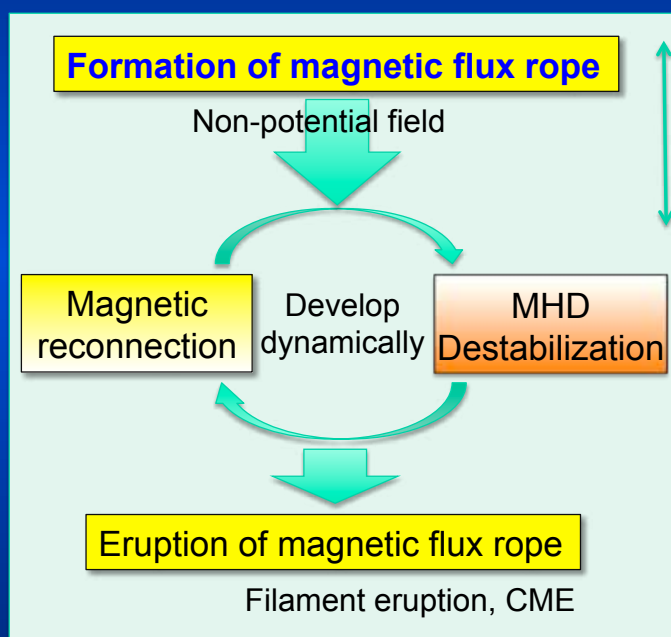


# *Magnetic twists and energy releases in solar flares*

**Toshifumi Shimizu**  
(ISAS/JAXA, Japan)

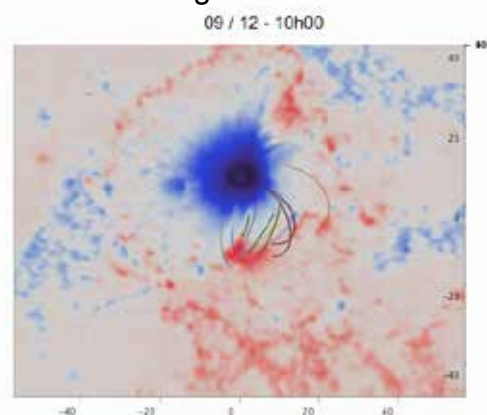
## **“Eruptive” solar flares**

### ■ General scenario



Free energy stored as a non-potential magnetic field in the corona

Active region in Dec 2006



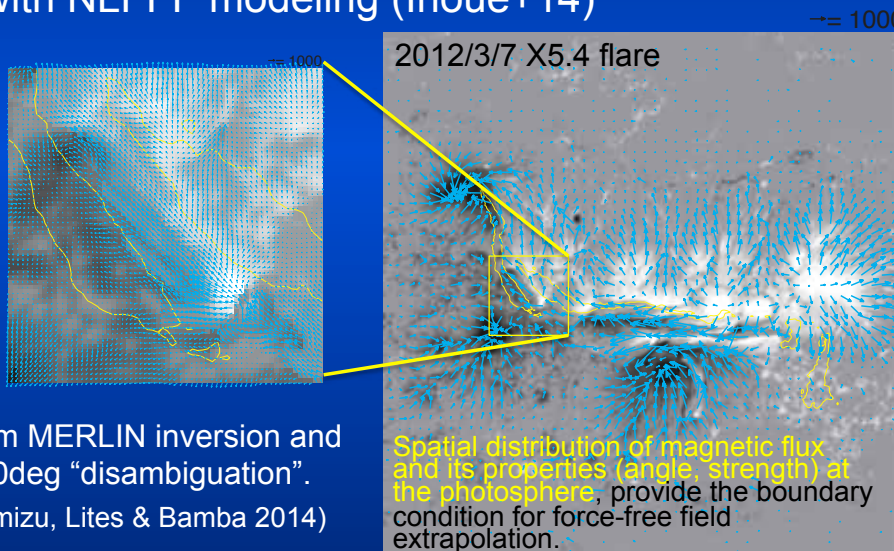
(Amari+14 Nature)

