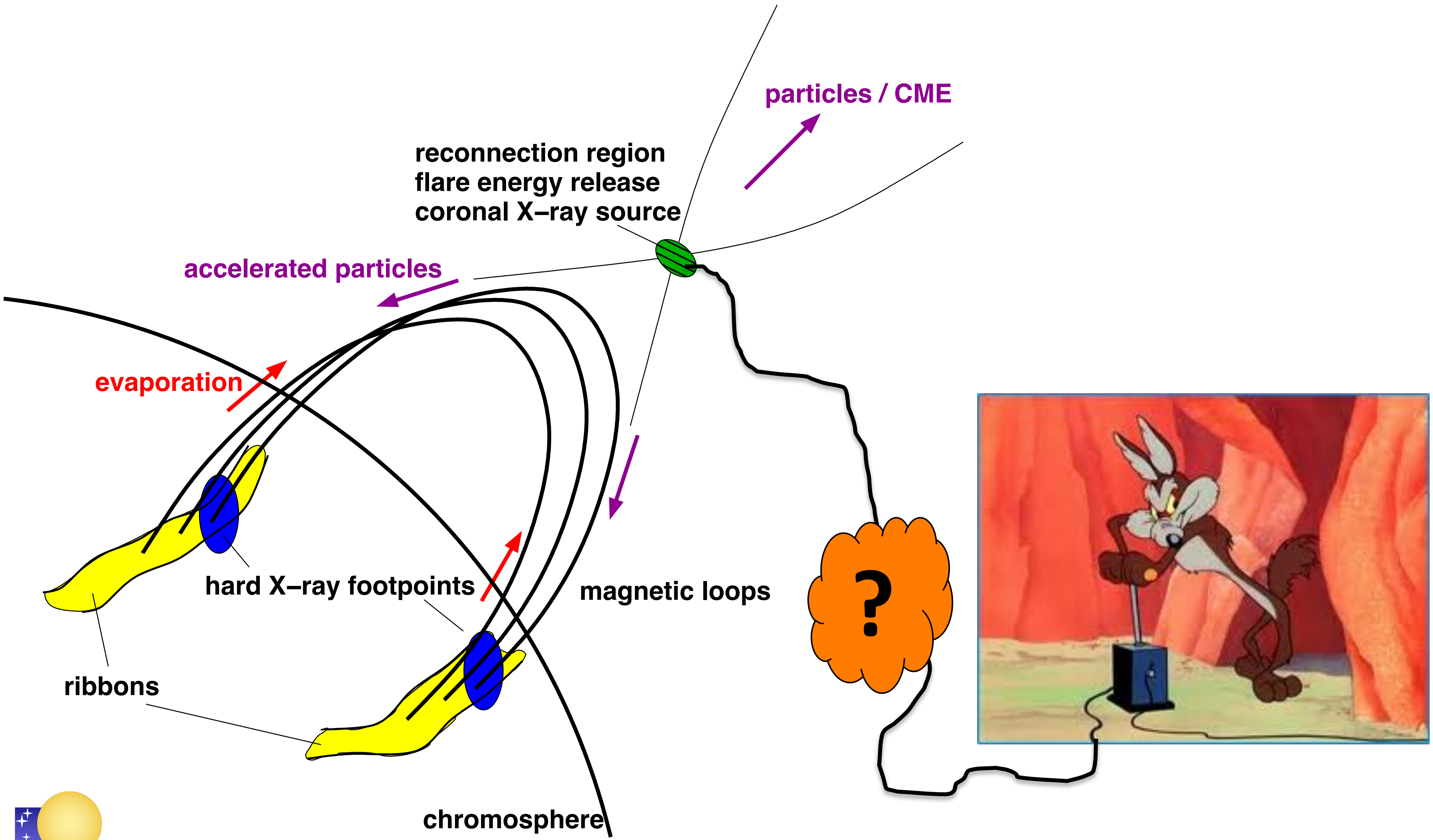
Photospheric and chromospheric magnetic field changes during solar flares

Lucia Kleint

Leibniz-Institute for Solar Physics (KIS), Germany

A Simple Picture of Flares



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Lucia Kleint, October 2019

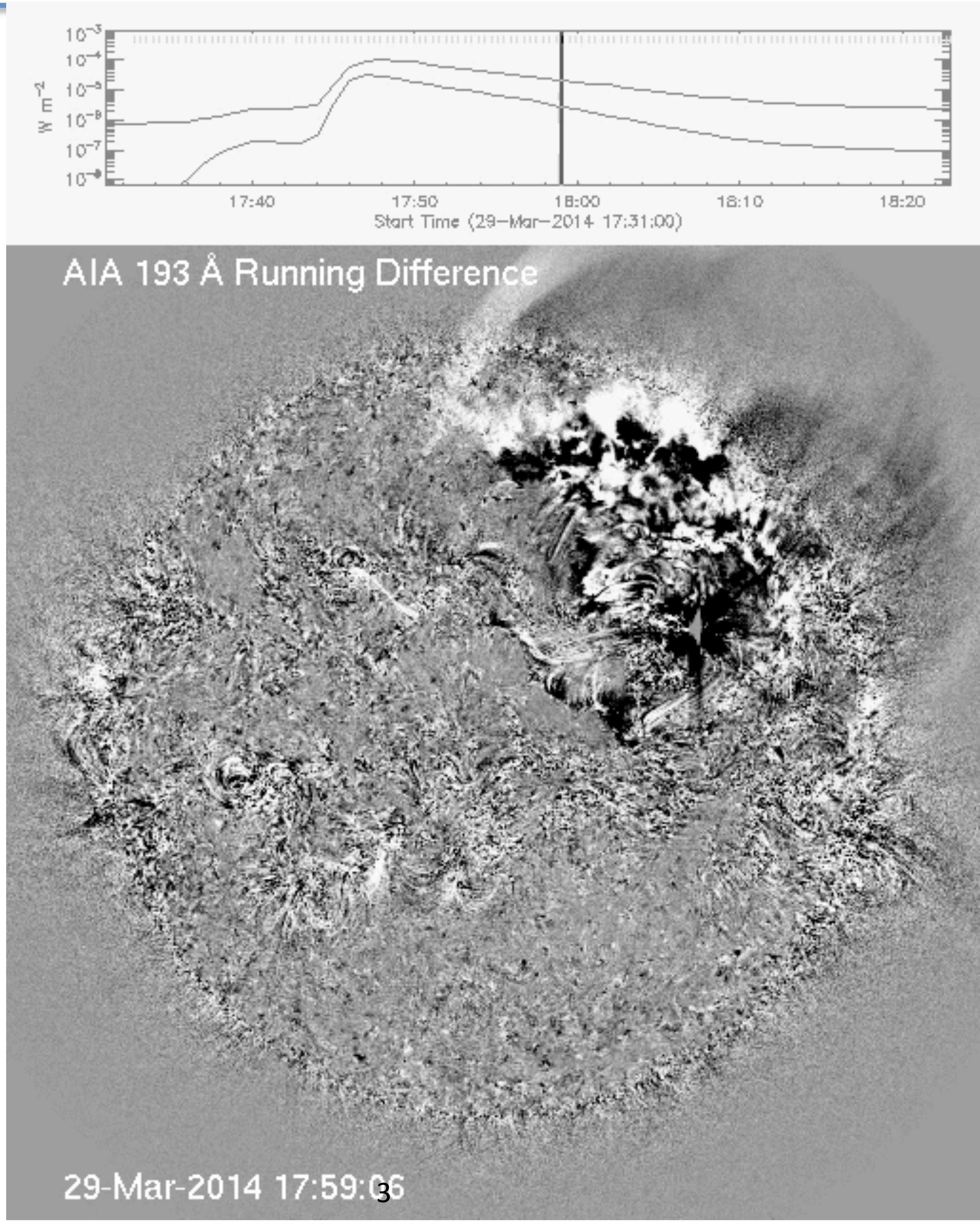
An Open Question in Flare Physics

How does the magnetic field structure change during flares?

-> one of the flare energy dissipation mechanisms.

Goal: study changes in the photosphere and in the chromosphere.
Compare to NLFFF models => free energy.

Running difference movie of a flare

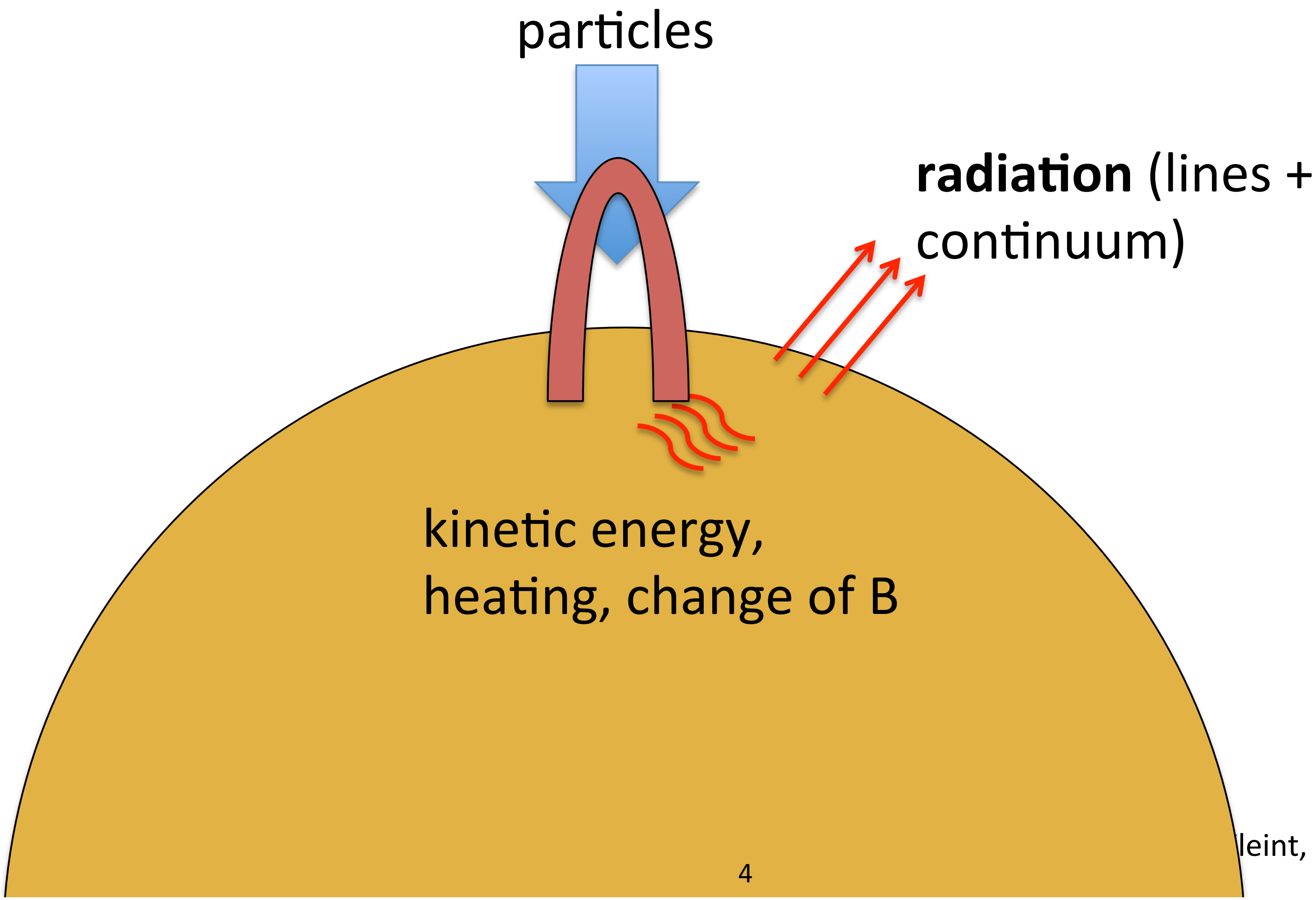


Global influence of flares.

