Hinode's Observational Result on the Saturation of Magnetic Helicity Injected into the Solar Atmosphere and its Relation to the Occurrence of a Solar Flare

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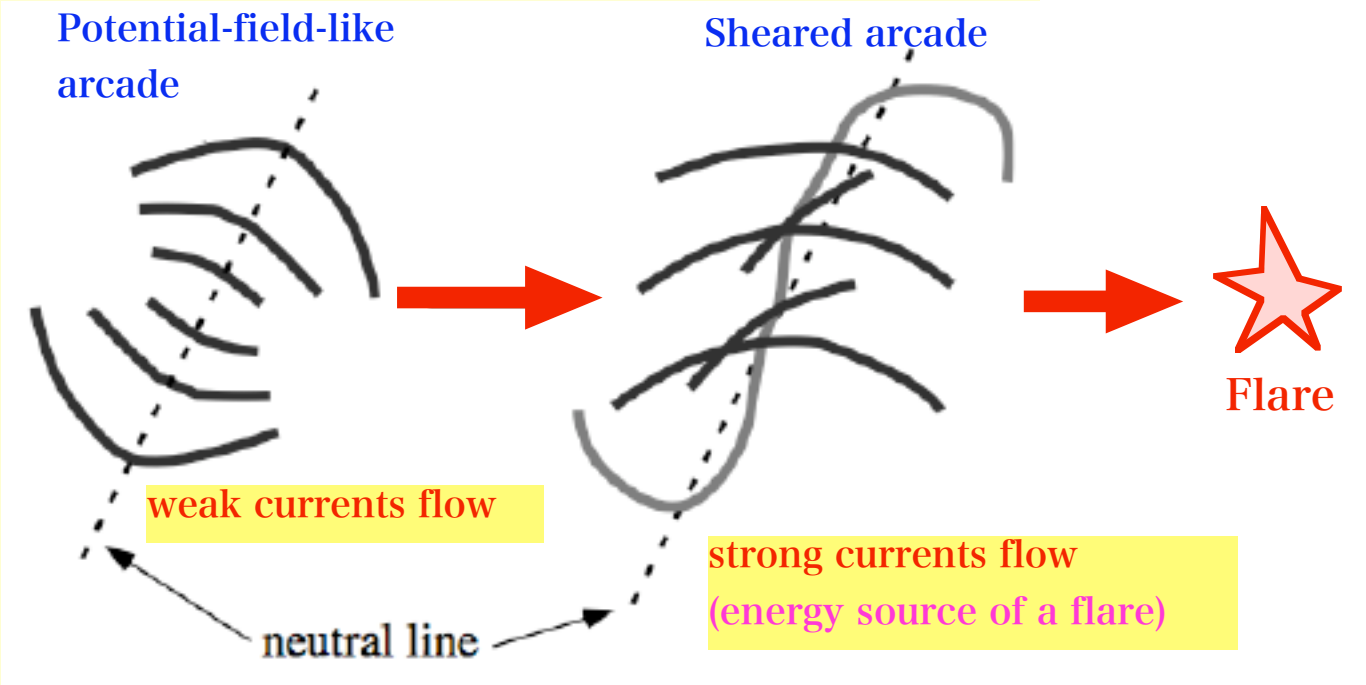
An important indicator of a solar flare:

development of magnetic shear

Magnetic shear develops during a preflare phase.



Objective of this study:

present a quantitative description of magnetic shear which is useful for the prediction of a flare

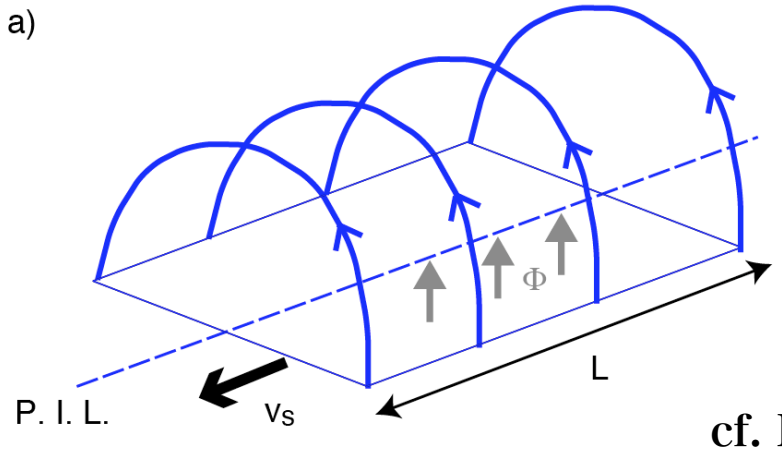
A quantity representing magnetic shear:

magnetic helicity

$$H = \int_V \boldsymbol{A} \cdot \boldsymbol{B}\, dV,\ \boldsymbol{B} = \nabla \times \boldsymbol{A}$$

$\boldsymbol{B}$: Magnetic field
$\boldsymbol{A}$: Vector potential of $\boldsymbol{B}$

Derive the evolution of magnetic helicity by using a prescribed model



$$\frac{dH}{dt} = v_S \frac{\Phi^2}{L}$$

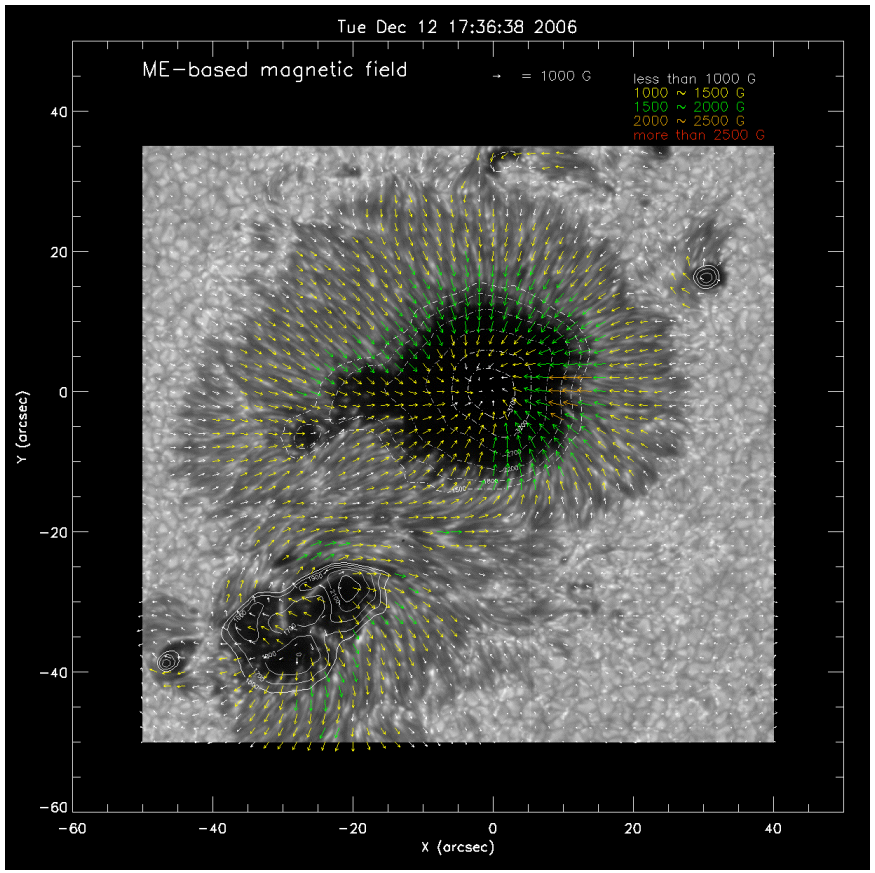
cf. Priest & Forbes (2000)

