THE PRE-ERUPTIVE BEHAVIOR OF CORONAL SIGMOIDS: A TOPOLOGICAL VIEW

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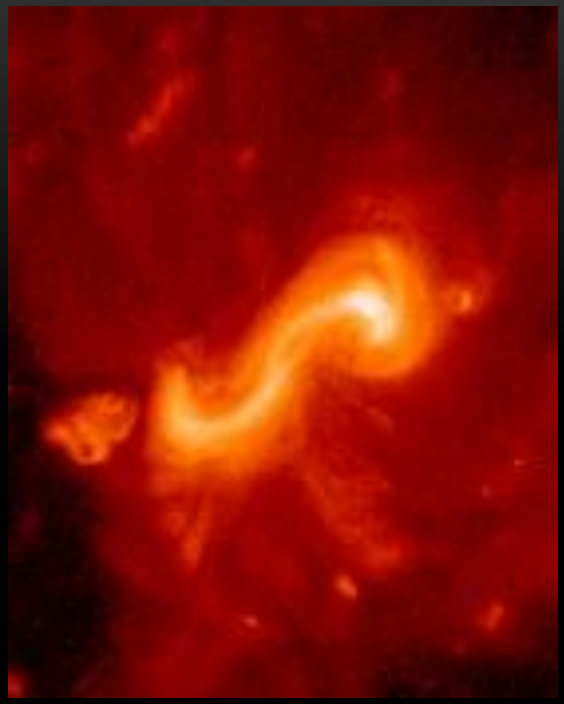
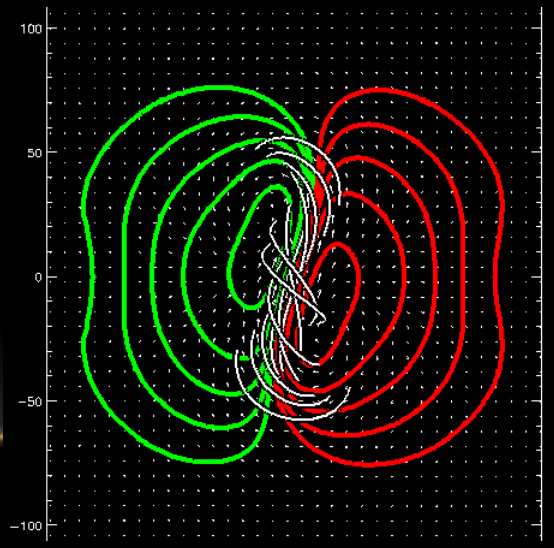
OUTLINE

- Sigmoids in general
- Magnetic field modeling – motivation
- The flux rope insertion method
- The topology analysis
- The sigmoidal story – from formation to flare ribbons

SIGMOIDS IN GENERAL

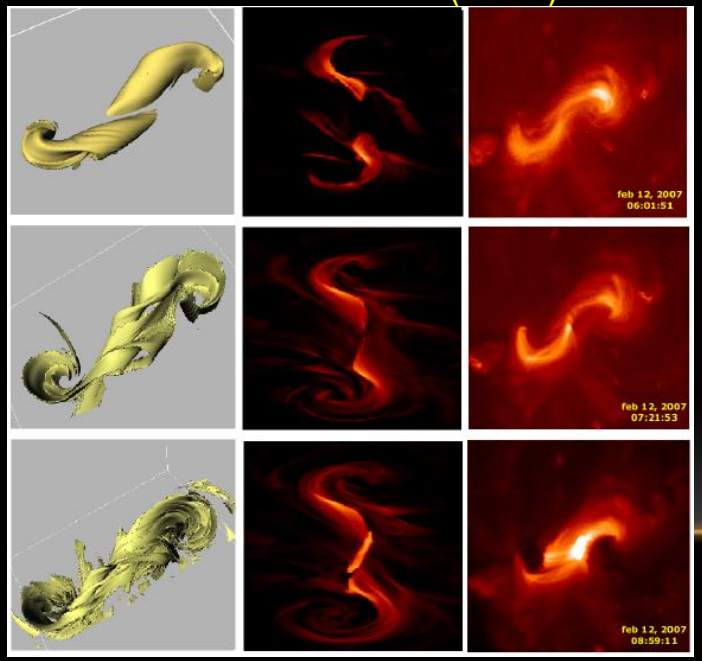
- Transient or long-lasting S (south) or inverse-S (north) shape
- Twisted and sheared magnetic field structures – great for storing magnetic energy
- Canfield et al. 1999 - 68% of eruptions originate in sigmoidal regions
- Often associated with H_α filaments, in dips of twisted flux ropes
- Best modeled by a weekly twisted flux rope in the core, held down by a potential arcade – Titov & Demoulin 1999



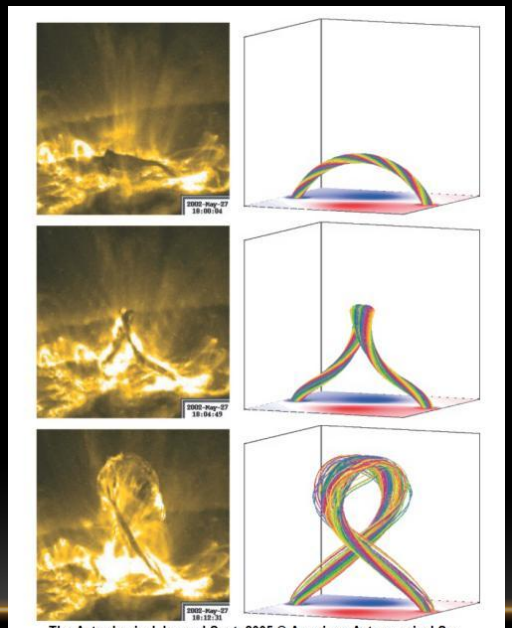


FLUX ROPES IN THE STANDARD FLARE MODEL

- The standard model
- Need loss of equilibrium
- Ideal instabilities – kink, torus
- Reconnection
- Archontis et al (2009)



