Helicity Injection by Flux Motions and Its Role in Flares and CMEs

P. Vemareddy
Udaipur Solar Observatory
Physical Research Laboratory
Udaipur-313 001, INDIA

Co-Authors: A. Ambastha, R. A. Maurya and J. Chae

I acknowledge the partial financial support by SPD-division to attend this meeting.

Outline

- Helicity and Its Injection Rate
- Motivation
- Data and Method
- Results
  - AR11158
  - AR11166
- Discussion
- Summary

Helicity and Its Injection Rate

Definition of Helicity

'Helicity' of a vector field is the integrated scalar product of the field and its vector potential

$$H = \int_V \mathbf{X} \bullet \nabla \times \mathbf{X}\, dV$$

Magnetic Helicity: Introduced by Elsasser(1956) and Woltjer (1958)

$$H = \int_V \mathbf{A} \bullet \mathbf{B}\, dV \longrightarrow (1)$$

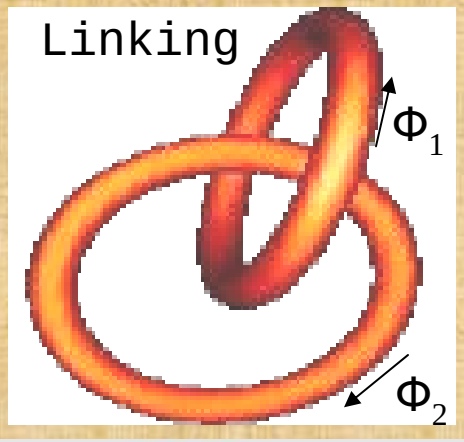
A measure of degree of linkage, twisted ness, and sheared ness of the magnetic field.

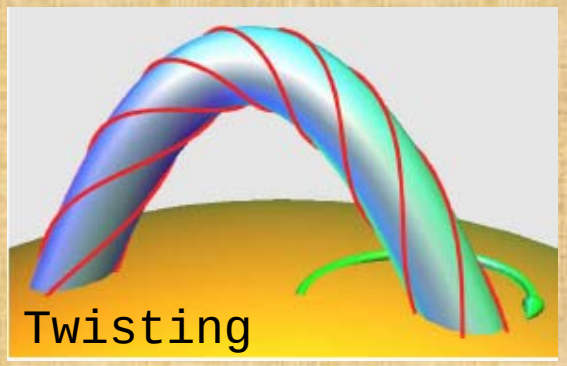
A is the vector potential of the magnetic field **B**

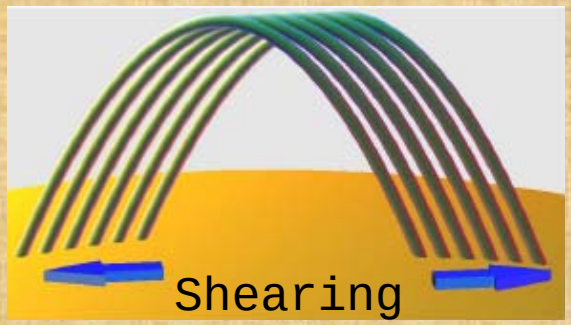
$$B = \nabla \times A$$

Magnetic Helicity is gauge-dependent quantity
It is conserved in ideal-MHD; approximately conserved during reconnection.

Magnetic helicity is not gauge-invariant for open volume
i.e. $\mathbf{B_n \neq 0}$







Helicity and Its Injection Rate

Relative Helicity Berger and Field (1984) defined a relative magnetic helicity by subtracting the helicity of a reference potential field $\mathbf{B_P}$ which has the same $\mathbf{B_n}$ distribution on S.

$$H_R = \int_V \left(A \pm A_p\right) \bullet \left(B \mp B_p\right) dV \longrightarrow (2)$$

Helicity Injection Rate The time variation of H_R as derived by Berger & Field (1984)

$$\frac{dH_R}{dt} = \underbrace{2\int_S (\mathbf{A}_p \bullet \mathbf{B}) v_n d\mathbf{S}}_{\text{Advection term}} - \underbrace{\int_S (\mathbf{A}_p \bullet \mathbf{v}) B_n \, d\mathbf{S}}_{\text{Shear term}} \longrightarrow (3)$$

First term => inflow (or outflow) of helicity through S (advection term) – VMG data (B|| and v⊥) needed

Second term => helicity flux by foot point motions parallel to S (shear term) – only LOS or B|| data adequate

$$G_A = 2\int_S (\mathbf{A}_p \bullet \mathbf{v}) B_n d\mathbf{S} \xrightarrow{\text{Pariat et al}} \frac{dH}{dt} = \frac{-1}{2\pi} \int_s \int_{s'} \frac{\left[(\mathbf{x}-\mathbf{x}') \times (\mathbf{u}-\mathbf{u}')\right]_n}{|\mathbf{x}-\mathbf{x}'|^2} B_n(\mathbf{x}') B_n(\mathbf{x}) d\mathbf{S}' d\mathbf{S}$$

Motivation

- Magnetic helicity is the most important observational parameter which links the surface magnetism with the solar interior on the one hand, and with interplanetary space on the other.
- Magnetic reconnection cannot expedite the decay of helicity but can only transfer it from one flux system to another.
- Impulsive variations of magnetic helicity injection rate associated with eruptive X- and M- class flares accompanied with CMEs were reported by Moon (2002).
- Recently, Park et al (2010) conjectured that the occurrence of the X3.4 flare on 2006 December 13 was involved with the positive helicity injection into an existing system of helicity. Similarly Chandra et al 2010, Romano et al 2011
- We mainly studied the presence of opposite helicity flux spatially and temporally in flare and CME associated regions for a possible role of helicity injection by flux motions to trigger them.

Data and Method

- HMI line of sight (LOS) magnetograms
  - 12min cadence; 0.5arcsec/pixel
  - 45sec cadence; 0.5arcsec/pixel

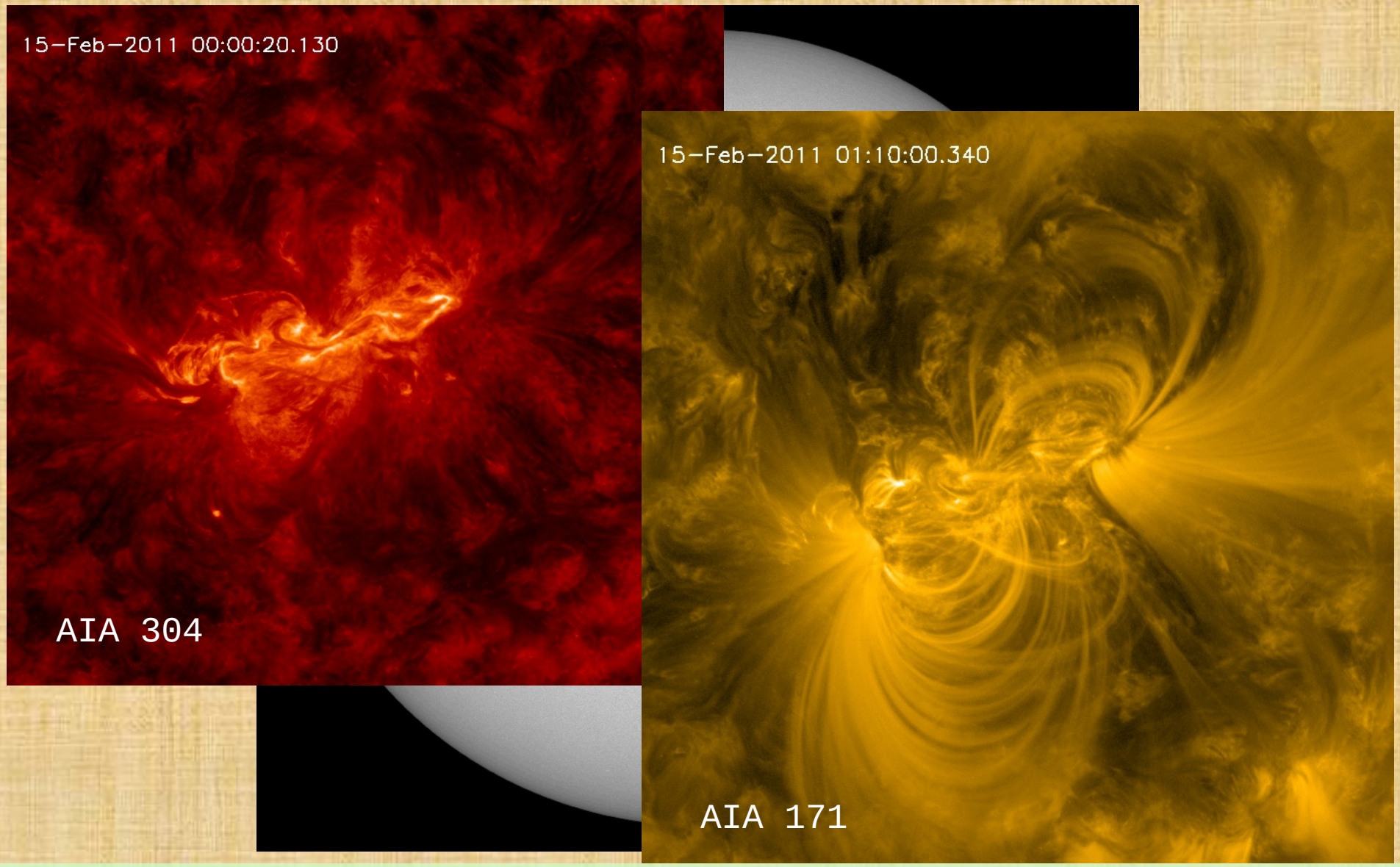
- GOES information, AIA quick look images

