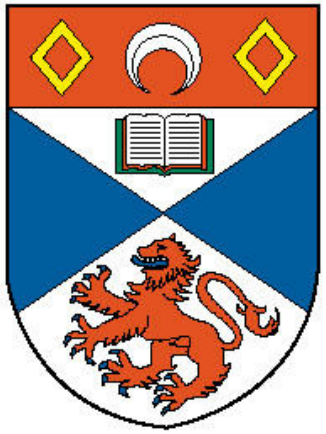
Magnetic Configurations for Filament Formation



Duncan H Mackay

Solar and Magnetospheric Theory Group

University of St. Andrews

Scotland.

Contents

- Classification Schemes.

- Observations of Filament Formation.
  - Gaizauskas et al. (1997)/(2001).
  - Lites et al. 1995/Okamoto et al. (2008).

- Theoretical Models: Magnetic Dips.
  - Mechanisms employed.
  - Surface Models/Subsurface Models.
  - Origin of Hemispheric Pattern (Yeates et al. 2008).

- Future Studies.

Observational Classifications

- Filaments form over a wide range of latitudes (Engvold 1998):

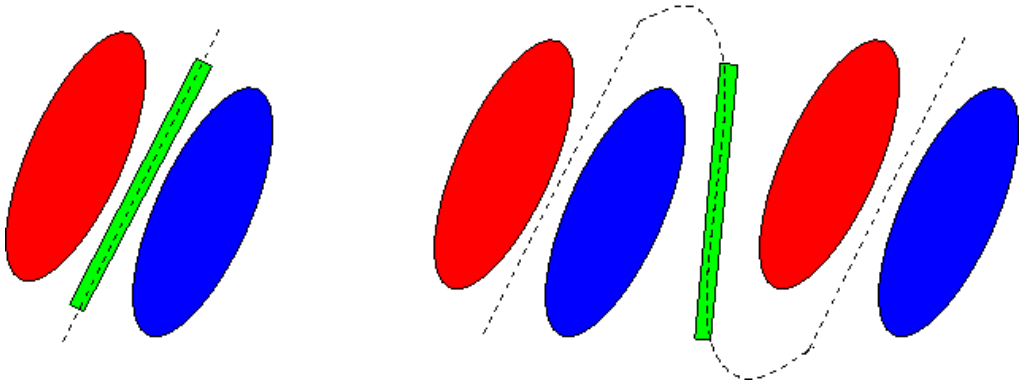
  ARF - Active Region Filament

  IF - Intermediate Filament

  QF - Quiescient Filament

- May be classified wrt magnetic polarities (Tang 1987):

IBR EBR

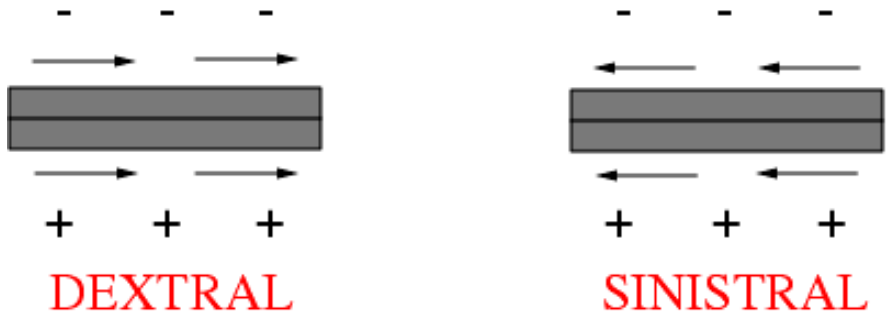


Mackay et al. (2008):

92% form in non-bipolar config. (EBR, I/EBR, DBR).

7% in single bipole (IBR)

- Hemispheric Pattern (Martin et al. 1995):



Dextral – NH

Sinistral – SH

Observations of Filament Formation

- Very few "clean" examples of the formation of filaments ever observed : exact formation mechanism is still a mystery (5 papers).

- Consider 2 separate cases with opposing views:

Case 1 : Surface motions reconfiguring coronal field (Gaizauskas et al. 1997/ 2001).

IF (5 days), QF(27 days)

Common features:

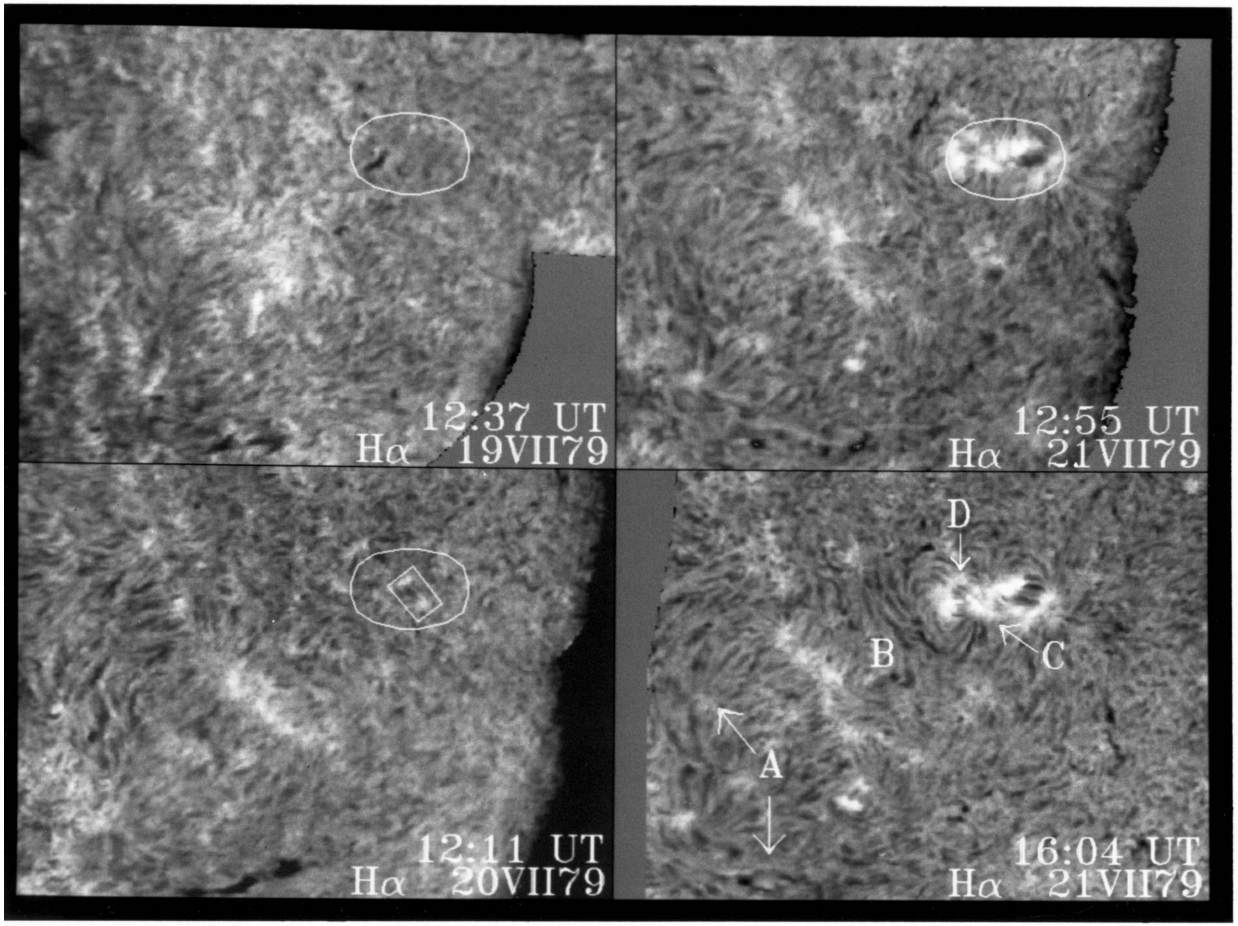
Only formed after flux emergence ceased.
Convergence/cancellation of flux at PIL.
Evidence of helicity in emerging flux from chromospheric fibrils.
(see also Wang and Muglach 2007, Martin 1998)

Case 2 : Emerging horizontal Flux Rope (Lites & Low 1997/Okamoto et al. 2008).

small unstable active region filament (ARF)

Case 1: Gaizauskas et al. (1997)

- Formation of IF occurred over a period of five days 20-25th July 1979 (southern hemisphere).
- Two separate flux regions ~ Old remnant region (McMath 16159).
  New emerging region (McMath 16166).
- Emergence occurs at location free from strong fibril alignment.