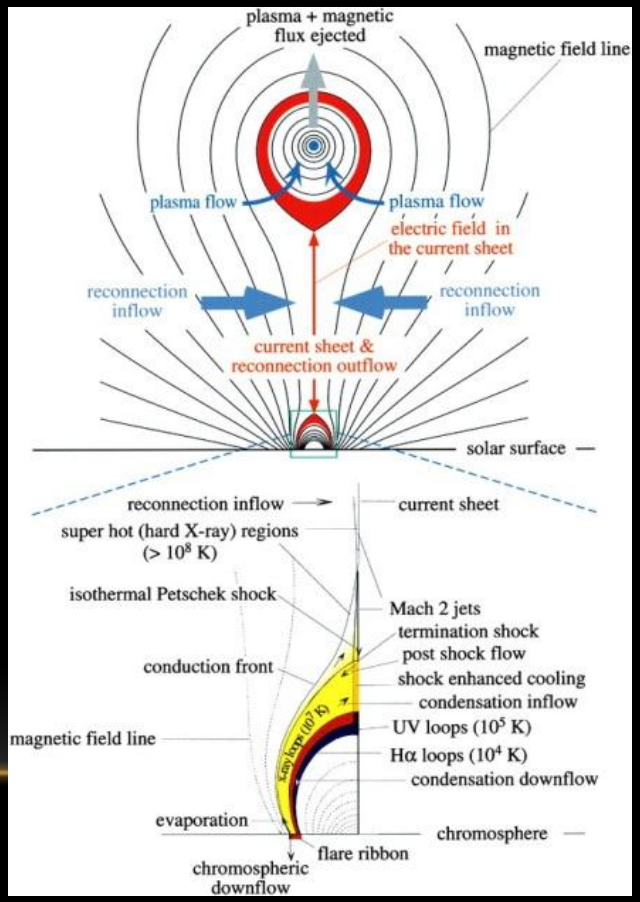
Torok & Kliem 2005



The Astophysical Journal Sept. 2005 © American Astronomical Soc.

FIG. 1.—*Left*: *TRACE* 195 Å images of the confined filament eruption on 2002 May 27. *Right*: Magnetic field lines outlining the core of the kink-unstable flux rope (with start points in the bottom plane at circles of radius $b/3$) at $t = 0$, 24, and 37. The central part of the box (a volume of size 4^3) is shown, and the magnetogram, $B_z(x, y, 0, t)$, is included.

Lin 2004

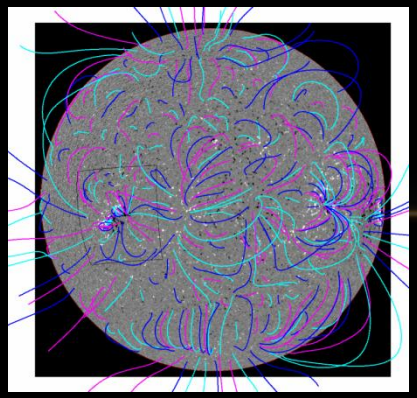
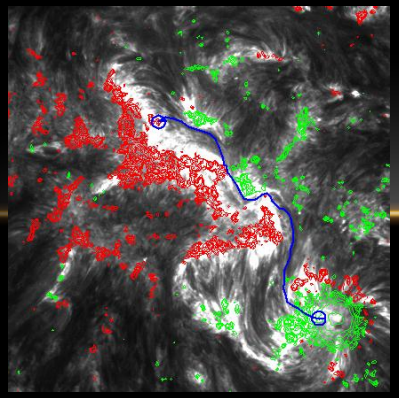
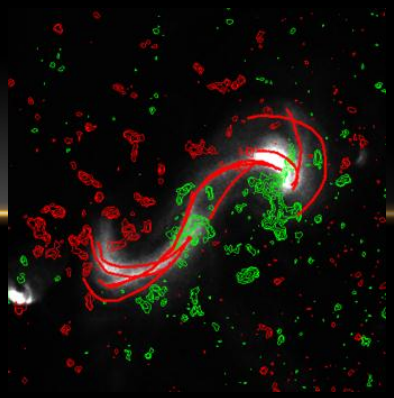
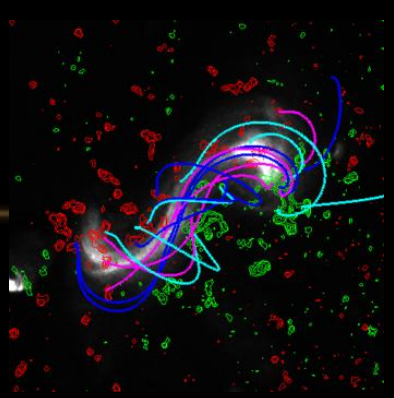


MAGNETIC FIELD MODELING

- Need model of the magnetic field when region is on disk
- Corona in equilibrium – force-free, **J** II **B**, $\nabla \times \mathbf{B} \approx \alpha \mathbf{B}$
- NLFFF - torsion parameter α constant along field lines, different for different FLs
- NLFFF models most accurately describe the sheared and twisted core AND the potential arcade
- Based on real magnetogram data → gives the 3D field in the corona
- We can study:
  - Field topology and current build-up
  - Can estimate flux and energy budgets
  - Conditions for instability, probable reconnection sites

THE FLUX ROPE INSERTION METHOD

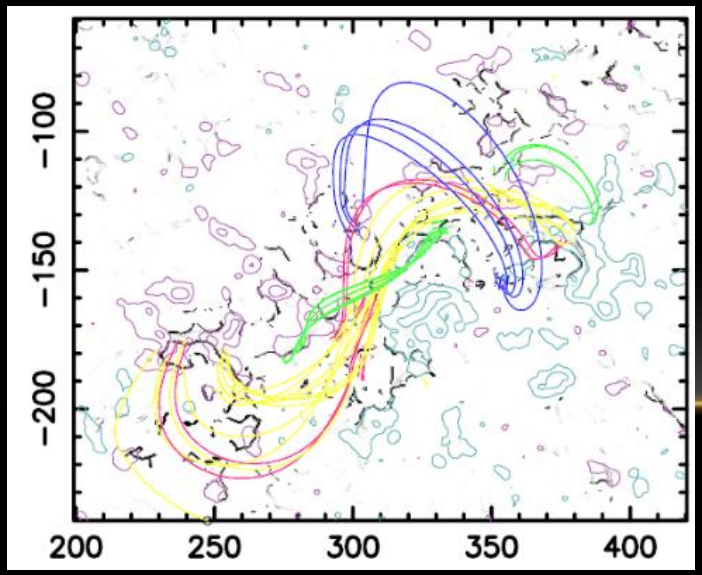
- van Ballegooijen 2000, 2004, 2007
- Global potential field extrapolation from SOLIS Carington magnetogram B.C.
- Potential field extrapolation from a HiRes LoS magnetogram (MDI or HMI)
- Clear up a cylindrical cavity with no B
- Insert flux rope as a combination of axial and poloidal flux – use filament path as guidance
- Relax by magnetofriction with hyperdiffusion
- Fit model to observed coronal loops