# Energy storage and triggering flares

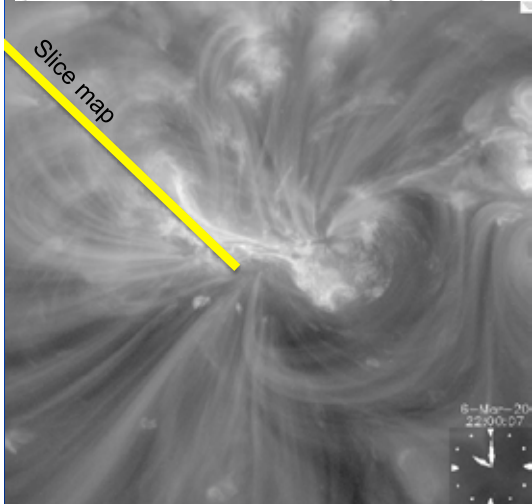
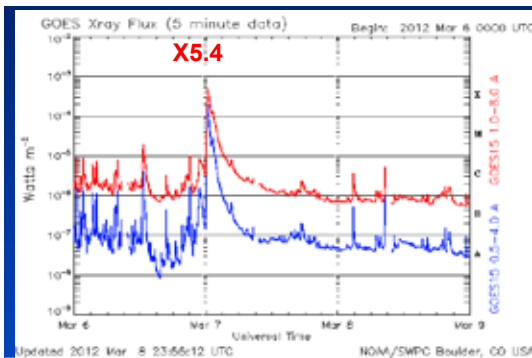
- How the magnetic twist is distributed in AR?
  - The spatial distribution of “free” energy stored in magnetic fields
- Which twists are involved in energy releases?
- The 3D magnetic configuration at the site of energy release, i.e., magnetic reconnection, in the corona.
  - Why the reconnection is triggered at this specified site?

## Data

- Hinode SOT/SP provides the most accurate measurements of magnetic flux at the photosphere.
- The boundary condition for deriving 3D coronal magnetic fields with NLFFF modeling (Inoue+14)



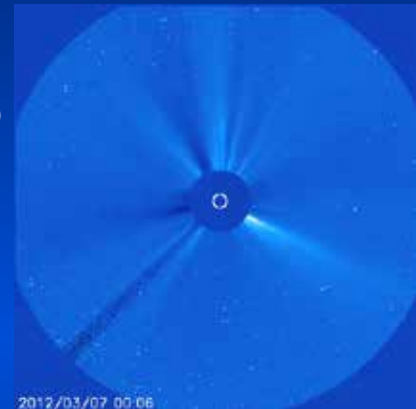
SP level2 from MERLIN inversion and AZAM for 180deg “disambiguation”.  
(Shimizu, Lites & Bamba 2014)