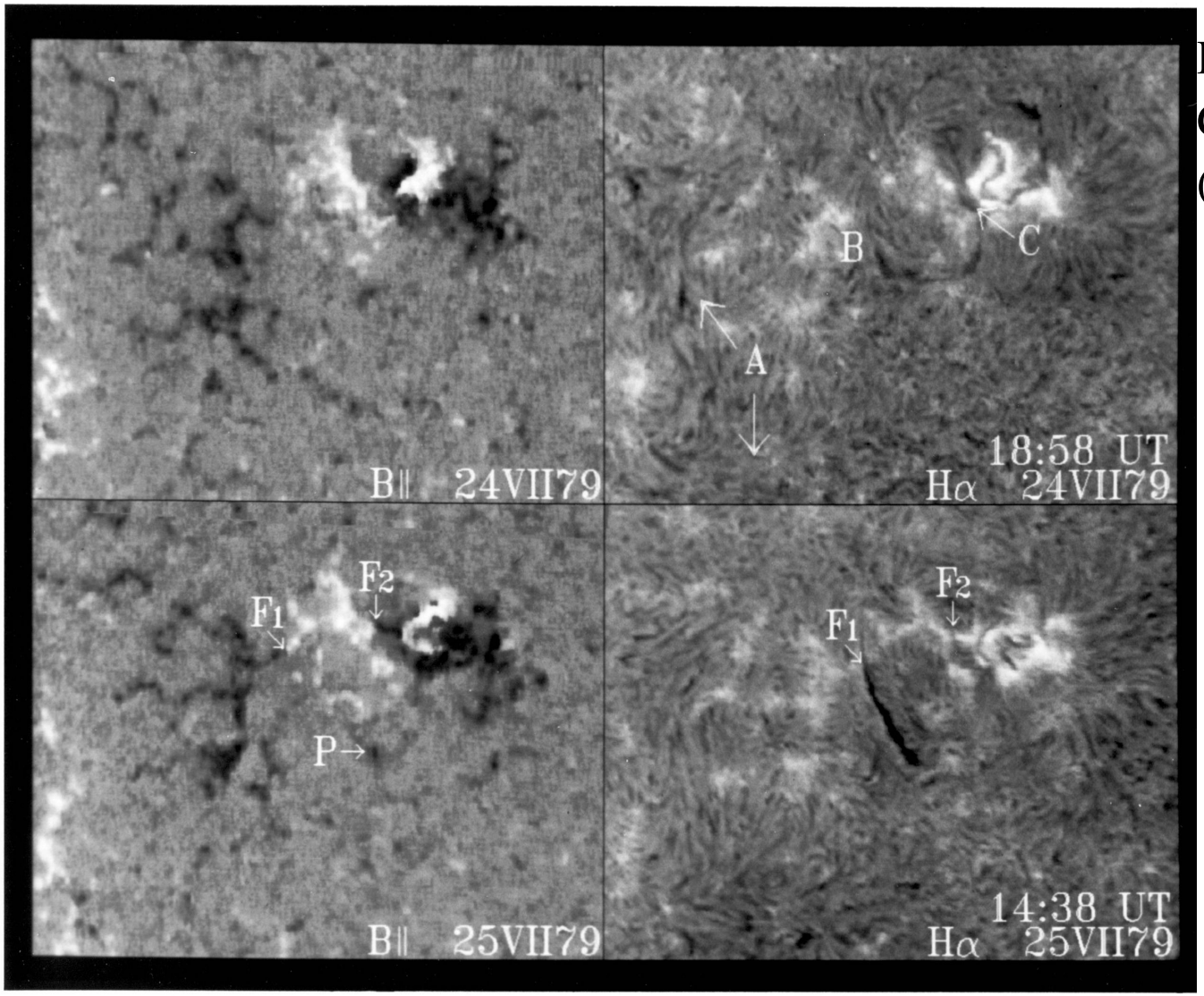


Halpha images from Gaizauskas et al. (1997).

Fibrils form around new region in three hours.

Fibrils show that extended field of activity complex is non-potential..

- Emergence of flux ceases on 23rd July after which the activity complex disperses out.
- Convergence and cancellation of flux occurs on fifth day at F1 and Sinistral filament forms after convergence.

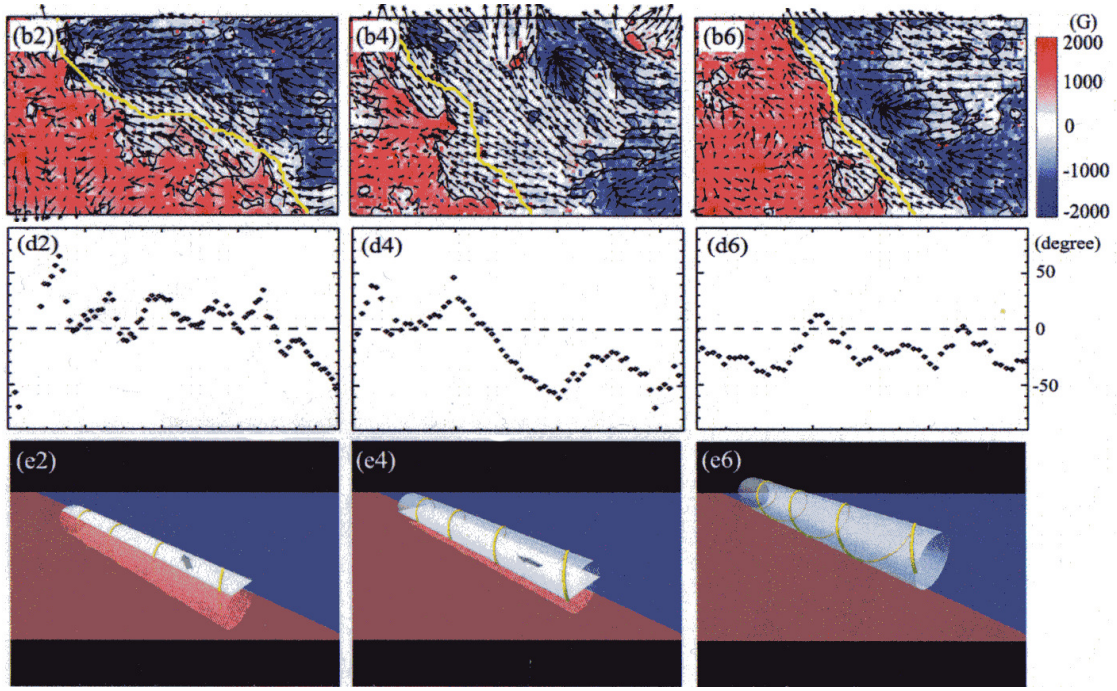


Halpha images from Gaizauskas et al. (1997).

The magnetic structure/sinistral chirality of the prominence can only be represented by a non-potential magnetic field (+ve, Mackay et al. 1997).

Case 2:Okamoto et al. (2008)

- Hinode/SOT observations of the emergence of a helical flux tube under an existing AR filament – enhances the filament.



- Main features:

  Widening/narrowing of channel

  Horizontal Field changes from

  NP $\rightarrow$ IP

- Explain filament formation by buoyant rise of twisted fields from convective layer pulling cool plasma into corona (Rust and Kumer 1994, Deng et al 2000, Rust 2001).
- Lites and Low (1997): Small Hα AR filament forms along PIL during emergence (lifetime of 2 days).

MHD Models of Filament Formation

- A wide variety of models for filament formation have been constructed (only consider 3D models).

Split into two types:

Plasma Thermodynamic models (origin of mass).

Magnetic evolution models (origin of dipped magnetic structure) : flux rope

- Many filament formation mechanisms have been used.

