Toward understanding 3D and dynamic nature of solar prominences

T. Magara

(Hinode Science Center, NAOJ)

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Solar prominence...

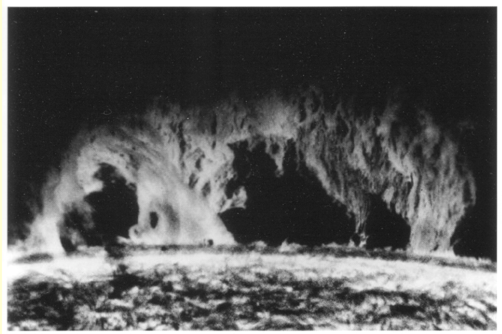
composed of relatively cool & heavy plasma floated in the corona

gas density ($10^{11}\ cm^{-3}$)... 100 times higher than coronal plasma

temperature ($10^{4}\ K$)... 100 times lower than coronal plasma

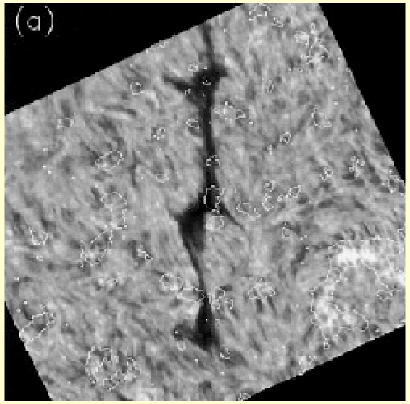
When observed above the solar limb

... called 'prominence'



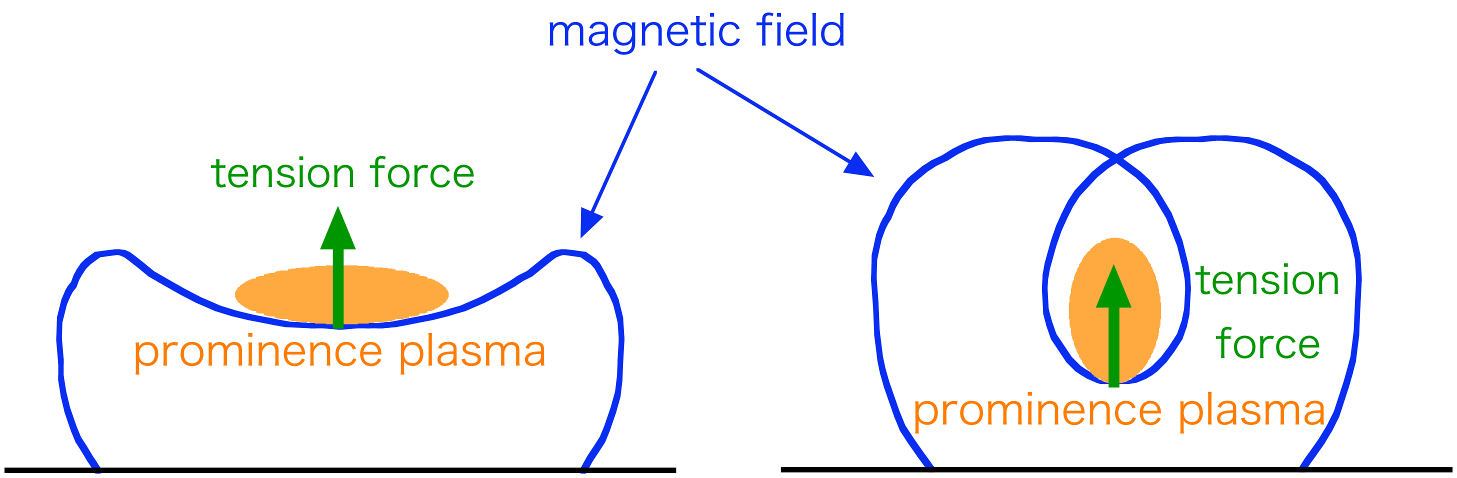
When observed in the solar disk

... called 'filament'



Previous modeling...

focus on 2D configuration and static nature

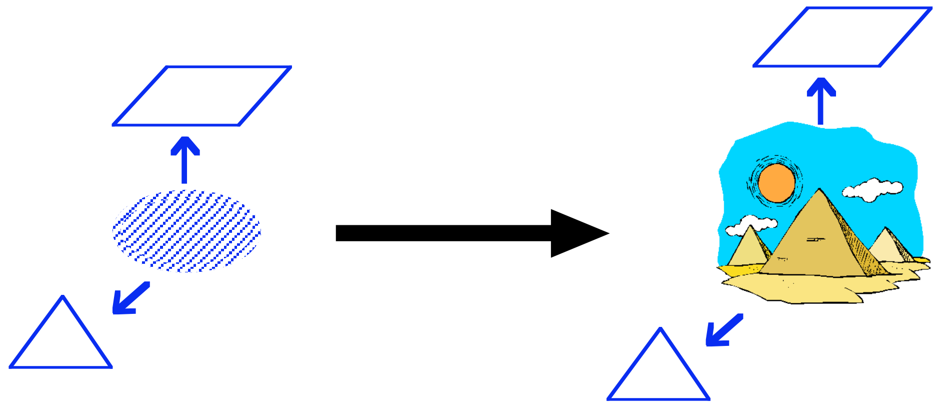


Magnetic force (tension of magnetic field lines) supports prominence plasma against gravitational force.

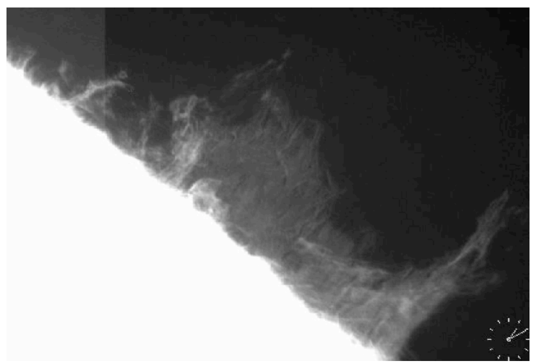
New modeling...

should focus on 3D configuration and dynamic nature

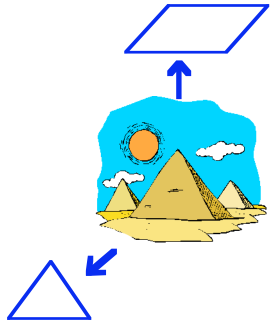
Derive the 3D configuration from 2D observations

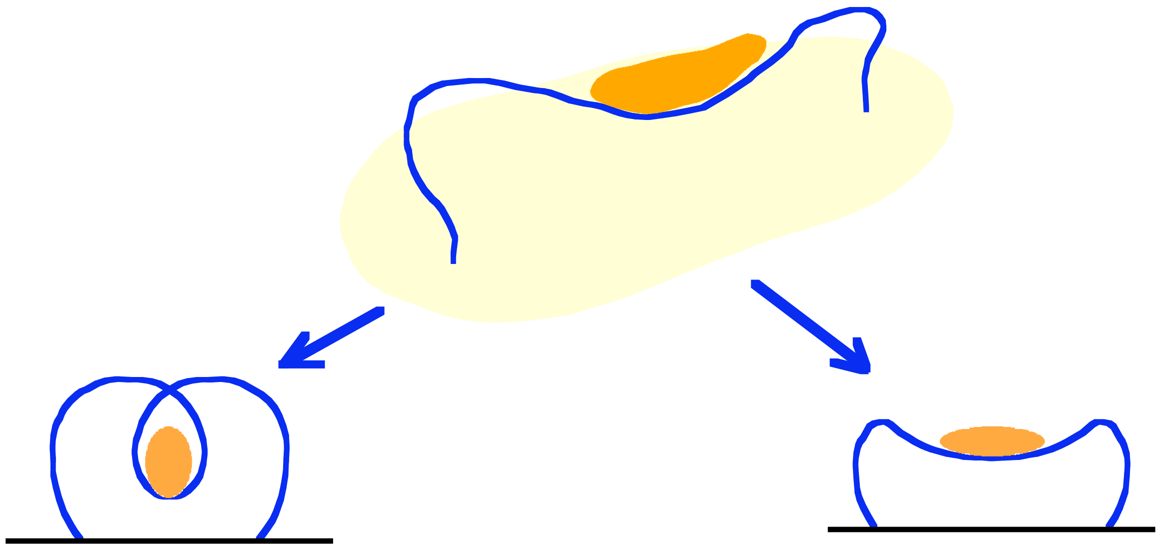


Use time-sequences of data to understand dynamics



A 3D object generally gives different 2D shapes, depending on viewing angles.

