Solar Eruptions: the CME-Flare Relationship

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Basic Questions (?)

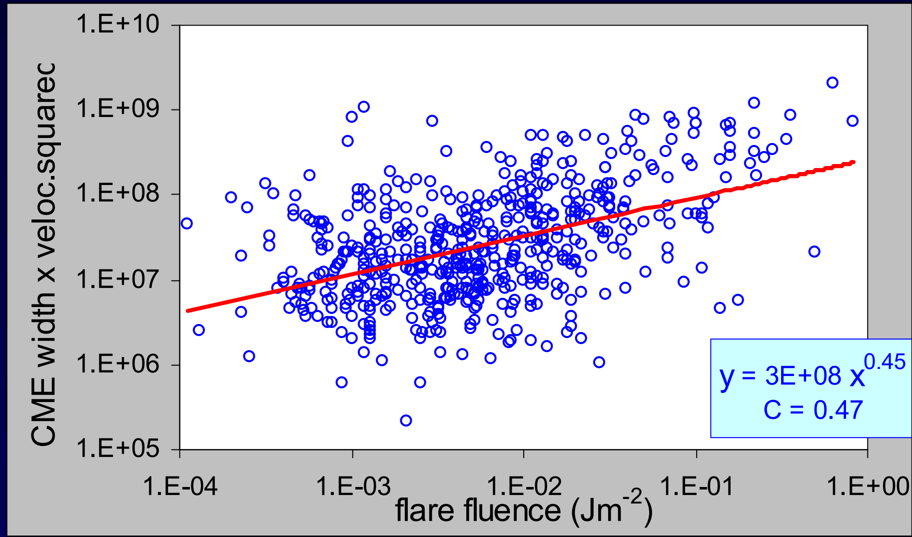
- CME (cause) -> flare (consequence)
- Flare (trigger) -> CME (consequence)
- CME/flare feed-back relationship

  - ideal instability -> resistive instability
  - resistive instability -> ideal instability
  - ideal/resistive feed-back relationship

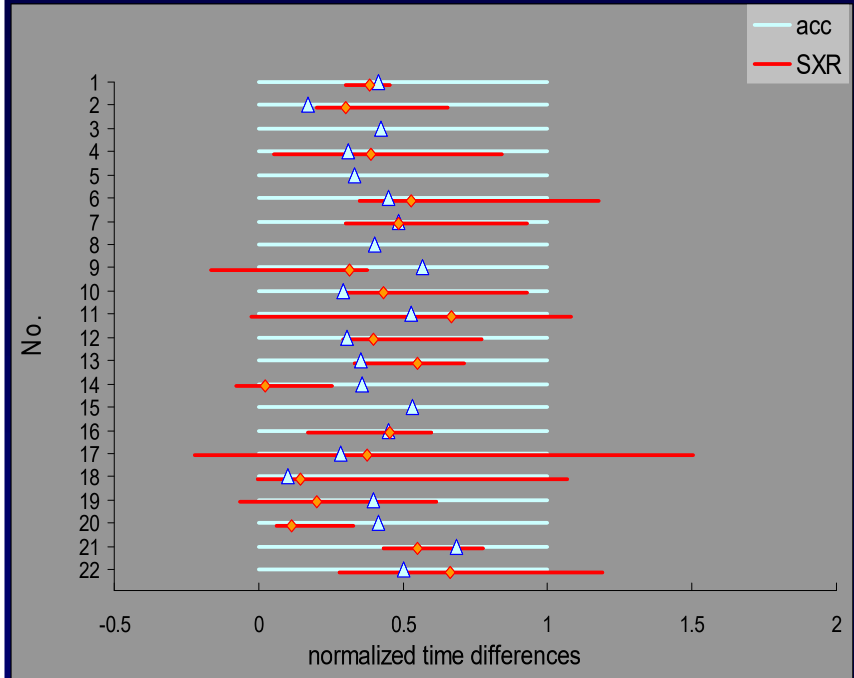
In any case, an unstable/metastable configuration is needed