movie by LMSAL

Standard Flare Model and Energy Dissipation

Total energy of a large flare: 10^{32} erg
(comparison: Hiroshima $8*10^{20}$ erg)

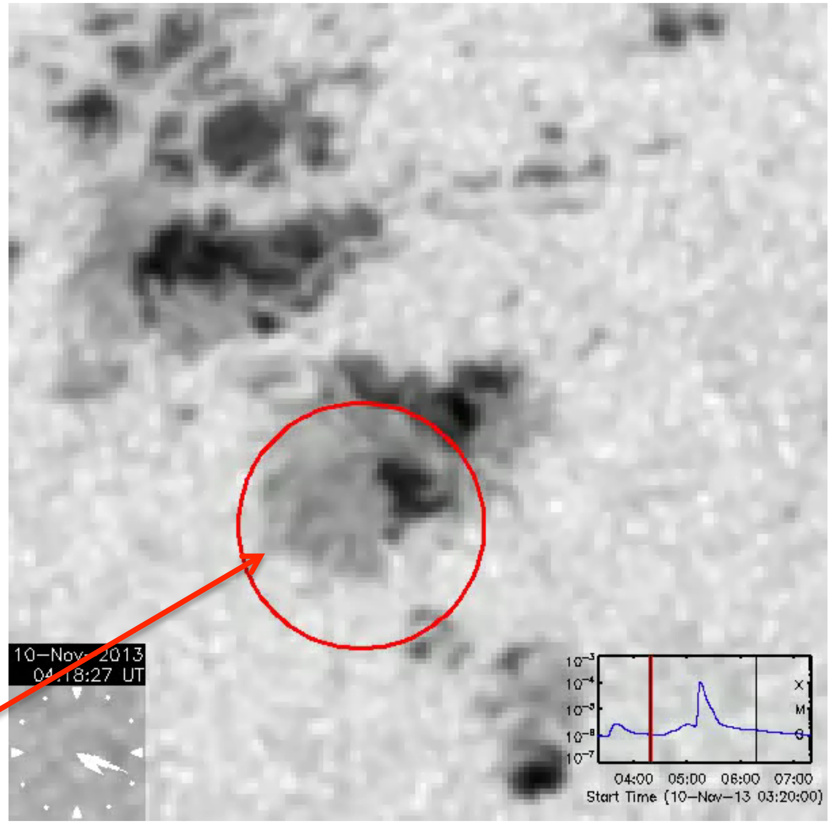


Magnetic Field Changes

Photospheric B has been found to change during strong flares and penumbra has been seen to disappear.

- e.g. Kosovichev & Zharkova 1999, Wang et al 1994, Sudol & Harvey 2005 : 15 X-flares, median 90 G change.

For chromospheric B changes, there is only 1 flare measurement: X1 flare on 2014-03-29

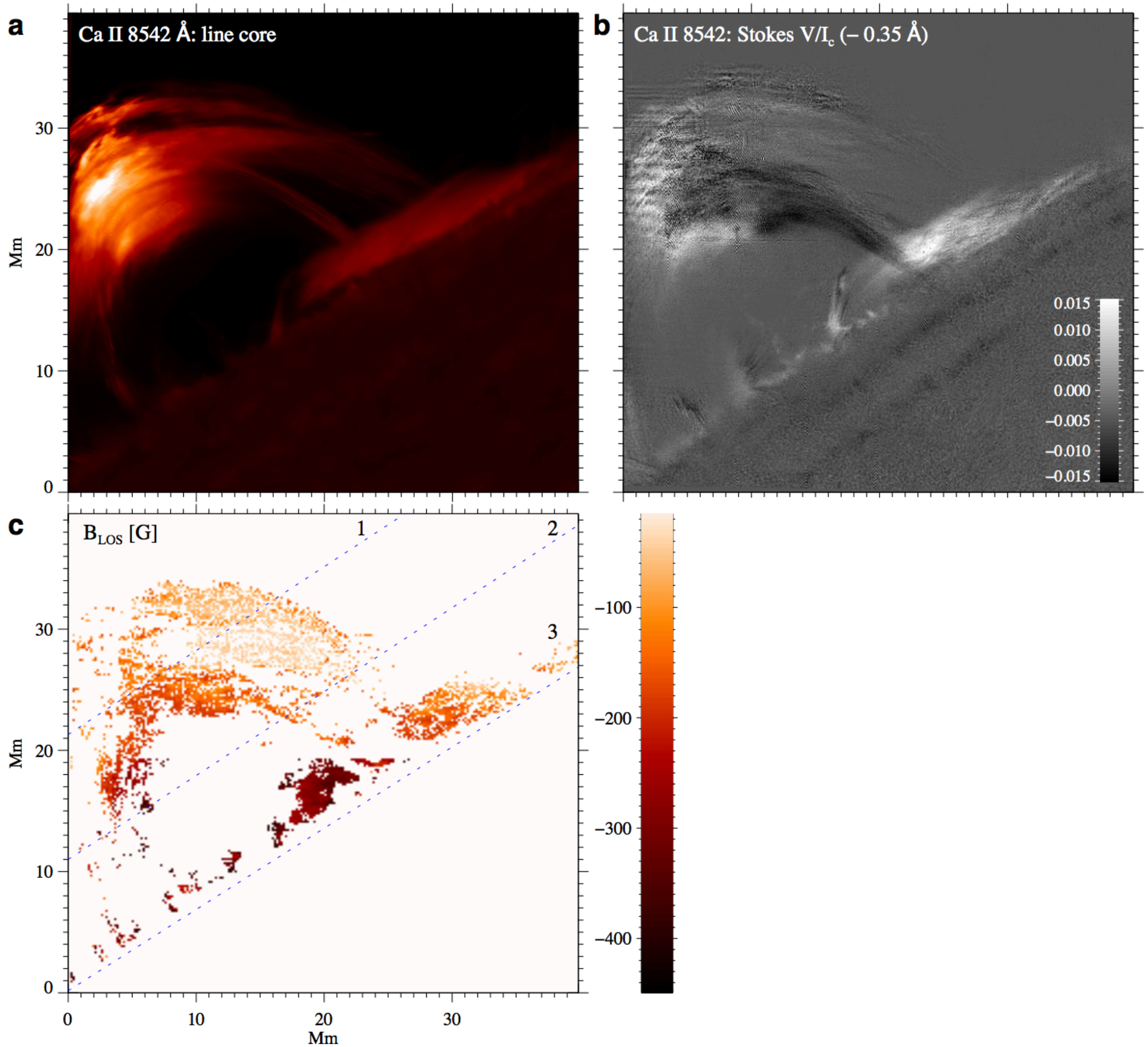


bright flash: continuum (“white light”) emission

Chromospheric Flare Measurements

B can be measured off-limb and on-disk

Very few chromo-spheric observations during flares.



Kuridze et al., ApJ, 2018

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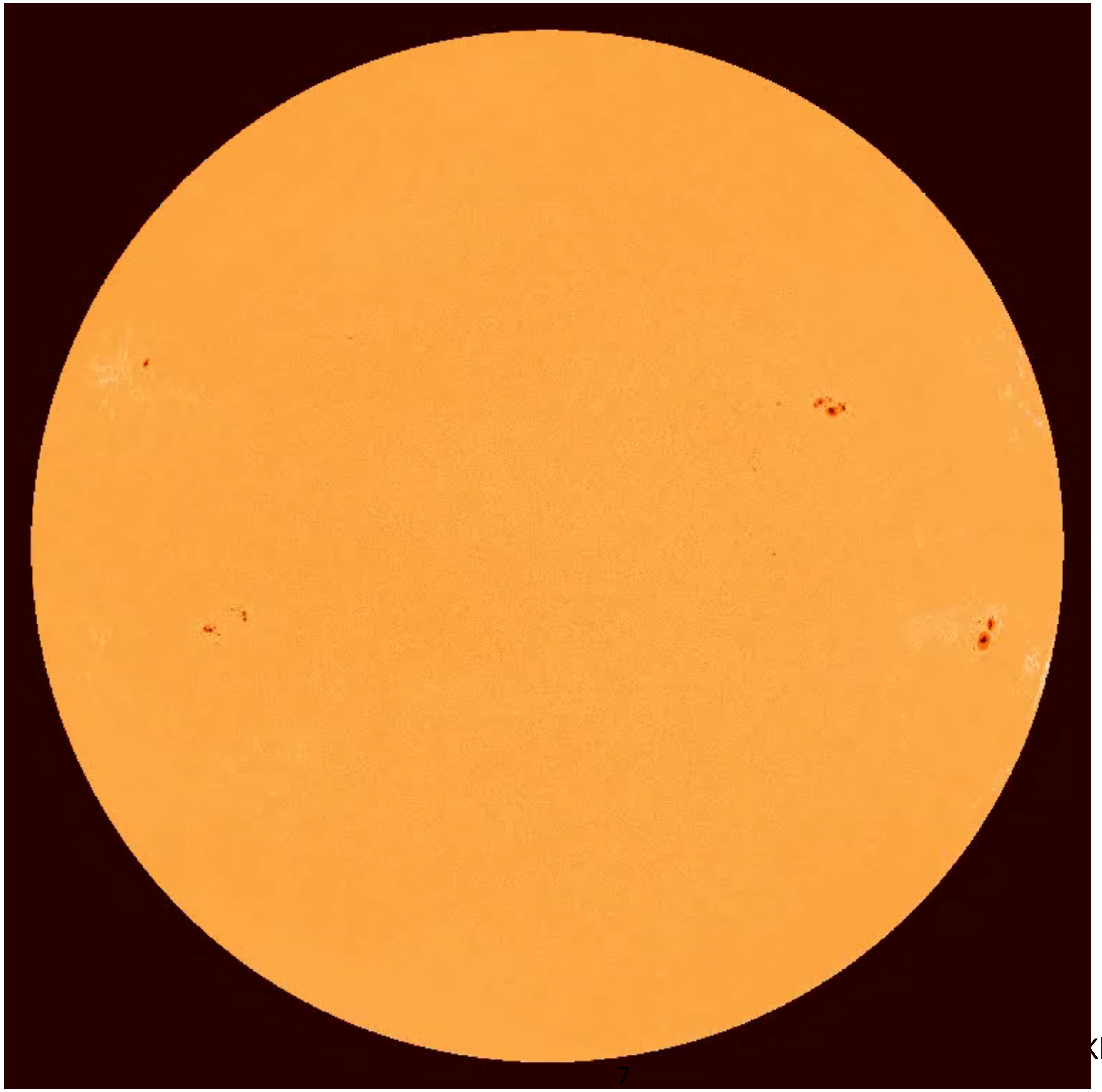
Magnetic Field Changes: 2014-03-29 X1 flare