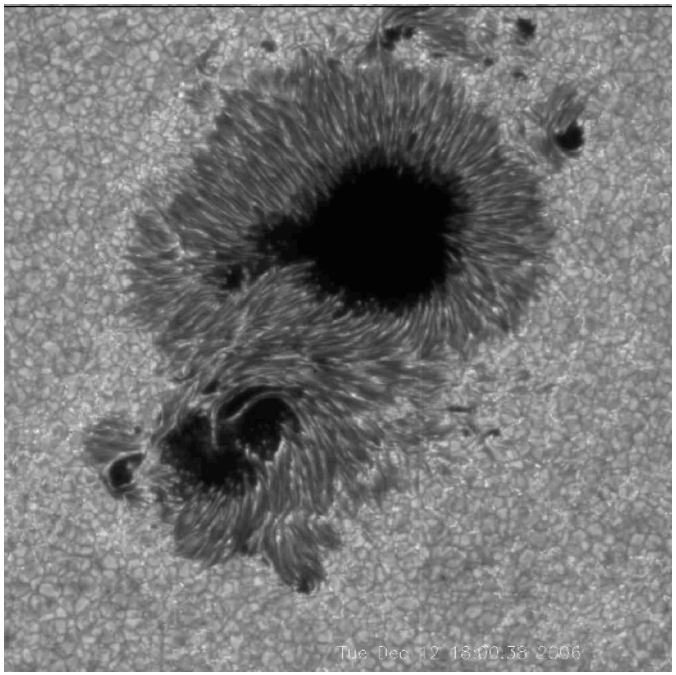
We calculate the temporal development of H in a flare-productive region to see the feature of helicity evolution that relates to the occurrence of a flare.

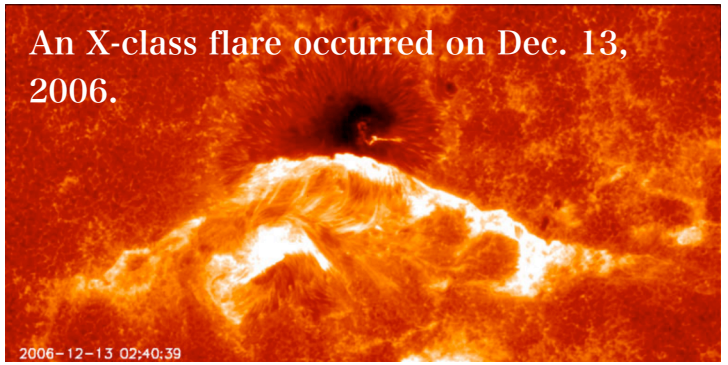
Target region:

NOAA10930

observed in December 2006

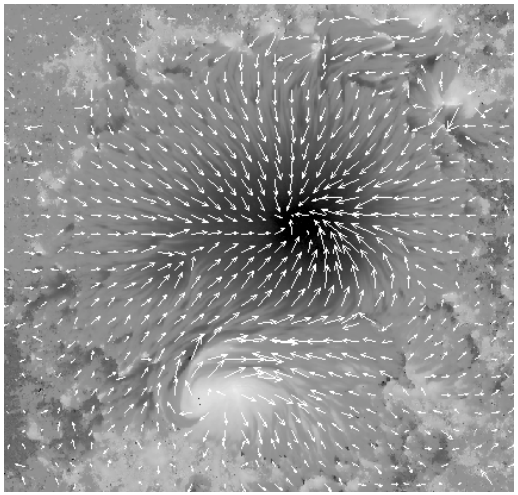






The method of analysis:

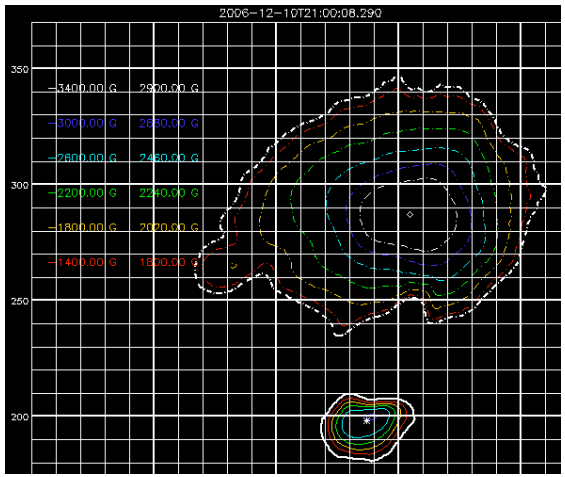
Observed coordinates



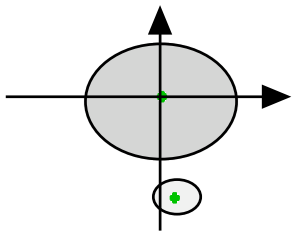
Vector magnetic field obtained by using the Milne-Eddington approximation (Yokoyama, Katsukawa, & Shimojyo, in preparation)

