Initiation of solar eruptions by the kink instability

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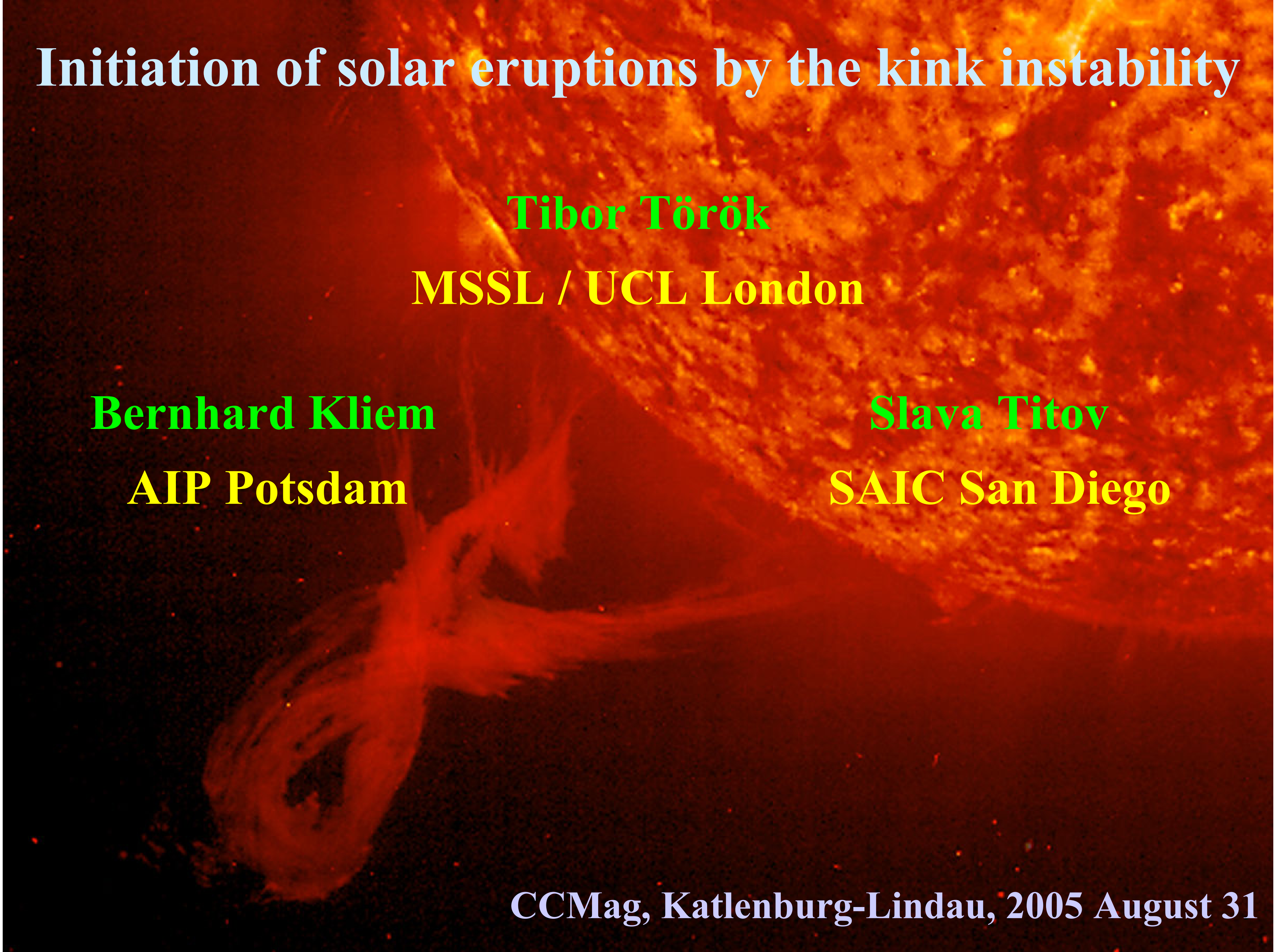
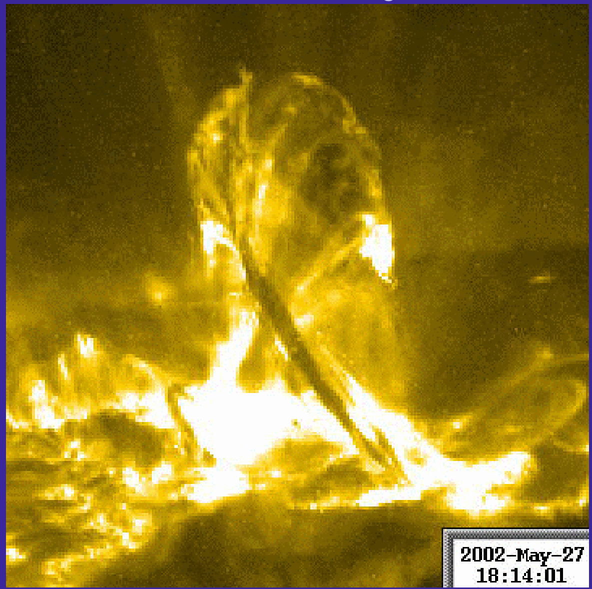
CCMag, Katlenburg-Lindau, 2005 August 31

