Hinode-7, Takayama, Japan
12-15 November 2013

High speed photospheric flows observed around polarity inversion lines of a delta-type sunspot

X5.4 (& X1.3) flare on 7 March 2012

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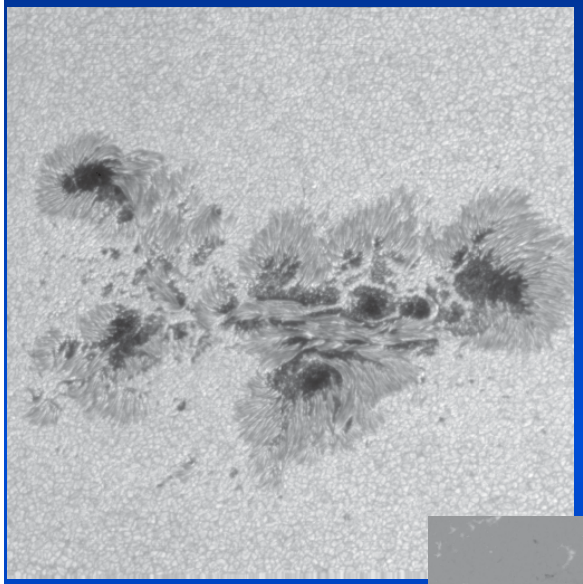
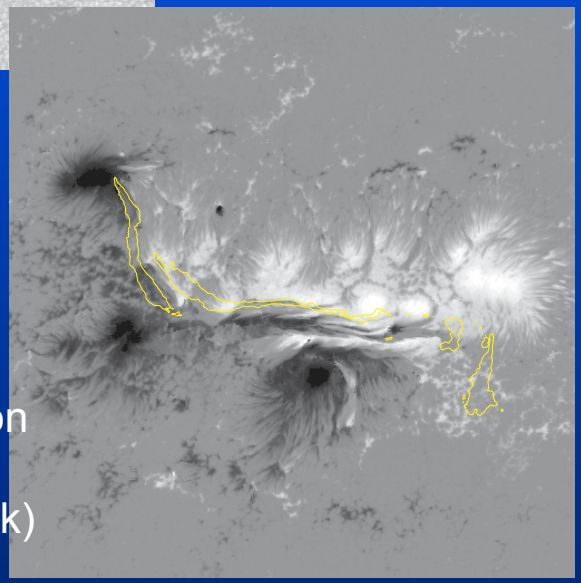
Photo: Hinode's best shot of Transit of Venus

Major flares produced in δ-type sunspots

- **δ-type sunspots:** a penumbra enclosing umbrae of both positive and negative polarity. [Mt. Wilson (Hale)'s magnetic classification]

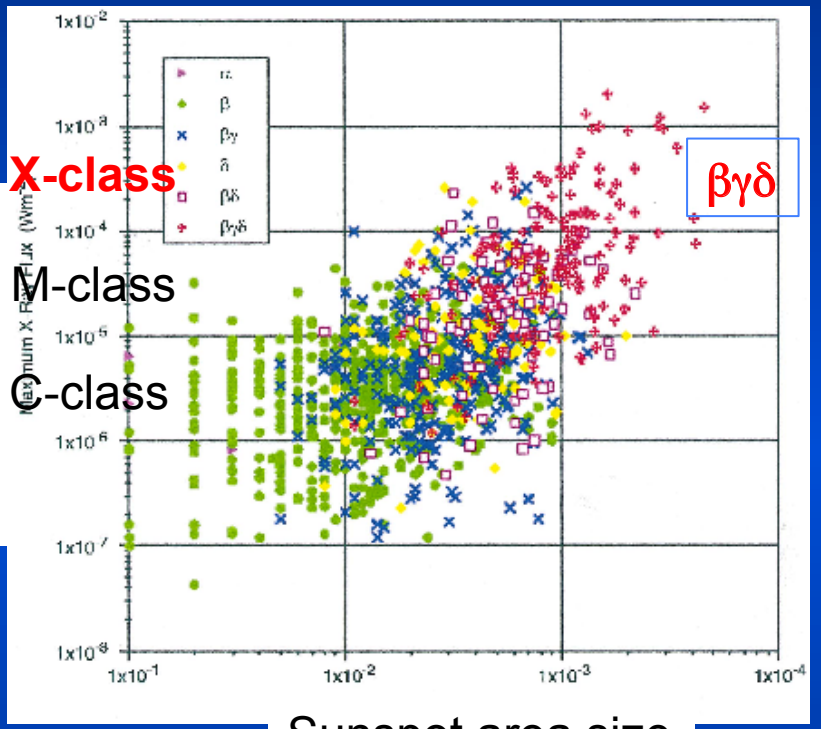


Continuum



Magnetic flux Bz

δ-type Sunspot in complex active region NOAA 11429 (discussed in this talk)



(Sammis, Tang, Zirin 2000)