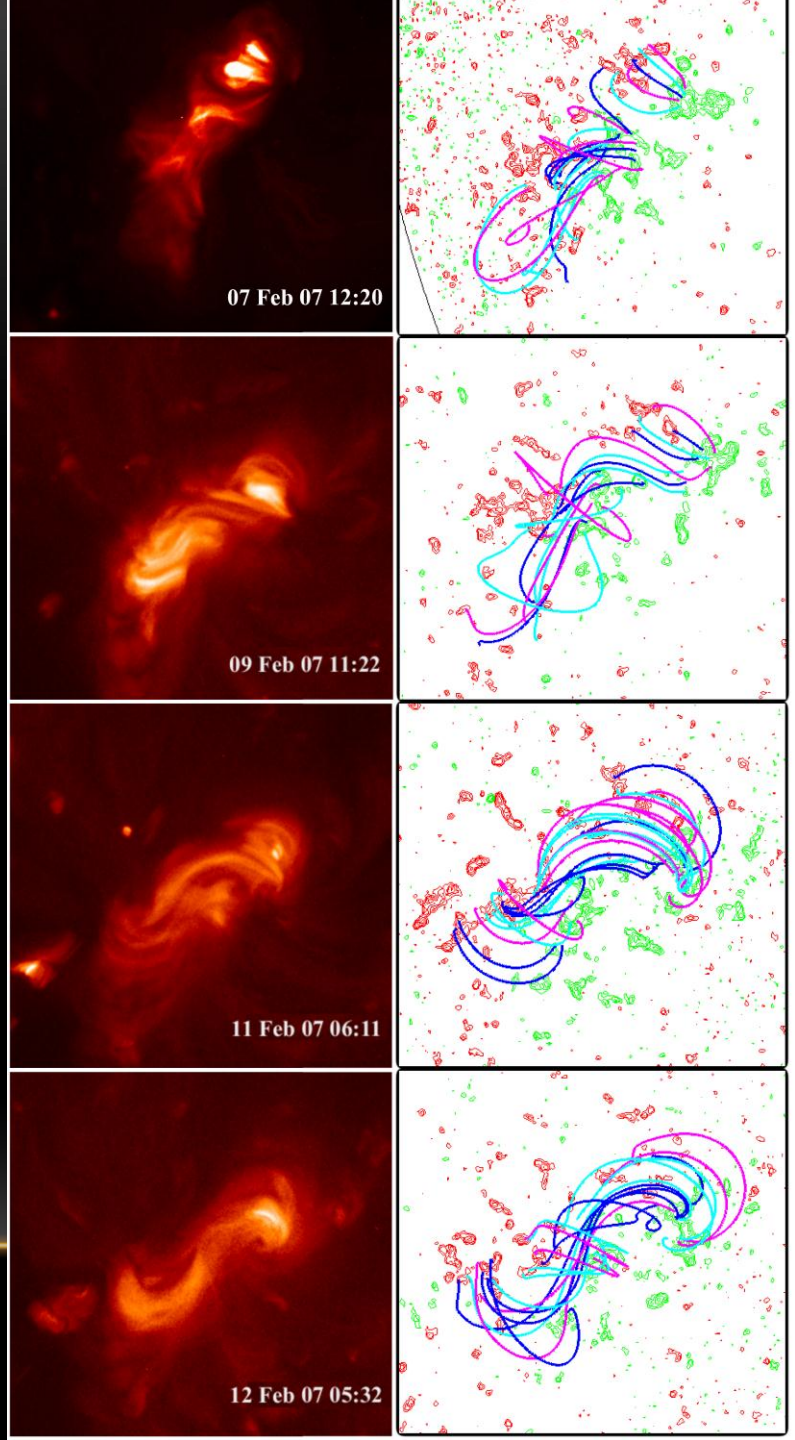





A NLFFF MODEL FOR FEB 2007 SIGMOID

- Evolution over 7 days
  2 eruptions – Feb 07, 12

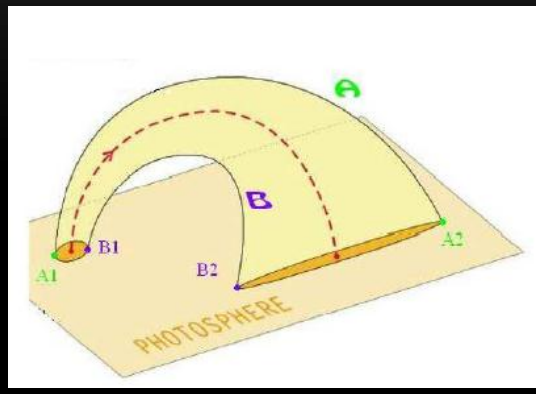
  Types of field lines:
  - J - shaped
  - S- shaped
  - Sheared arcade
  - Potential arcade
  - Short under the FR

