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

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

(MDI, and EIT/MDI)
- Magnetic connection of filament to overlying corona unclear
- Flare heating follows filament activation
“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.)

(b) t=430
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)
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**

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

(Moore et al)
• 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

(from, DeVore et al, 2005; Aulanier et al, 2005)
2.5D Breakout Model

- 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

(From J. 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?

(From Gao 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
• 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!

(from Lynch et al 2005)
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.