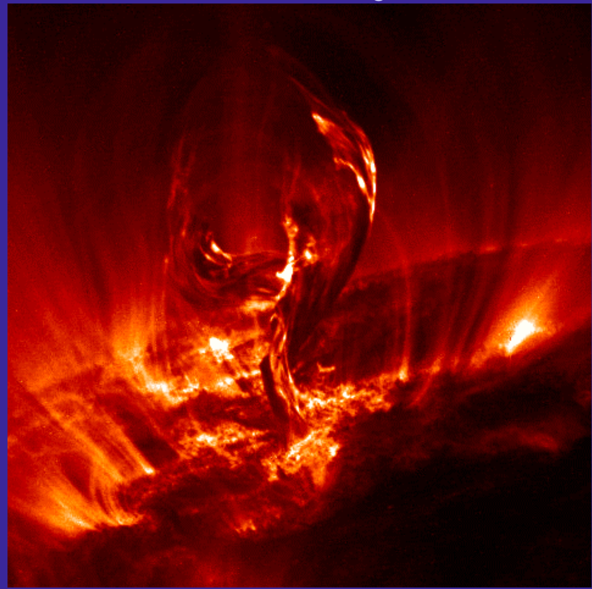


kink instability (KI) in solar eruptions

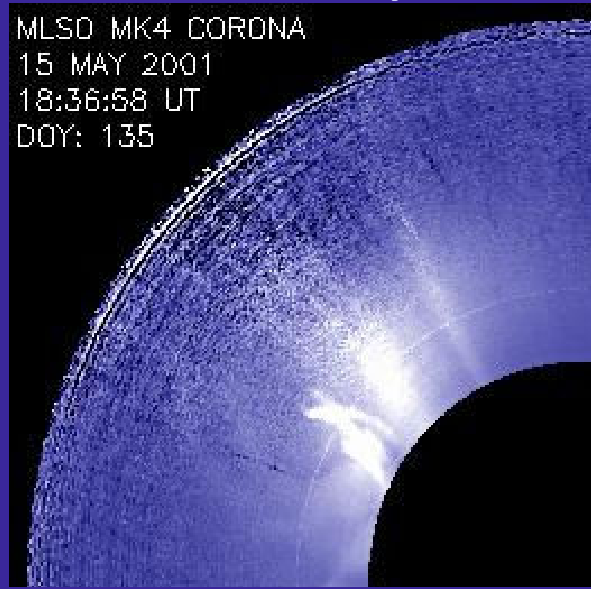
2002 May 27



2000 July 19

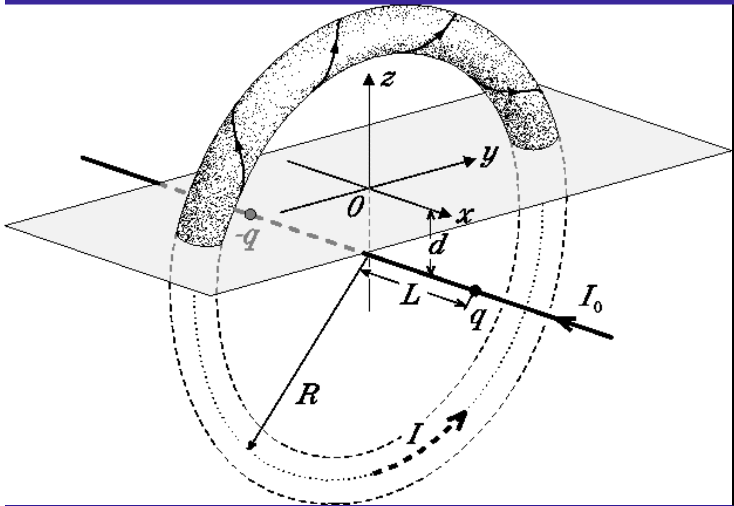


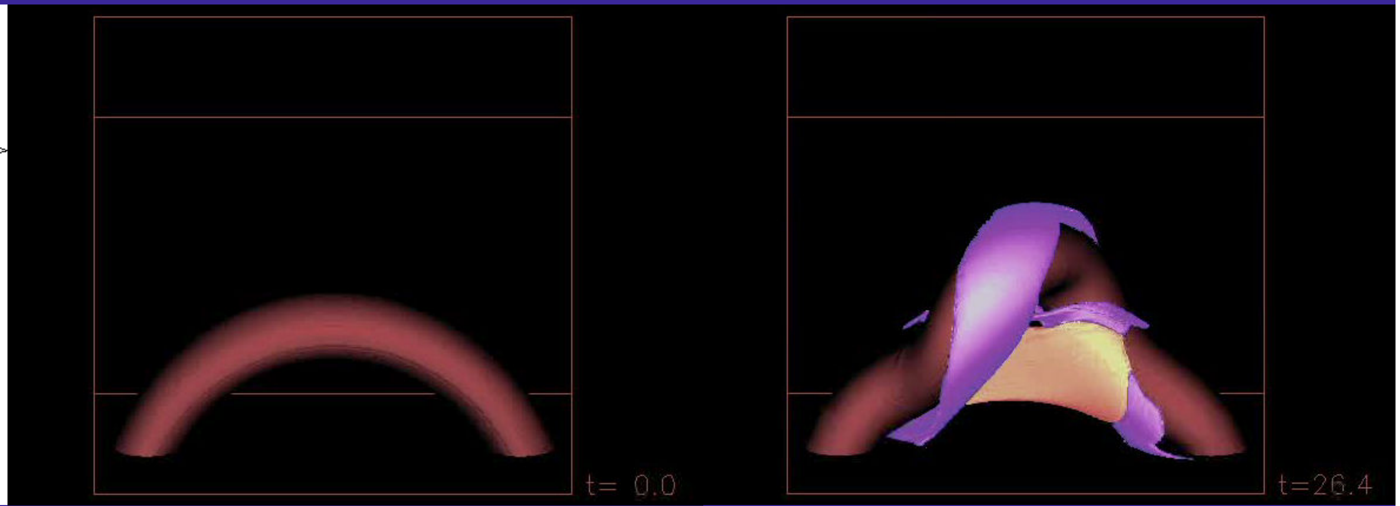
2001 May 15



- 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



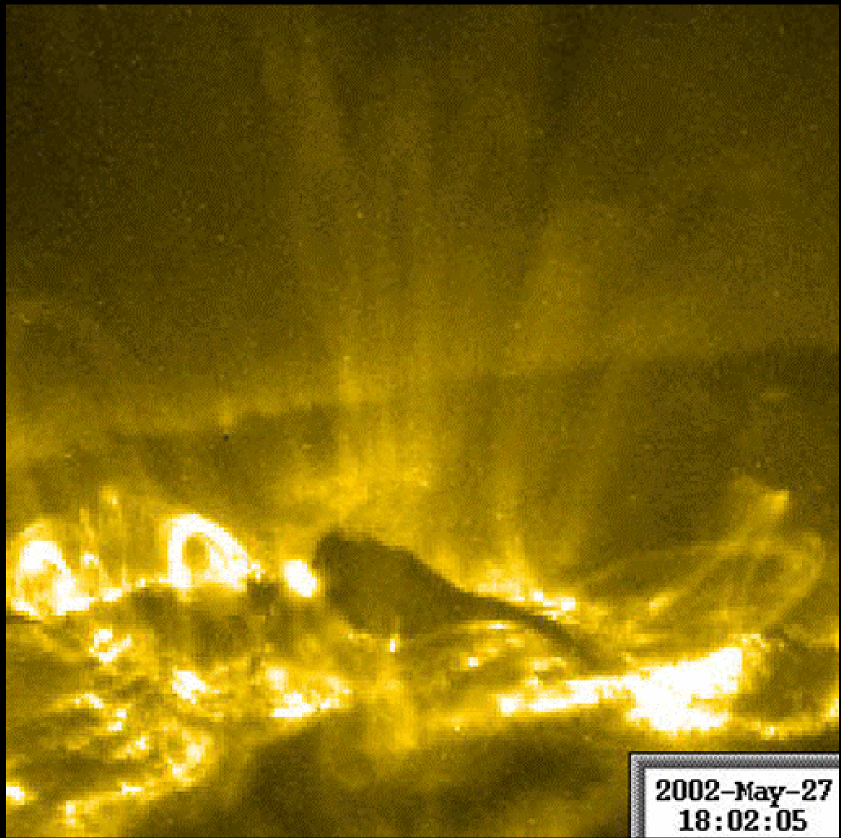


(Titov & Démoulin, 1999)