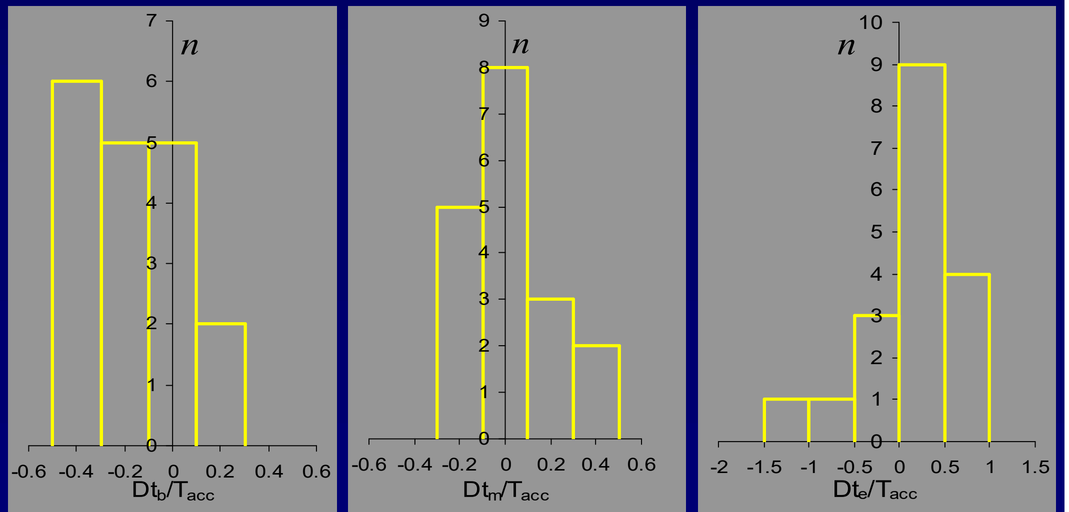
Empirical Relationships & Scalings

Statistical studies



Vrsnak et al. 2005, A&A 435, 1149



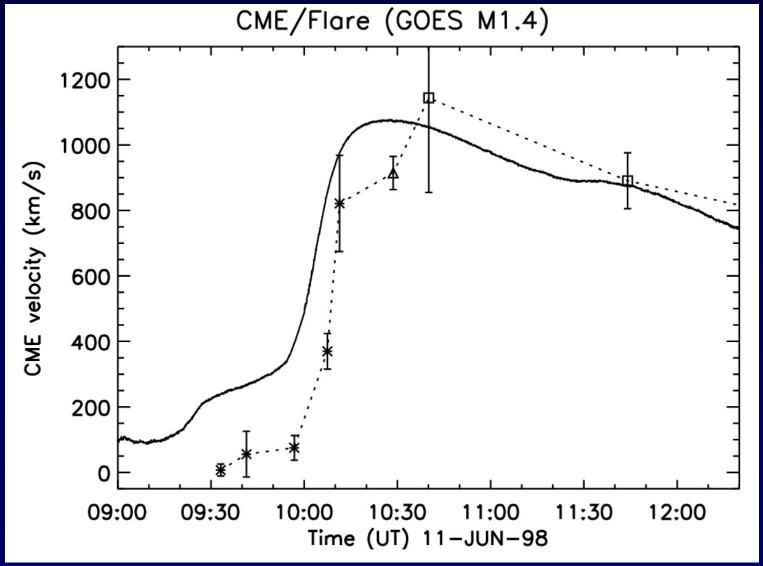


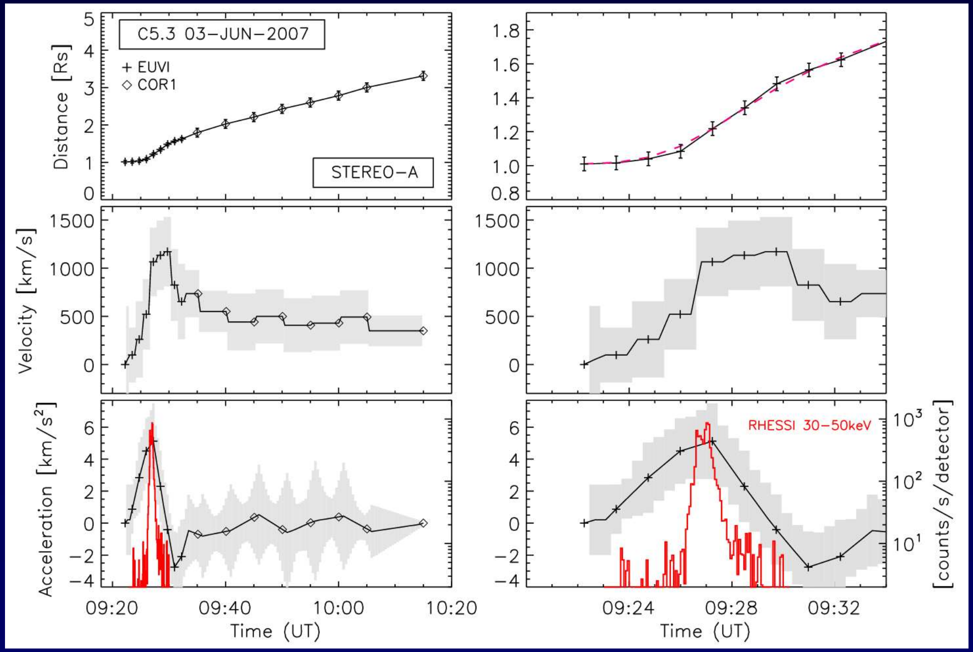
Maricic et al. 2007 SPh 241, 99

Bein et al. 2012 ApJ 755, 44