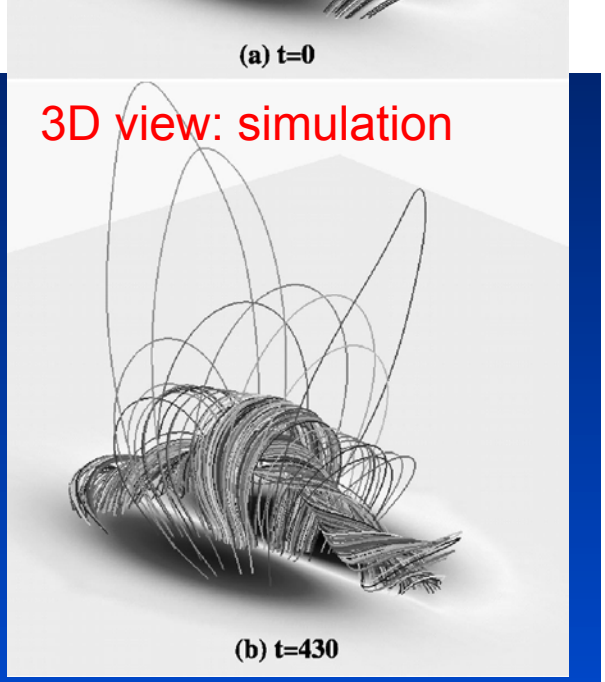
- **Non-potential magnetic field**

  Sigmoidal structure in corona, free energy stored as a non-potential

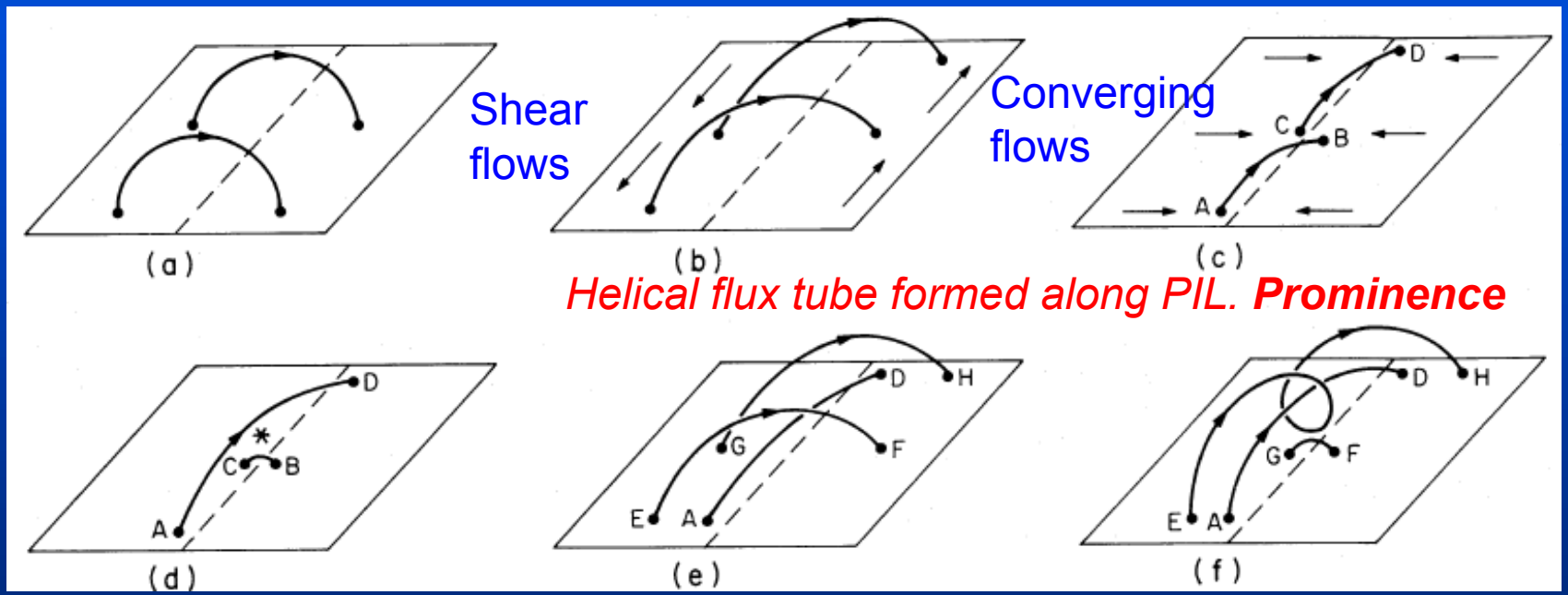
Formation and destabilization of sigmoidal coronal structures

Footpoint motions at the photosphere

- Shear flows along polarity inversion line (PIL)
- Converging flows toward the PIL
- Emergence of twisted flux (e.g., Archontis & Hood 2012)



(Amari et al. 2000)

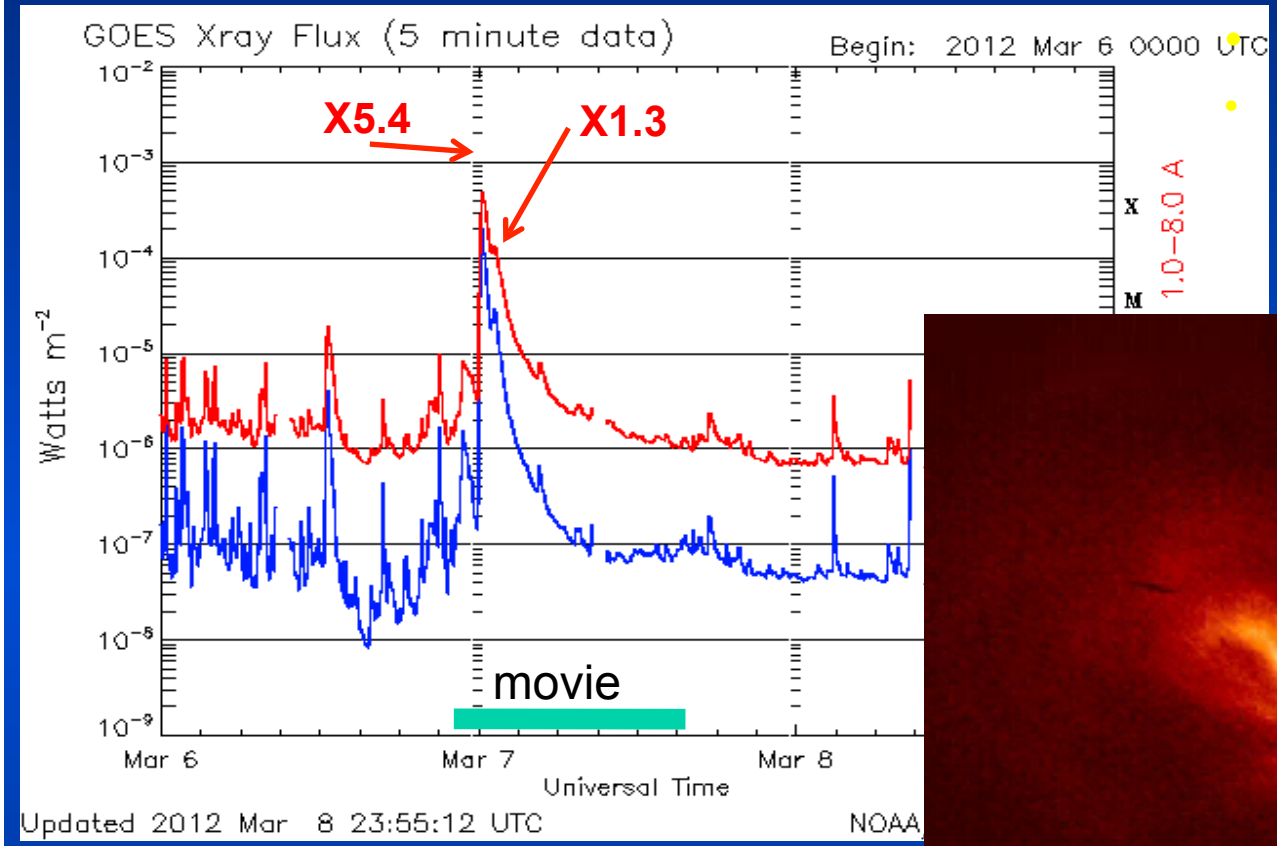


(van Ballegooijen & Martens 1989)

