Theory of Large Scale Magnetic Activity

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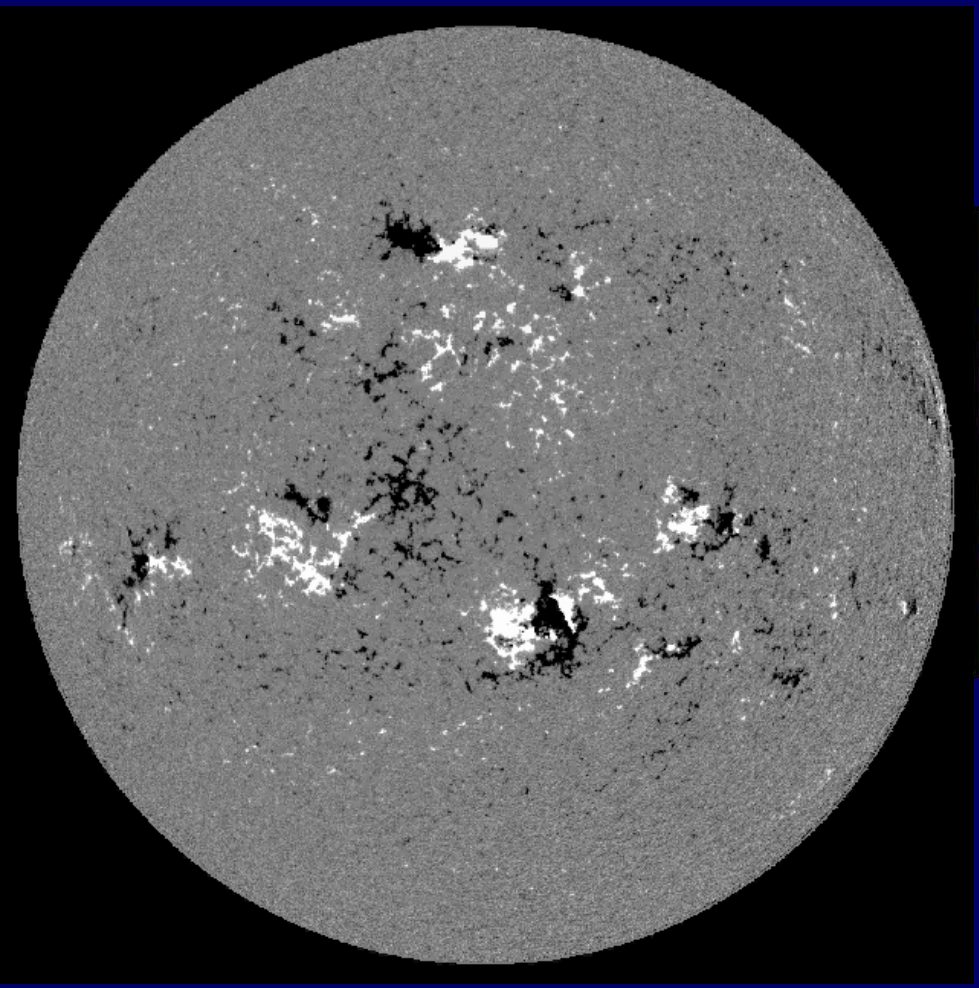
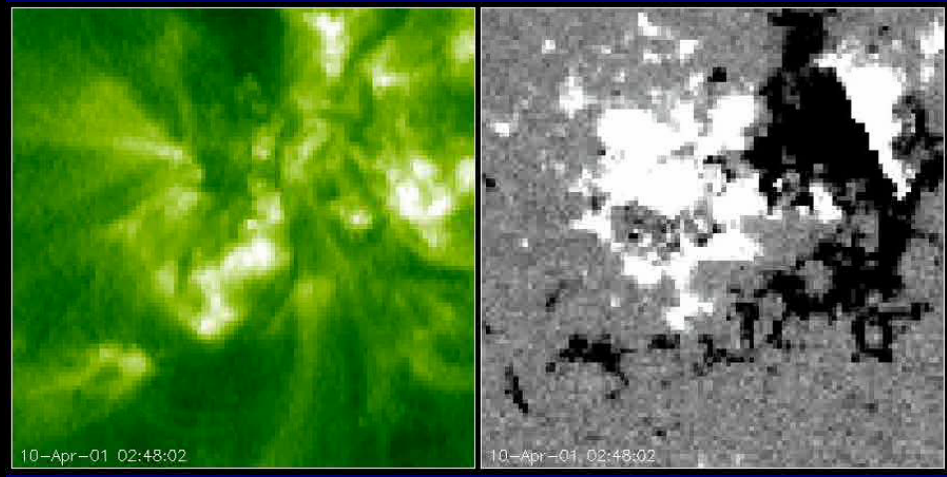
- Large-scale solar activity main driver of major space weather
  - Focus of all upcoming SH space missions
- Substantial theory/modeling progress recently
  - Many interesting/controversial issues remain
- Provides strong justification and opportunities for observing coronal/chromo B
  - Must be coupled to theory/modeling

2001/04/10 Event: Photosphere

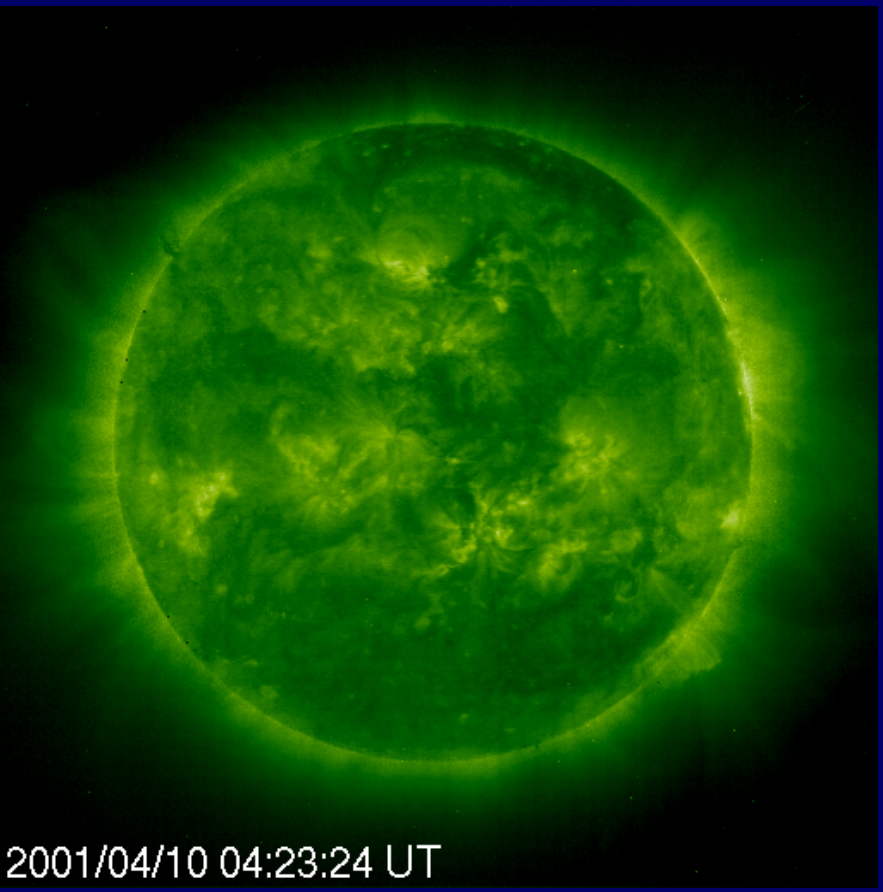




(MDI, and EIT/MDI)

