Magnetic Structure of Solar Prominences

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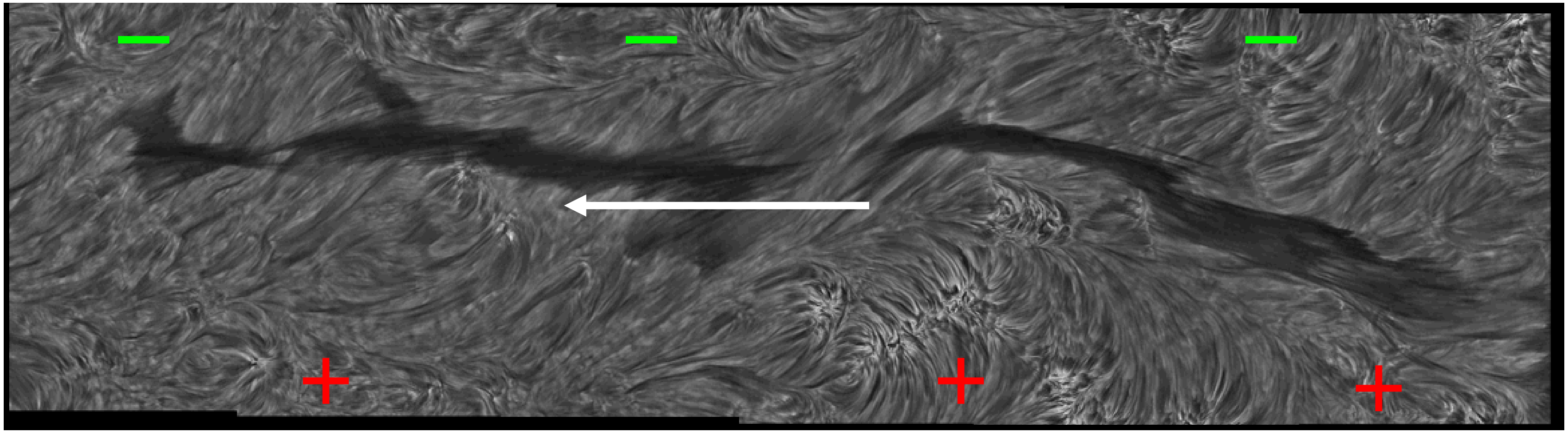
Introduction

- Prominences (a.k.a. filaments) consist of cool plasma (~ 10^4 K) embedded in corona above *polarity inversion lines* (PIL).
- Magnetic fields play an important role in prominence support, and in insulating the prominence from the hot corona.
- Prominences provide an opportunity to study the *non-potential structure* of the solar corona, which is important for understanding solar flares and coronal mass ejections.

Prominence/Filament Observations

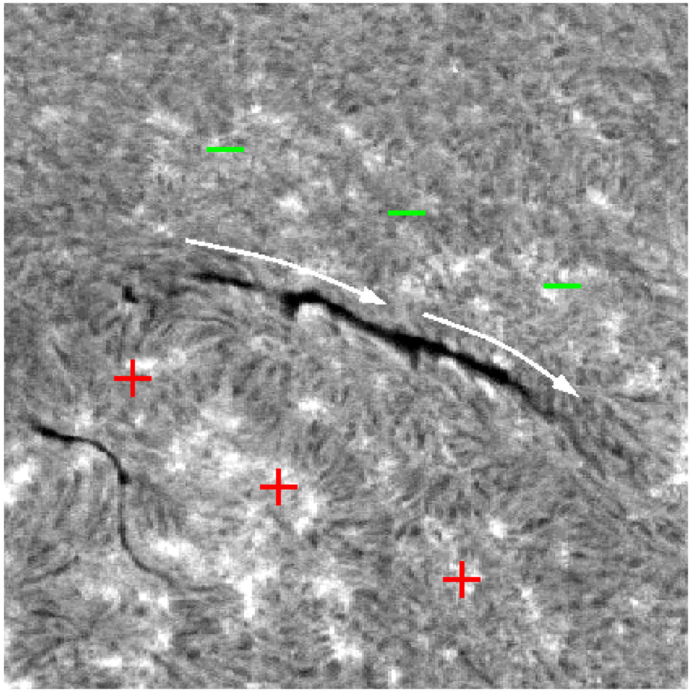
- Filaments are located in *filament channels*, regions where the chromospheric fibrils are aligned with the PIL.
- Streaming direction of fibrils indicates direction of axial field (Foukal 1971).
- Channels are either *dextral* or *sinistral* (direction of axial field as seen from the positive polarity side of the channel; Martin et al. 1994).

Sinistral channel observed with Dutch Open Telescope (DOT), 2004/10/06:

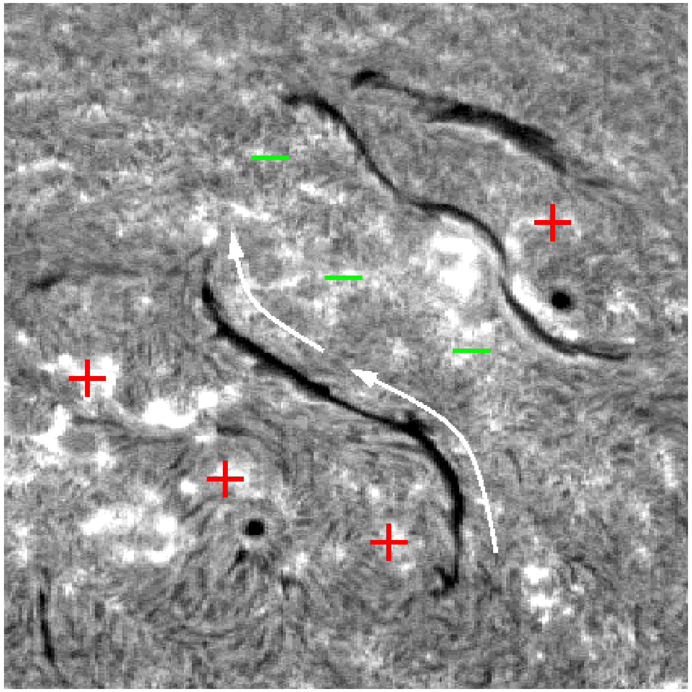


Prominence/Filament Observations

- Filaments have appendages (*barbs* or *legs*).
- Barbs are either *right*- or *left-bearing* (as seen from above).
- Filaments in dextral channels always have right-bearing barbs, and those in sinistral channels have left-bearing barbs (Martin et al. 1992).



dextral

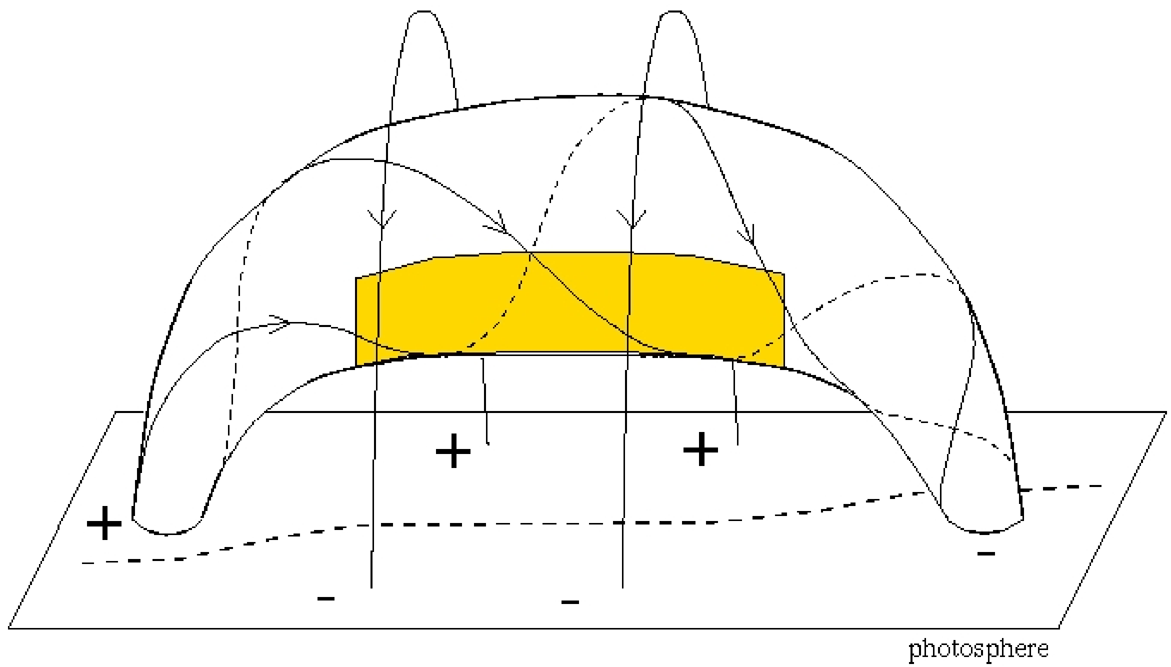


sinistral

Prominence/Filament Observations

Q: Why do dextral (sinistral) filaments have right (left)-bearing barbs?