Motivations and purpose

- The polarity inversion lines (PIL) of δ-type sunspots include magnetic configuration and conditions leading to energetic flares
- Photospheric flows around the PIL are one of key information for understanding energetic flares and associated plasma eruptions.
- What kinds of photospheric flows are commonly observed at PIL of δ-type sunspots?
- Hinode SOT's Stokes Polarimeter (SP): Doppler shift of photospheric spectral lines

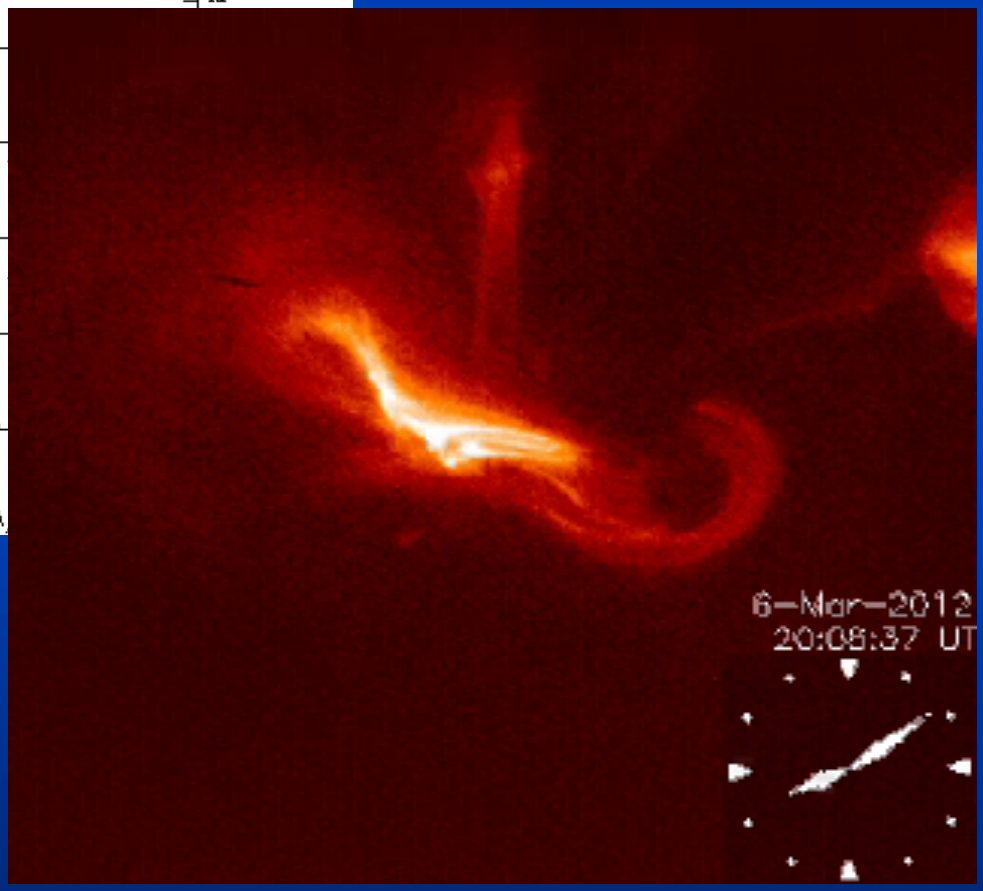
2012/3/7 X5.4 & X1.3 Flares



Sigmoidal structure

→ A bright "**confined**" loop structure（X5.4）

→ Evolved to the formation of a larger arcade (X1.3)