Empirical Relationships & Scalings

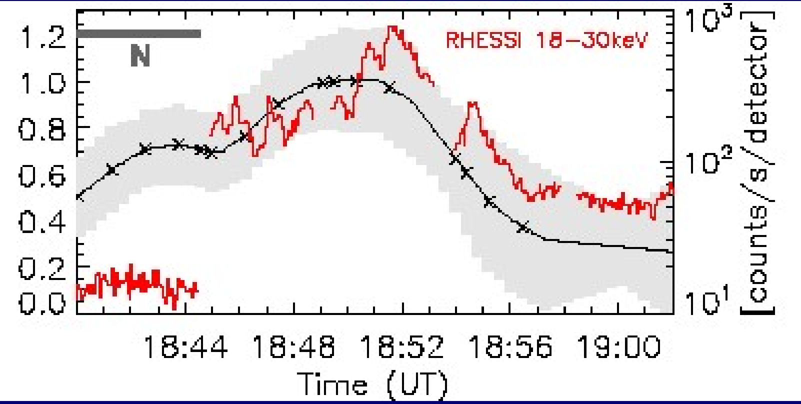
Case studies



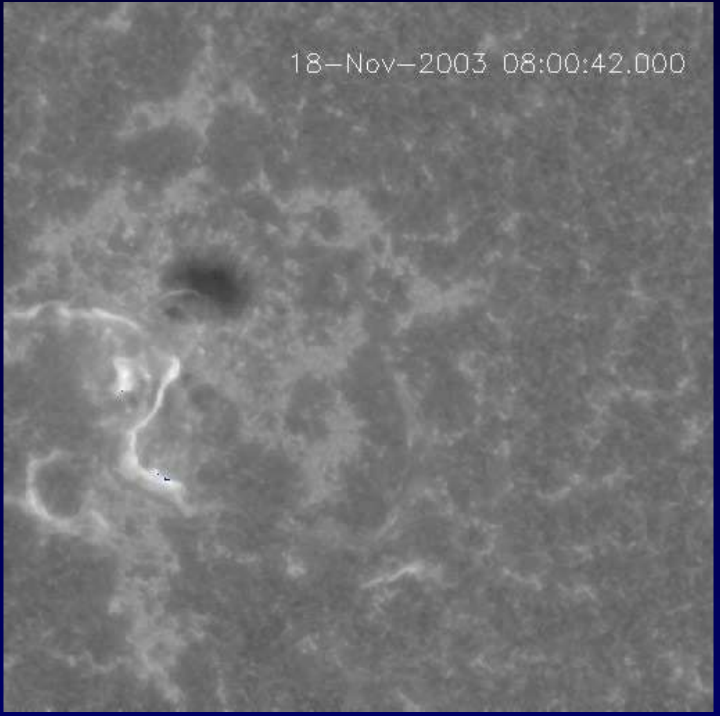


Zhang et al. 2001 ApJ 559, 452

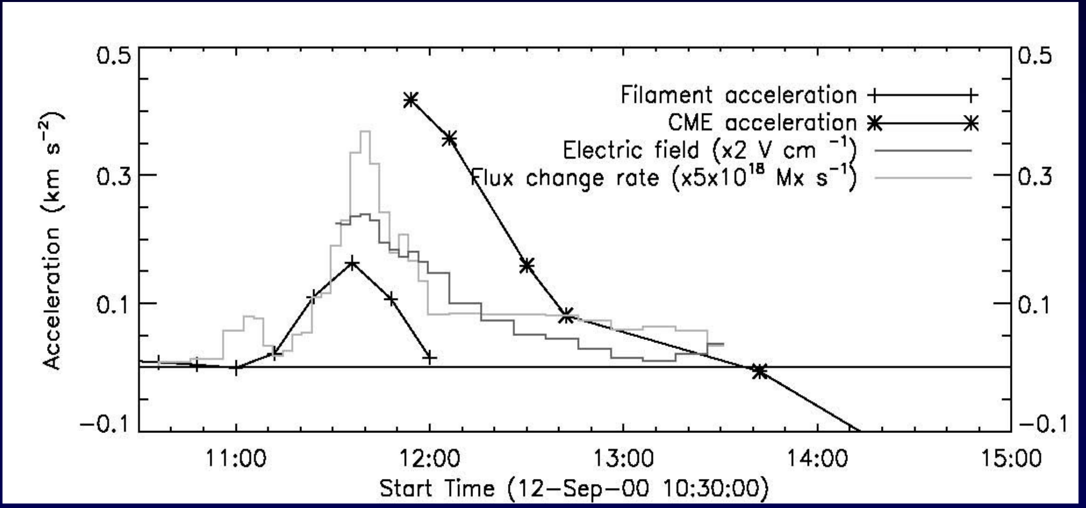
Temmer et al. 2008 ApJ 673, L95
Temmer et al. 2010 ApJ 712, 1410
Bein et al. 2012 ApJ 755, 44