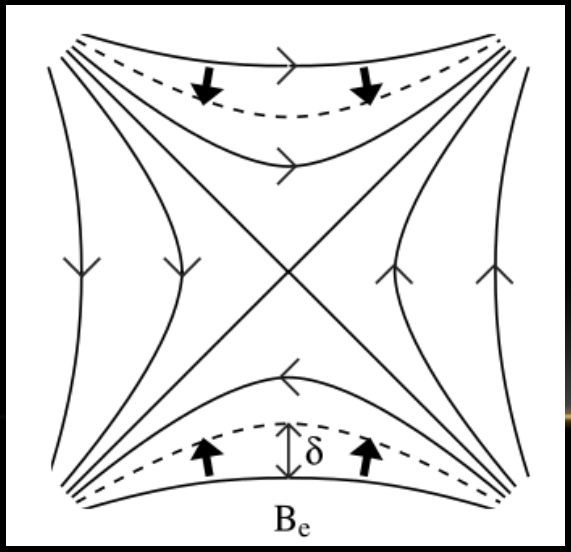


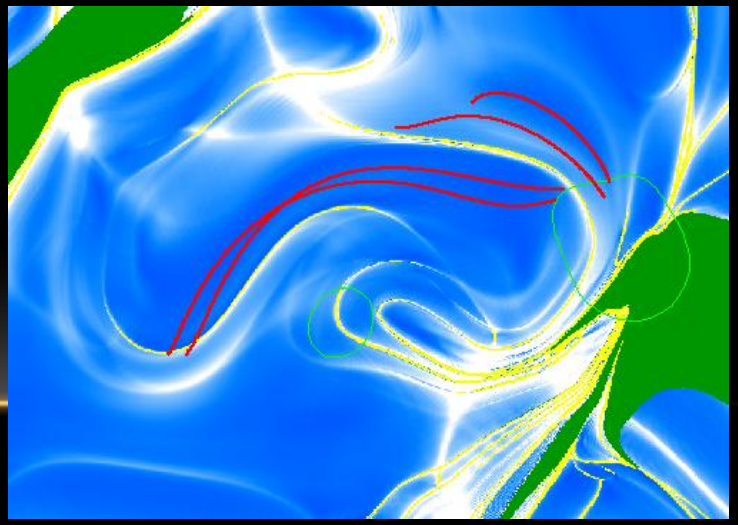


TOPOLOGY ANALYSIS

- Gradient of the mapping from one set of neighboring footpoints to the other – Priest & Demoulin 1995, Demoulin et al.
- Circle maps into ellipse - squashing factor (Q) – Titov '99, 07
- Separatrices – discontinuous mapping, infinite Q
- Quasi-Separatrix Layers (QSLs) – where field line linkage drastically changes but is still continuous, large but finite Q
- Current sheet formation at QSLs – preferred site for reconnection