Hot flare structures

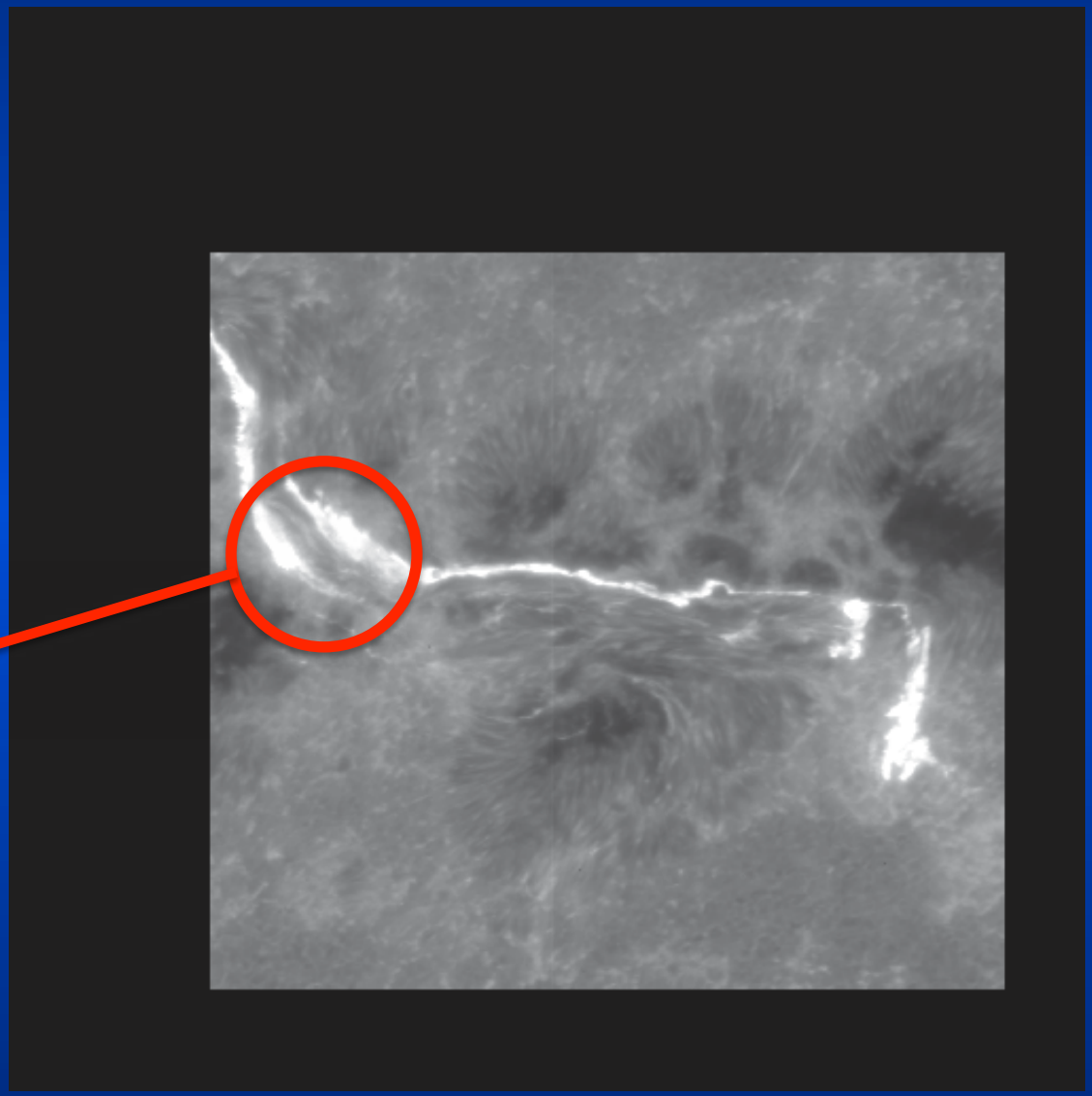
Soft X-ray movie

Hinode XRT

Be Thin + others

Position of flare ribbons (Ca II H)

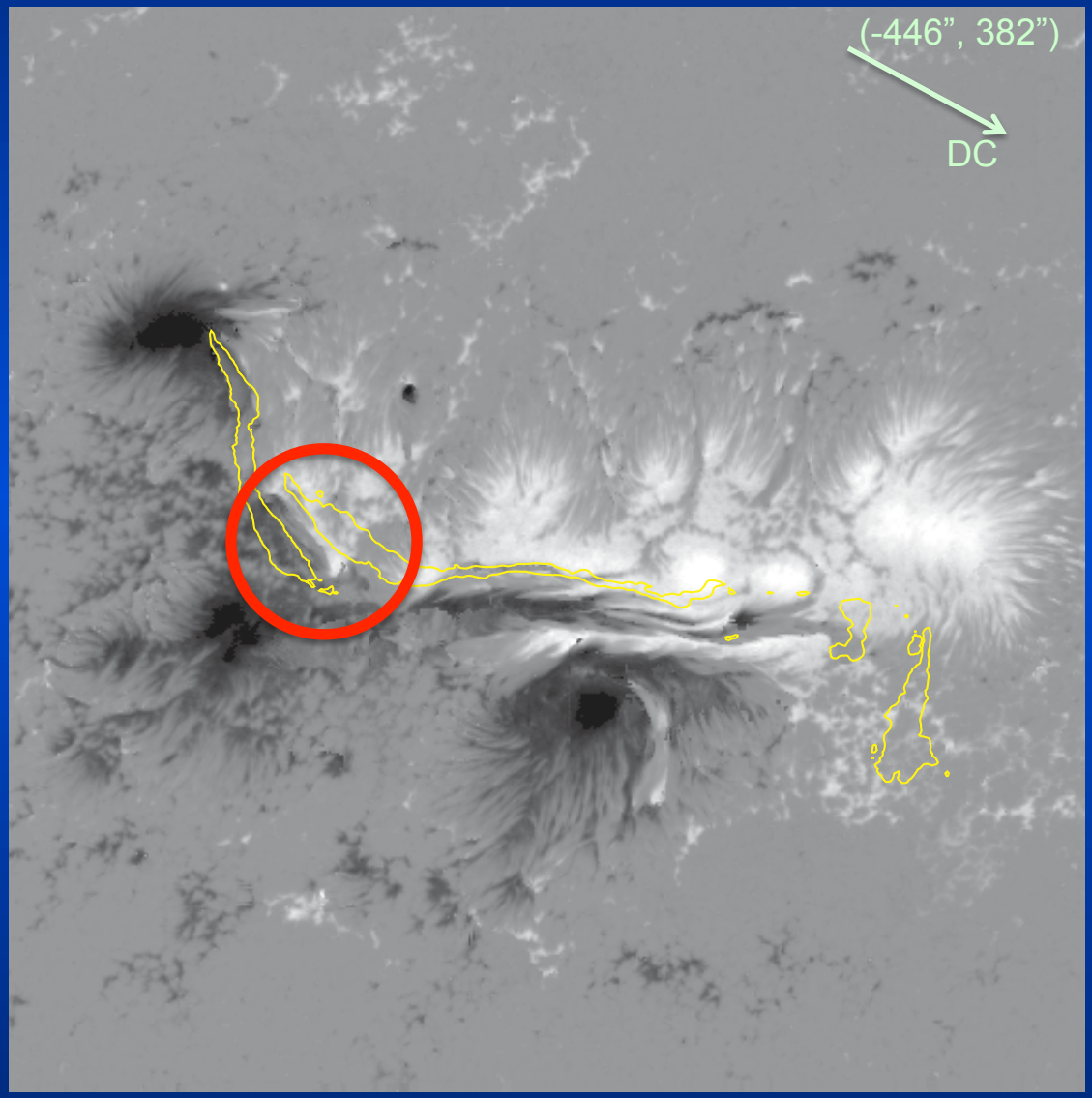
- Chromospheric Ca II H image acquired just at the onset of the flare (00:07:25 UT on 7 March 2012)



Magnetic flux distribution at photosphere

Hinode SOT's Spectro-Polarimeter (SP)