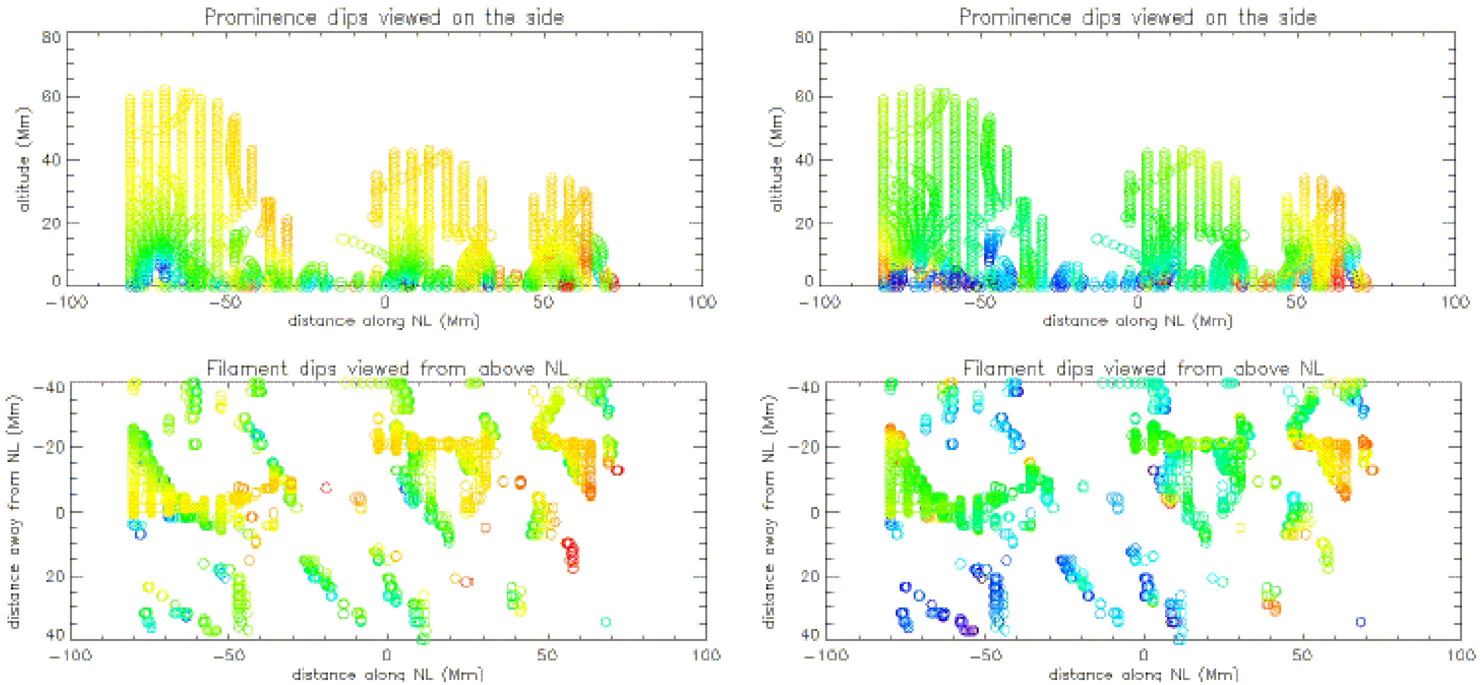
One interpretation is that filaments are located in *twisted flux ropes*, and that cool plasma is located at the *dips* in the helical field lines:



Prominence/Filament Observations

Models of prominences using constant-α force free fields with $\alpha \approx 2\pi/L$, where L is domain size. Figure shows dips in a model for a quiescent filament observed on 1999 November 4 (Aulanier & Demoulin 2003):

color = B   color = θ



Prominence/Filament Observations

Problem with interpretation of barbs as a collection of dips:

- Barbs extend *downward* from the main body of the filament.
- High-resolution observations show barbs to be *field-aligned* (Lin et al. 2005a,b).
- There are *counter-streaming flows* along barbs (Zirker et al. 1998; Lin et al. 2003) from the spine to the chromosphere.

Clearly, cool plasma is present on inclined field lines.

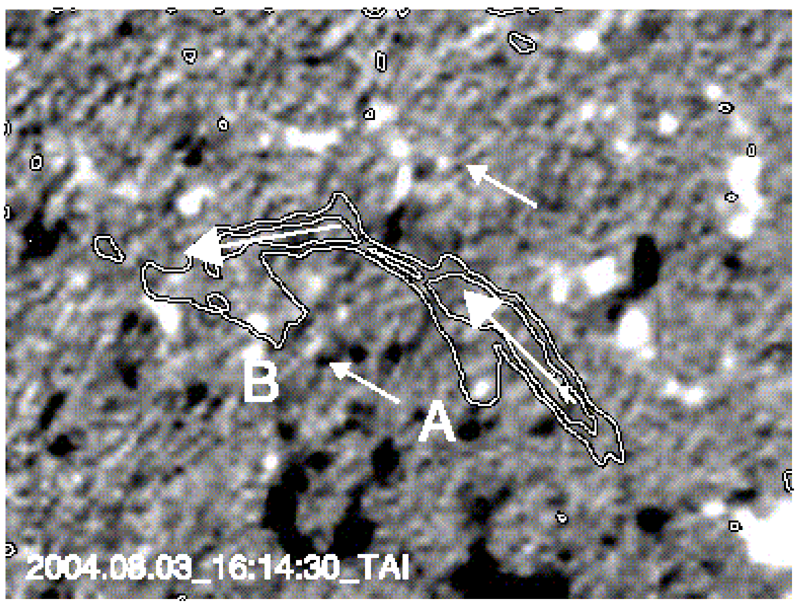
Is this plasma supported by waves (e.g., Pesceli & Engvold 2000) or hot plasma at lower heights (Karpen et al. 2001)?

Need search for observational signatures of such hot plasma.

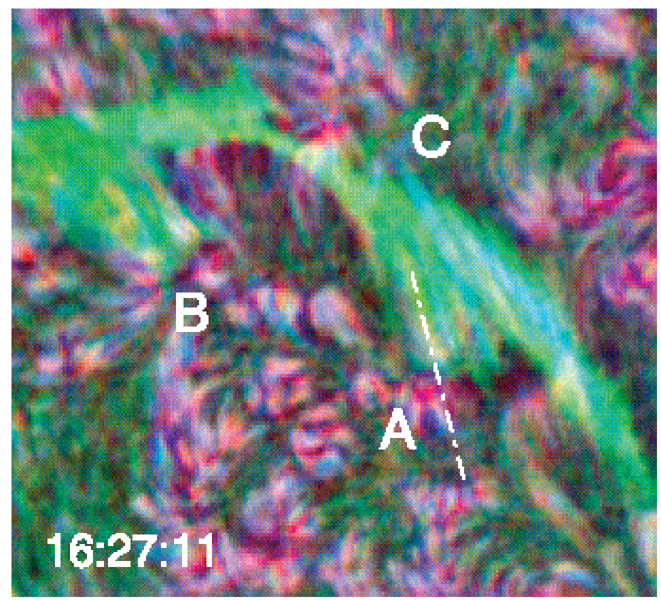
Prominence/Filament Observations

The termination points of barbs are located at *parasitic elements* with minority polarity (Martin & Echols 1994; Martin 1998), or at small inversion lines between major and minor polarity elements where magnetic flux is canceling (Wang 2001; Chae et al. 2005):

MDI



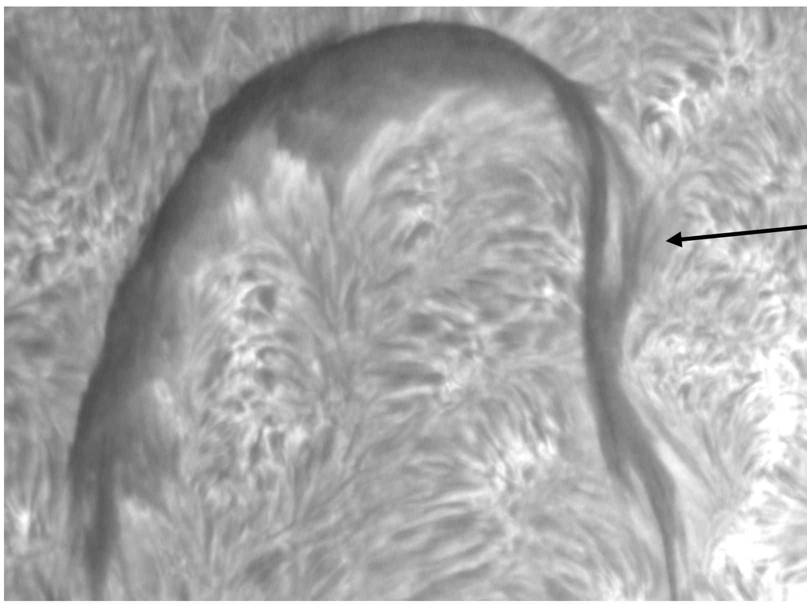
BBSO, Hα



From: Chae et al. (2005)