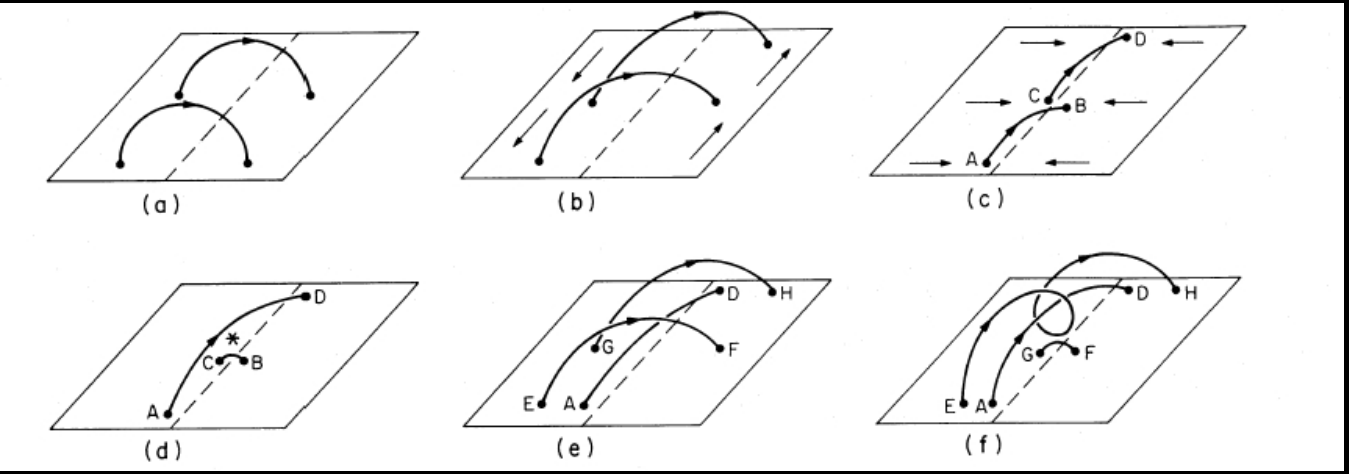




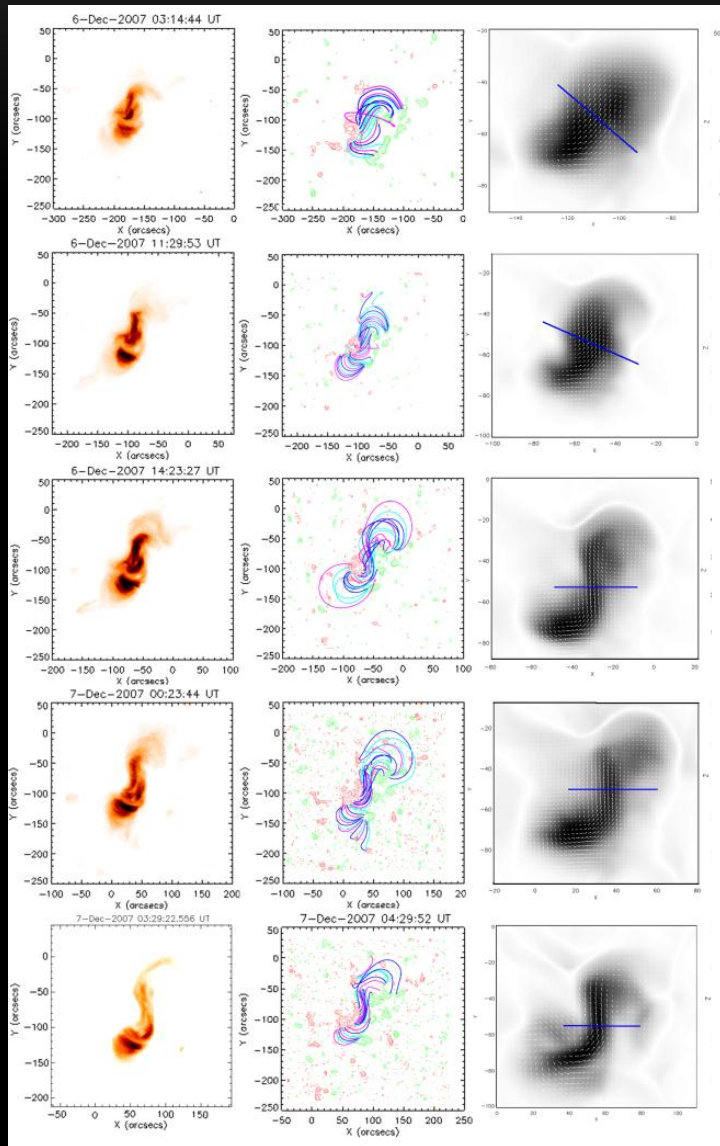


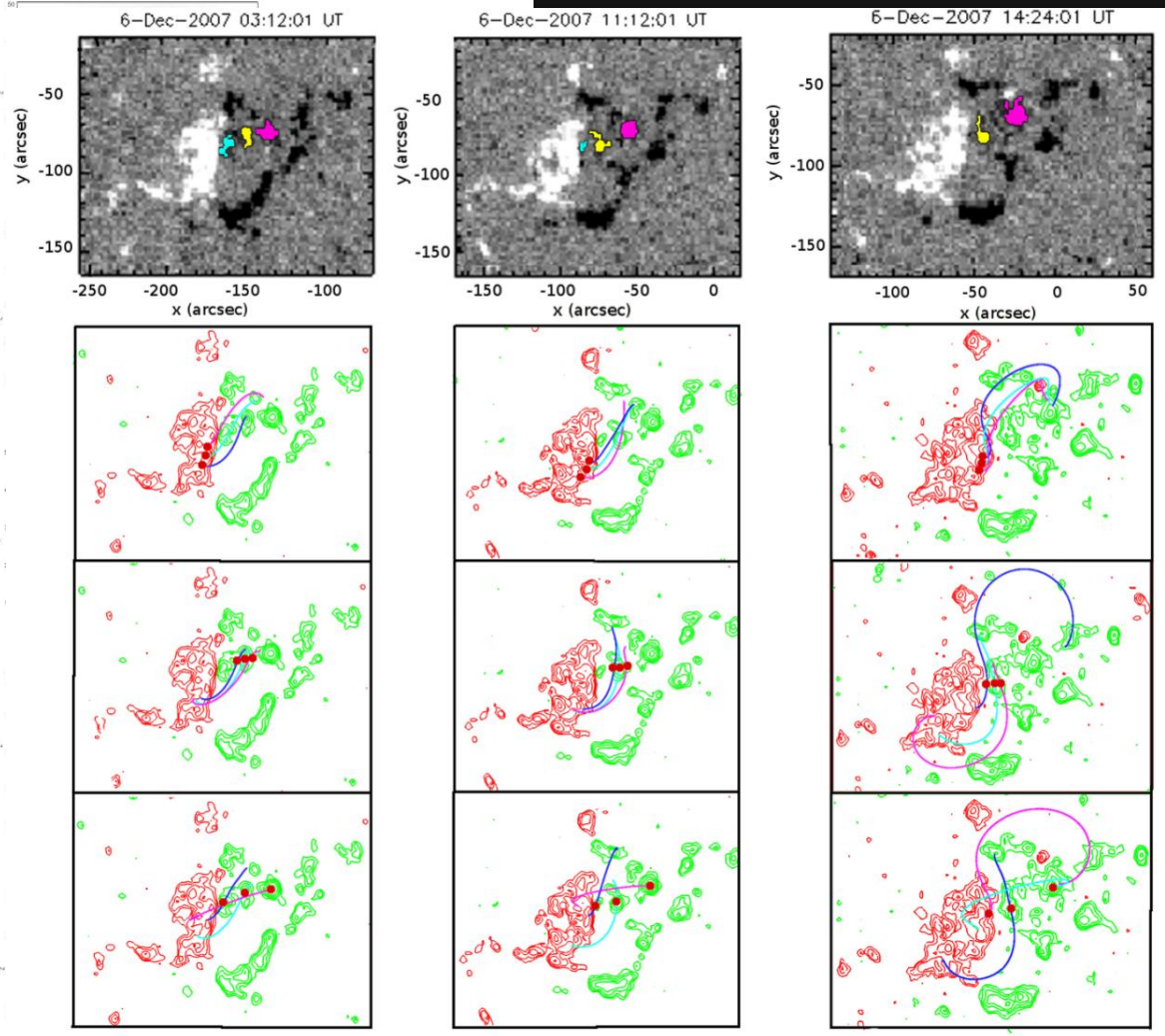
THE STORY OF CORONAL SIGMOIDS: FORMATION AND EVOLUTION

- Flux rope formation via flux cancellation in decaying AR
- (van Ballegooijen & Martens 1989)