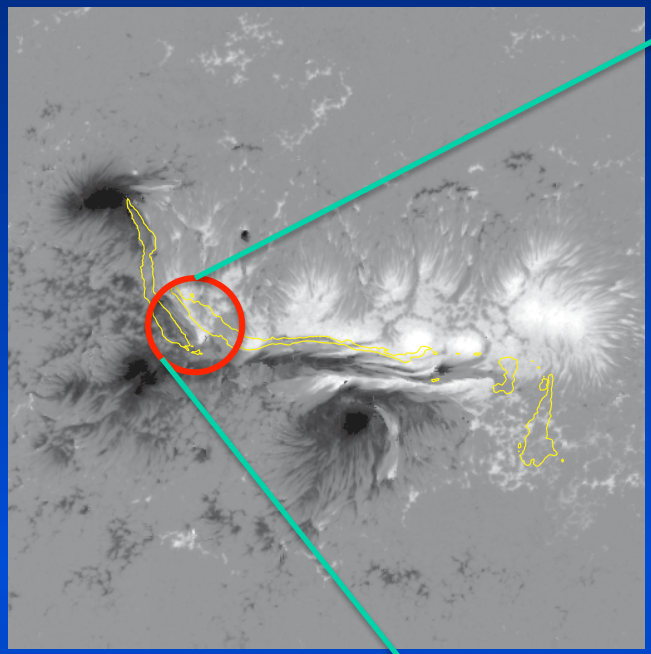
Bz in local frame

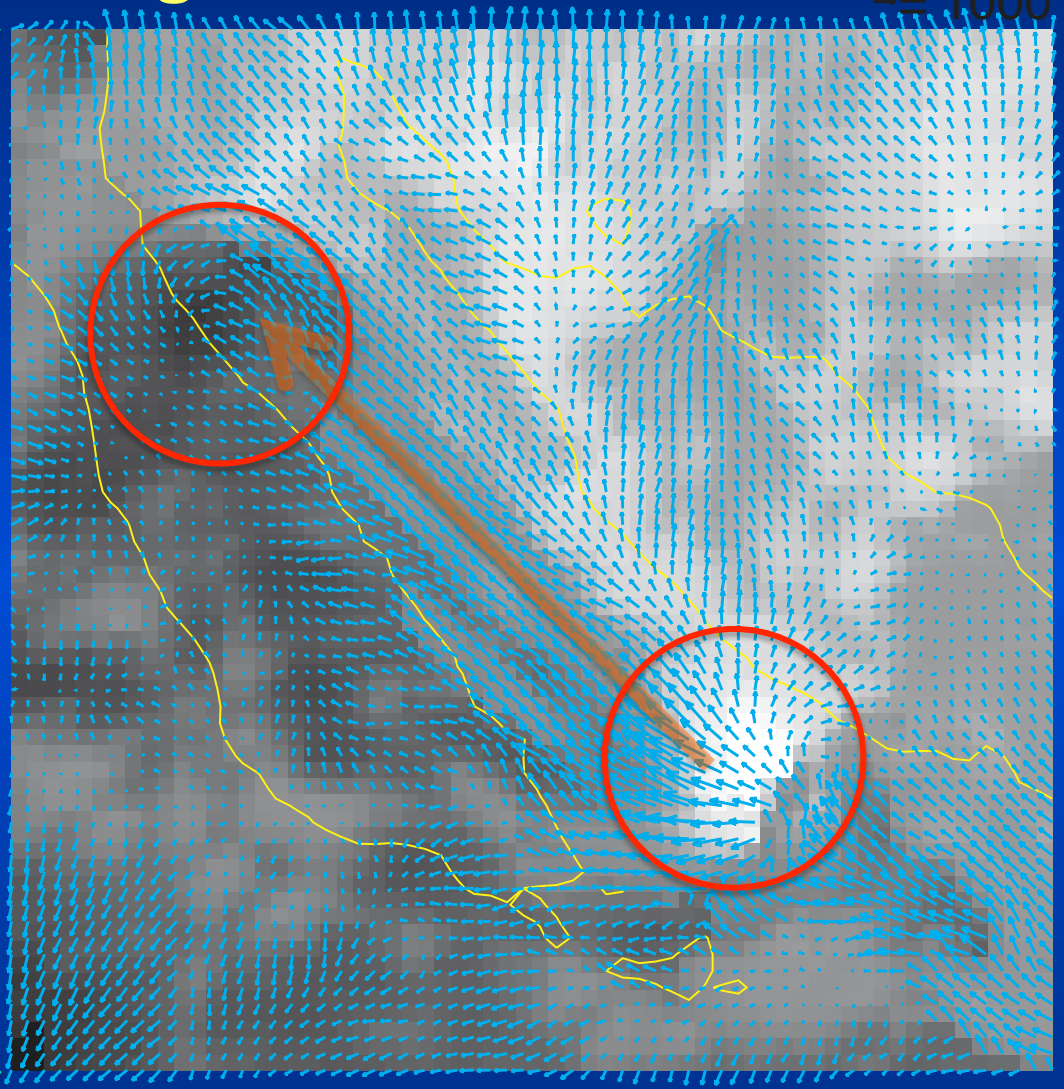


Yellow contours:
Position of flare ribbons (Ca II H) at initial phase (2012 Mar 7 00:07:25UT)

Vector magnetic field

FOV 20”x20”





Field is almost parallel to PIL.
Highest magnitude of shear

According to Bamba et al. poster, (S4-P-12)
RS (reversed-shear)-type config.
(Kusano et al.2012)

Image: Bz, arrows: (Bx, By) (in local frame)
Yellow contours: flare ribbons

(Azimuth ambiguity resolution was double-checked by B. Lites)