- Photospheric B-field does not evolve – need coronal B obs.!!
- Activity always associated with sheared PIL, often complex polarity

Filament Ejection & Flare

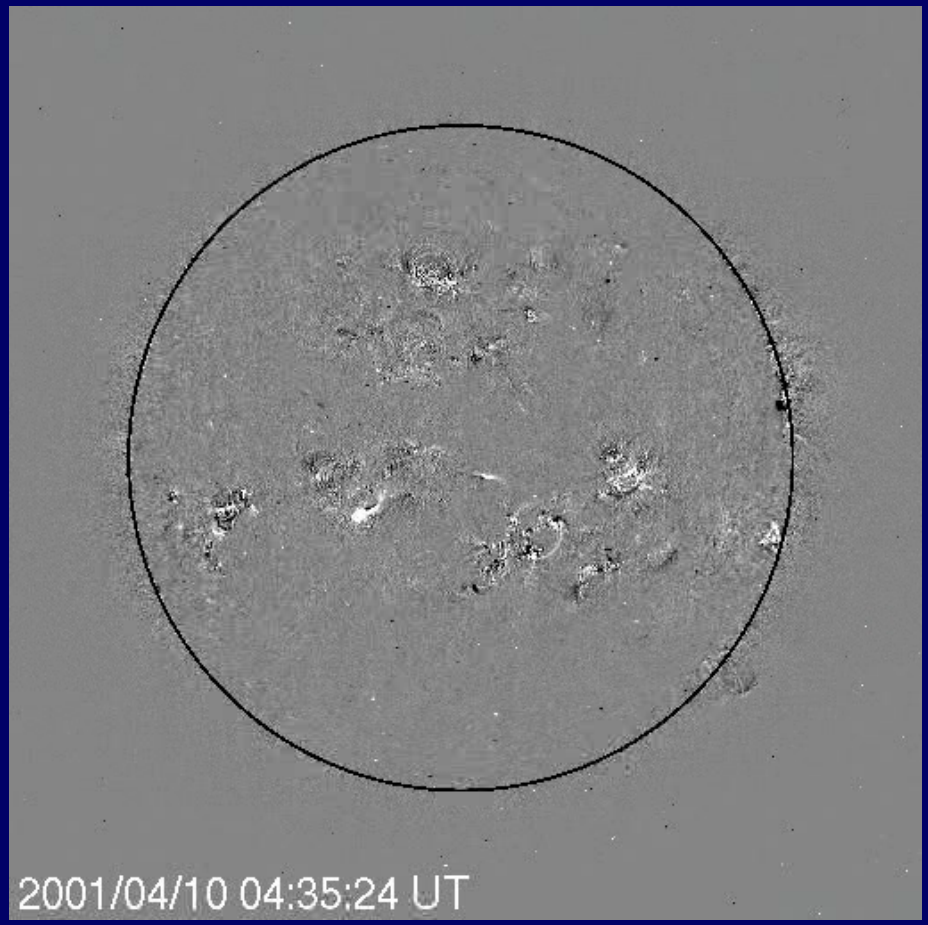


(EIT)

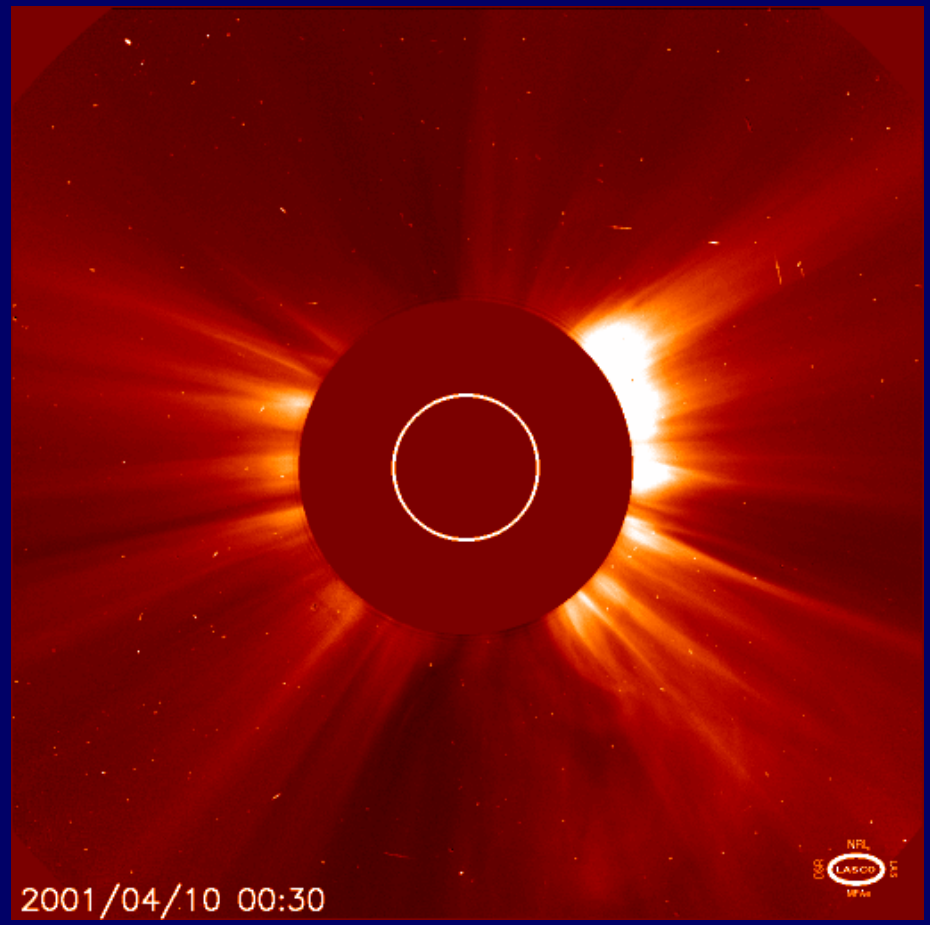
(TRACE)

- Magnetic connection of filament to overlying corona unclear
- Flare heating follows filament activation

Coronal Mass Ejection



(EIT)



