ROLE OF TOPOLOGY IN CMEs

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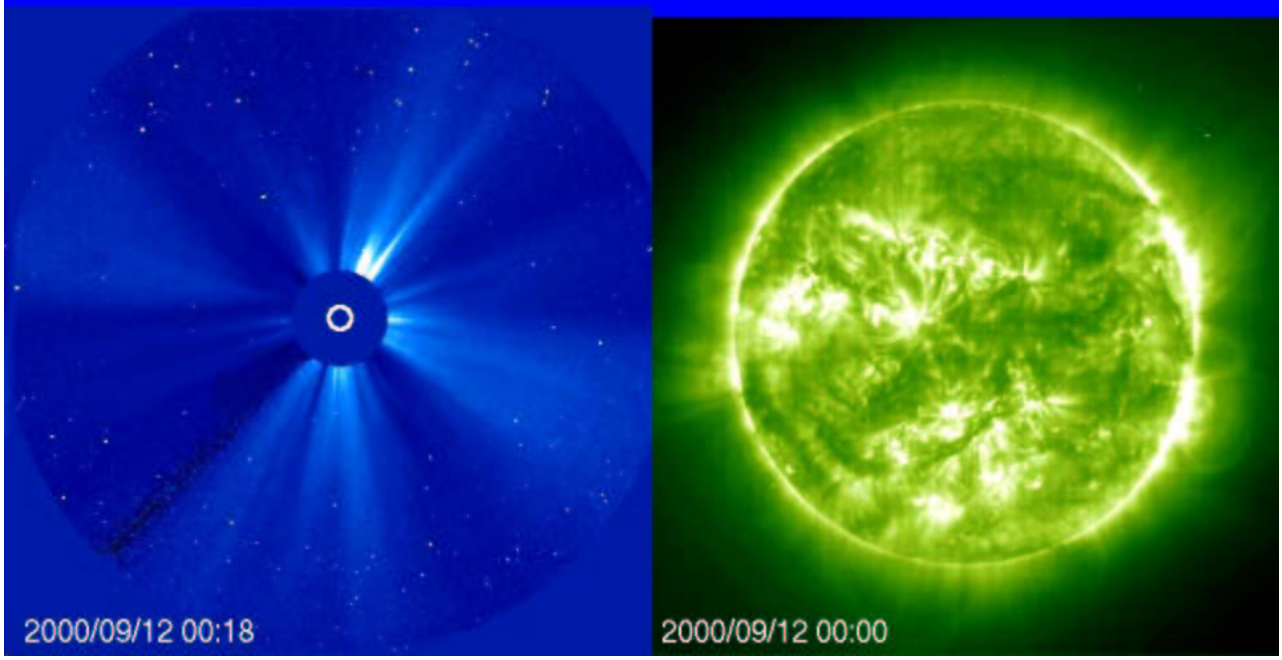
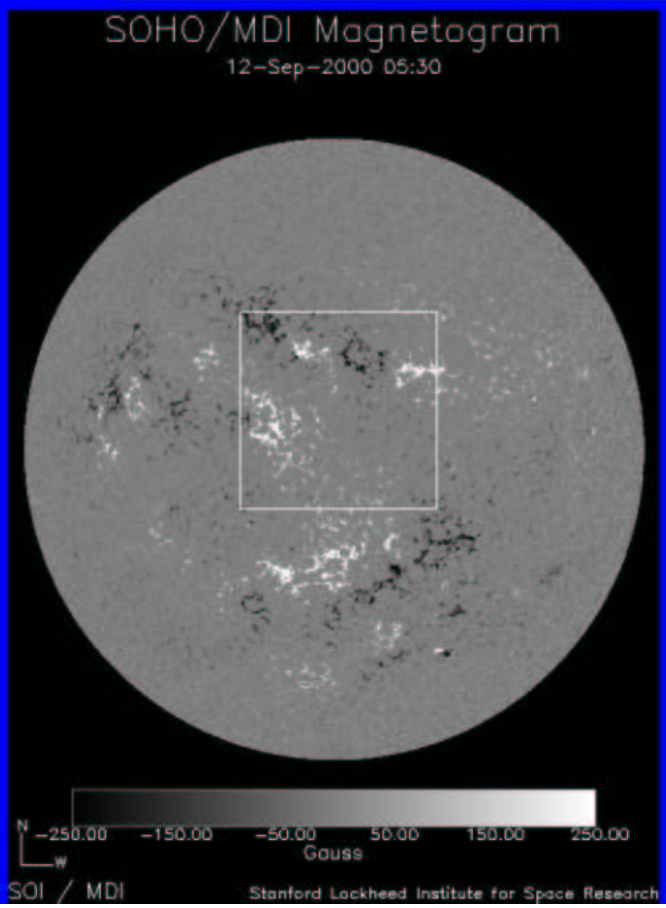


O9/12/00 MDI Observations of Sun's Magnetic Field



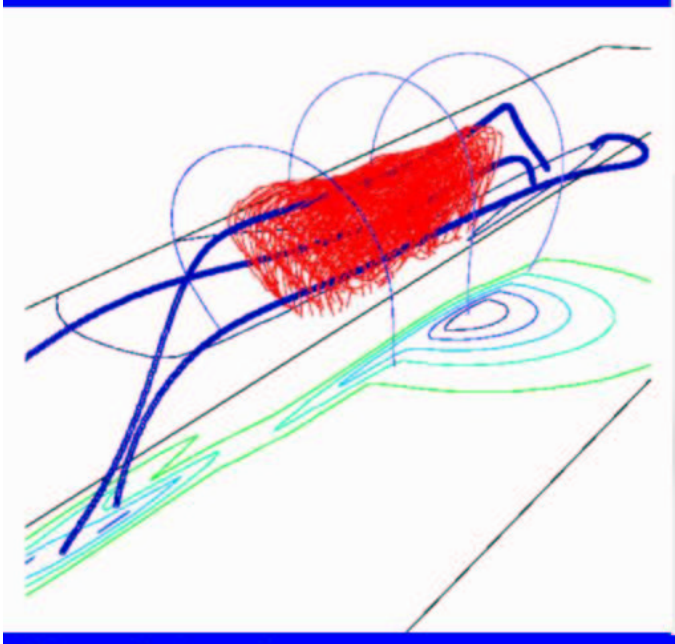
- photospheric magnetic field -- white/black indicates field directed toward/away from observer
- eruption occurs over magnetic polarity inversion line
- note presence of neighboring polarity inversion lines -- complex topology