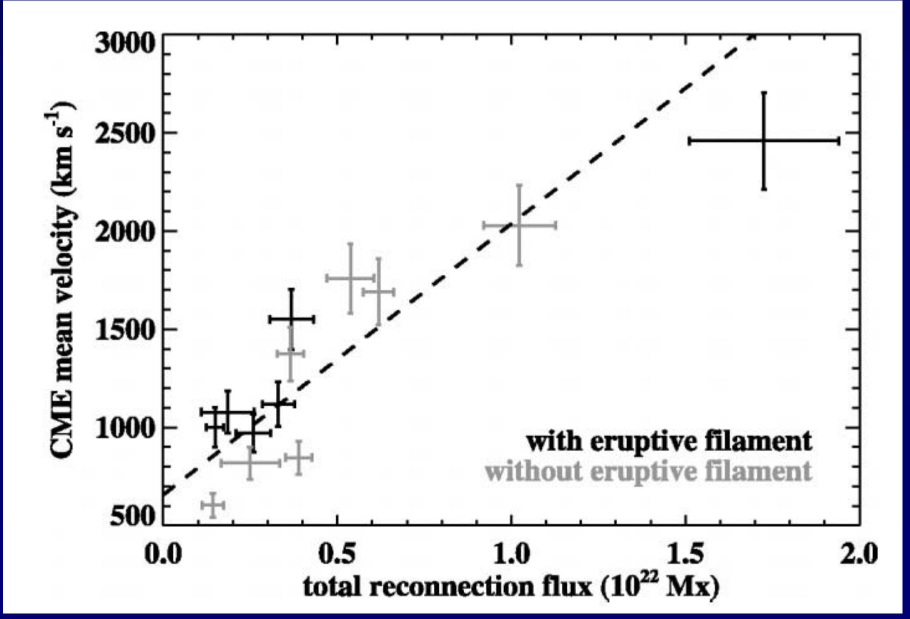
CME Acceleration and “*v*x*B*” Proxy



Miklenic et al. 2007 A&A 461, 697
[idea proposed by:
Poletto & Kopp, 1986]

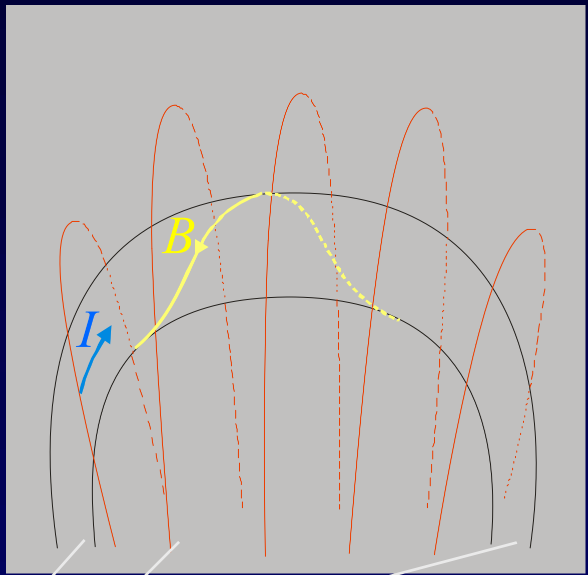


Qiu et al. 2004, ApJ 604, 900

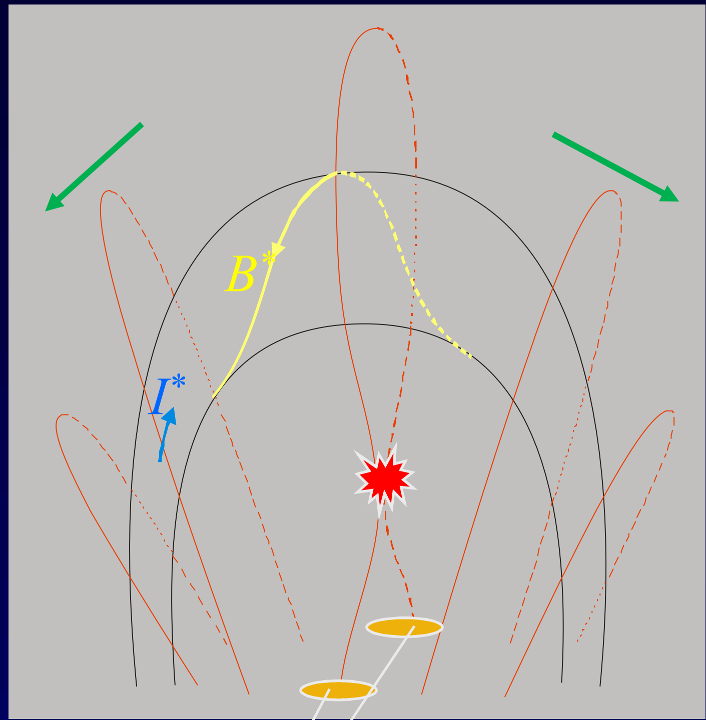


Qiu & Yurchyshin
2005, ApJ 634, L121

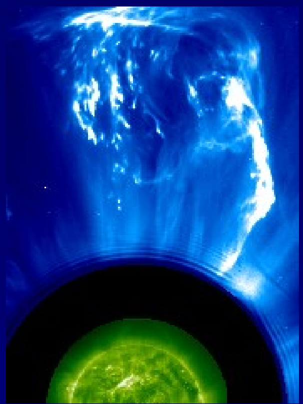
Physical Background



"line-tying"

