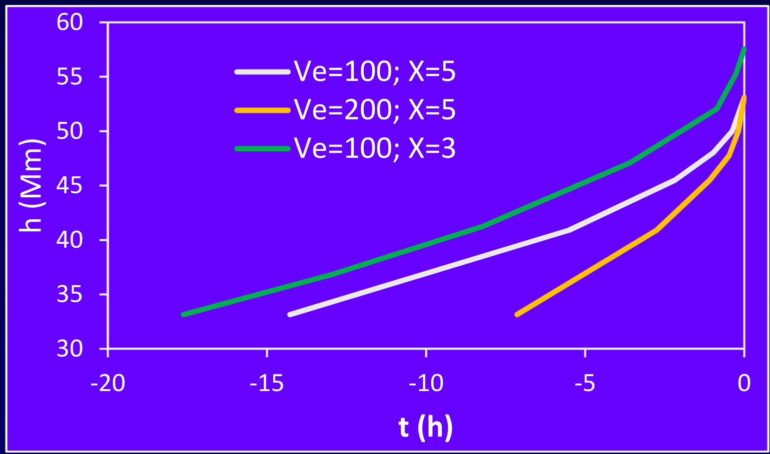
$Ve = 100$ m/s

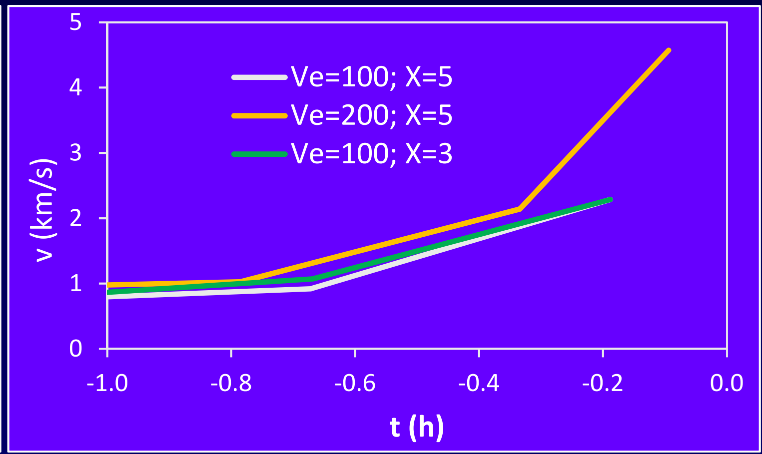


Diamagnetic effect („mirror current”; Kuperus & Raadu, 1974)

$d\psi/dt = \mu dI/dt = B_e V_e$

$\Rightarrow dC_L/dt$





$\psi^* = 10^{12}$ Mx/cm, $C_L = 11;\ 11;\ 12$ m/s^2

$d\psi/dt = 1;\ 2;\ 1\ \times 10^9$ Mx s^{-1} cm^{-1}

(d=50 Mm) $\Rightarrow$ $d\Psi/dt = 1;\ 2;\ 1\ \times 10^{16}$ Mx/s (~ few 10^{19} Mx/h)

$P_z = E_r B_x = V_z B_x B_x = V_z B_x^2$

Conclusion

- Emerging flux causes evolution through a series of equilibrium states (slow rise)
- Poloidal flux injection: rise at 0.1-1 km/s
- Background flux emergence: rise at 1-10 km/s

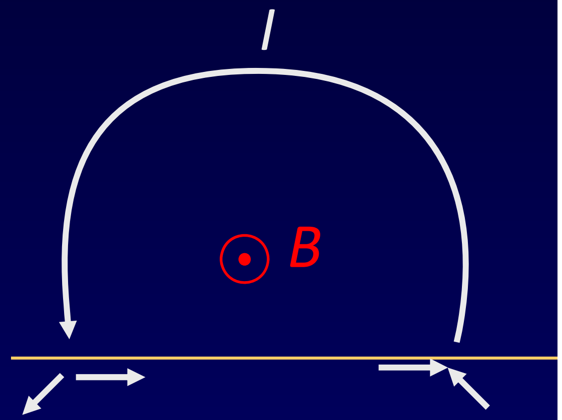
Thank you

for

your attention

Physical Background – Role of Reconnection

Forces & Energies



Free energy of non-potential magnetic field $\Rightarrow$ Electric current, I

$$E_{\mathrm{mag}} = L\, I^2 / 2$$

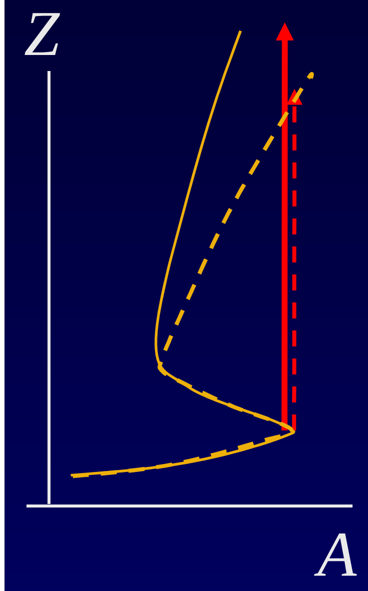
$$\left.\begin{array}{r} \Phi = L\, I \\ \Phi \approx \text{const.} \end{array}\right\} \Rightarrow \quad I \propto L^{-1}$$