Constraints on CME Theories

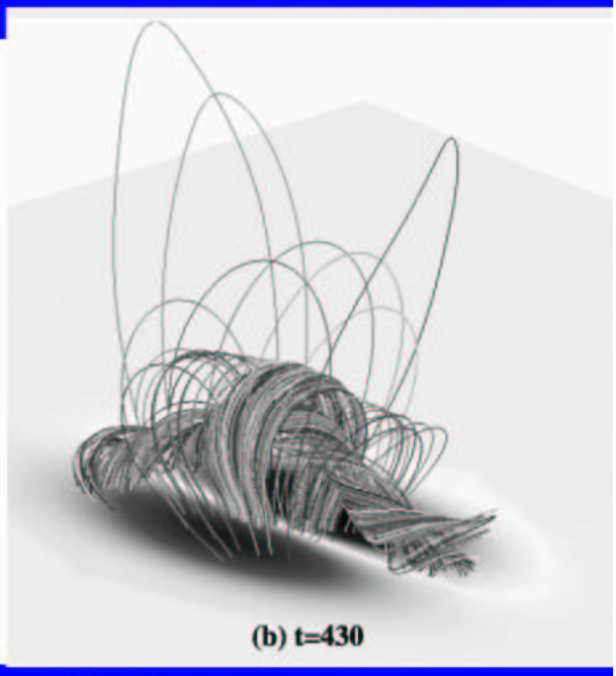
- Requirements for CMEs
  - V > 1,000 km/s, mass > 10^{15} gm, time scales < 1000 sec
  - $E_B > E_K > 10^{32}$ ergs
  - Energy must be ***stored*** in corona – (filament channel B ?)
  - Pre-existing force balance
  - Positive feedback mechanism for explosive growth
    - e.g., ideal or resistive MHD instability
- Topological Properties of Sun's Corona
  - Infinite volume – limits amount & location of free energy
  - Line-tying at high-beta photosphere – limits reconnection
  - Complex polarity distribution at photosphere

Topology of Pre-Eruption Force Balance

- Low-lying stressed and high-lying unstressed B
  - Need concave up field for prominence support



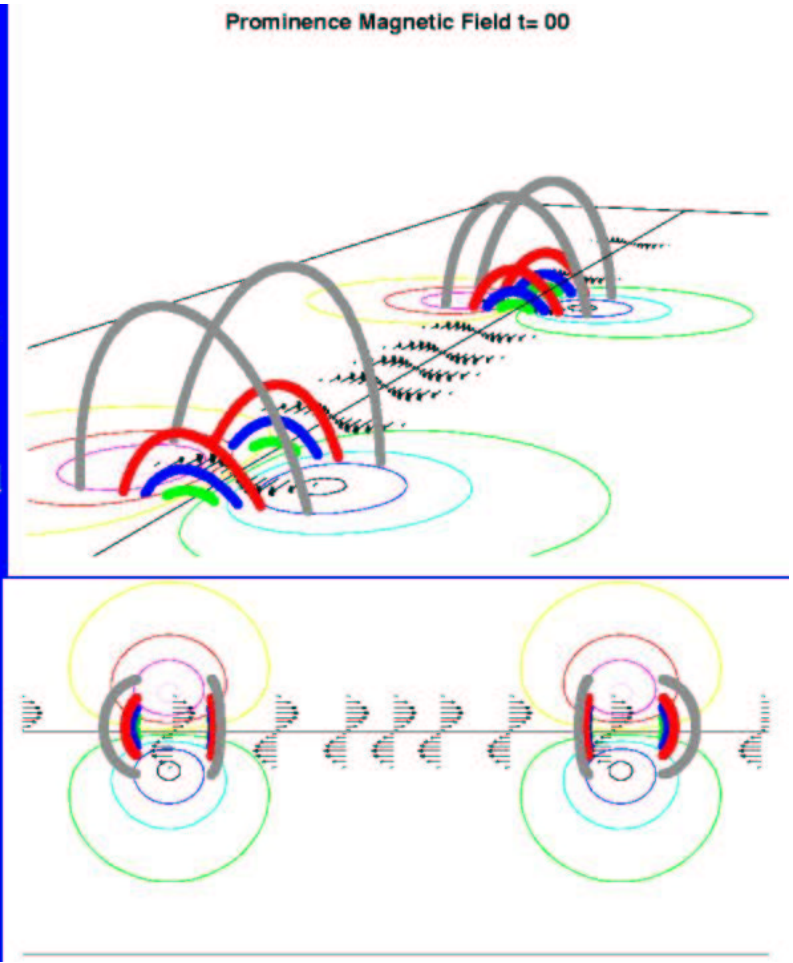
Sheared Arcade (DeVore & Antiochos)