Transformed

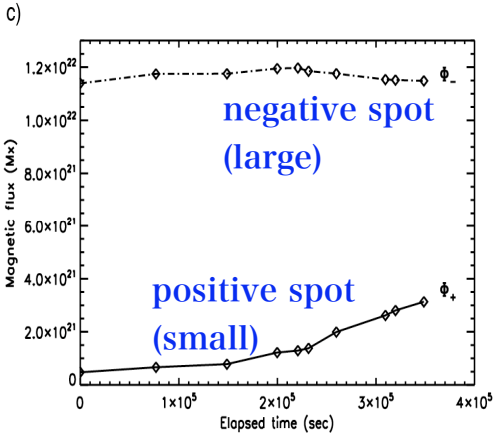
Disk-center coordinates

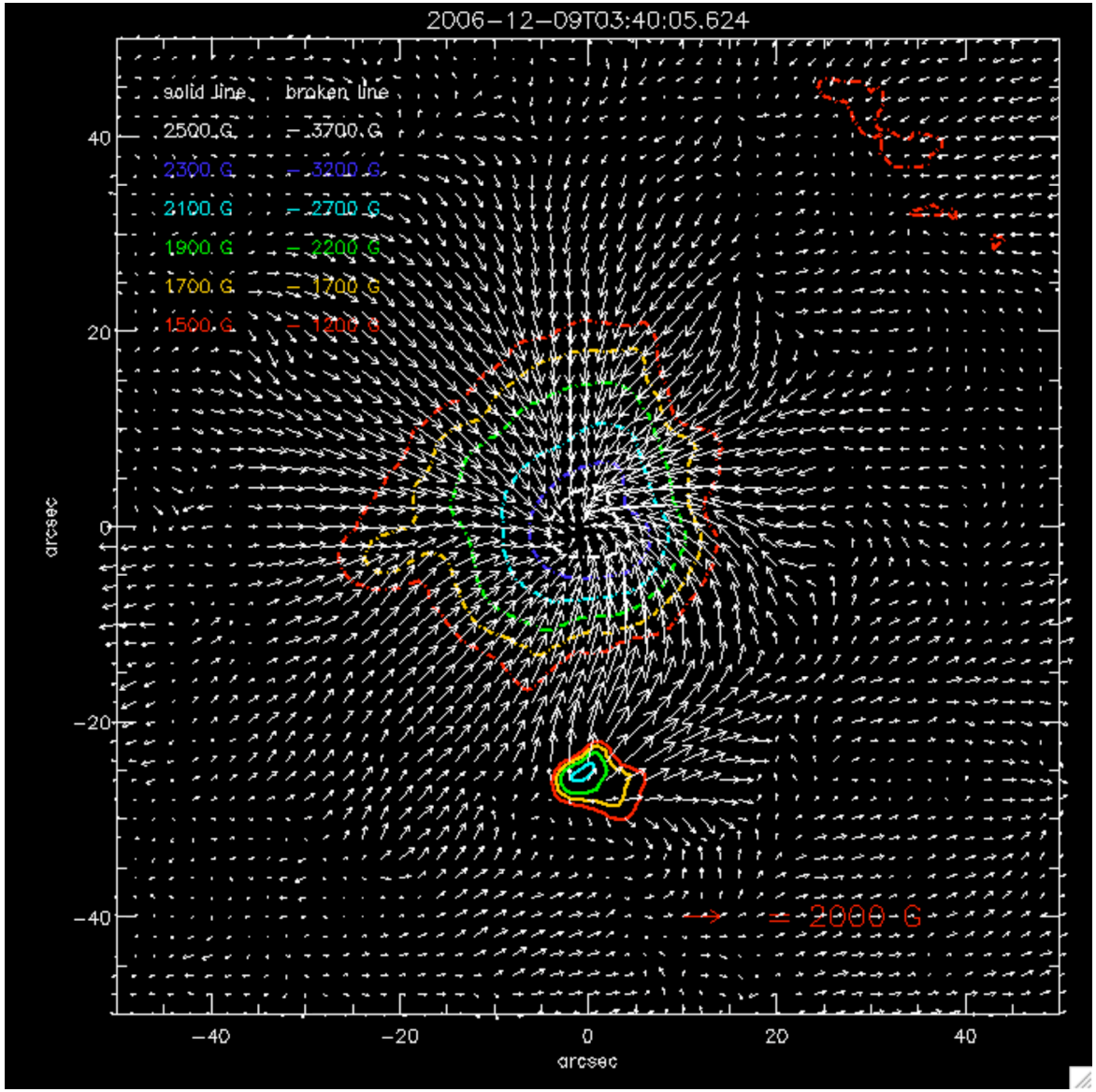


Projection effect is removed in the coordinates where the disk center is fixed at the peak flux location of the negative spot.



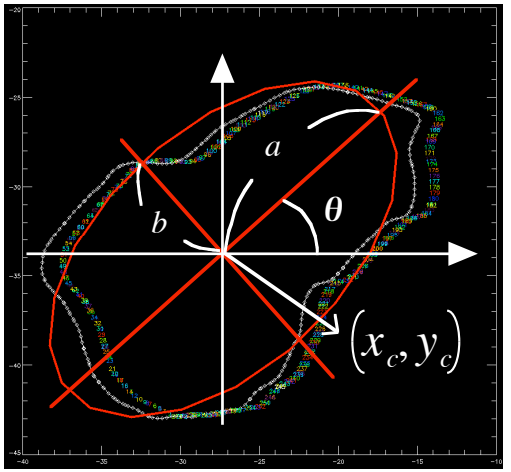
Evolution of photospheric magnetic field (vector map)