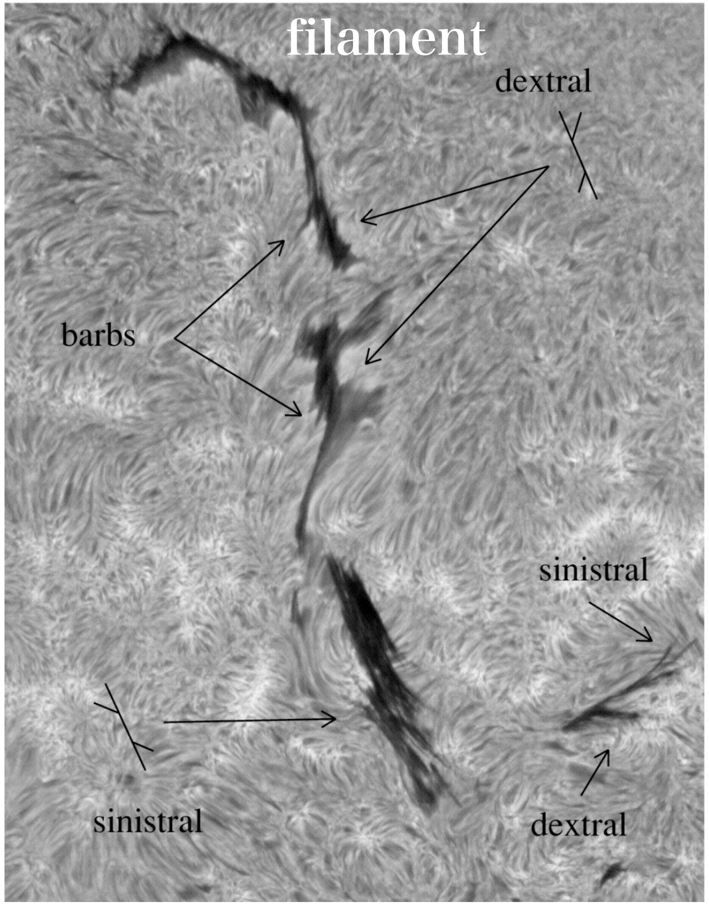




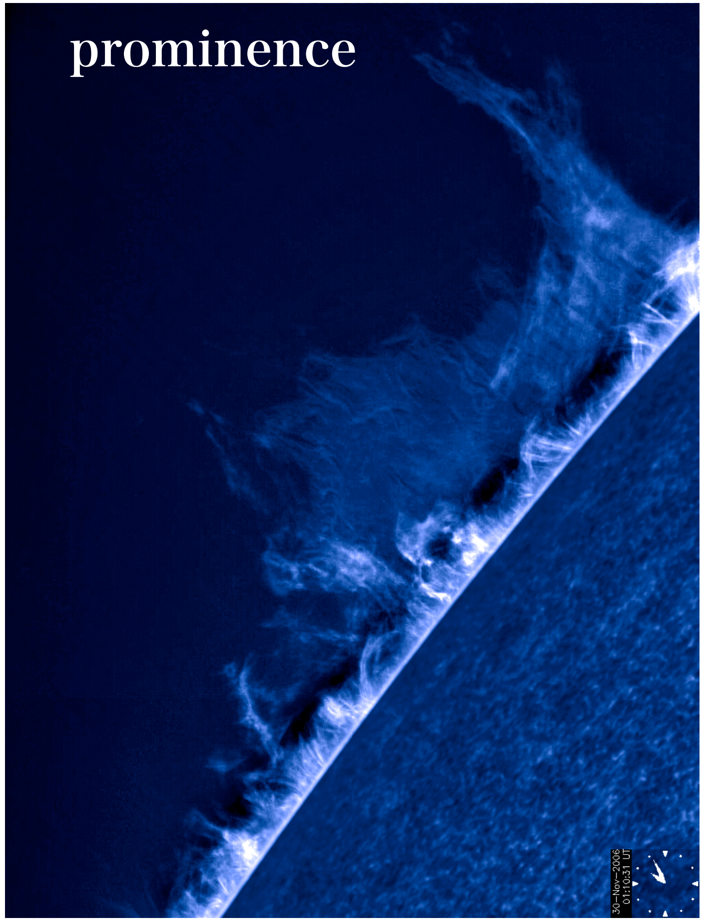
It is therefore important to combine various 2D observations for understanding the 3D configuration.

2D observational information:

top view (filament) & side view (prominence)



Pevtsov et al. (2003)



Berger et al. (2007)

The works on which we base to build a 3D dynamic model of prominences/filaments

Canfield, Hudson, McKenzie (1999)

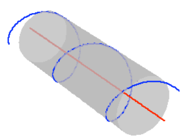
TABLE II

CHIRALITY OF SOLAR ACTIVE REGIONS [37] AND SHAPE OF THE CORONAL SIGMOIDS [38] BY HEMISPHERE.

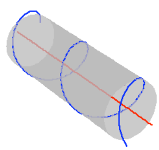
	N-hemisphere	S-hemisphere
Positive α	38%	66%
Forward S	41%	68%
Negative α	62%	34%
Backward S	59%	32%

... dominant part

negative α... left-handed flux tube provides a dextral filament dominant in the N. hemisphere



positive α... right-handed flux tube provides a sinistral filament dominant in the S. hemisphere



Martin (1998)

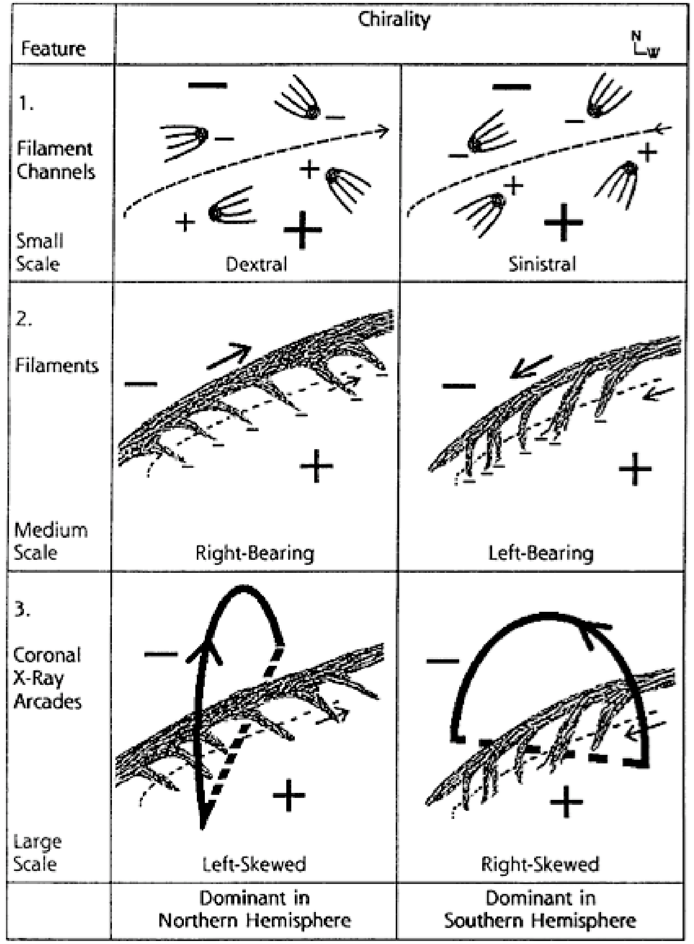


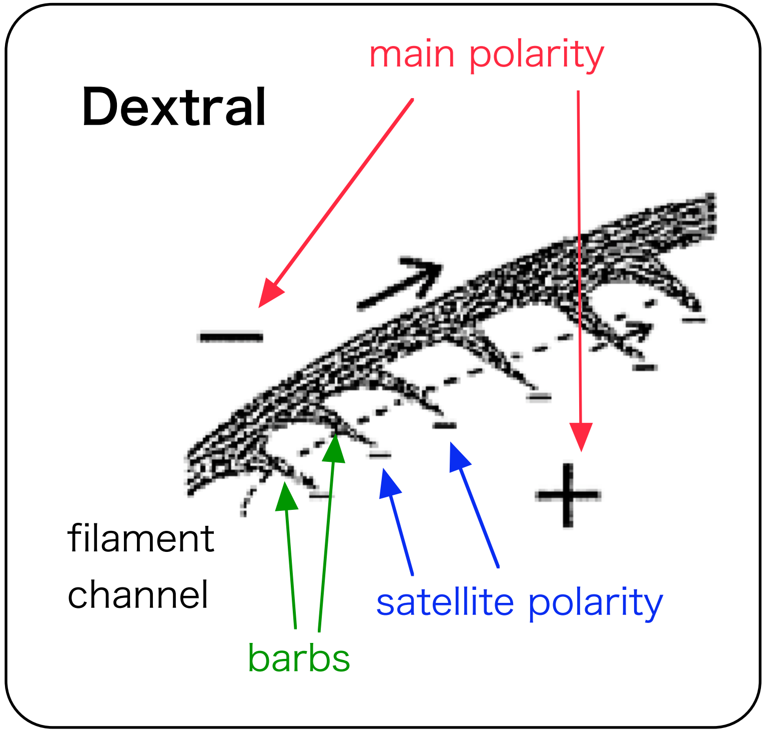
Figure 10. One-to-one chirality relationships for (a) fibril patterns, (b) filament spines and barbs, and (c) overlying arcades of coronal loops, are shown in each column. The patterns in the left column are dominant in the northern hemisphere and those in the right column are dominant in the southern hemisphere. Exceptions exist to this hemispheric preference but there are no known exceptions within the sets of chirality relationships. Illustration from Martin (1998).

