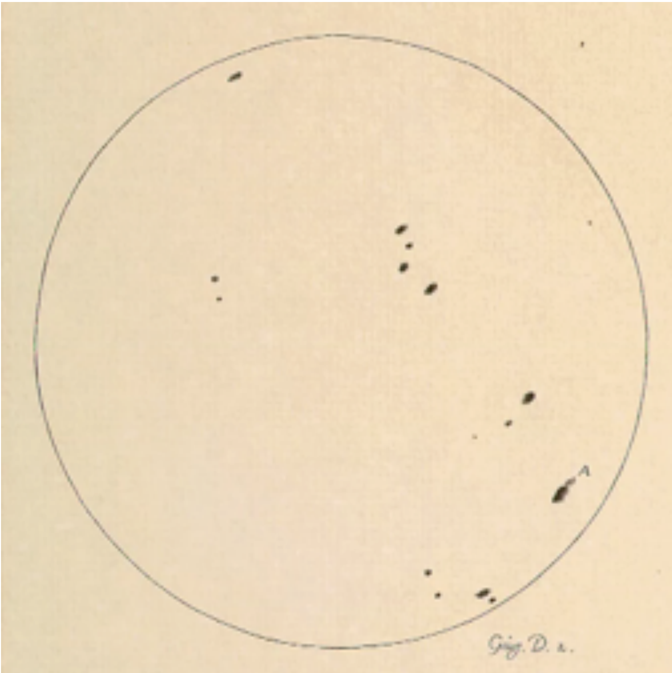
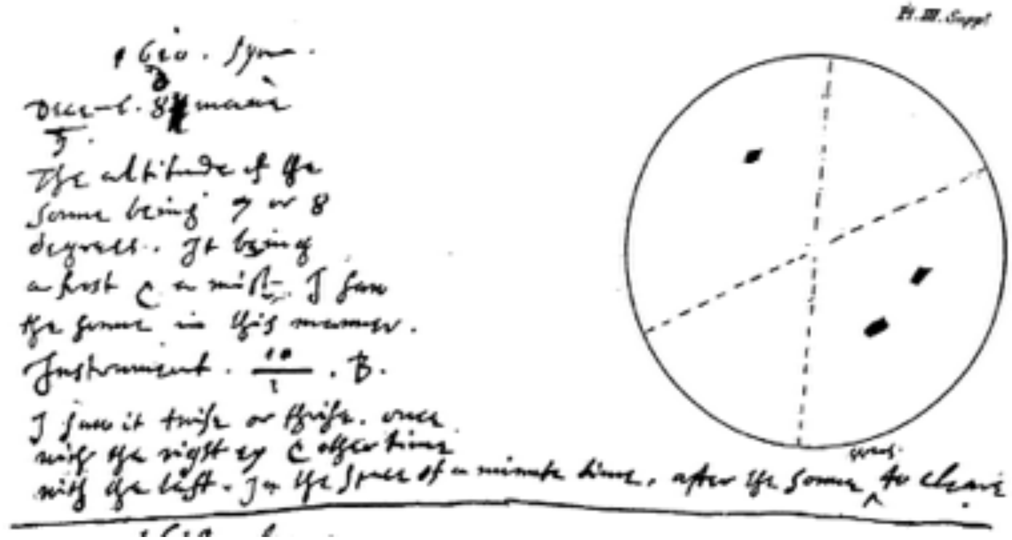
Solar active regions: flare and CME activity throughout their lifetimes

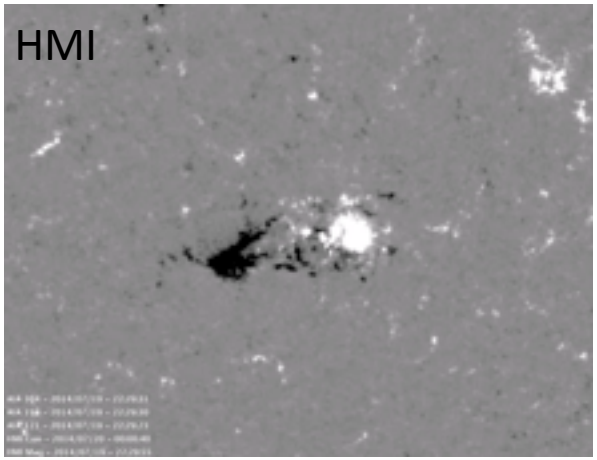
Lucie Green

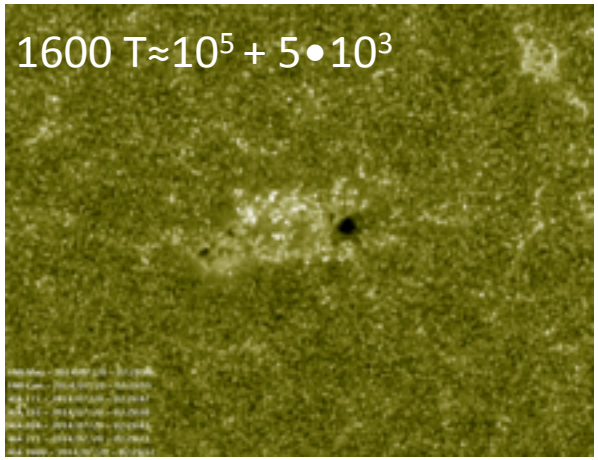


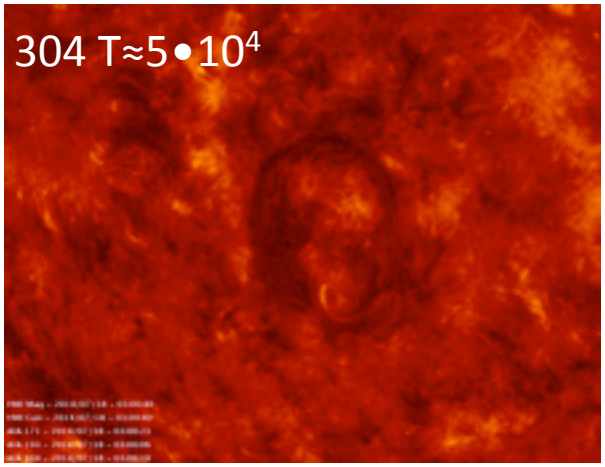

1610. Syon.
Dec. 8. mane.
The altitude of the sonne being 7 or 8 degrees. It being a frost & a mist. I saw the sonne in this manner.
Instrument. 10/1. B.
I saw it twise or thrise. once with the right ey & other time with the left. In the space of a minute time, after the sonne was to cleare.

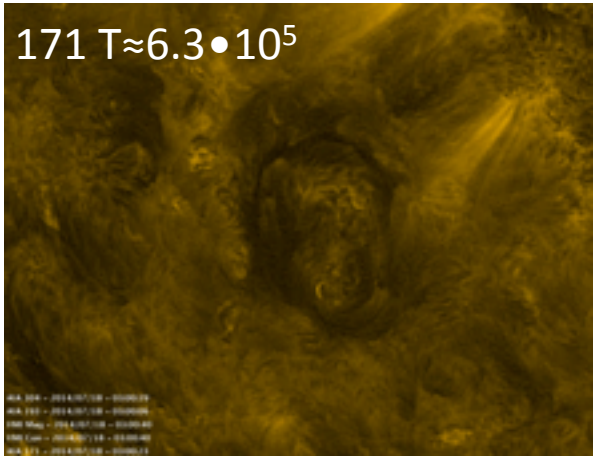
Solar active regions

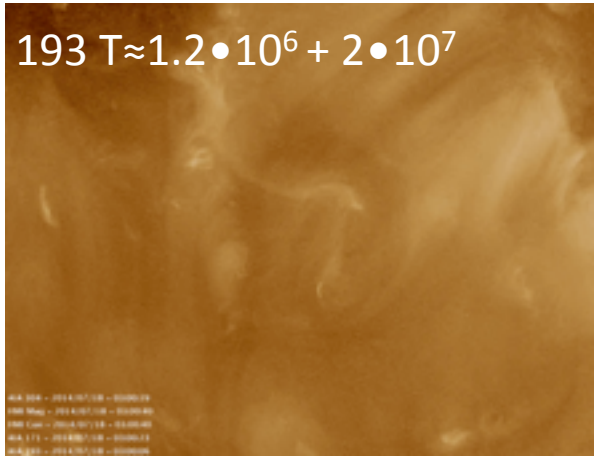
18-23 July 2014 – evolution of a small AR of 2.5 x 10^{21} Mx