- The AR at different times is remapped to disk center by correcting by a factor of cosine of its angular distance.

- Then, the time sequence magnetograms are tracked by the technique of Differential Affine Velocity Estimator (DAVE; Schuck 2005, 2006) for retrieving horizontal flux motions.

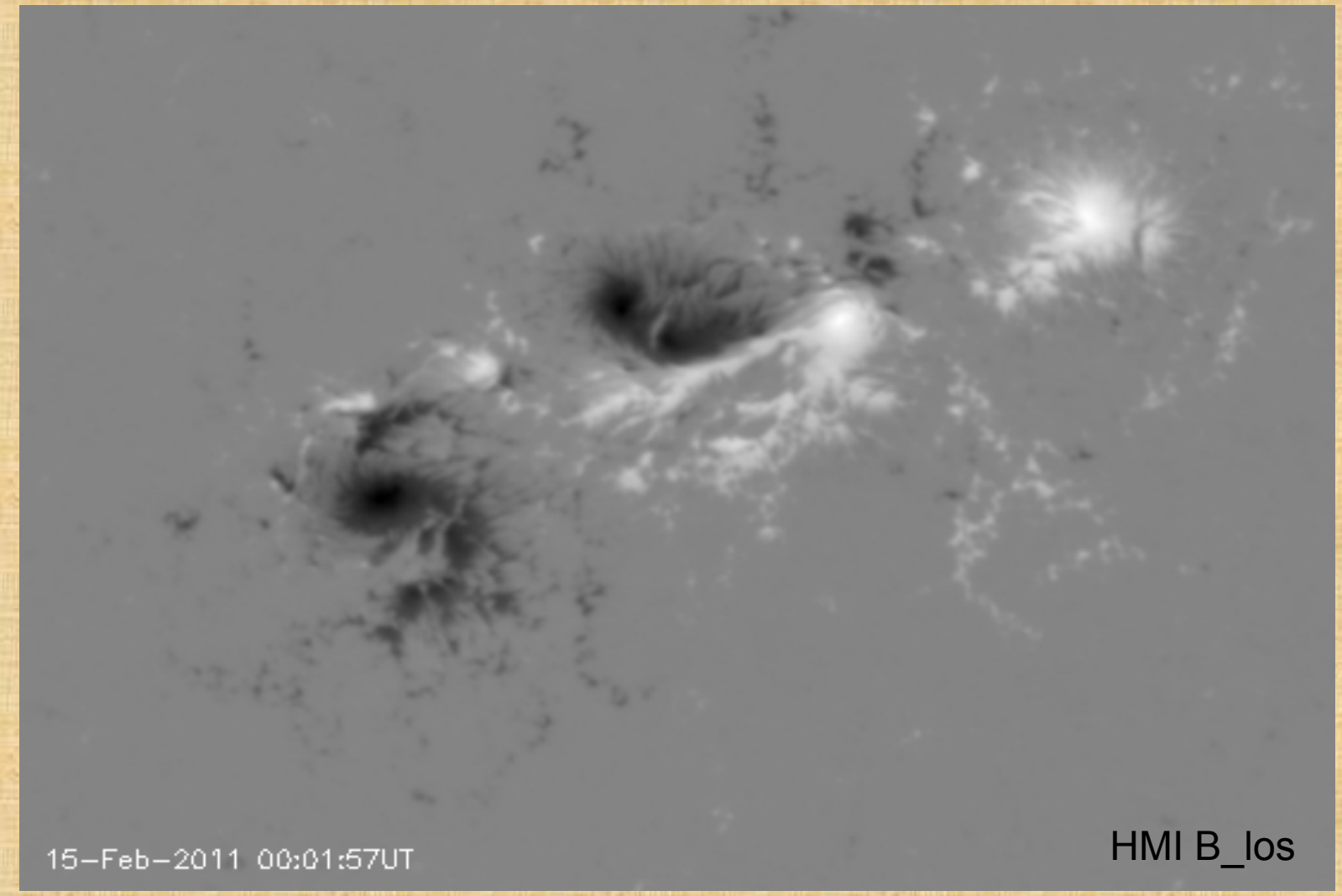
- With these velocity and LOS magnetic field information, we computed the helicity flux density maps and injection rates and further analyzed their association with observed eruptive events.