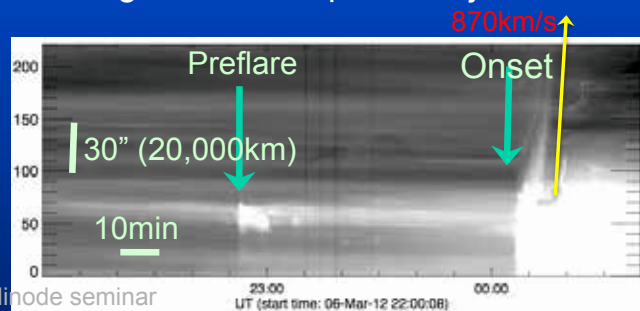
## 2012/3/7 X5.4 Flare

### A geoeffective solar flare

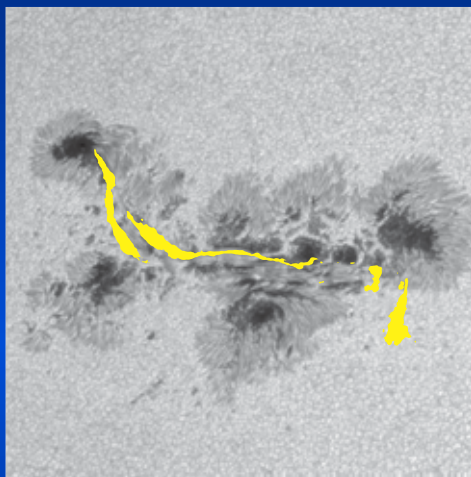
coronagraph  
LASCO



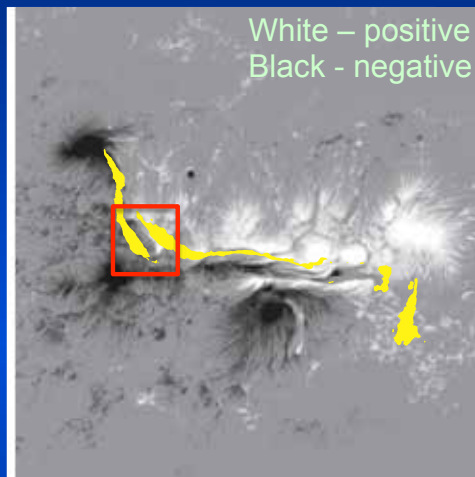
Magnetic field surrounding the flare core,  
producing launch of a plasma ejection



## A strong shear in the entire magnetic system



Solar surface: Continuum



Magnetic flux Bz

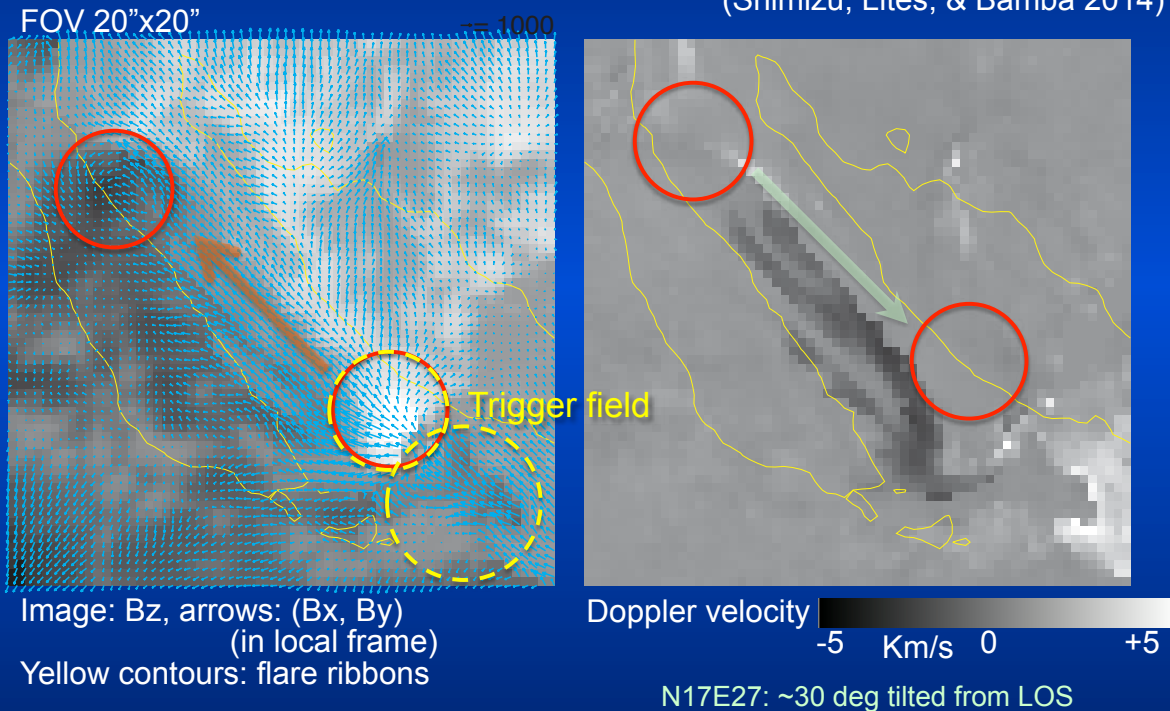
Yellowed areas – flare ribbons at the beginning of the X5.4

- A small-scale trigger field identified near the polarity inversion line.
- Spatial distribution of twisted field. Which twisted fields involved in the flare?