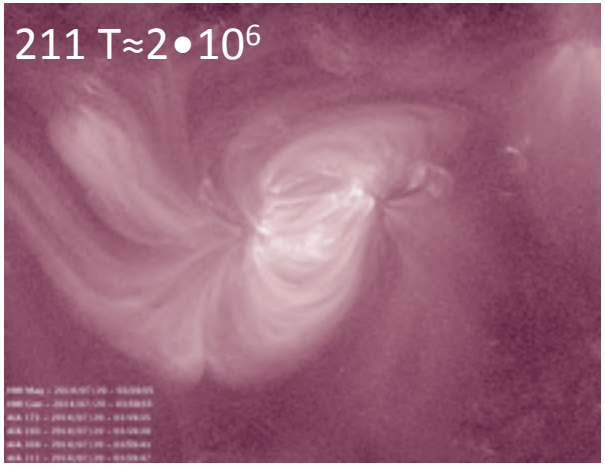




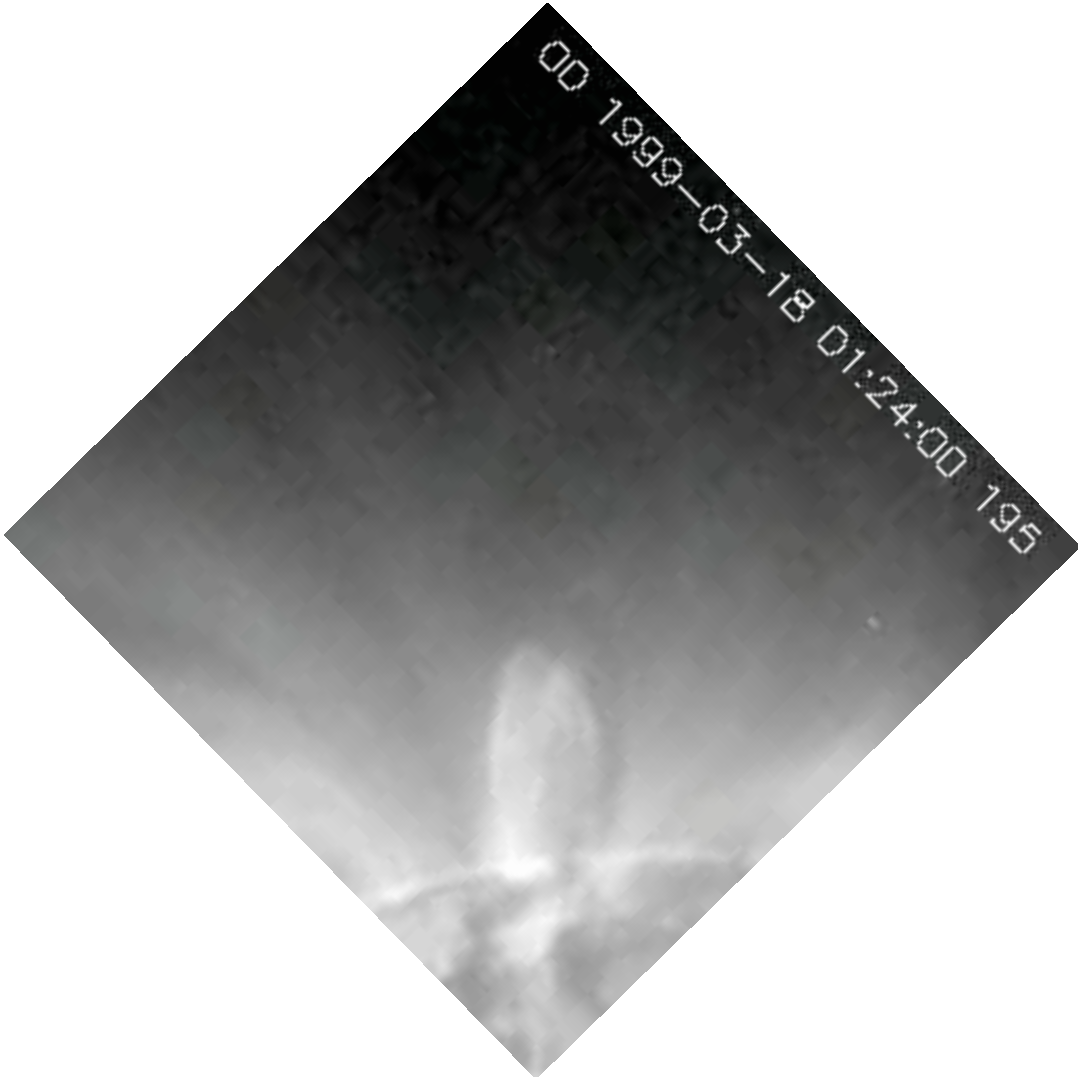








Flare - CME relationship



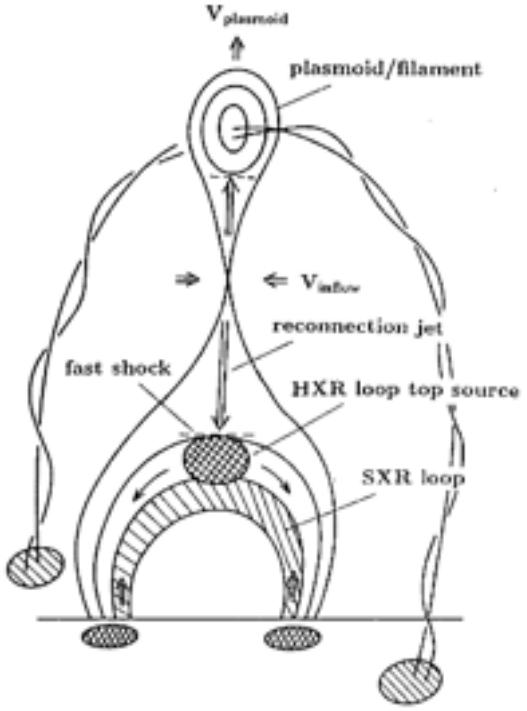
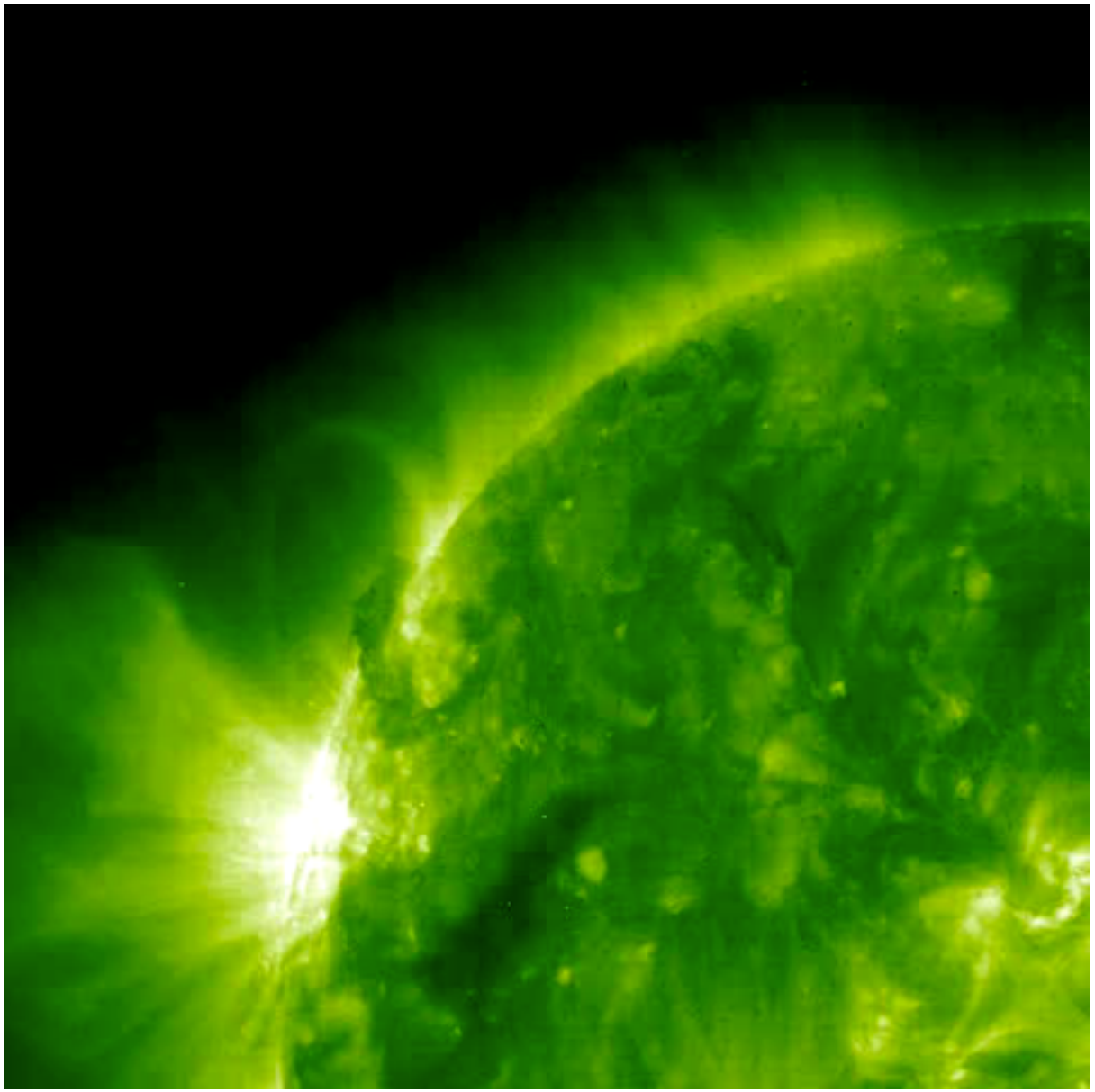


Fig. 1. A unified model of flares: *plasmoid-induced-reconnection model* (Shibata *et al.*, 1995). This is an extention of a classical model of eruptive solar flares, called the CSHKP model.

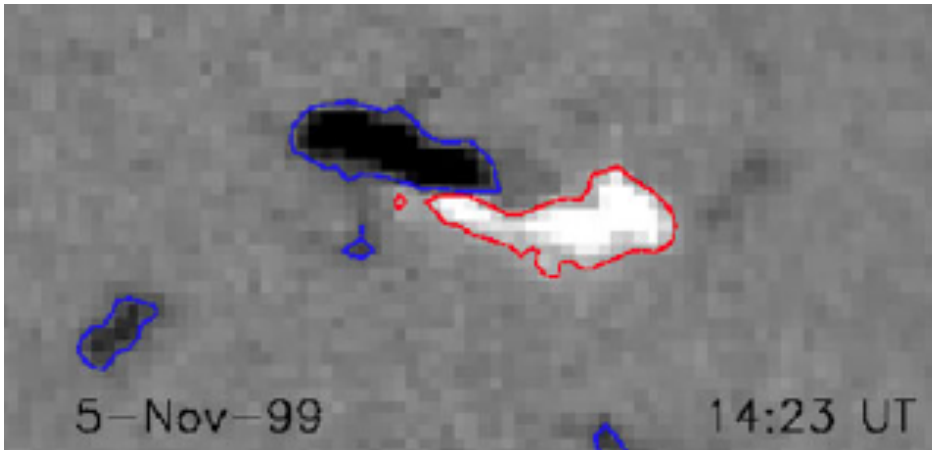
Shibata (1995)

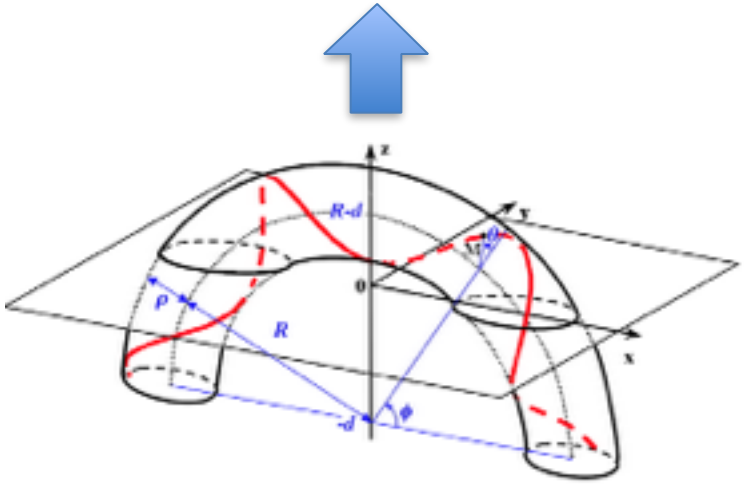


Emergence phase characteristics

- Electric currents grow with the emerging flux (Leka et al., 1996)
- Magnetic tongues show the presence of twist in the emerging rope (López Fuentes et al., 2003)
  - Twist is relatively low, but it is evident in practically all ARs (Poisson, et al., 2015)
  - MHD simulations show such tongues (e.g. Archontis and Hood, 2010)
- Photospheric field distribution reflects the nature of the emerging flux