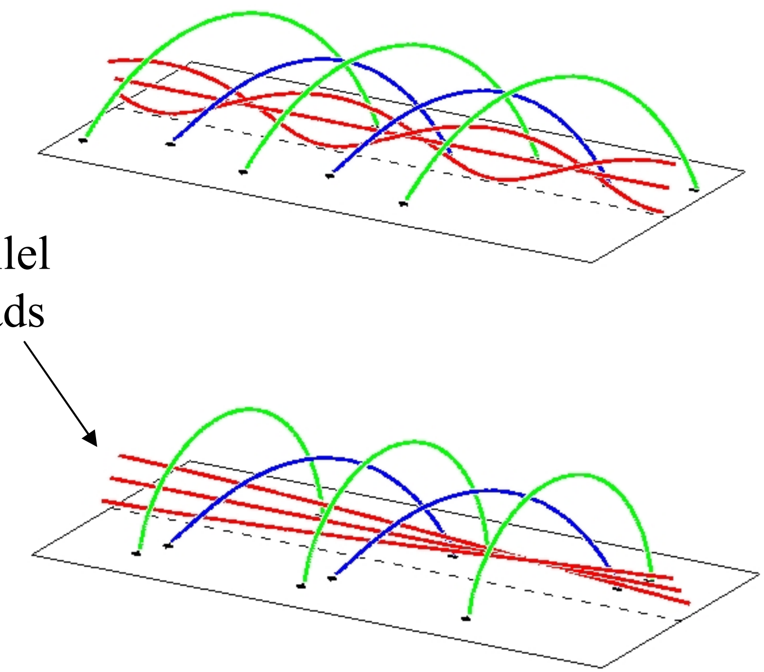
Prominence/Filament Observations

Active region filaments often have long parallel strands, suggesting such filaments are embedded in *untwisted* (or weakly twisted) field:



SVST, 1998/06/21

parallel
threads



Filament Models

Need 3D models of magnetic field in actual observed prominences.

Models should be based on a variety of observational constraints:
- Photospheric B-fields (e.g., MDI, SOLIS, IVM, Solar-B, SDO).
- Direct measurements of prominence B-field (Hanle effect).
- Fine structures in H-alpha filament/prominence.
- Structure of surrounding coronal loops (e.g., TRACE, Solar-B, SDO).

Here I present *non-linear force free fields* (NLFFF) models.

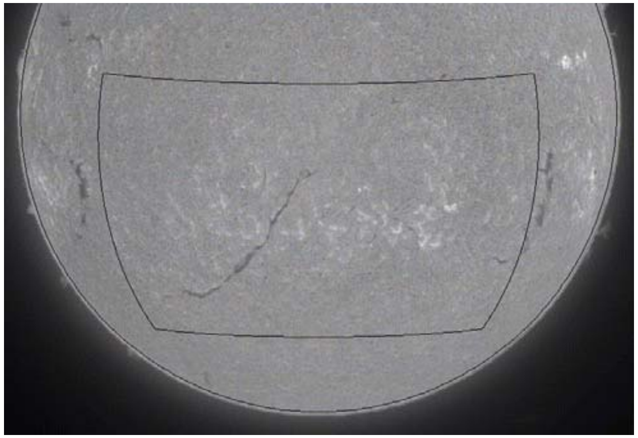
These models describe the corona *at one instant of time*.
Processes of flux rope formation and eruption are ignored.

Filament Models

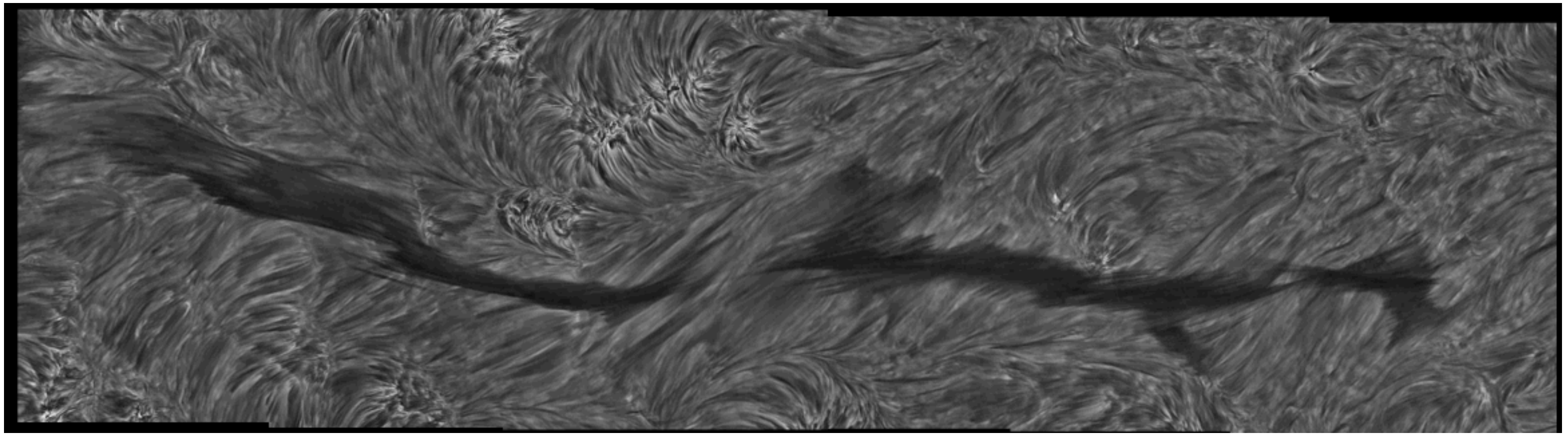
Method I: Construct NLFFF containing a magnetic flux rope overlying the PIL (van Ballegooijen, ApJ, 612, 519, 2004).

Hα filament
2004 October 6

BBSO
16:30 UT

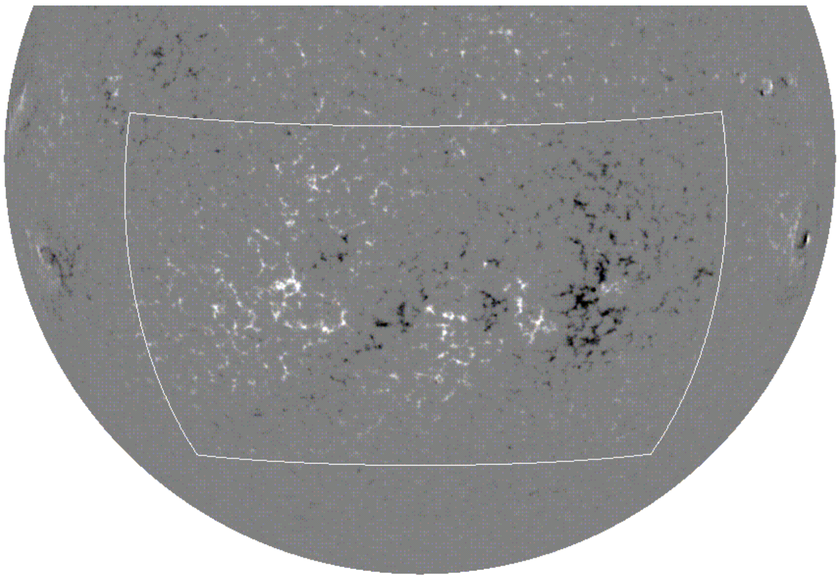


Dutch Open Telescope
8:45-9:42 UT

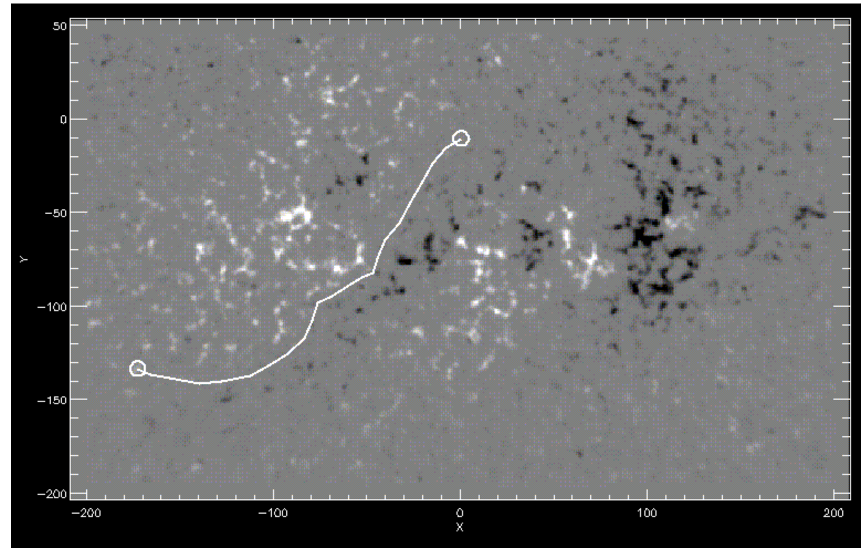


Filament Models

Step 1: Extract magnetic field from SOLIS magnetogram (18:34 UT)