## Surface gas dynamics

### ■ Conditioning the magnetic structure for flare trigger

(Shimizu, Lites, & Bamba 2014)

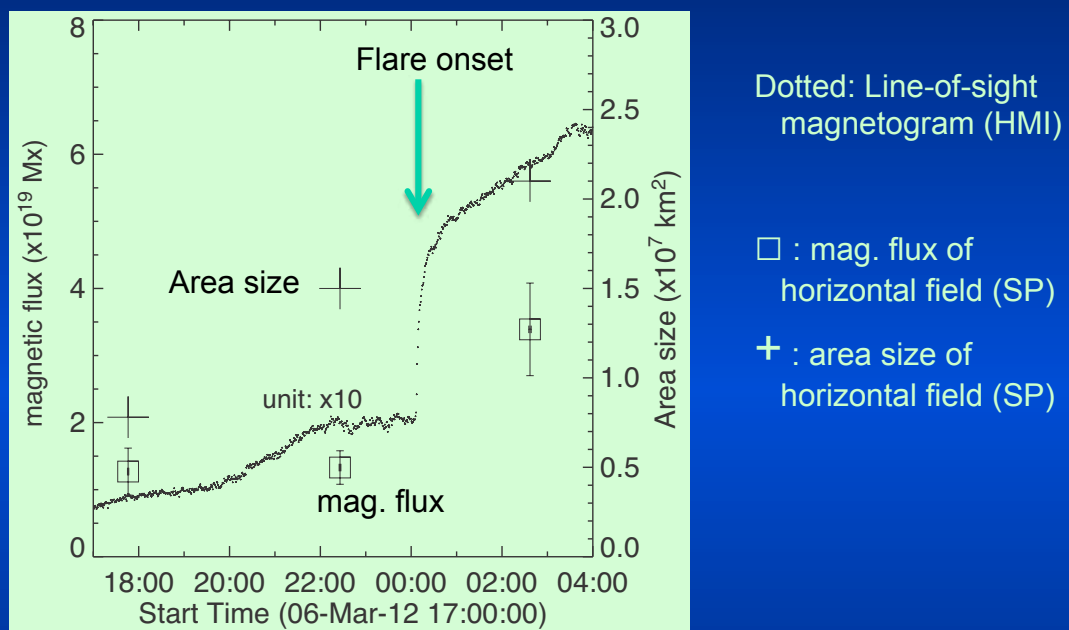


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## Evolution of horizontal magnetic flux



- The photospheric magnetic field near PIL becomes more horizontal after eruptions, related to the newly formed low-lying fields during flares
- No flux increase before the flare indicates no emergence of magnetic flux.

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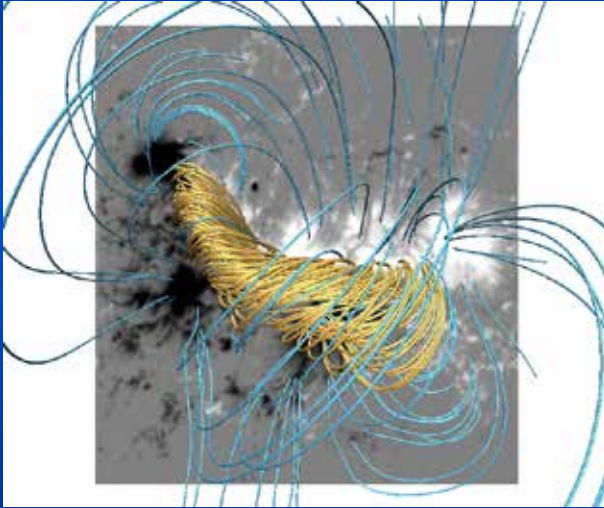


