# Prominences and the Corona: Energetic and Magnetic Stability

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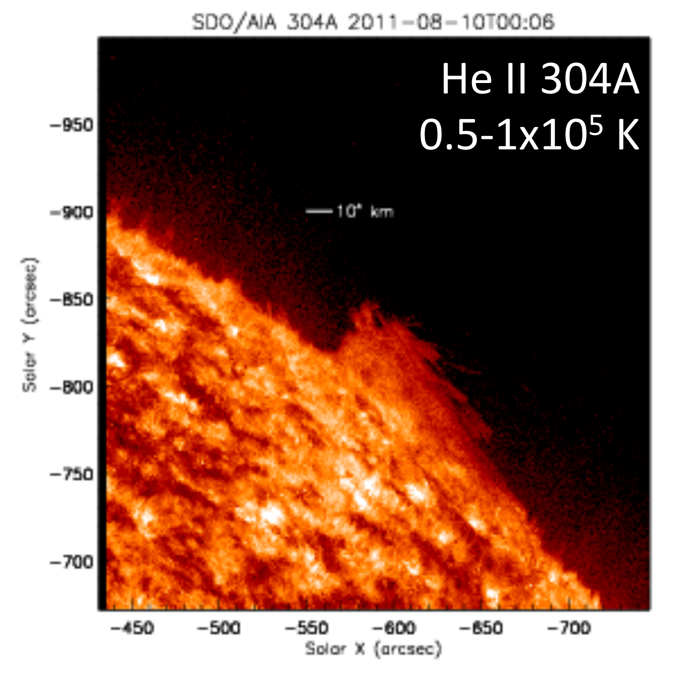
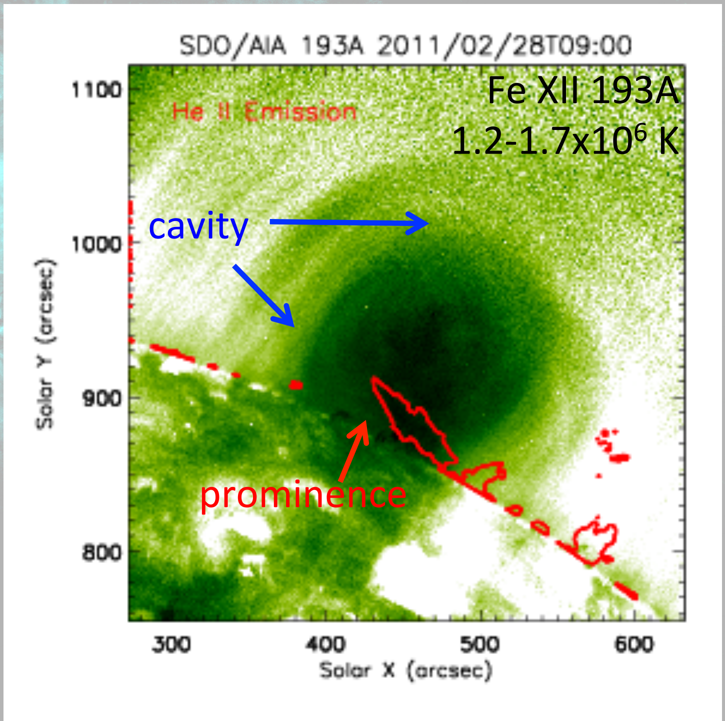
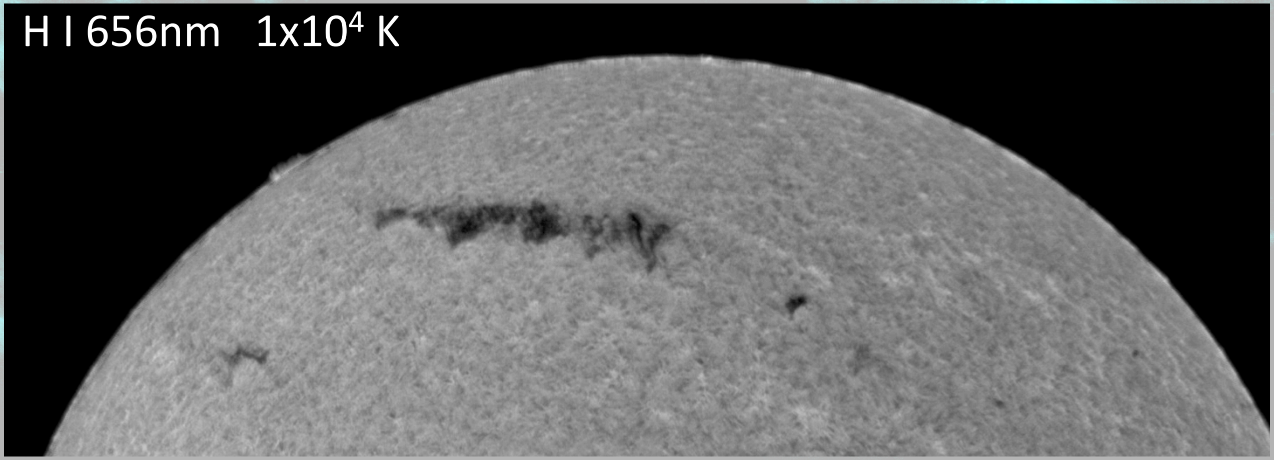
# Prominence-Cavity System