Step 2: Select filament path along PIL

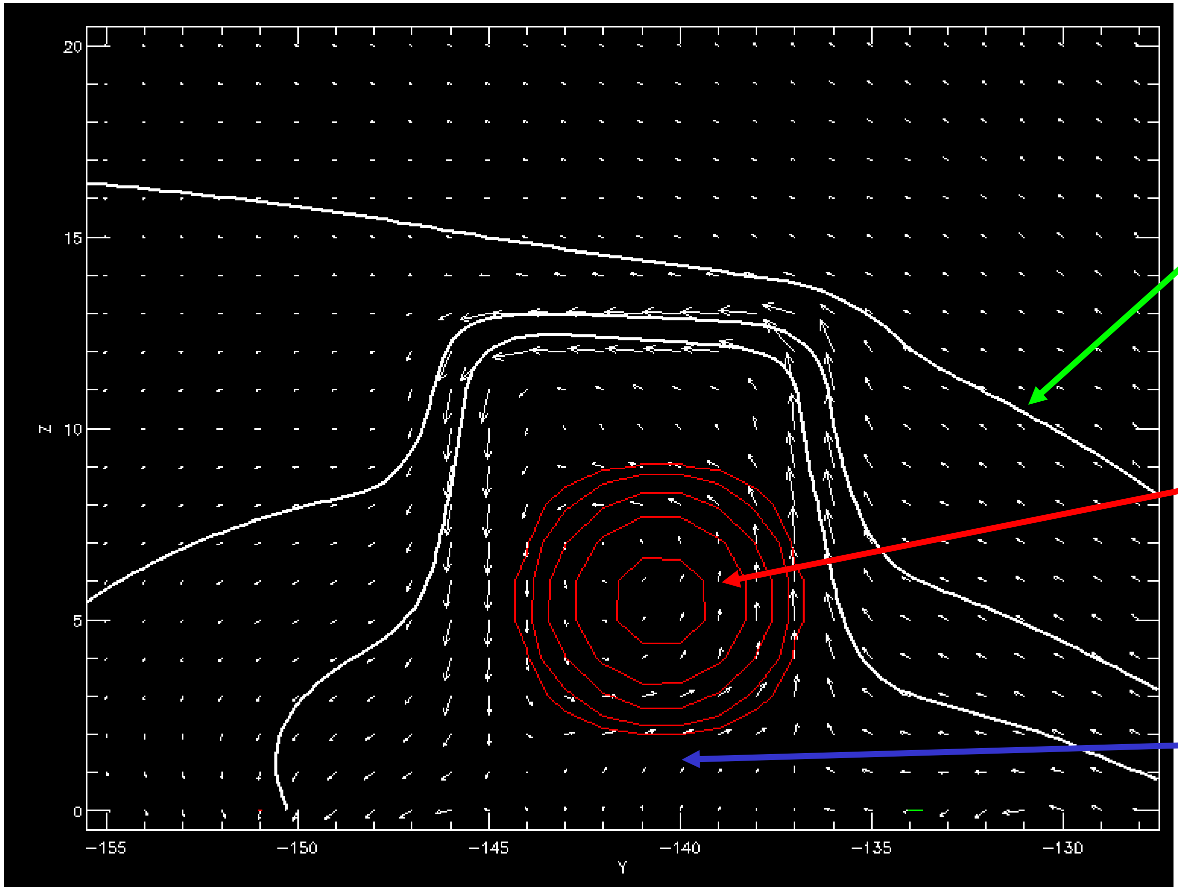


Step 3: Compute potential field (= overlying coronal arcade).
Step 4: Create field-free cavity above the selected path.
Step 5: Insert flux rope with specified axial and poloidal fluxes into cavity:

$$\Phi_{axial}=1.5x10^{20}\ Mx, \quad F_{pol} = 7x10^{9}\ Mx/cm$$

Filament Models

Insertion of axial and poloidal fluxes (vertical cross-section near PIL):



potential field
(lines and vectors
outside cavity)

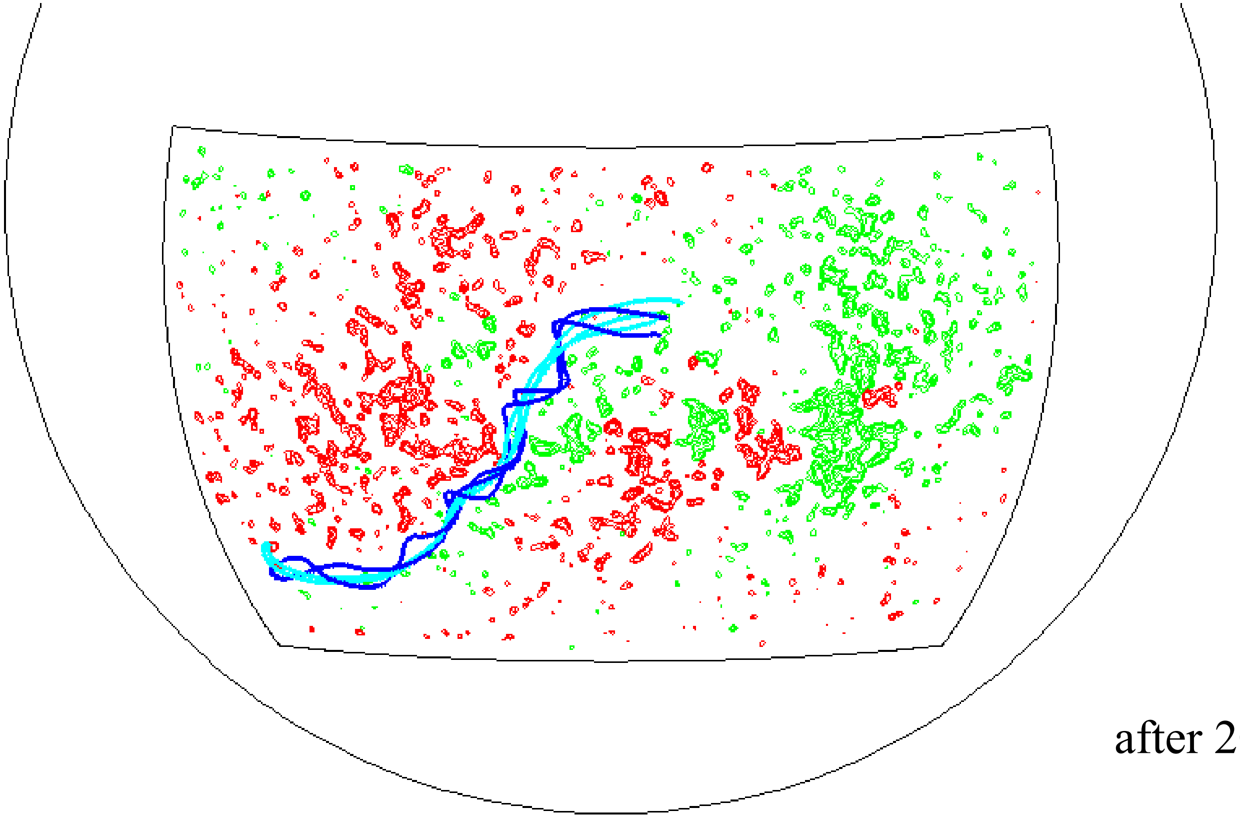
axial field
(red contours)

poloidal field
(vectors in cavity)

Filament Models

<u>Step 6</u>: *magneto-frictional relaxation:*
(drives the field to a NLFFF)