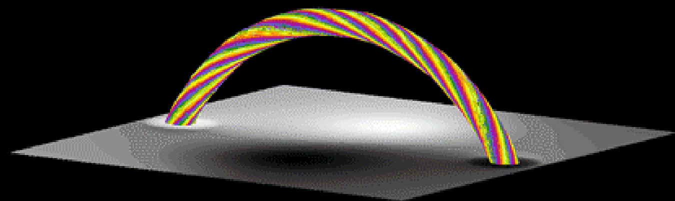
$\Phi_{\text{loop}} \approx -5\pi$

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

confined eruption I

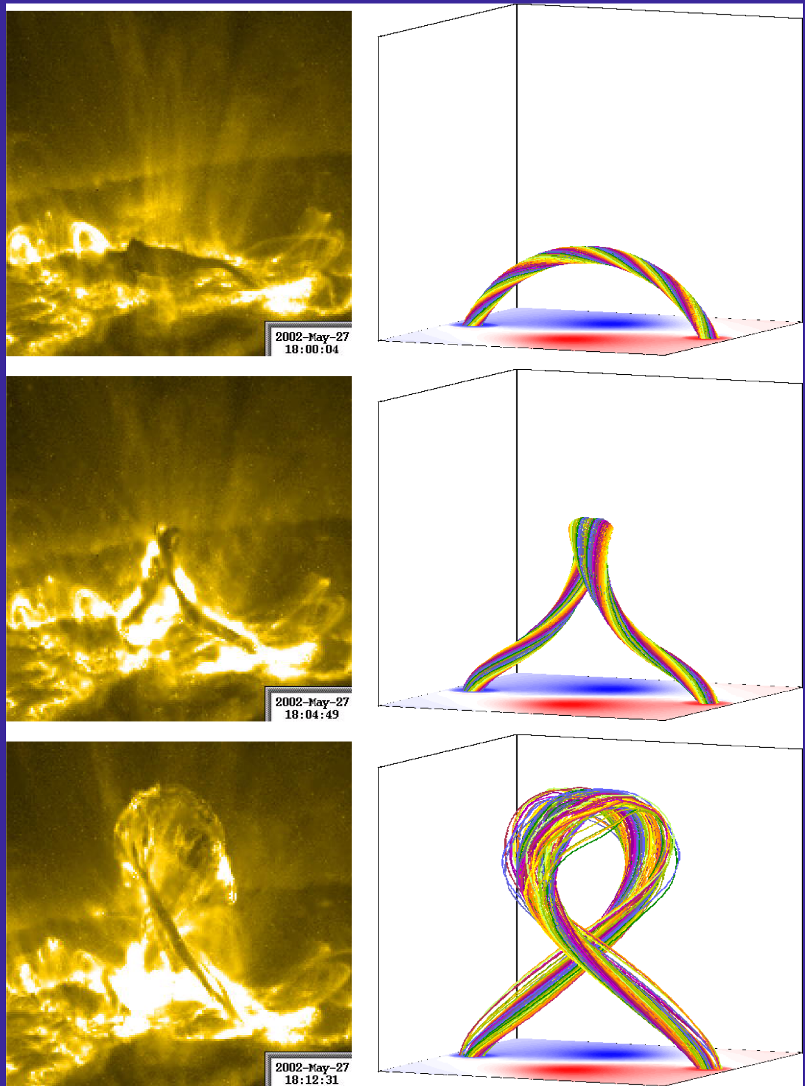