Strong Doppler shift signals in horizontal fields along PIL

SP/Doppler shift

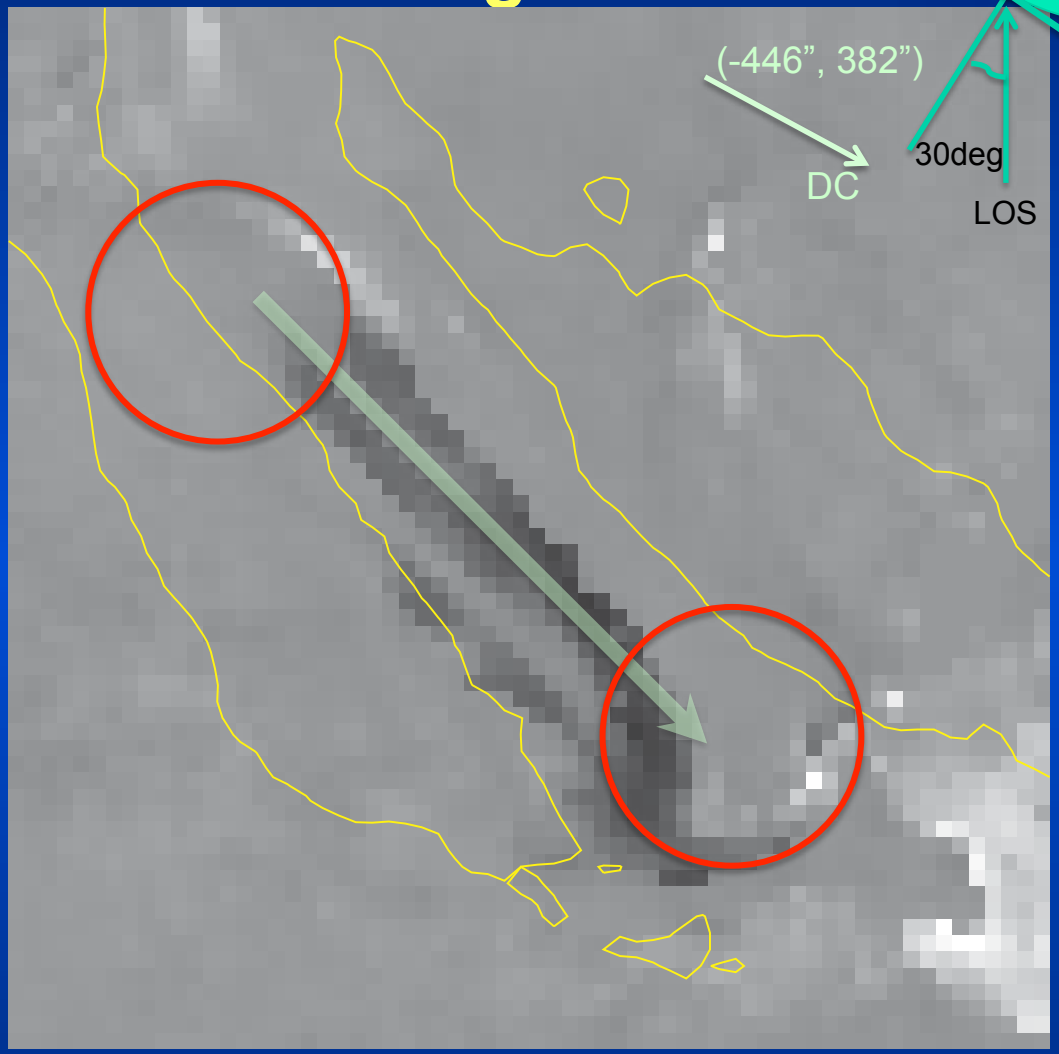
Blue-shifted Red-shifted

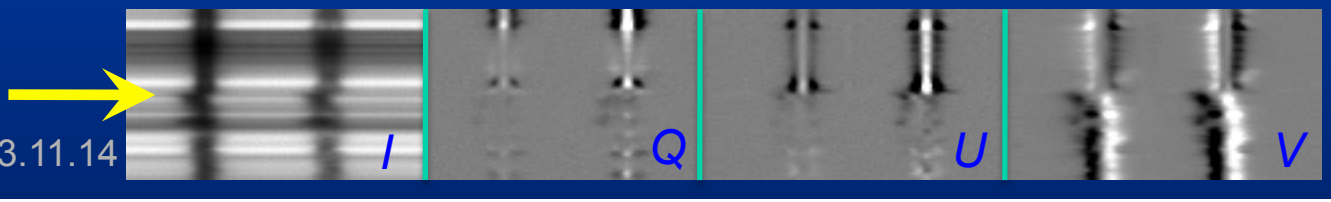
-5 0 +5

Km/s

Dark is toward the observer and bright is away from the observer.

- A gas flow excited in the horizontally-oriented fields connecting the negative to positive islands.





2-5km/s

Persistent gas flow and penumbral development

- The observed gas flow has already appeared 6hrs earlier than the flare onset. It continues to develop even after the flare onset.

