Where Do Solar Filaments Form ? : Consequences for Theoretical Models

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Classification of Filaments

- Filaments form over a wide range of latitudes (McInotsh 2002, Ambroz & Schroll 2002) .
- Engvold (1998): Relative to active regions

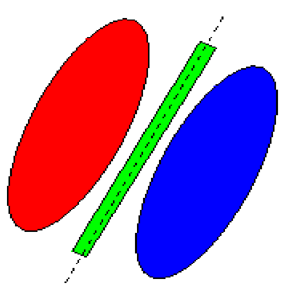
ARF - Active Region Filament

IF - Intermediate Filament

QF - Quiescient Filament

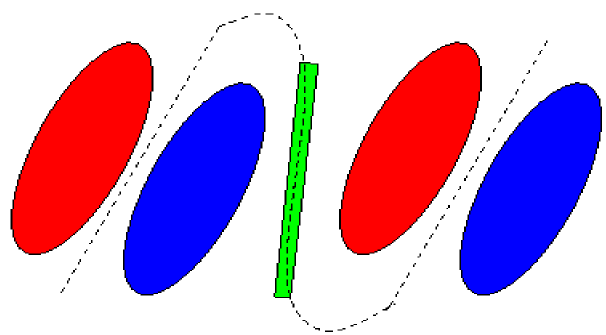
- Tang (1987) : Relative to underlying magnetic polarities:

Interior BR Filament



Type A

Exterior BR Filament



Type B (Tangberg-Hanssen 1995)

Tang 1987 : 60 % Exterior.

(see also Gaizauskas and Zwaan 1997)

Aims and Classification Scheme

- Reconstider where large, stable solar filaments (IF, QF) form relative to underlying magnetic polarities.

Four distinct phases of the Solar Cycle.

Compare this to theoretical models.

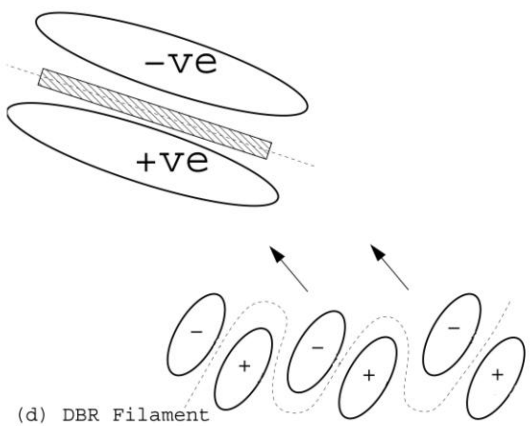
Four categories for filaments.