- Solar Dynamics Observatory (SDO)
- Extreme ultraviolet (EUV) emission lines

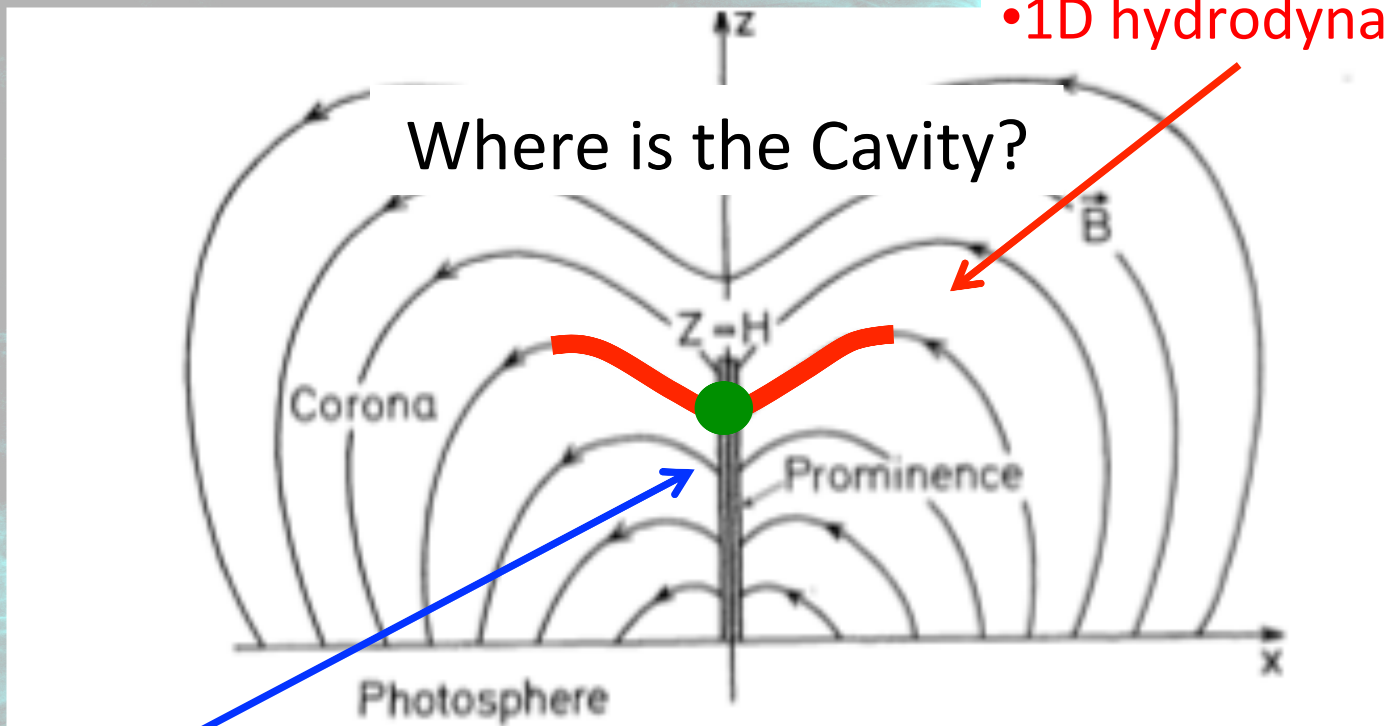


# Prominence Cartoon

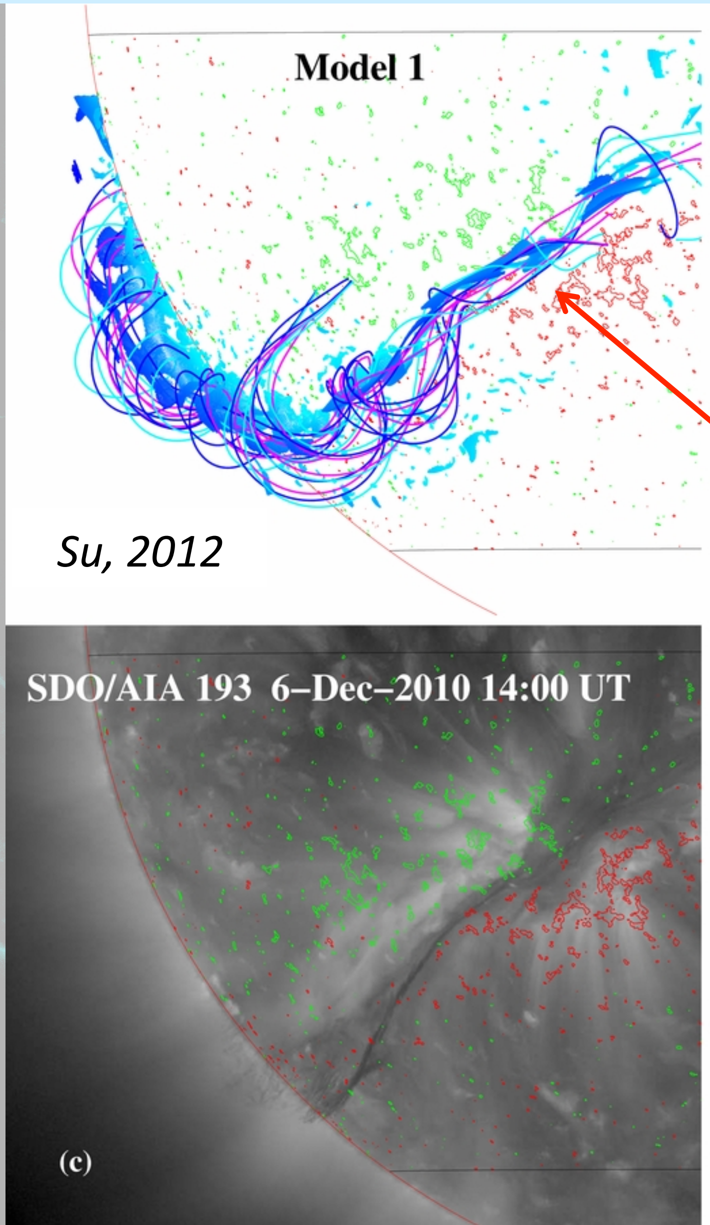
Mass Source
- Thermal Instability
- 1D hydrodynamic models