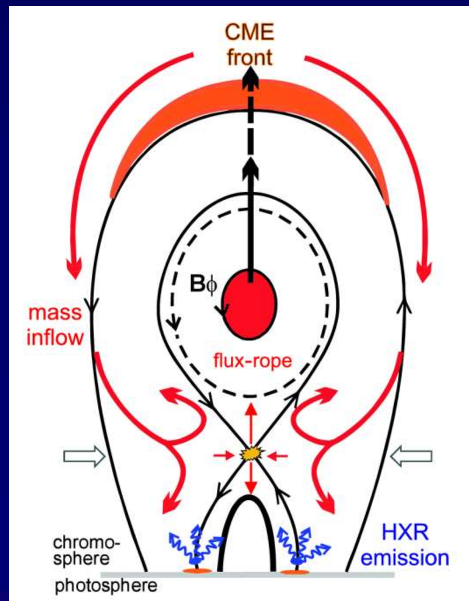


HXR, Hα



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
....

Temmer et al. 2010
ApJ 712, 1410

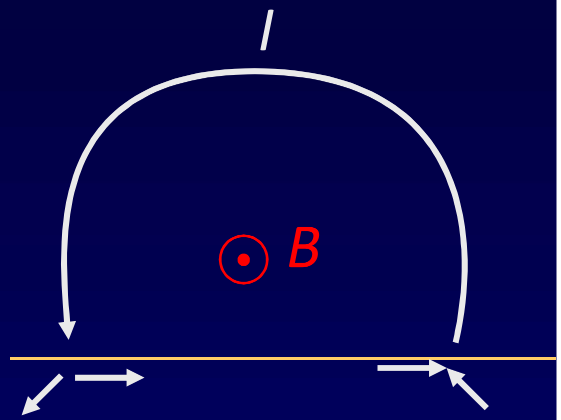


Physical Background – Role of Reconnection

Forces & Energies

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

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



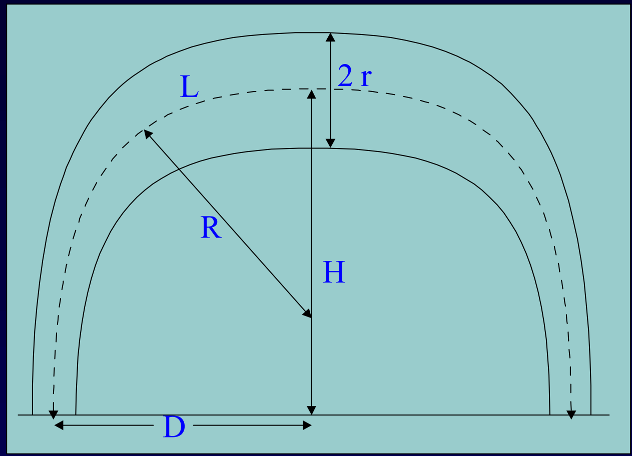
$$\left.\begin{array}{l}\Phi = L\,I \\ \Phi \approx \text{const.}\end{array}\right\} \Rightarrow I \propto L^{-1}$$

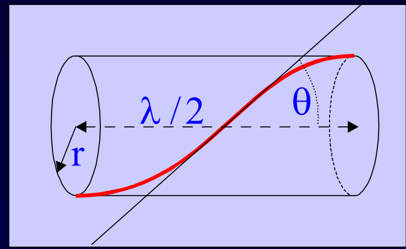
$$\left.\begin{array}{l} I \propto L^{-1} \\ L \propto R\end{array}\right\} \Rightarrow \Delta I/\Delta R < 0,$$

$$\Rightarrow \Delta F_L/\Delta R < 0$$

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

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





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

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

$$n = l/\lambda, \quad n = const.$$

$$a = a_\mathrm{L} - g - a_\mathrm{d}$$

$$a_\mathrm{L} = A\,(l/h + l/R - 2l/RX^2) \pm kI/lr$$

$$A = \frac{\mu I^2}{4\pi M} = \frac{B_\phi^2}{\mu \rho l} = \frac{X^2 B_\parallel^2}{\mu \rho l} \approx \frac{v_A^2}{l} = \frac{l}{\tau_A^2} = l\omega^2$$