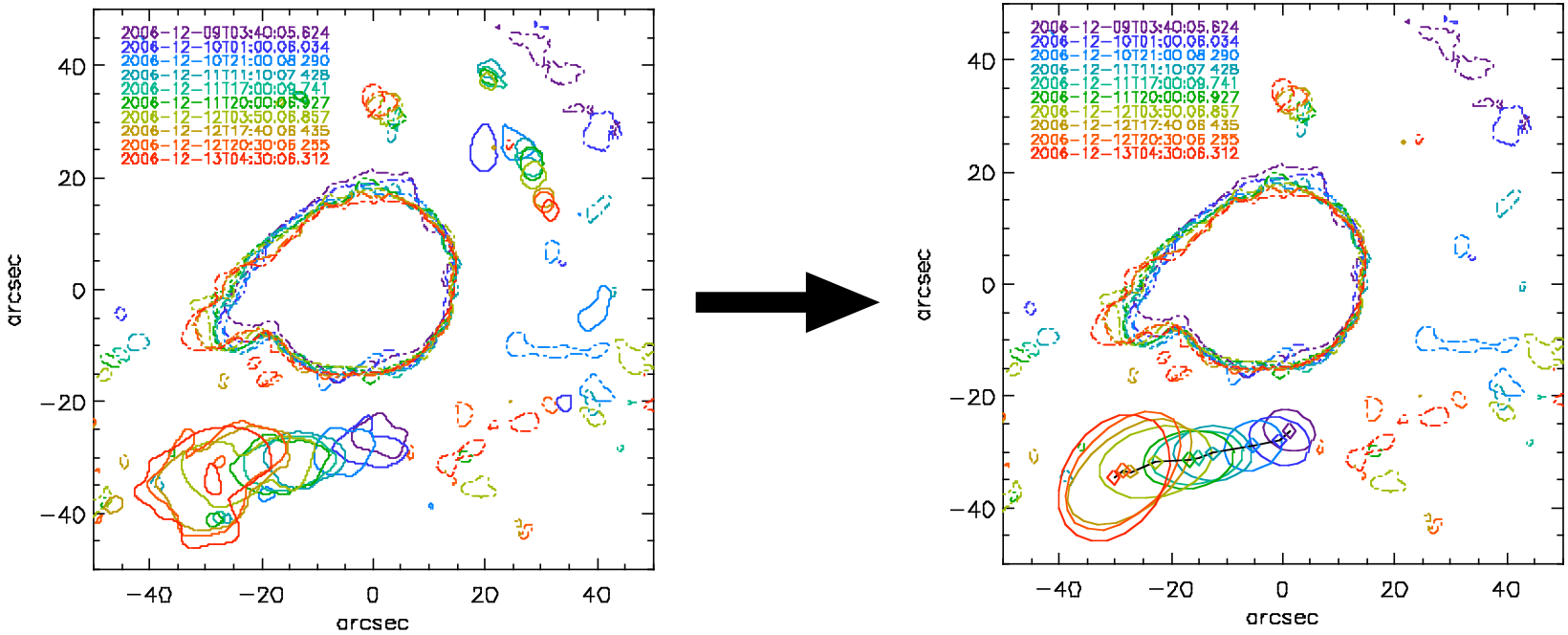




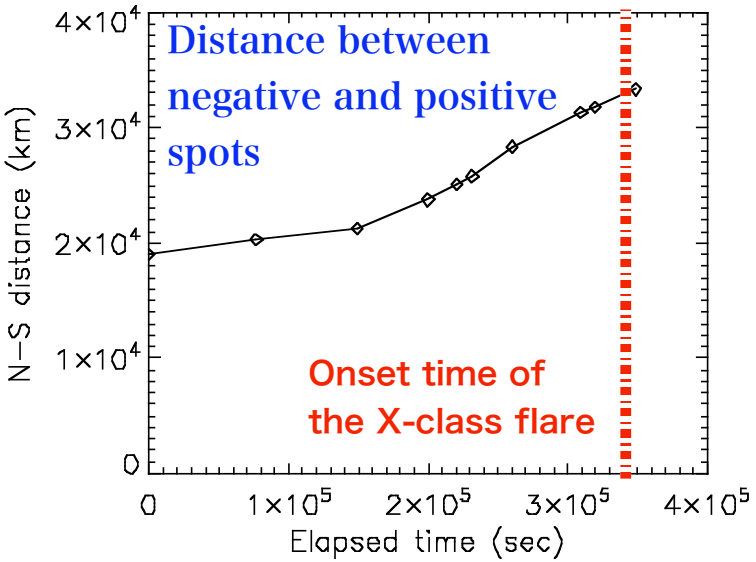
Elliptic fitting

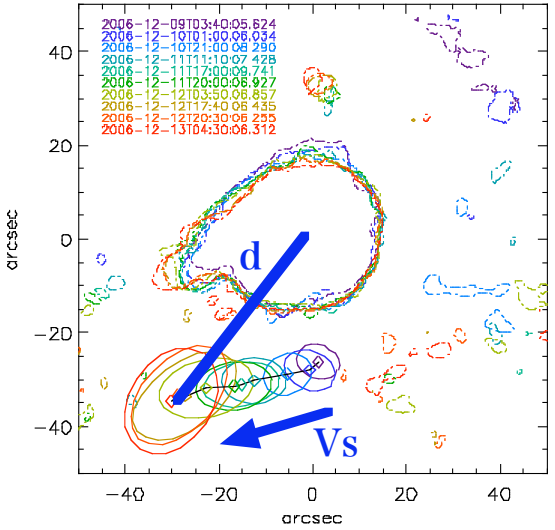
... to define the location of the positive spot

