# The Evolution of Solar Sigmoidal Active Regions

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> SPD Meeting 10 July, 2013

# Sigmoidal active regions

- S or inverted S-shape in X-rays
- Transient or long-lasting
- Often associated with filaments
- Modeled as flux ropes held down by a potential arcade
- Canfield et al. (1999, 2007) majority of eruptions in sigmoids







## Some questions about sigmoids

- What is their magnetic field structure and topology?
- How do sigmoids form? How is the flux rope built up?
- What is the free energy content and how is it stored?
- Eruption mechanisms
  - What instabilities play a role in the eruptions?
  - Is reconnection important? If so locate probable sites for reconnection and instabilities?
  - How can we reconcile the model for sigmoid eruptions with the standard model for flares/CMEs?

- Need model of 3D magnetic field when region is on disk
- Non-linear Force Free Field model (NLFFF)
- The flux rope insertion method van Ballegooijen (2004)
- Coronal field constrained by photospheric **B** and coronal observations
- Estimate flux and energy budgets
- Current distributions
- Field topology
- Conditions for instability



#### Evolution by Flux Cancellation Savcheva et al. (2012c)

- Transition from sheared arcade to flux rope (Dec 2007)
- Current evolves correspondingly
- Flux cancellation builds flux ropes
- Free energy increases, stored in FR
- Van Ballegooijen & Martens (1989) picture for building flux ropes and storing magnetic free energy

(e)

(f)



# Magnetic field topologies

- Topology persists under smooth deformations
- Connectivity domains
- Gradient of the mapping of a set of neighboring footpoints from one boundary to the other – Priest & Demoulin '95, Demoulin et al. '96, '97
- Circle generally maps onto ellipse squashing factor (Q) Titov '99, '02, '07
- Quasi-Separatrix Layers (QSLs) where field-line linkage drastically changes, large but finite Q





### QSL maps Savcheva et al. (2012a, b)

- First QSLs from a data-driven NLFFF model
- Large complexity in B = large complexity in QSL
- Comparison with MHD simulation (Aulanier et al 2010)
- Large complexity but similar features
- Sharp current sheets at main QSLs



## The Hyperbolic Flux Tube Savcheva et al. (2012a, b)

- Inverted tear-drop shape
- HFT appears shortly before flares
- At the location of the flare
- Robust topological feature





## The eruption scenario Savcheva et al. (2012a, b)

- 2 J-shaped field lines meet at HFT and reconnect
- Flux is transferred to flux rope
- Flux rope is elevated
- Torus instability kicks in
- n = -dlnB/dlnz > 1.5 at the edge of the flux rope
- Not enough twist for kink



Flare ribbons and QSL maps Savcheva et al. (2013a, in prep)

- Chromospheric
  QSLs from unstable
  models match flare
  ribbons
- QSLs and ribbons move away in time
- Extension of the standard model to 3D
- Implications to reconnection and SEP studies

2007/02/12



2007/12/07



2010/04/08



2010/08/07



2012/05/08





## Conclusions and Future work

- NLFFF models accurately produce observed coronal features
- Flux cancellations builds flux ropes and free energy in decaying active region (long-lasting sigmoids)
- First topology analysis of NLFFF
- Topological comparison with an MHD simulation
- Identified robust topological features that can be used as eruption predictors
- Reconnection at HFT torus instability feedback scenario for eruption
- 3D Extension of standard flare/CME model
- Future plans
  - Using NLFFF models as initial conditions to high-resolution partial Sun MHD codes to study the formation and evolution of sigmoidal regions
  - Using NLFFF models as initial conditions to global MHD codes to propagate CMEs, constrained by observations, into the corona and heliosphere
  - Provide input to 3D reconnection and SEP studies

# Thank you!

## NLFFF modeling The flux rope insertion method

- van Ballegooijen (2004) the Coronal Modeling System (CMS)
  - Potential field extrapolation (data)
  - Insert flux rope along a filament (model)
  - Relax to force-free state via magnetofriction (model)
  - Make a grid of models, then match to observed coronal loops (data)



## Ribbon separation and QSL evolution



18:09 UT - 60,000



18:24 UT - 90,000





18:04 UT - 45,000