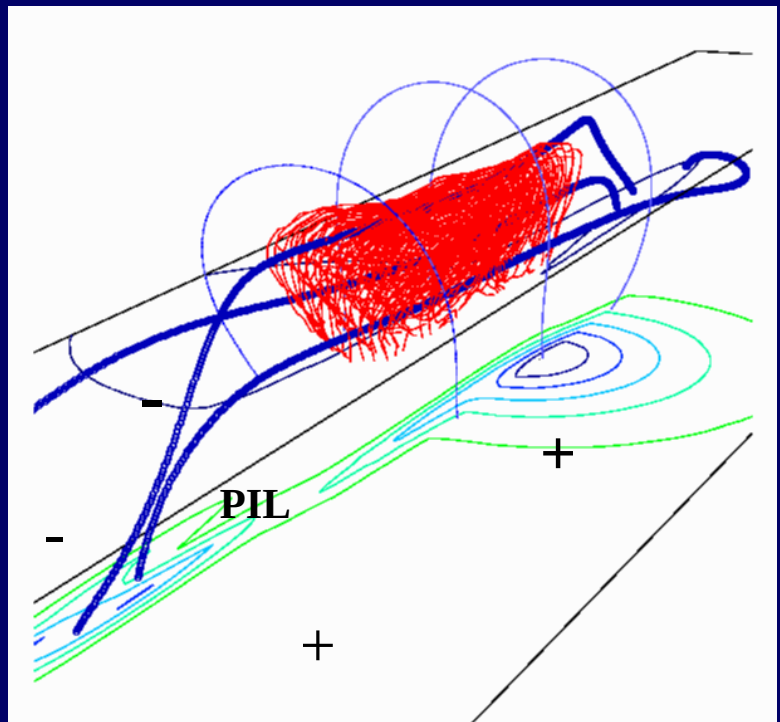
(LASCO)

- "Standard" event consists of fast CME, filament eruption, and flare
- Relative timing of CME and filament ejection unclear

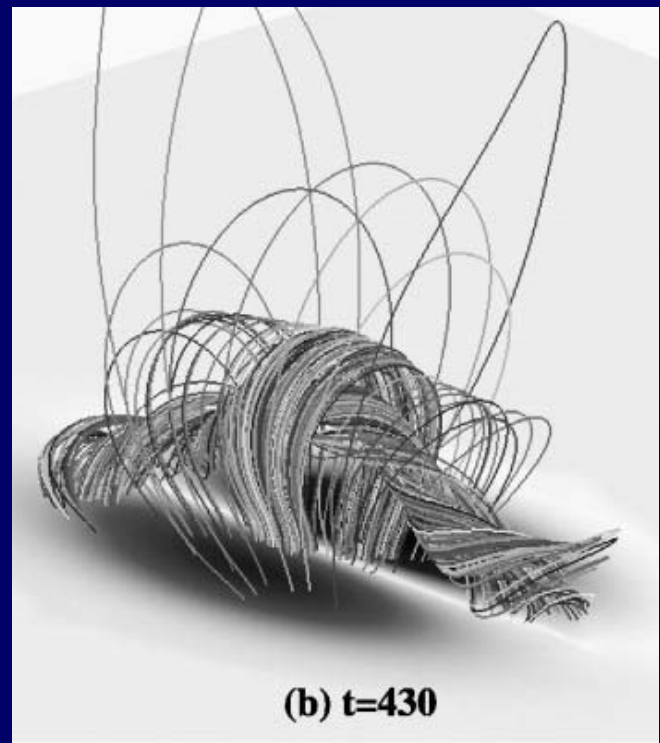
Generic Picture of Large-Scale Activity

- Strongly non-potential field forms in narrow filament channel
  - Formation process TBD
  - Topology TBD: sheared arcade or twisted flux rope or ??
  - Filament field held down by ~ potential overlying coronal field
- Force balance breaks down: where and why? TBD
- Field reconnects below eruption to a more potential state
- All need explosive removal of overlying field

(Antiochos et al.)

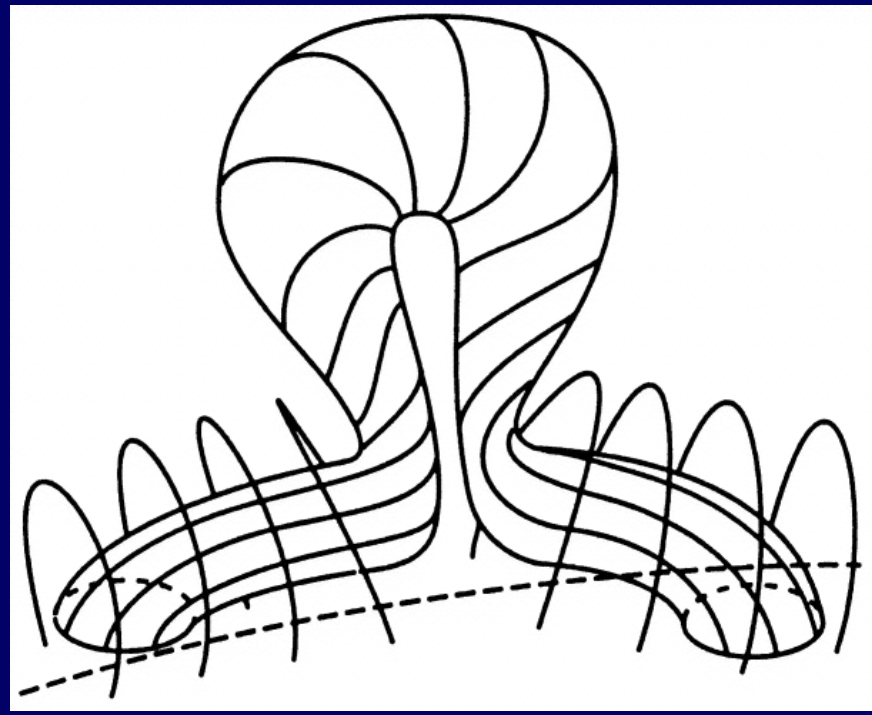


(Amari et al.)



Theories for CME Initiation

- Twisted flux rope models: (e.g., Forbes et al, Low, van Ballegooijen et al, Sturrock, Mikic &Linker, Roussev et al, Fan et al, …)
  - Twist is necessary element of pre-eruption state
  - Generally discontinuous coronal topology
    - Generally bipolar polarity region
  - Ideal instability/loss-of-equilibrium
  - Role of reconnection not clear
    - (e.g., Fan 2005)



(Sturrock, 2002)

Issues for Twisted Flux Rope Model

- Twisted field lines not observed in XUV before eruption
  - Do see lots of sheared lines
  - No evidence for tangled pre-eruption fields
  - Need definitive coronal B topology obs.!!
- Rarely erupt whole filament channel
  - Sometimes see CME/flare over undisturbed cool filament
  - Post-eruption field can show substantial shear
  - Again need definitive coronal B obs!
- Will require close coupling between models and observations