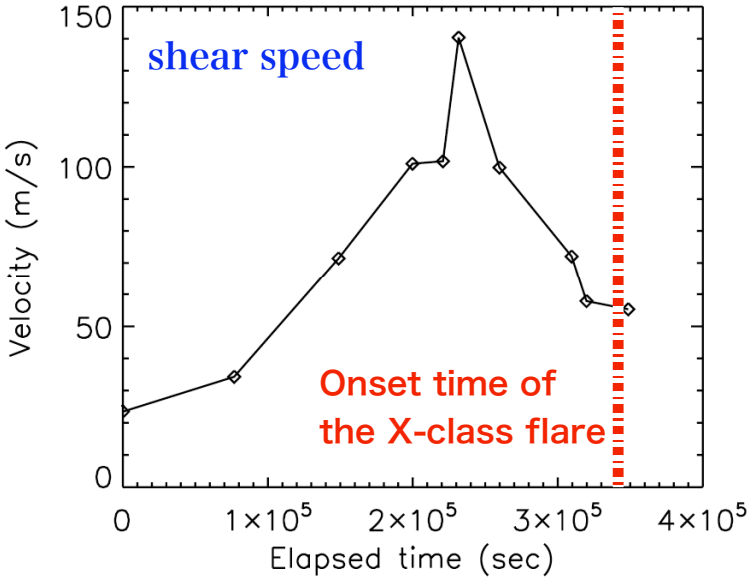




Distance and shear speed

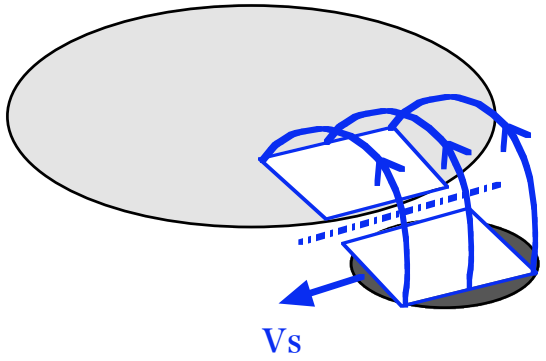


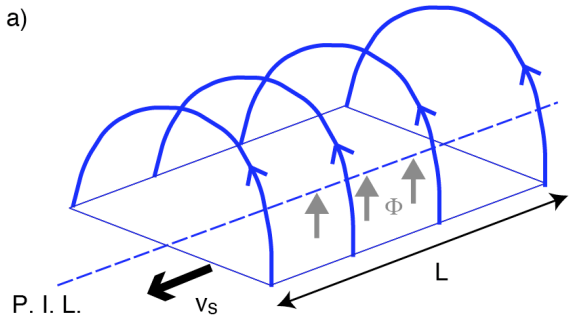


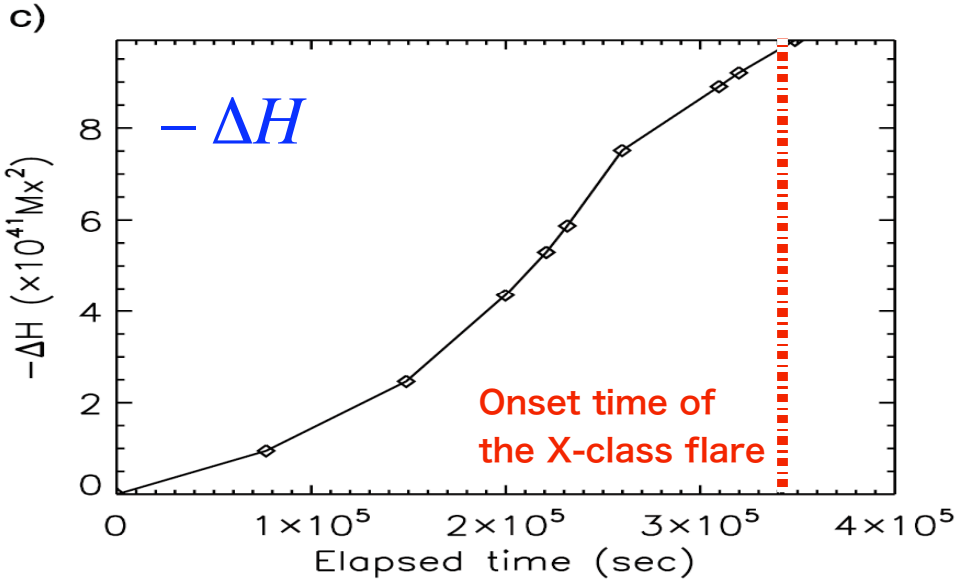


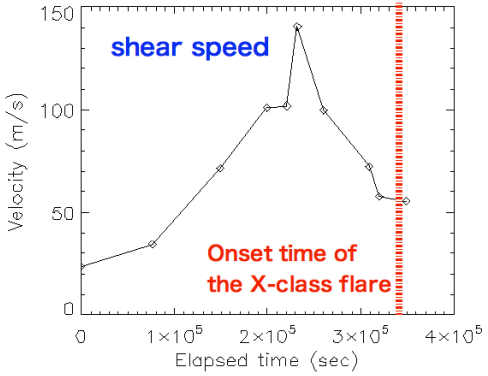
The distance and shear become saturated toward the onset of a flare.

Helicity evolution





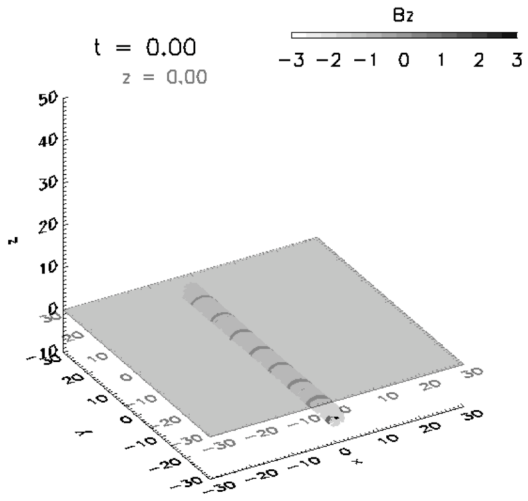




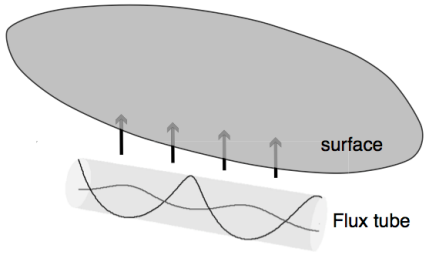
ΔH becomes saturated toward the onset of a flare.

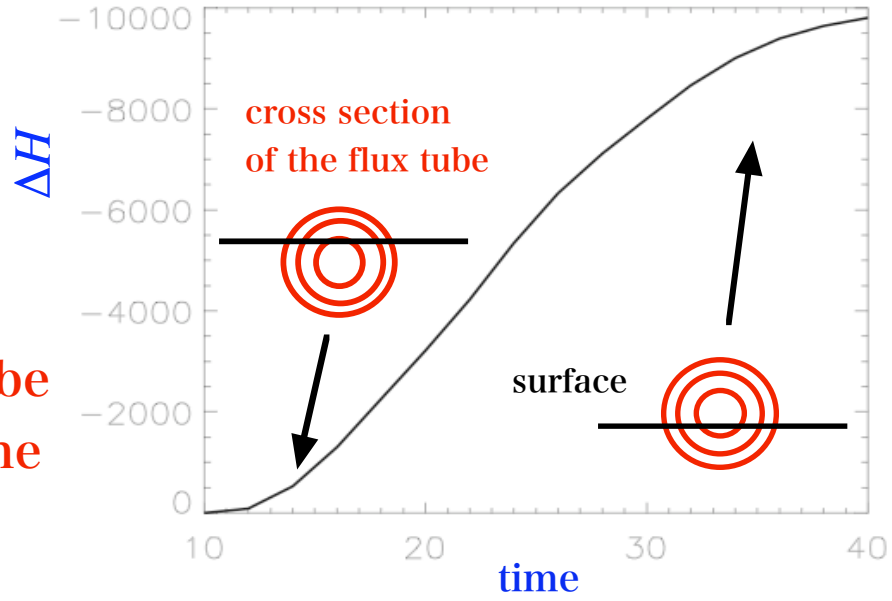
Physical explanation of the saturation:

A suggestion from a flux-emergence simulation

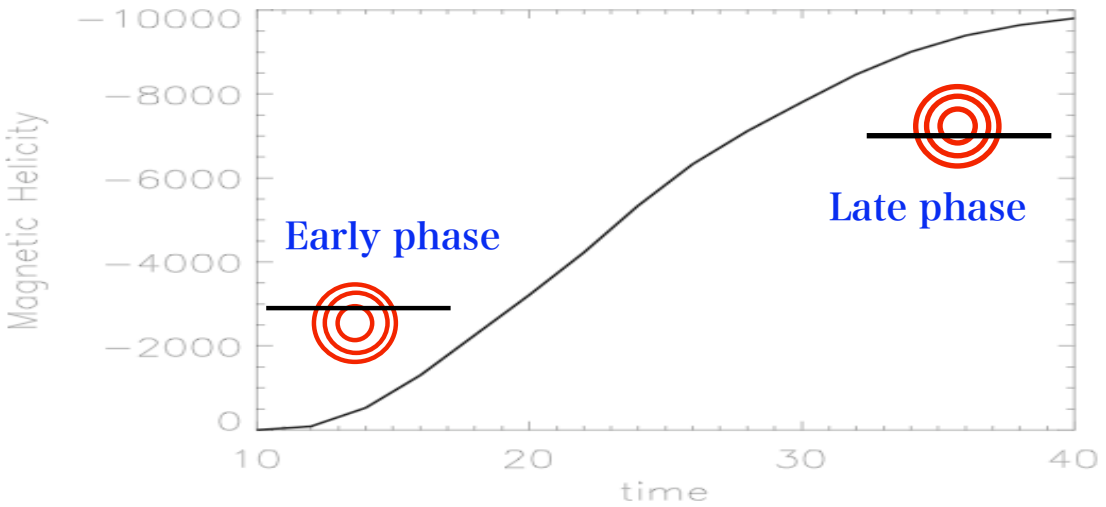


MHD simulation from Magara (2004)





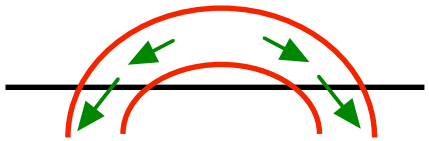
After the axis of the flux tube emerges into the surface, the saturation occurs.