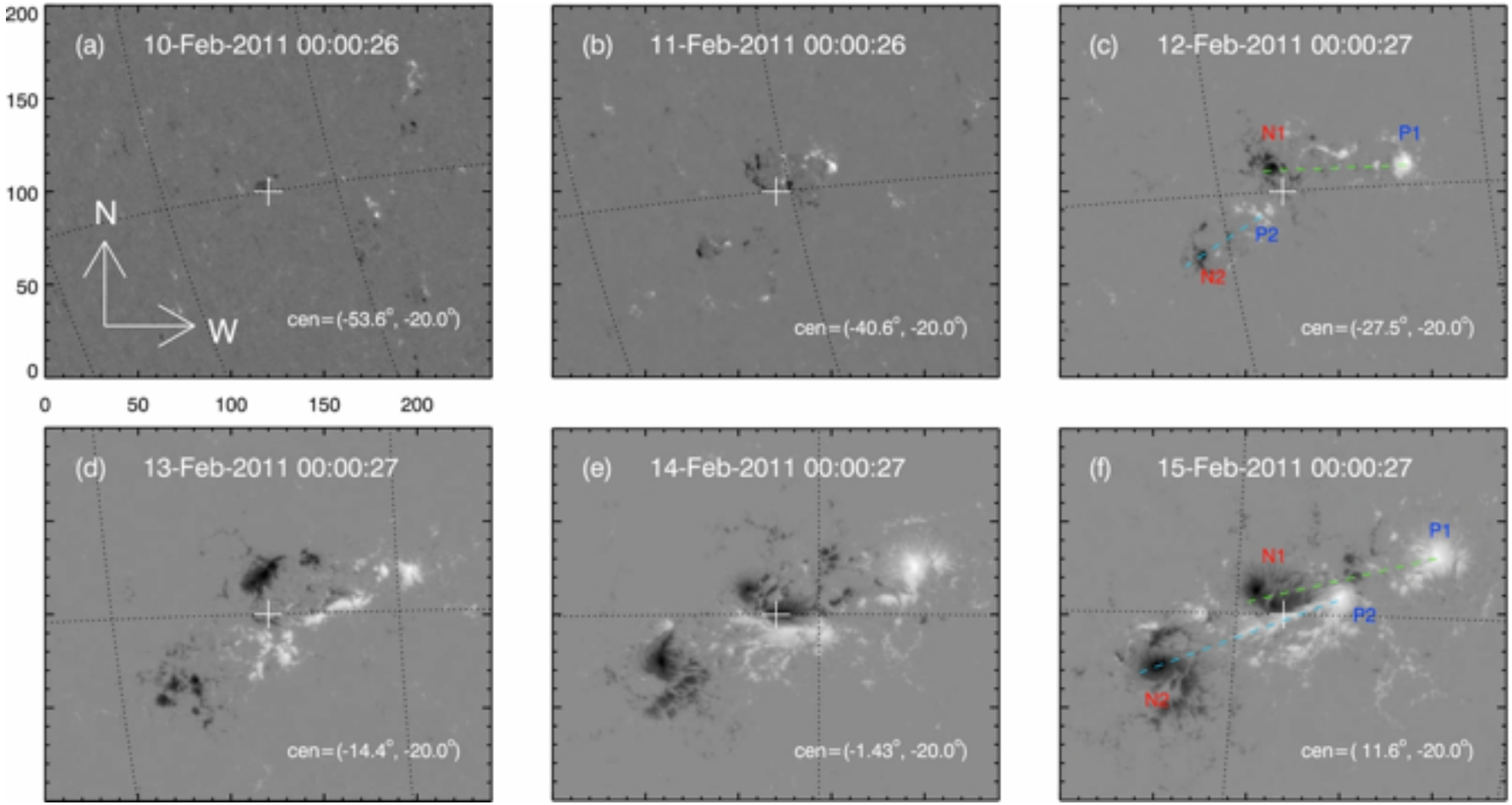
Luoni et al. (2011)





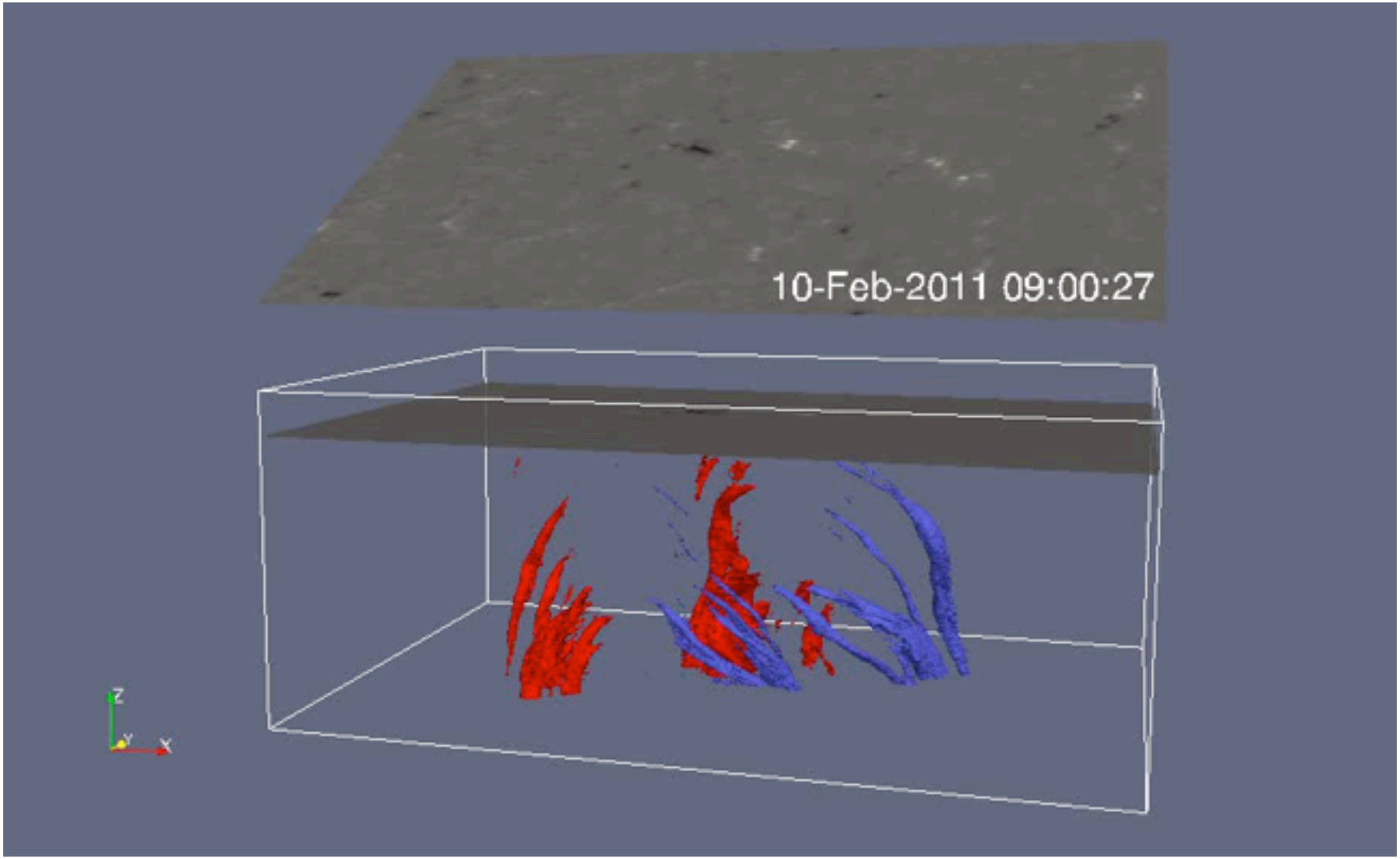
More complex emergence: e.g. AR 11158

Chintzoglou et al., 2013



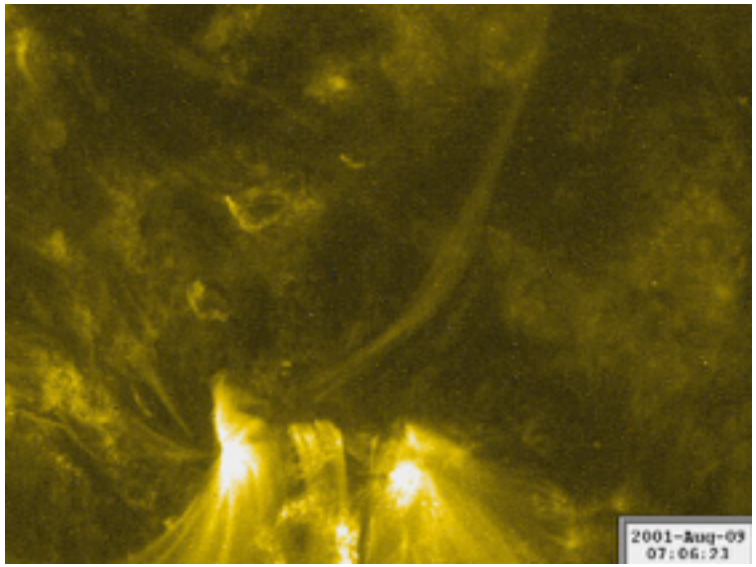
Sub-surface structure of AR 11158

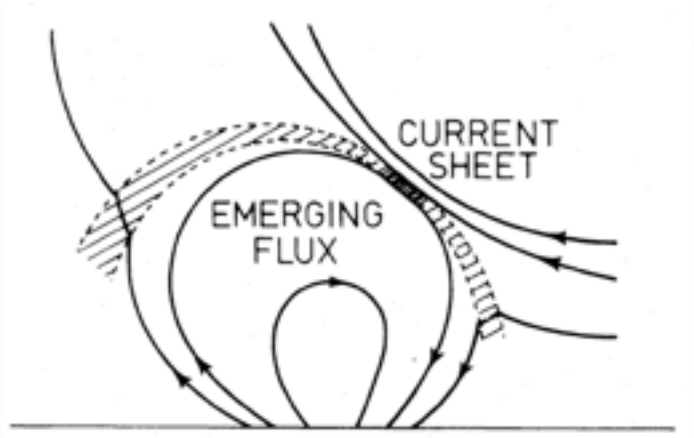
Chintzoglou et al., 2013



Emerging flux as flare & eruption trigger

- Low-level flare activity starts quickly as current sheets form between emerging structure and pre-existing field, and within the emerging field itself
- Flare activity associated to factors such as free mag. energy, complexity, growth rate
- Favourably orientated bipole emergence could trigger eruption:
  - quiescent filament eruptions (Feynman and Martin, 1995)



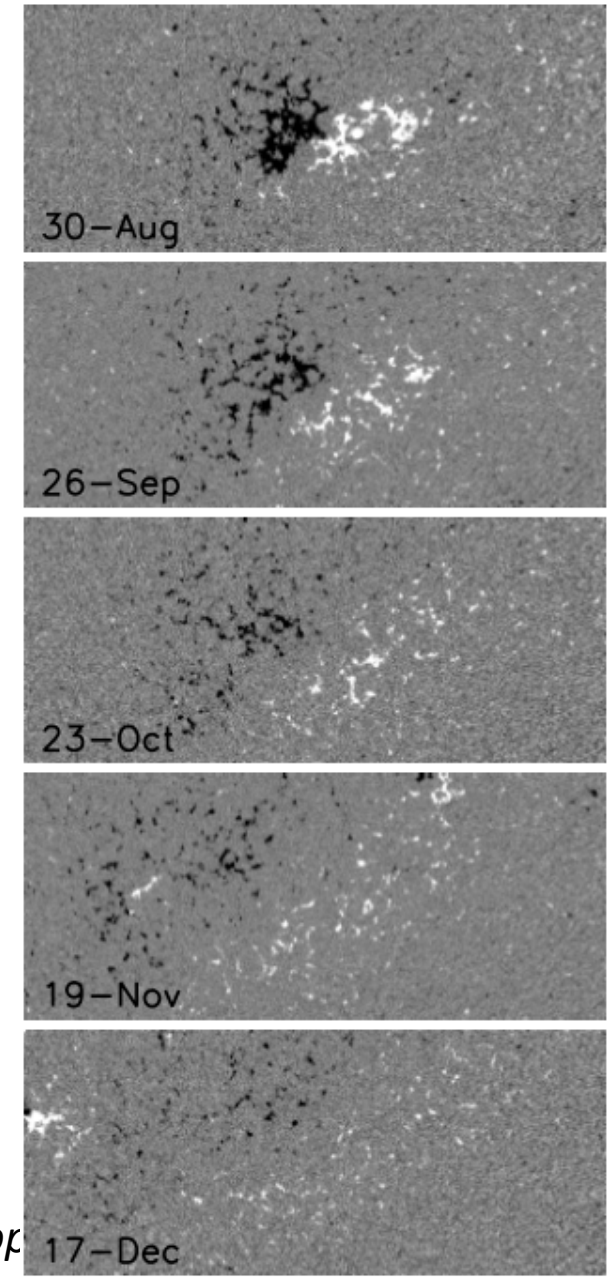


Heyvaerts et al. (1977)