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Magnetic Field Changes

PHOTOSPHERE (HMI, IBIS)

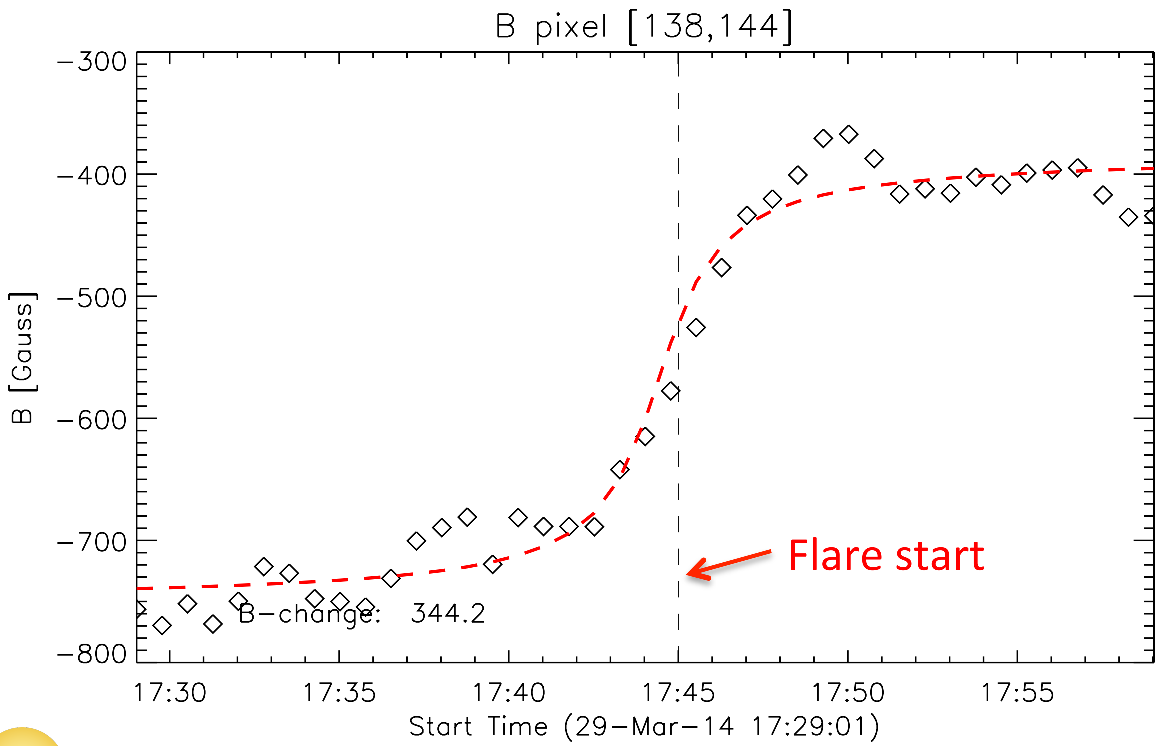
analyze evolution of B_{LOS}

Photospheric Magnetic Field Changes

Method: Fit $B_{LOS}(t)$ with a stepwise function

$$B(t) = a + bt + c\left\{1 + \frac{2}{\pi}\tan^{-1}[n(t - t_0)]\right\}$$

Sudol & Harvey, 2010



A HMI pixel changing from -750 G to -400 G.

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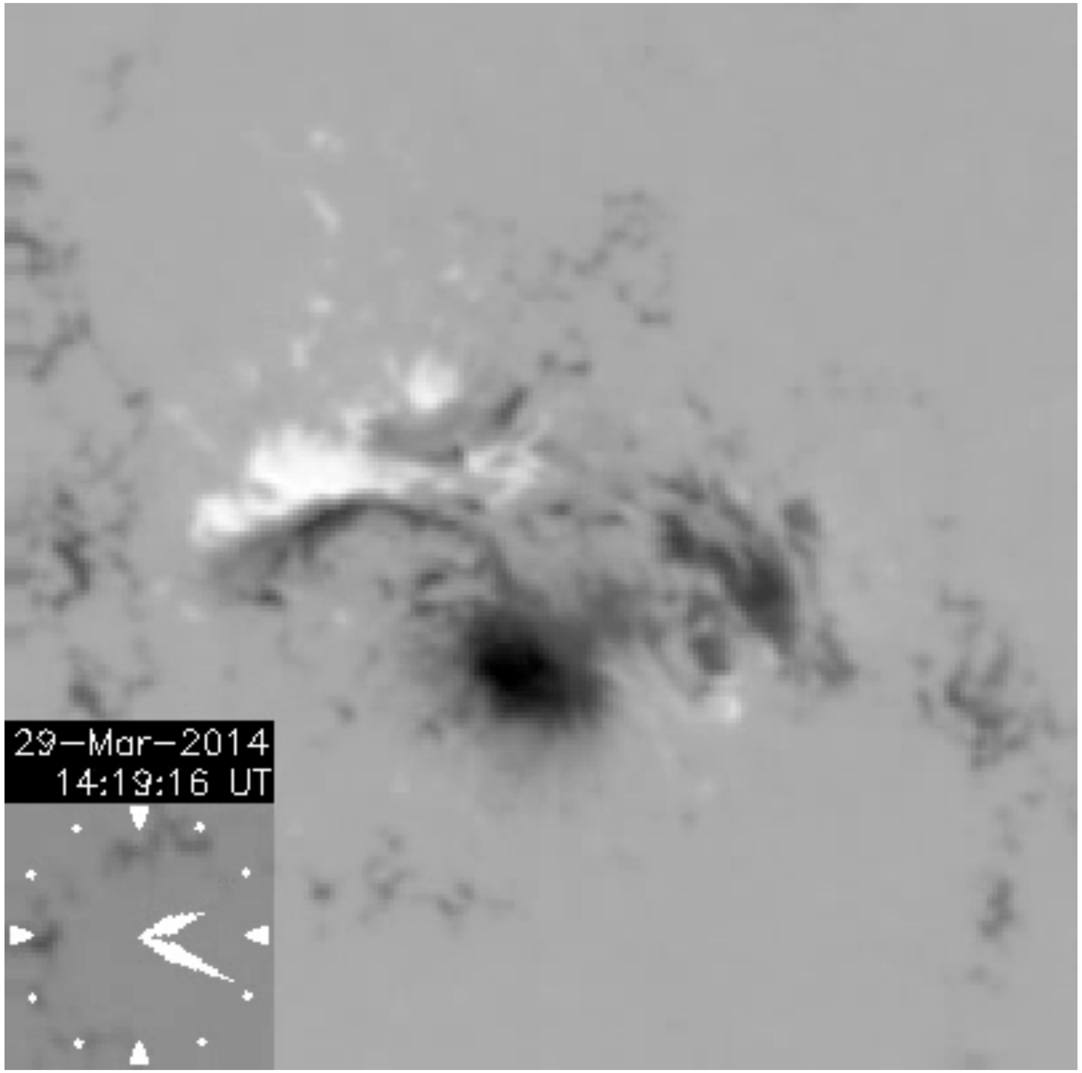
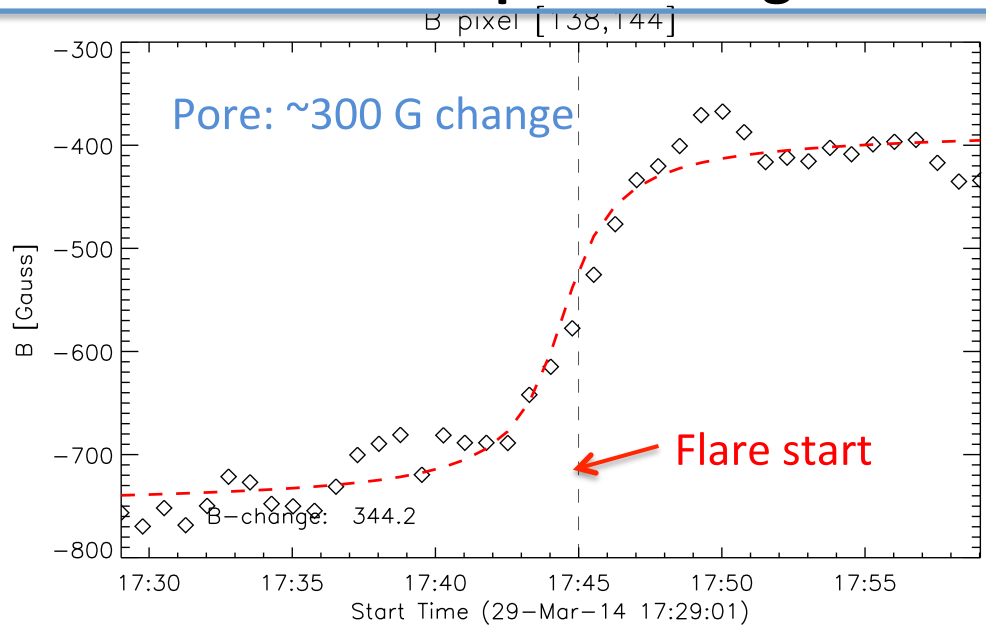
Magnetic Field Changes during the X1 flare on 2014-03-29

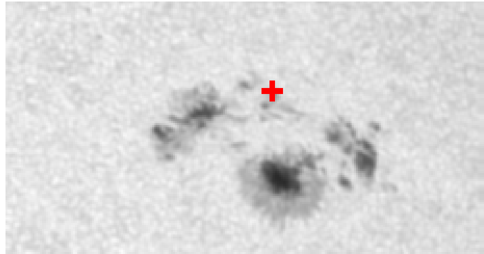
Evolution of B_{LOS} on 2014-03-29 (X1 flare at 17:45)

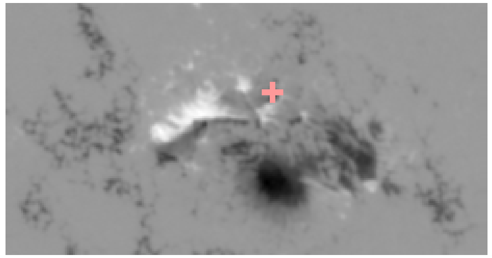
Looking for sudden changes, not solar evolution / flux emergence.