SP Doppler shift

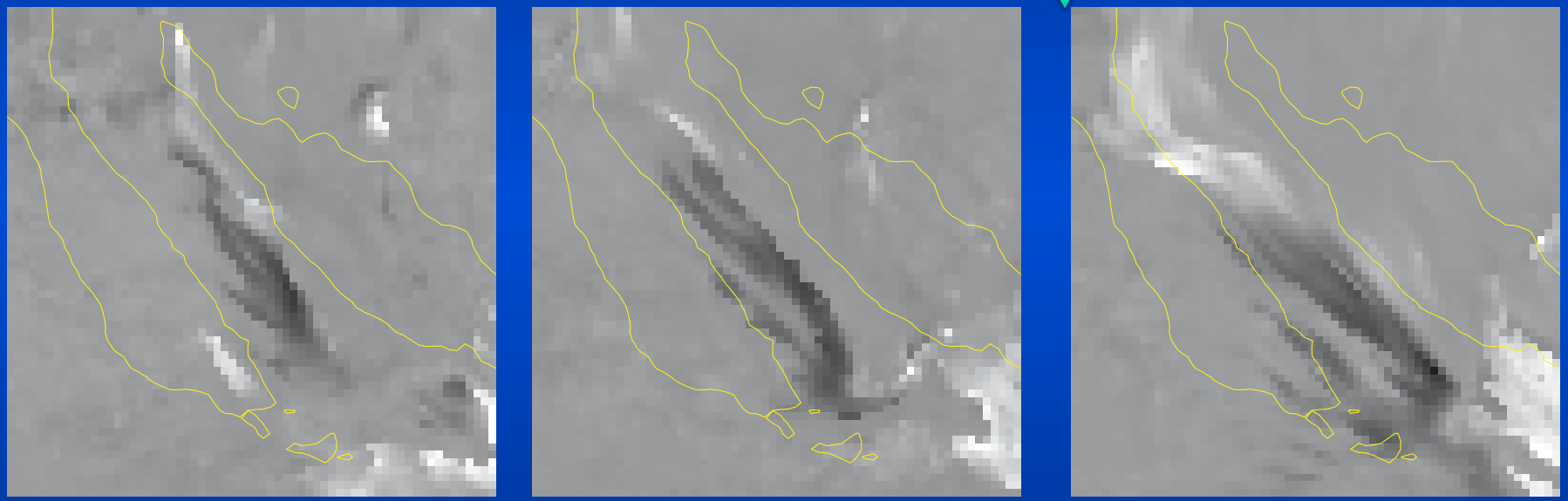
17:46UT

22:26UT

Flare onset

0:07UT

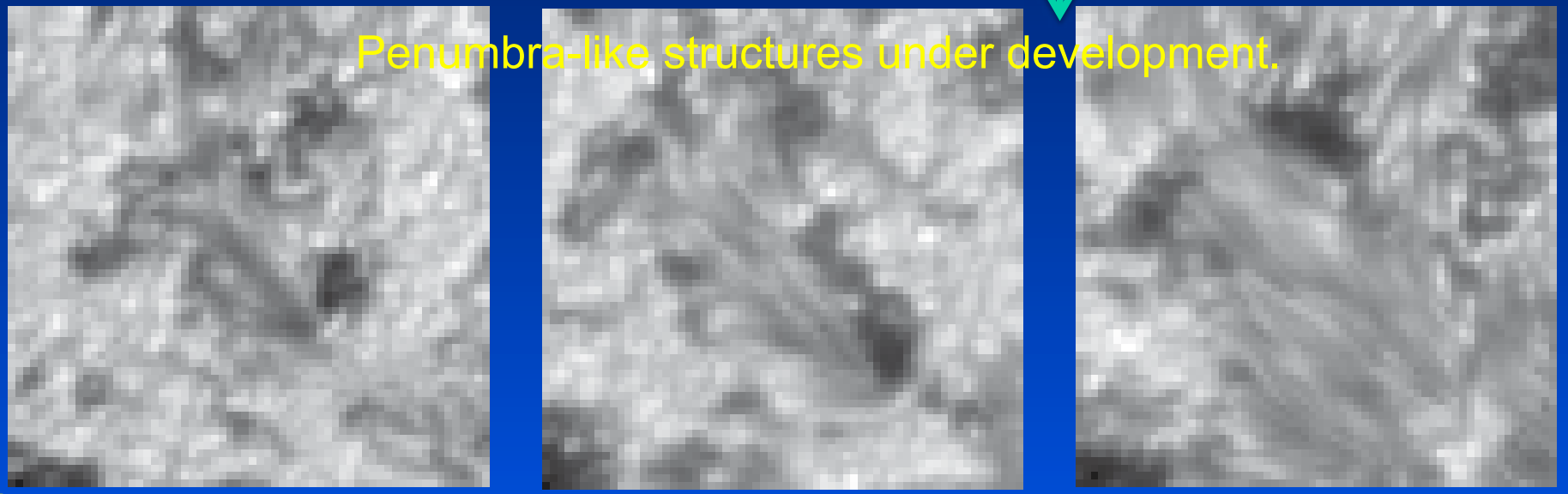
2:37UT



- The kinetic energy of the gas flow is in order of 10^{29} ergs.
- The flow may stretch and apply the shear force to the magnetic field.

Flare onset

17:46UT 22:26UT 0:07UT 2:37UT



Penumbra-like structures under development.

Continuum

The horizontally-oriented field is increased.

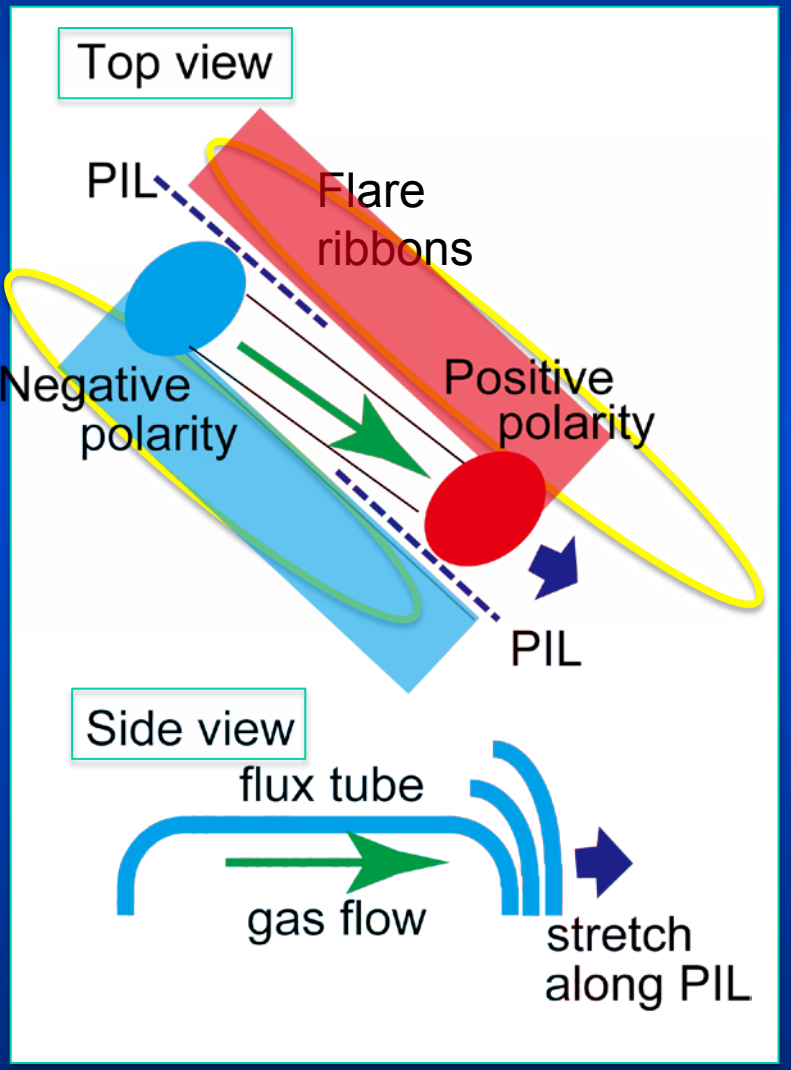
The island separation: 7,000 → 10,000 km (0.13->0.04km/s)

The positive island' flux : 9×10^{19} → 2×10^{19} Mx

Vector magnetic field (Bx, By, Bz)