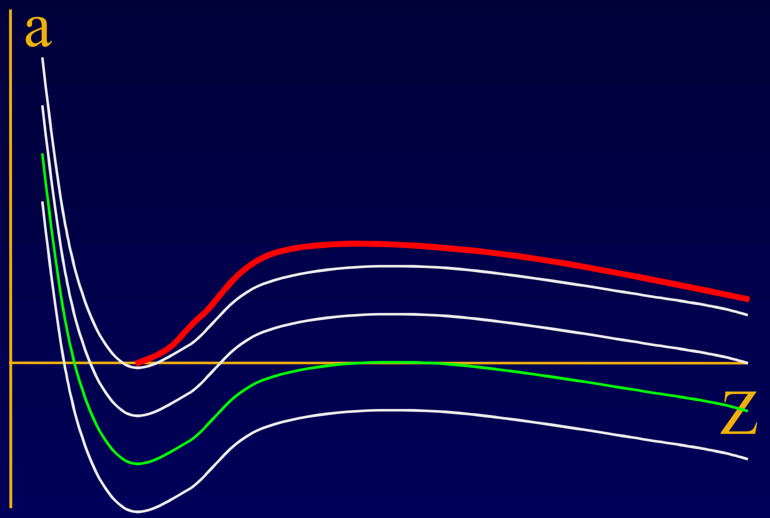
in the absence of reconnection:

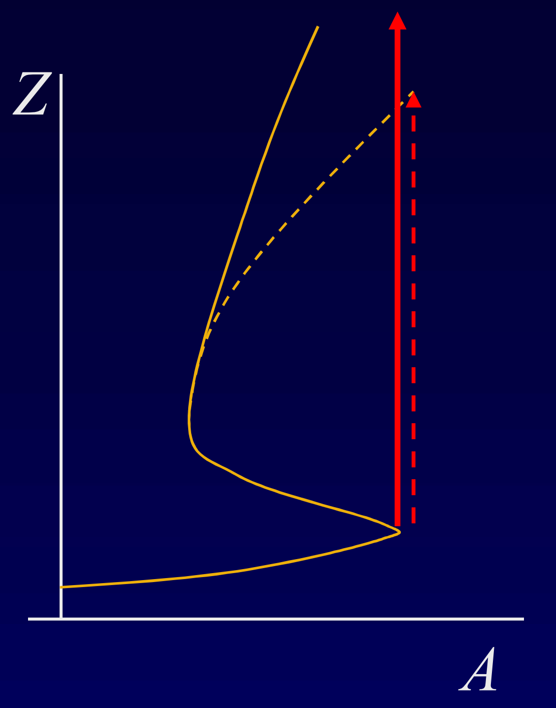
$$\Phi_\mathrm{e} = \mathrm{const.} \propto I\,l\,[\ln(8R/r) - 2]$$

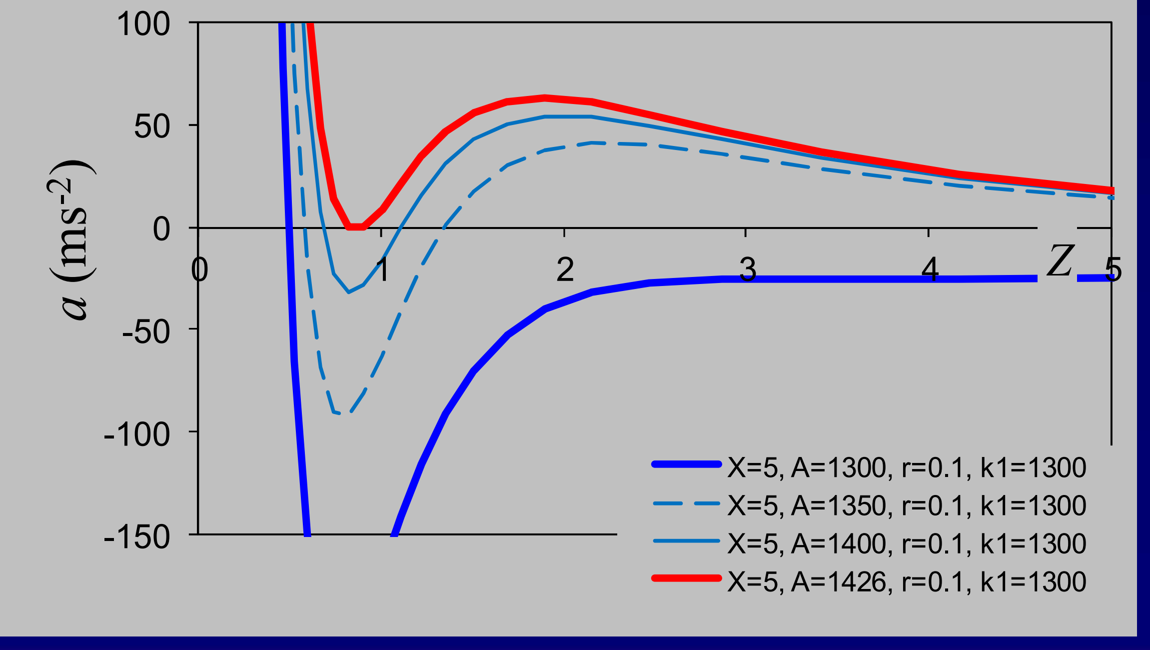
$$\Phi_\mathrm{i} = \mathrm{const.} \propto I\,l$$