Key features:

- Main polarity regions form a channel along the polarity inversion line (PIL), called filament channel.

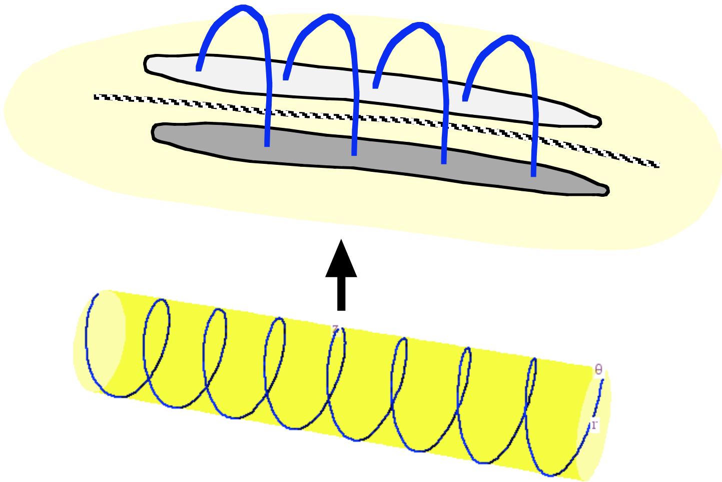
- Satellite polarity regions that have the opposite polarity to the nearby main polarity region are distributed closer to the PIL.

- Field lines connecting to satellite polarity regions have dip-like structure, forming filament feet called barbs.



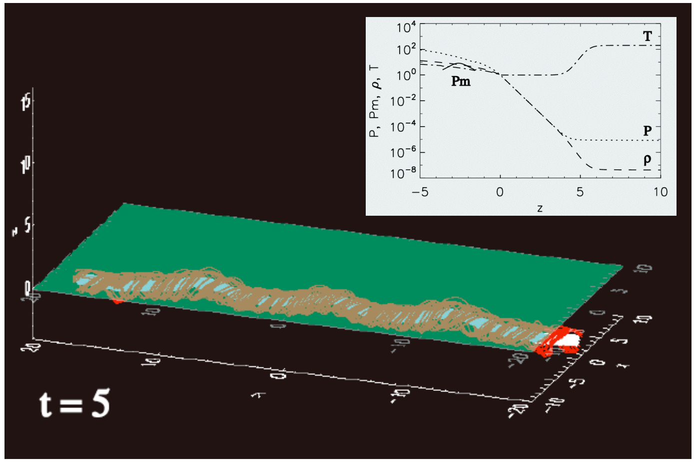
Does the emergence of a left-handed (or right-handed) flux tube provides a dextral (or sinistral) filament?

Simple consideration tells that there appear a filament channel and main polarity regions, although there may not appear satellite polarity regions.

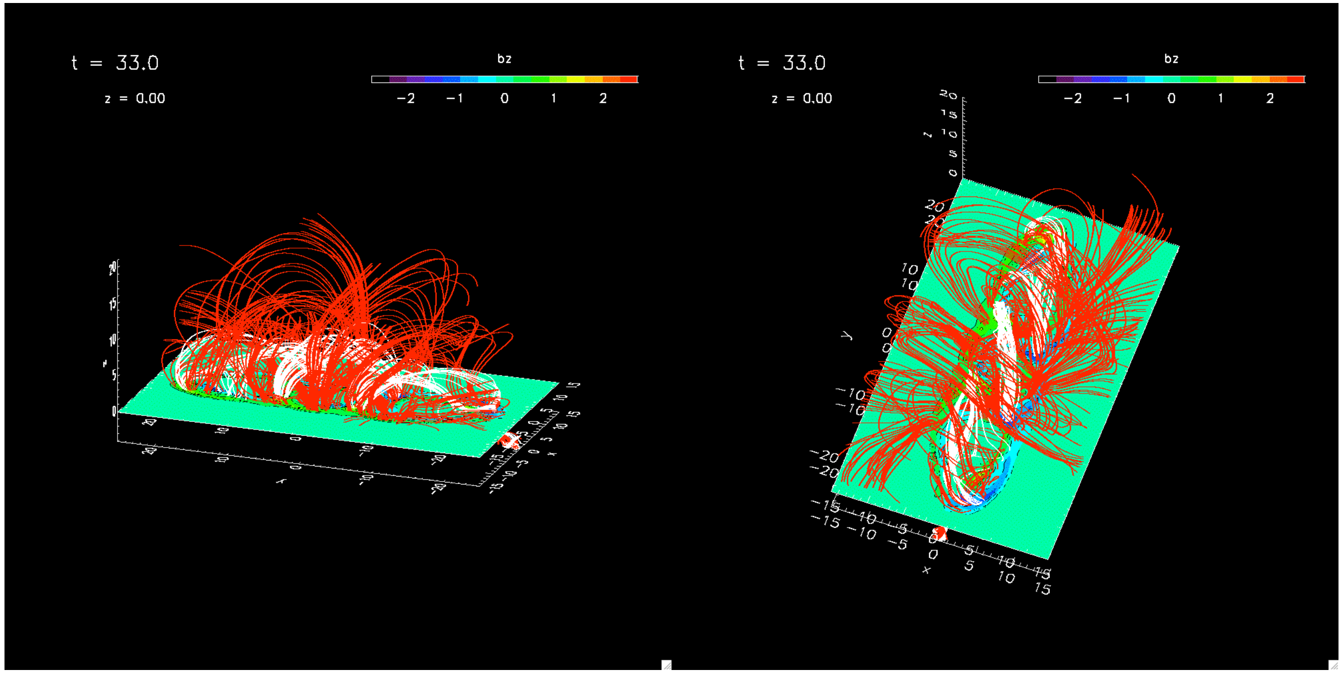


How does the magnetic structure with those features is formed via flux emergence?

We should focus on a 3D aspect of flux emergence, that is, the undulation of an emerging flux tube.