Force balance
- Magnetic dips are graviational wells
- 3D MHD models

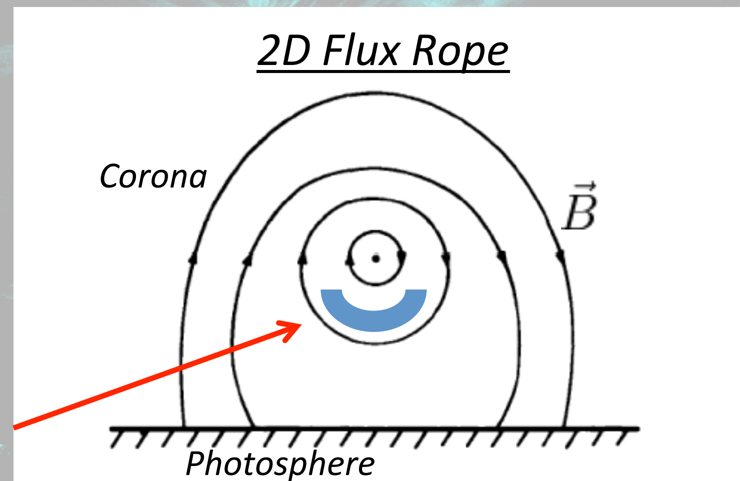
Anzer 1972

# Dipped Magnetic Geometry




*Su, 2012*

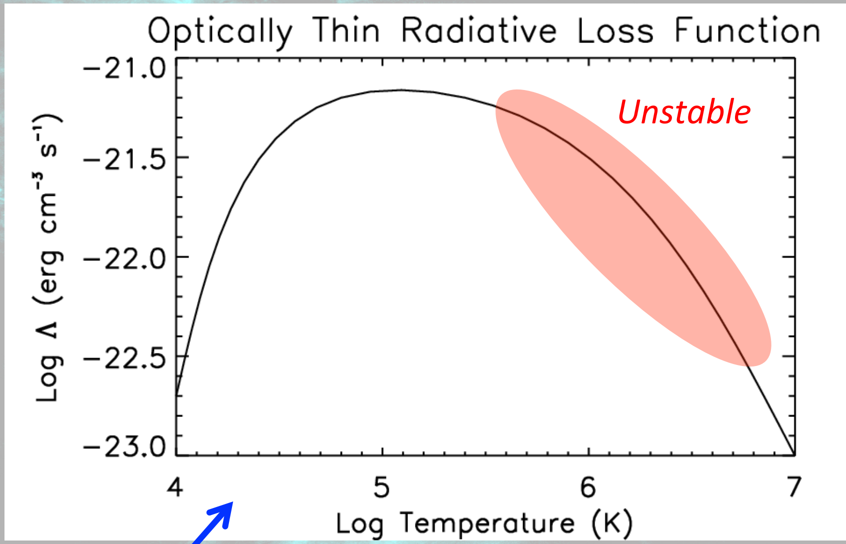
Dips




- The magnetic field must support the prominence against gravity
- Dips=stressed magnetic configuration

# Coronal Equilibrium and Thermal Instability

- Coronal Energy balance: Heating-Conduction=0
- Thermal (radiative) Instability: Field, 1965; Meerson, 1996
  - Corona unstable to isobaric, long wavelength perturbation
  - Cooling time: $10^5$ s




Heating | Thermal conduction | radiation

$$E + \nabla \cdot \kappa \nabla T - n^2 \Lambda = 0, \ \nabla p = \mu n \mathbf{g}$$

energy equation (static) | momentum equation (static)

# Coronal Thermal Stability

*Eq. 1*

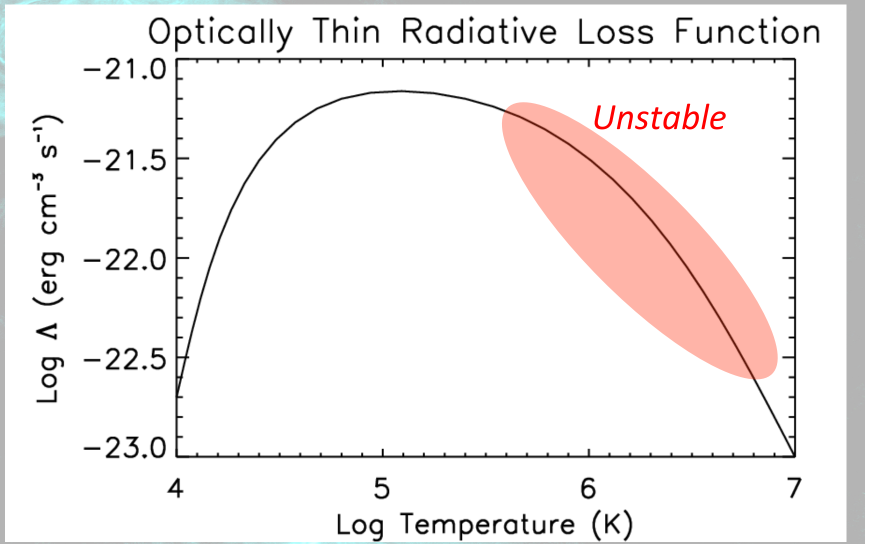
$$\frac{1}{\gamma - 1}\frac{dp}{dt} - \frac{\gamma}{(\gamma-1)}\frac{p}{\rho}\frac{d\rho}{dt} = E + \frac{d}{ds}\kappa\frac{dT}{ds} - n^2\Lambda$$

*Eq. 2*

$$a(t,s) = a_0 + a_1 \exp(\tau t - iks)$$

*Eq. 3*

$$\frac{\tau}{\gamma-1}p_1 - \frac{\tau c^2}{\mu(\gamma-1)}n_1 = k^2\kappa_0 T_1 - n_0^2 T_1 \frac{d\Lambda}{dT}_{T_0} - n_0 n_1 \Lambda_{T_0}$$




Isobaric Perturbation (Condensing Mode)