Decay phase characteristics

- Sunspots break up and flux gets redistributed over a larger and larger area
- Magnetic structure simplifies and becomes more bipolar
- Overall rotation of the bipole may occur
- The flux tube of the active region apparently gets disconnected from its toroidal roots

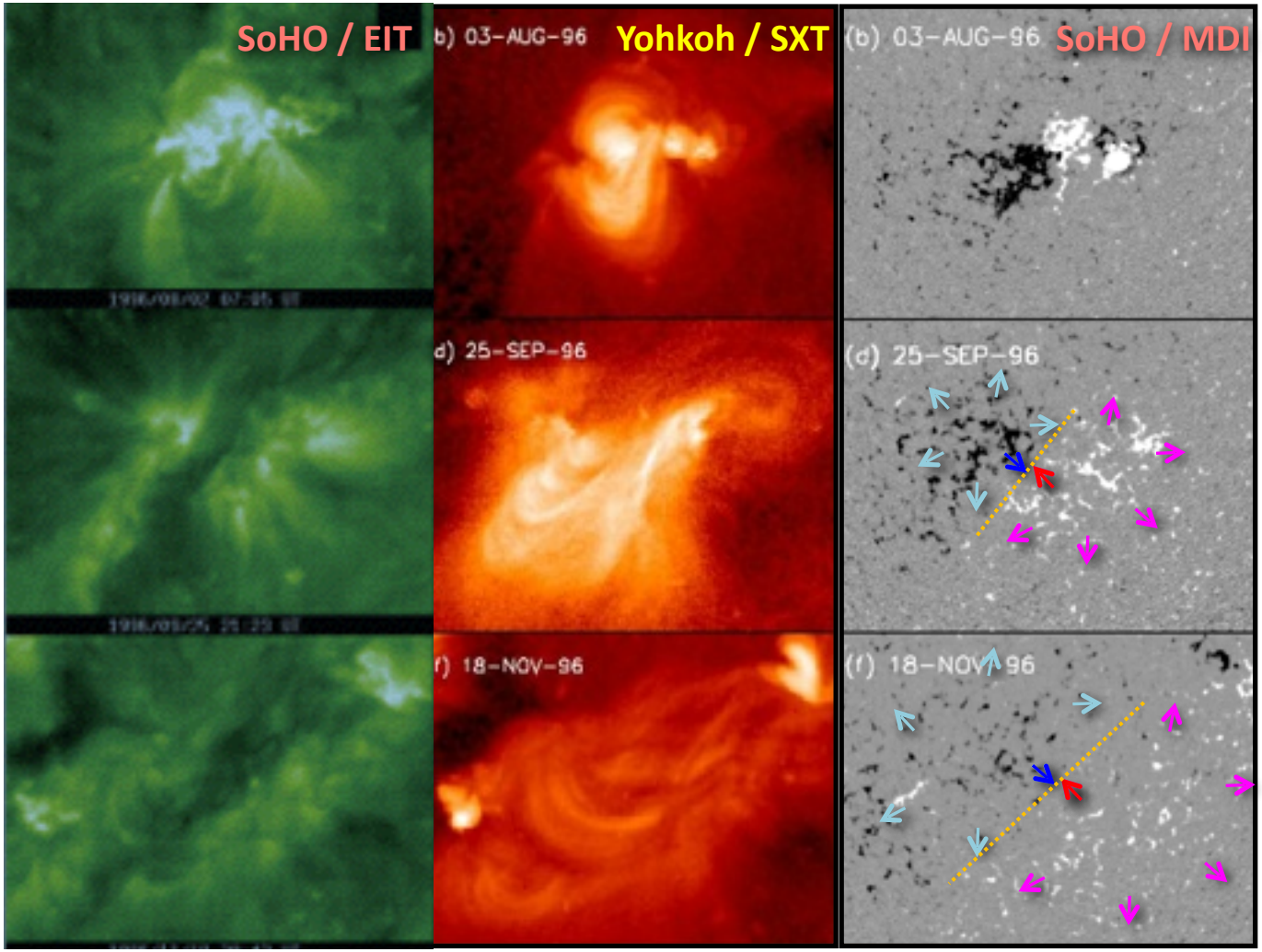
Démoulin et al.. 2002



Decay phase: physical processes at play

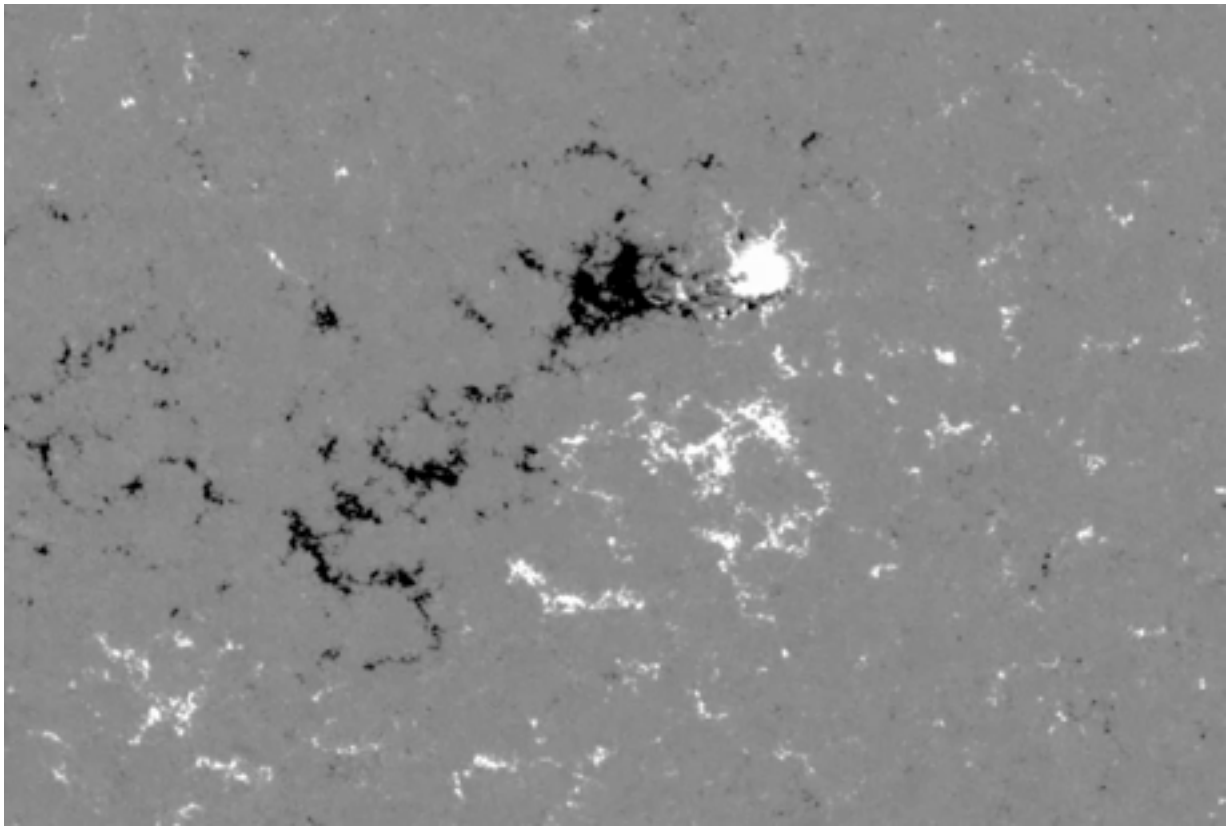
Démoulin et al. (2002)
van Driel Gesztelyi et al. (2003)

- Supergranular flows
- Flux cancellation at PILs
- Differential rotation



Flux cancellation

- Natural part of active region evolution during decay phase
- Can also take place during emergence phase



Timescales of emergence and decay phases

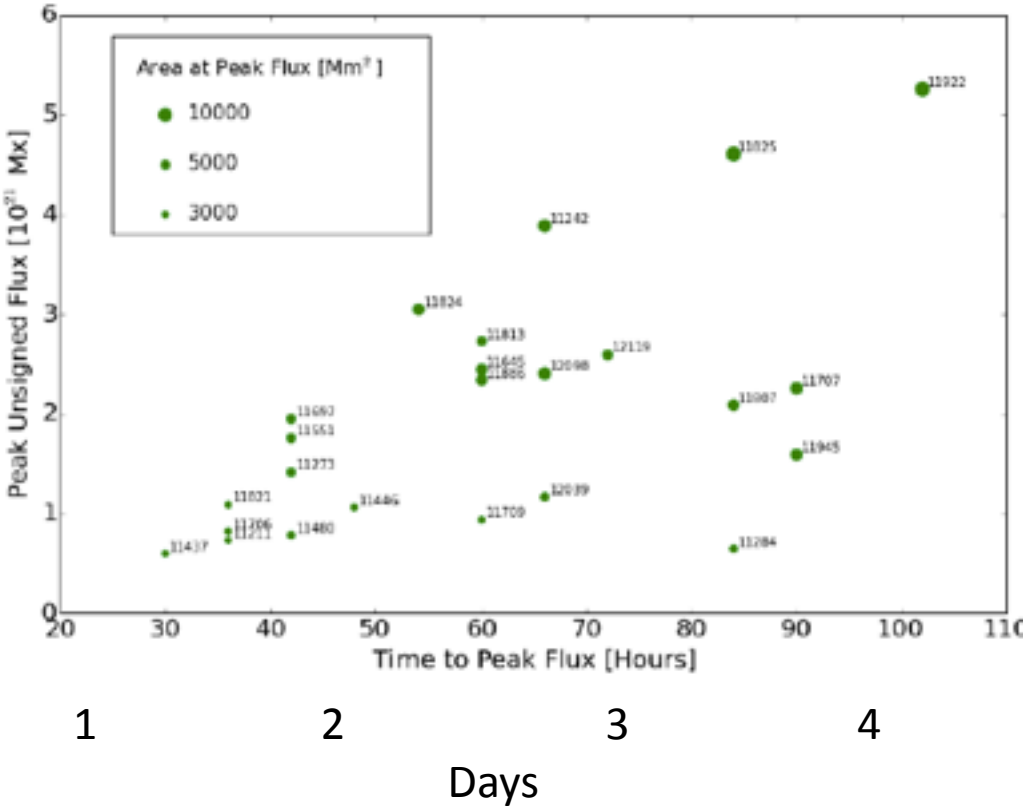
- Active regions emerge in < 5 days

Lifetime: t_{AR} (days) = 15 Φ / 10^{21} Mx

- where Φ is the total magnetic flux of the active region. Approx. 5 months for a major AR (Schrijver & Title, 1999)

- 70 - 94% of their lives decaying (Harvey, 1993)