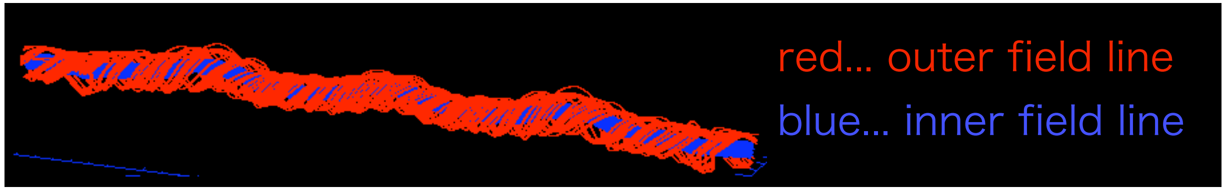


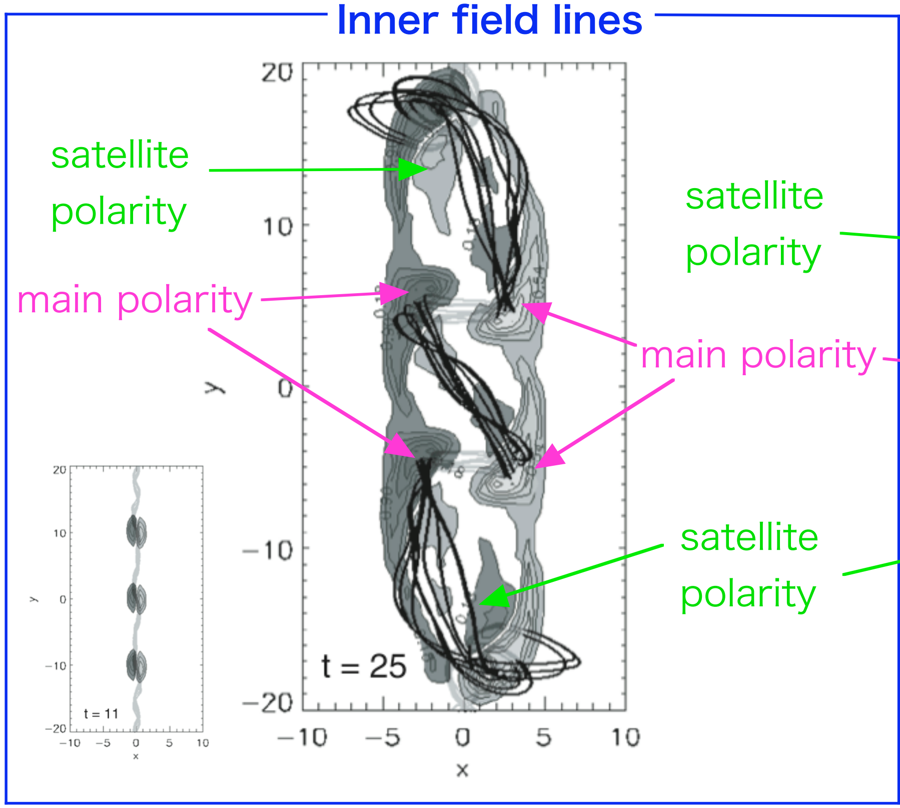
Magara (2007)

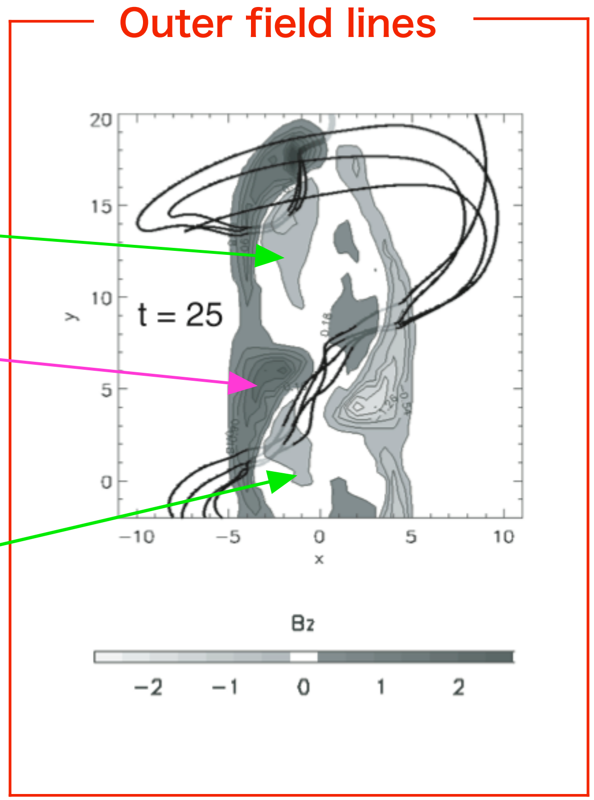


The 3D effect:

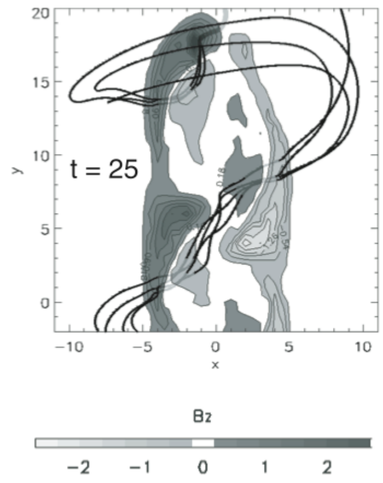
The inner field lines form main polarity regions on the photosphere, while the outer field lines contribute to forming satellite polarity regions.







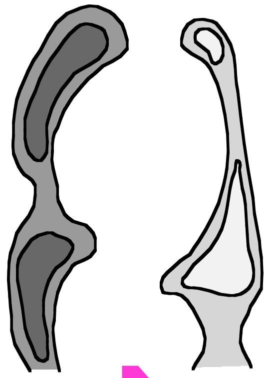
Bipolar or Multipolar



Ideal MHD calculation

=> smooth distribution

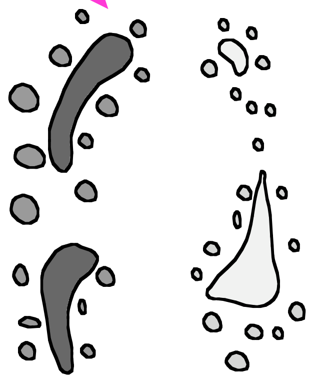
main polarity forms a bipolar structure



Real world (with convective motions)

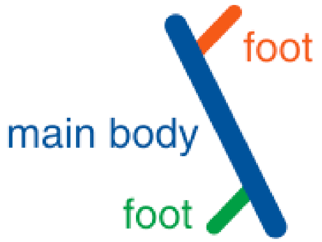
=> disintegrate weak-field regions

main polarity forms a multipolar structure

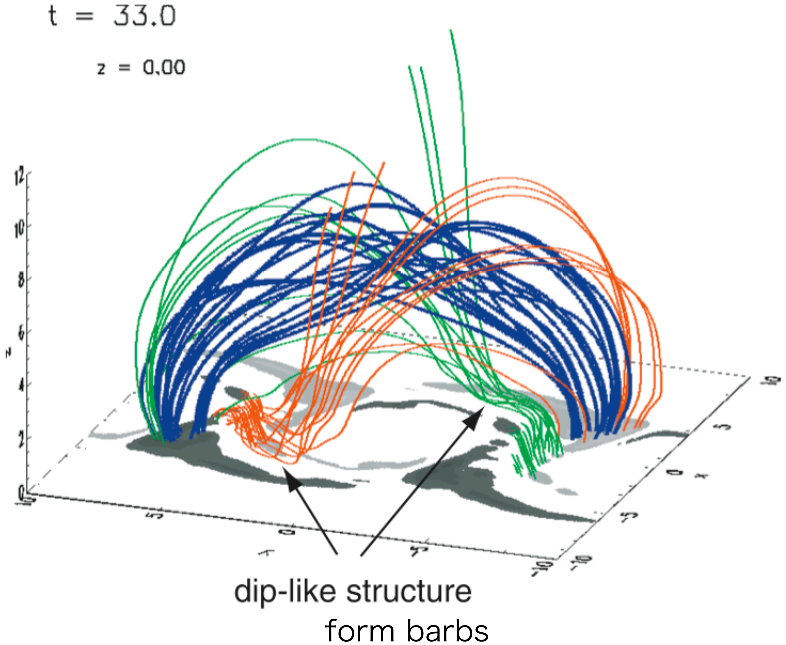


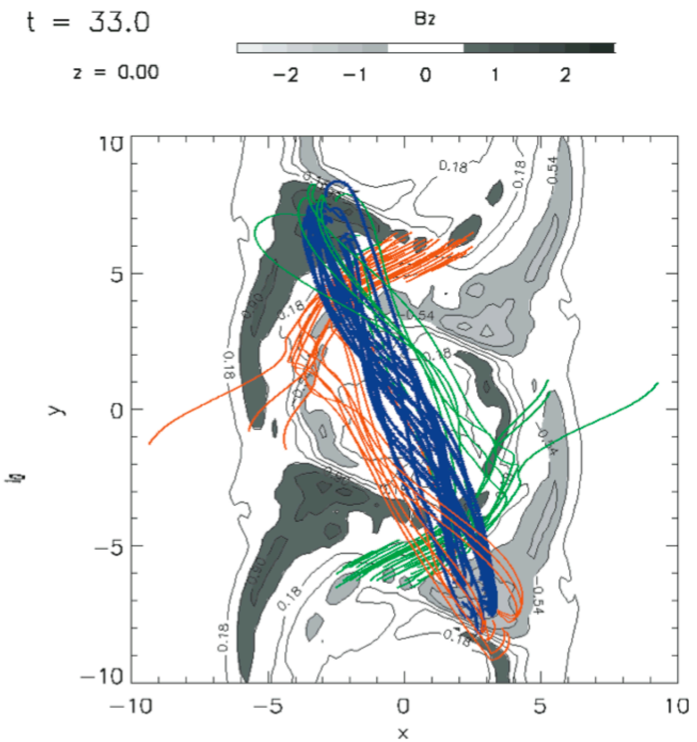
3D configuration formed by an emerging flux tube

Field lines connecting to satellite polarity regions form barbs, and the top view of these field lines is reminiscent of observations of a dextral filament.