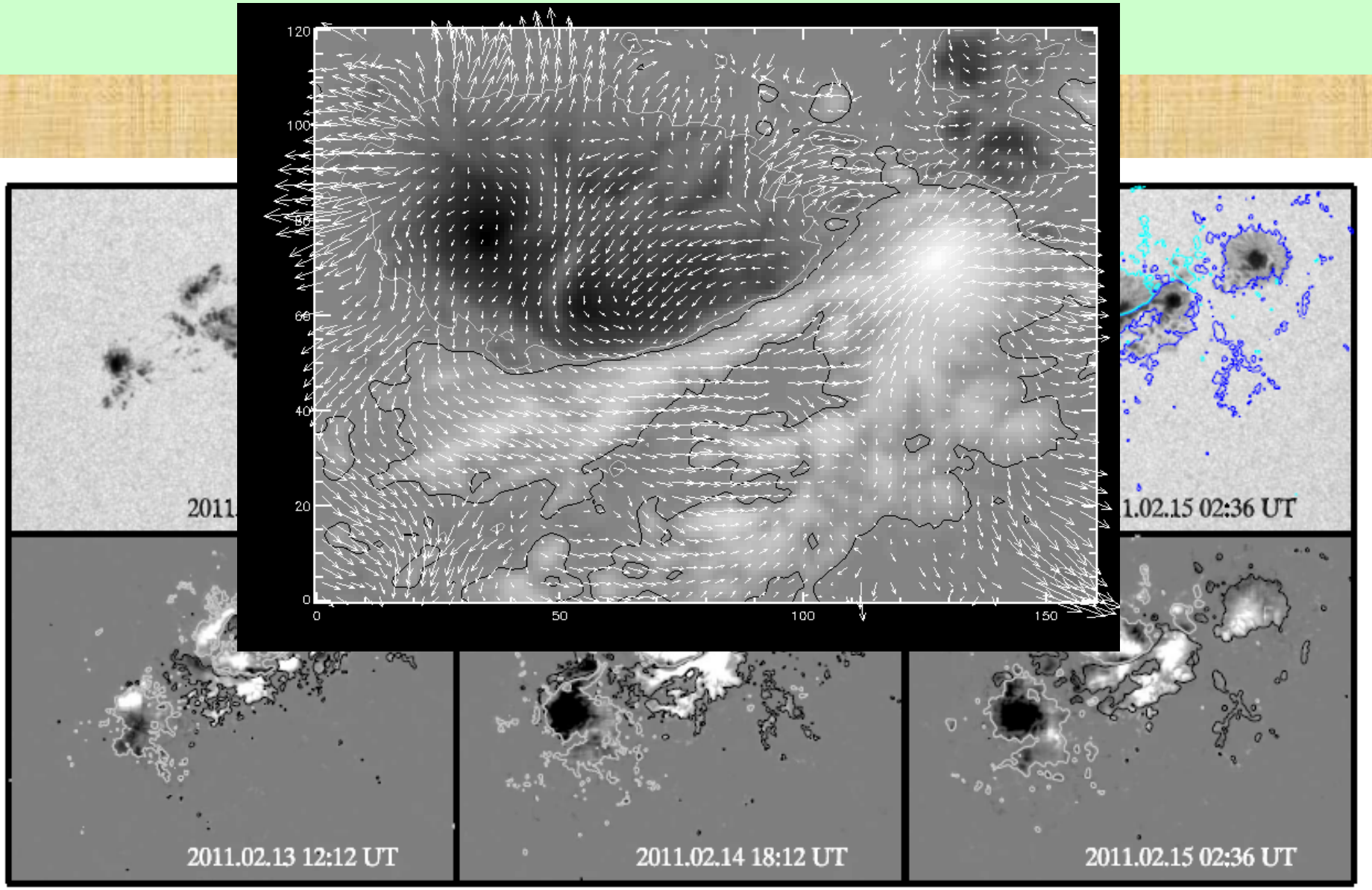
Results: AR 11158

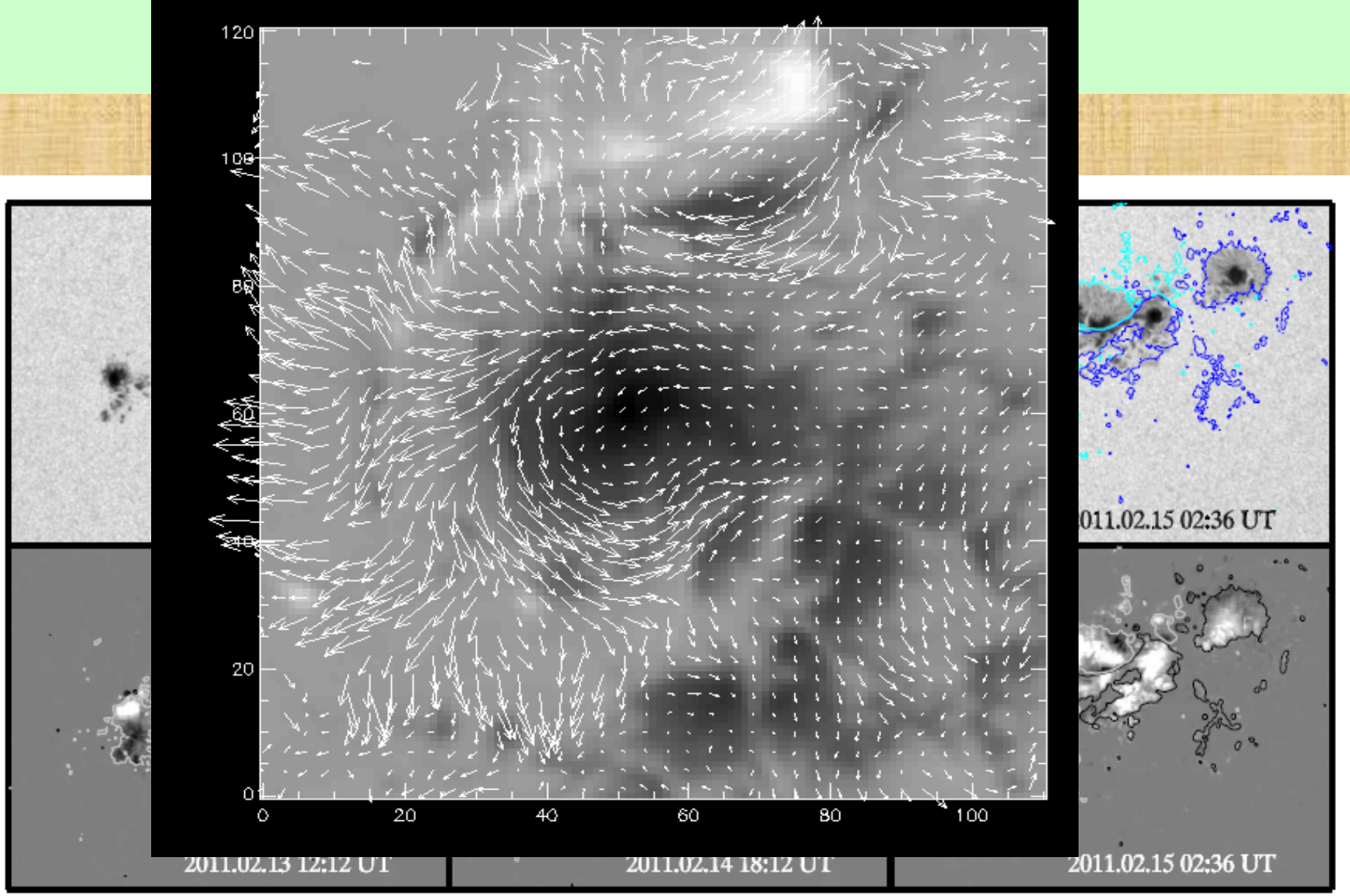


Results: AR 11158

Need precise alignment

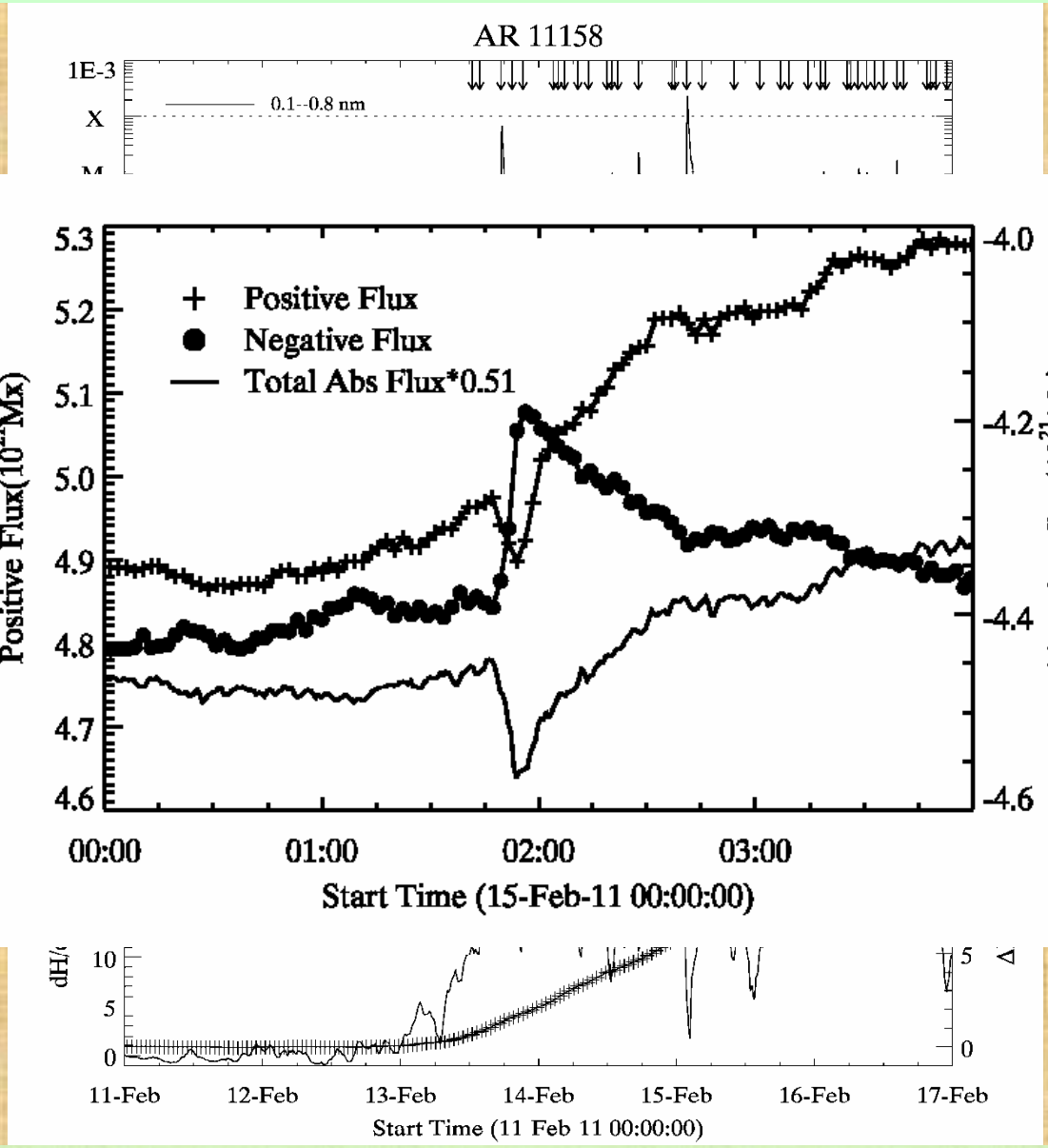



120
100
80
60
40
20
0
0