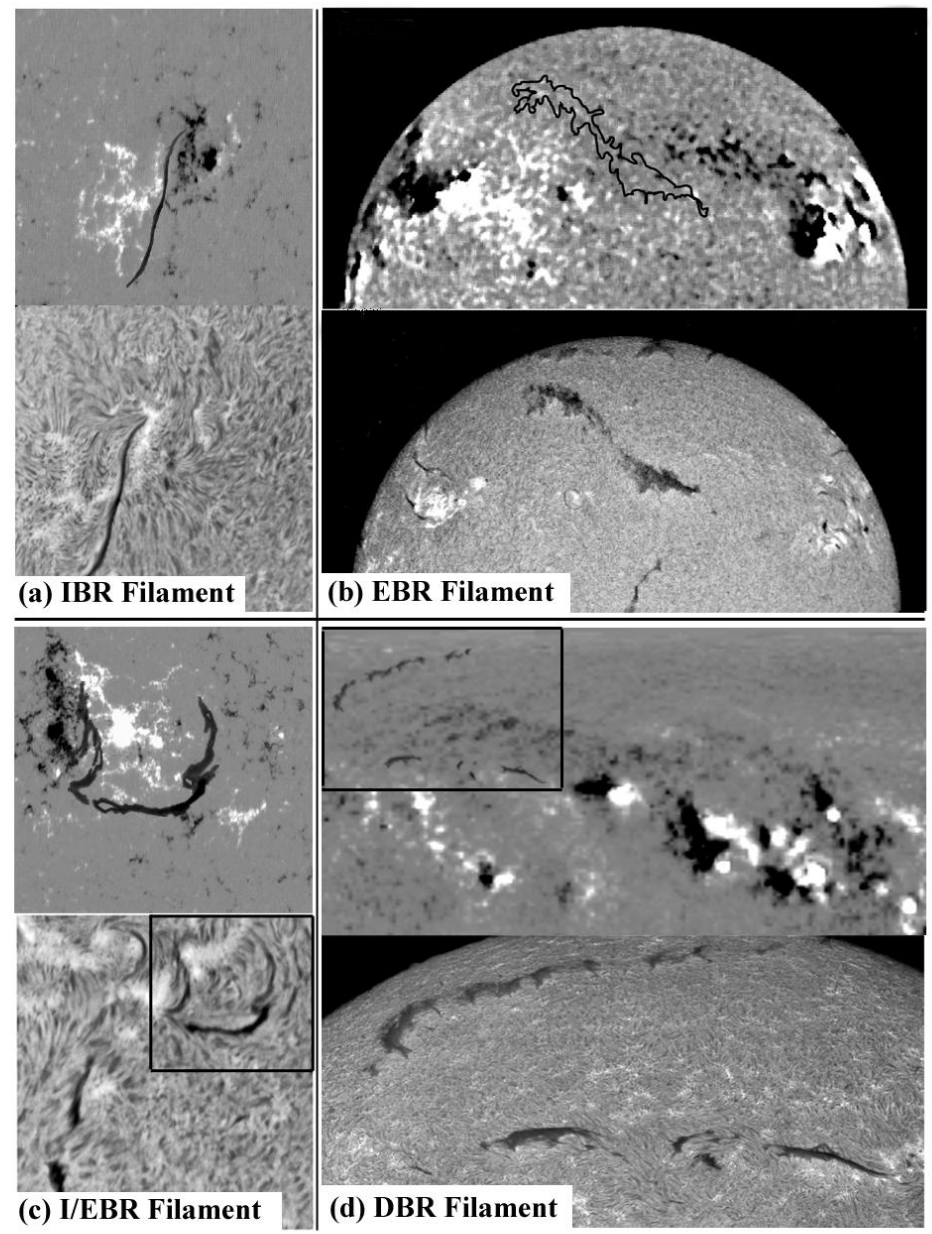
IBR - Interior BR Filament.

EBR - Exterior BR Filament.

I/EBR – Interior/Exterior BR Filament.

DBR – Diffuse BR Filament.



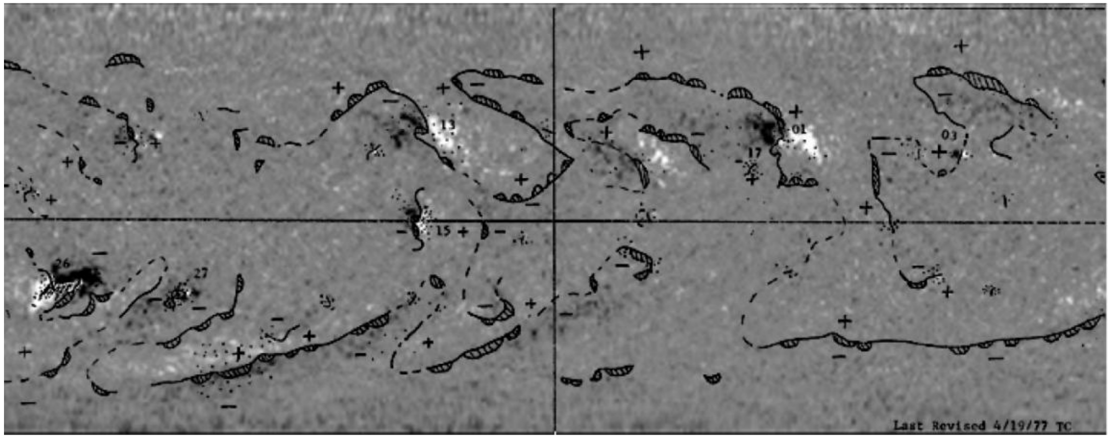


Data Sets

- Periods Considered:
  - Set 1 : CR1653-1658, 101 Filaments
  - Set 2 : CR1680-1685, 234 Filaments
  - Set 3 : CR1720-1725, 149 Filaments
  - Set 4 : CR1747-1752, 119 Filaments

- Analysis Technique:

Hα Synoptic Maps SGD.
He 10830 Synoptic Images.
KP Synoptic Magnetograms.