Dacie et al., 2016

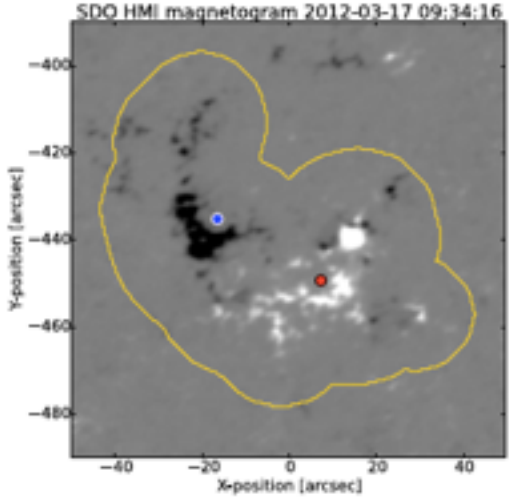


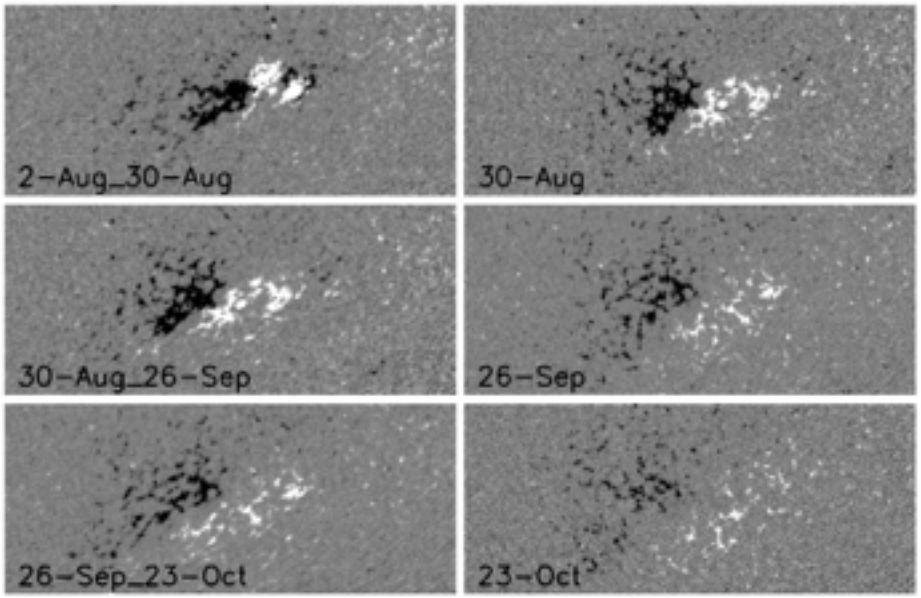
1 2 3 4

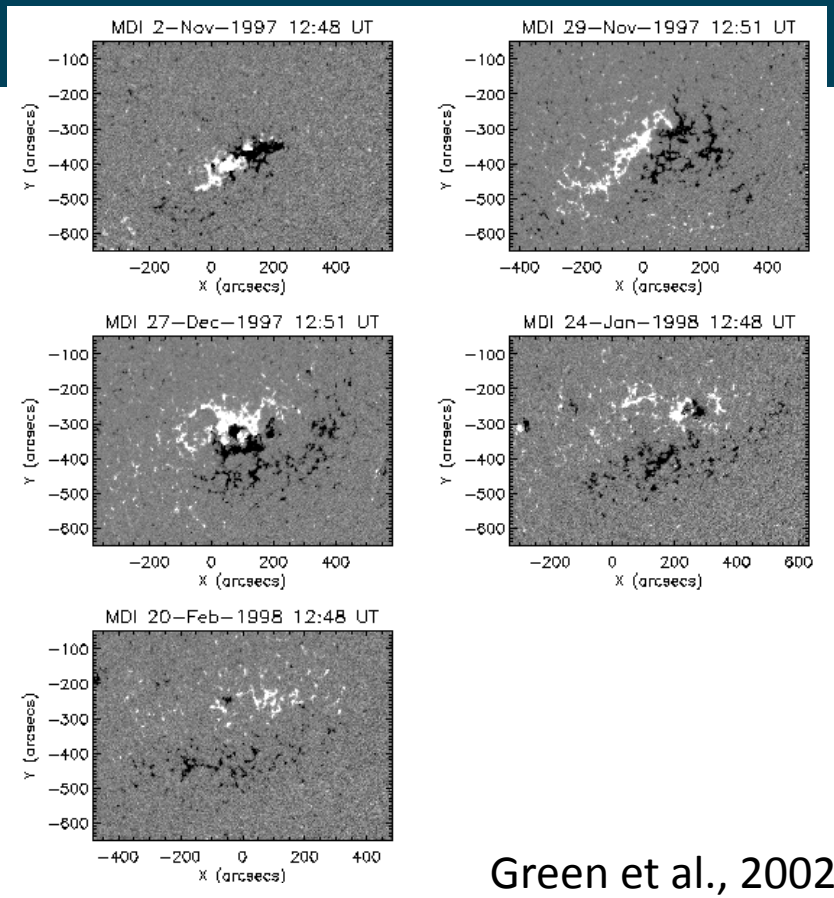
Days

CME activity in small bipolar active regions

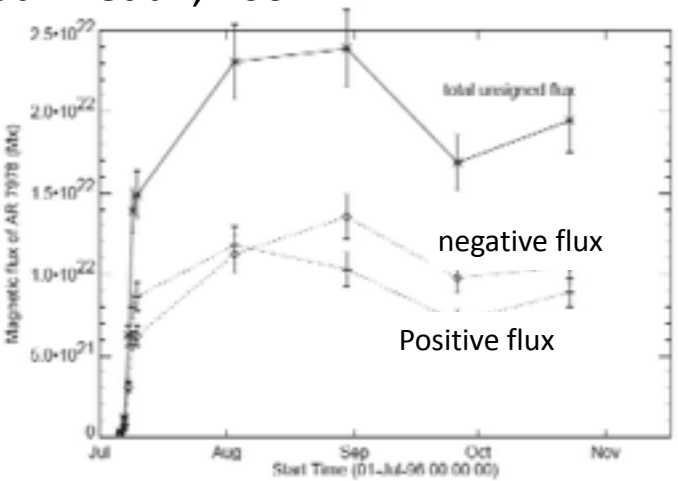
- Study of 20 bipolar active regions, from first observation of flux emergence over a few days (Yardley et al., 2017 in prep)
- Different CME classifications
  - eruption of pre-existing structure
  - formation & eruption of structure
- 14/20 were associated with a CME during the time studied
- CMEs occur during emergence and decay phase



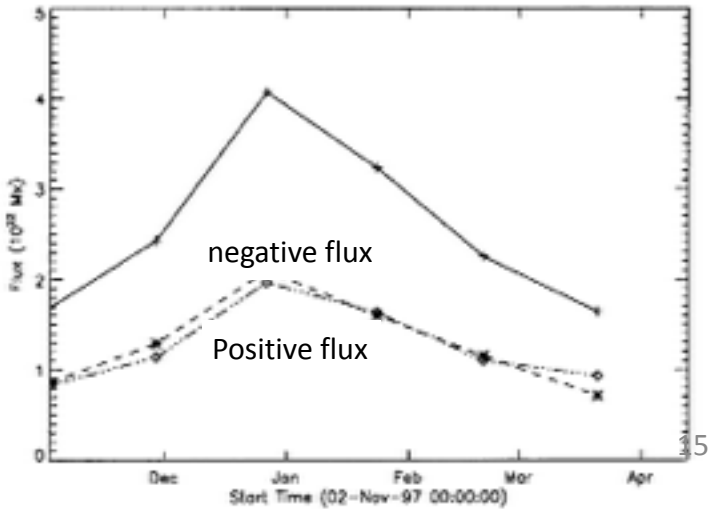


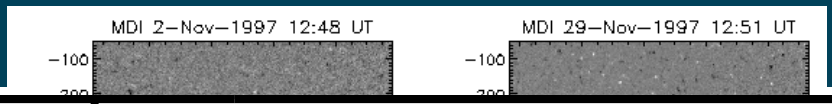


Démoulin et al., 2002



Green et al., 2002

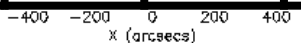




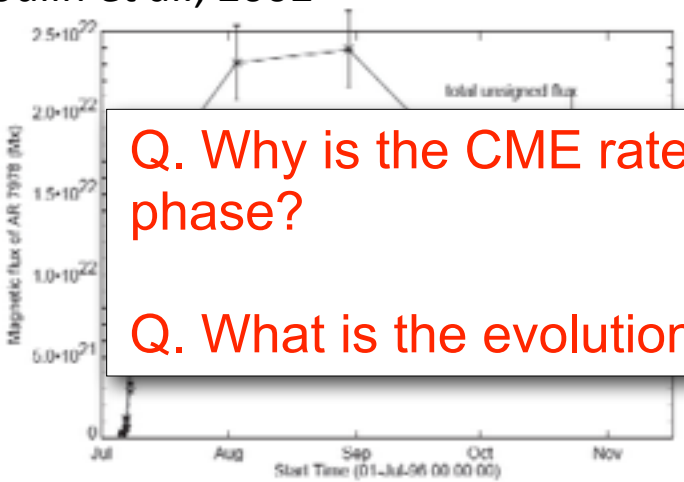
Rot.	AR 7978				
	X	M	C	B	CMEs
1	1	2	14	16	11
2	-	-	1	17	5
3	-	-	-	2	3
4	-	-	-	-	5
5	-	-	-	1	4

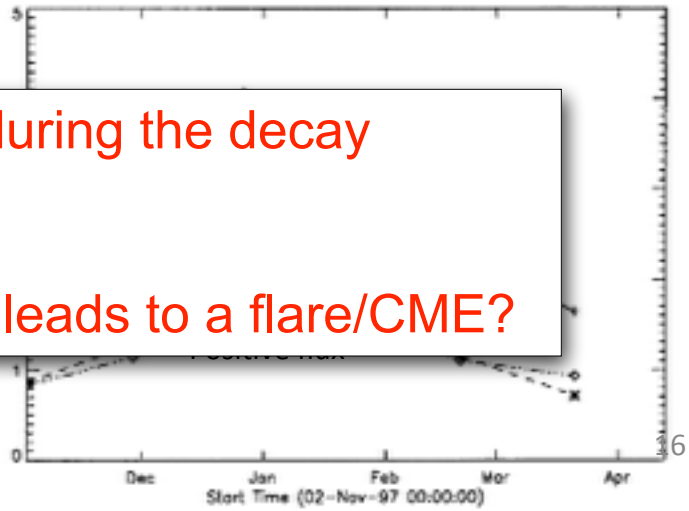
Démoulin et al., 2002

Rot.	AR 8100				
	X	M	C	B	CMEs
1	2	4	24	4	24.1
2	-	-	3	4	2.5
3	-	1	7	8	11.7
4	-	-	3	3	16.8
5	-	-	-	-	9.6