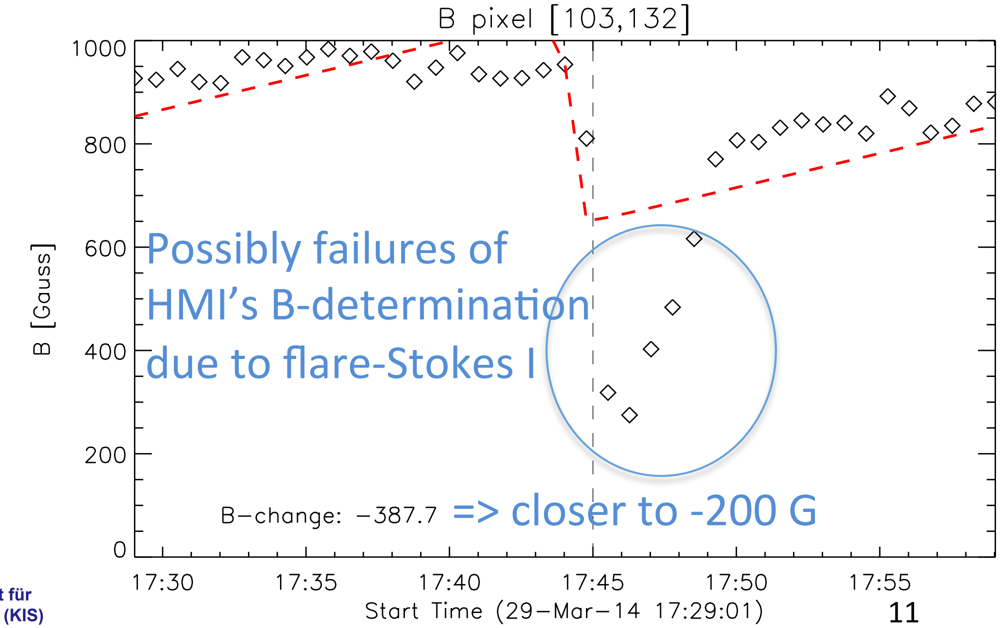


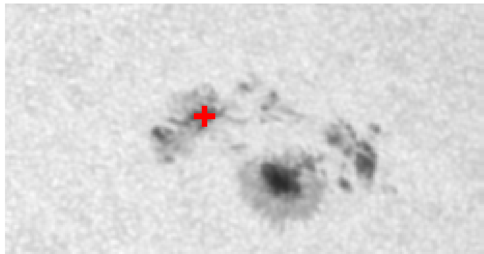
Photospheric Magnetic Field Changes

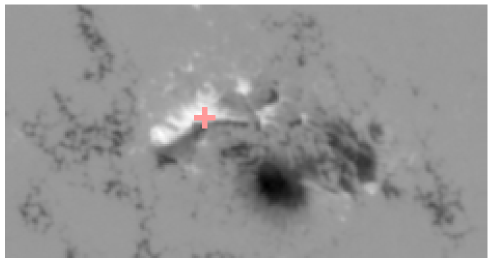




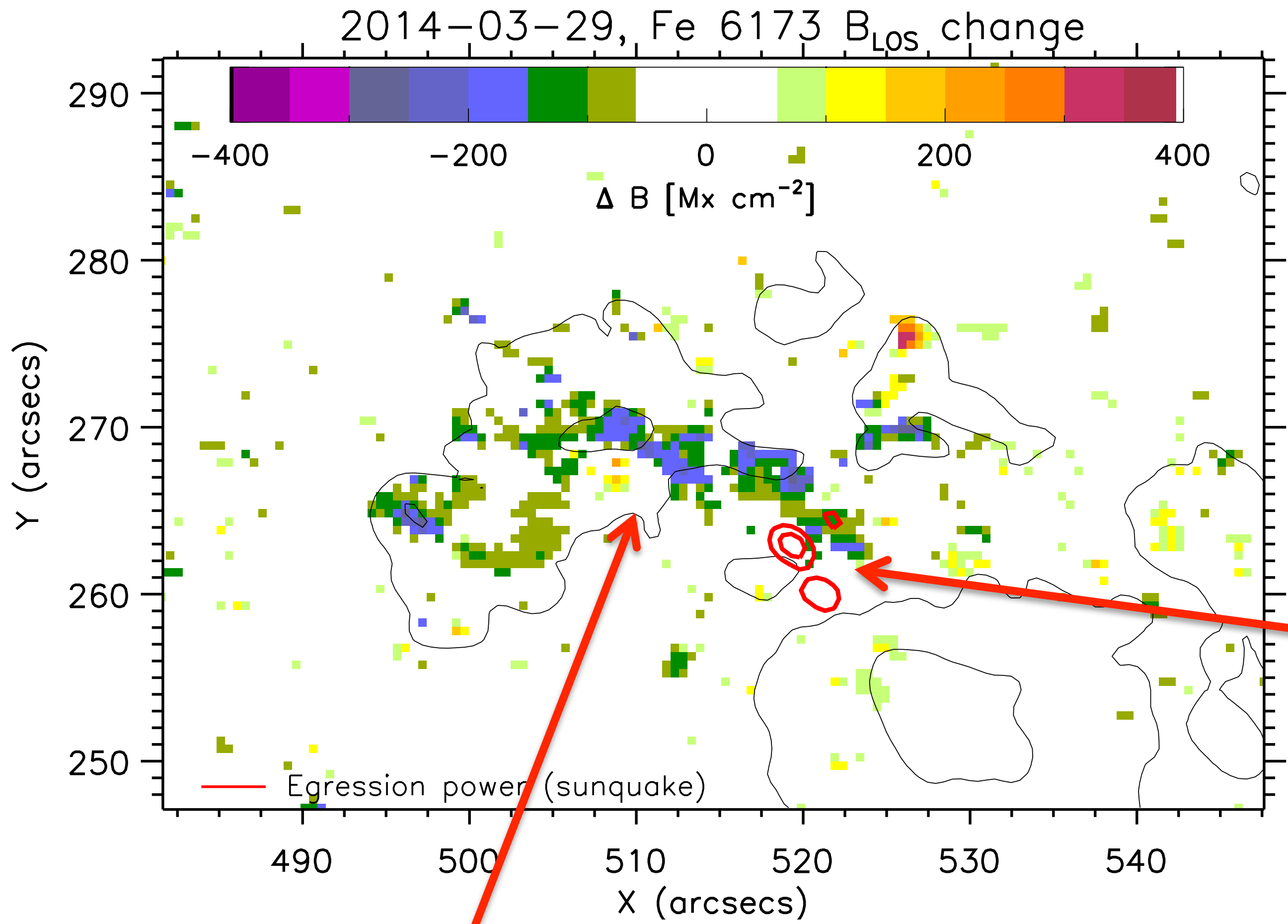








Photospheric Magnetic Field Changes



Photospheric changes are below 320 G.

small sunquake (not co-spatial)

Colored pixels = magnetic field changed permanently

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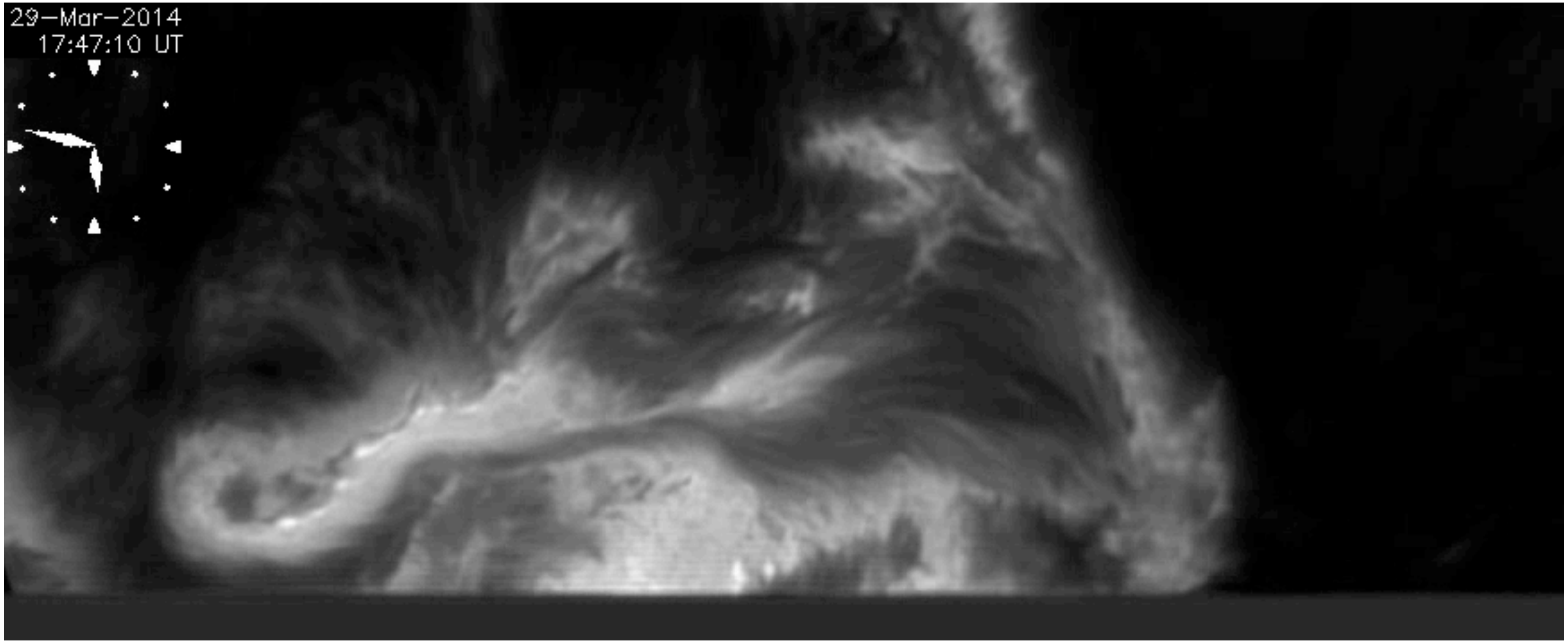
Chromospheric Magnetic Field Changes

CHROMOSPHERE (IBIS)