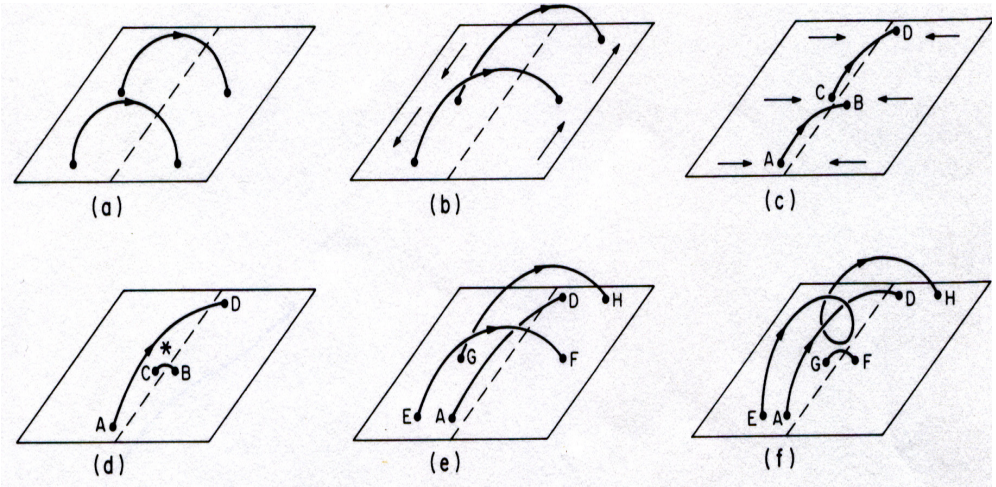
Surface	Subsurface
Differential Rotation (shear flows)[1]	Subsurface motions[2]
Converging flows[3]	
Magnetic reconnection (atmosphere)[4]	Magnetic reconnection (sub-surface)[5]
Flux Emergence (bipoles)[6]	Flux emergence (U-loops)[7]
Magnetic Helicity[8]	Magnetic Helicity[9]
Flux Cancellation/Diffusion[10]	

MHD Models of Filament Formation(cont)

Surface Models		Subsurface Models	
Single Bipole	Multiple Bipoles	Single Bipole	Multiple Bipoles
van Ballegooijen and Martens (1989)[1,3,4,10]	Kuperus (1996)[1,3,4]	Low (1994)[7]	Priest, van Ballegooijen and Mackay (1996)[2,3,4,6]
DeVore and Antiochos (2000)[1,4]	Kuijpers (1997)[3,4,8,10]	Rust and Kumar (1995)[7,9]	
	Mackay et al. (1998)[3,4,6,8,10]	Gibson (2004)[7,9]	
	Galsgaard and Longbottom (1999)[3,4]	Low and Hundhausen (1995)[7,9]	
	van Ballegooijen, Priest and Mackay (2000)[1,4,10]	Fan and Gibson (2004,2006)[7,9]	
	Martens and Zwaan (2001)[3,4,10]	Gibson and Fan (2006)[7,9]	
	Lionello et al. (2002)[8,10]	Magara (2006)[7,9]	
	DeVore, Antiochos and Aulanier (2005)[1,3,4]	Magara (2007)[7,9]	
	Mackay and van Ballegooijen (2005)[1,4,8,10]		
	Welsh, DeVore and Antiochos (2005)[3,4,8,10]		
	Litvinenko & Wheatland (2005) [3,4,8,10]		
	Yeates, Mackay and van Ballegooijen (2008)[1,4,8,10]		

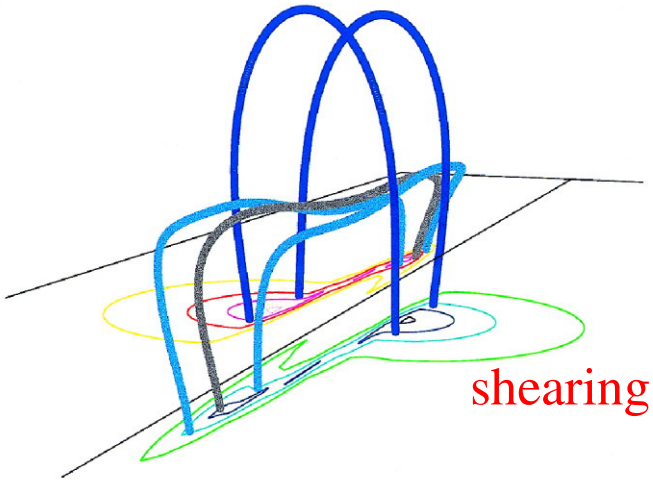
Surface Models

- van Ballegooijen and Martens 1989[1,3,4,10]