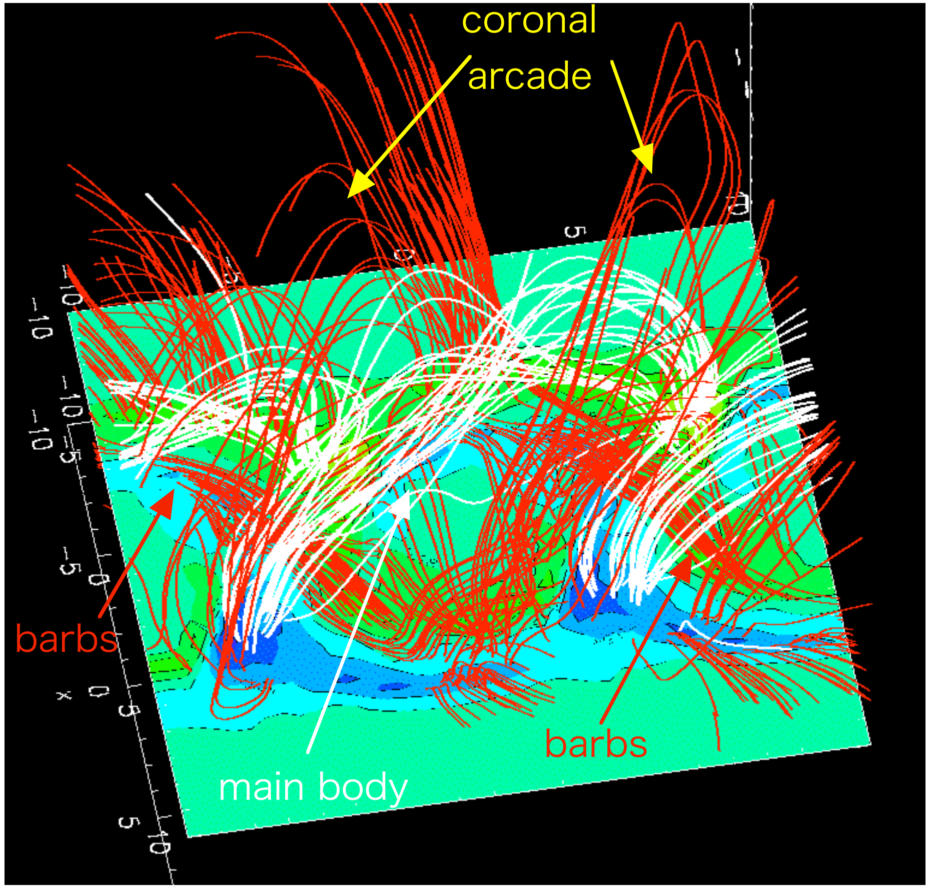


dextral filament

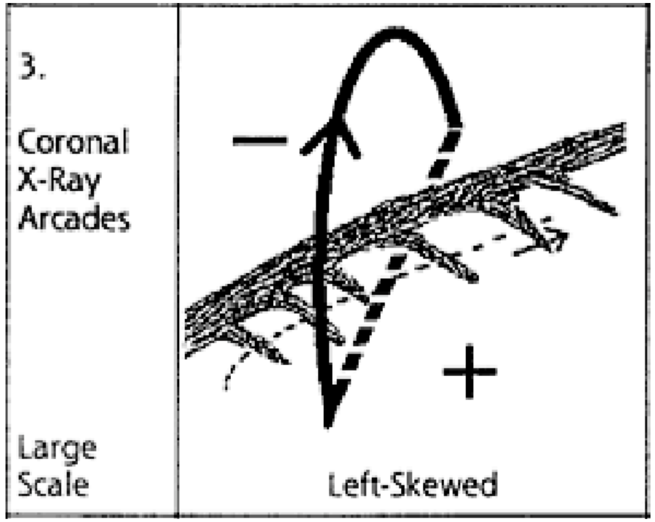




Spatial relation between coronal arcade and filament structure



dextral filament

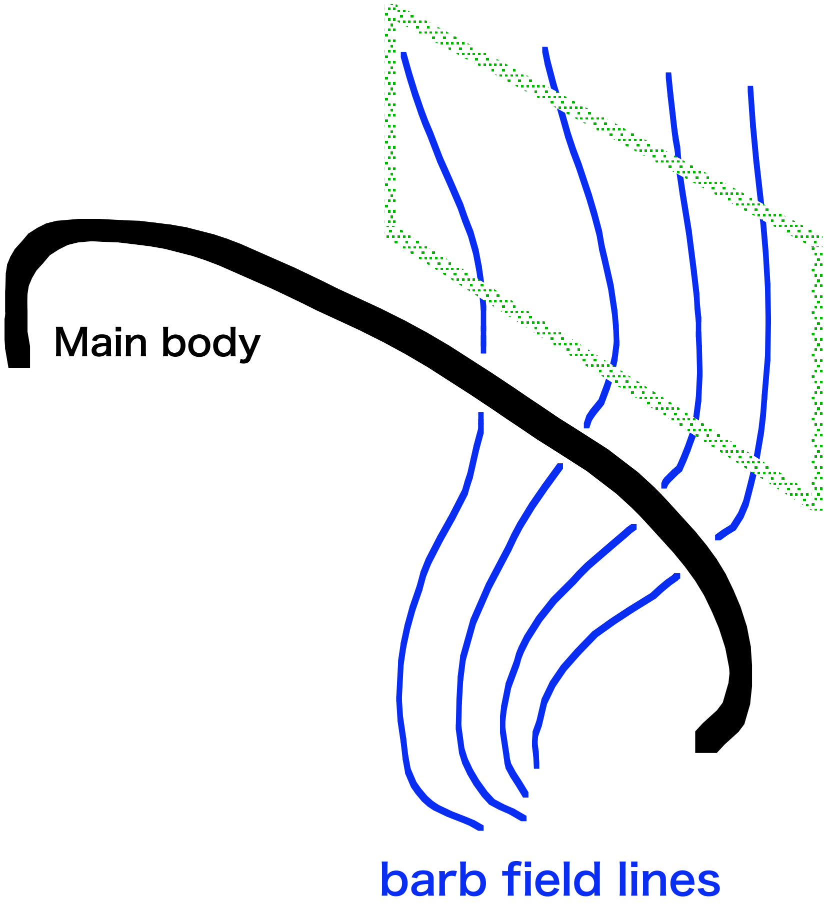


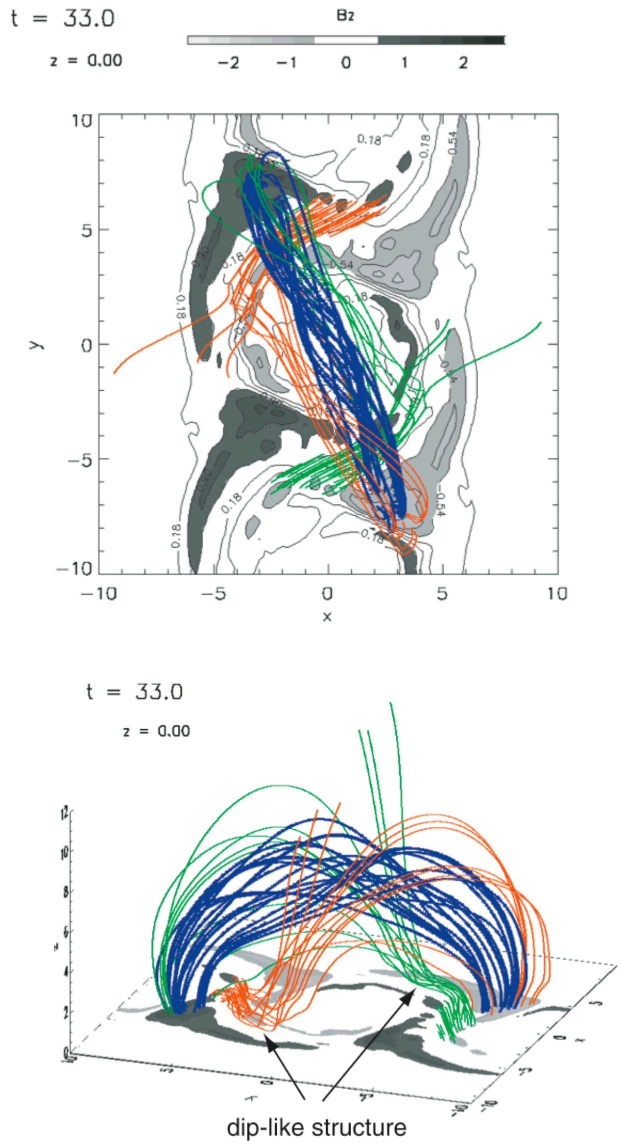
The outer field lines form a coronal arcade above the main body of a filament, while they form barbs below the main body.