more complicated to get B_{LOS}
=> used weak-field approximation

Chromospheric Flare Observation



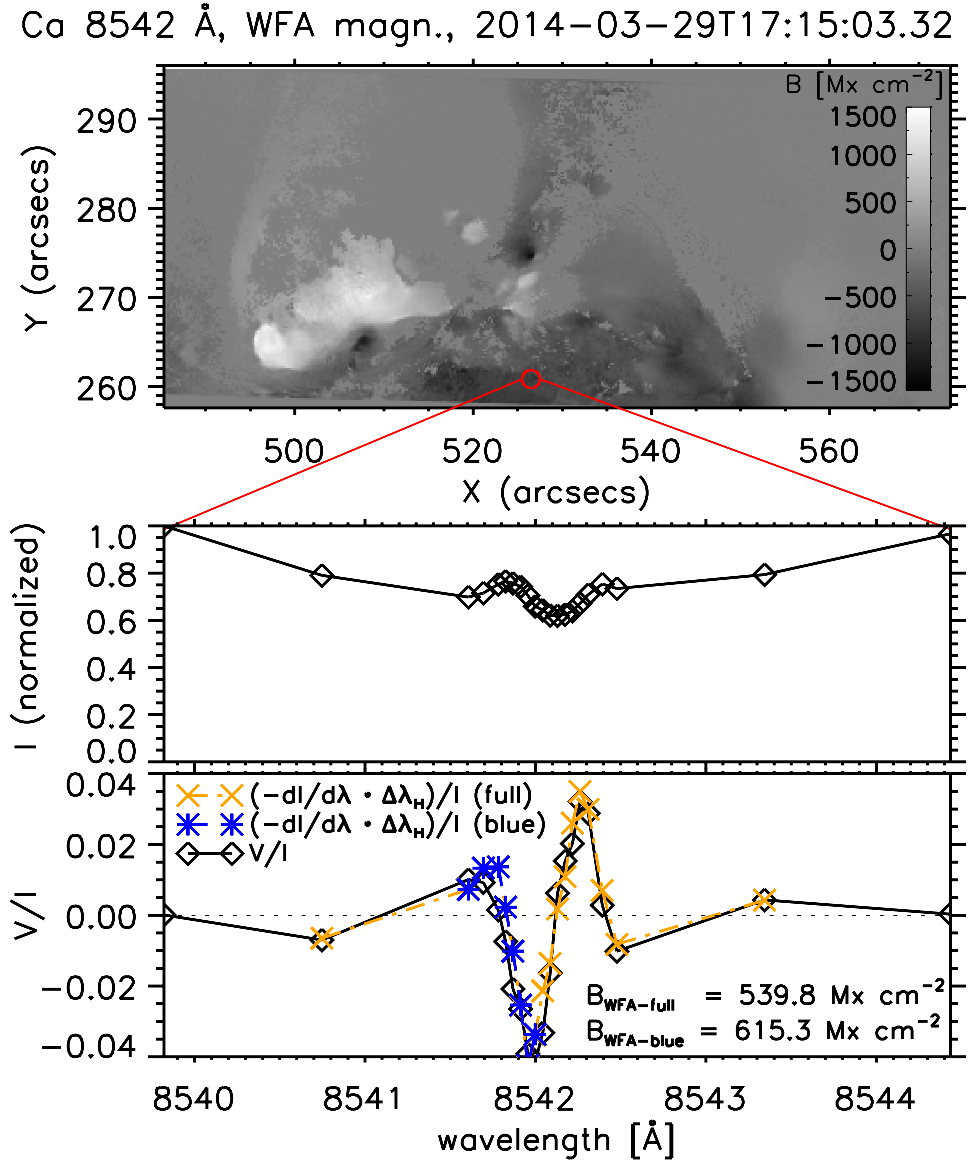
- Speckle-reconstructed Ca II 8542 images (80” x 40”) from IBIS.
- more complicated to get B_{LOS} than for HMI => used weak-field approx.

Chromospheric Magnetic Field Changes

Compare Stokes V to the derivative of the intensity.

$$V(\lambda) = -\Delta\lambda_H \cos\theta \frac{dI(\lambda)}{d\lambda}$$

proportional to B



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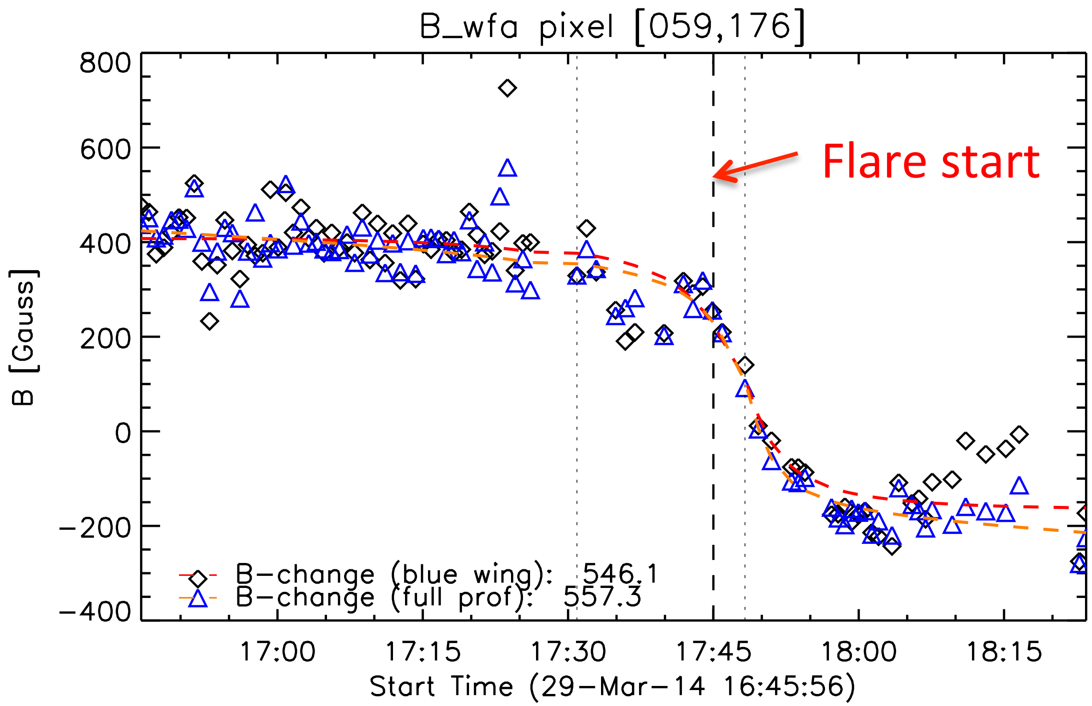
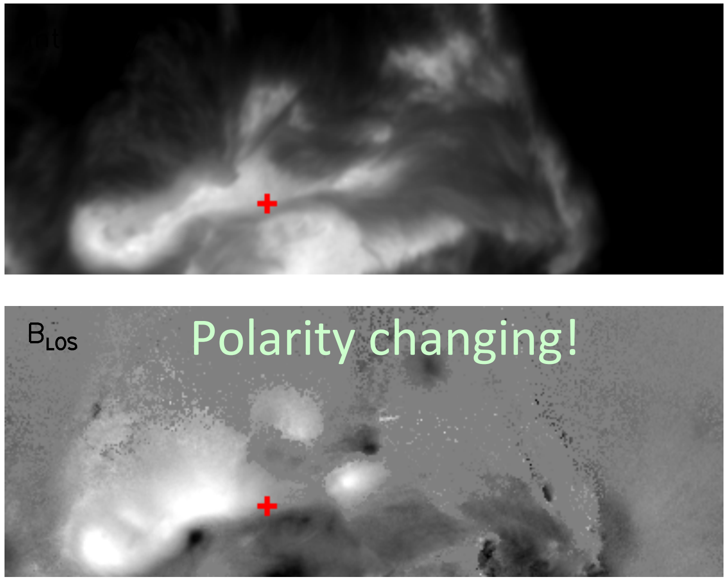
Chromospheric Magnetic Field Changes





change: >500 G!

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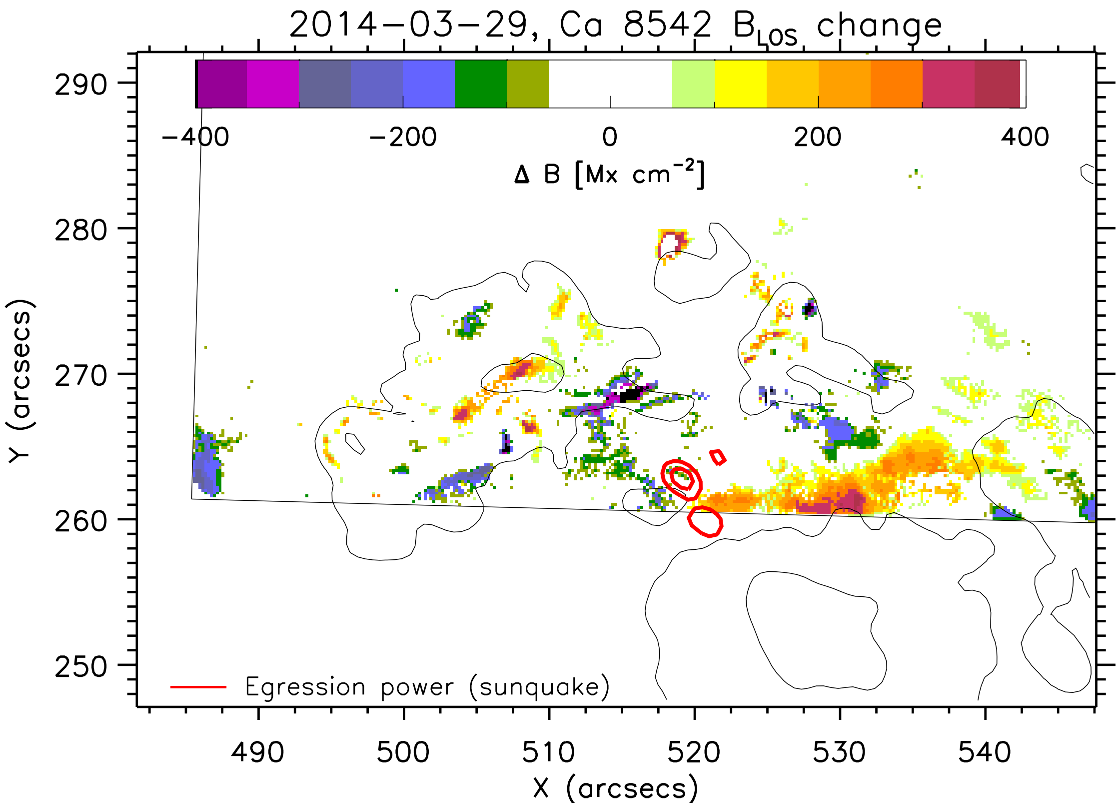
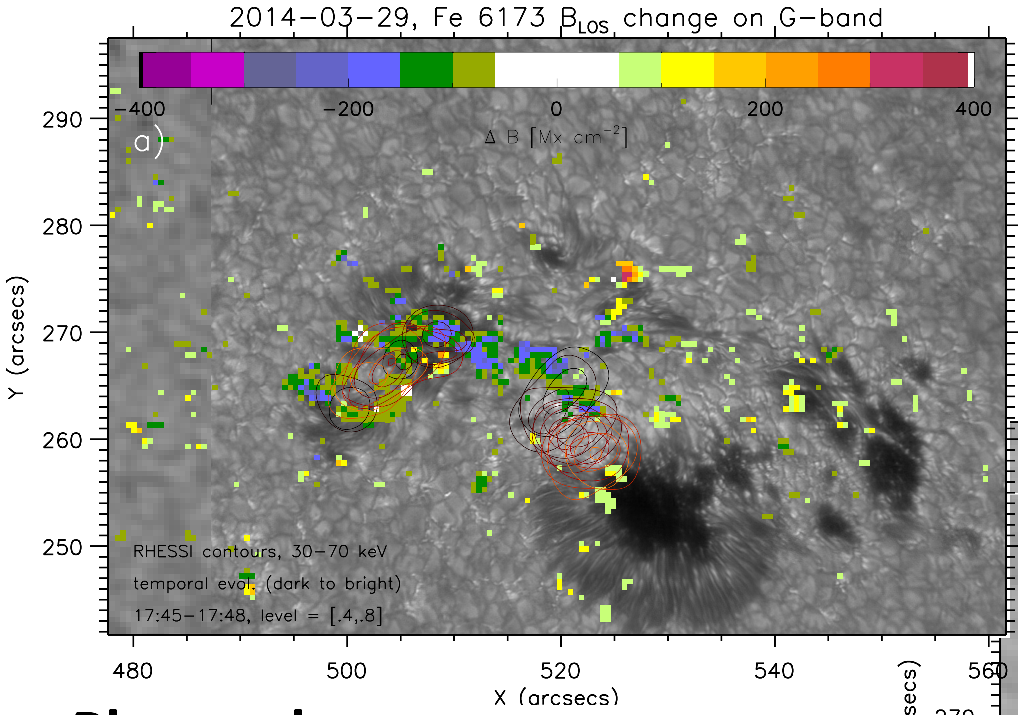
Chromospheric Magnetic Field Changes