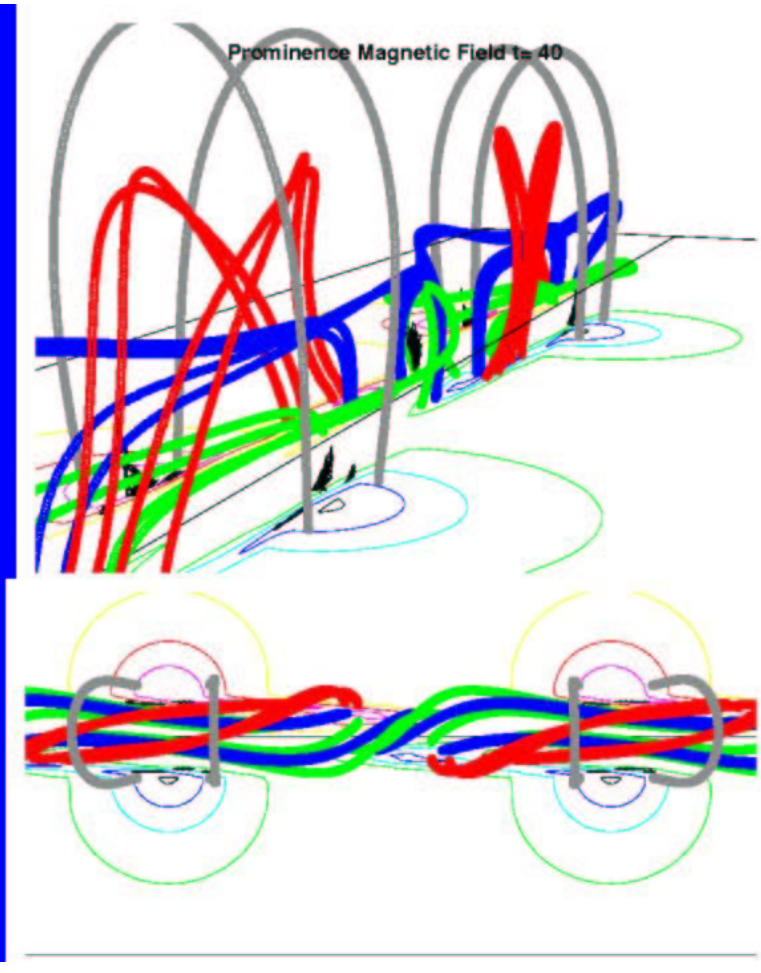
Flux Rope (Amari et al)

Formation of Filament Topology (DeVore et al)

- Shear double-dipole field
- Reconnection/diffusion enhances shear of core field