*Eq. 4*

$$p_1 = 0,\ n_1 > 0,\ T_1 < 0$$

Linear Growth Rate

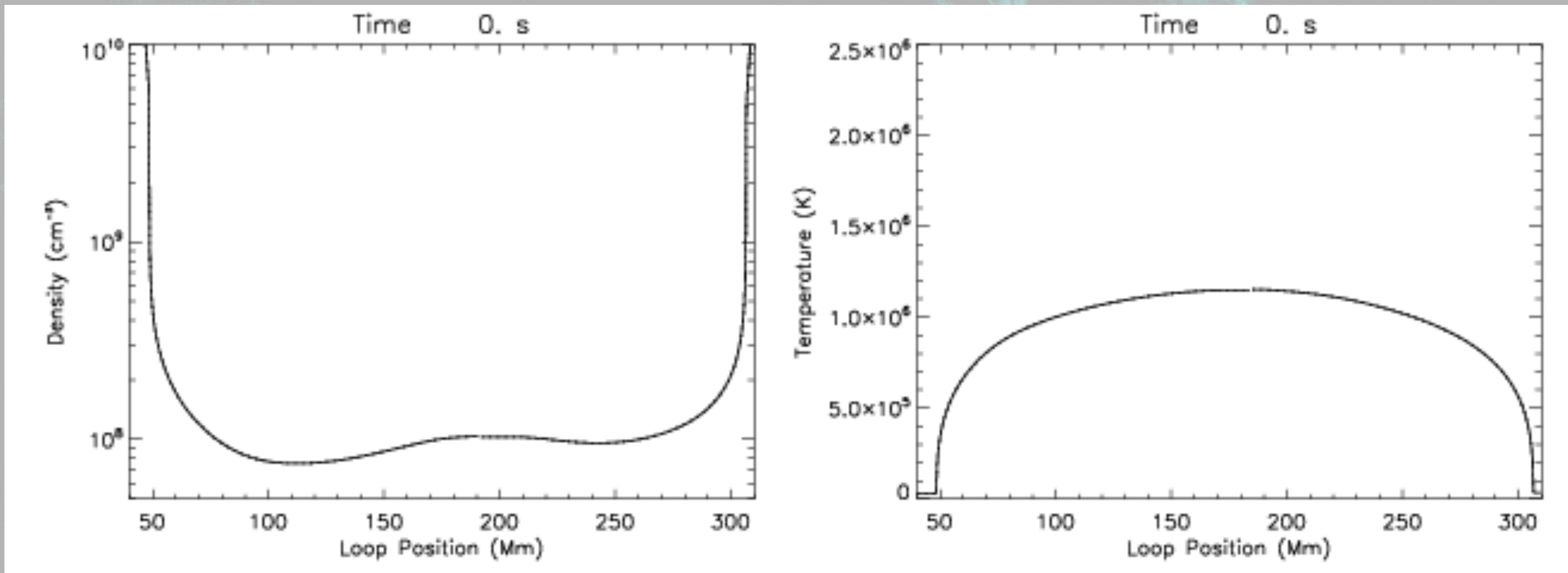
*Eq. 5*

$$\tau = (3\mu c^2 n_1/2)^{-1}\left(k^2\kappa_0 T_1 + 2n_0 n_1 \Lambda_{T_0} + n_0^2 T_1 \frac{\partial\Lambda}{\partial T}_{T_0}\right)$$

*Term 1* *Term 2* *Term 3*

Coronal plasma is susceptible to cooling-condensing thermal perturbation

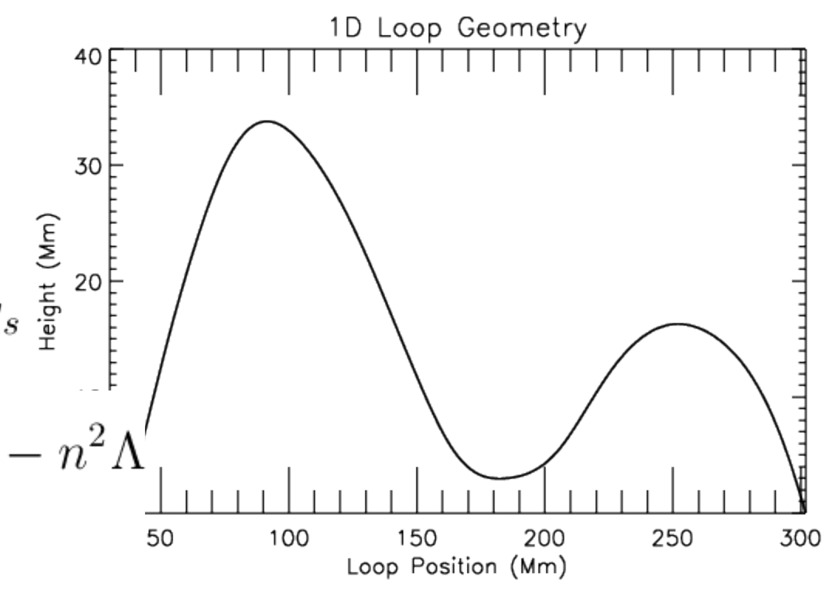
# Catastrophic Cooling




- Catastrophic cooling through increased heating? (Karpen,2001; Antiochos, 1999)
- 1D single-fluid hydrodynamics (ARGOS)

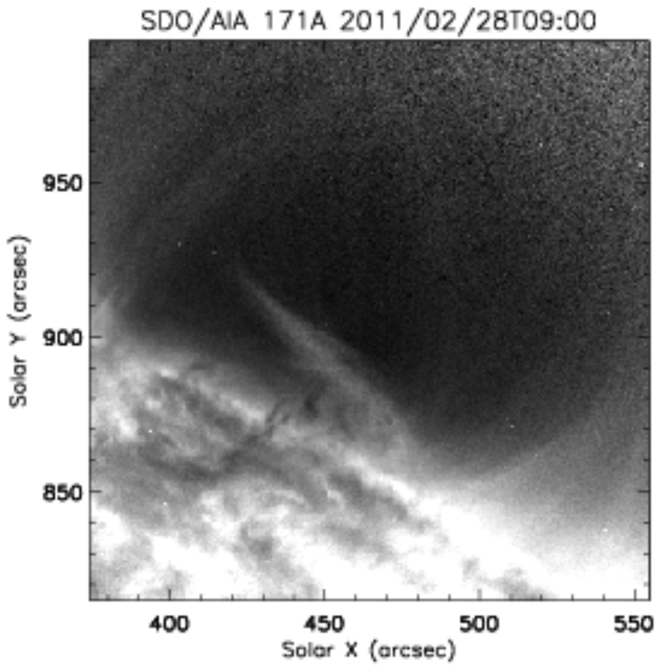
$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial t}\rho v = 0 \qquad \frac{\partial}{\partial t}\rho v + \frac{\partial}{\partial s}\left(\rho v^2 + p\right) = -\rho g_s$$

$$\frac{\partial}{\partial t}U + \frac{\partial}{\partial s}Uv + p\frac{\partial v}{\partial s} = E + \frac{\partial}{\partial s}\left(\alpha T^{5/2}\frac{\partial T}{\partial s}\right) - n^2\Lambda$$



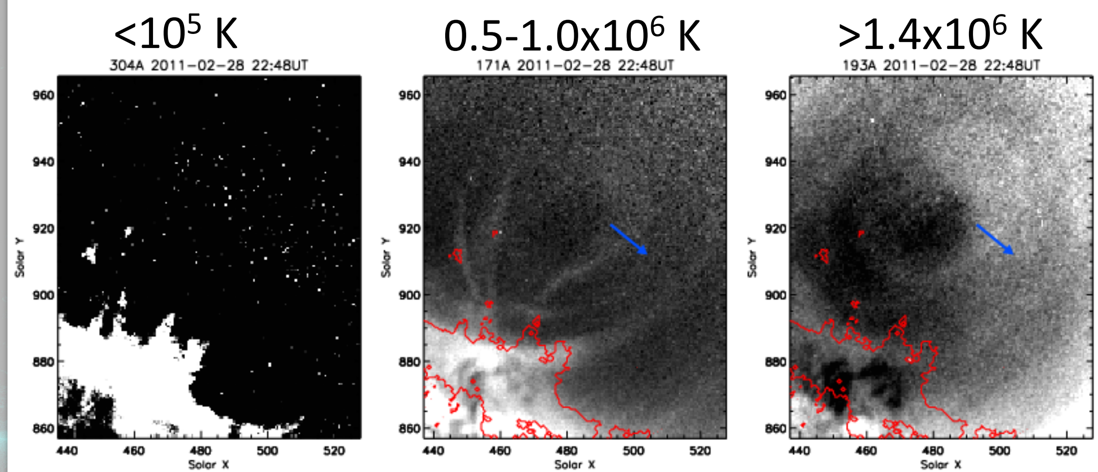
# Prominence-Corona Dynamics

Fe IX Emission (171A)