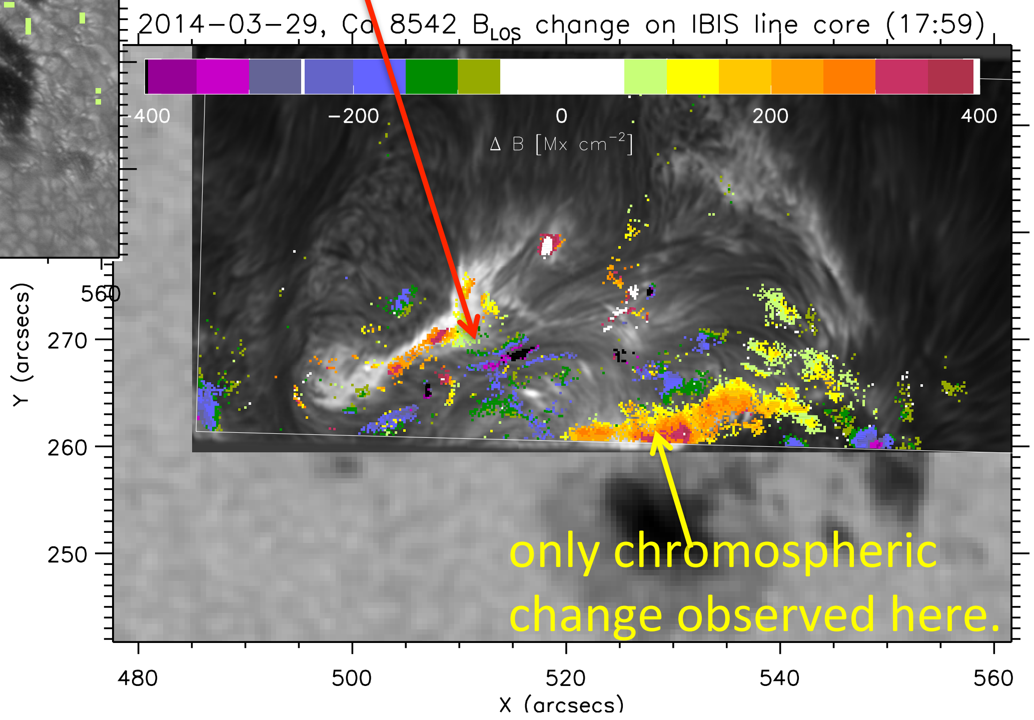


- Changes occur in coherent areas
- Chromospheric changes are stronger than photospheric changes (640 G vs. 320 G)

Comparison of photosphere and chromosphere



Photosphere



similar pos. to photosphere

Chromosphere

Chrom. changes are stronger and occur in larger areas.

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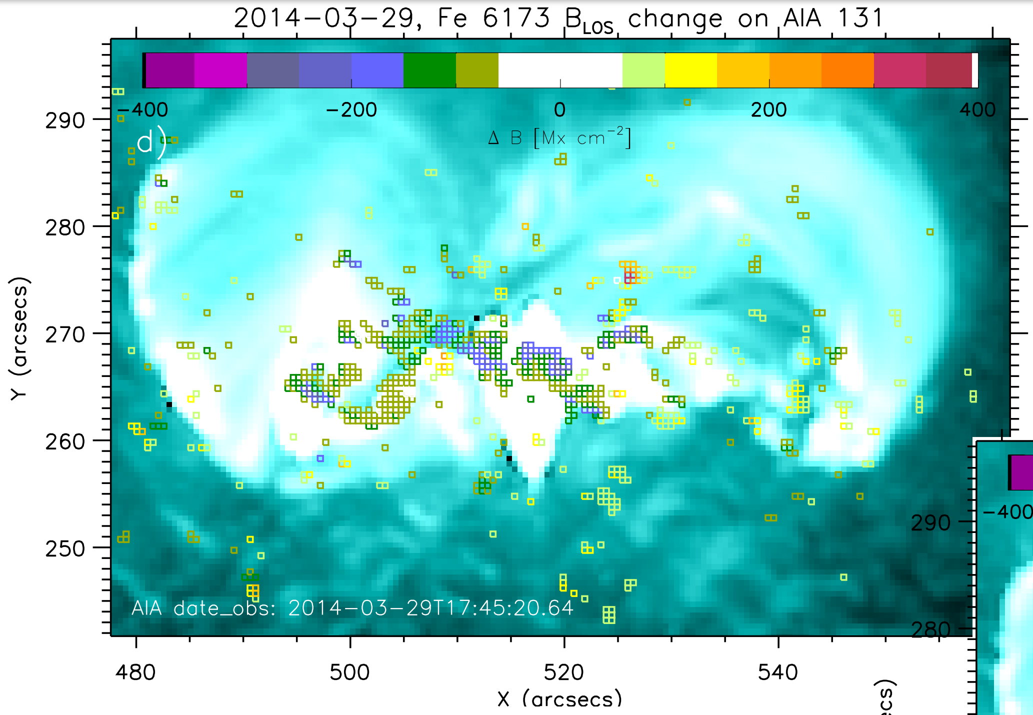
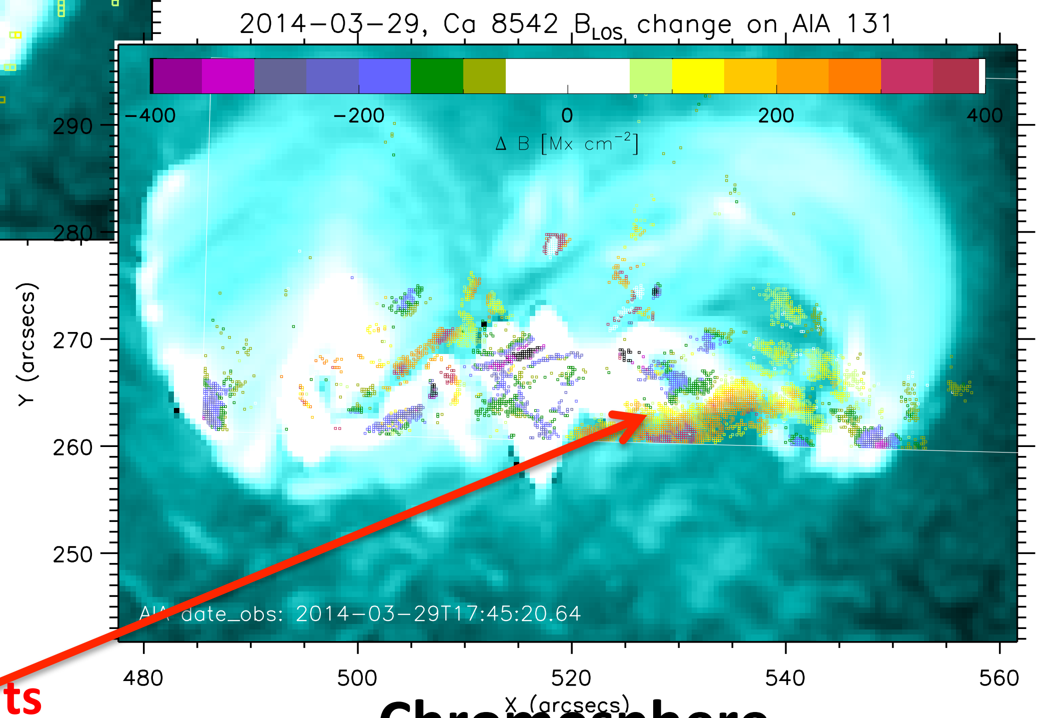
Comparison of photosphere and chromosphere



Photosphere



Chromosphere

Chrom. changes near loop footpoints

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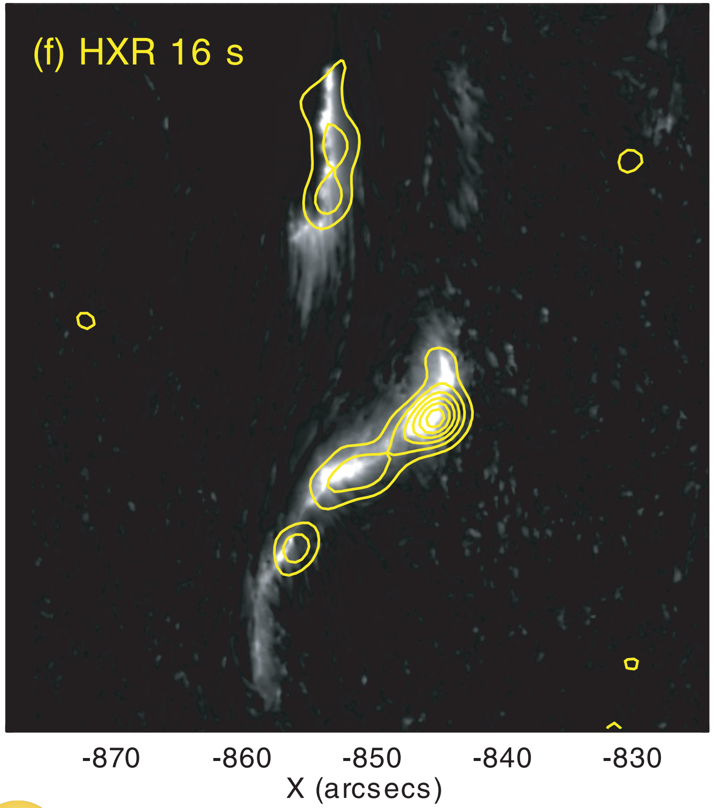
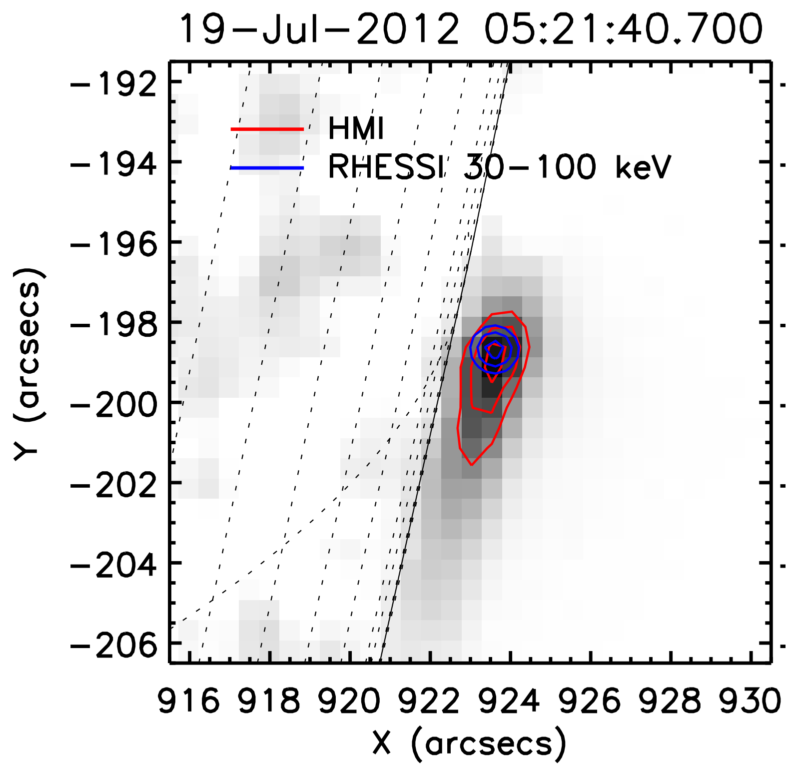
X-rays and continuum emission: context

X-rays (from e^- stopped in chromo-sphere) generally agree with WL emission

If magnetic field changes also agree spatially, there may be a common mechanism.