# NLFFF & Twist Map(-1<Tn<0)

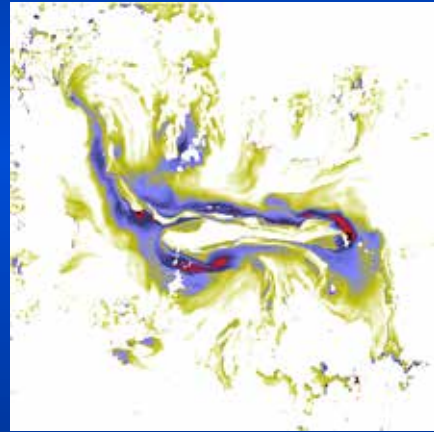
3D coronal field from NLFFF modeling

Pitch (twist number) of each field line

22:00 UT on 2012 March 6



$$T_n = \frac{1}{4\pi} \int \alpha dl$$



Force-free condition

$$\nabla \times B = \alpha B$$

-1  $T_n$  0

$T_n$  definition from Inoue+12

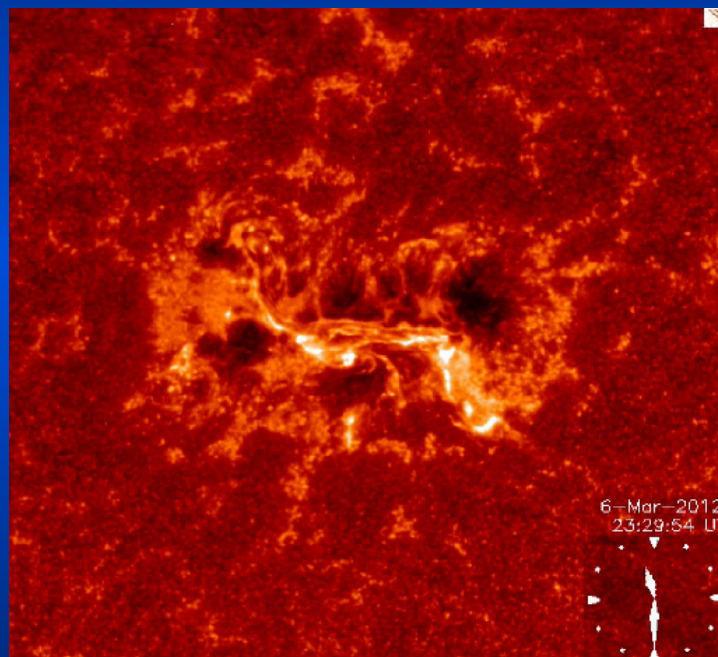
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## Bright kernels in flare ribbons

- Trace the footpoint locations of the magnetic field lines involved in the energy release.