Barb field lines...

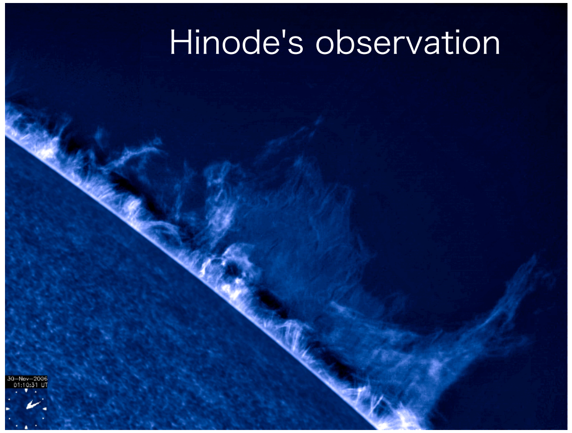
form a vertical curtain-like structure

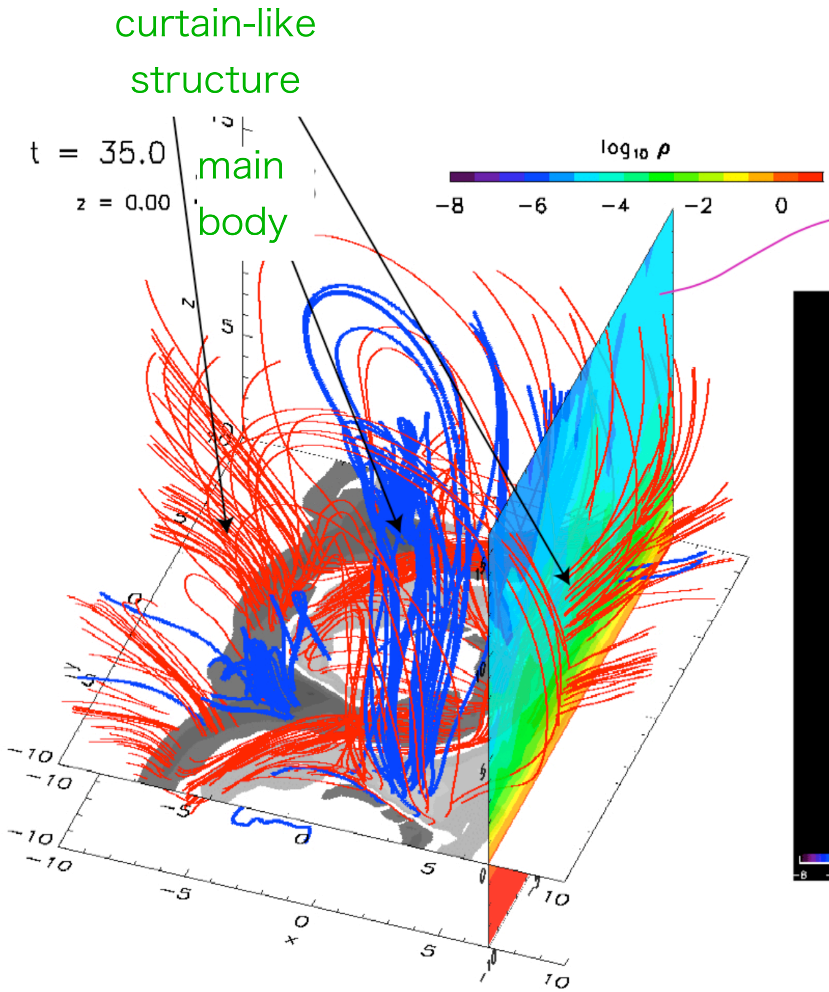
in the upper atmosphere



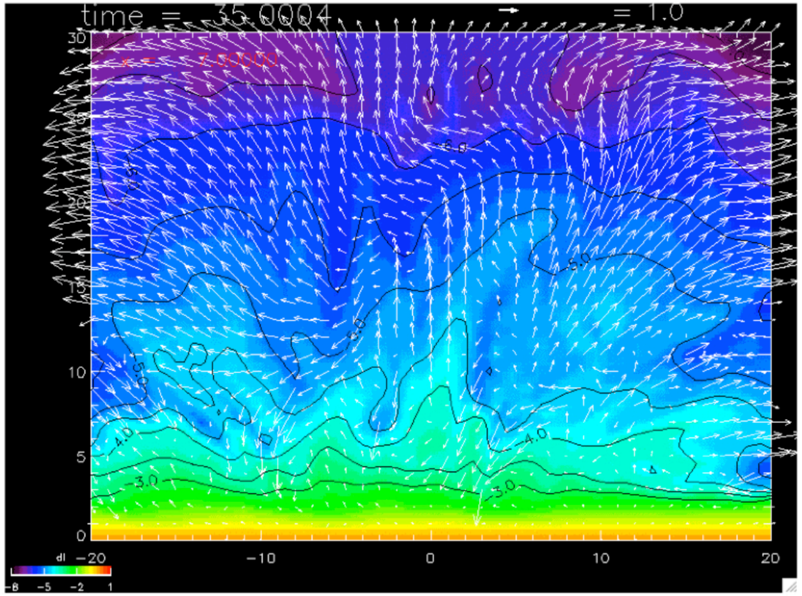


Investigate the vertical structure formed by barb field lines...