Green et al., 2002



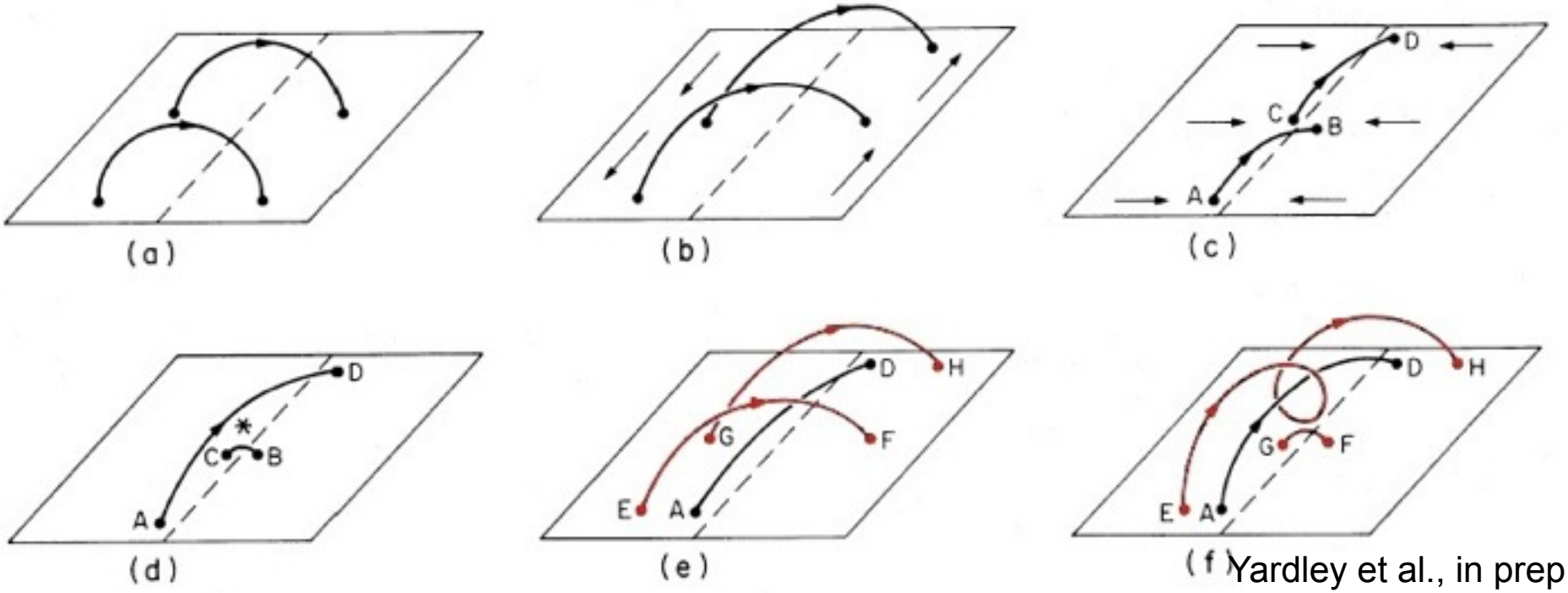


Q. Why is the CME rate maintained during the decay phase?

Q. What is the evolutionary path that leads to a flare/CME?

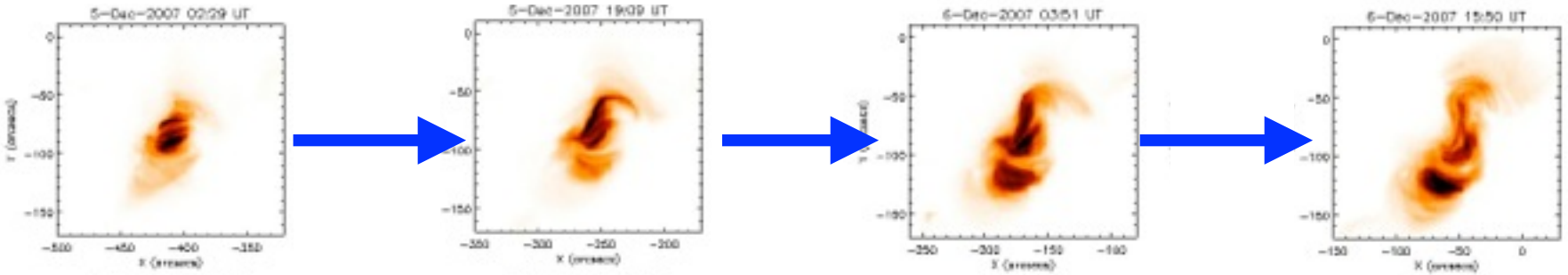
Eruptive magnetic field formation I

van Ballegooijen & Martens, 1989



Yardley et al., in prep

Green, Kliem & Wallace, 2011; Savcheva et al., 2012; Green & Kliem, 2014

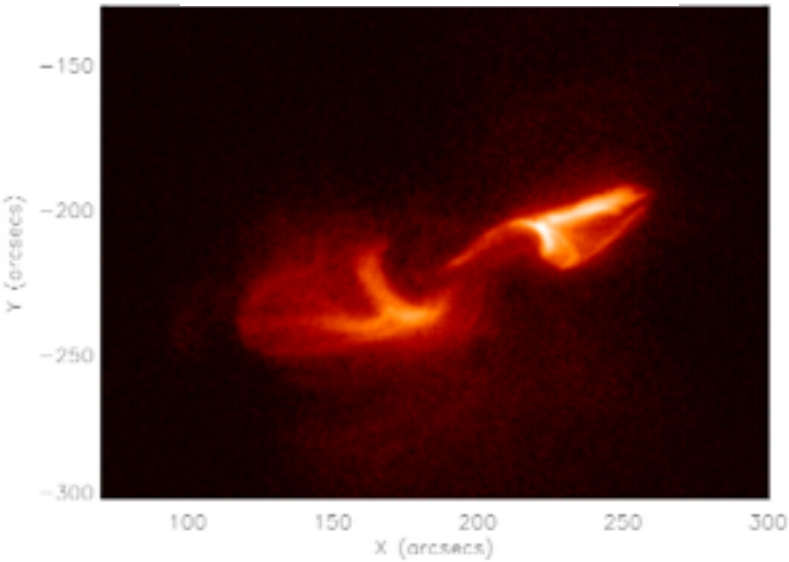


Application: emergence phase of complex active regions

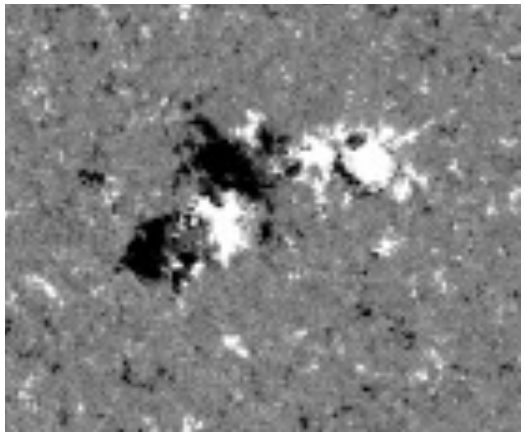
- Interaction between emerging bipoles in complex region

- Strong flux emergence, shearing, rotation and presumably flux cancellation.