$$\left.\begin{array}{l} I \propto L^{-1} \\ L \propto R \end{array}\right\} \Rightarrow \Delta I / \Delta R < 0,$$

$$\Rightarrow \Delta F_{\mathrm{L}} / \Delta R < 0$$

$$\Rightarrow \Delta E_{\mathrm{mag}} / \Delta R < 0$$

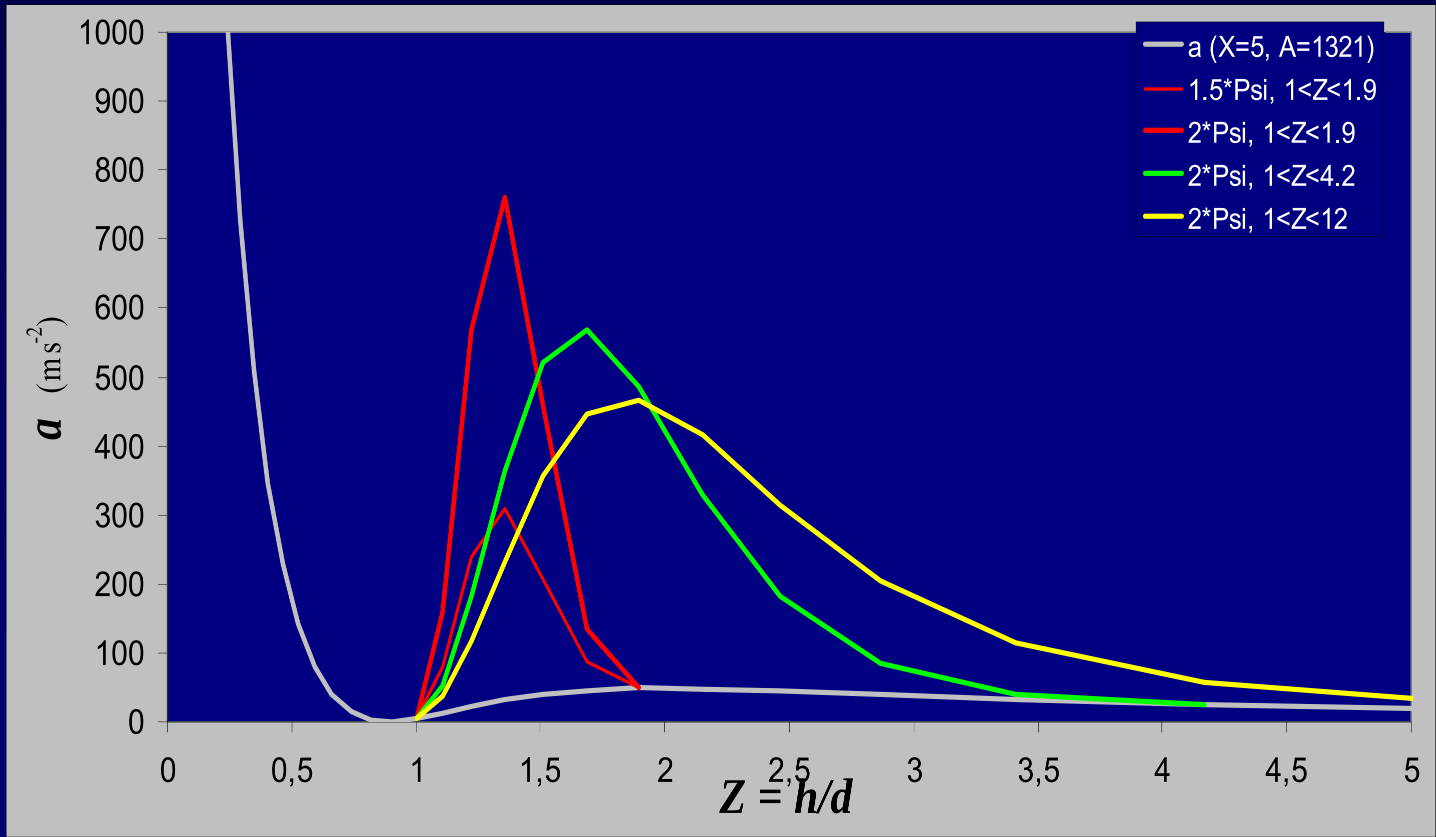
$$\Delta E_{\mathrm{mag}} = \Delta E_{\mathrm{kin}} + \Delta E_{\mathrm{pot}} + W_{\mathrm{drag}}$$