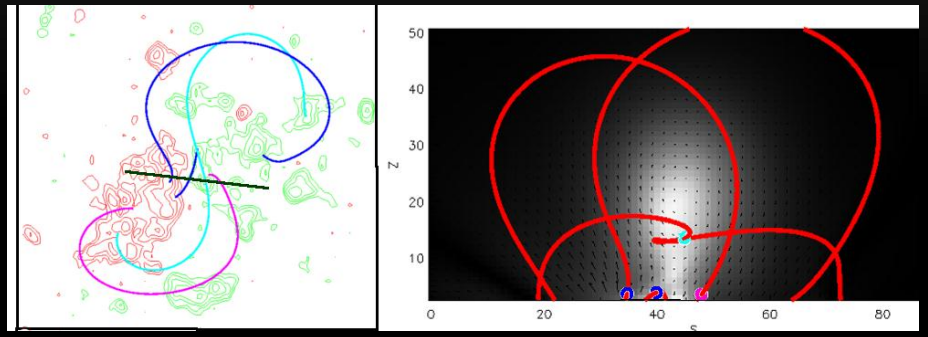
AN EXAMPLE OF FLUX CANCELLATION



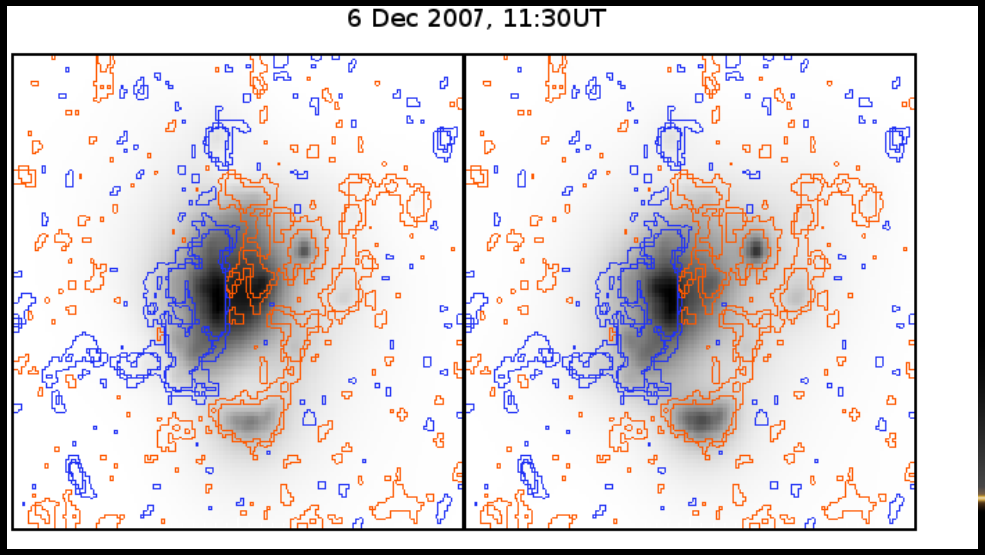


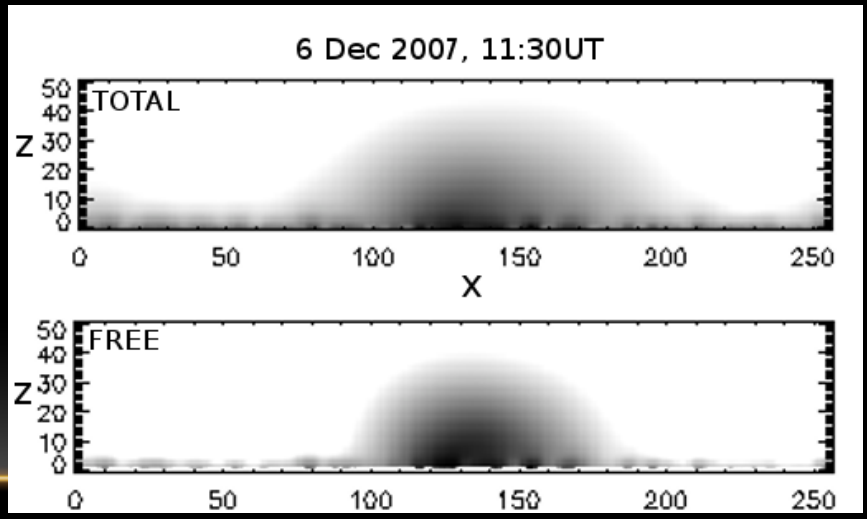
THE STRUCTURE AT THE FLUX CANCELLATION SITE PRIOR TO ERUPTION

- Field line types at the flux cancellation site



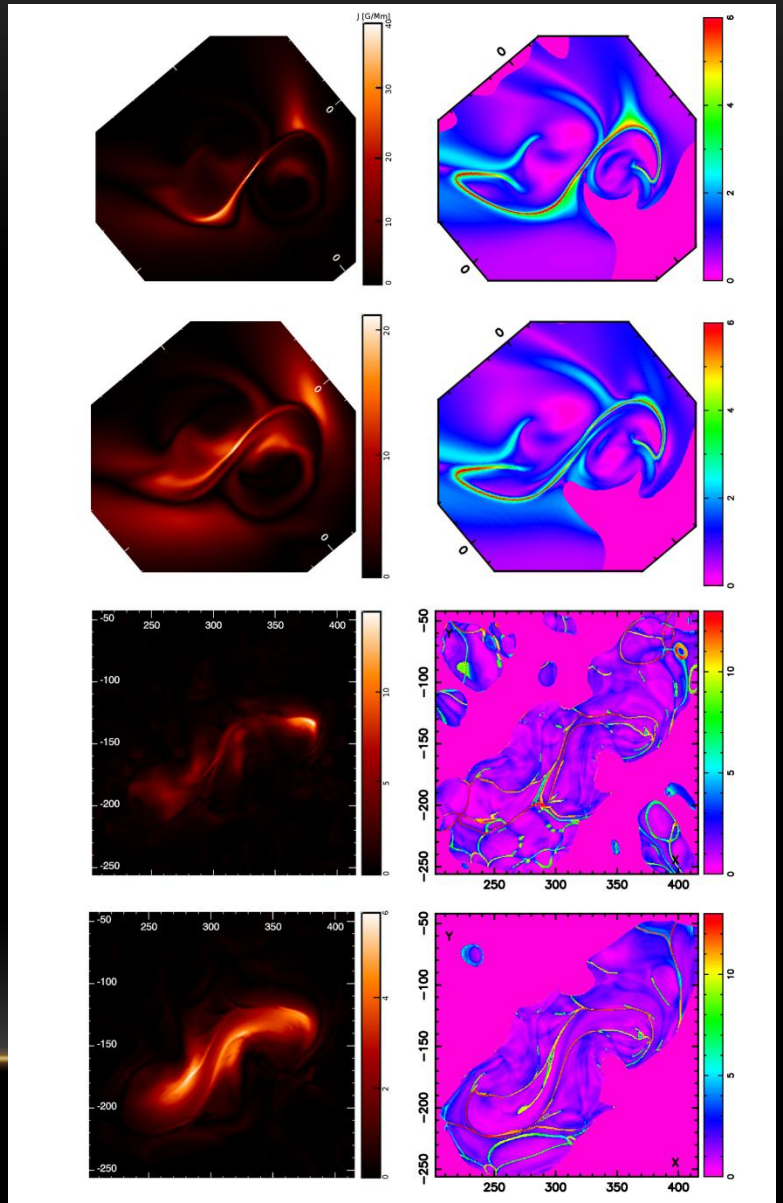
- Free energy at the cancellation site





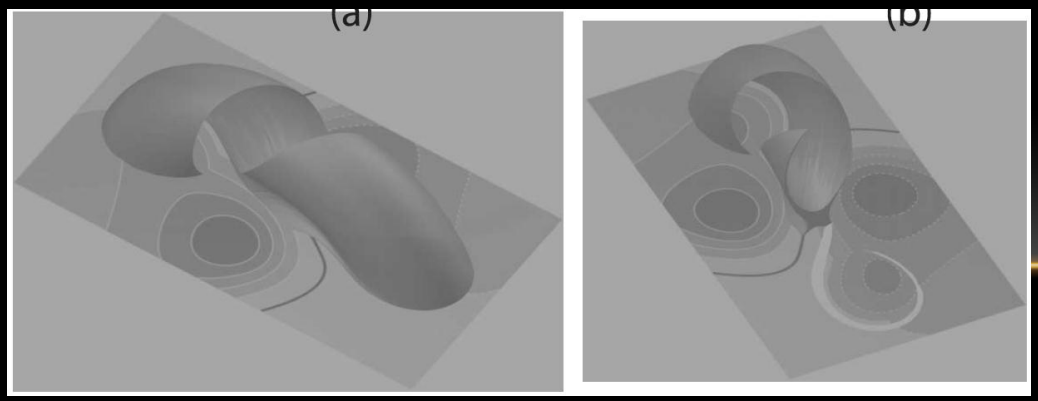
TOPOLOGYCAL STUDY OF THE PREERUPTIVE CONFIGURATION: QSL MAPS

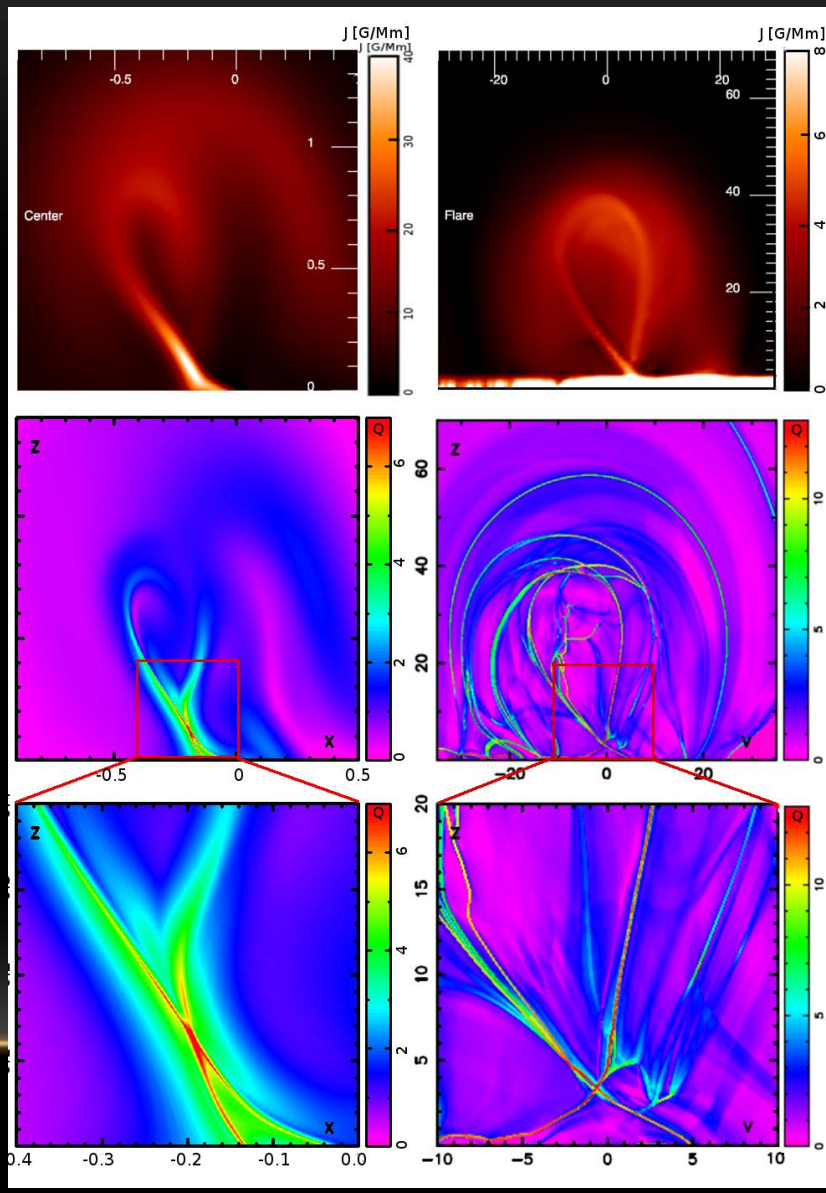
