Initiation of solar eruptions by the kink instability

Tibor Török
MSSL / UCL London

Bernhard Kliem
AIP Potsdam

Slava Titov
SAIC San Diego

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kink instability (KI) in solar eruptions

- **original suggestion:** Sakurai 1976 (prominence eruptions)

- **recent years:** KI explanation only for **confined** events (e.g. work of Baty, Gerrard & Hood, ...)

- **very recently:** KI also triggers **ejective** events (CMEs) observations (Romano et al. 2003, Rust & La Bonte 2005) simulations (Fan 2005, Török & Kliem 2005)
numerical simulation

(Titov & Démoulin, 1999)

- ideal 3D MHD simulation ($\beta = 0$, gravity neglected)
- kink instability occurs for sufficient twist $\Phi_{\text{loop}}$
- essential features of solar eruptions reproduced
- after exp. rise: rope is slowed down $\rightarrow$ confined eruption

$\Phi_{\text{loop}} \approx -5\pi$
confined eruption I

TRACE, 195 Å EUV

$\Phi_{\text{loop}} \approx 5\pi$
confined eruption II

morphology and rise characteristic reproduced

→ destabilization of filament due to KI

(data from Ji et al. 2003)
ejective eruption

- ejection of T&D flux rope prevented by strong overlying field
- modified model: overlying field drops faster → full eruption
2001 May 15

eruptive non-AR prominence & fast CME

data from Maričić et al. 2004
2004 November 10

filament eruption, X 2.5 flare, and very fast CME

simulation could also be scaled to this AR filament eruption
(see poster P.45 by Williams et al.)
release of magnetic energy

confined
≈ 5 percent released

\[ \left| \Phi_{\text{loop}} \right| \approx 5\pi \]

2002 May 27 (confined M2 flare):
\[ h_0 \approx 23 \text{ Mm} \]
with \( B_0 = 200 \text{ G} \):
\[ \approx 10^{31} \text{ ergs} \]

2001 May 15 (eruptive C4 flare):
\[ h_0 \approx 115 \text{ Mm} \]
with \( B_0 = (10 - 40) \text{ G} \):
\[ \approx (10^{31} - 10^{32}) \text{ ergs} \]

ejective
≈ 25 percent released
flare / CME - relationship

Zhang 2001

observation:
close correlation between CME velocity and Soft X-ray flux

simulation:
- reconnection (flare) and instability (CME) closely coupled
- apparently the instability drives eruption
summary

- Titov & Démoulin flux rope kink-unstable for $|\Phi| > \Phi_c$
- essential features of solar eruptions reproduced
- full eruption achieved with modified model
  $\rightarrow$ profile of magnetic field strength important

conclusion

- the reproduced helical deformation and rise profiles are characteristic of many eruptions $\rightarrow$

helical kink instability is the initiation mechanism and initial driver of many solar eruptions, both confined and ejective
however ...

... the kink instability cannot be the whole story

see talk by B. Kliem tomorrow!