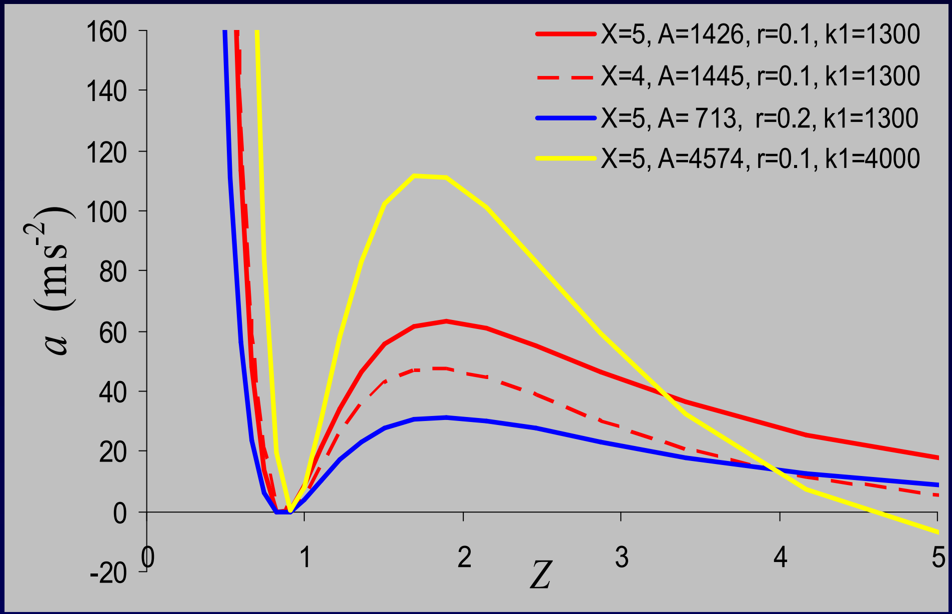
$$\Rightarrow \quad I \propto l^{-1}, \quad r \propto R, \quad X \propto r/l$$