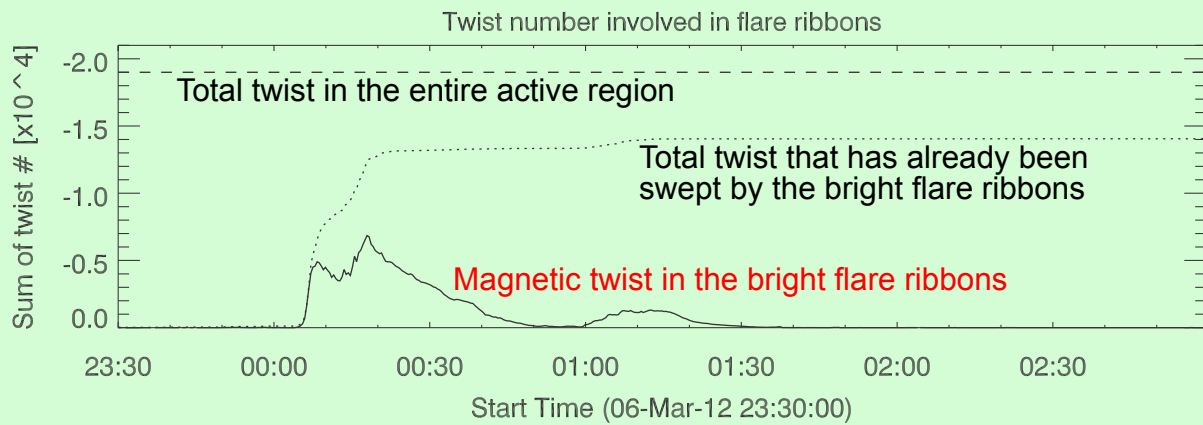


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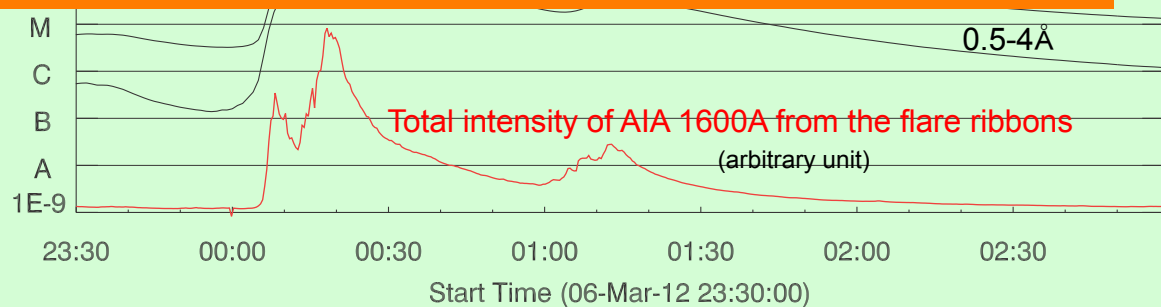
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- More free energy is released when more twisted fields are involved in the event.

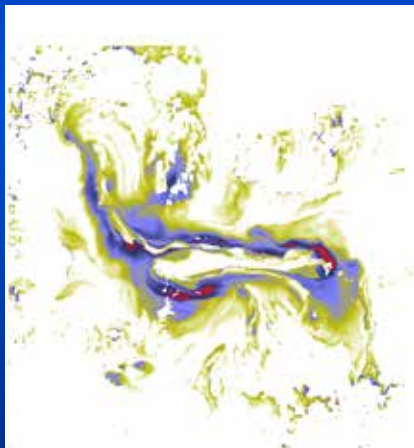


## Field twist after the X5.4 flare

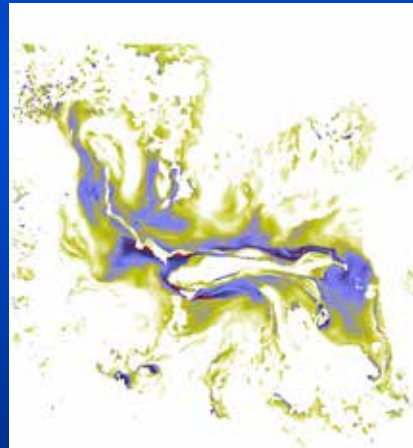
$$T_n = \frac{1}{4\pi} \int \alpha dl$$

- The magnetic twist was changed (reduced and redistributed), particularly around the core region of the X5.4 flare.