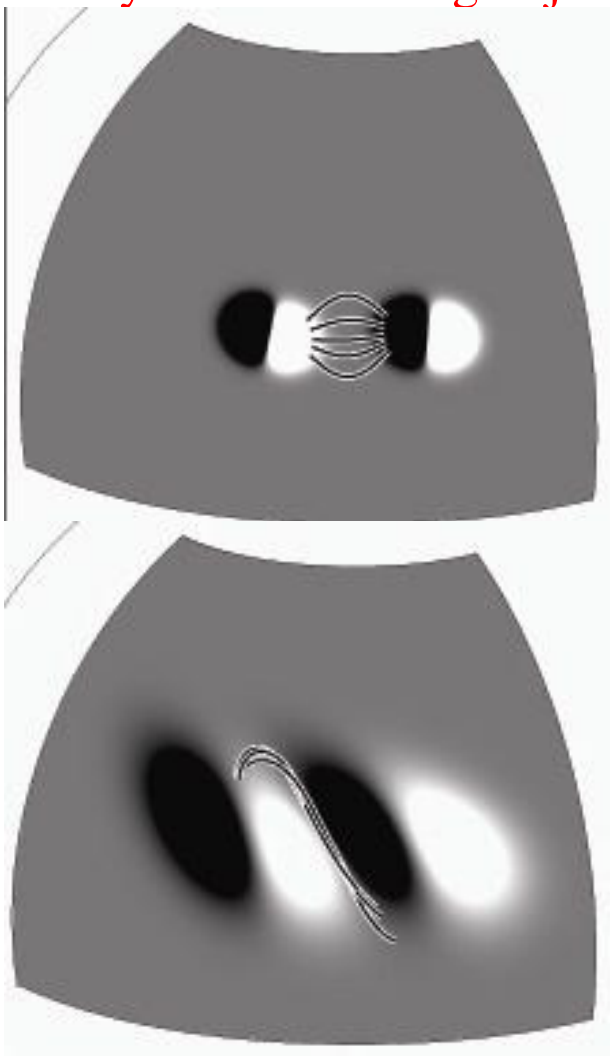
shearing motion + convergence + cancellation

- DeVore and Antiochos[1](2000)



shearing motion

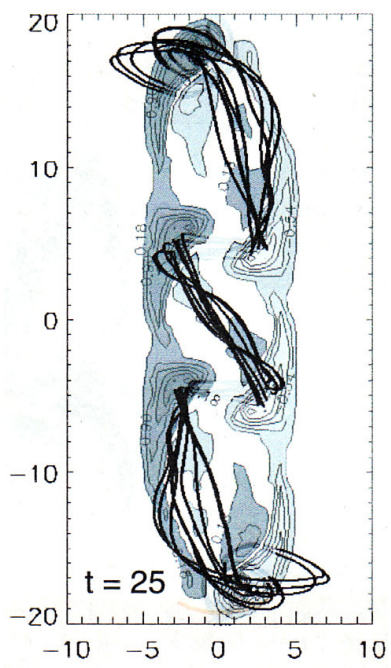
Mackay and van Ballegooijen[1,4,8,10]

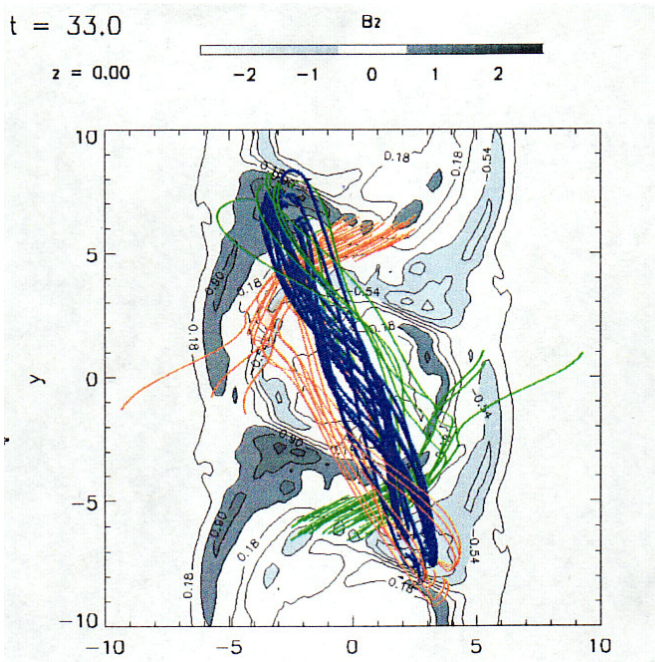


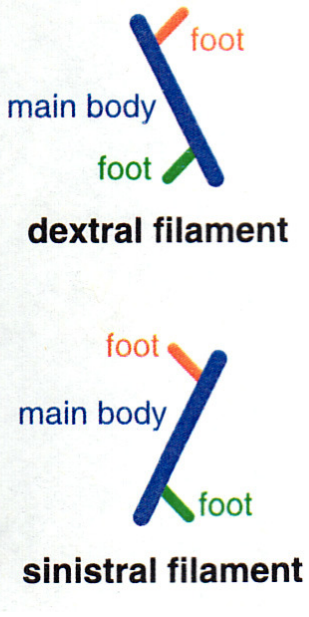
flux transport + helicity + surface diffusion

Subsurface Models

- Magara (2006) [7,9] - consider multi-Ω-loop emergence may reproduce some filament features.







- Filament forms through the emergence of a horizontal twisted flux rope.
  - tube forced to emergence through imposed vertical velocity.
  - 3 different portions rise.
  - dominant/minority polarity regions.
  - main body/barbs.

- See also Rust and Kumar (1994) and Gibson and Fan (2006).

Origin of the Hemispheric Pattern

- Mackay and van Ballegooijen (2005) : interaction of 2 magnetic bipoles.

  Dominant : Dominant bipole tilt angles (-10:30)/dominant helicity
  Exceptions : large +ve tilt angles/ minority helicity

- Yeates, Mackay and van Ballegooijen (2008, Sol. Phys.) considered origin of axial field for 109 filament over 6 months:

  1) Determine the chirality and location of all filaments over 6 months.