Early phase: before the axis emerges into the surface

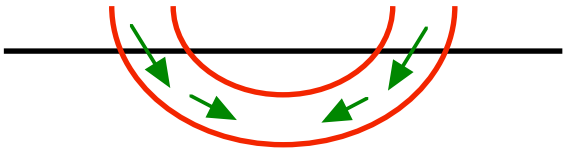
Late phase: after the axis emerges into the surface

Ω-shaped loop



Plasma drains
=> enhances buoyancy
=> active emergence

U-shaped loop

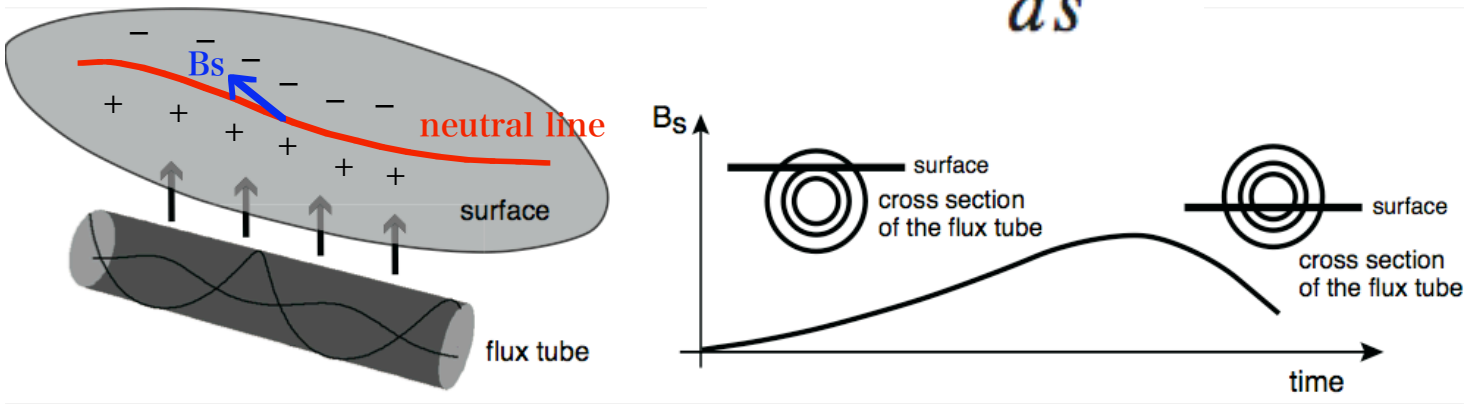


Plasma accumulates at the dip
=> reduces buoyancy
=> slow emergence

Observational investigation into the emergence of a twisted flux tube

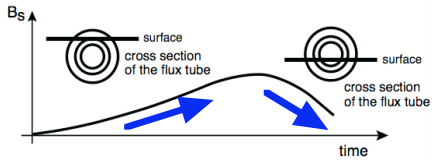
transverse comp. vector along the N.L.

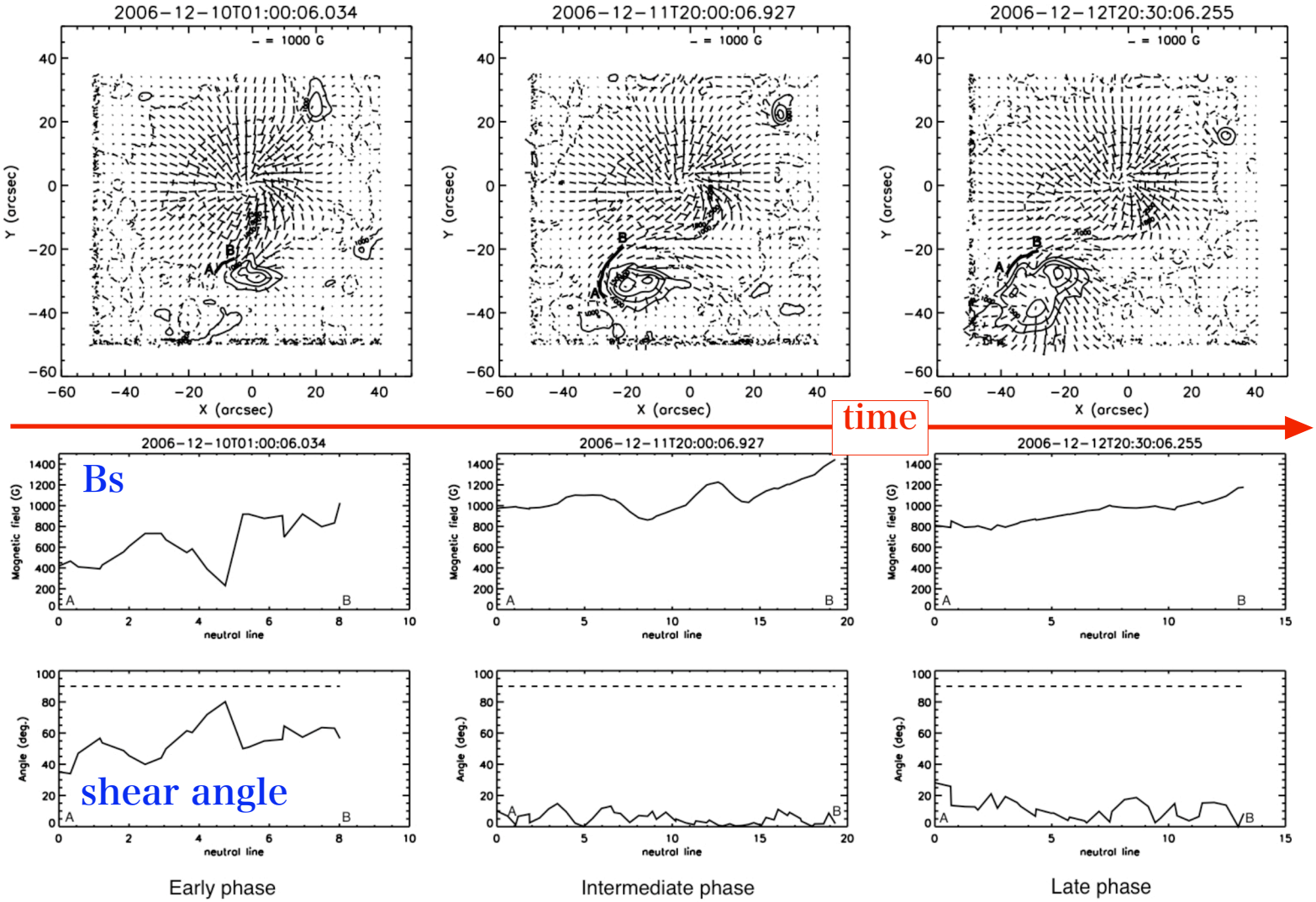
$$B_S = \frac{\boldsymbol{B}_\perp \cdot \boldsymbol{ds}}{ds}$$



The evolution of photospheric vector magnetic field gives an observational evidence that a twisted flux tube emerges into the surface.