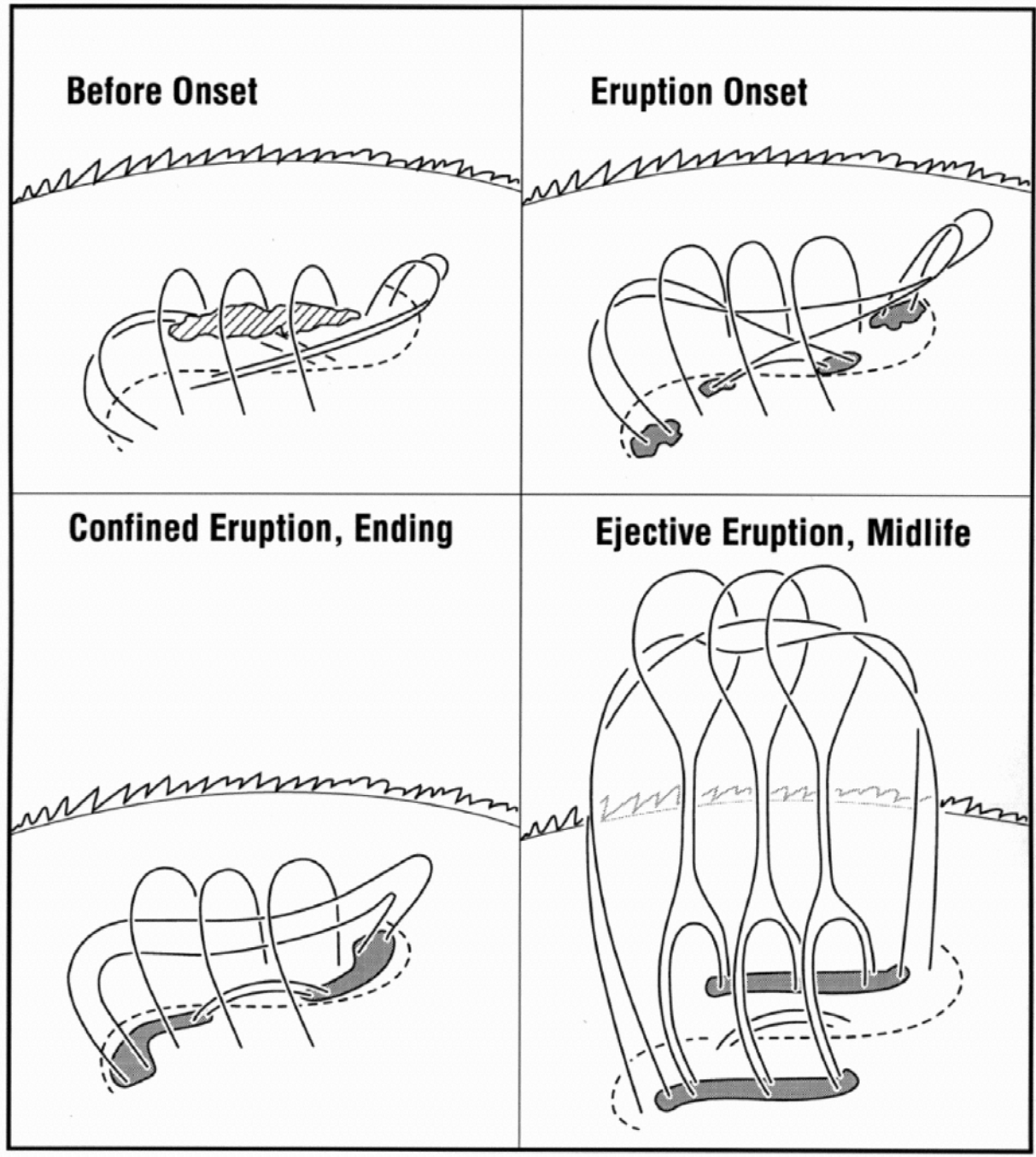
Models for CME Initiation

- Reconnection models (Resistive): (e.g., Sturrock, Moore et al, Antiochos et al, Aulanier, MacNeice et al, …)
  - Generally sheared arcade topology
  - Use reconnection to change topology, removing overlying field
  - Tether-cutting: reconnection in filament channel
  - Breakout: reconnection outside filament channel
    - Needs multi-polarity system, but generally present in corona

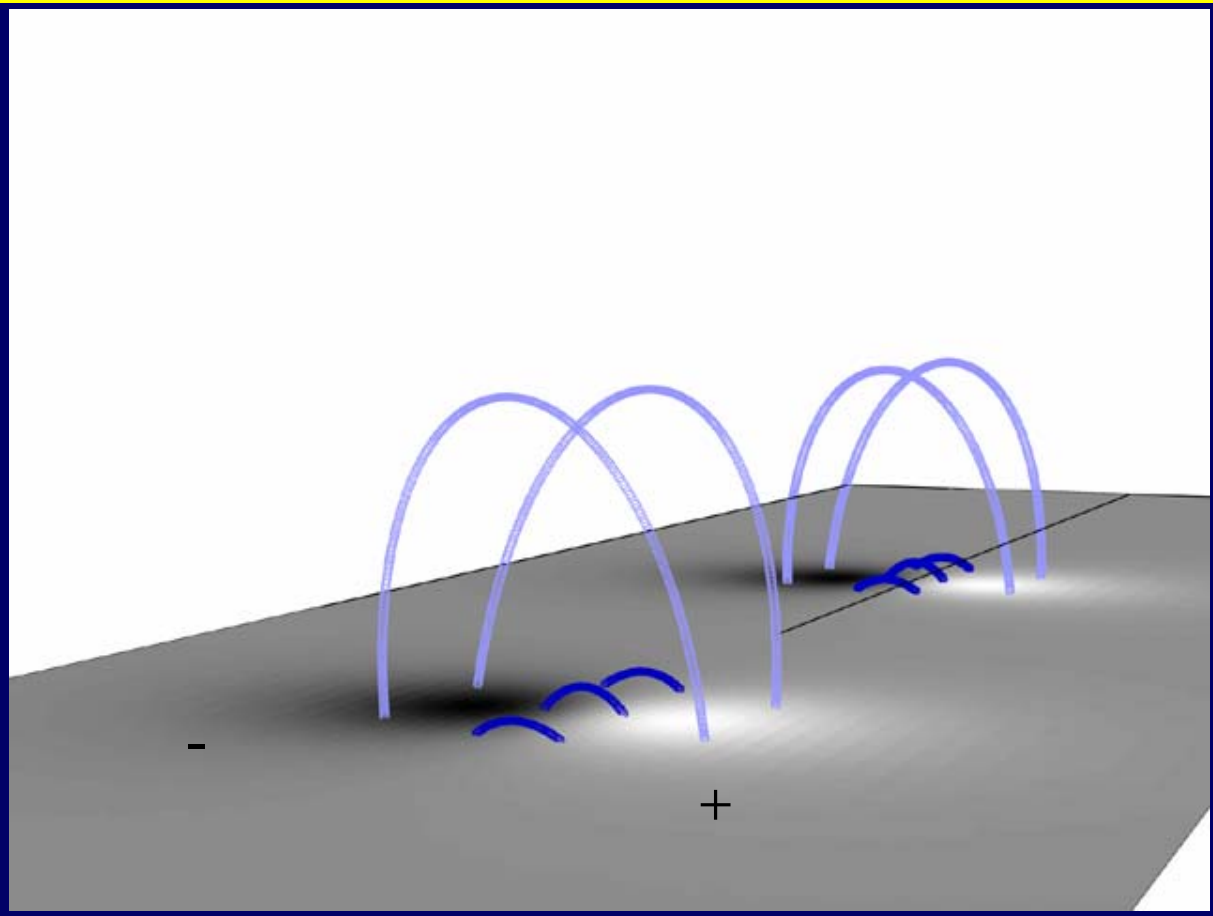
Tether Cutting Model

(Moore et al)