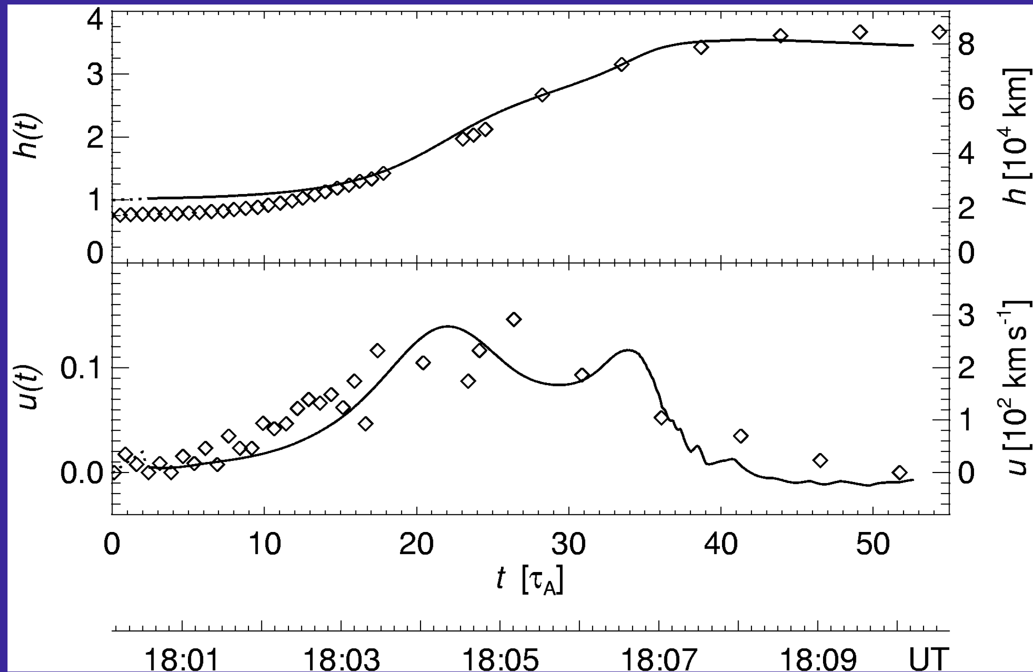
TRACE, 195 Å EUV



$\Phi_{\text{loop}} \approx 5\pi$

confined eruption II



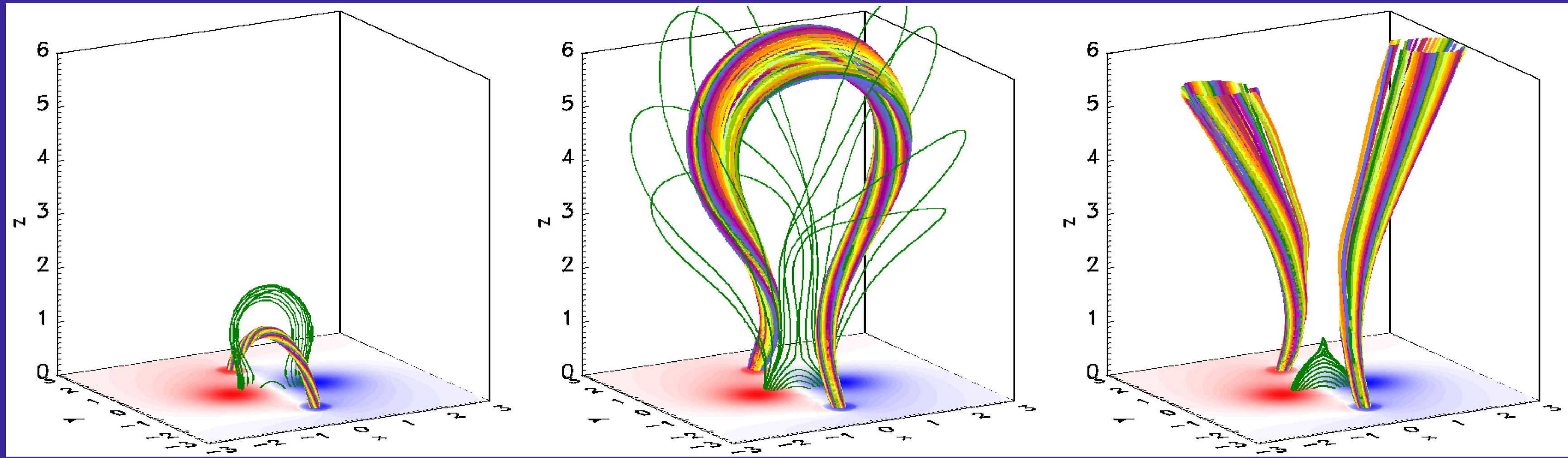


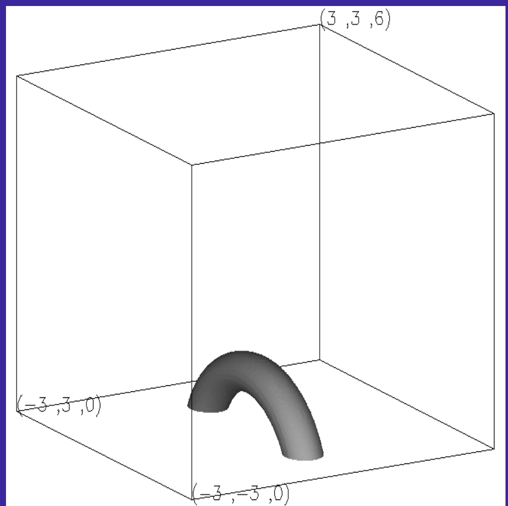
(data from Ji et al. 2003)