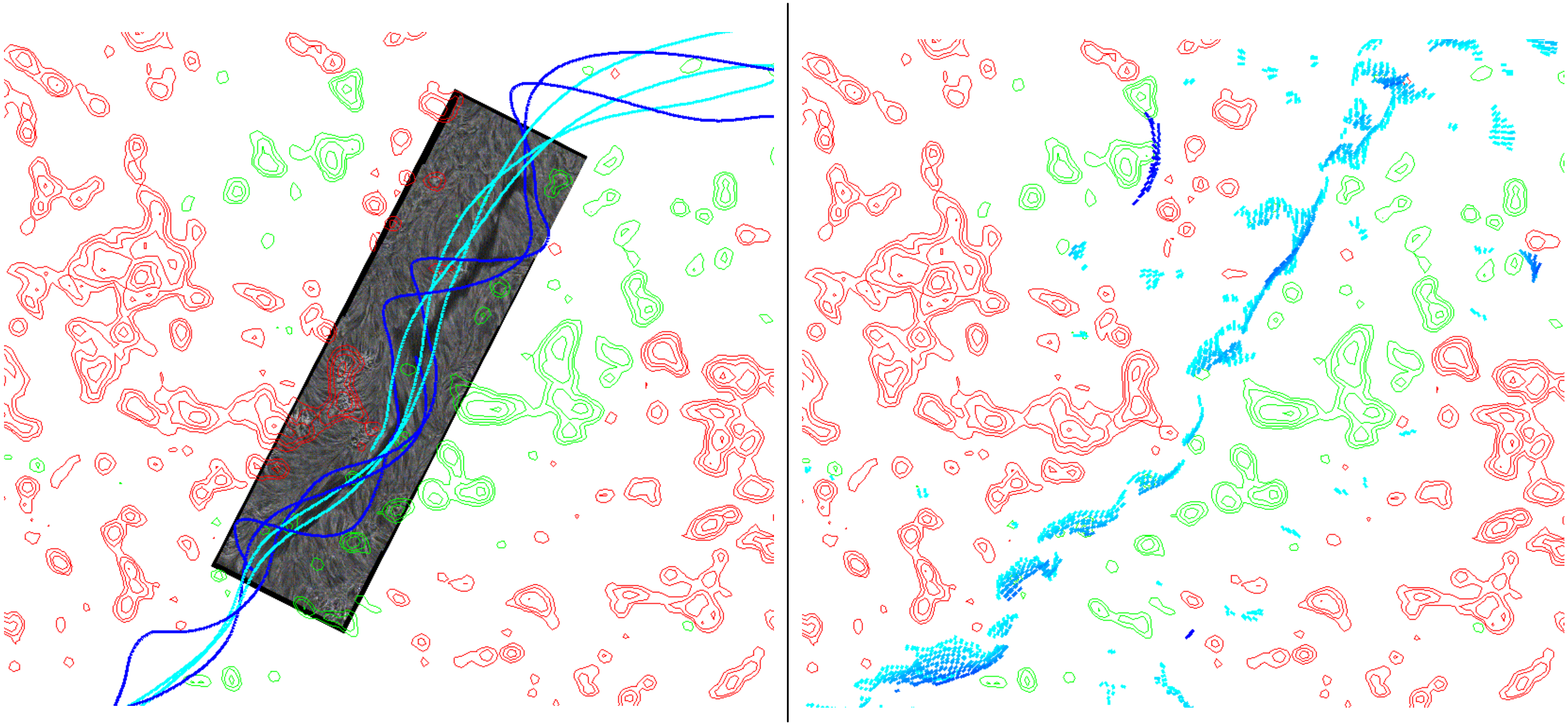
$$\frac{\partial \vec{A}}{\partial t} = \vec{v} \times \vec{B}, \qquad \vec{v} = \frac{\eta}{B^2}\left(\vec{\nabla} \times \vec{B}\right) \times \vec{B}.$$



after 2000 iterations

Filament Models

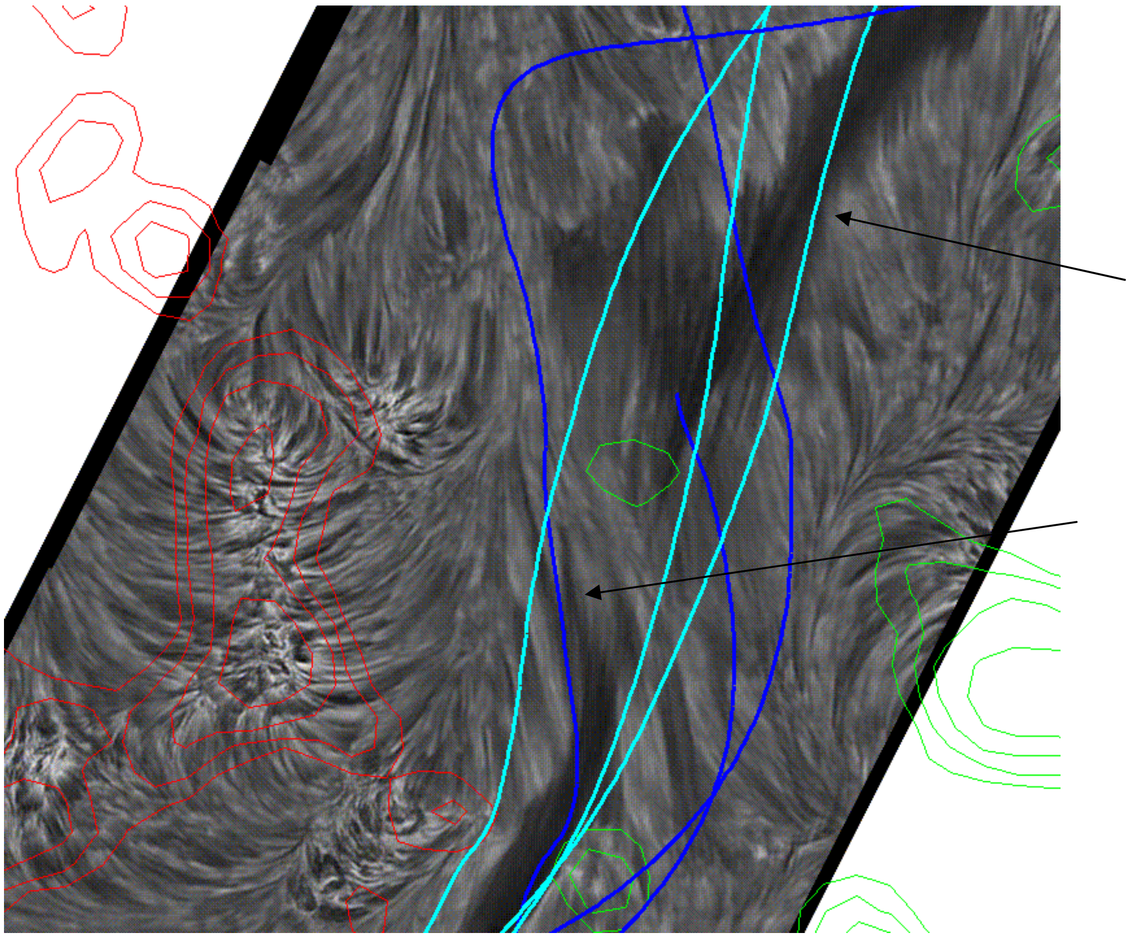
Medium-scale view of magnetic field lines (*left panel*) and dips (*right*):



<u>Note</u>: dips are not continuous along the length of the filament.

Filament Models

Observed fine structures match magnetic field lines at certain heights:



Near the 3 crossing points:

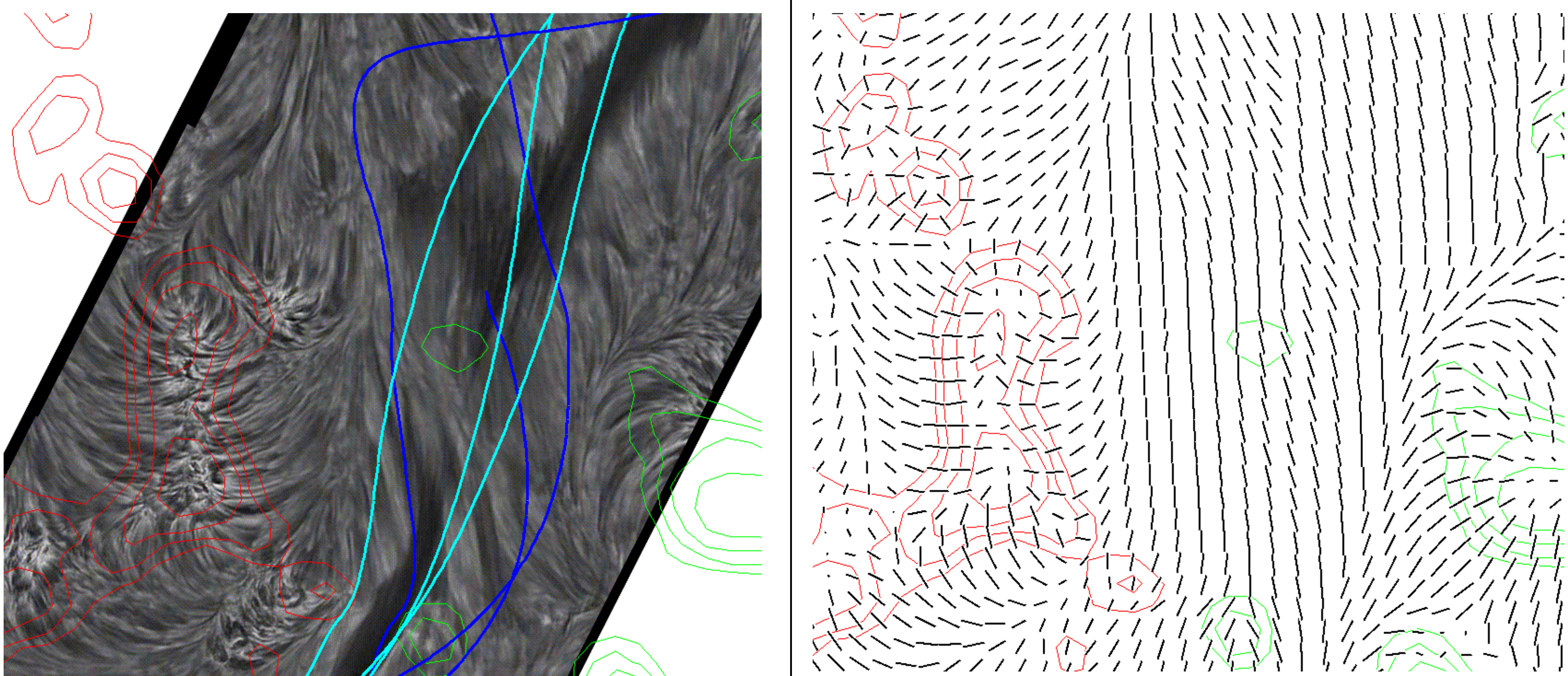
Light blue for higher-altitude field lines (h=7 Mm) in the filament.

Dark blue for low-lying field lines (h=1.4 Mm) that follow the chromospheric fibrils.

SOLIS+DOT, 2004 Oct 6

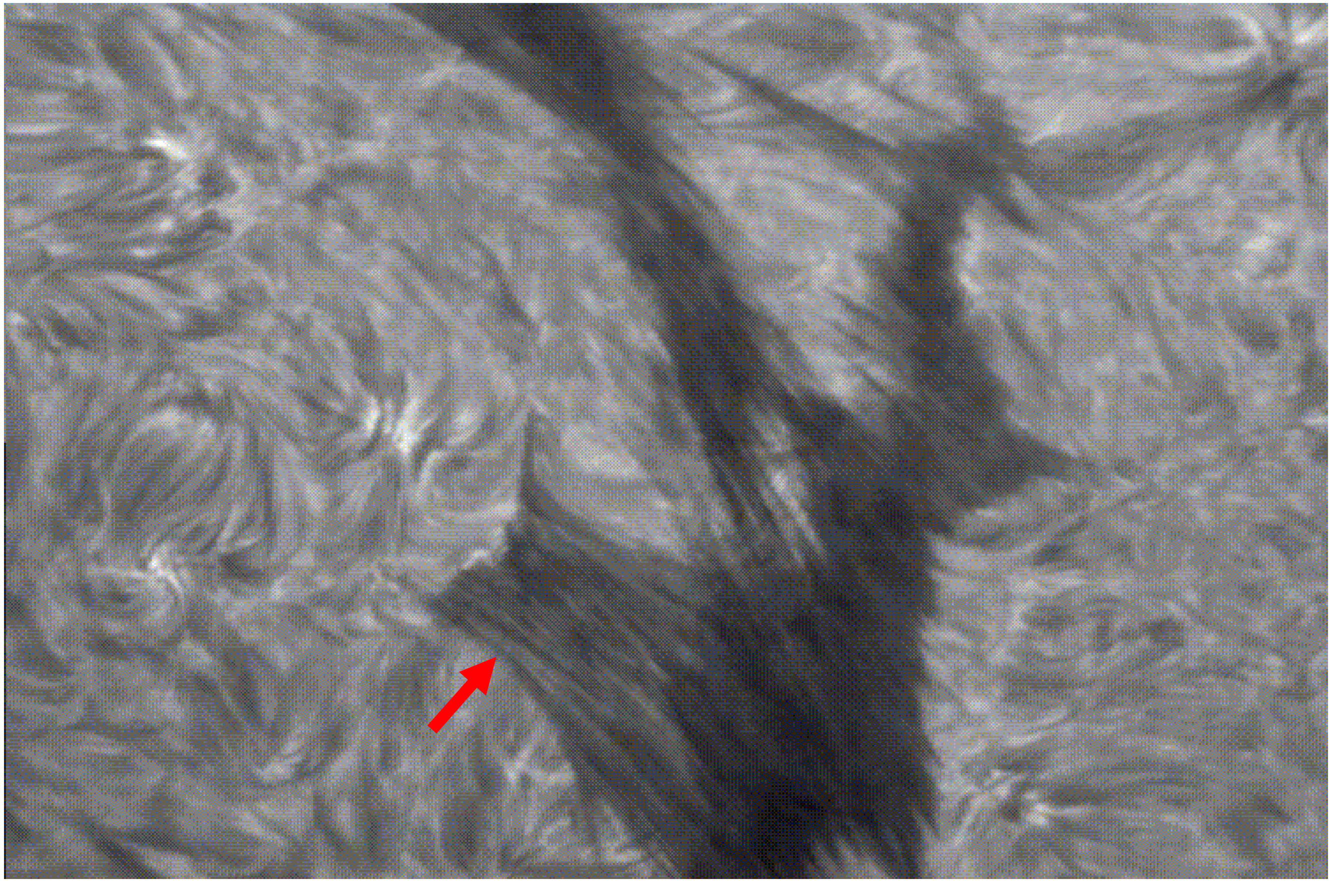
Filament Models

Model reproduces the observed directions of chromospheric fibrils in filament channel (height=1.4 Mm):



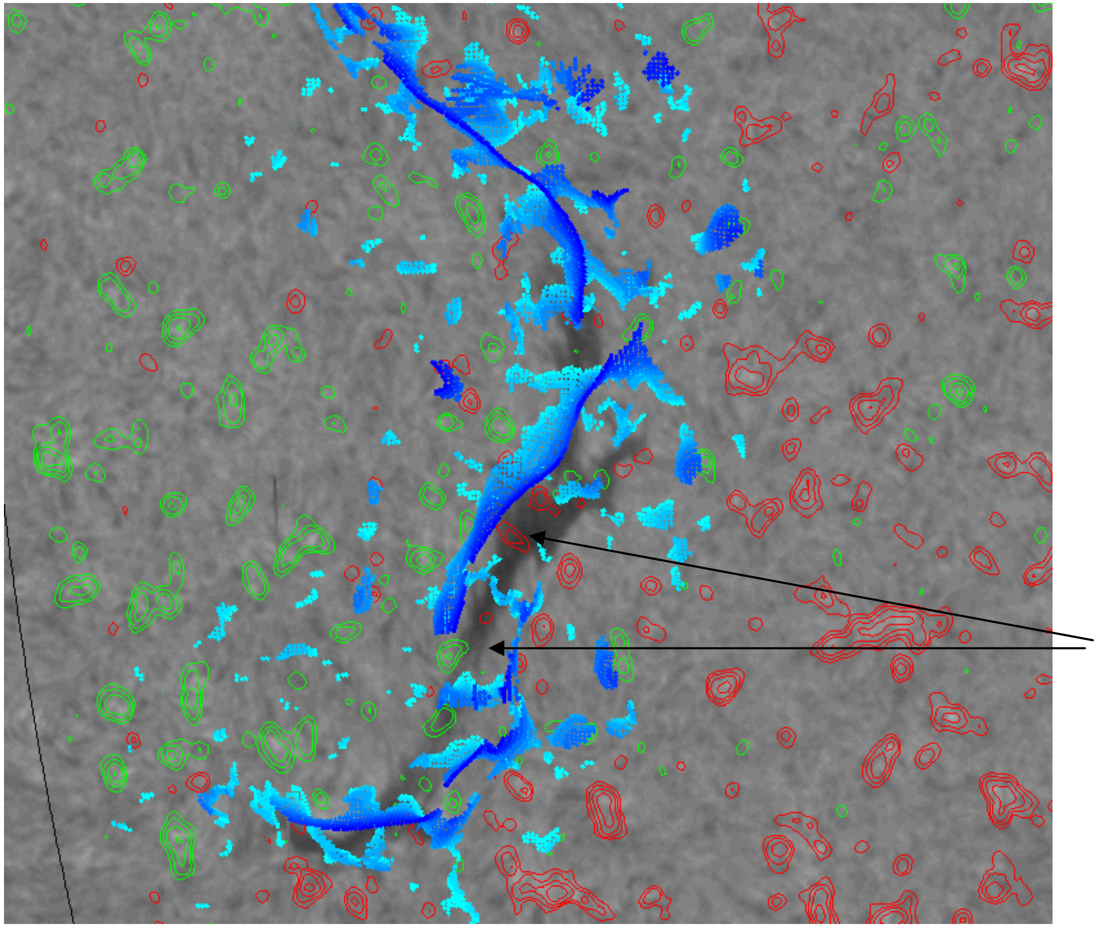
Filament Models

<u>Another filament</u> observed on 2003 August 25 with the Swedish Solar Telescope (Lin et al. 2005). Barb has field-aligned structure (arrow):