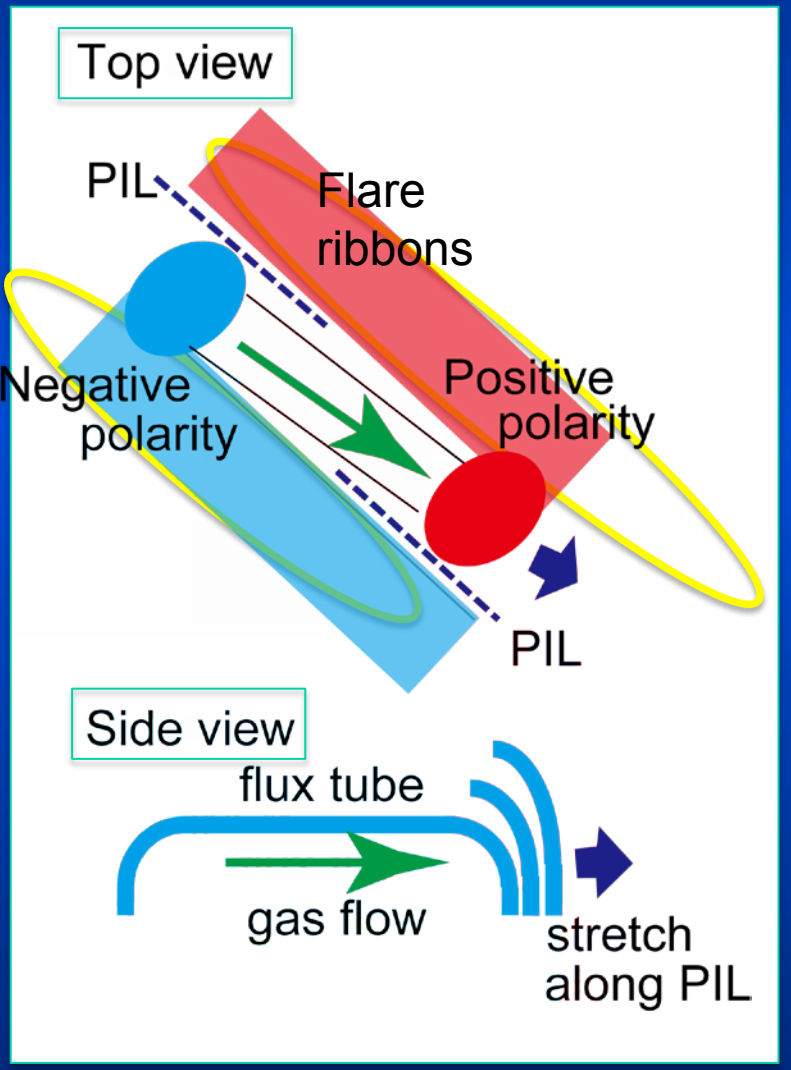
Discussions

- **Strong Doppler shift signals along PIL between flare ribbons.**
  - What did we observe?
    - A pair of magnetic islands exists at the PIL.
    - High-speed one-directional gas flow is persistently excited in horizontally-oriented field formed between the islands.
    - The horizontally-oriented field is also recognized as the development of “penumbra”-like features in continuum.



Discussions

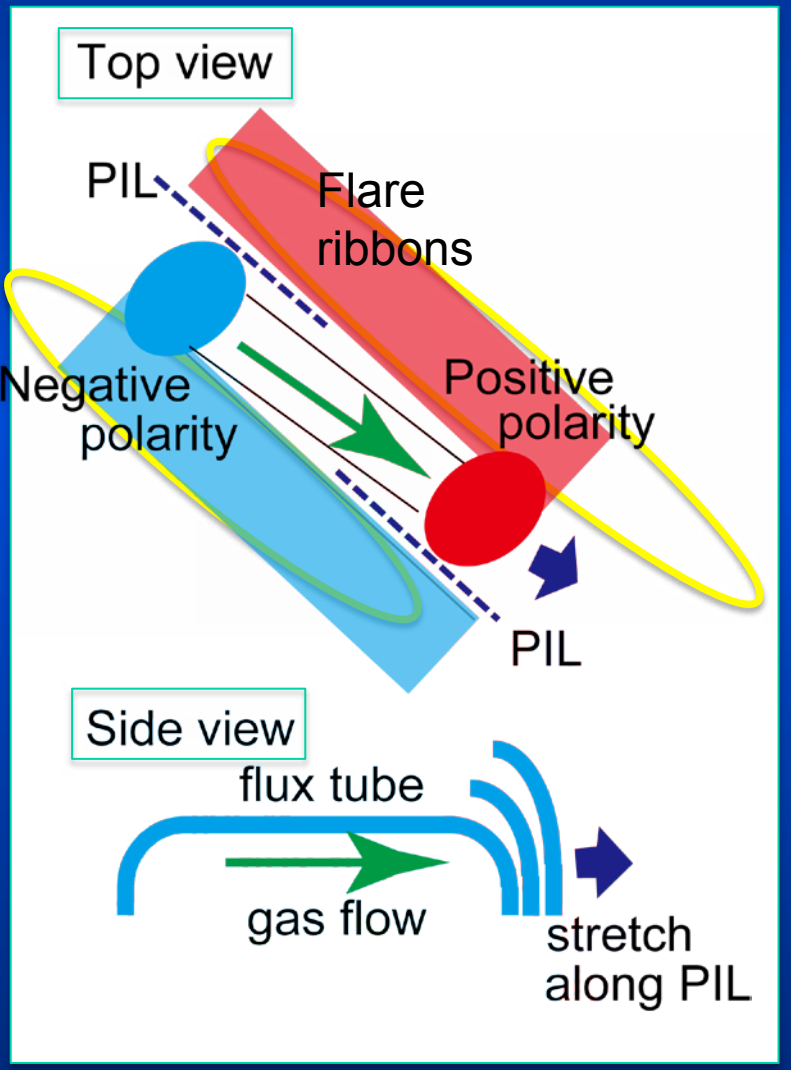
- **Strong Doppler shift signals along PIL between flare ribbons.**
  - What did we observe?
    - The separation between the islands is slowly increased /w time.
    - The magnetic flux of the islands is decreased /w time.
    - Thus, the islands and horizontally-lying field do not represent “emergence” of new flux.
    - The driver of one-directional gas flow is NOT flux emergence.



Discussions

- **Strong Doppler shift signals along PIL between flare ribbons.**
  - What is possible roles of such plasma flows for flares/ energetic eruptions?
    - The flow is not "converging" flows at PIL.
    - One-directional flow may stretch the field and push the positive-polarity island outward along the PIL.

      → Work as "shear" flows at PIL.
    - High β plasma at photosphere.



Summary

- Hinode SOT/SP observations of a large (X5.4) flare on 7 March 2012
- **High-speed one-directional gas flow** is persistently excited **in horizontally-oriented field formed between the magnetic islands located along the polarity inversion line** between flare ribbons at the photosphere.
- **This gas flow may work as shear flows**, which are important for developing flares/energetic eruptions.