Two hours **before** the flare onset



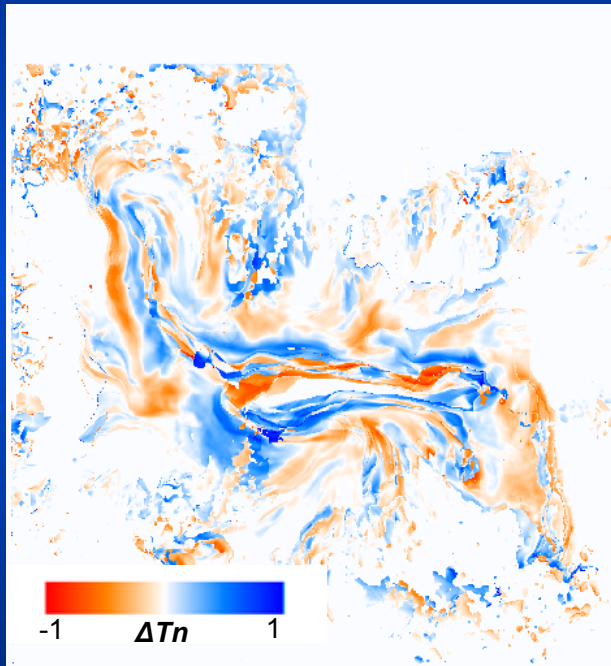
Two hours **after** the flare onset



## Field twist after the X5.4 flare

$$T_n = \frac{1}{4\pi} \int \alpha dl$$

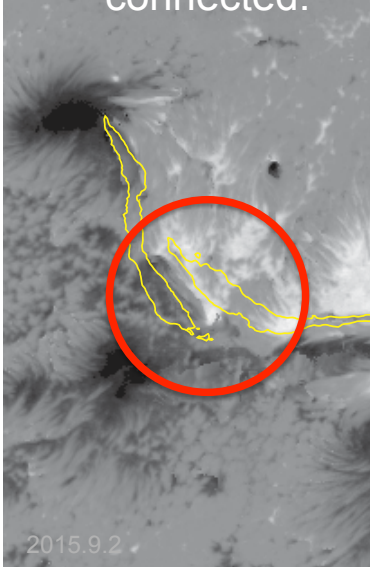
Changes of magnetic twist



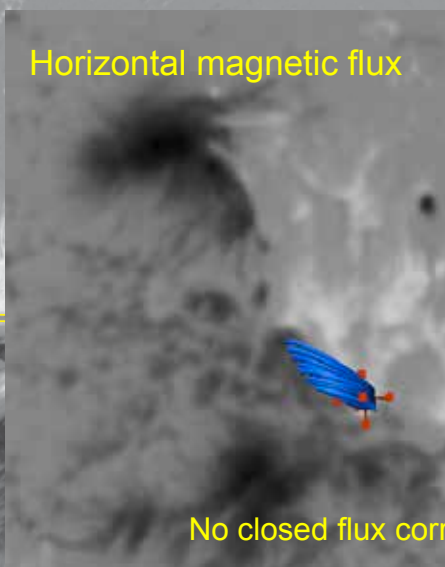
- $\Delta T_n = 1$  means that magnetic twist is reduced from -1 to zero.
- $\Delta T_n = -1$  means that magnetic twist is increased from zero to -1.

## Magnetic connectivity at flare core

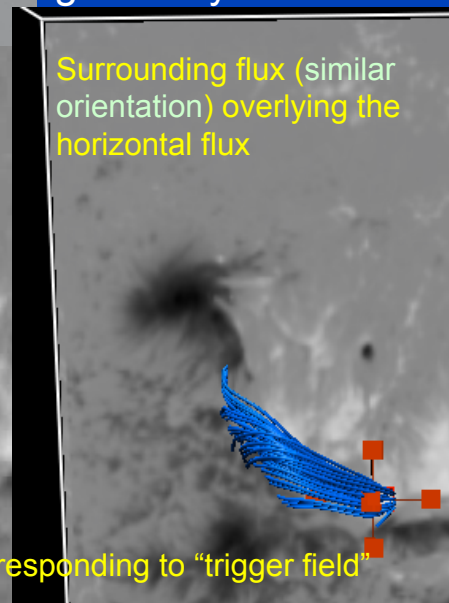
- Magnetic fields must be connected from a bright kernel to another kernel in flare ribbons.
- We confirm with the 3D coronal fields from NLFFF modeling that bright kernels in flare ribbons are magnetically connected.



Horizontal magnetic flux



Surrounding flux (similar orientation) overlying the horizontal flux

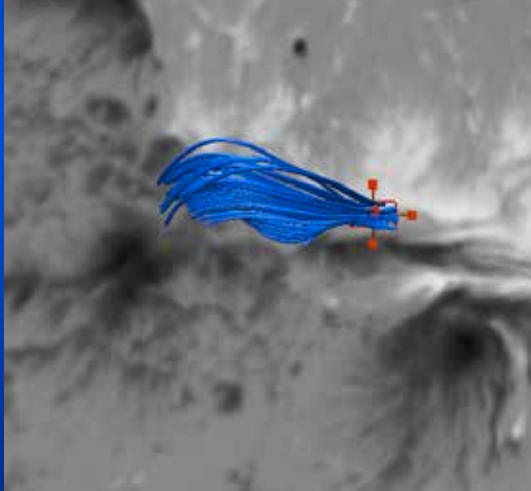


No closed flux corresponding to "trigger field"