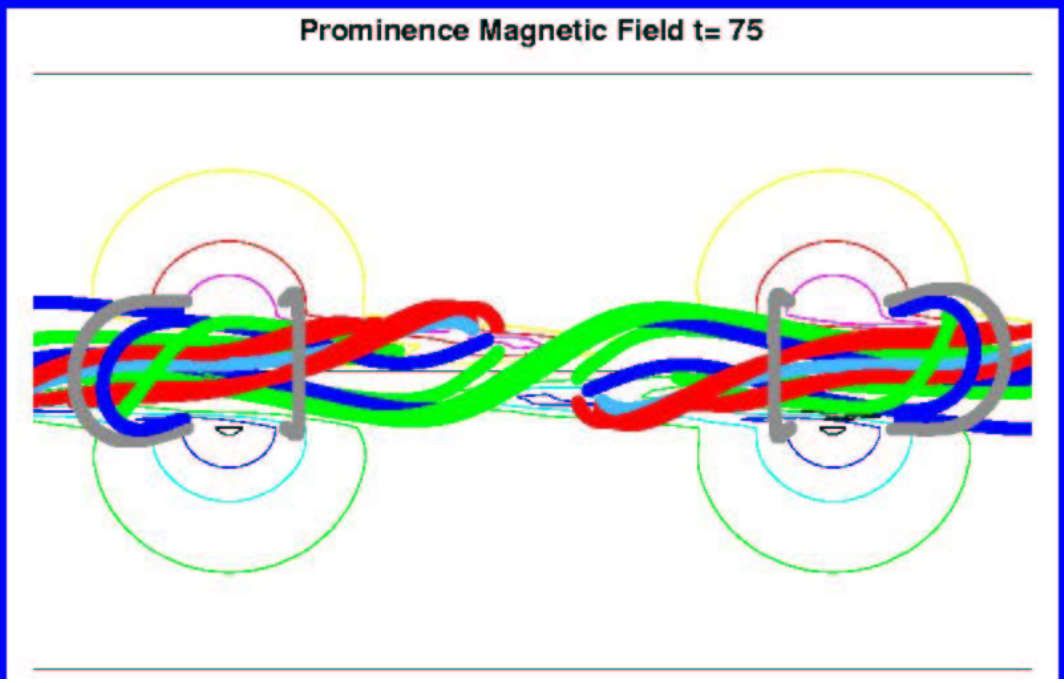


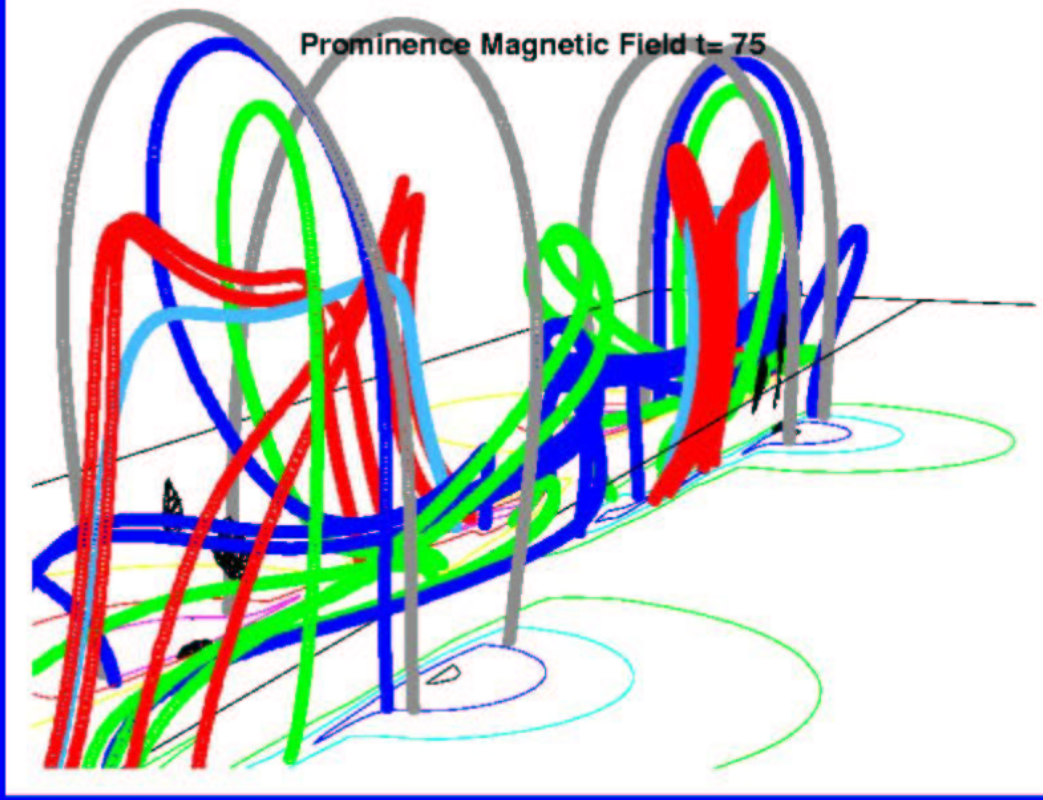
Field at end of shearing phase



Topology of Filament Channel

- reconnection of field lines tends to increase shear
- obtain complex sheared/intertwined field
- no evidence of coherent flux rope





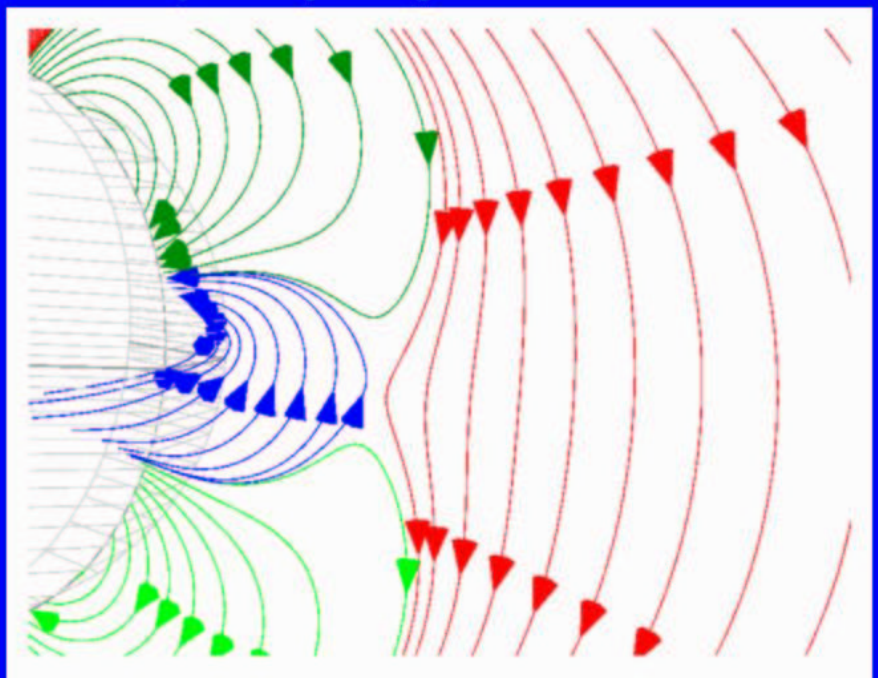
- Also no evidence for eruption, see only central aneurysm
- Basic problem is that reconnection does not remove overlying tethers

Topology of Explosive Eruption

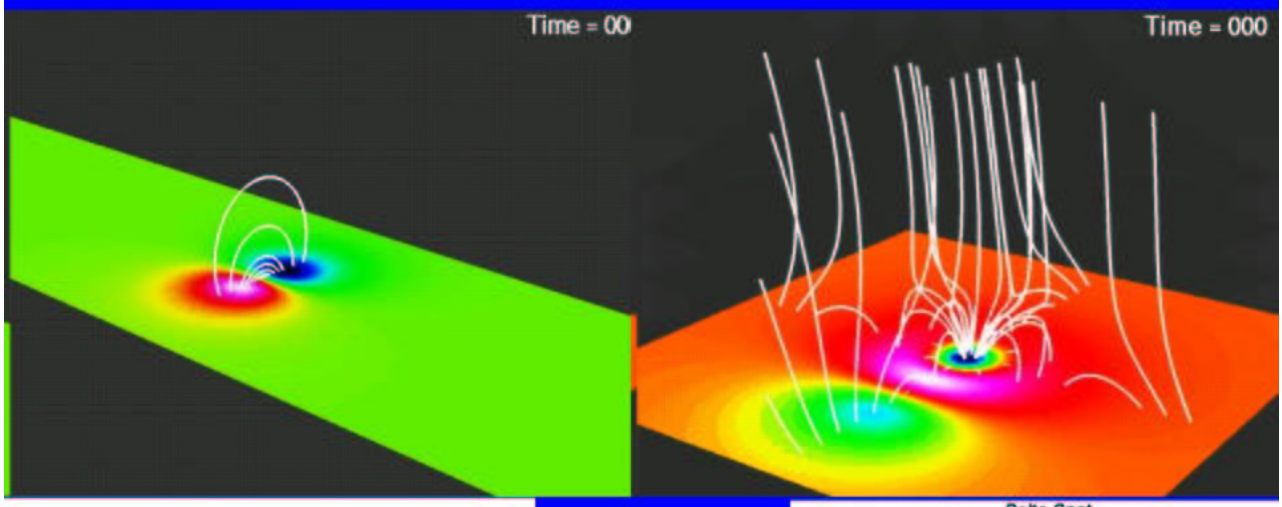
- Aly- Sturrock conjecture
- Quasi-static force-free system unlikely to open explosively to state it can attain by simple expansion
- Conjecture supported by many numerical simulations
  - energy always below that of open state
  - no evidence for ideal energy release
- Reconnection necessary for explosive eruption