Loss of equilibrium



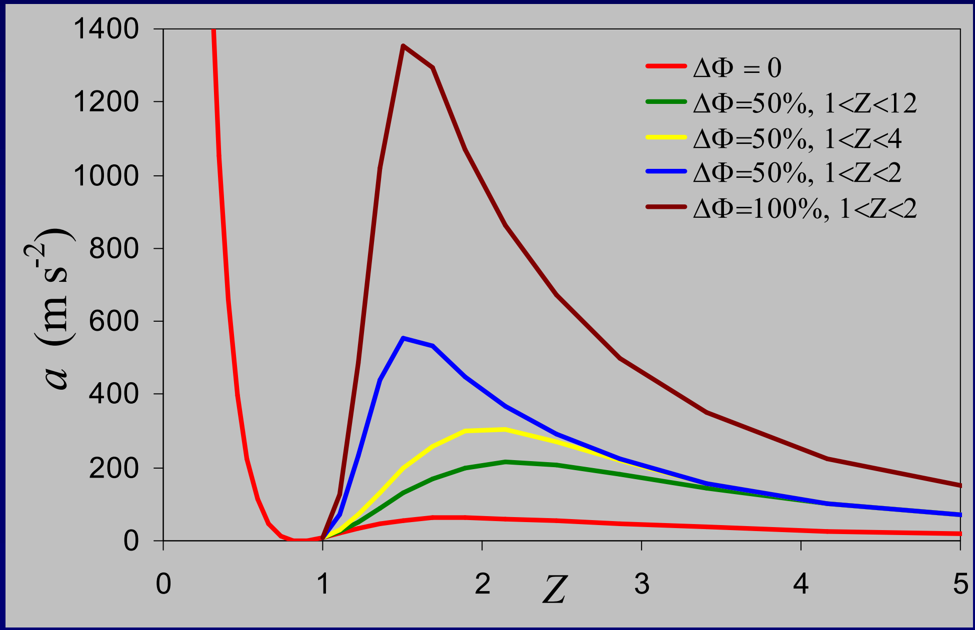


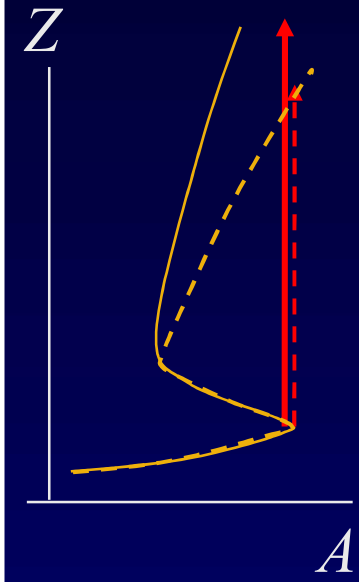




without reconnection

with reconnection

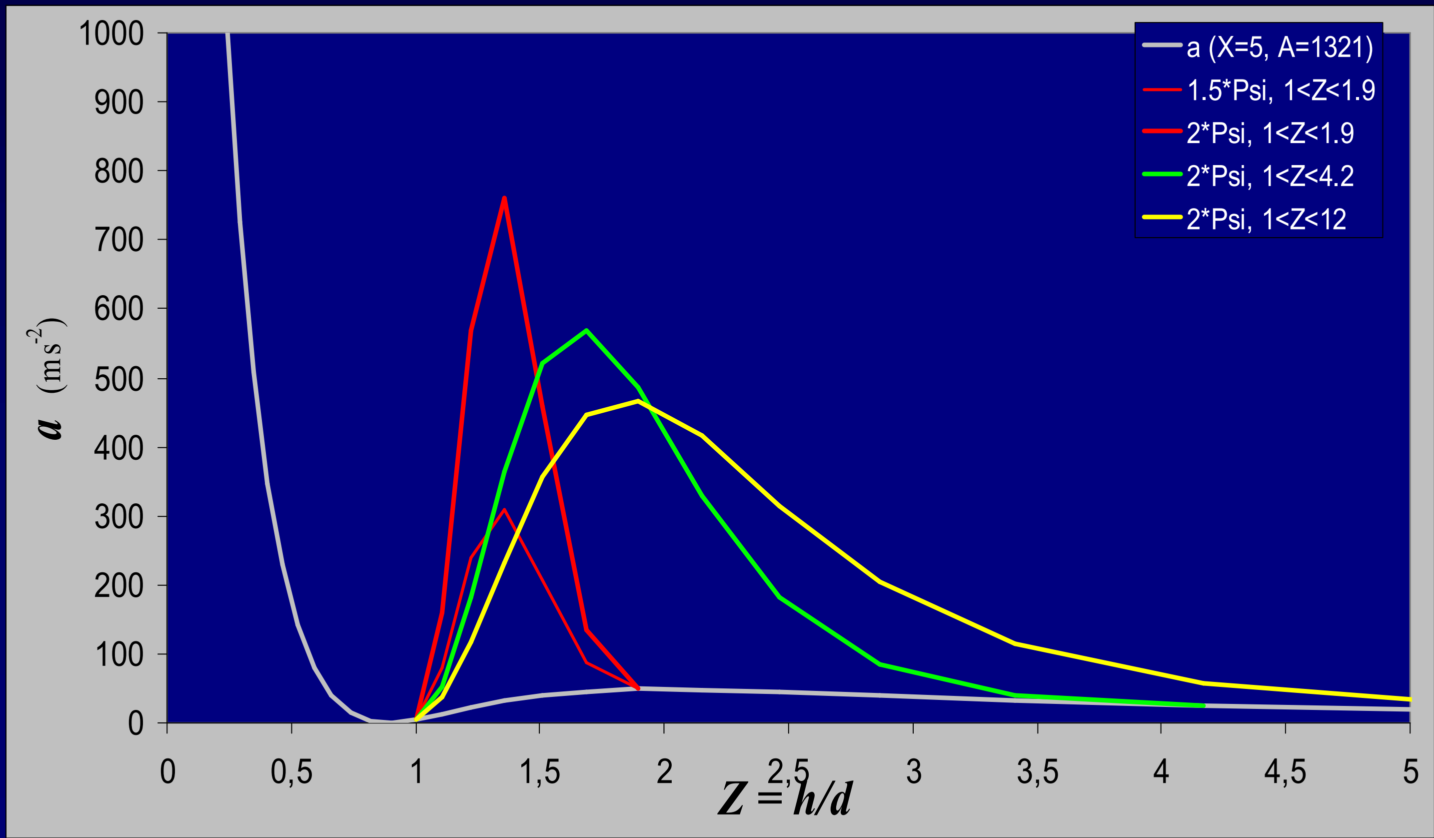




$$I = \Phi/L$$

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

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



Scenarios

“Standard“ = eruption->flare (dynamical / two-ribbon /CSHKP…):

- evolution through a series of quasiequilibrium states (slow rise)
- onset of ideal instability at critical height (kink, torus,…)
- current sheet formation below erupting structure
- onset of reconnection (d/h ~ 1/10)
- rapid acceleration stage

“Alternative“ = flare->eruption:

- evolution through a series of quasiequilibrium states
- onset of resistive instability = flare
- restructuring by reconnection -> unstable configuration
- eruption -> “standard scenario”

Thank you

for

your attention