50
100
150
1.02.15 02:36 UT
2011.02.13 12:12 UT
2011.02.14 18:12 UT
2011.02.15 02:36 UT

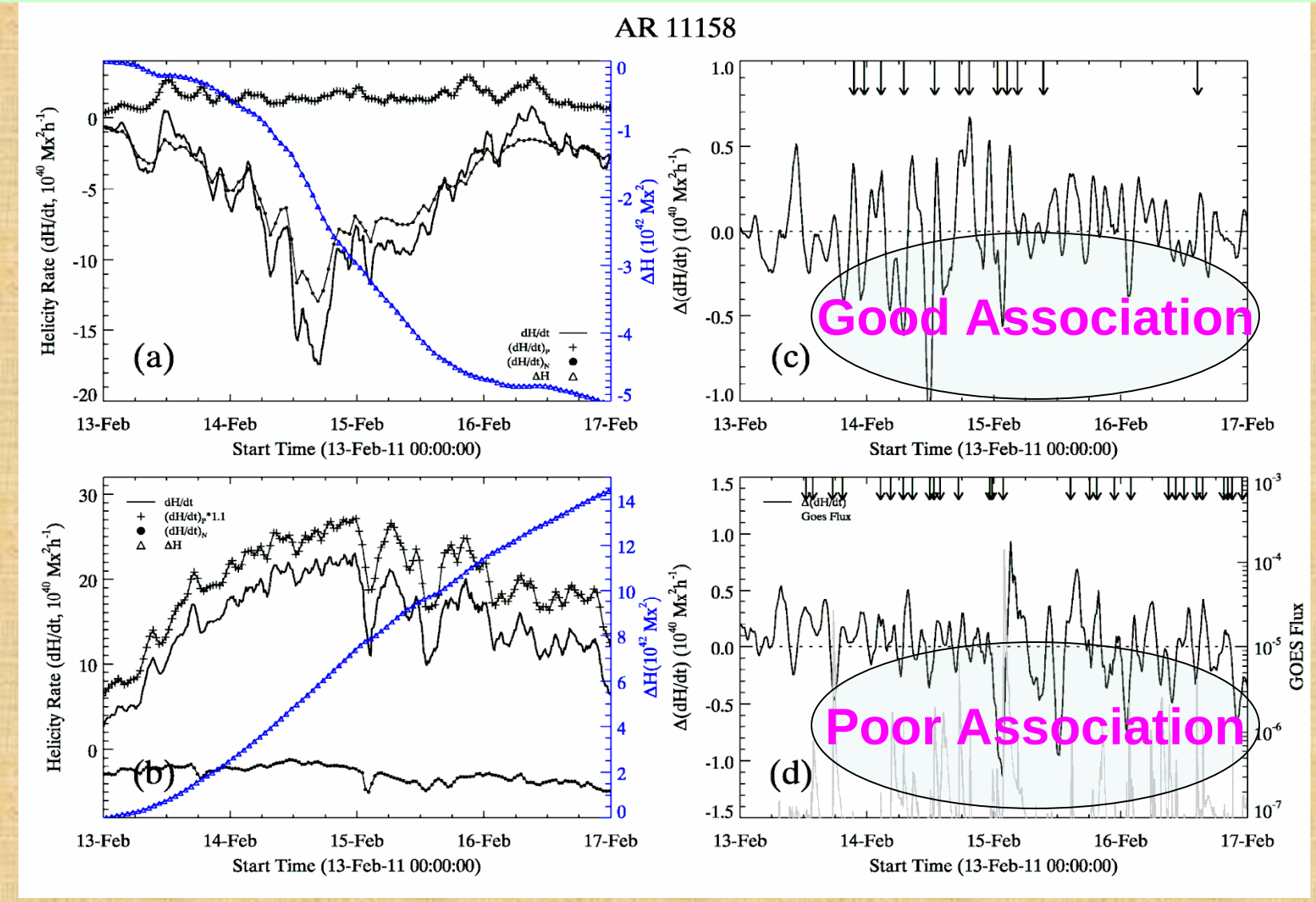


See also the E-poster Ballroom, relating rotation of sunspots and twist parameters