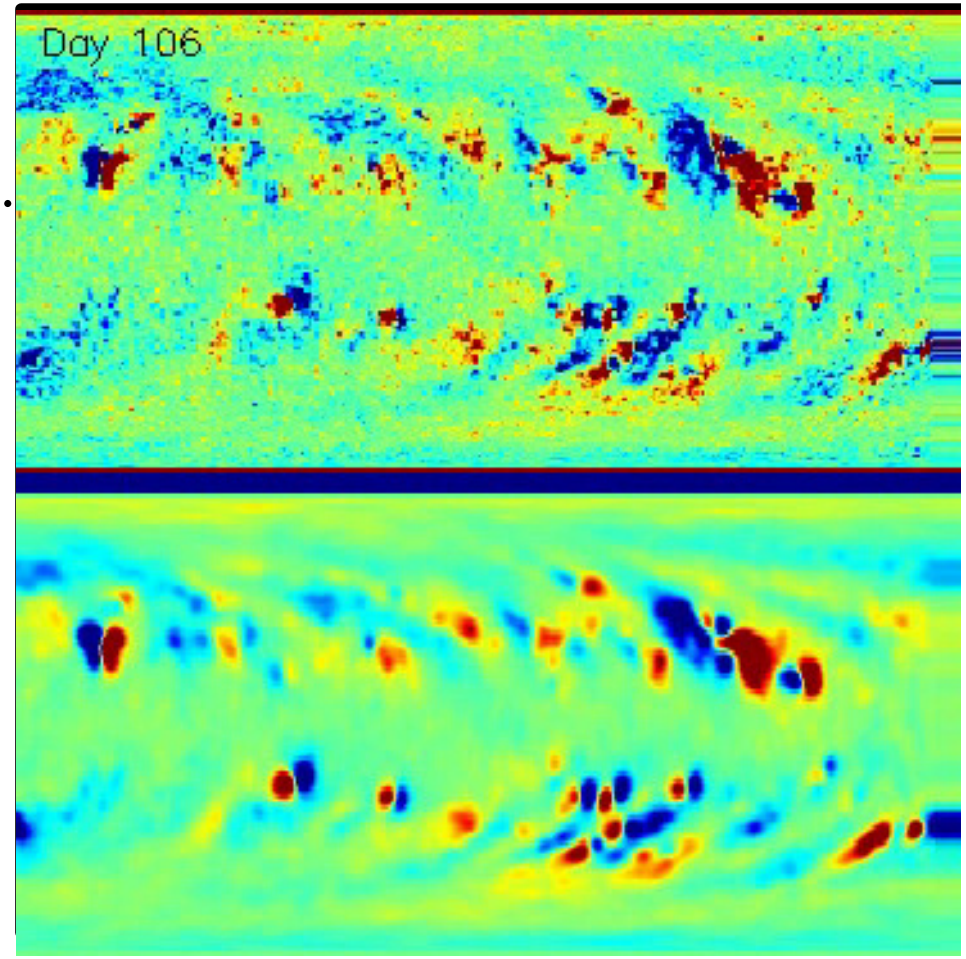
  2) Simulate coupled evolution of photospheric/coronal fields.
     - continuous nlfff simulations (without resetting the photospheric/coronal fields)
     - Photopshere: flux transport processes & flux emergence (Yeates et al. 2007, SP), dispersal of helicity (Yeates et al. 2008, APJL)
       Corona: nlfff fields (van Ballegooijen et al. 2000).

  3) Test the chirality produced by the model with observed chirality at the exact observed location of each filament.

Photospheric Boundary Condition

- 6 KP synoptic maps (CR1949-1954)

Used to produce a continuous series of photopsheric boundary conditions.



- Start from rotation 1949.

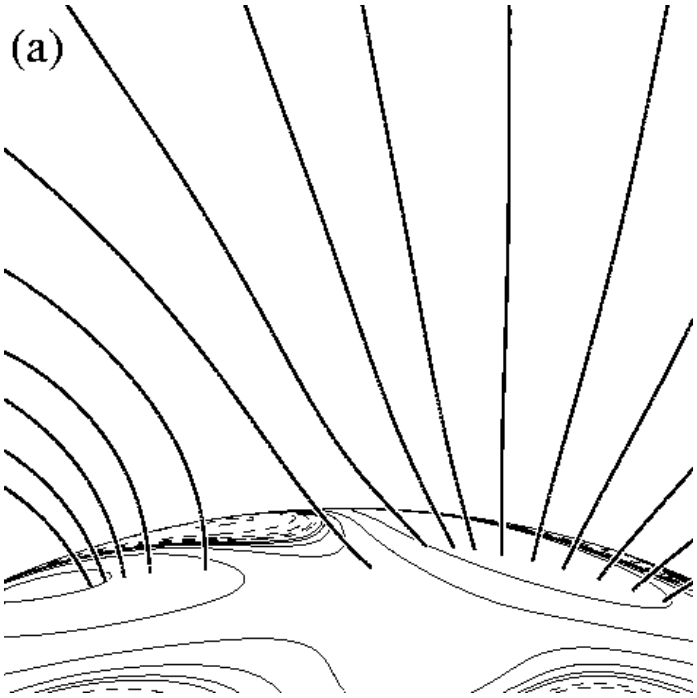
- Evolve forward in time using flux transport effects.