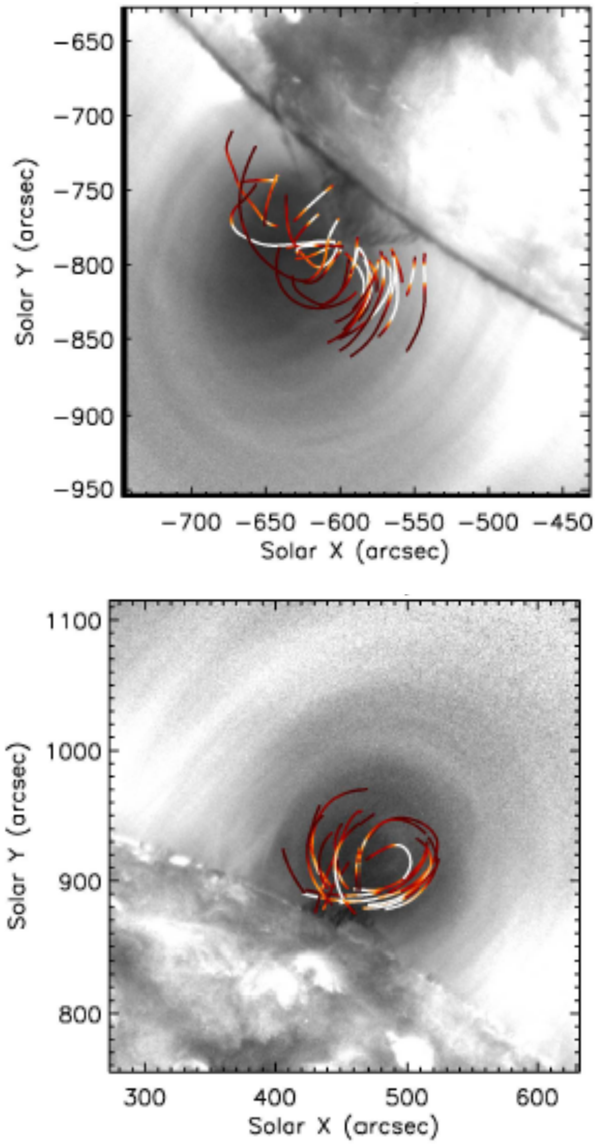

- Spectroscopic observations in extreme ultraviolet distinguish multi-thermal plasmas
- Timescale of dynamic emission implies field aligned processes
- How does the prominence connect to the cavity?

<u>Temperature Regimes</u>



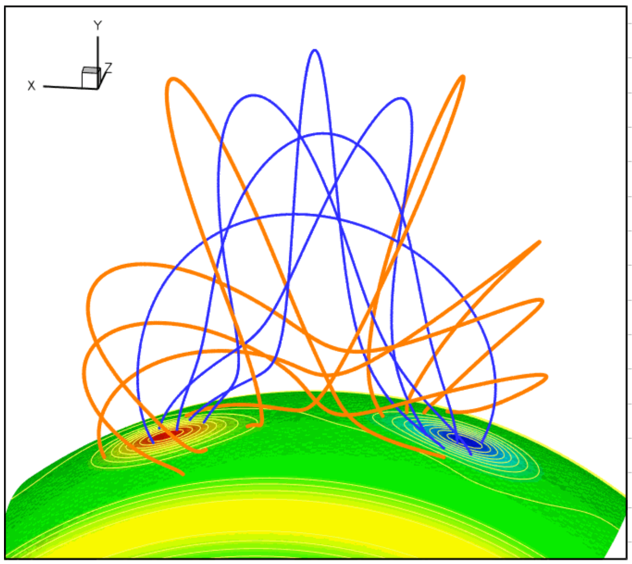
# Observational Evidence for Flux Ropes

Field Aligned Dynamics




- Correlated prominence-corona dynamics provide magnetic skeleton
- Compare with Fan and Gibson (2007) flux rope
- Projection effects?