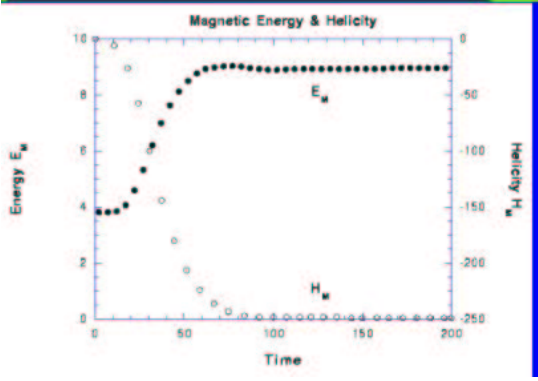
Role of Topology in Magnetic Reconnection

- Physics of reconnection:
  - diffusion becomes important in small (<<L) regions – current sheets
  - small diffusion can produce large changes in system
  - effective only at null point/separator

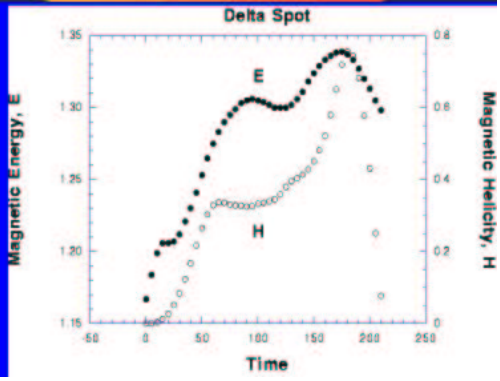


3D Evolution of Bipolar and Multi-polar Fields



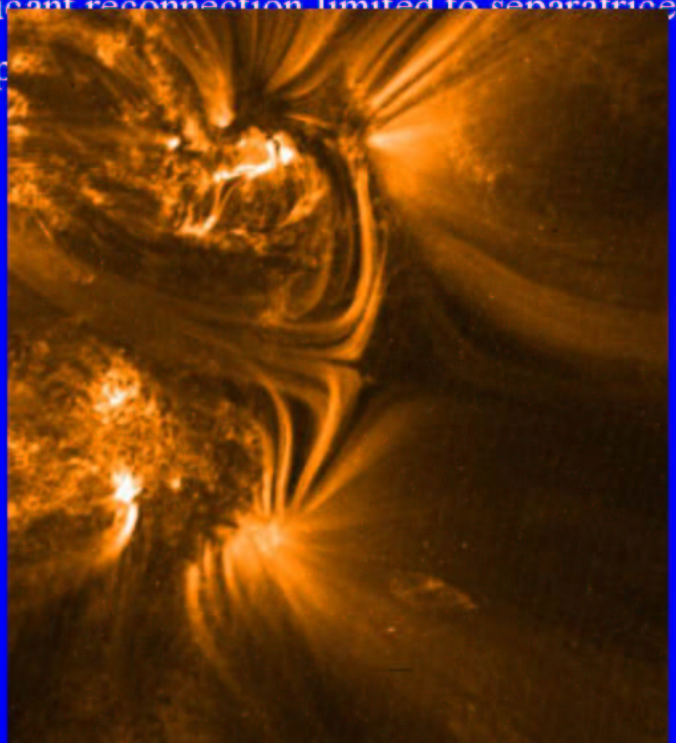


DeVore & Antiochos



Role of Topology in Magnetic Reconnection

- Multi-polar fields necessary for coronal reconnection
  - Signifi[illegible] reconnection limited to separatrices
  - Need p[illegible]