A result obtained by Hinode

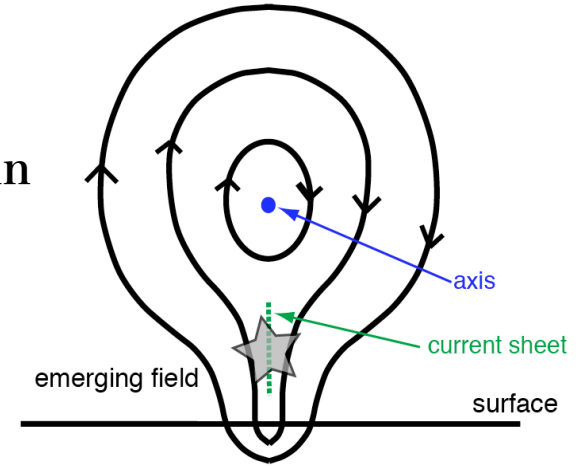




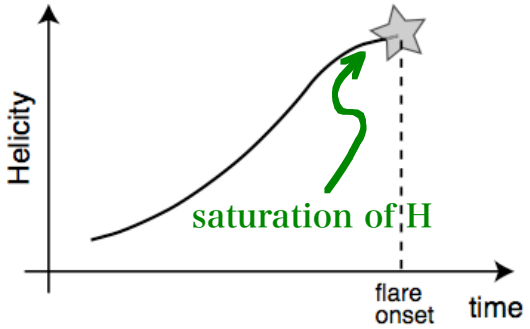
A key process leading to the onset of a flare

... Emergence of the axis of a flux tube

Below the emerged axis a current sheet forms, in which reconnection occurs to produce a flare.

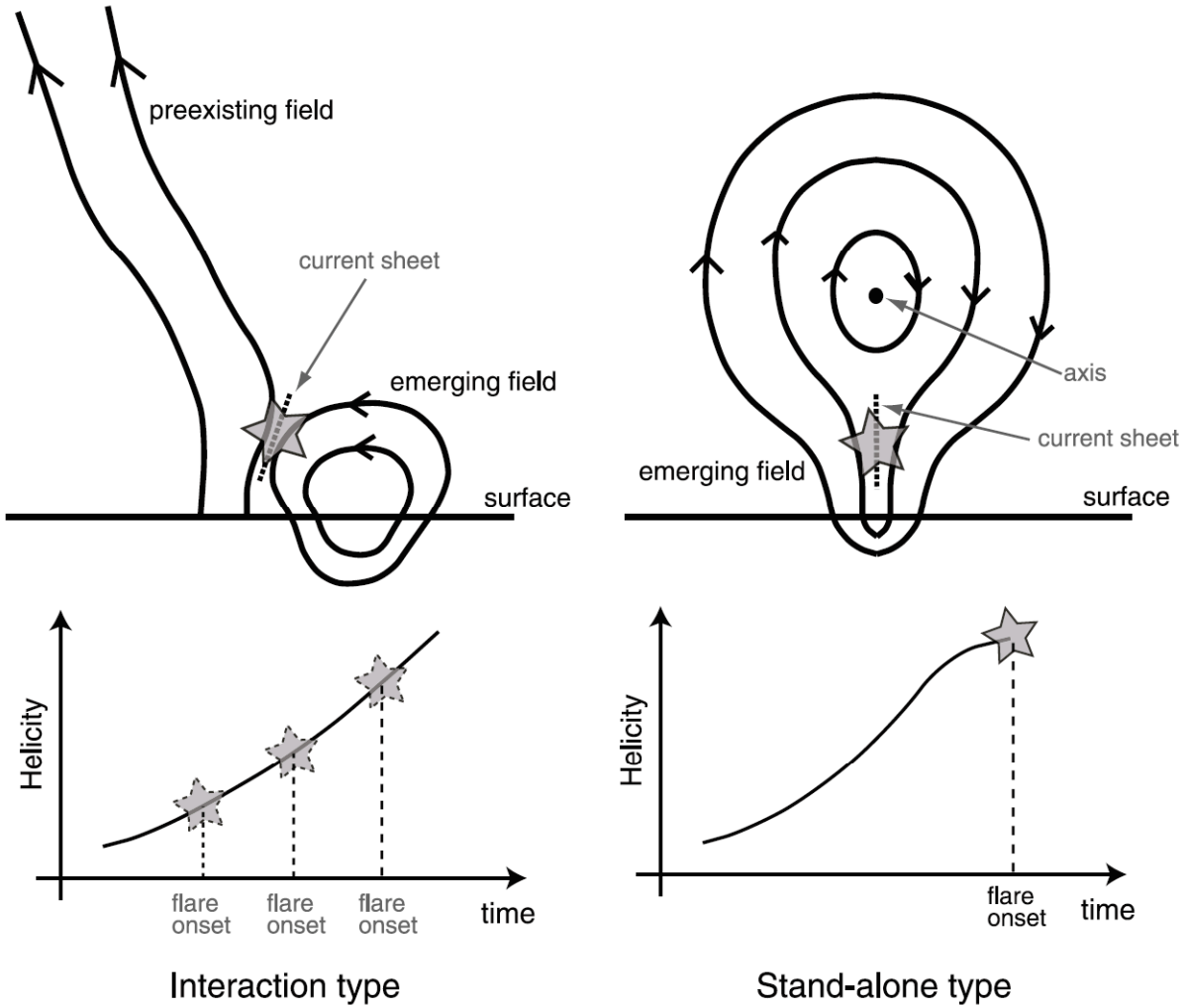


Although it may not be observed directly, the emergence of the axis can be expected from the saturation of helicity, which is obtained from photospheric observations.



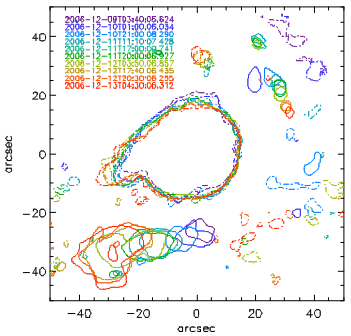
The saturation of helicity is an indicator of the possible occurrence of a flare.

Flare type and helicity evolution



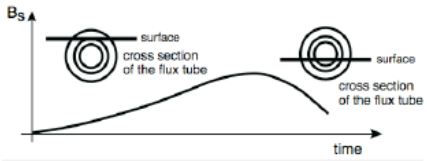
Conclusion & Summary

Hinode's time-series (four days) data of photospheric vector magnetic field have the following advantages.