- QSLs coincide with ridges in the current density
- Both QSLs and current concentrations outline the FR cavity
- Current is more diffuse in NLFFF model due to relaxation process
- MHD simulation has footpoint motions – hence sharp currents at QSLs



HYPERBOLIC FLUX TUBE

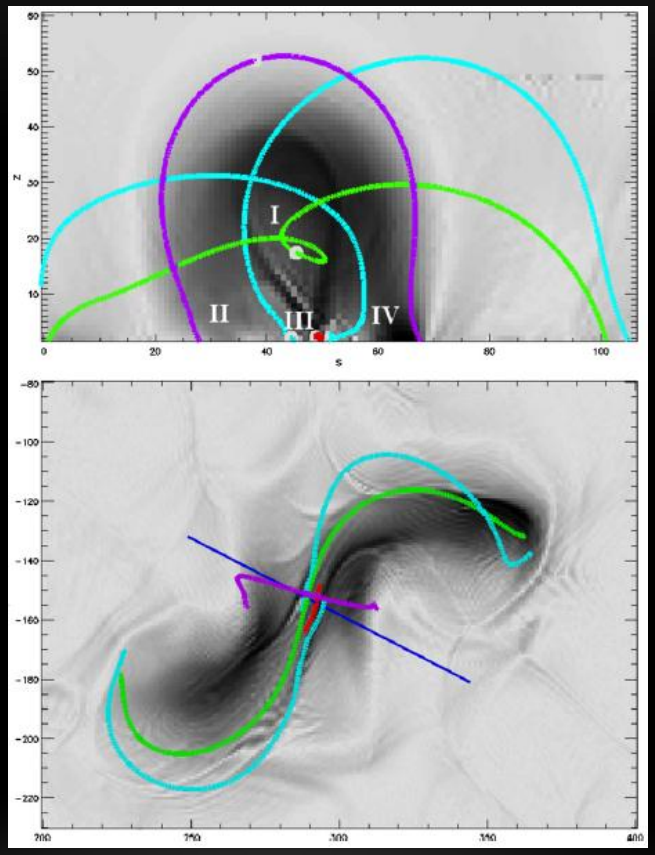
- Highest Q region in the volume (Titov '07)
- QSL folds on itself
- 4-way saddle point – like an X-line
- Reconnection can happen for large Q
- HFT appears at the location of the eruption in both cases