Internal Geometry of a Flux Rope



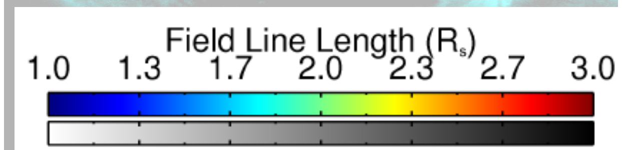
# Classifying Magnetic Substructure

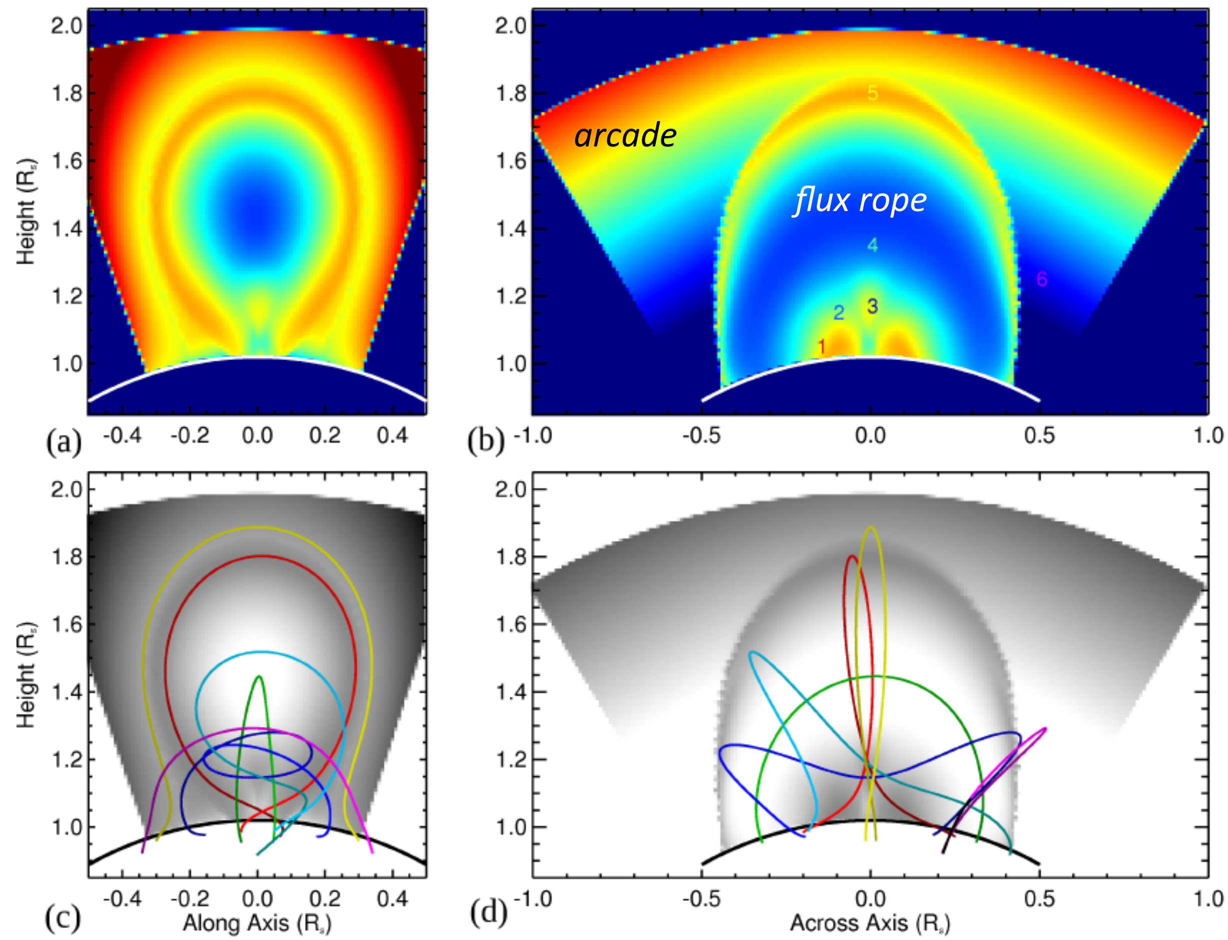
*Field line length in cross sections of the flux rope*

•Sharp gradients in field line represent geometric differences

•Length also factors in to energy balance

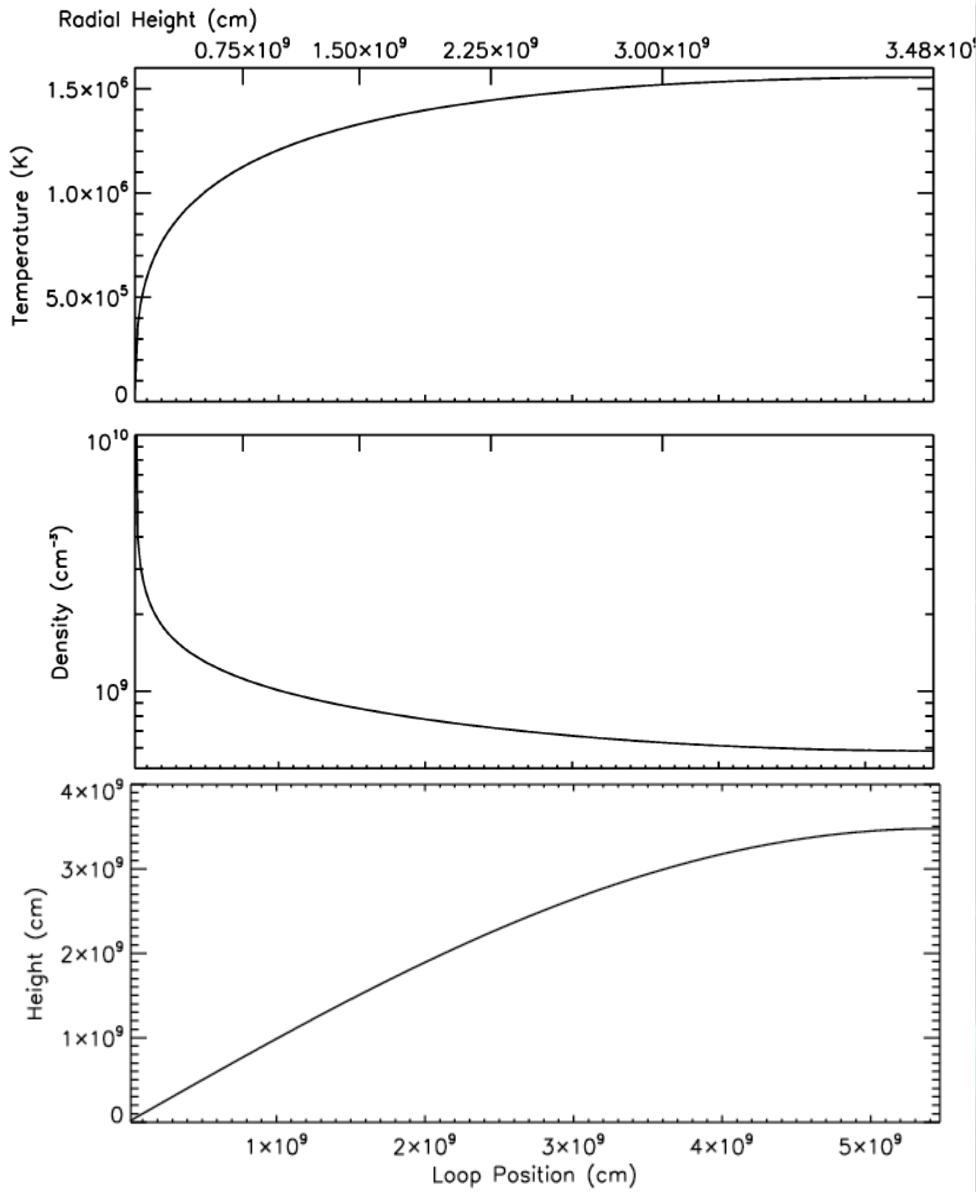
•Which geometries are cavity? prominence?