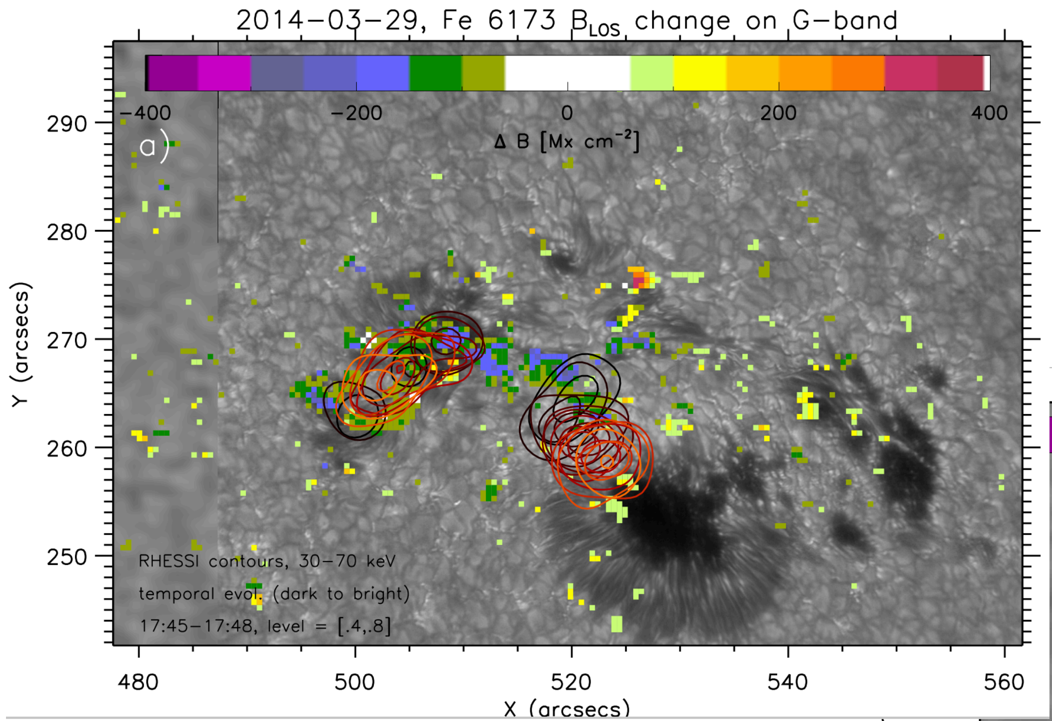


Krucker et al. ApJ 739, 2011

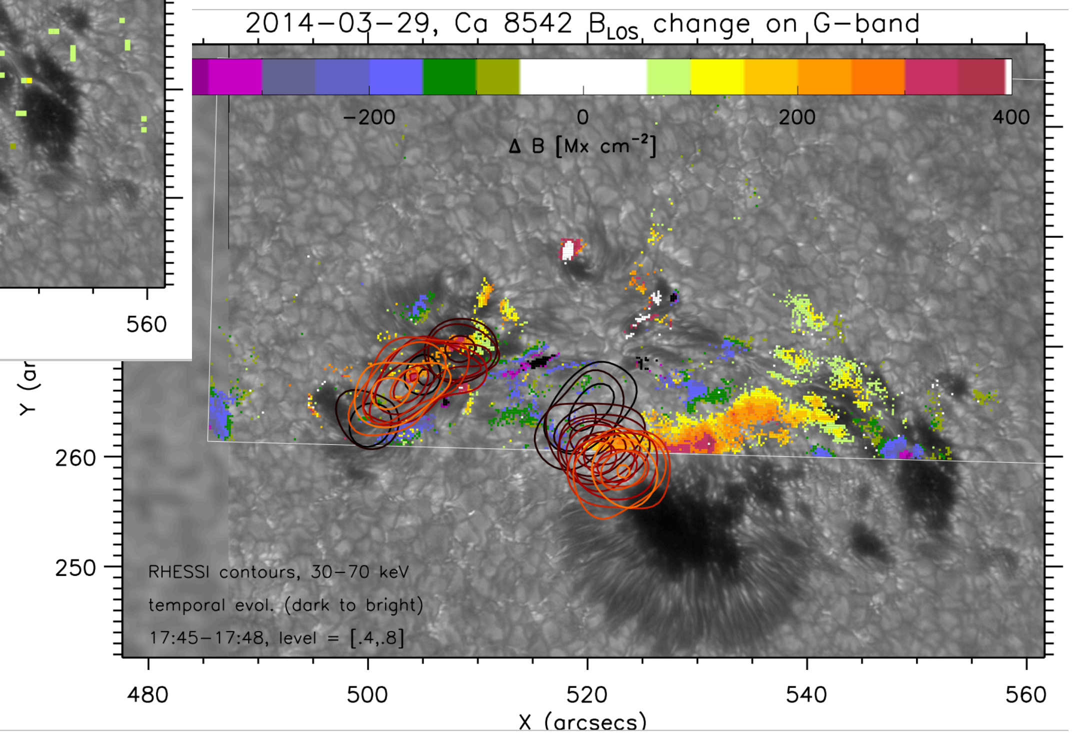


Heinzel et al., ApJ, 2018

Overlap with X-rays?



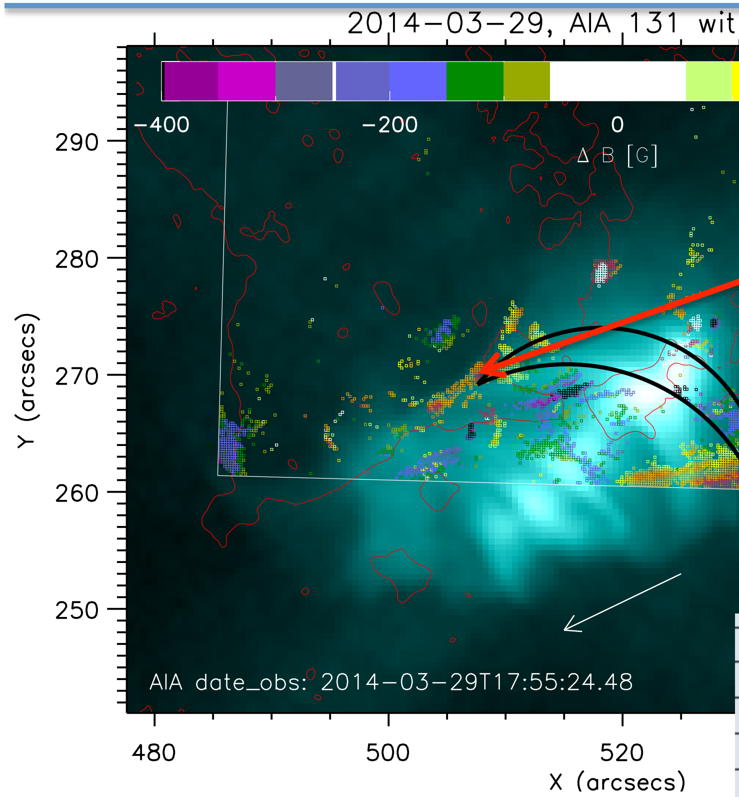
Photosphere



Not much overlap. Most changes occur where no X-ray signatures are seen.