- Reconnection within sheared field presumed to destabilize system
- Does not actually remove overlying flux
- Eruption not observed in our simulations



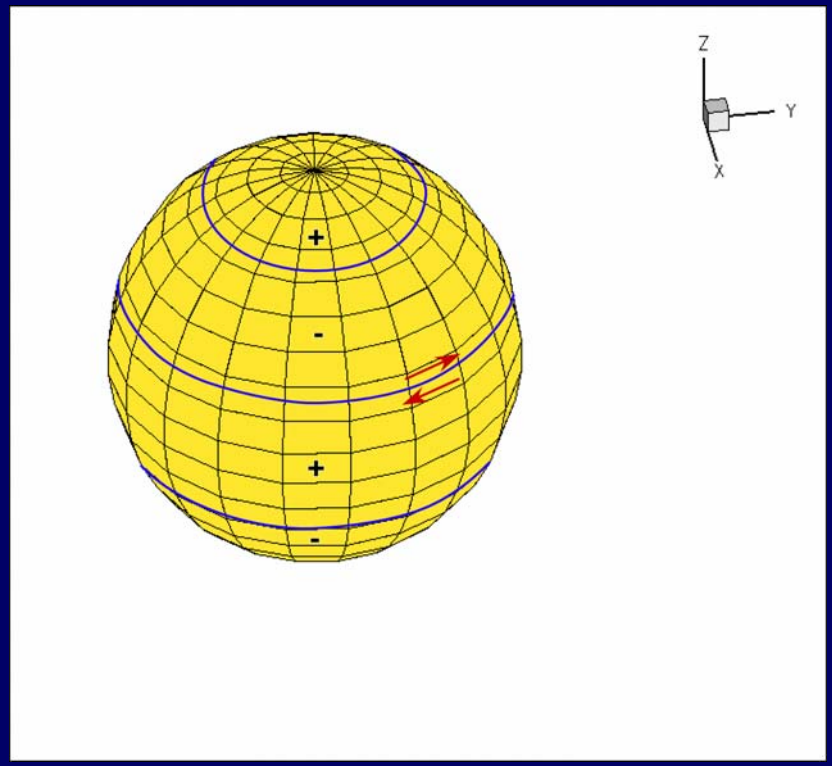
Filament Formation / Tether Cutting Test



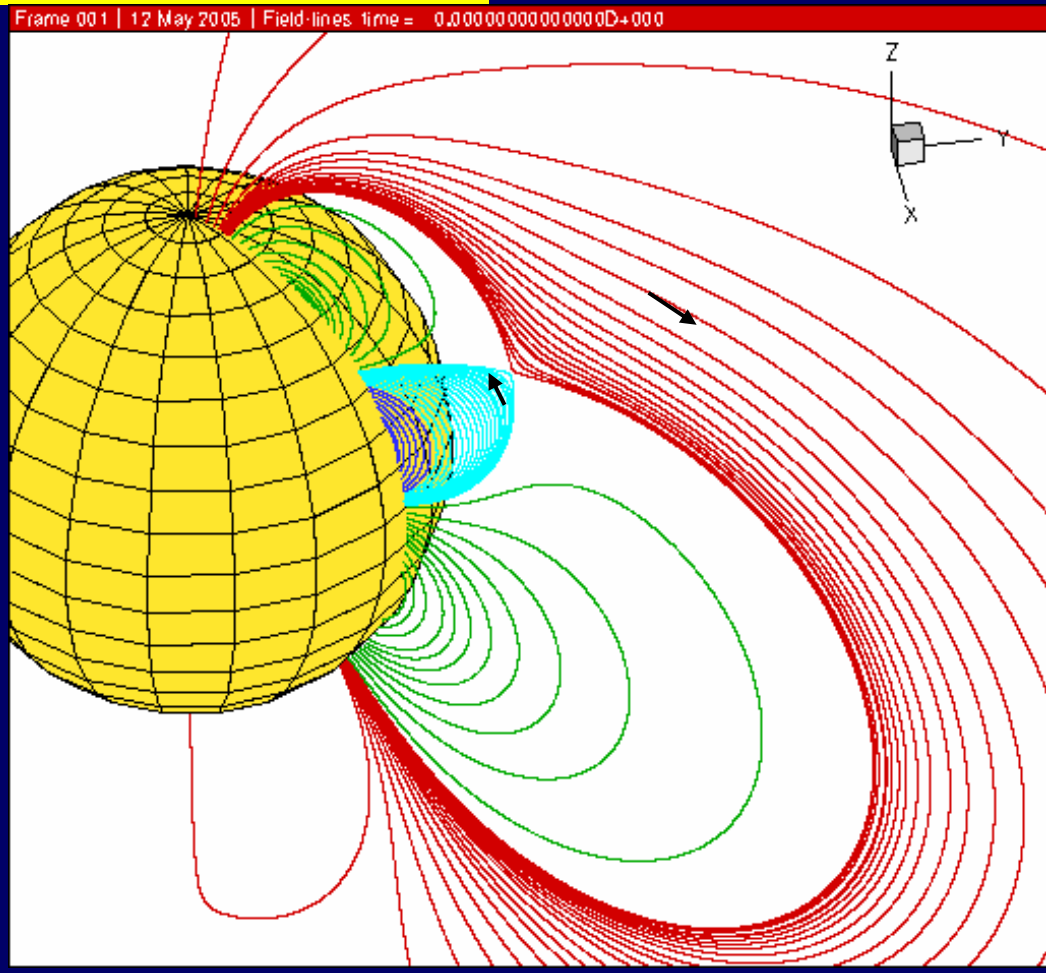
(from, DeVore et al, 2005; Aulanier et al, 2005)

- Bipolar (one polarity inversion line) initial magnetic field
- Impose footpoint motion to generate modest magnetic shear
- Filament-field formation by shear flow and reconnection
- See pronounced expansion & bulging – but stable