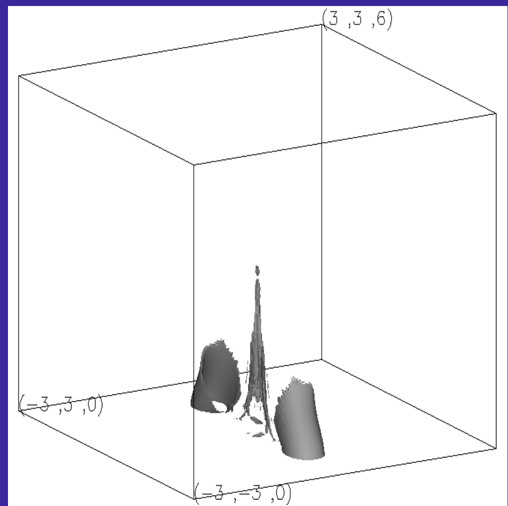
morphology and rise characteristic reproduced

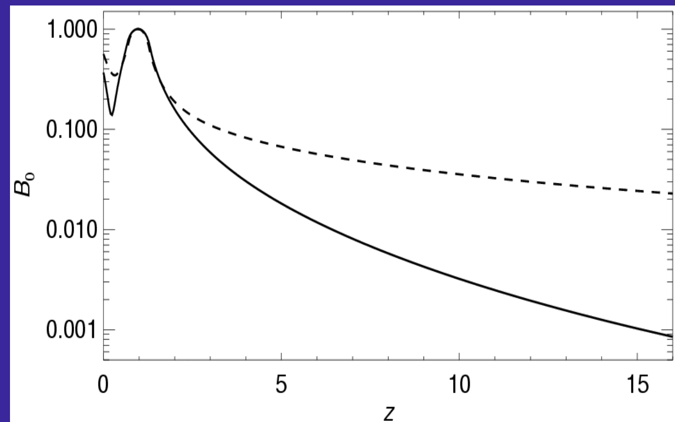
→ destabilization of filament due to KI

ejective eruption





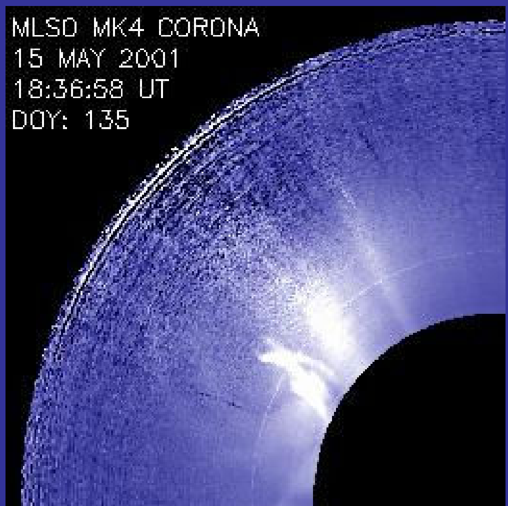


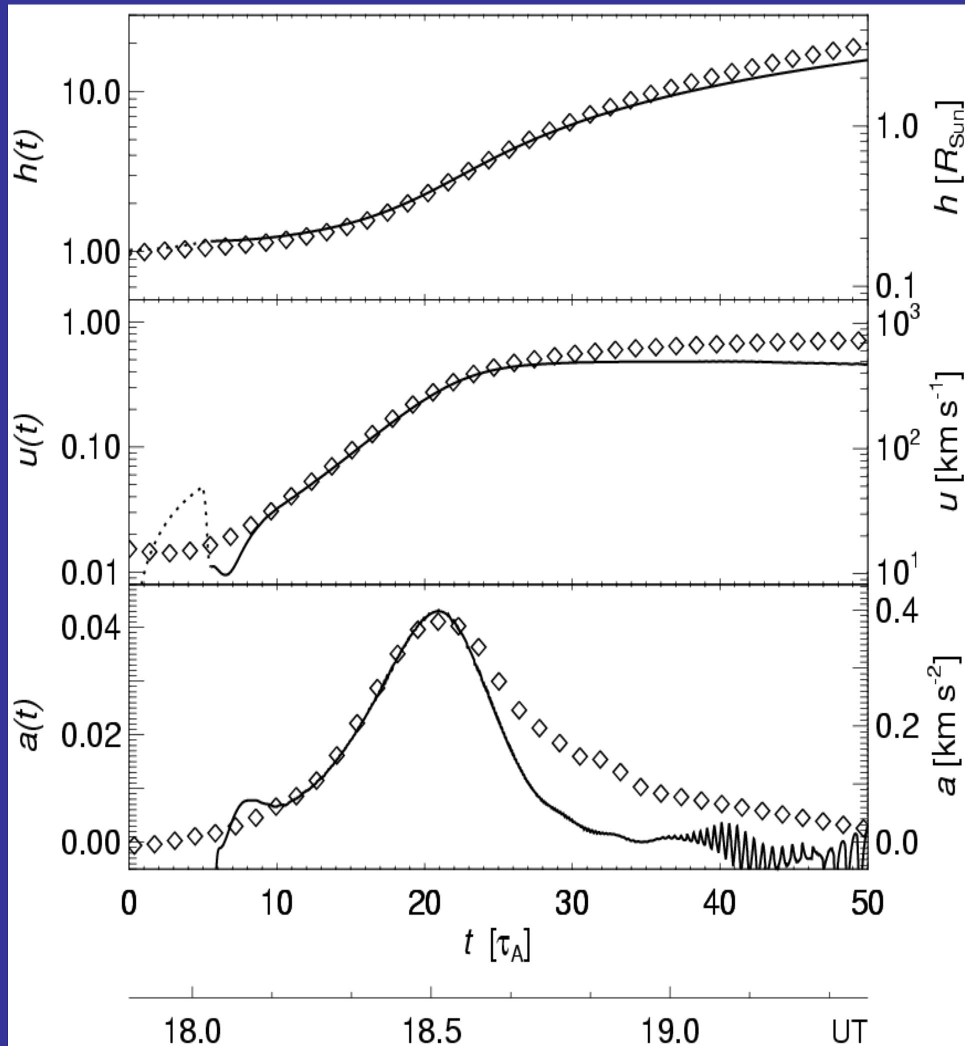


- ejection of T&D flux rope prevented by strong overlying field
- modified model: overlying field drops faster → full eruption