Filament Models

Flux rope model for sinistral filament on 2003 August 25:



Based on magnetogram (red/green contours) from NSO/KPNO.

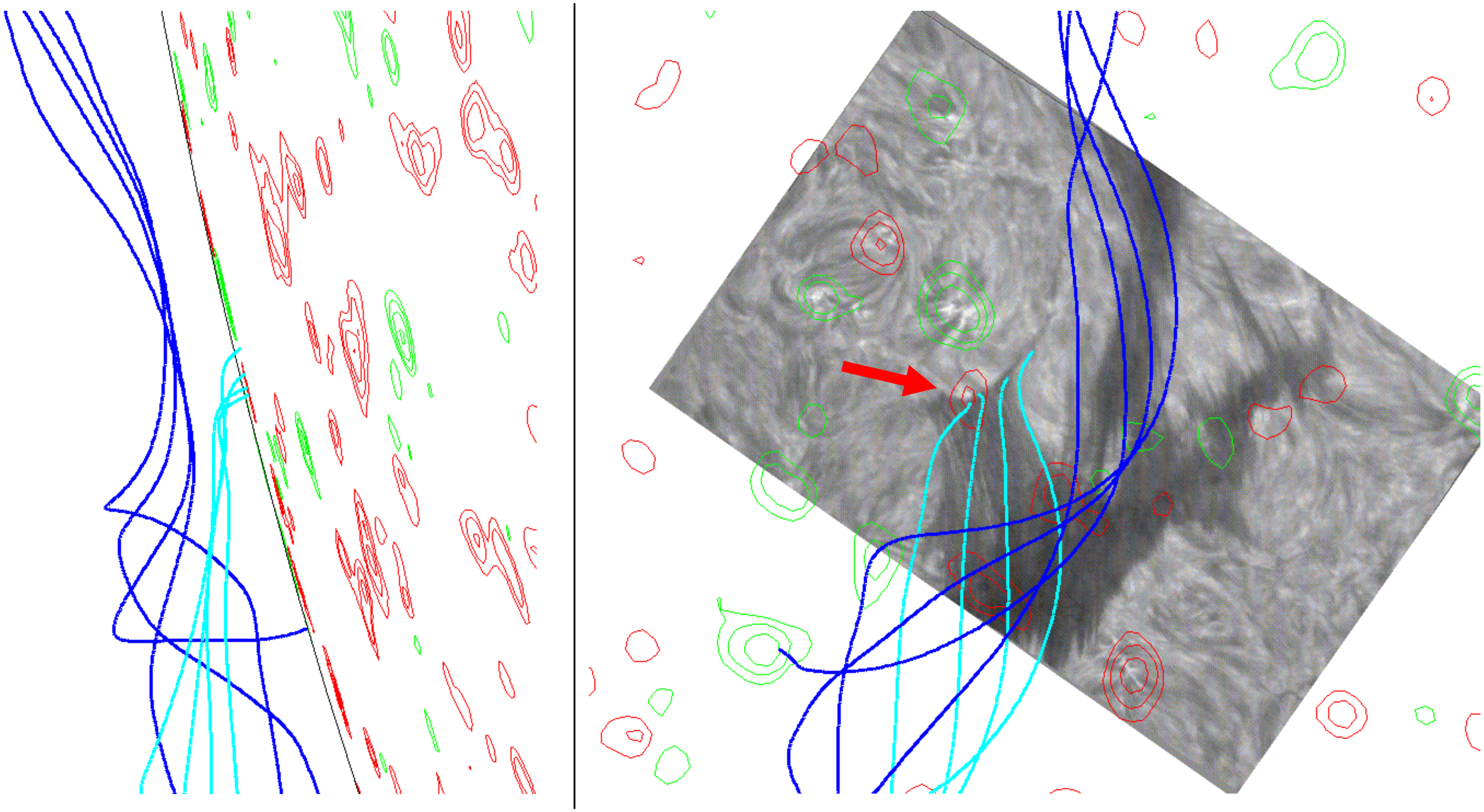
Hα image (BBSO).

Blue: field-line dips

Note: flux rope distorted by elements in filament path.

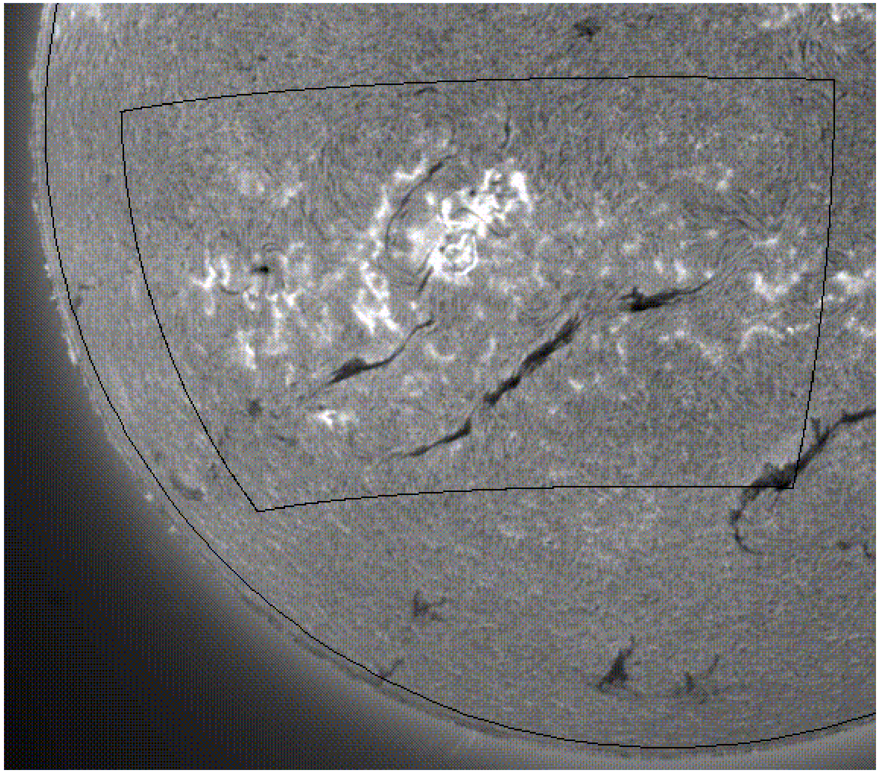
Filament Models

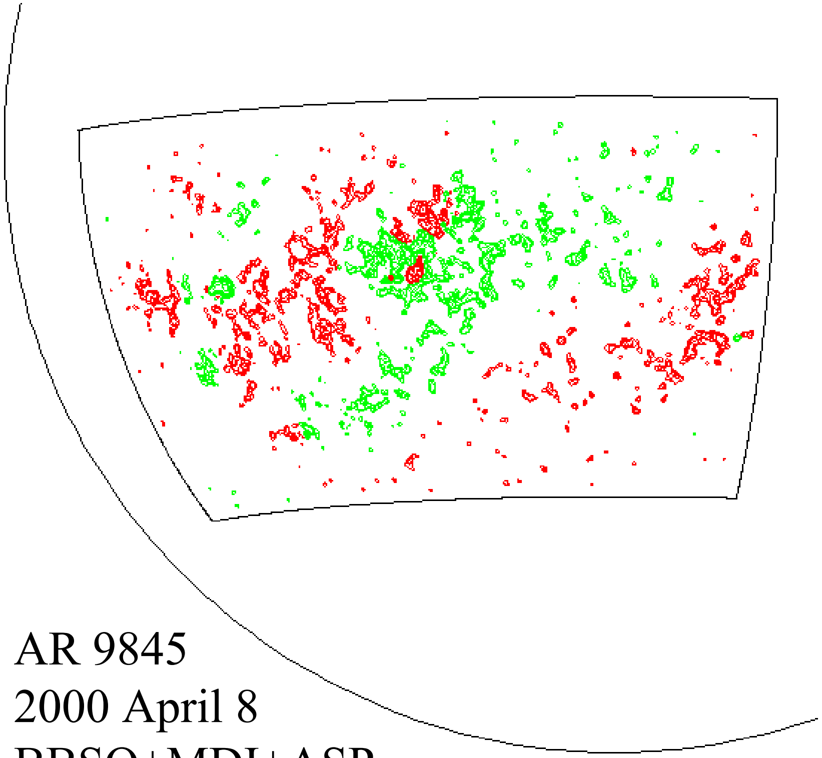
Filament barb terminates at flux element (*arrow*) with parasitic polarity. Barb is located on <u>inclined</u> field lines (*light blue*):