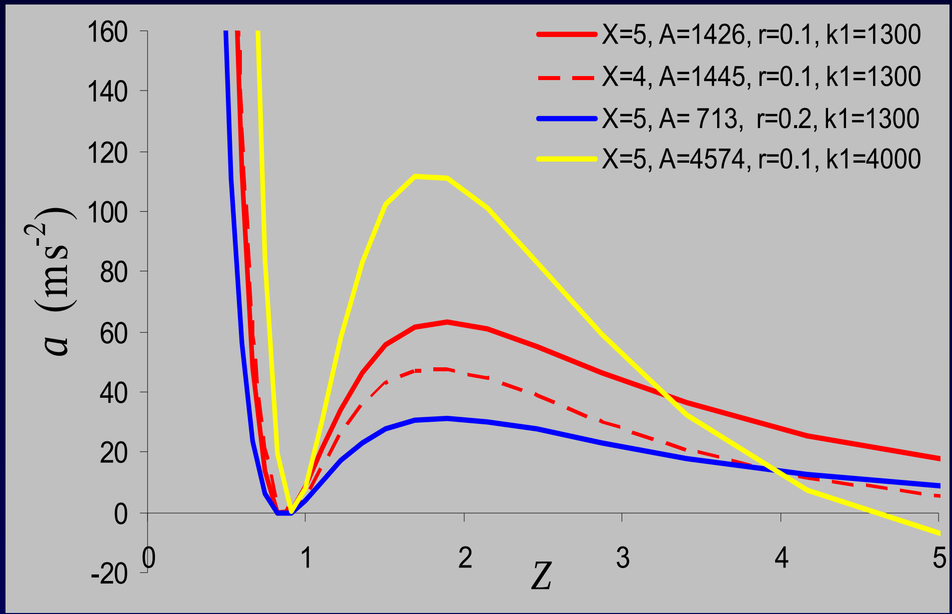


$$I = \Phi / L$$

a) $\Phi_0 = \text{const}$ $\qquad I \propto \Phi_0 / L \propto 1/R$

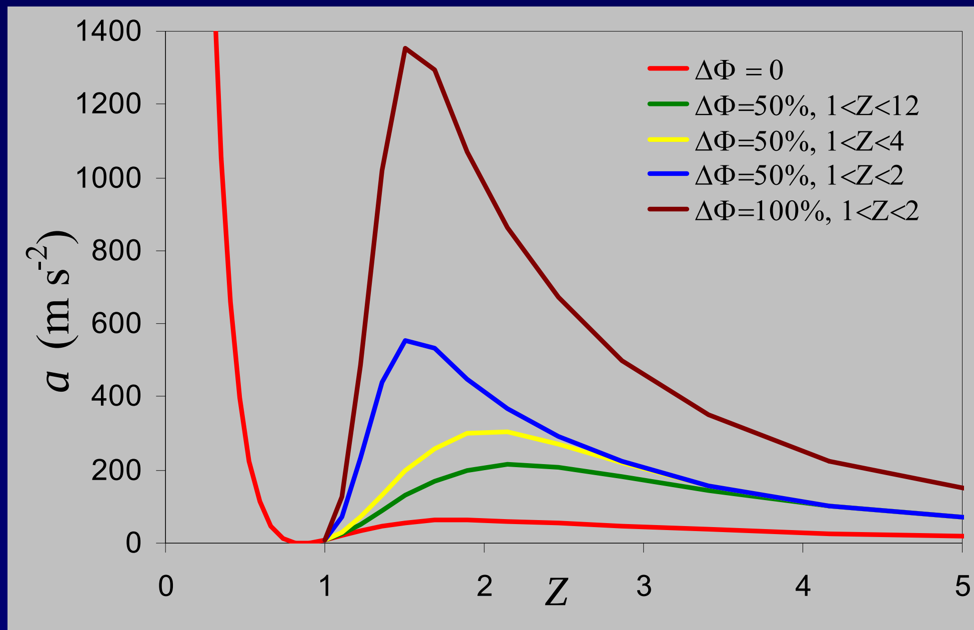
b) $\Phi = \Phi_0 + \Delta\Phi$ $\qquad I \propto (\Phi_0 + \Delta\Phi) / L$





without reconnection

with reconnection



Other Options

Aurass, etc.

Interpretation

AnnGeo
Manu feed-back