2001 May 15

eruptive non-AR prominence & fast CME

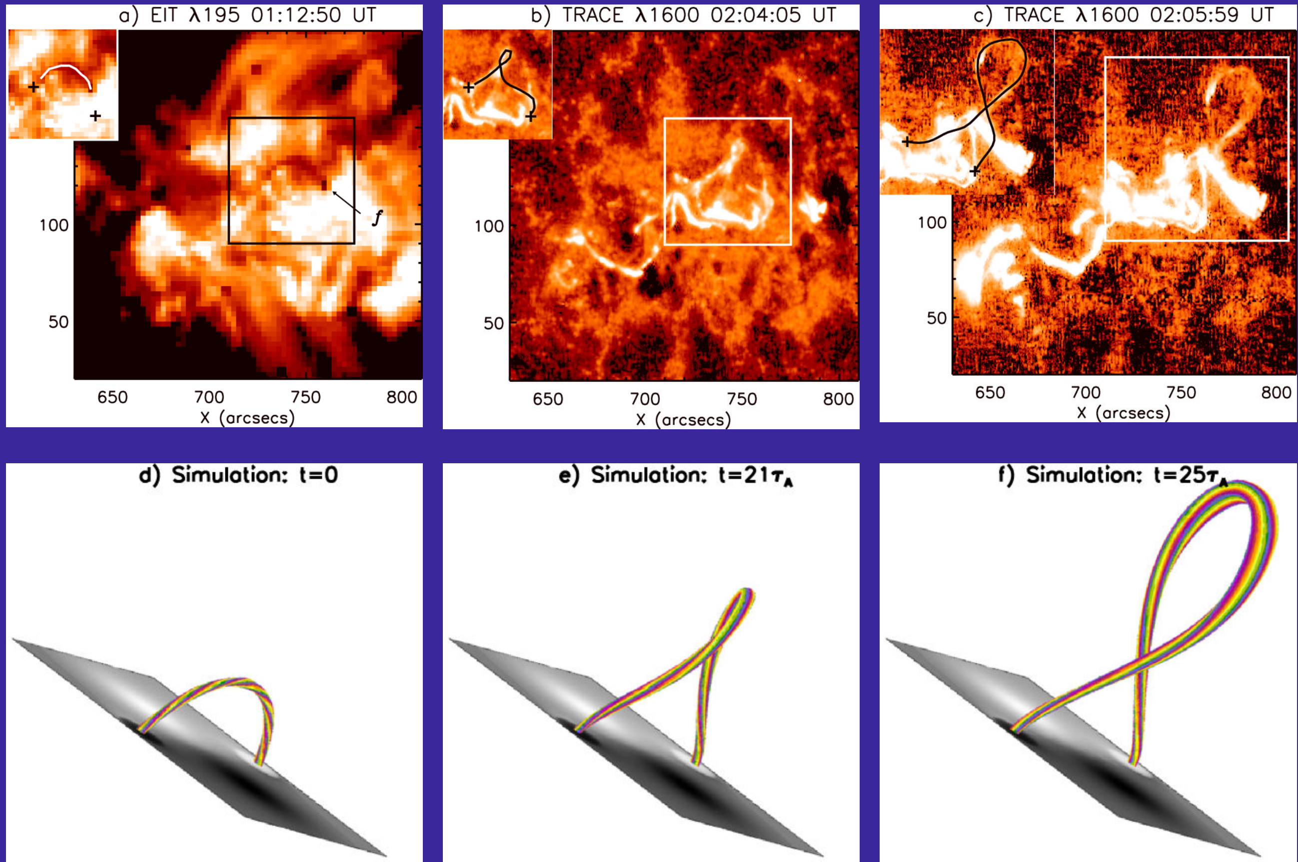


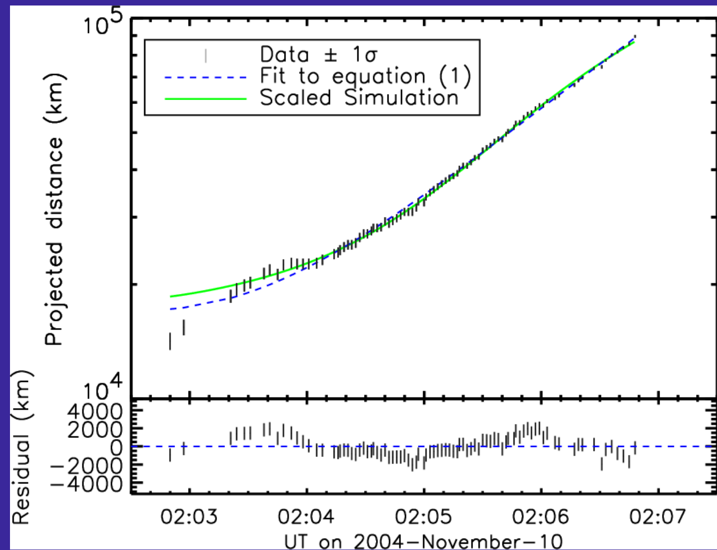


data from Maričić et al. 2004

2004 November 10

filament eruption, X 2.5 flare, and very fast CME

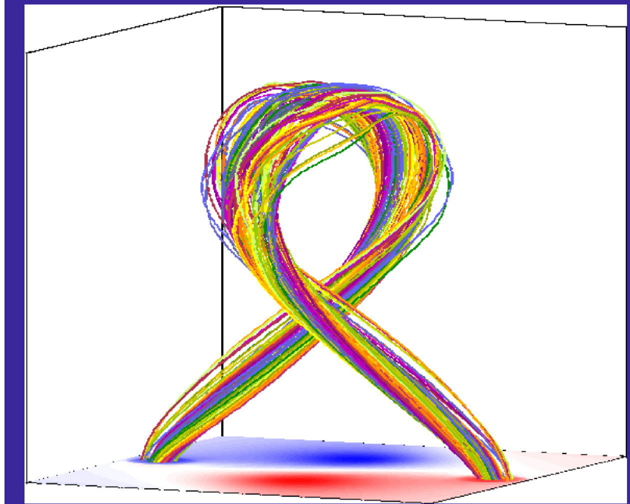


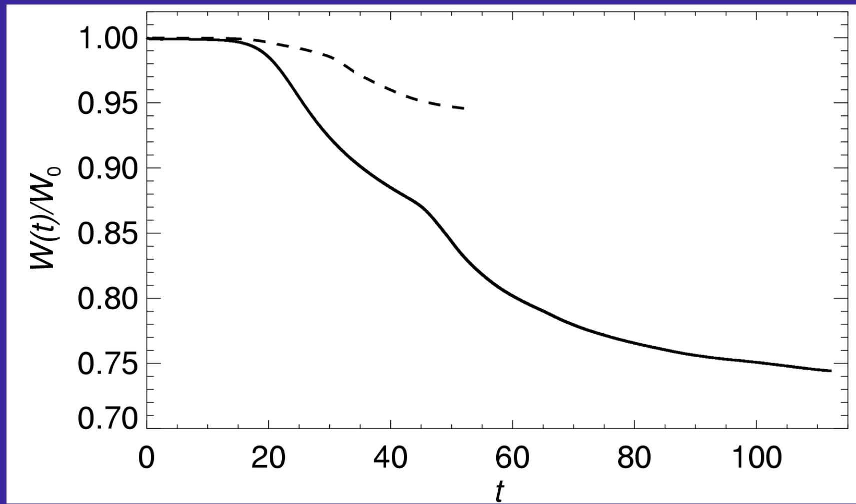


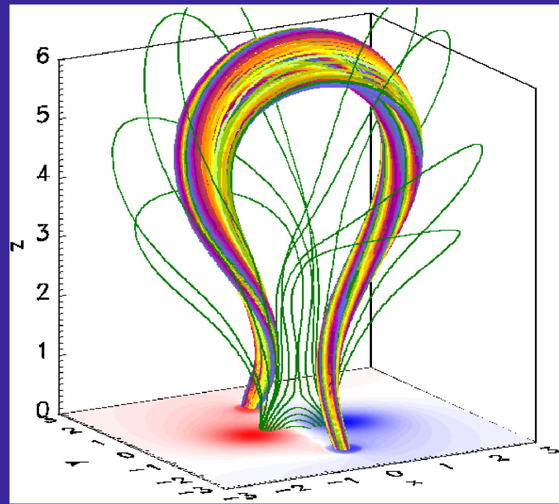