- Flux emergence (119 bipoles)

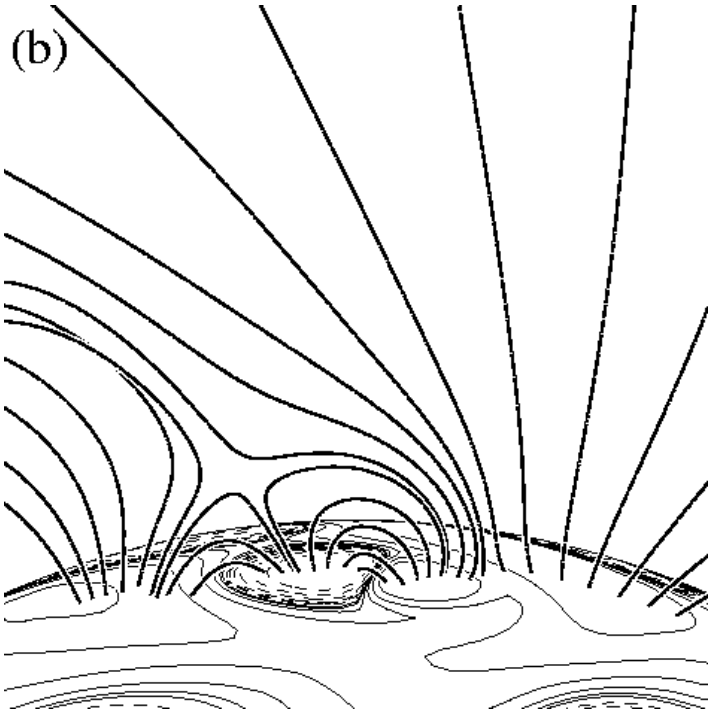
- More details see Yeates et al. (2007)

3D Inserting Bipoles

• Bipoles are inserted as an isolated field containing either +ve or -ve helicity both in the photosphere and corona.