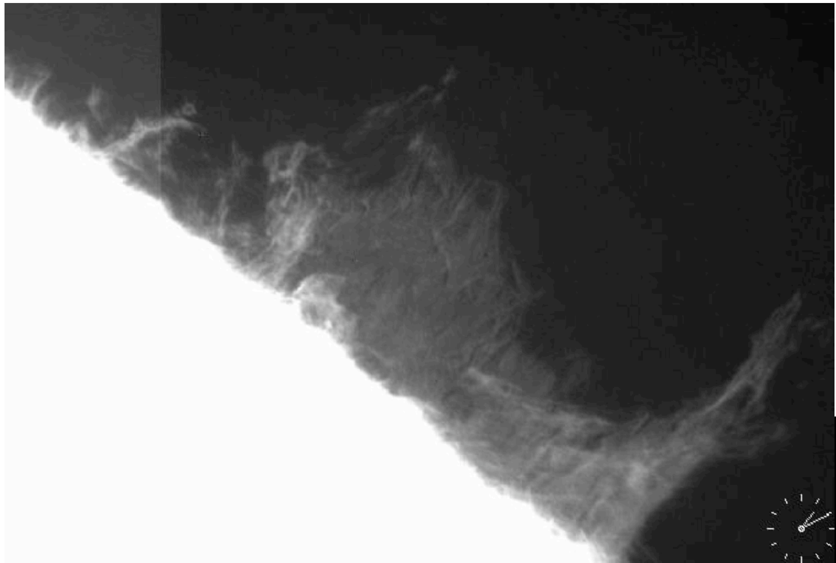


cross section



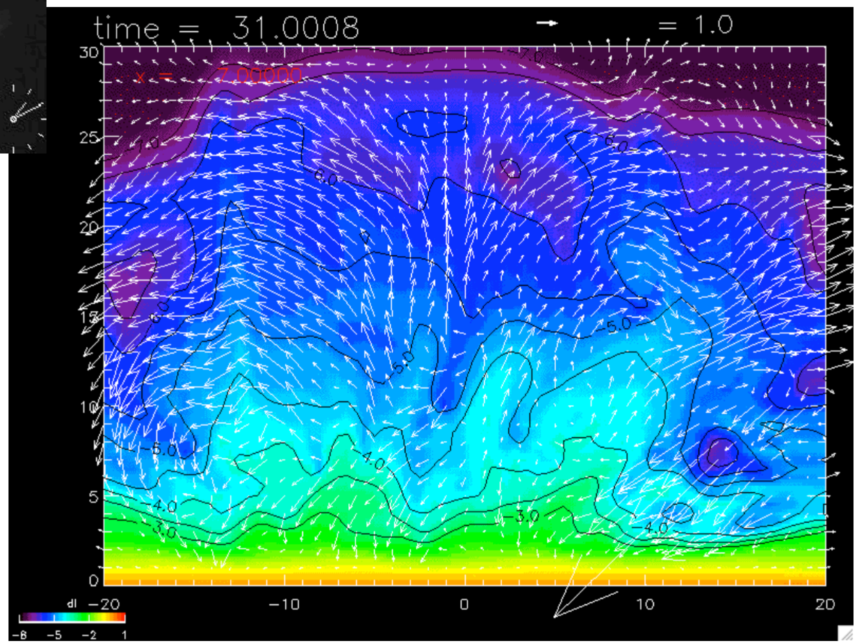
color: density, arrows: velocity

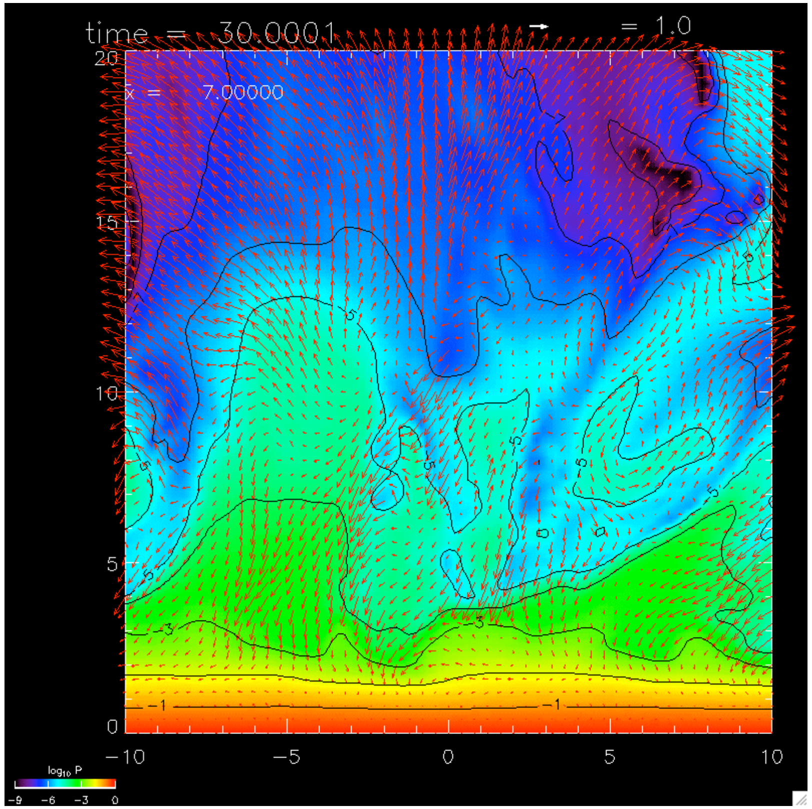
Dynamic behavior observed in the curtain-like structure



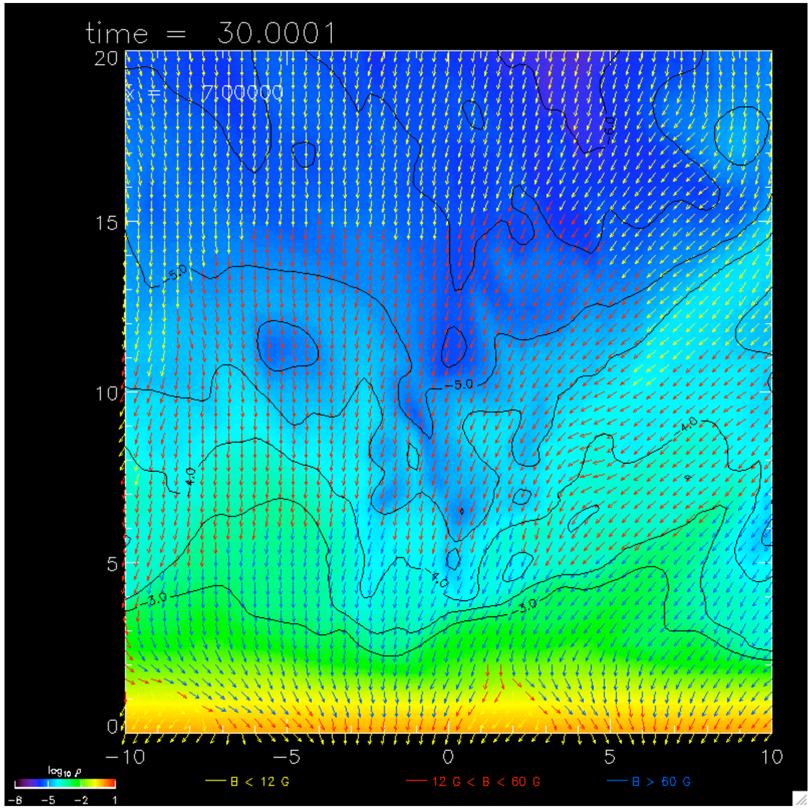
Hinode's observation

MHD simulation



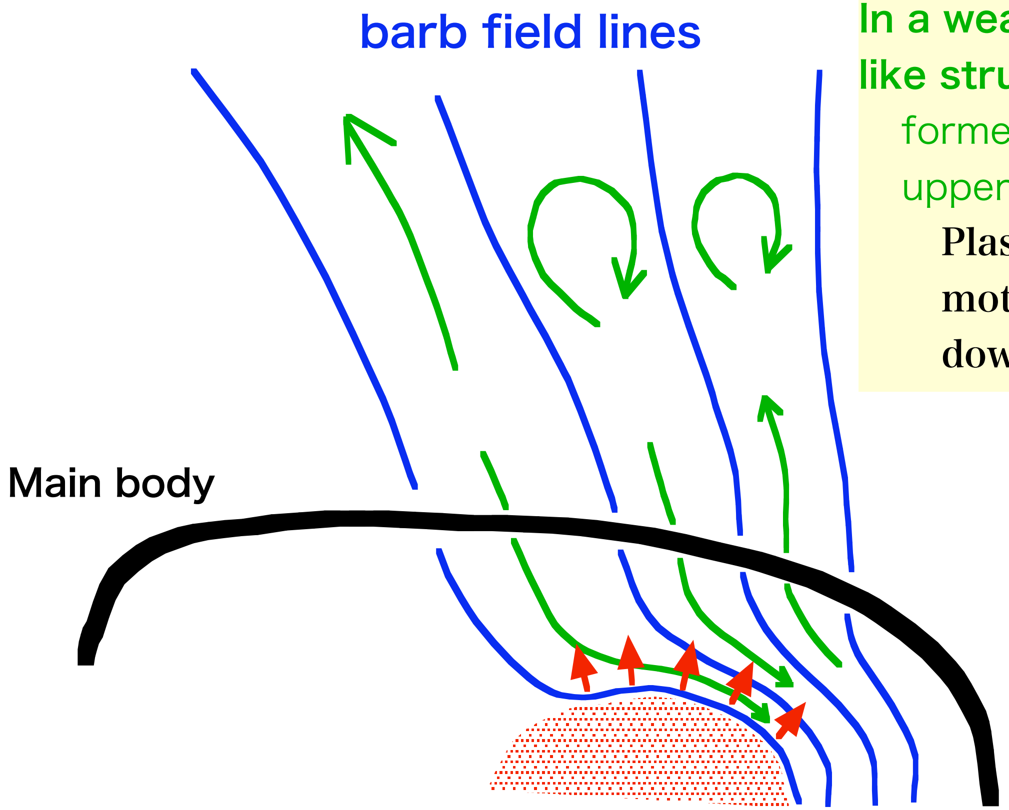


Color: gas pressure
Arrows: fluid velocity



Color: gas density
Arrows: magnetic field

A possible scenario



In a weak-field region (curtain-like structure)

formed by barb field lines in the upper atmosphere

Plasma shows a variety of motions, such as convection, downflow, jet-like upflow.