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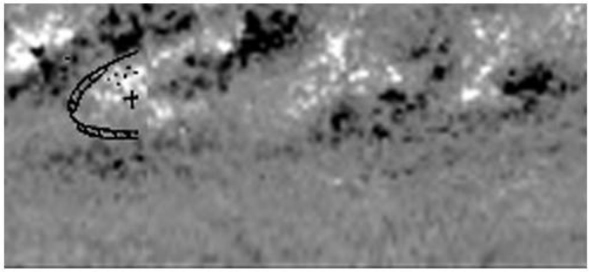
KP Full Disk Magneograms
Large Scale Hα Images (ORSO)
Flux Transport Simulations
(Yeates et al. 2007)

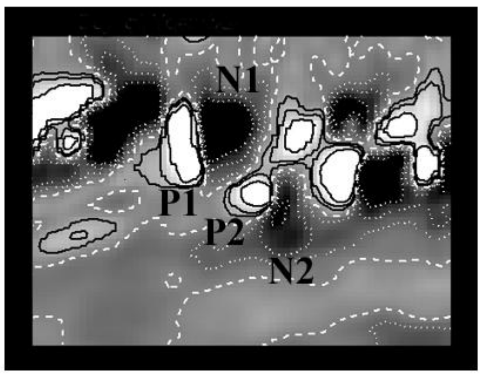
→ Classification

Application of Flux Transport Simulations

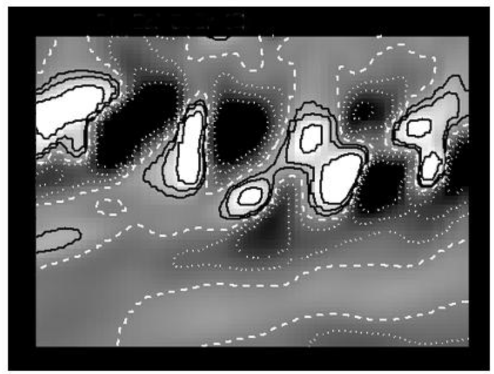
- Used to determine the history of the PIL and origin of source flux regions.
-



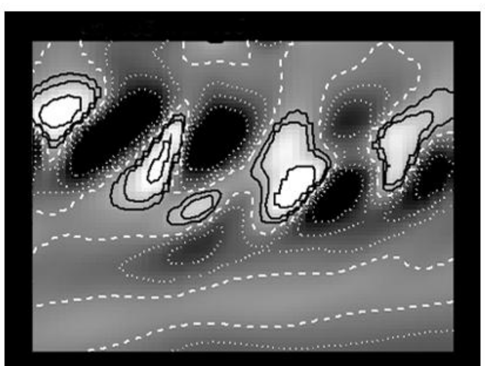
(a) Magnetogram and Filament Contours



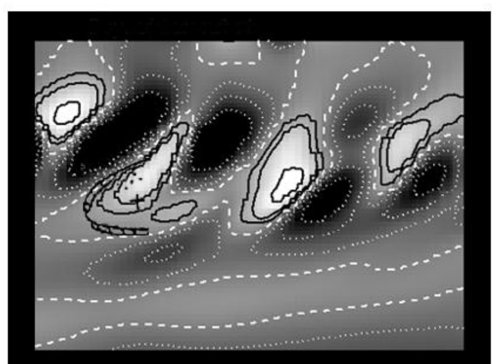
(b) Simulation (Day 83)



(c) Simulation (Day 91)



(d) Simulation (Day 103)



(e) Simulation (Day 113)

Details of simulation

- accuracy of Br for long time periods (months-years)
- identification of new bipoles.
- emergence of bipoles in simulation.