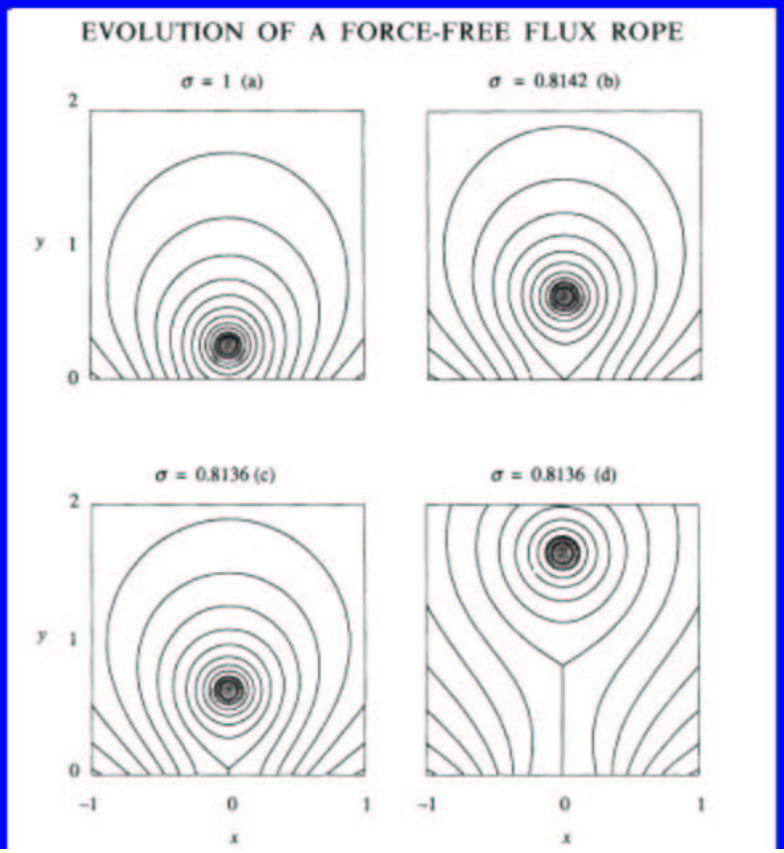
Topologies of CME Reconnection Models

- Flux rope – reconnection at photosphere (Forbes et al, van Ballegooijen, Amari, Mikic et al, …)
- Tether-cutting – reconnection in corona inside filament (Sturrock, Moore et al, …)
- Breakout – reconnection in overlying field, above filament (Antiochos et al, Aulanier et al, Sterling et al, …)

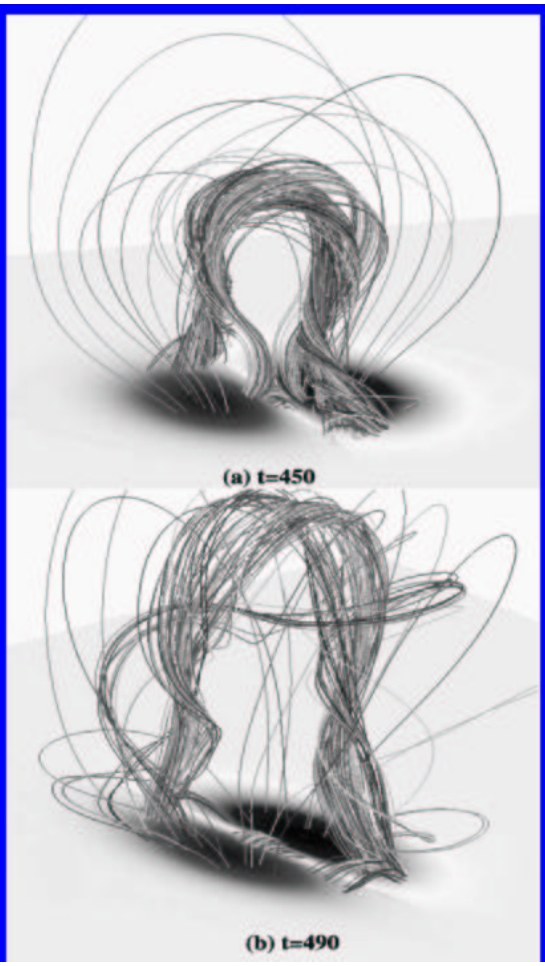
Flux Rope Model

(Forbes et al)

- Field topology is flux rope within bipolar arcade
- Rope forms by reconnection at photosphere
- Growth leads to ideal instability



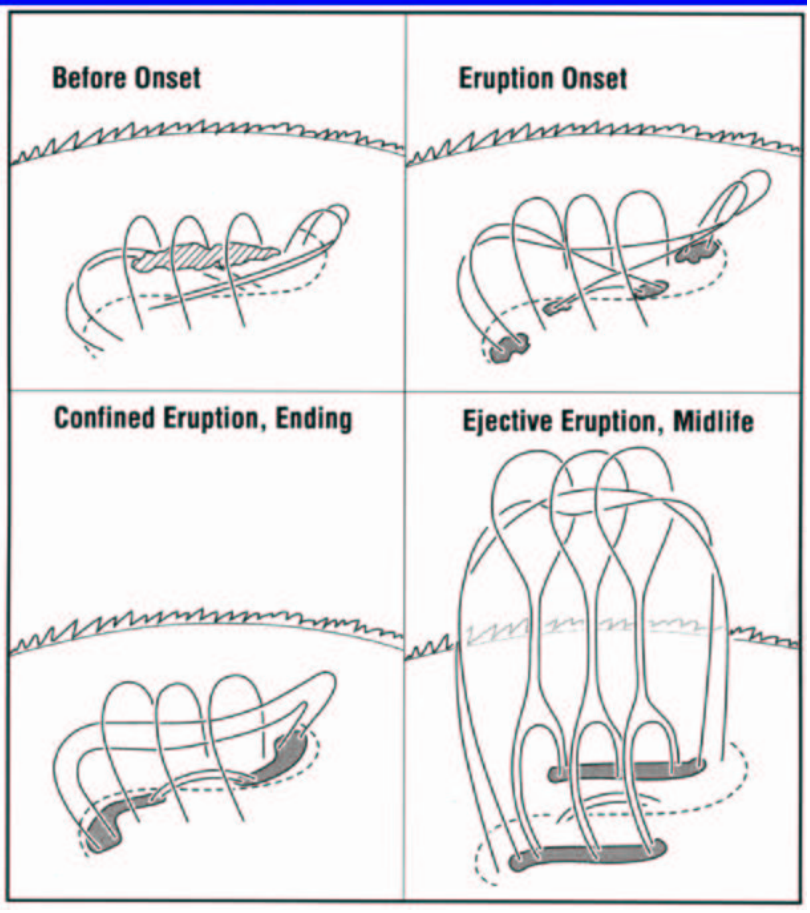
- 3D simulation by Amari et al, 2000, (also Mikic & Linker et al)
- role of reconnection in eruption itself is not clear