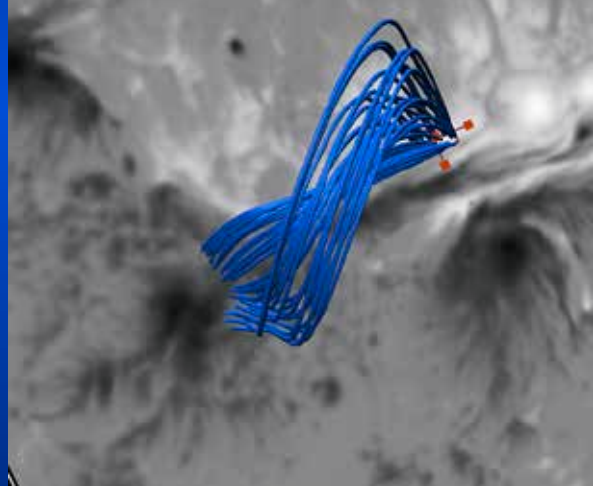
## Magnetic connectivity at flare core

- 3D coronal magnetic fields from the brightest kernels, which are closely associated with the X5.4 energy release.

Magnetic flux originated in the brightest kernel at 1<sup>st</sup> peak



Magnetic flux originated in the brightest kernel at main (2<sup>st</sup>) peak



Magnetic configuration preferable to partial reconnection

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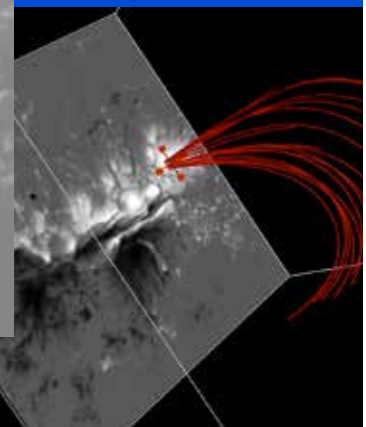
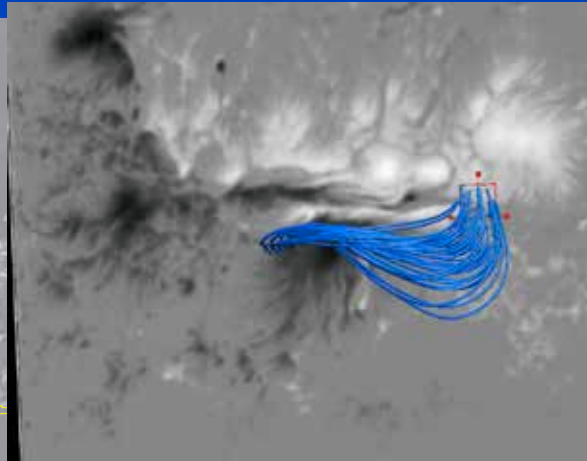
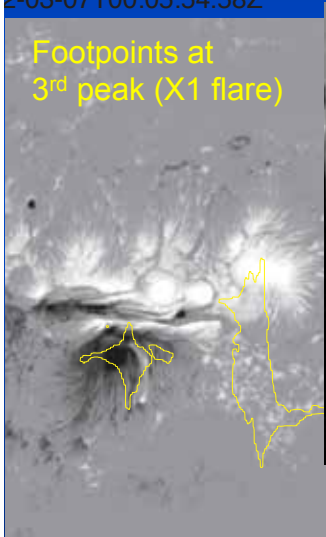
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## Note: NLFFF: outer magnetic fields

- Large-scale fields from sunspots near the FOV edge may not represent reliable connectivity, affected by boundary condition (potential field at the walls).
- Improvements are needed for investigating global field configuration.

2-03-07T00:05:54.58Z

Footpoints at 3<sup>rd</sup> peak (X1 flare)



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# Summary

- Some key observational elements for producing flares, from photospheric magnetic-field measurements by SOT
  - A high-speed gas dynamics at the solar surface for leading to the onset of flares (Shimizu, Lites & Bamba 2014).
  - The magnetic twist formed in the corona
- A good correlation in temporal evolution shows that the magnetic “free” energy is more released when magnetic fields with larger twist are involved in energy release.
- Magnetic twist is redistributed in coronal fields with X5.4 flare.
- Low-lying fields around PIL are well described with NLFFF modeling, although caution is needed in global field configuration derived with NLFFF modeling.