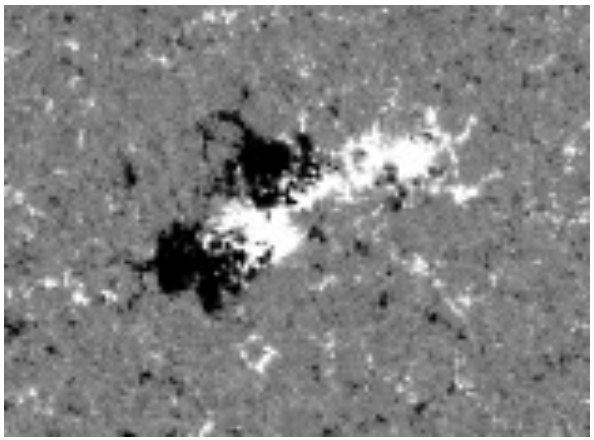
14 Feb 2011, 23:46 UT



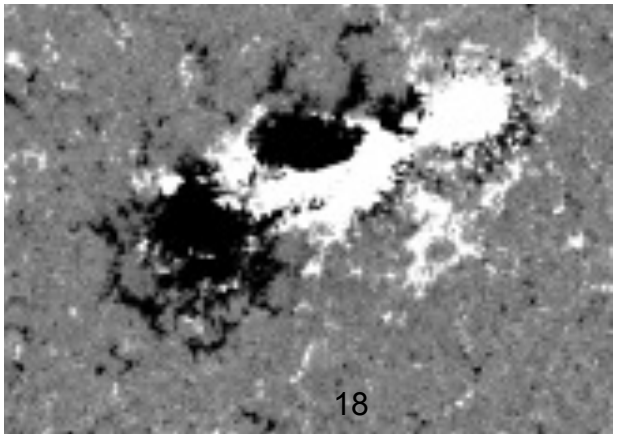
12 Feb 2011, 12:00 UT



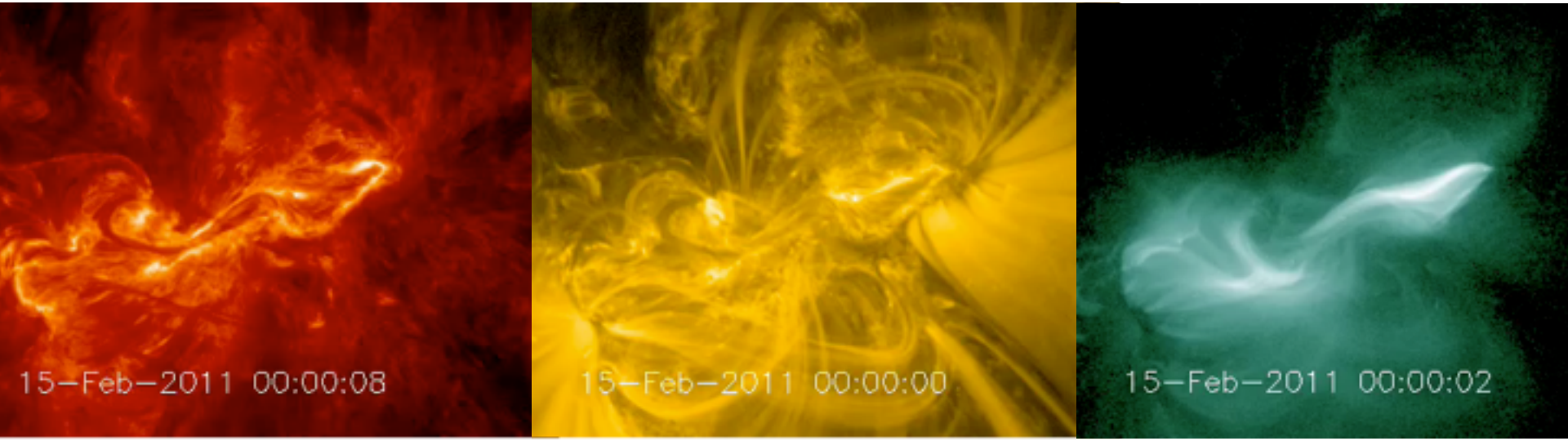
14 Feb 2011, 11:00 UT



14 Feb 2011, 23:30 UT

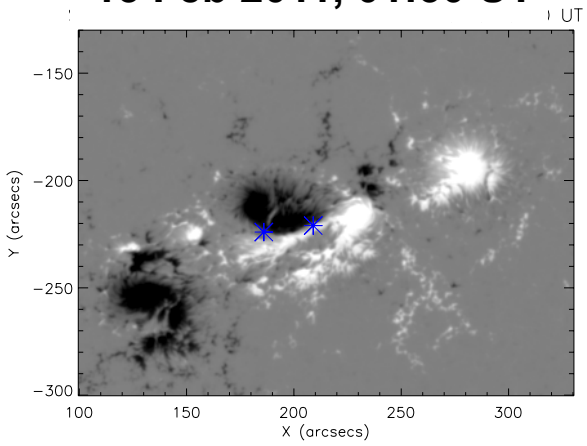


AR 11158



This flux rope apparently formed prior ~ 2 hours before eruption

15 Feb 2011, 01:30 UT

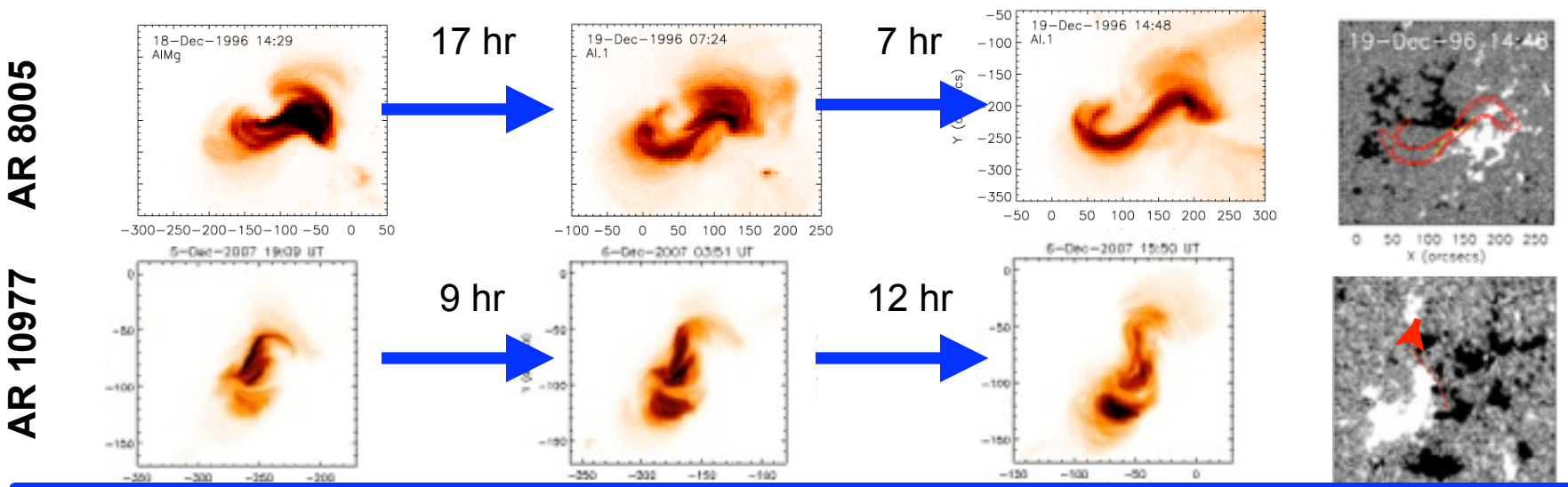


Application: decay phase of bipolar active regions

2) Increasing shear **3) Double-J formation** **4) Continuous S**

Evolutionary stages in isolated bipolar regions

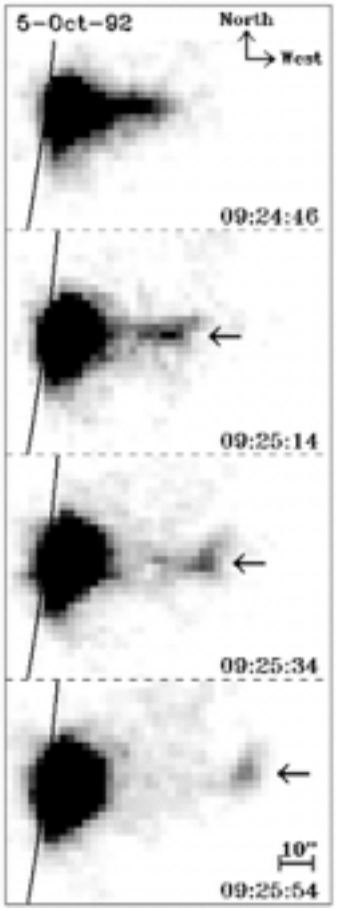
Driven by photospheric field evolution



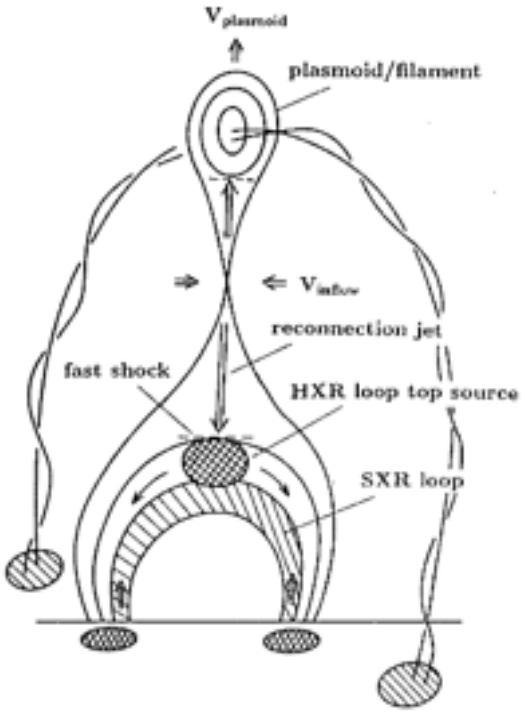
Observations show these flux ropes form on a timescale of ~ few days up to 14 hours prior to their eruption

Eruptive magnetic field formation II: Hot flux ropes

Seen at the solar limb - line-of-sight is ~parallel with the flux rope axis



Ohyama and Shibata (1995)



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Shibata (1995)

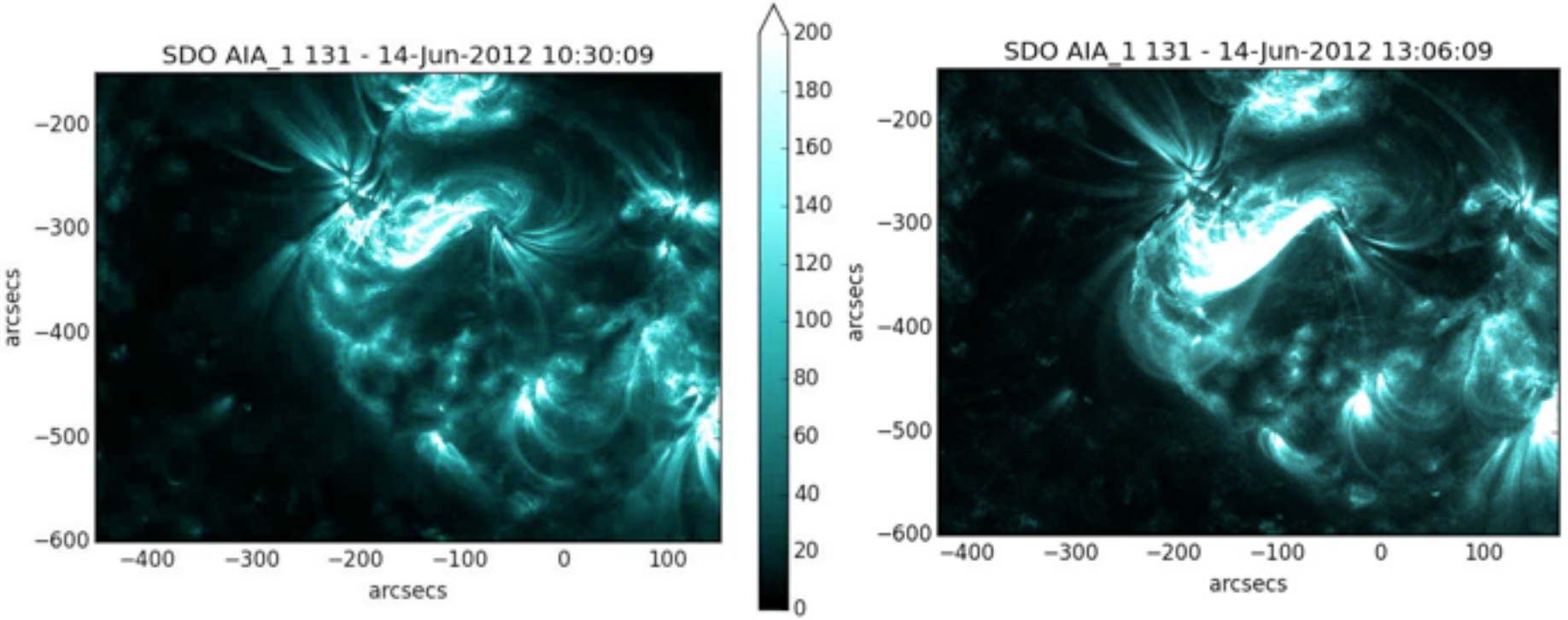
Patsourakos, Vourlidas, Stenborg (2013): Flux rope formed on a timescale of 20 minutes around 7 hours prior to its eruption

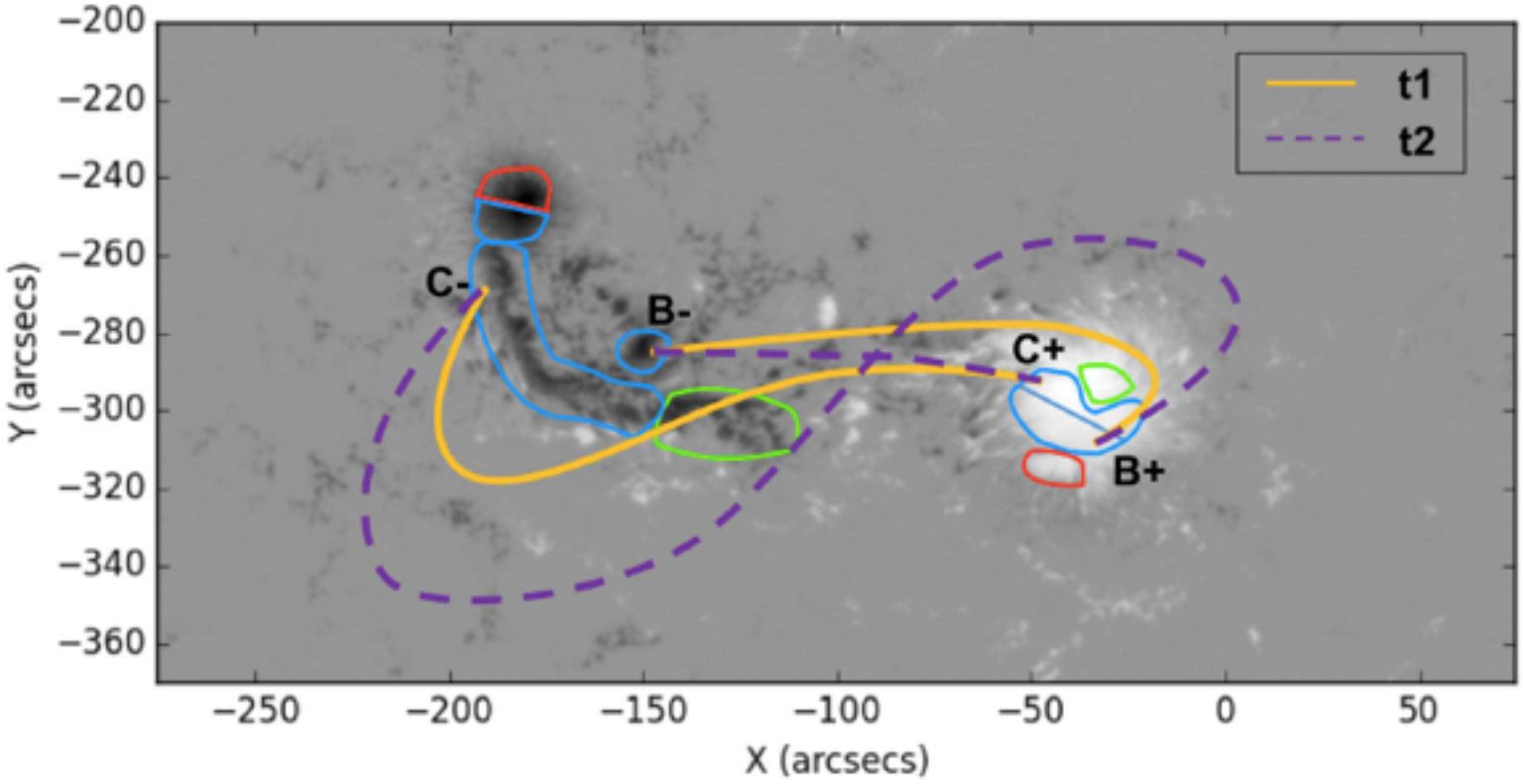
Patsourakos, Vourlidas, Stenborg (2013)