2.5D Breakout Model

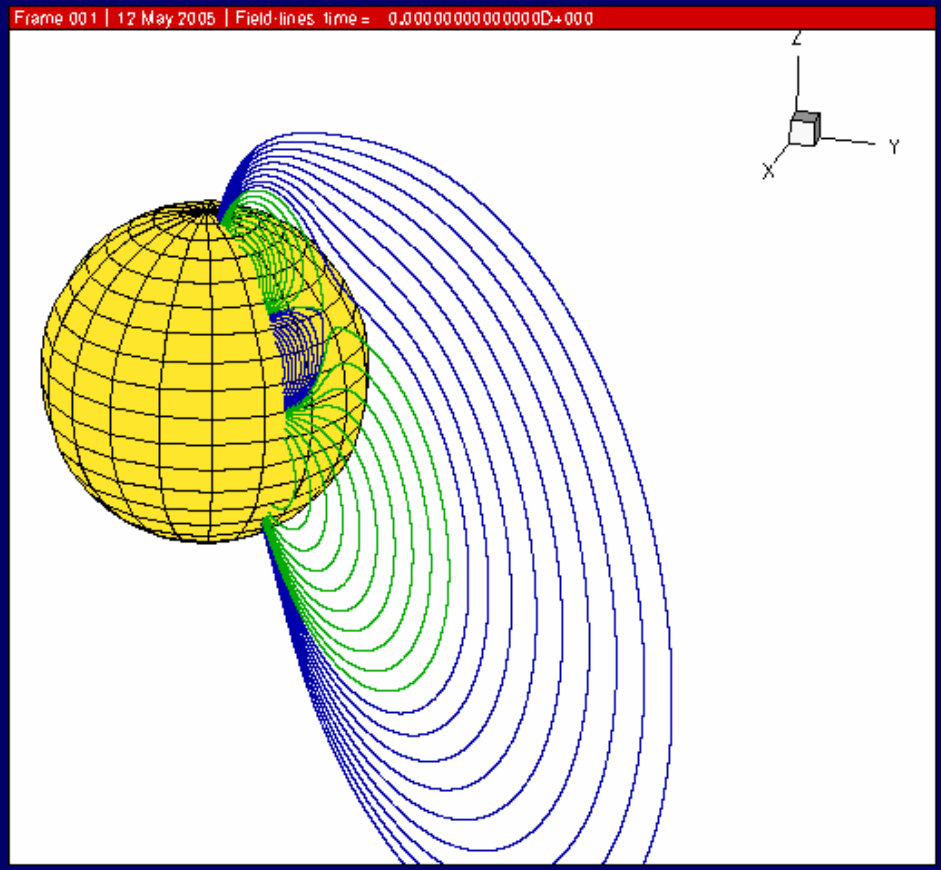


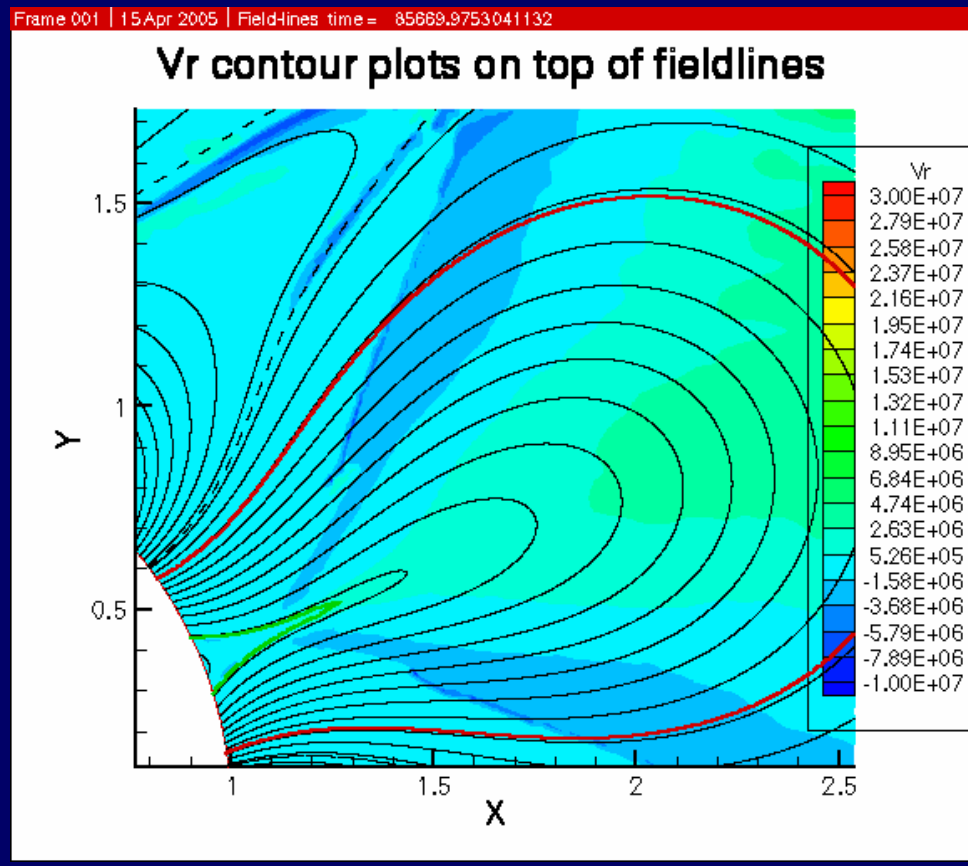
(From J. Gao et al , 2005)



- Add 2D (axisymmetric) “active region” dipole to global dipole
- Field has four-flux topology with coronal null line
- Outward expansion drives breakout reconnection in corona
- Global evolution controlled by small-scale diffusion region