simulation could also be scaled to this AR filament eruption

(see poster P.45 by Williams et al.)

release of magnetic energy







confined

$\approx$ 5 percent released

$|\Phi_{loop}| \approx 5\pi$

ejective

$\approx$ 25 percent released

2002 May 27 (confined M2 flare):

$h_0 \approx 23$ Mm

with $B_0 = 200$ G :

$\approx 10^{31}$ $ergs$

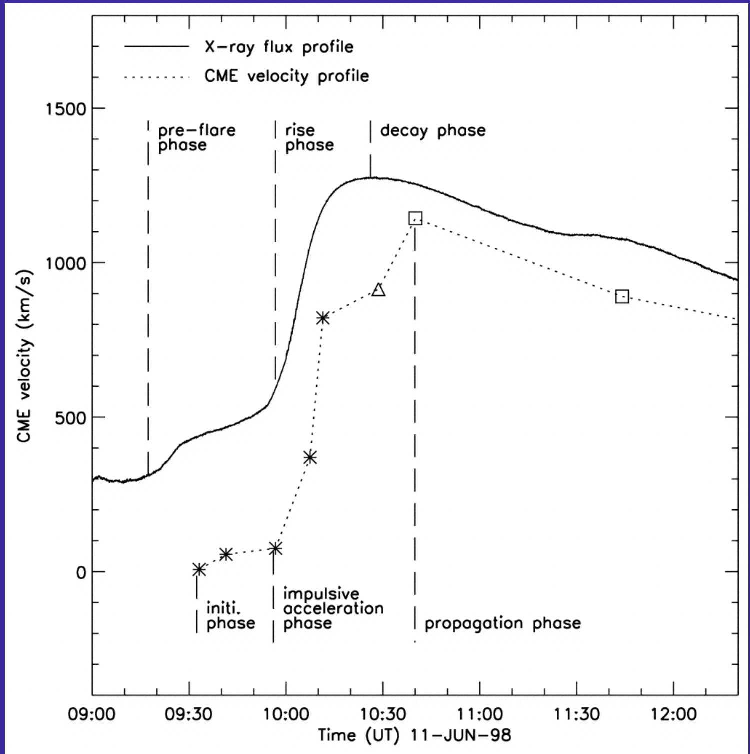
2001 May 15 (eruptive C4 flare):