Eruptive magnetic field formation II

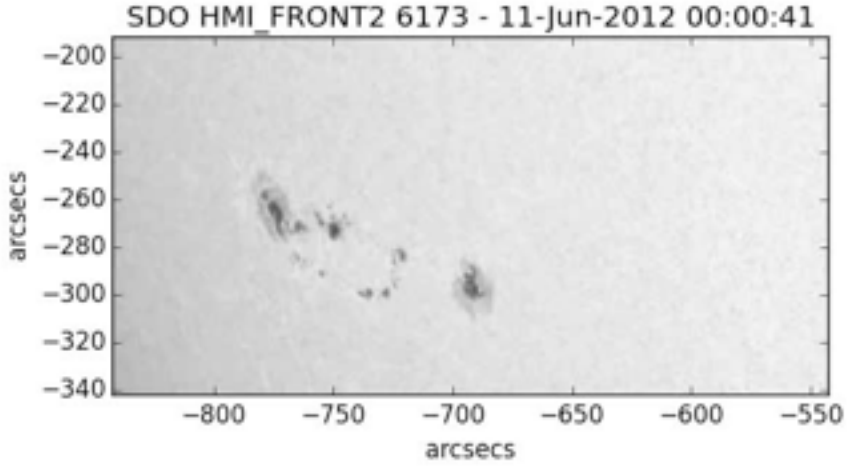
Flux rope formed at least 2 hours prior to its eruption

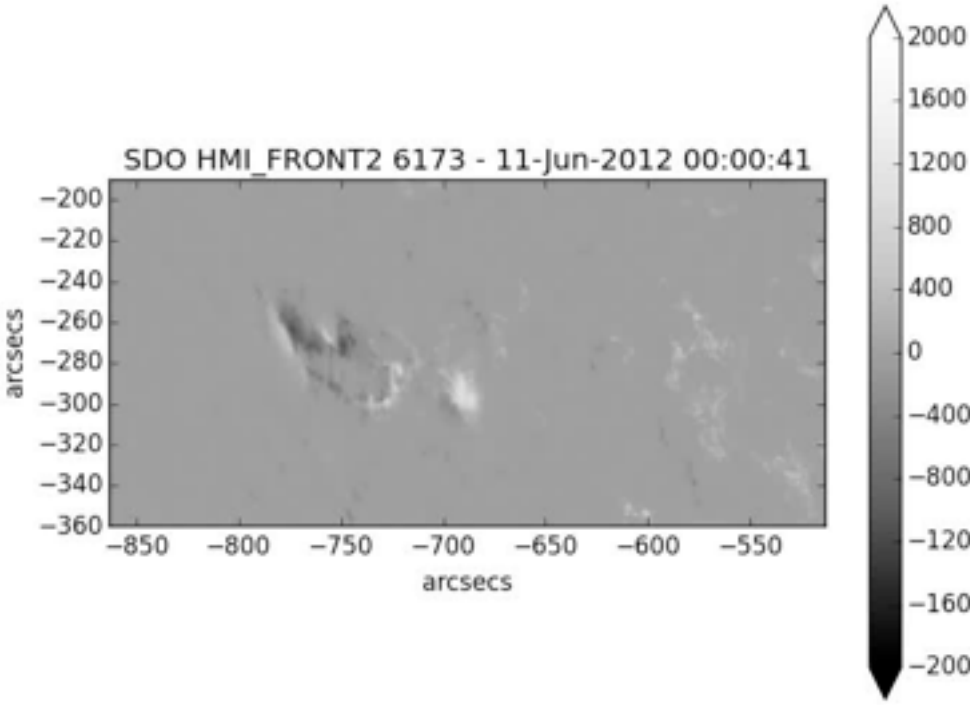
James et al. (submitted)





James et al. (submitted)





James et al. (submitted)

Flux rope forces

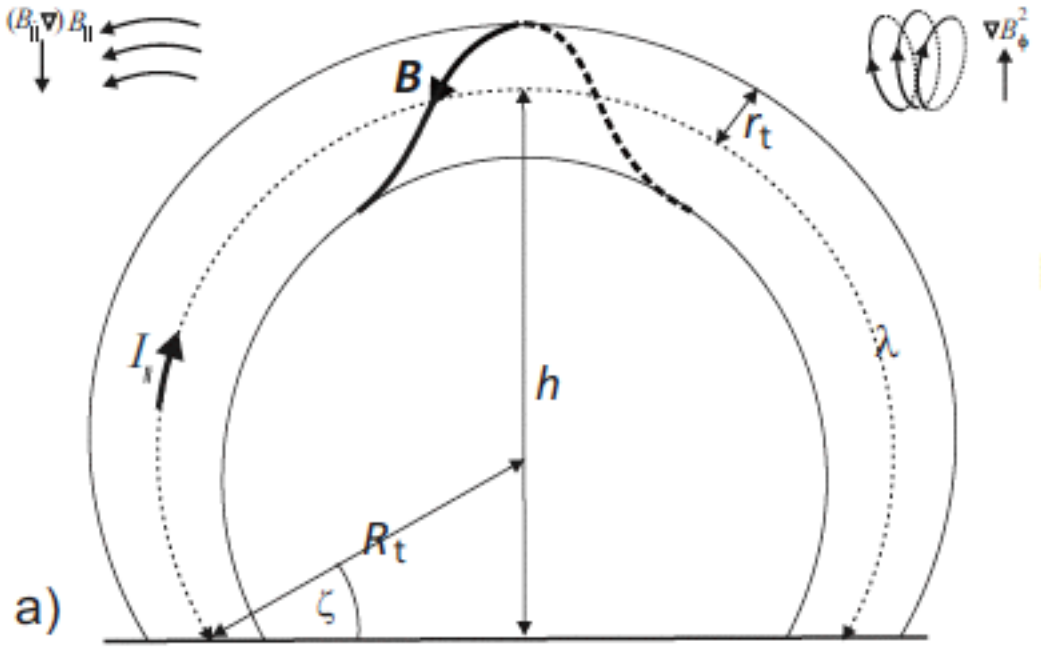
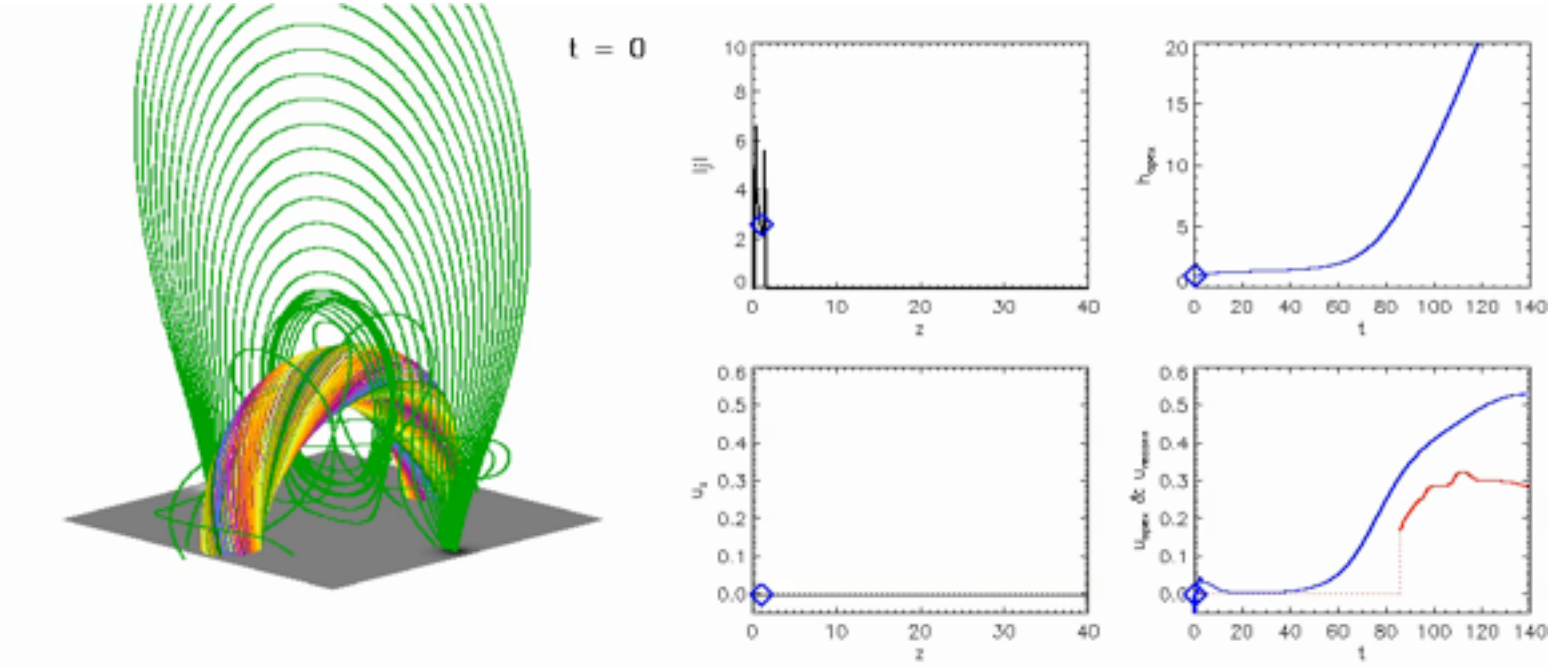


Image courtesy of B. Vrsnak

Flux cancellation studies: force balance

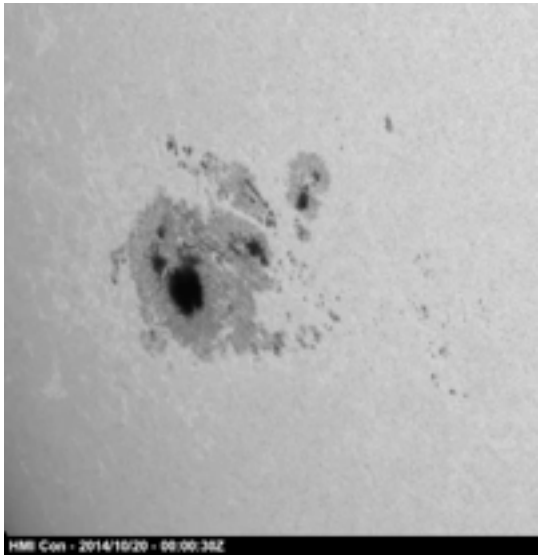
Modelling Study	*Φ*
Bobra et al (2008)	*1:9*
Savcheva and van Ballegooijen (2009);	*1:6*
Savcheva et al-2012	*1:1.5*

Observational Study	*Φ*
Green, Kliem, Wallace (2011)	*1:1.5*
Yardley et al. (2016)	*1:0.9*
Yardley et al. (2017, in prep)	*1:2* *1:3.5*



Simulation by B. Kliem

Why didn't AR 12192 produce CMEs?



- 6 X-class flares but no CMEs
- High peak flux (~16x10^{22} Mx)
- Sun et al. (2015)
  - Weakly non-potential in the AR core
  - Strong field overlying the AR core
- There is a separation of the main positive and negative mag
  collision
- Small bipoles
  the 'serpenti
  emergence p
- Overall one main bipole, with at least 2 new bipolar emergences on the periphery of the sunspot region or near centre but later in time.

No systematic flux cancellation/coronal reconnection therefore no flux rope formation/CME?
Influence and strength of the overlying field?