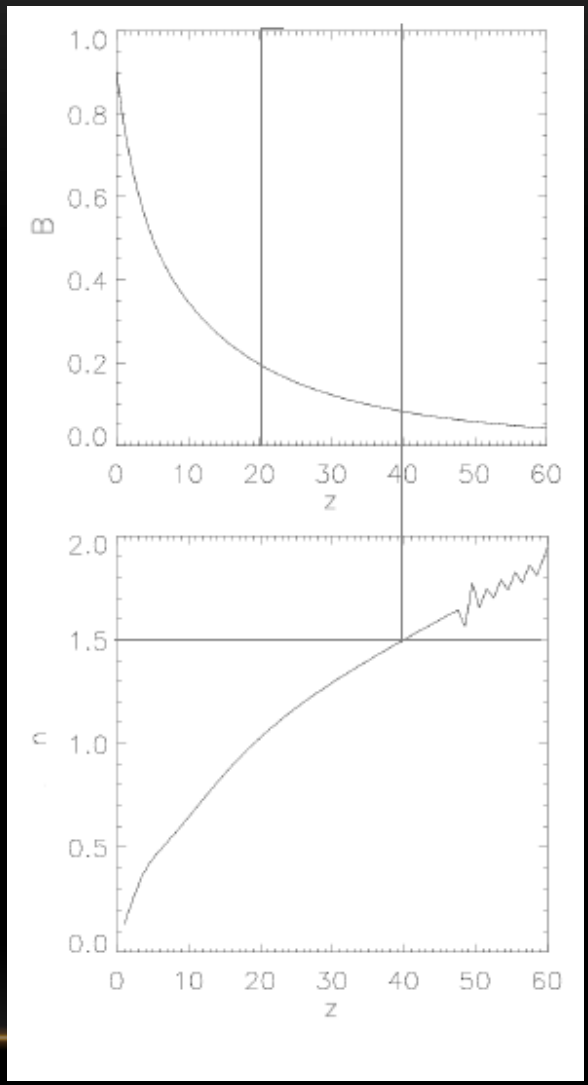




THE CME SCENARIO

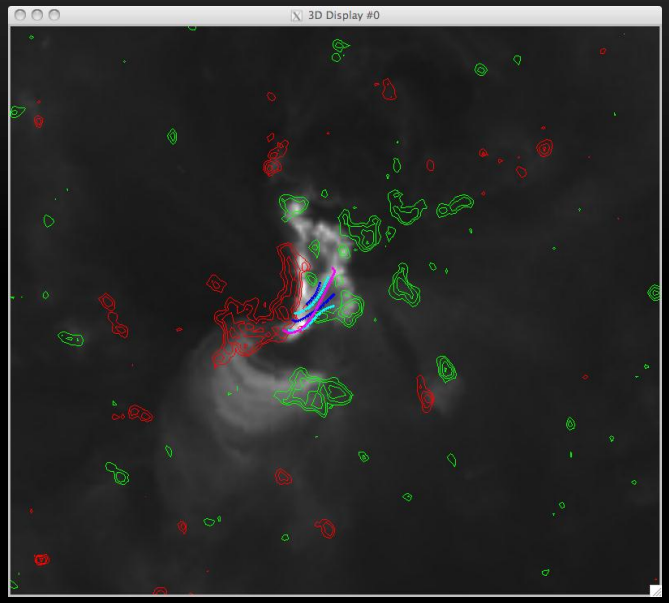
- The feedback between torus instability and reconnection at the HFT
- Reconnection at the HFT elevates the FR more and it enters the torus instability regime in the MHD simulation (Aulanier et al. 10)
- Torus instability when the potential arcade falls off with heights as n=dlnB/dlnz=-1.5
- Evidence for possible torus instability in the modeled 3D magnetic field
- n=1.5 at the edge of the FR, continued expansion will lead to torus instability

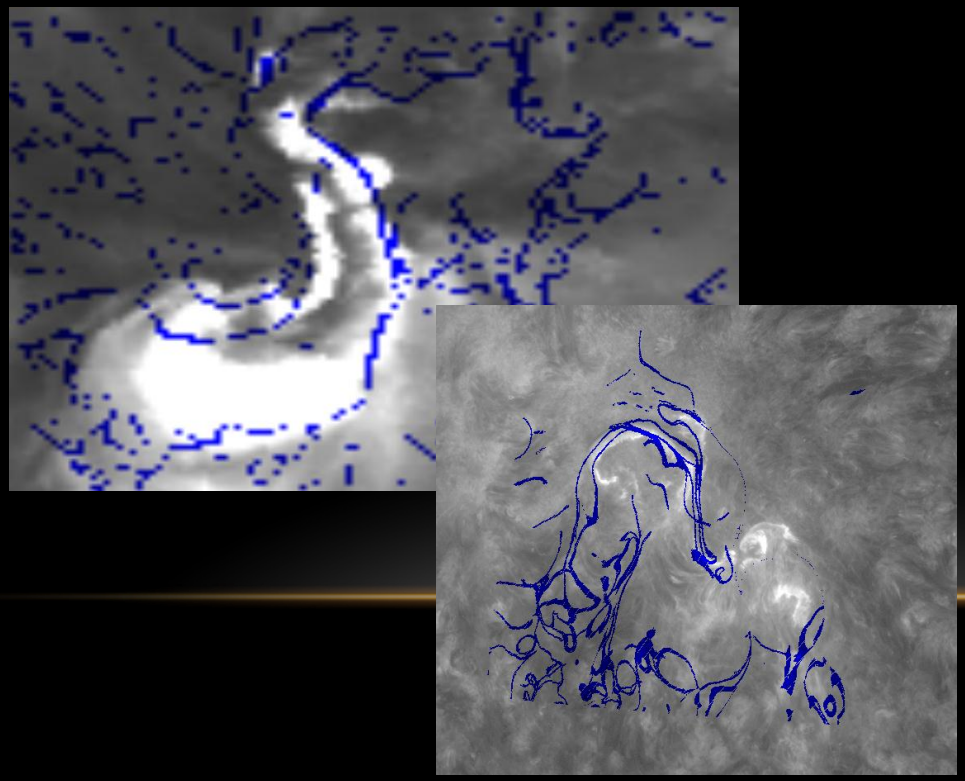


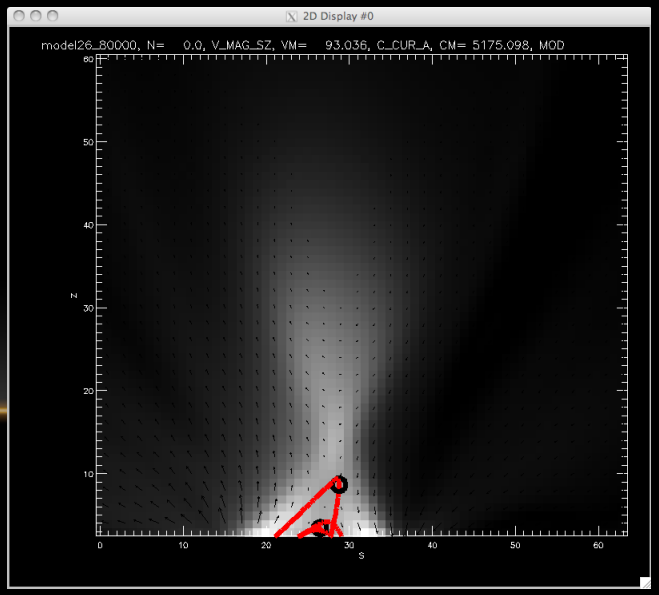


POST FLARE FEATURES IN A TOPOLOGICAL CONTEXT

- Compute unstable models
- Flare ribbons match QSL close to the surface
- Post-flare loops match loops under the rising flux rope
- Dimmings (transient CHs) are also matched







CONCLUSIONS

- We study the formation, evolution, and eruption of coronal sigmoids
- Formation mechanism by flux cancellation – will be confirmed by sigmoid catalog
- Application of QSL maps to understanding the sigmoid structure over time
- Found robust topological features – tracer of unstable behavior
- QSLs can explain fare and CME-related features such as ribbons, post-flare loops, and dimmings
- Agreement with MHD simulation
- Need more test cases