$h_0 \approx 115$ Mm

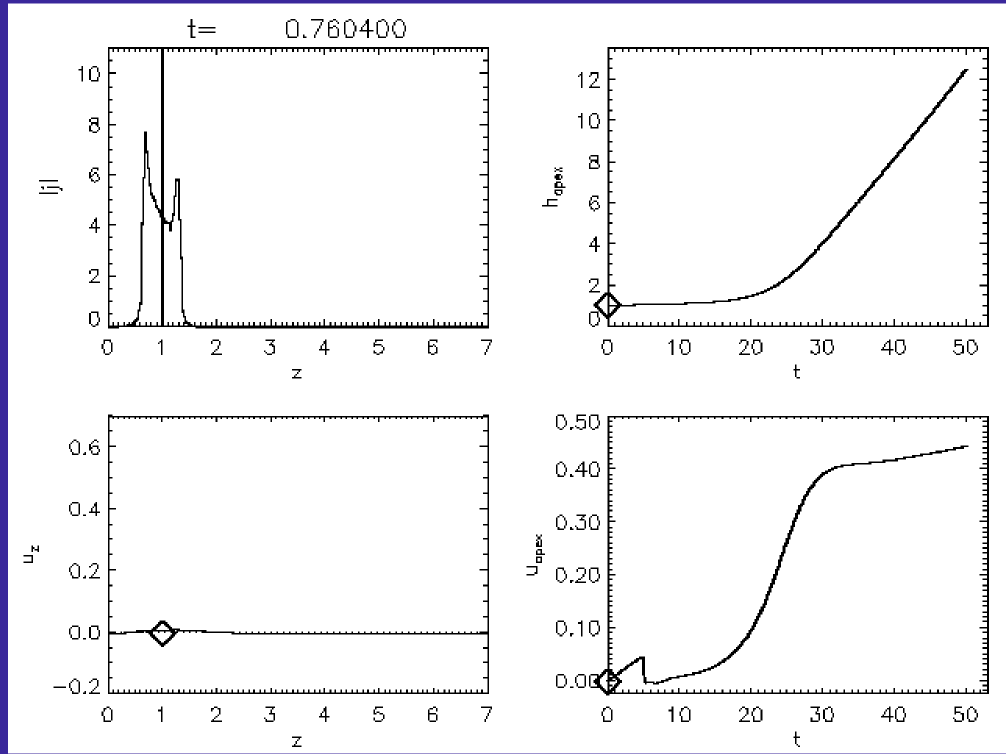
with $B_0 = (10-40)$ G :

$\approx (10^{31} - 10^{32})$ $ergs$

flare / CME - relationship



Zhang 2001



simulation

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

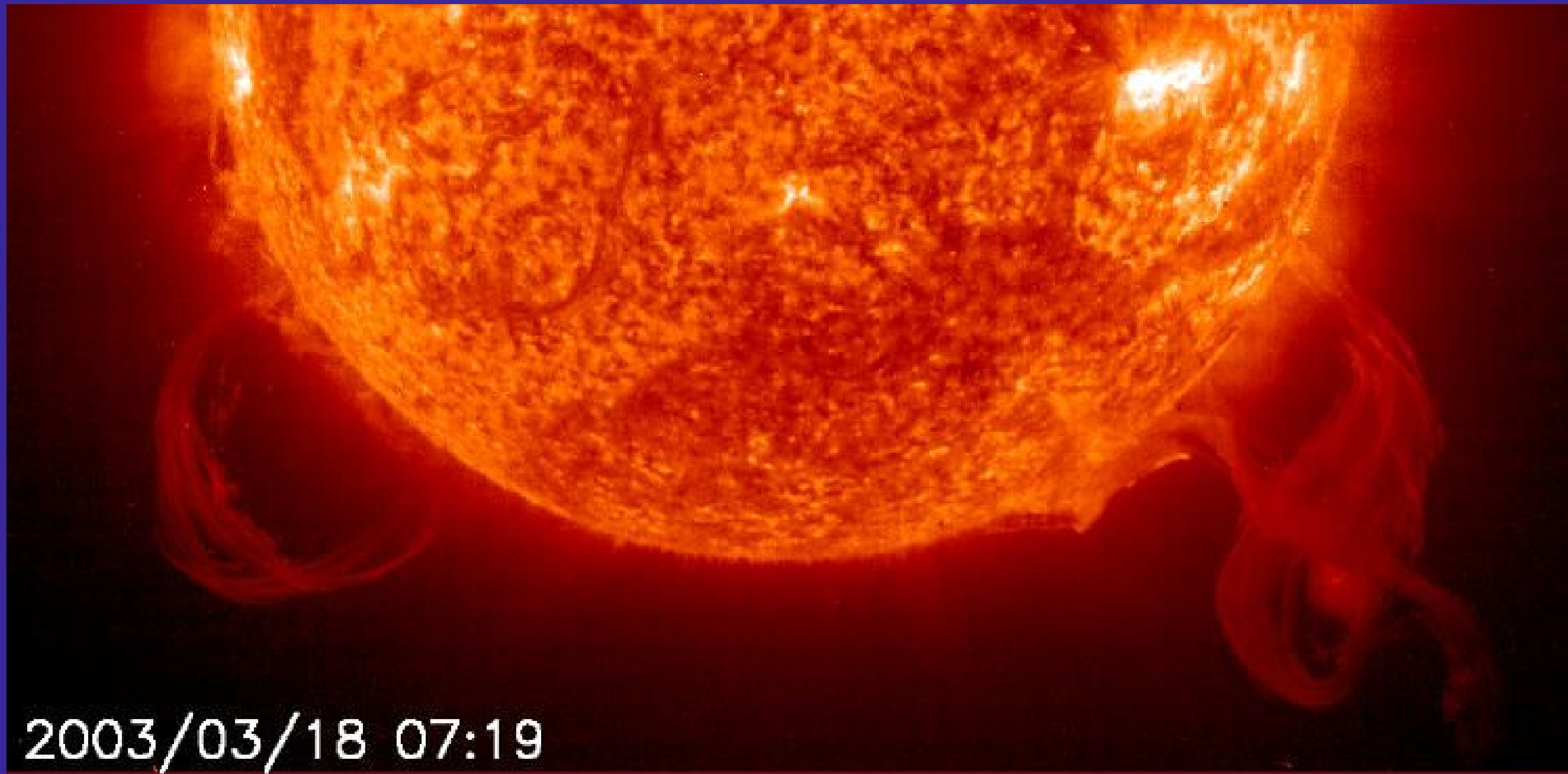
  → profile of magnetic field strength important

conclusion

- the reproduced helical deformation and rise profiles are characteristic of many eruptions →

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 !