2.5D Breakout Model

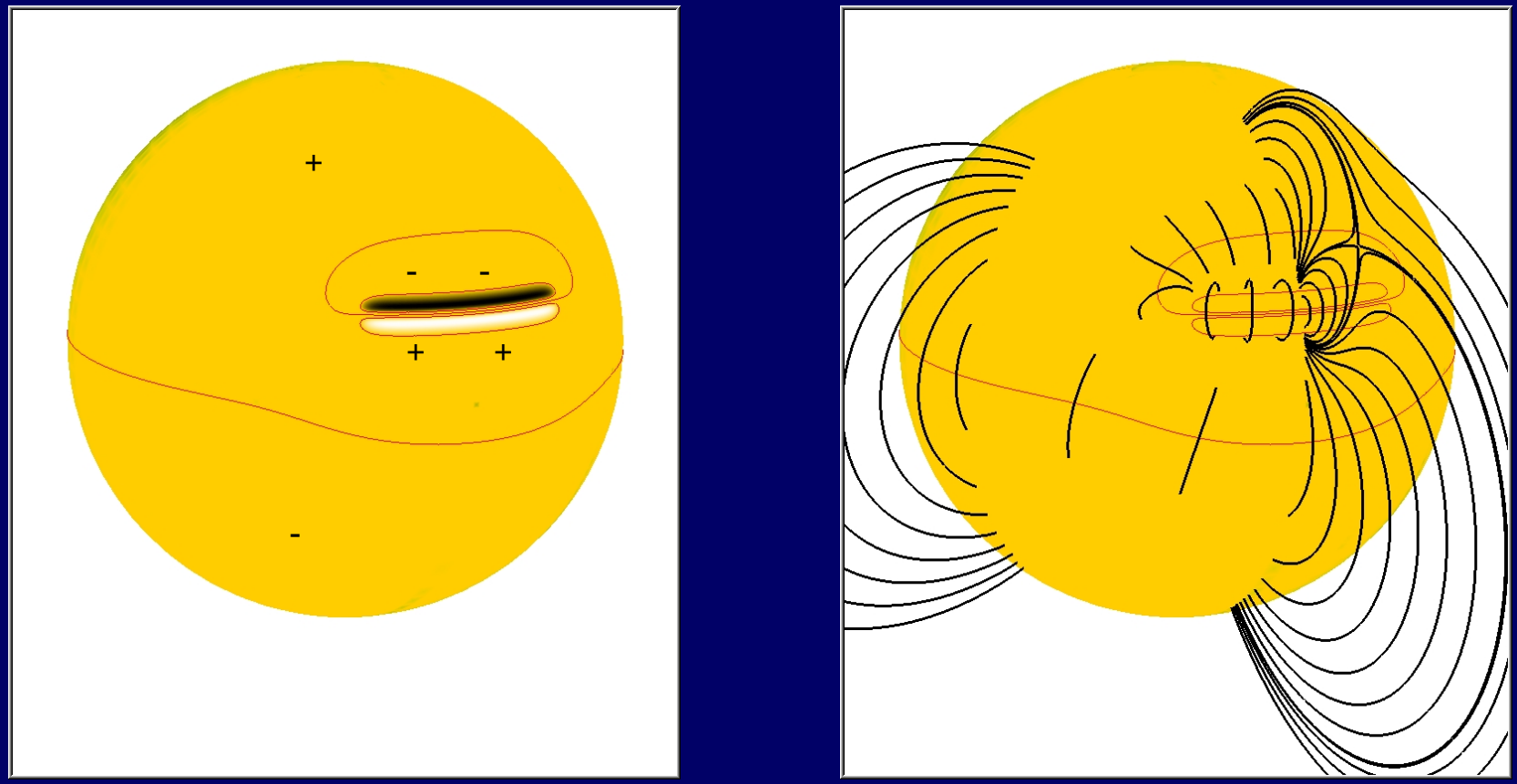




(From Gao et al , 2005)

- Breakout reconnection results in fast plasmoid ejection
- Flare reconnection produces rising arcade of loops
- Fast upward/downward flows – shocks – energetic particles?

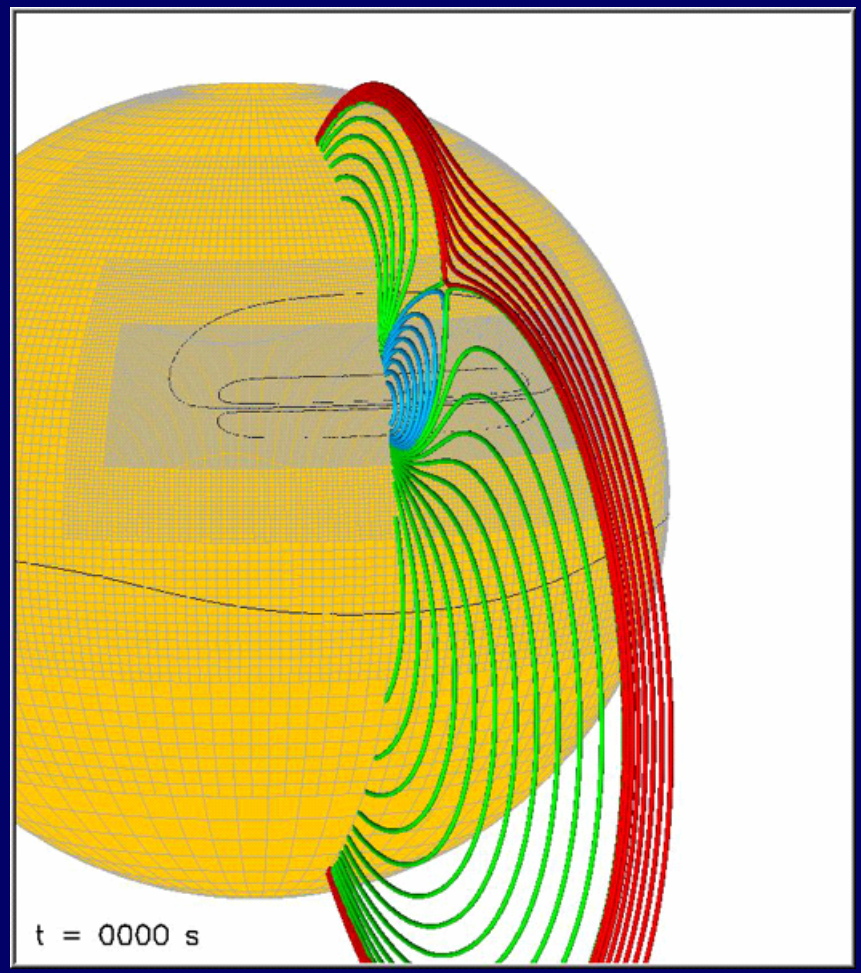
3D Breakout Model

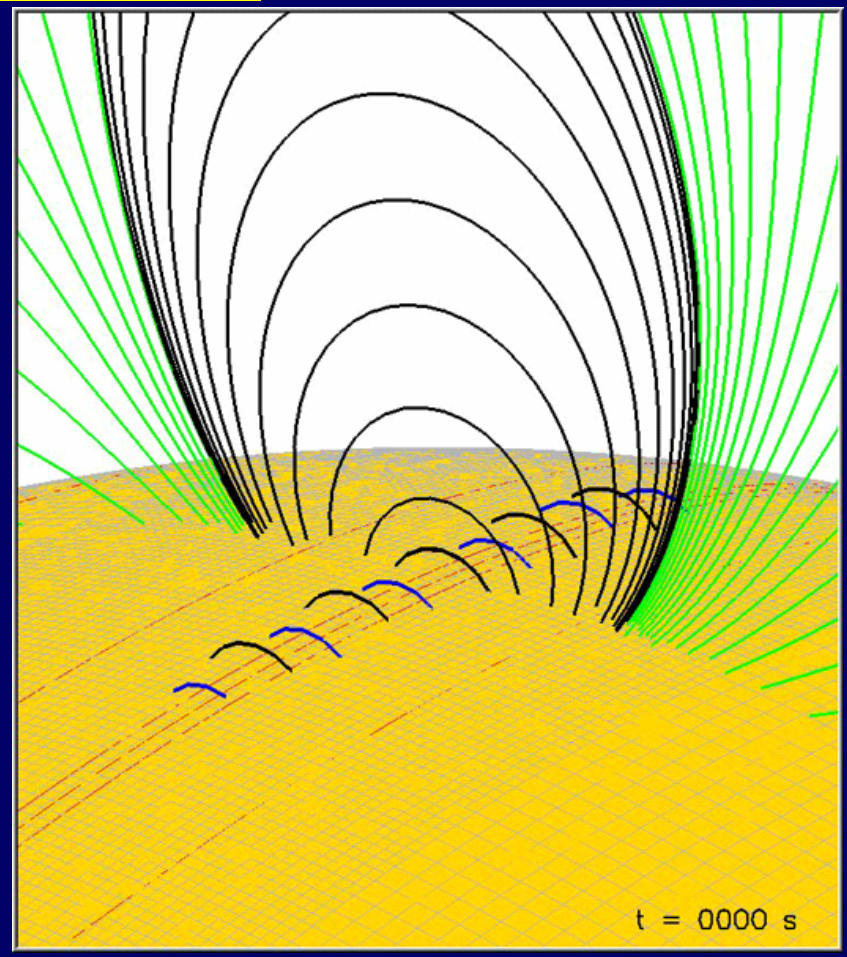


(from Lynch et al 2005)