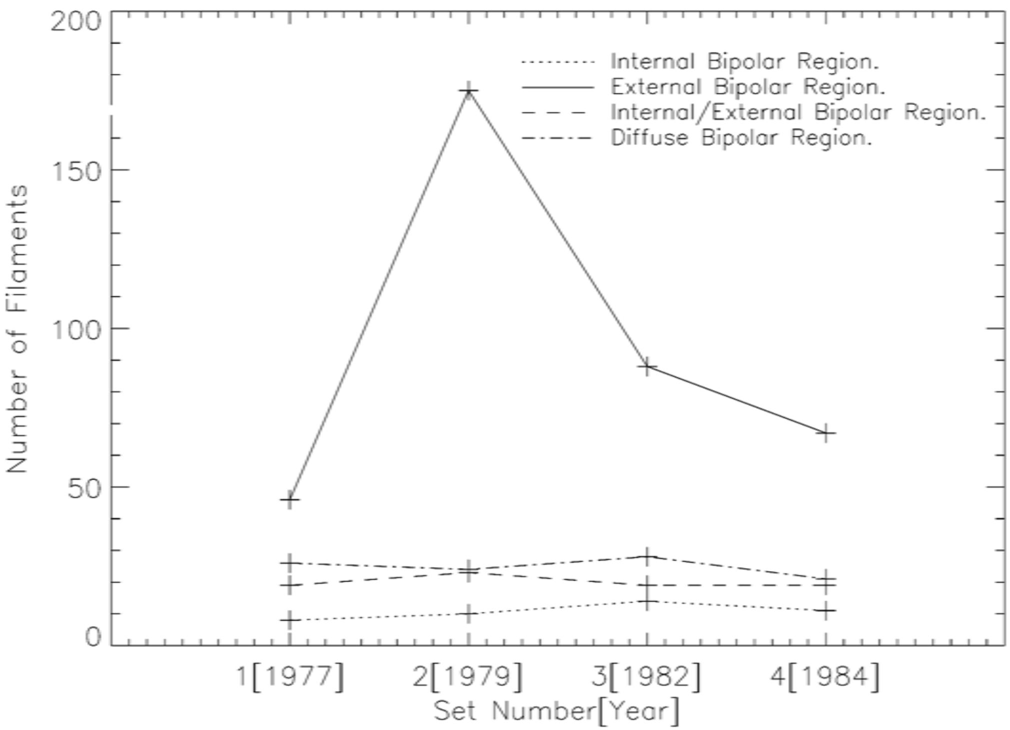
see Yeates et al. (2007,2008) Solar Physics.

- Results

Type	IBR	EBR	I/EBR	DBR	U
Percentage %	7	63	13	16	1
Latitude Range	40º	50º	50º	40-70º	

92% of filaments prefer to form in non-bipolar flux distributions (results consistent with Tang 1987 when 4 categories reduced to 2).

- Variation throughout Solar Cycle



No cycle dependence for IBR.

Only EBR filaments show a strong solar cycle dependence.

Formation mechanism must be related to amount of magnetic flux

Flux rope emergence ??
Reconfiguration coronal fields ??

Consequences for Theoretical Models

- Argument applies only to large stable solar filaments – IF, QF

  - 92% of filaments involve multiple bipole interactions – models which apply this are the most appropriate.

  - IBR filaments show no cycle variation: not formed by emerging flux ropes.

  - EBR show strong cycle variation: related to amount of magnetic flux.

  convergence leading to cancellation or coronal reconnection

  - Supported by obs. : Gaizauskas et al. (1997,2001) -IF,QF;
  Martin (1998); Wang and Muglach (2007) – IF

- No contradiction to the observations of Lites et al. (1995), Okamoto et al. (2008) as they are dealing with ARF filaments not considered in this study.

- Two mechanisms may form solar filaments ?

MHD Mechanisms and Models of Filament Formation

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	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]	

Conclusions

- Considered where large-stable solar filaments (IF,QF) form relative to PIL inside/outside magnetic bipoles.

- Filaments could be categorised into 4 types (IBR, EBR, I/EBR, DBR).

- 92% of filaments form in configurations requiring multiple bipole interactions.

- Only EBR showed any cycle variation.

- Proposed two methods of formation

  - small AR filaments: flux rope emergence.

  - larger IF,QF: convergence (cancellation or reconnection).