Tether Cutting Model

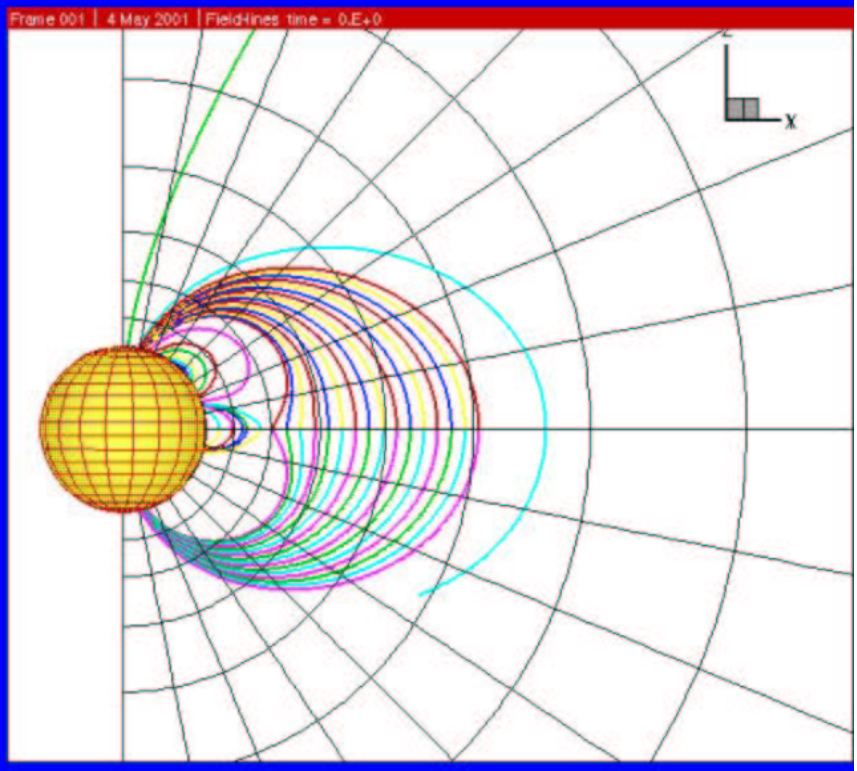
- Field topology is differentially sheared bipolar arcade
- Reconnection within sheared field destabilizes system
- Not observed in our simulations

(Moore et al)



Breakout Model

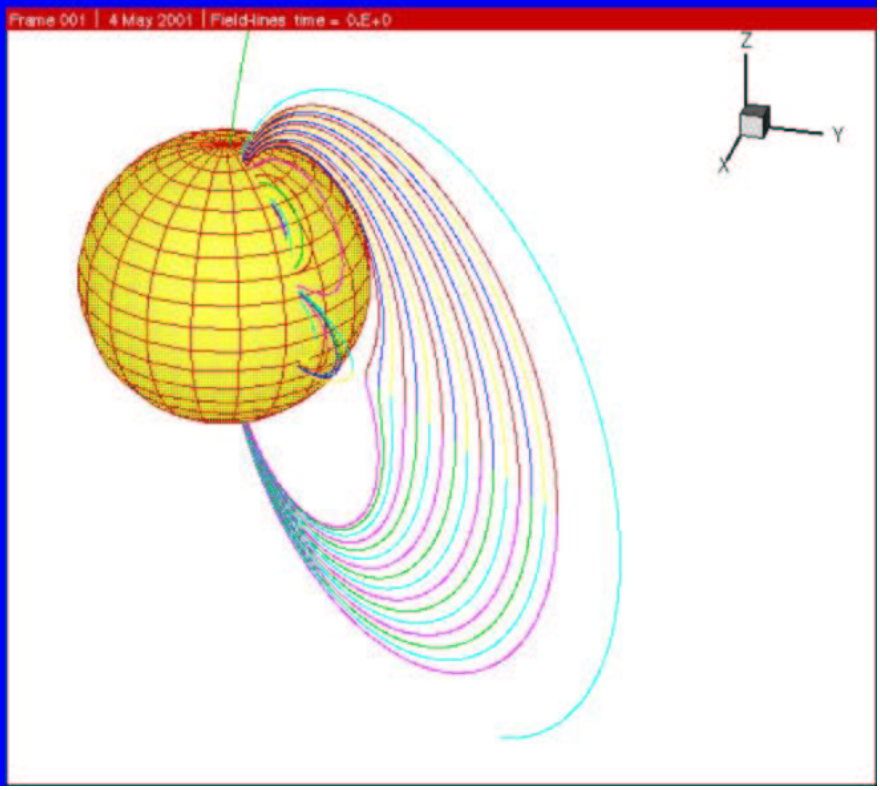
- Field topology is multi-polar field containing differentially sheared bipolar arcade
- Reconnection at coronal null destabilizes sheared arcade and provides necessary feedback



AMR simulation by (MacNeice et al 2001)

Breakout Model

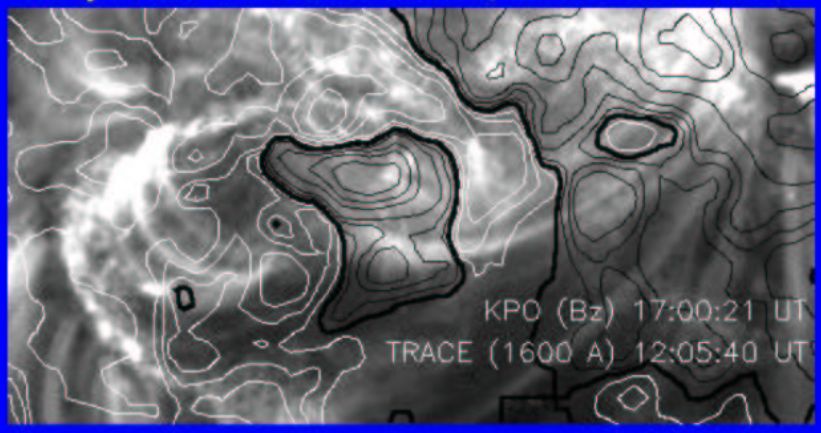
- Flux rope appears *after* eruption onset
- See two phases of acceleration
- Obtain V ~ 1,000 km/s