Vector-Field Extrapolation

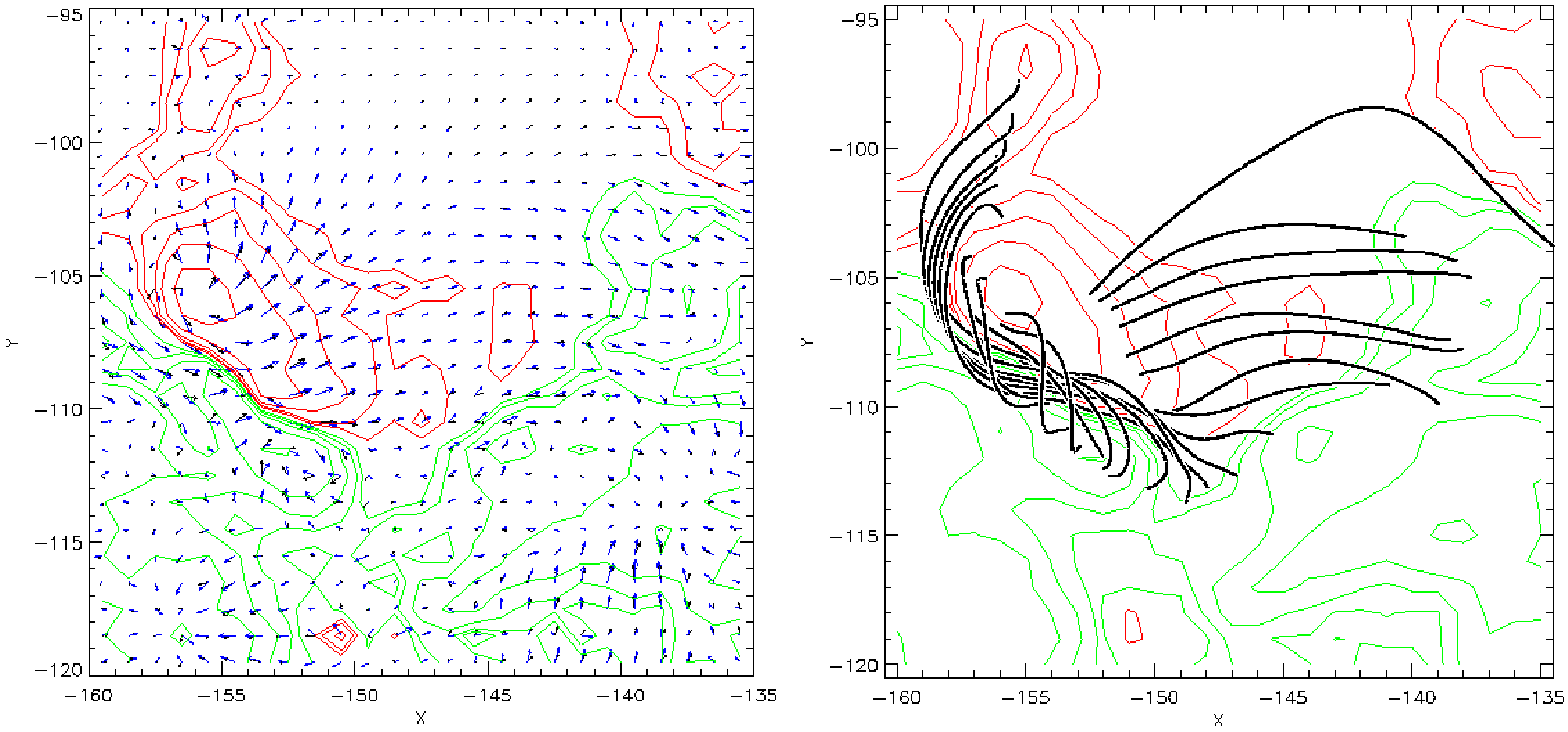
<u>Method II</u>: Using photospheric vector-field data from the Advanced Stokes Polarimeter (ASP), inject horizontal field at the base of the model:





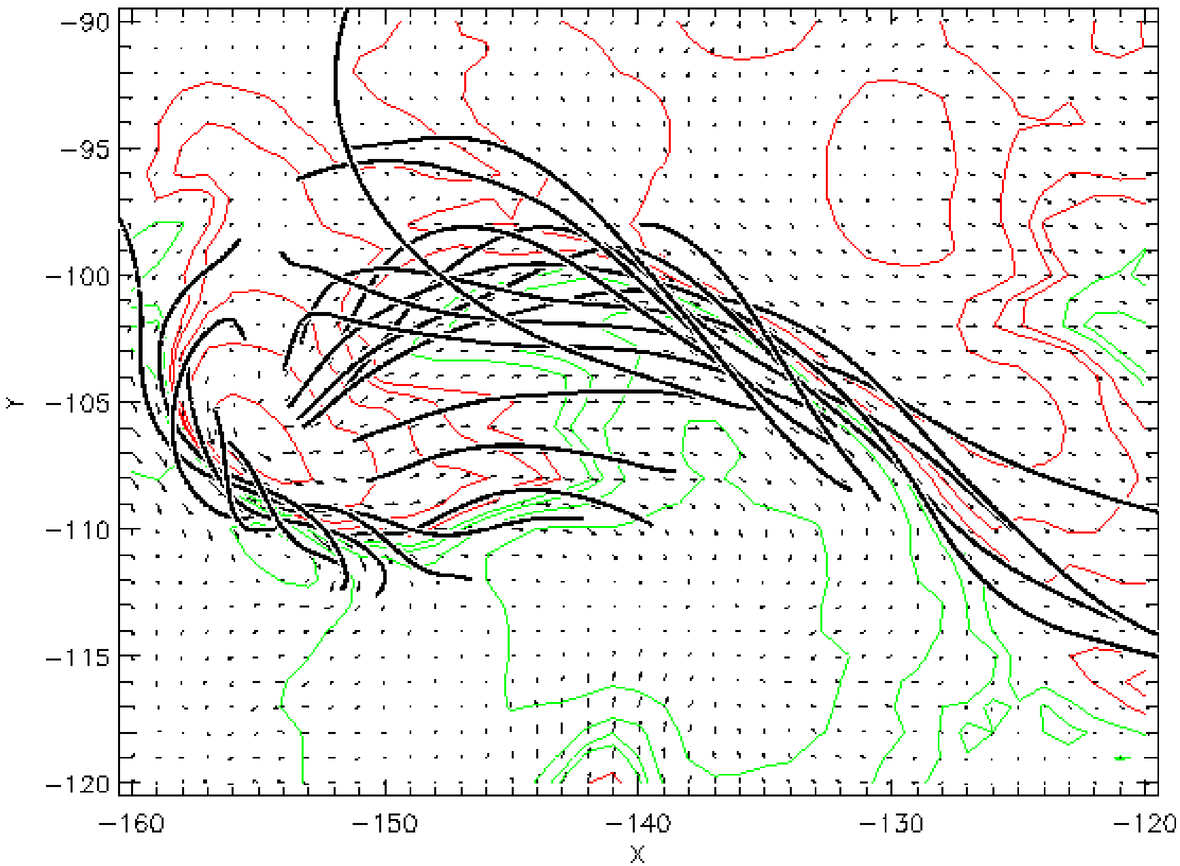
Vector-Field Extrapolation

Field lines (*right*) and photospheric vector fields (*left*) in 42 x 42 Mm area. Arrows show vector field in model (black) and ASP data (blue).



Vector-Field Extrapolation

Model shows presence of low-lying, weakly twisted flux ropes:



Area: 67x42 Mm

Summary

- Developed empirical models of coronal magnetic structures based on observed filaments, channels, and photospheric vector fields.
- Prominence plasma can exist on inclined field lines, but the support mechanism is not understood.