The flux rope is not a uniform magnetic structure

# Hydrostatic Loops




$$\frac{dn}{ds} = -\frac{n}{2kT}\left(mg + \frac{kF_c}{\alpha T^{5/2}}\right)$$

$$\frac{dF_c}{ds} = E - n^2\Lambda \qquad \frac{dT}{ds} = \frac{F_c}{\alpha T^{5/2}}$$

Coronal Loop Effects

$$p_0 = \int_0^{s_{max}} -\rho g \; ds \qquad s_{max} \equiv F_c = 0$$

- *Taller loops have a higher base density*

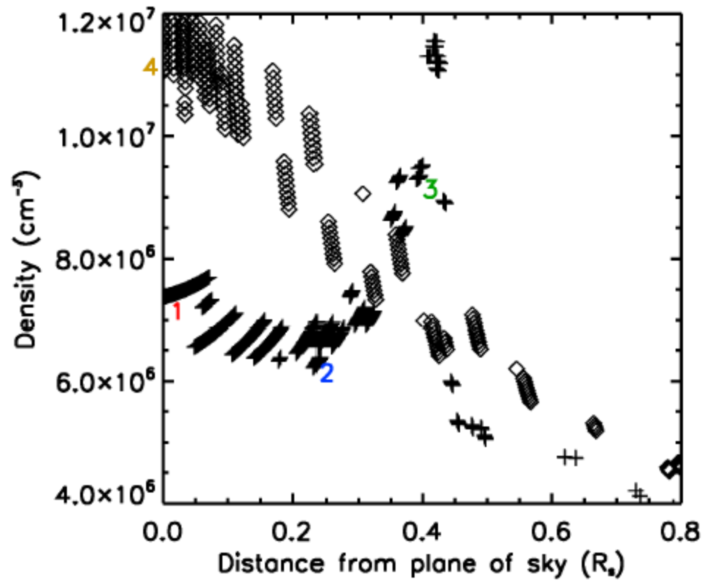
$$n_0^2 \Lambda_{T_0} s' \propto \int_{s'}^{s_{max}} E - n^2\Lambda \; ds = F_c\Big|_{s'}$$