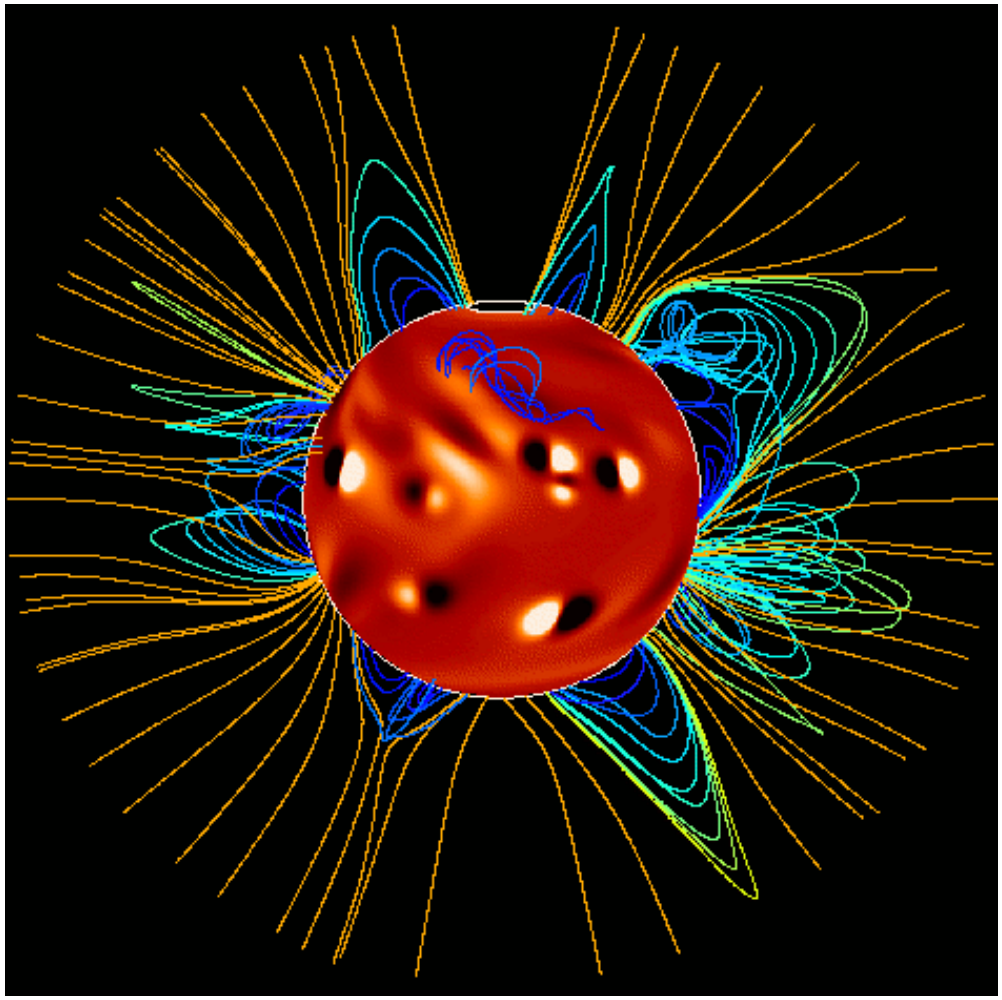


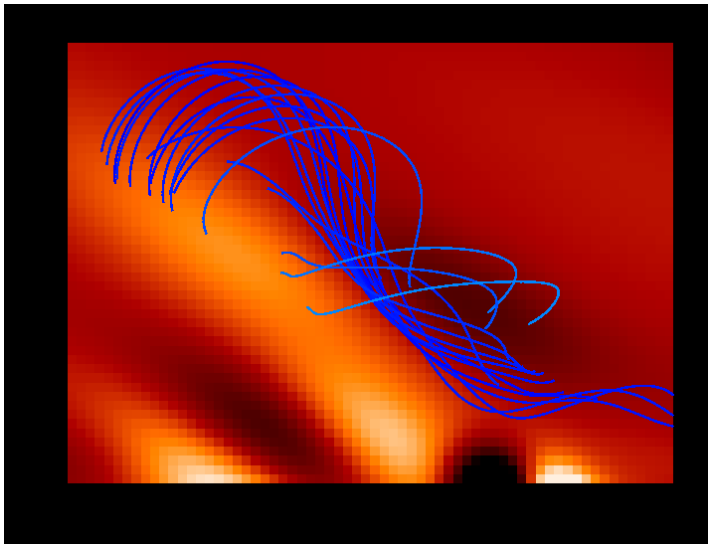
Day 250

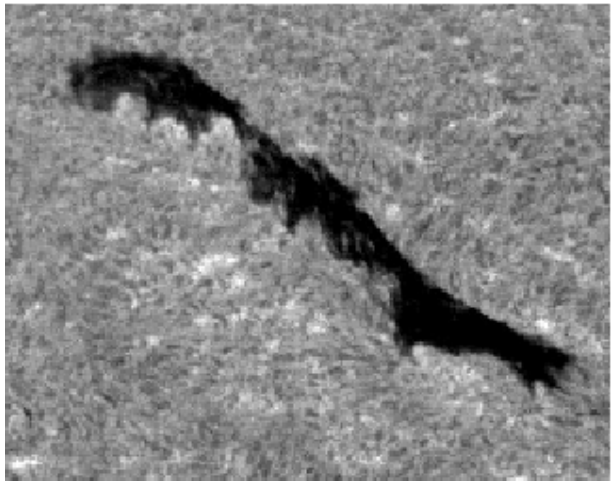


Day 251

Observational Test

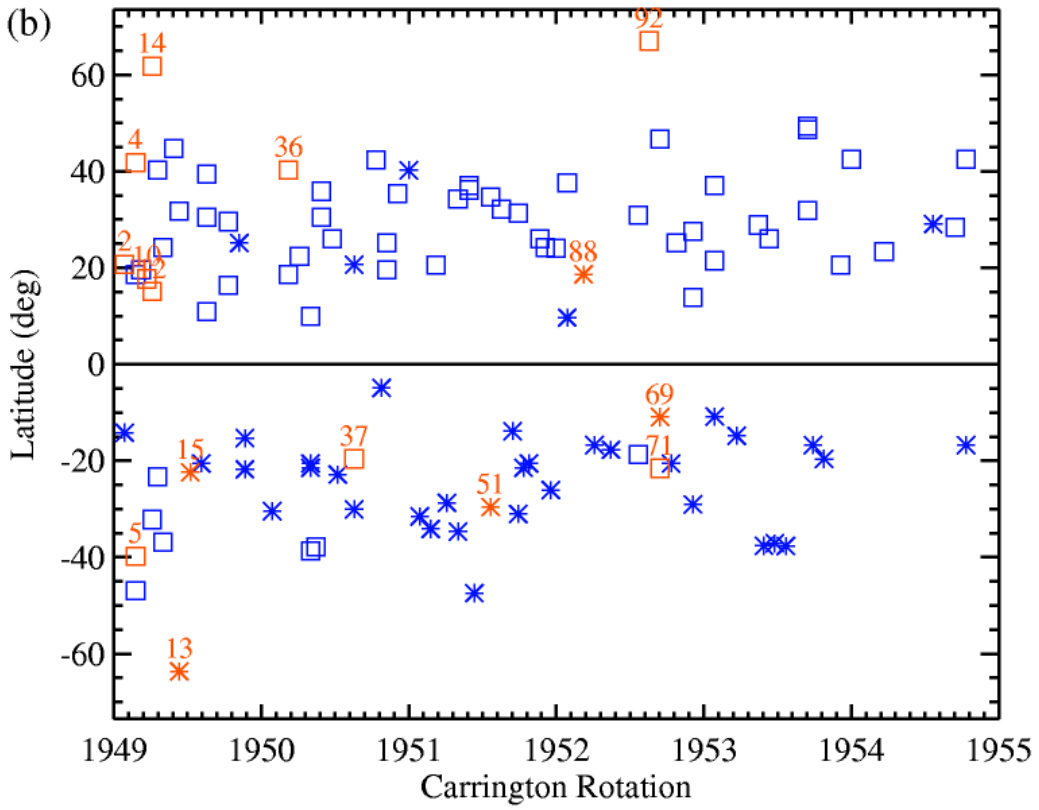






Results

- Hemispheric Distribution of Twist: NH ~ -ve and SH~ +ve



109 filaments

Shapes:

observed chirality

□ dextral

✳ sinistral

Colours:

correct wrong

Up to 96.9% correct

- Results improve the longer the simulation is run (Yeates et al. 2008,2009, Sol. Phys.)

Discussion

- Review of relationship between filaments and their underlying magnetic fields : observations and models of formation.

- Very few examples of filament formation :

  Surface affects: Helicity & transport/convergence of flux at a PIL (cancellation).

  Subsurface affects: Emerging flux ropes.

- Models of Hemipsheric Pattern- Interaction and dispersal of helicity from active regions key for axial field production.

- Could multiple mechanisms be working – depends on physical location ???

- Future : Observations of filament channel/filament formation (at all latitudes).

  Multi-wavelength observations (Hα - X-rays, doppler information).

  Plenty of good luck to be observing at the correct location (full sun rasters, synoptic data).