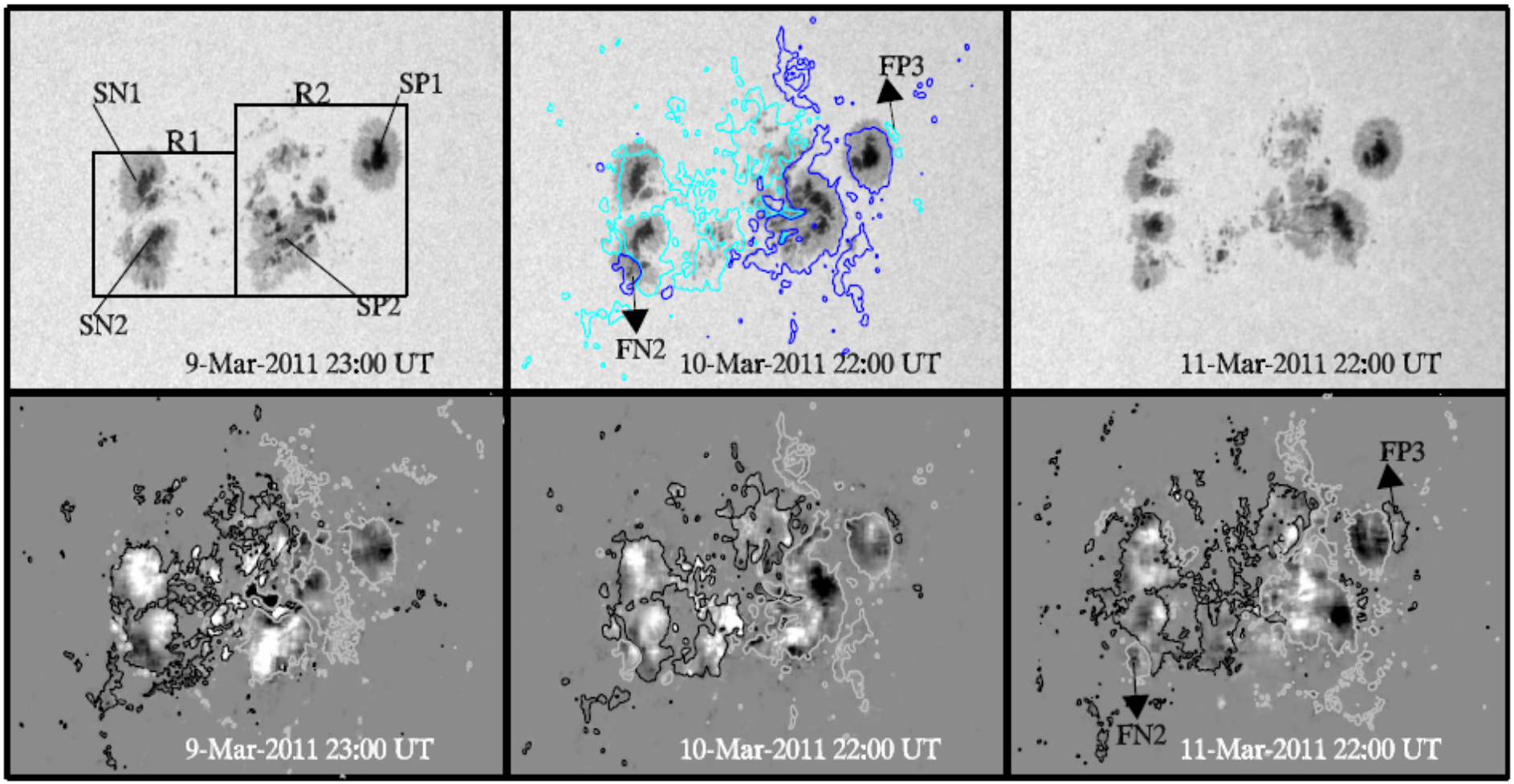
Results: AR 11158



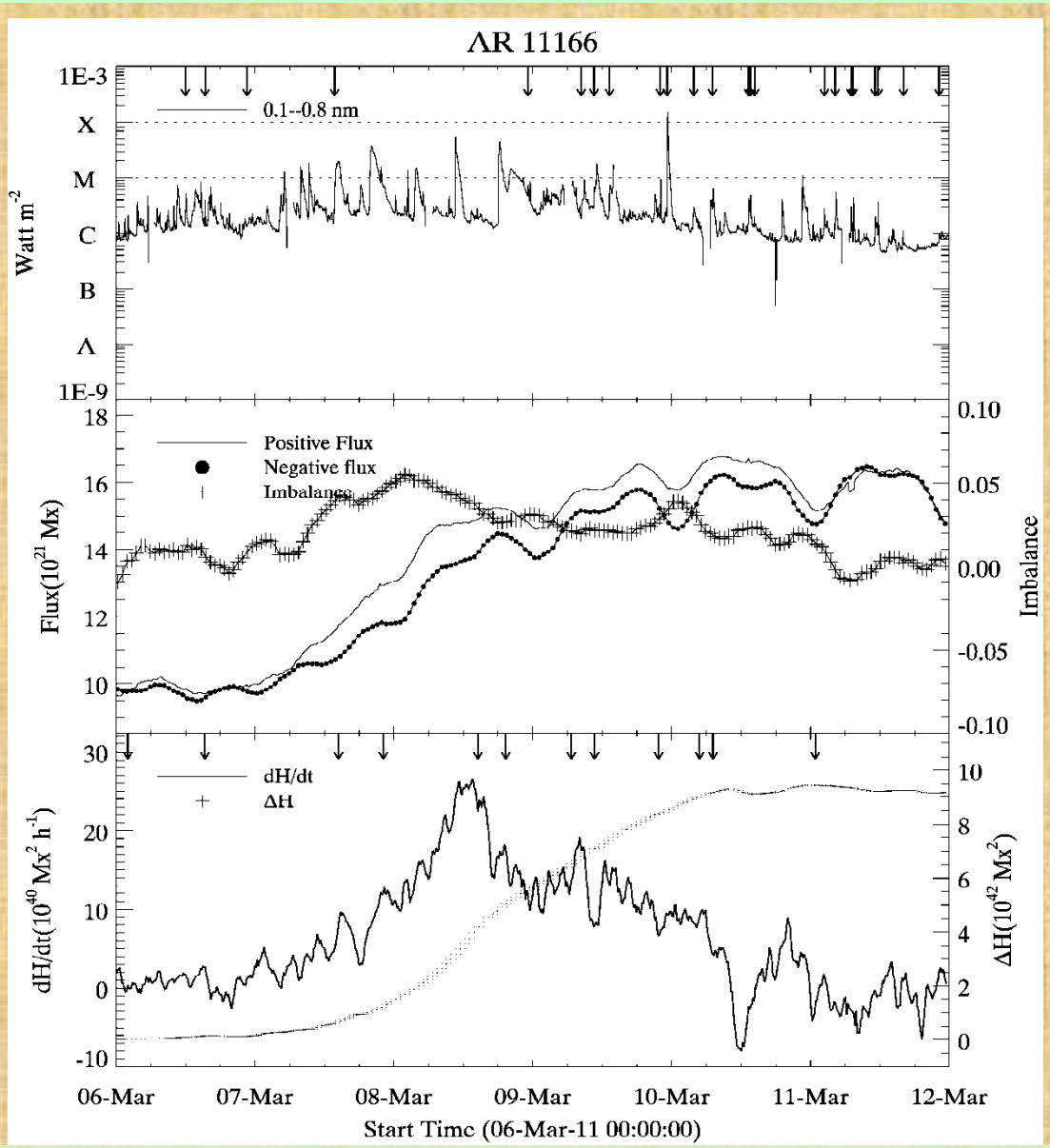
Results: AR 11158



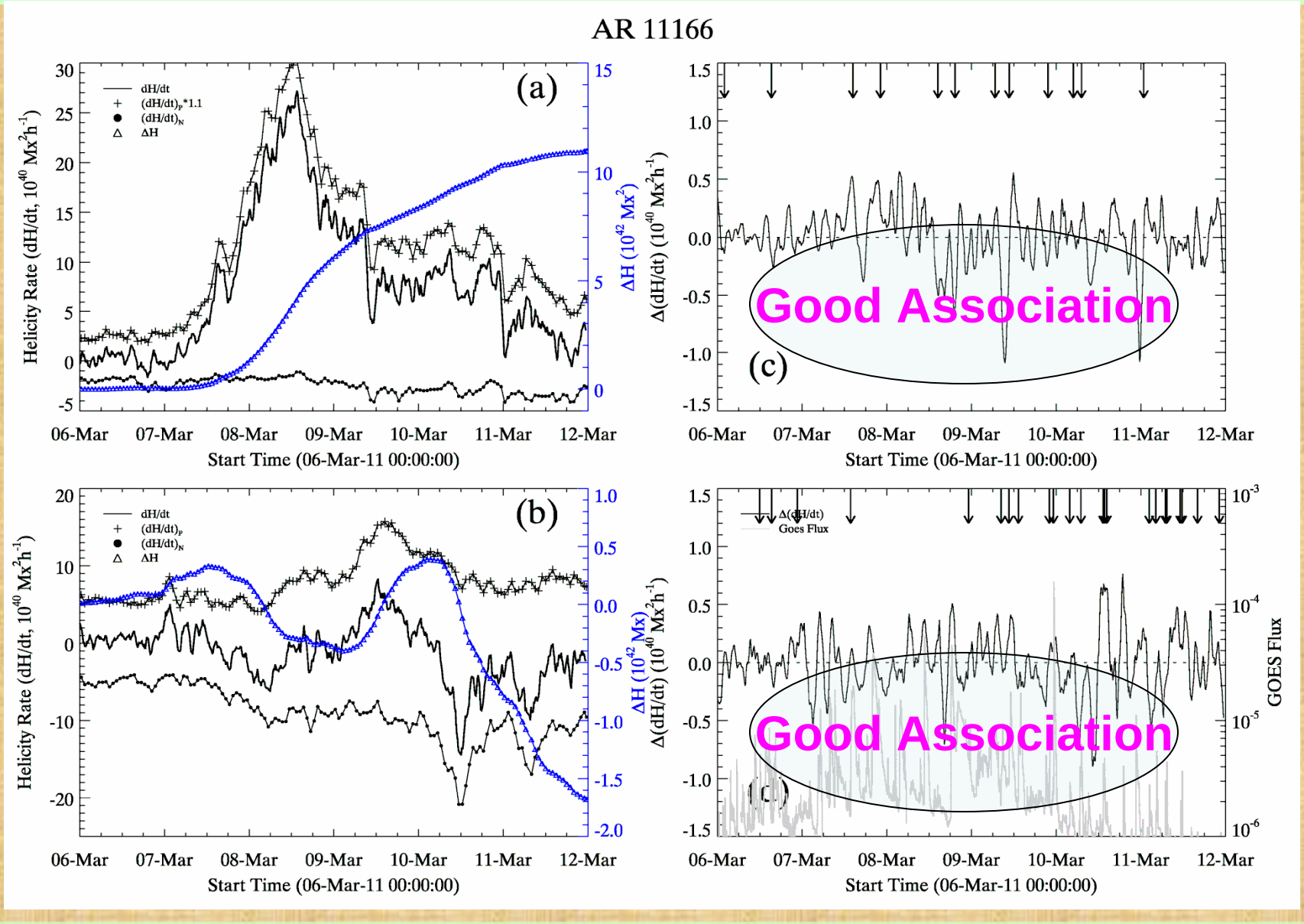
Results: AR 11166



Results: AR 11166



Results: AR 11158



Discussion: Physical Significance

Appearance of opposite signed helicity into the pre-existing helicity system

What could they be?

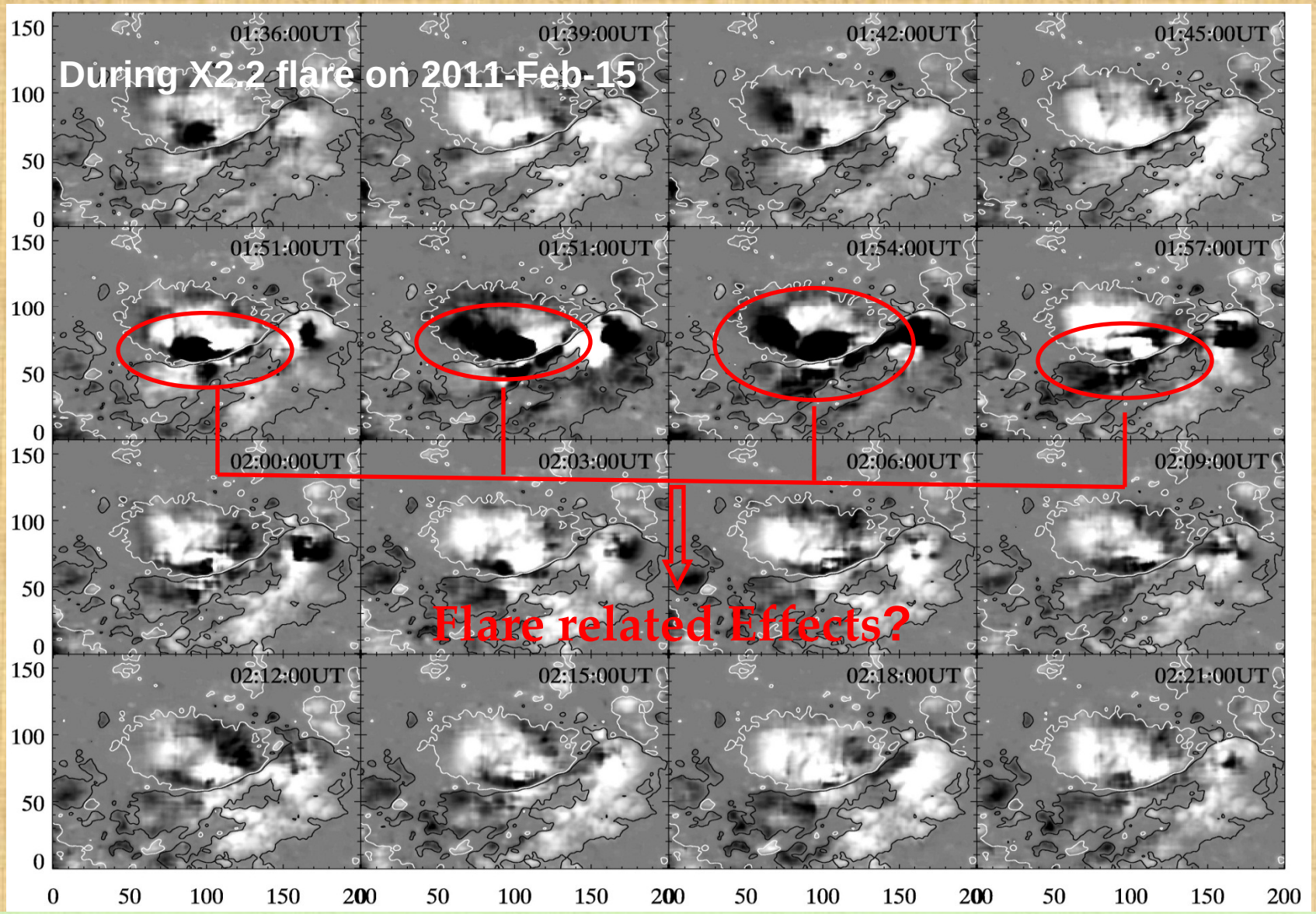
They can be due to transient effect of the flare during impulsive period inferring they are not real.

Suppose the injection of opposite helicity is real. Two physical processes that leads to this behaviour.

One is the local action of plasma motion on a pre-existing flux system that introduces injection of opposite helicity. This system can not be stable, and the helicities of opposite sign transfer along fieldlines until they annihilate each other.

The other possibility is that a new twisted flux system is emerging and colliding with pre-existing magnetic system of opposite helicity.