$$s' \equiv \frac{dF_c}{ds} = 0$$

- *Longer loops have a higher base density*

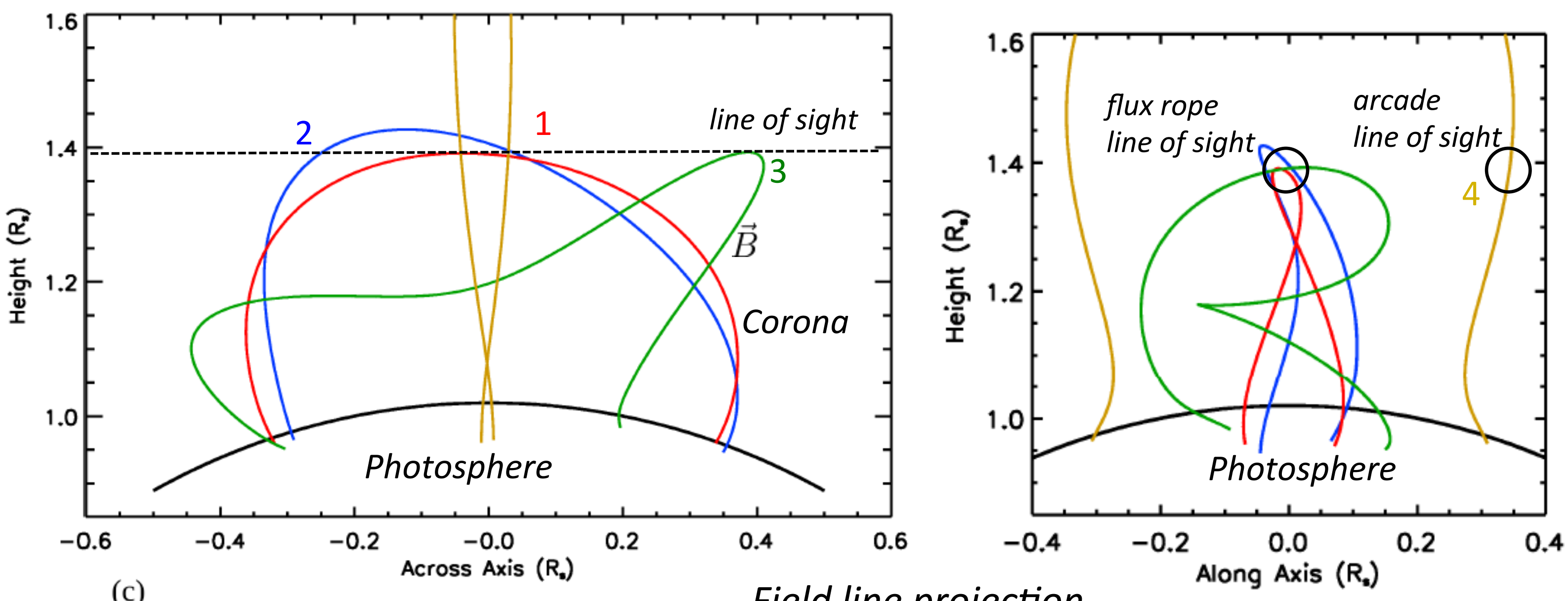
# Hydrostatic Flux rope

*Density variations along the line of sight*



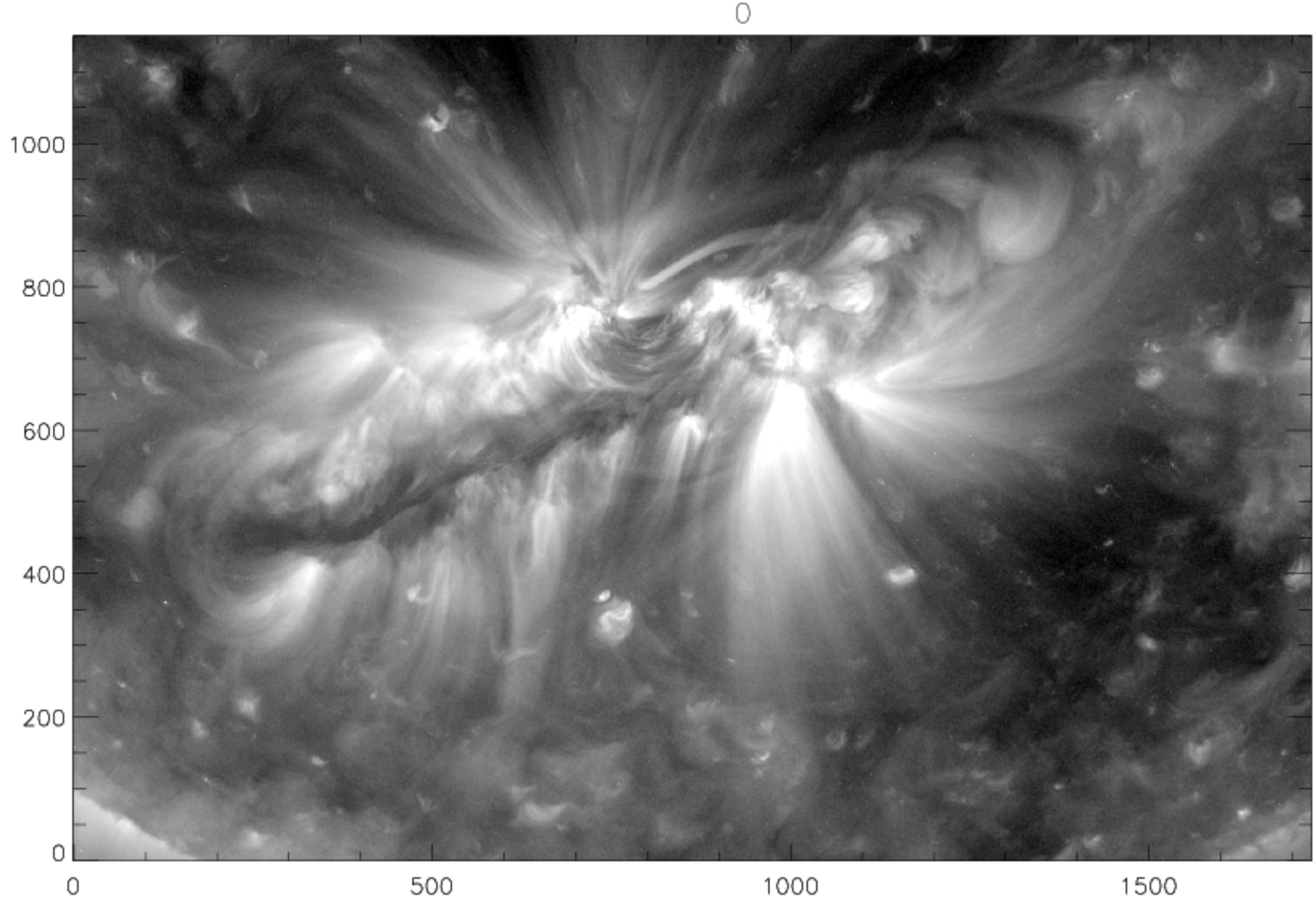

- The flux rope interior is lower density than the surrounding arcade.
  - -related to short (length and height) field lines
- Axial field forms the cavity, while dipped field forms the prominence
  - -density enhanced field lines comprise only a small fractional volume

*Diamonds: arcade line of sight*
*Crosses: flux rope line of sight*

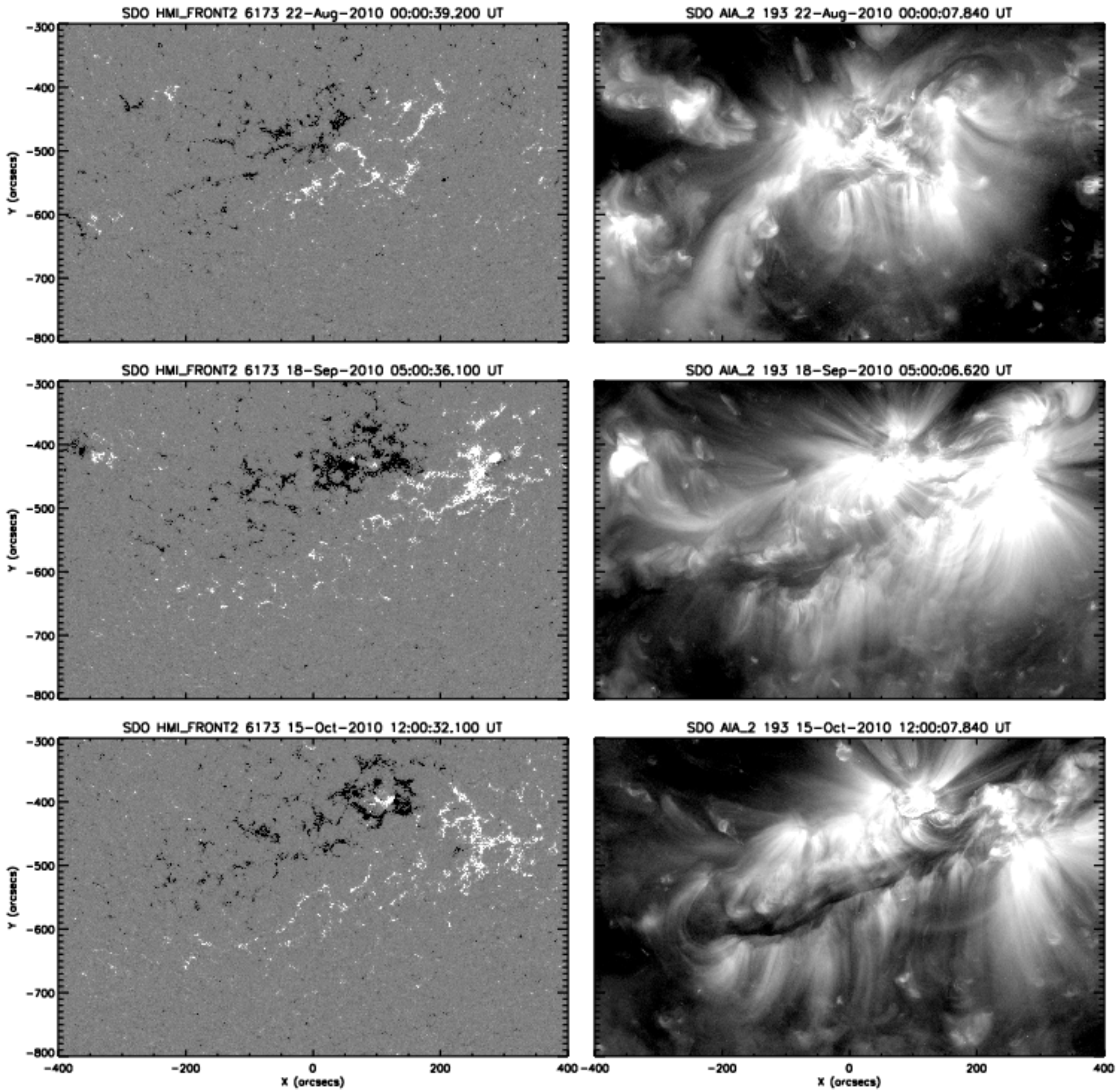



*Field line projection*

# What do we know about filament formation?



- How does the corona evolve?
- 18 day coverage with STEREO



# Future

- What is the dominant magnetic evolution mechanism for prominences?
  - Stereoscopic study of filament channels
- Reconnection as a source for condensation mass?
  - Pressure changes may supply mass to corona
- How is helicity distributed within the flux rope?