- Add 3D “active region” dipole to global dipole
- Stretch spot to allow for large shear & “overlying flux”
- Two flux system with null point – generic coronal topology

3D Breakout Model

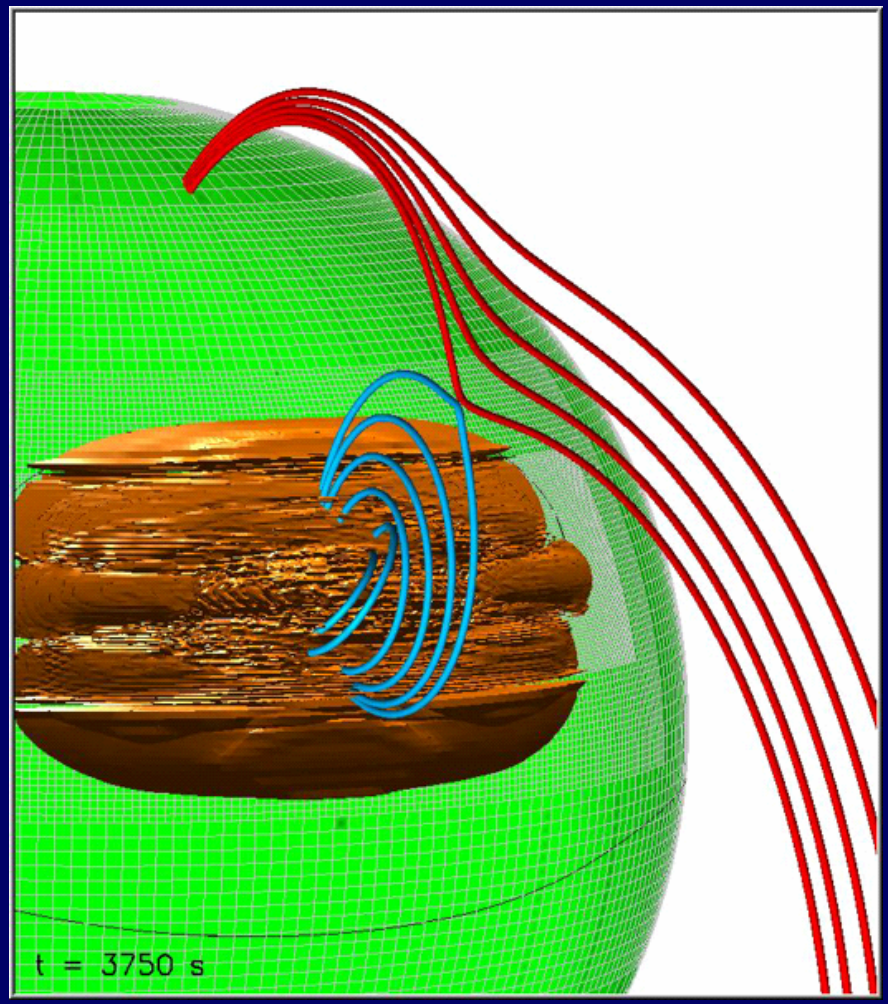


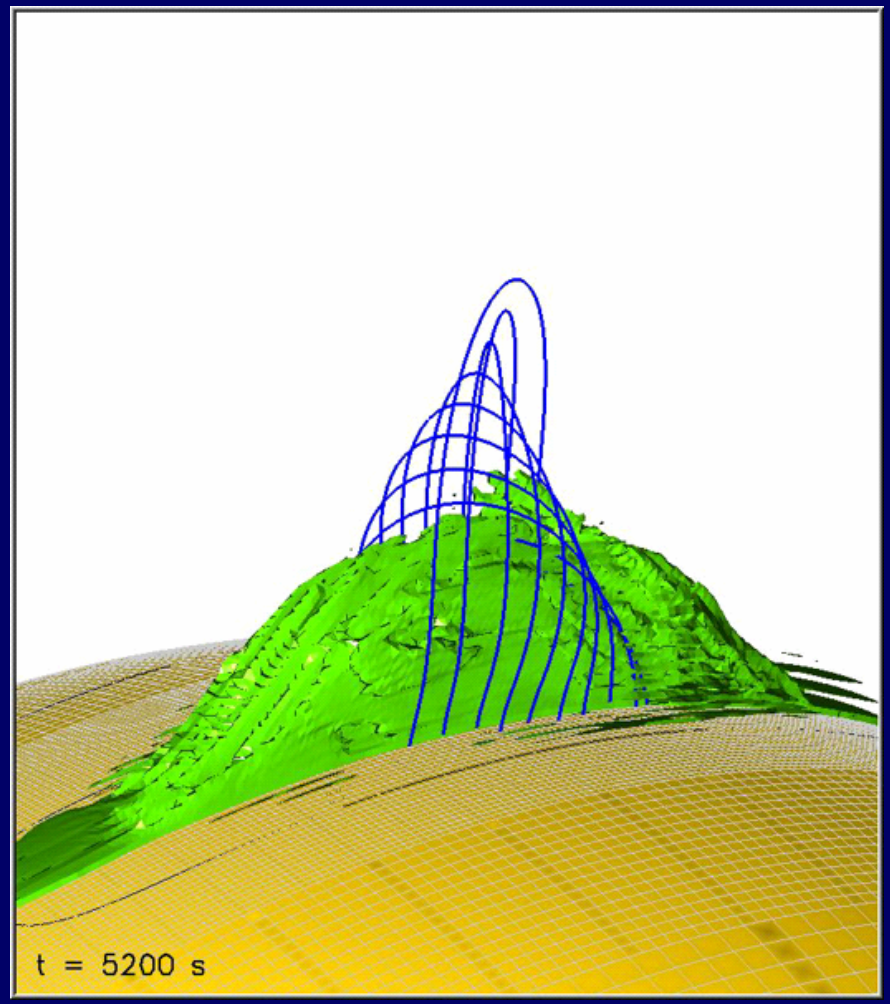


(from Lynch et al 2005)

- Eruption similar to axisymmetric case, except that all field lines remain connected
- Velocities > 1,000 km/s
- ONLY form of B-stress that will yield eruption!

3D Reconnection in Breakout Model





- Breakout reconnection occurs over large area
  - Requires strong deformation of null
- Flare reconnection appears very efficient

Issues for Resistive Models

- Tether-cutting: Filament generally appears to erupt before onset of flare reconnection
  - SDO may add more definitive constraints
- Breakout: No general evidence of pre-eruption reconnection / coronal dynamics
  - Probably best observed in radio
  - Perhaps observable in L-S coronal B
  - Again need close coupling theory/obs.