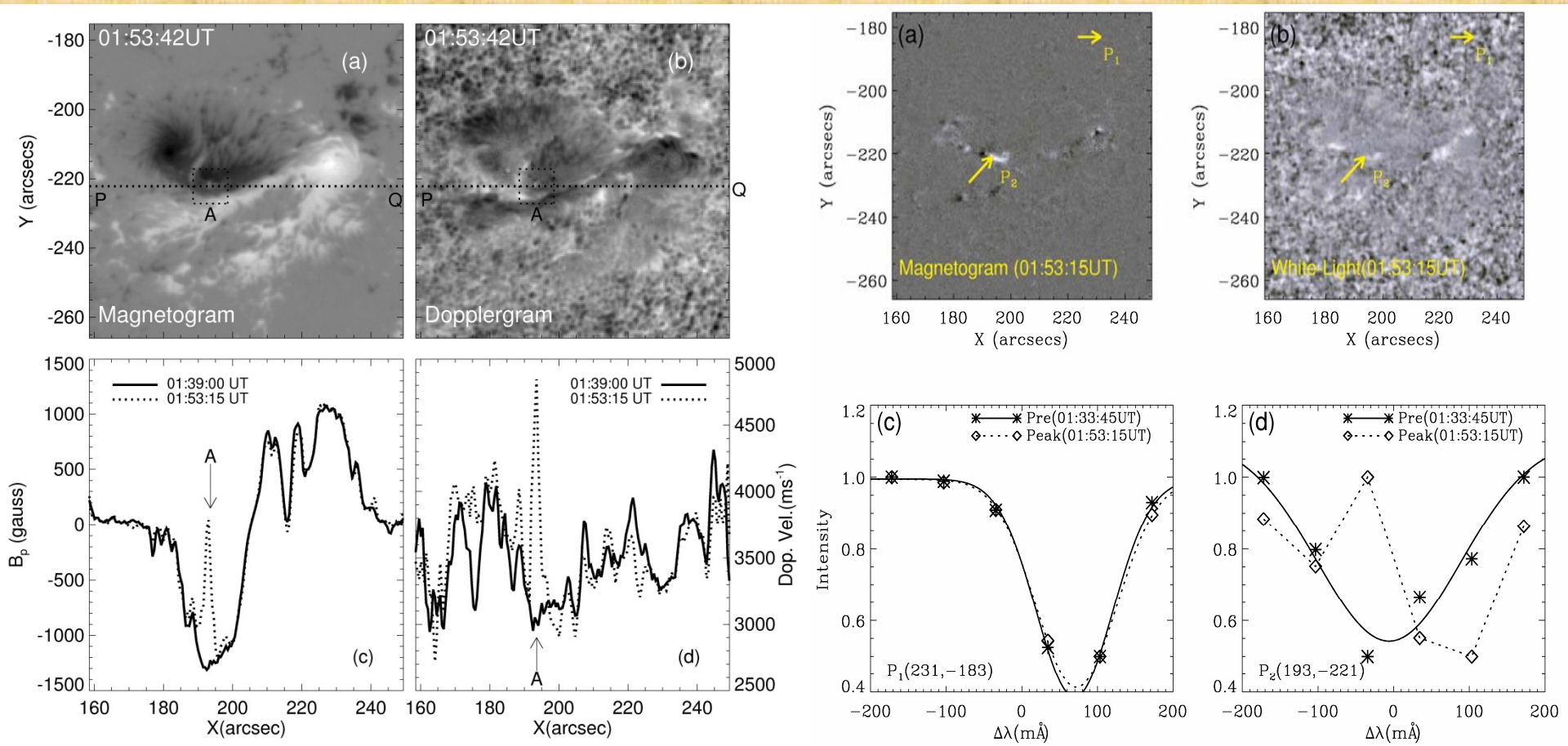
Results: Flare Related Effects



Results: Flare Related Effects

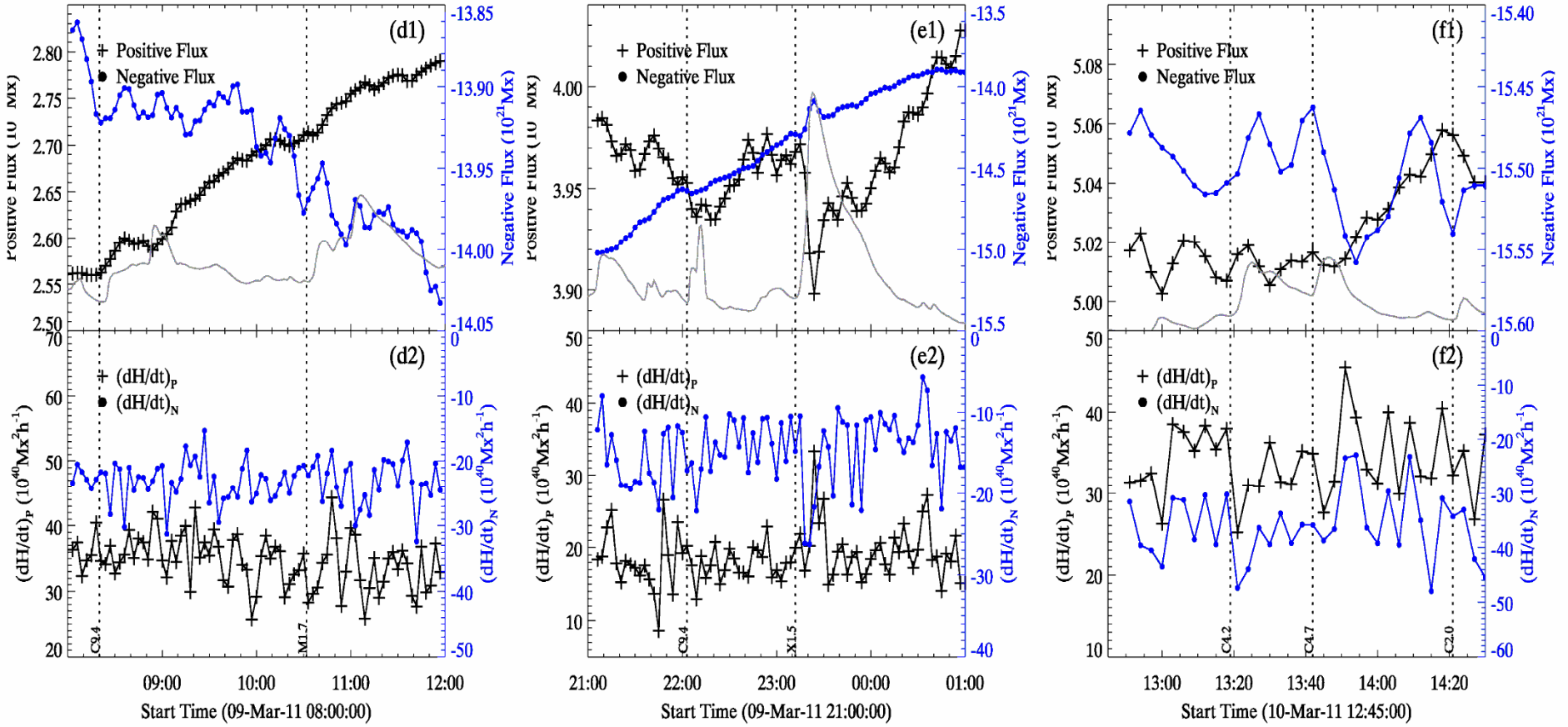
Difficulties in detecting transfer of true helicities?

- Flare Related Mag Field changes (Wang & Liu 2010, Wang et al 2012)
- Magnetic Transients and Line Reversal (Qiu & Gary 2004, Maurya et al 2012)