In a bubble region

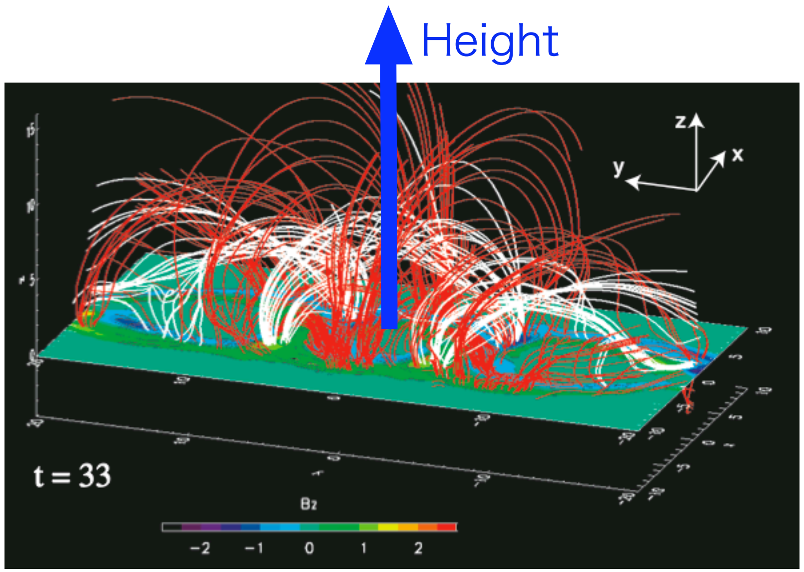
surrounded by barb field lines in the lower atmosphere

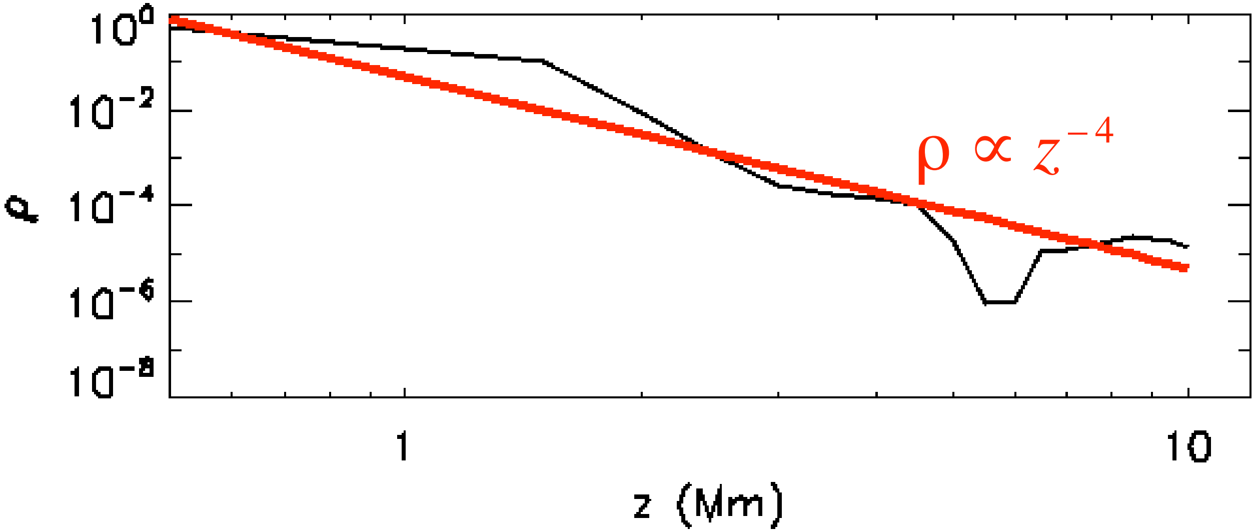
The bubble increases area due to the expansion of barb field lines.

Density distribution with height

A self-similar solution:

$$\rho \propto z^{-4}$$



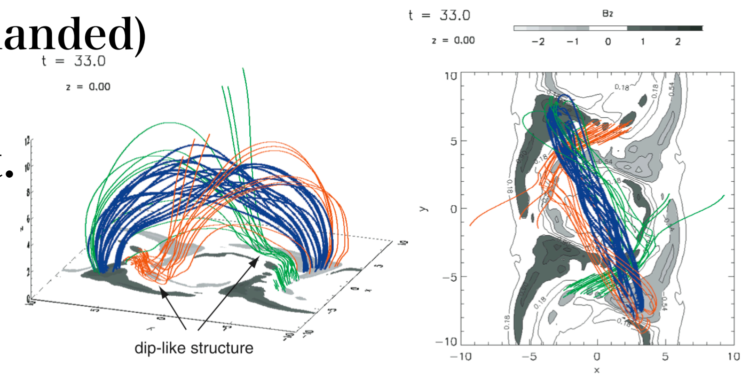


Summary

Toward a new modeling focused on 3D and dynamic nature of prominences

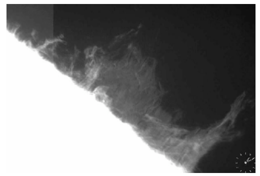
3D configuration...

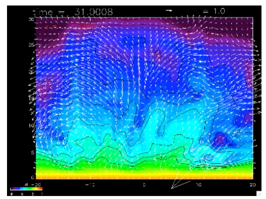
The emergence of a left-handed (right-handed) flux tube produces a possible magnetic structure of a dextral (sinistral) filament.



Dynamic nature...

The barb field lines form a curtain-like structure in a weak-field region where convective motions become dominant among vertical field lines.





Solar-cycle dependence

Bothmer & Rust (1999)

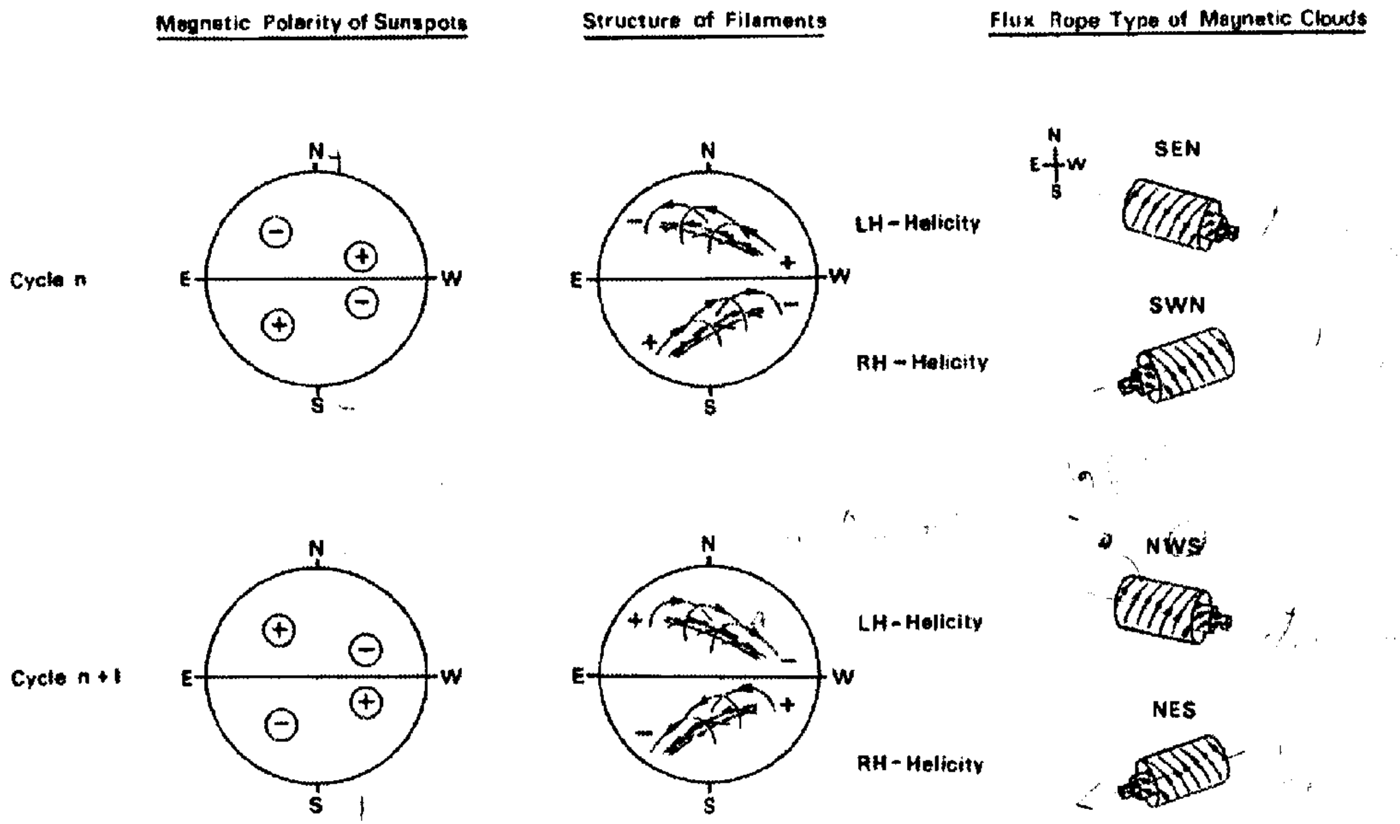


Figure 2. An extended association between the magnetic field structure of solar filaments and interplanetary magnetic clouds (MCs) that can explain the observed solar cycle variation of the field structure of MCs.