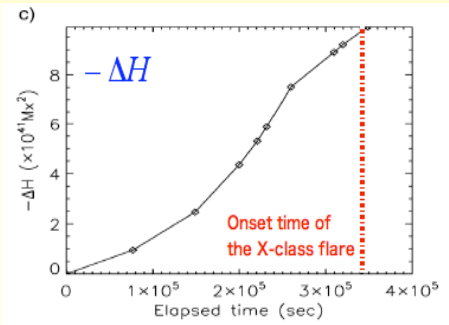


1) To show long-term evolution of photospheric polarity regions, where the projection effect is corrected

2) To present an observational evidence that the emergence of a twisted flux tube actually works and how magnetic shear develops in the surface

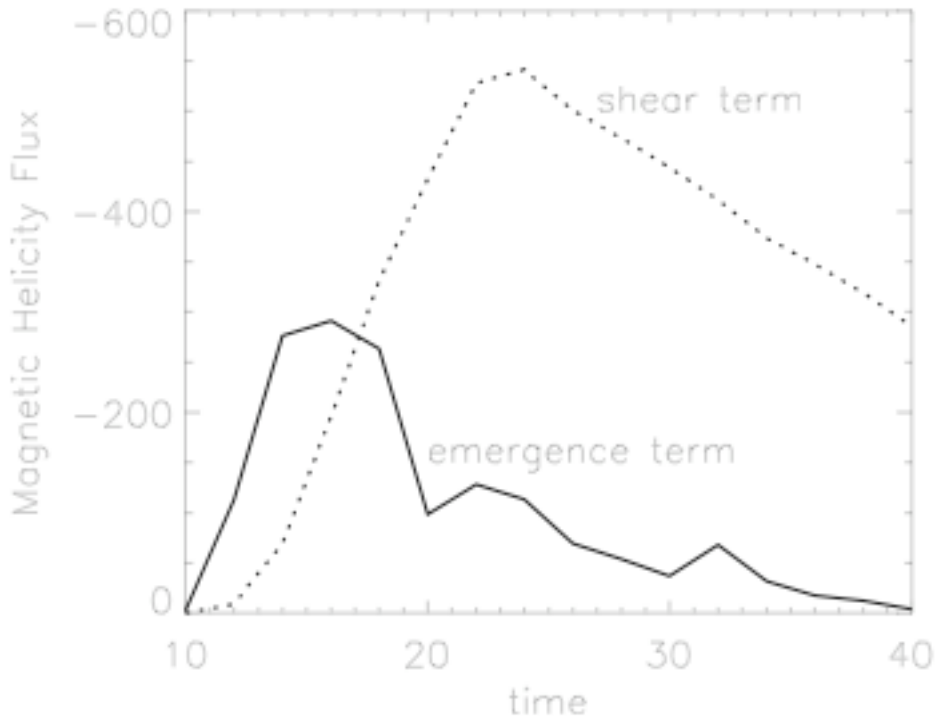


Using Hinode's observations, we investigate a key feature of a flare-productive region. The saturation of helicity is an important indicator of the possible occurrence of a flare.

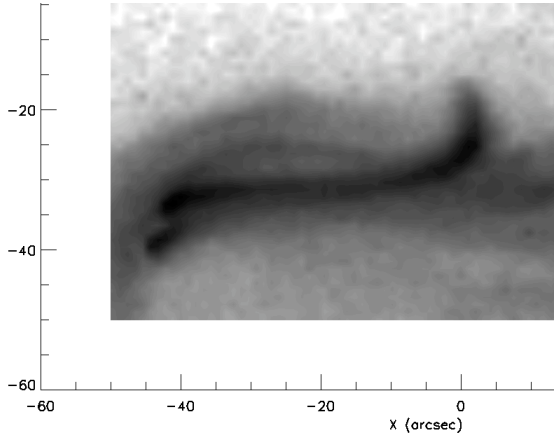


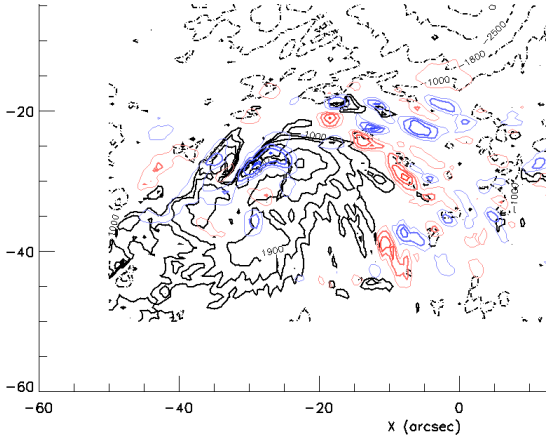
This work is reported in Magara & Tsuneta (2008).

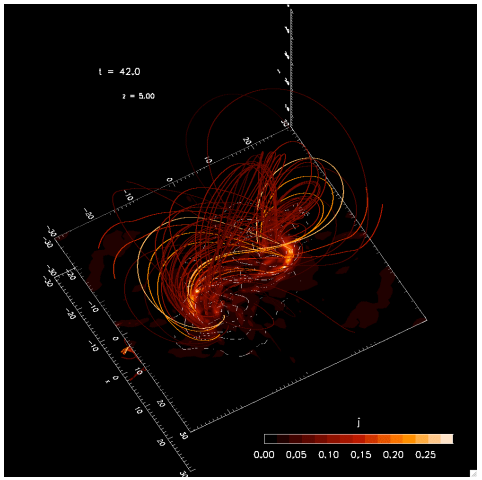
Shear effect is dominant at the late phase.

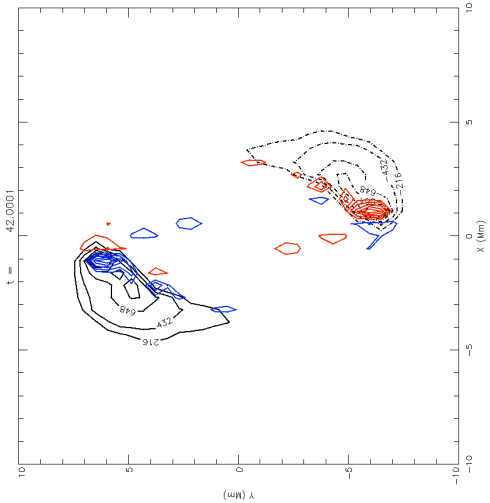


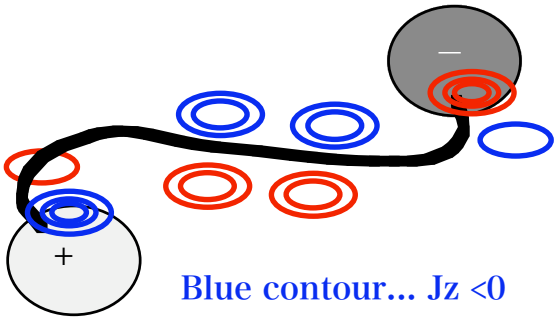
Photospheric distribution of current density in a flare-productive region (observation v.s. simulation)











Blue contour... Jz <0

Red contour... Jz > 0