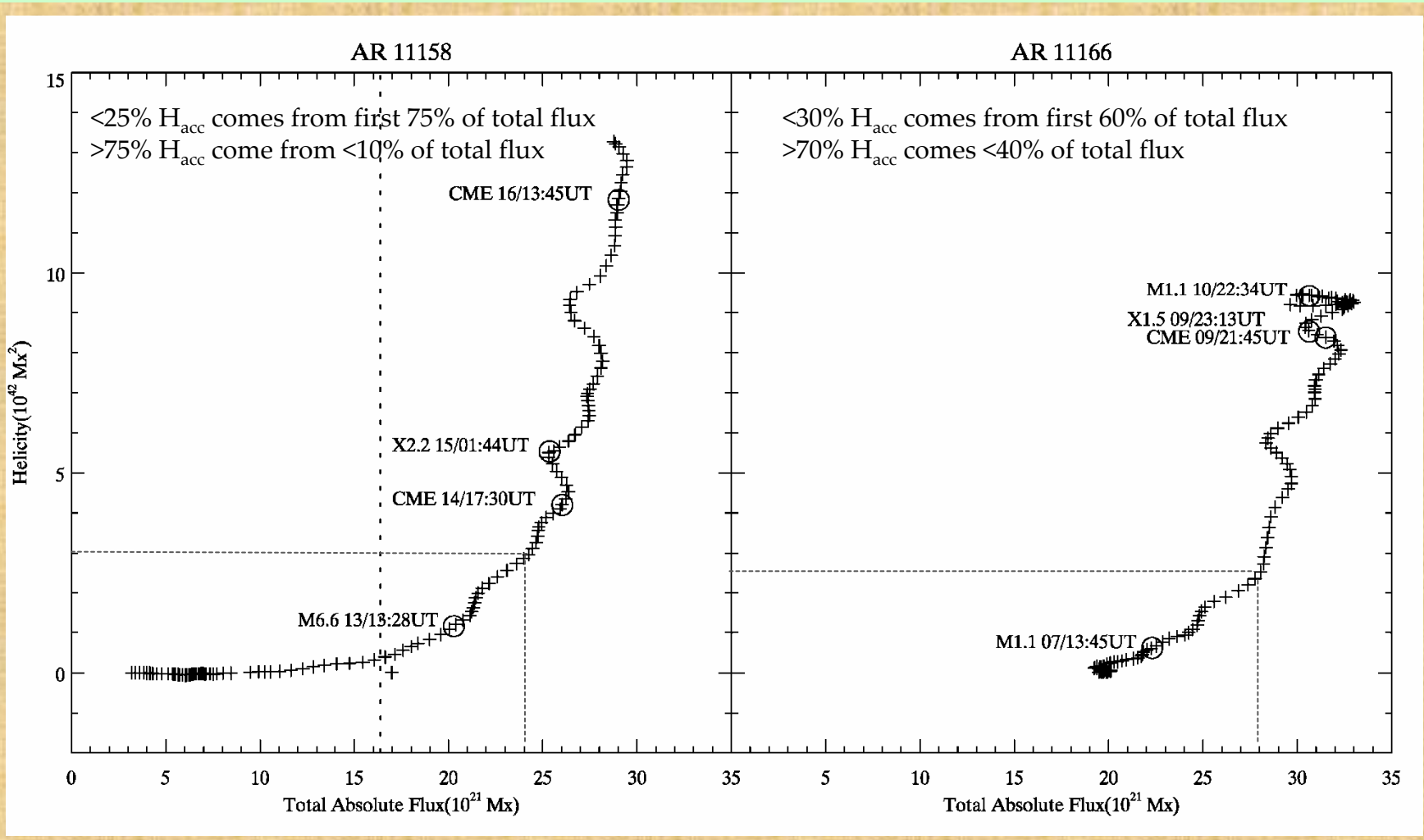
Results: Flare Related Effects

Temporal Evolution of Helicity Injection Rate in NOAA 11158 & 11166



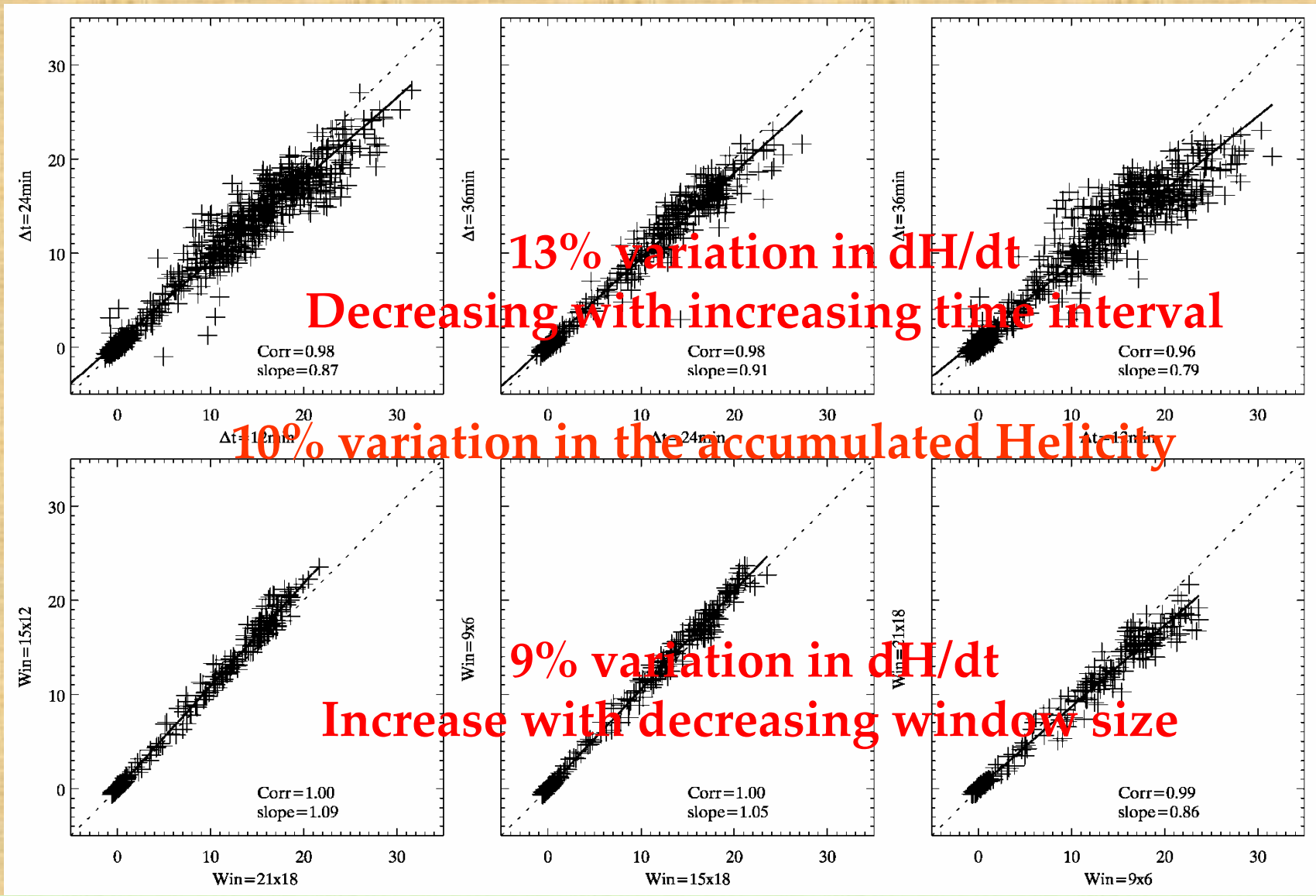
- Evidence for existence of opposite helicity fluxes during the flares
- Should be careful in interpreting the results against flare related effects

Discussion: Flux Vs Helicity



- Flux motions contribute more to H_{acc} than that what it is by flux emergence.
- Flux emergence may not always plays a major role in accumulating helicity flux.

Discussion: Dependence on Tracking parameters



13% variation in dH/dt

Decreasing with increasing time interval

10% variation in the accumulated Helicity

9% variation in dH/dt

Increase with decreasing window size

Summary

- Flux motions including shear as well as rotational motions are discernible in the studied ARs, and are important in twisting or shearing the magnetic field lines and thereby flux interactions.
- During 6 day period, 14.16 and 9.5×10^{42} Mx^2 helicity had been accumulated by these motions which are consistent with previous results.
- We found Spatial and temporal correspondence between flaring sites and variations in helicity injection during some strong flare/CMEs. Overall, we found good correlation with flares/CMEs with the absolute variations in helicity flux signal, suggesting role of helicity injection during flares and CMEs.
- Flare effects like line-reversal and underestimation of magnetic measurements are evident in impulsive phase of the flares which we believed to effect the true helicity signal.

Thank You

- We examine this issue using high temporal resolution LOS images. Flare effects indeed affect the magnetic fields and further the helicity flux signal. However, One can consider such helicity flux rate changes as true without these magnetic field changes.
- A focused study is needed at a time resolution of 3min to associate flare/CME occurrence with short term variation of helicity injection.
- The physical significance of these variations at the onset of the flares is very necessary to understand the role of the helicity injection in triggering them.
- Estimation of helicity injection rates depends on DAVE parameters used to track the motion of the fluxes. The accumulated helicity value varies by 10% as estimated by different choices of DAVE parameters.