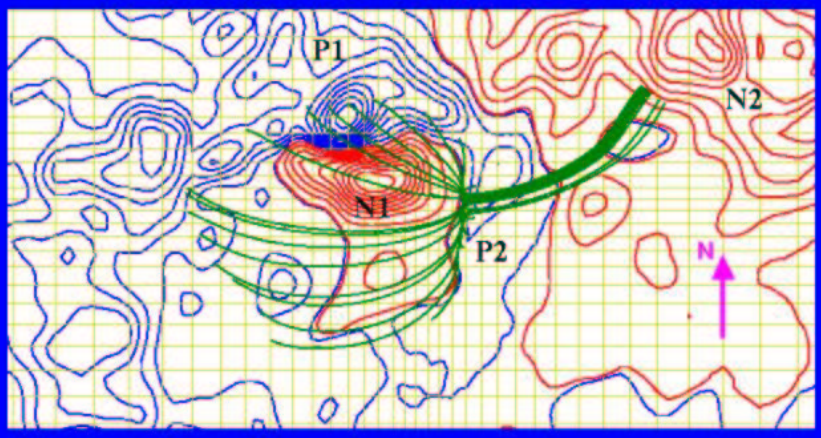


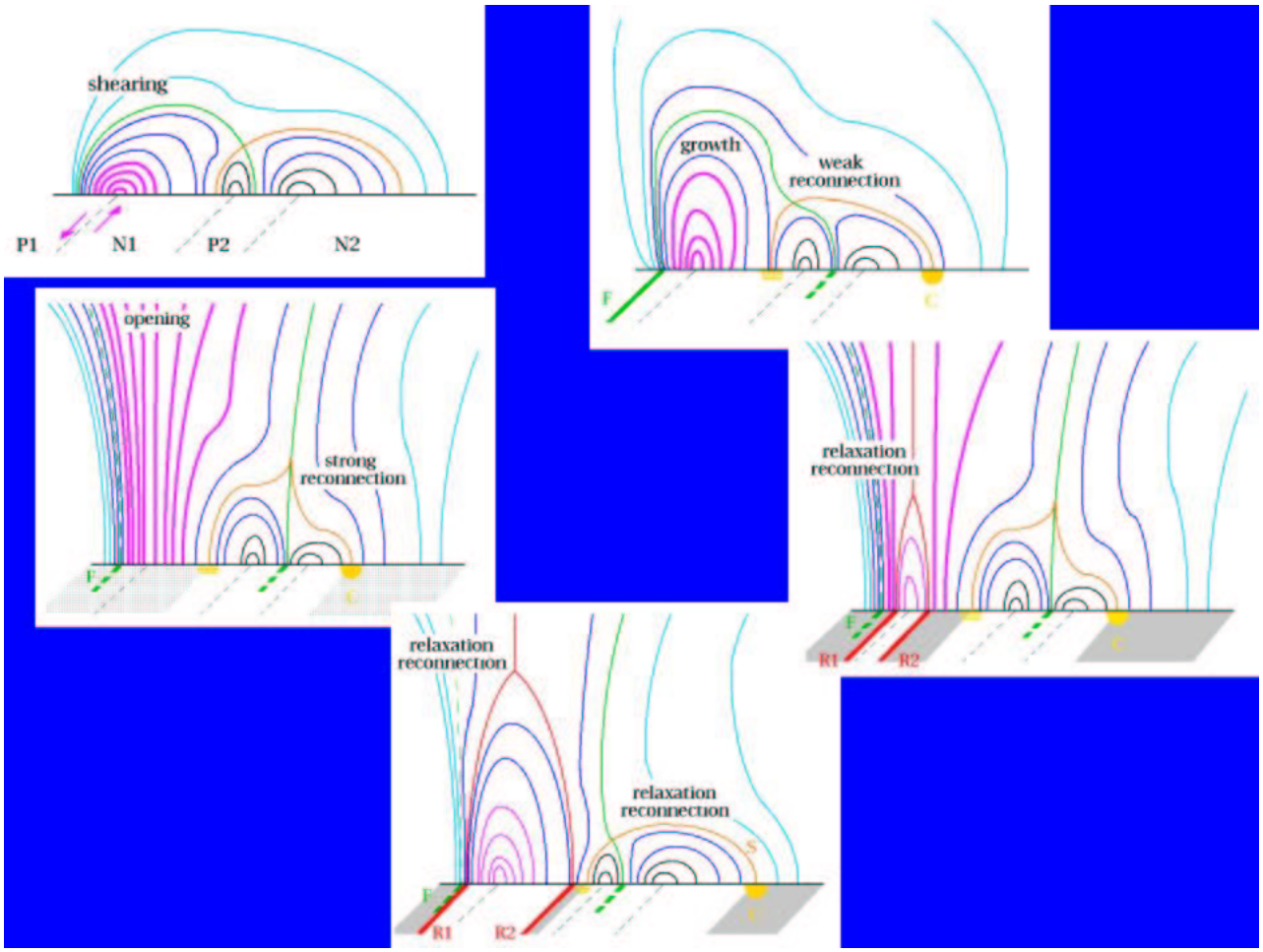
Importance of Topology in CMEs

- Issues:
  - What is detailed topology of filament channel field, global twist, intertwined, … ?
    - How does this topology form?
  - Does reconnection lead to the disruption of this topology?
    - Where does the reconnection occur?
    - How does it evolve in 3D?
    - What are the observational signatures?

Analysis of 07/14/98 Flare (Aulanier et al. 2000)







TRACE OBSERVATIONS

- Bastille day, 98 event
  - Apparent spine motions *before* flare
  - Aulanier et al 2000

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