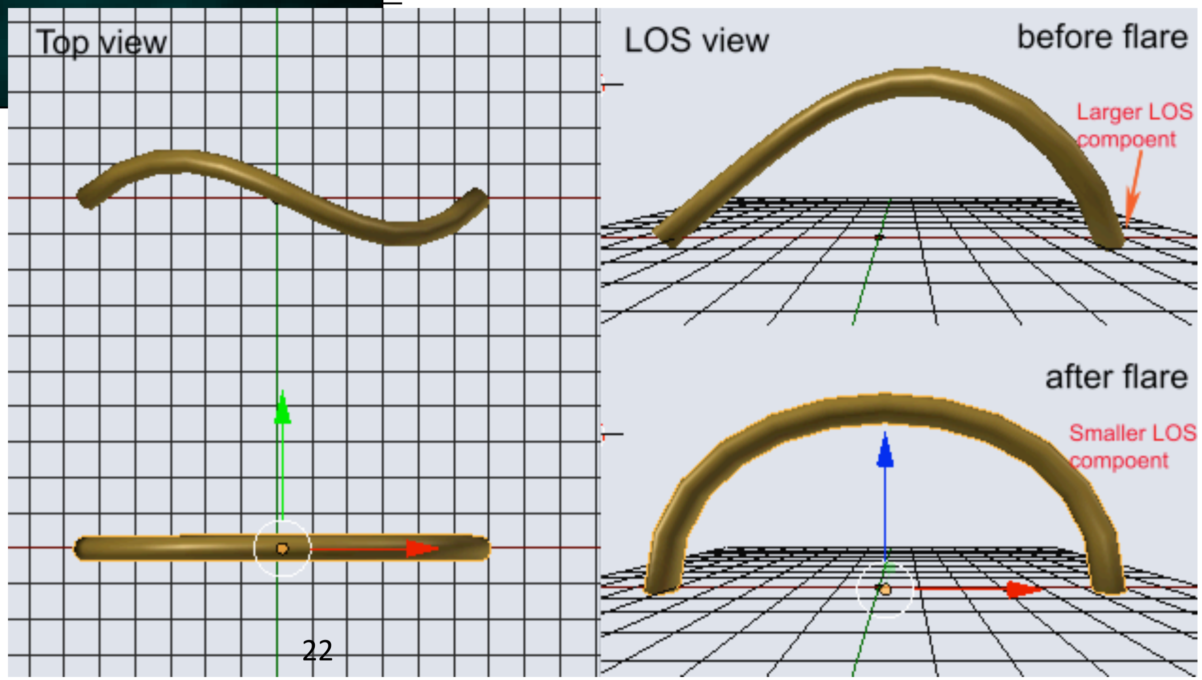
Chromosphere

Chromosphere: Geometry



Here B_{LOS} becomes larger after the flare

B_{LOS} becomes smaller after the flare



Chrom. changes near loop footpoints

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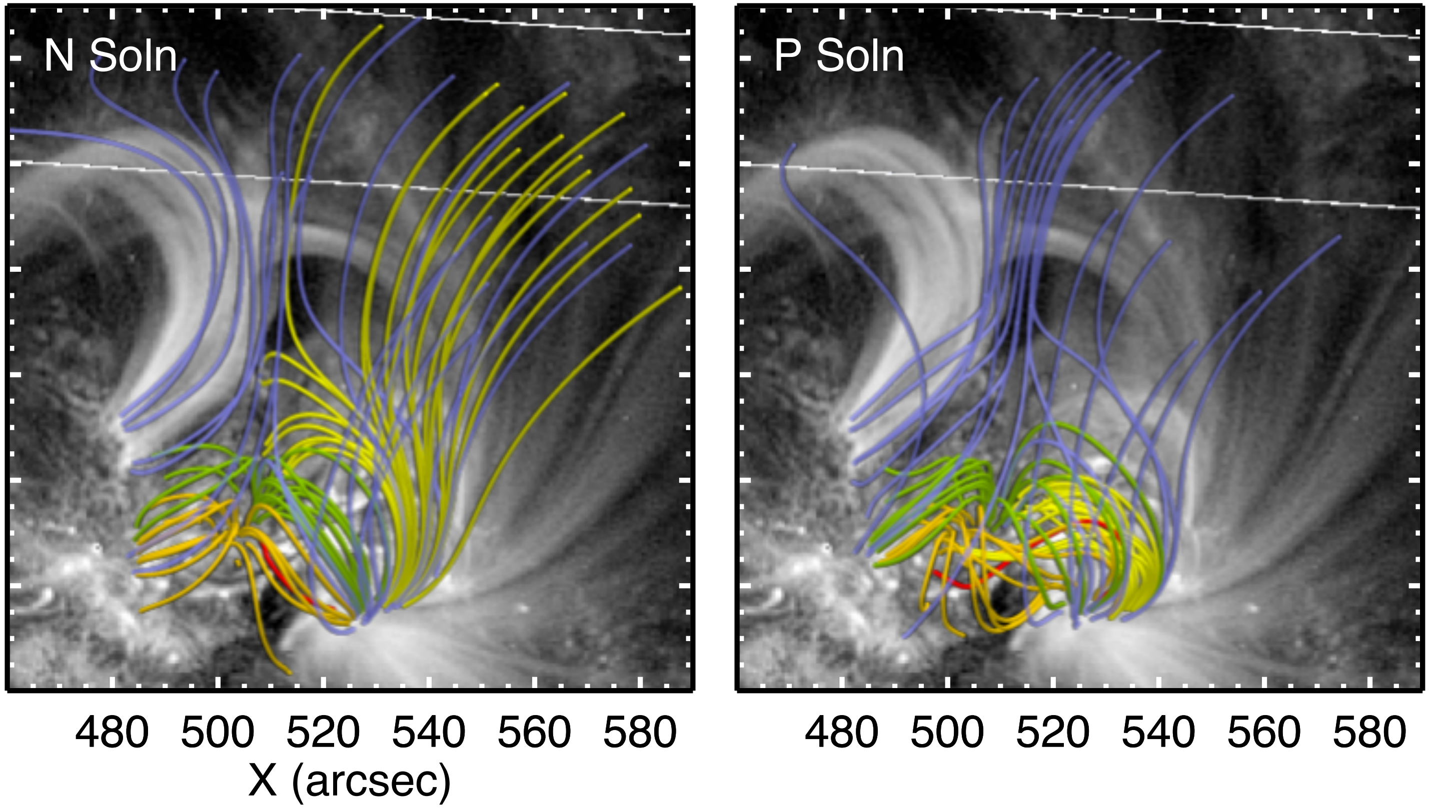
Modeling

Can NLFFF models reproduce the observed changes?

in collaboration with M. Wheatland, A. Mastrano, P. McCauley
University of Sydney, Australia

Comparison with NLFFF modeling

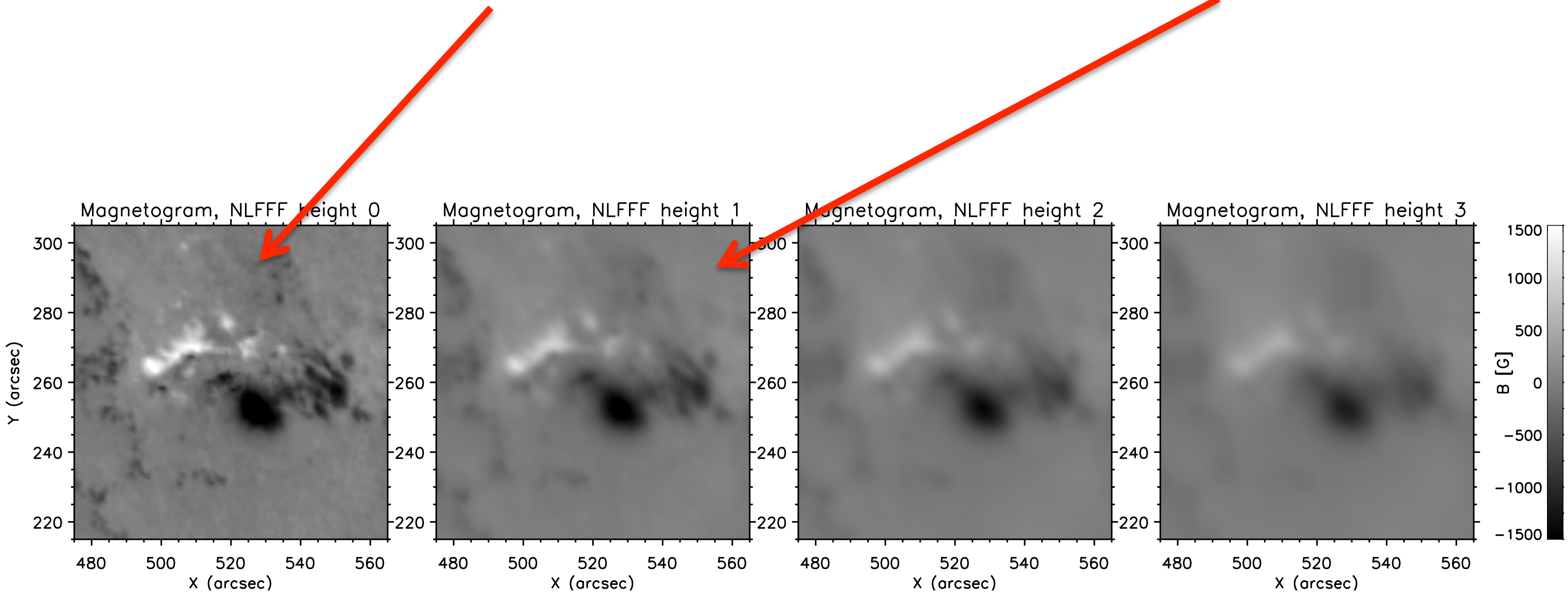
- Obtain NLFFF model every 135 s (from HMI vector data)
- 2 solutions: P and N, but P is more realistic
- Fit the same arctan function to all NLFFF models to obtain magnetic field changes



Kleint et al., ApJ 865, 146, 2018

Comparison with NLFFF modeling

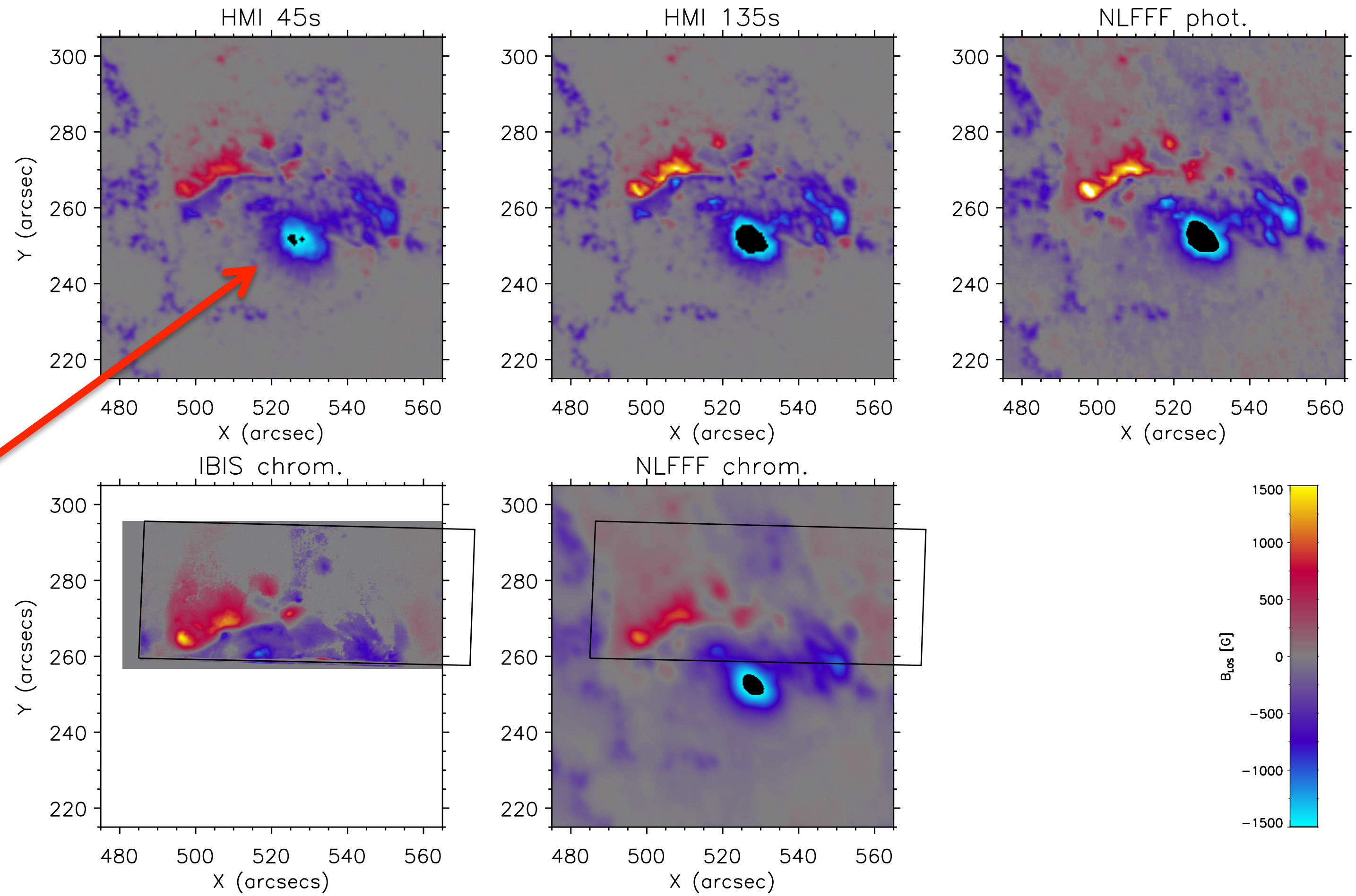
- Variation of magnetogram with height in NLFFF model.
- Use index 0 for photosphere, index 1 (h=725 km) for chromosphere



Comparison with NLFFF modeling

Magnetograms of obs. and model agree for both layers.

HMI 45 s data underestimate B_{LOS} (known).



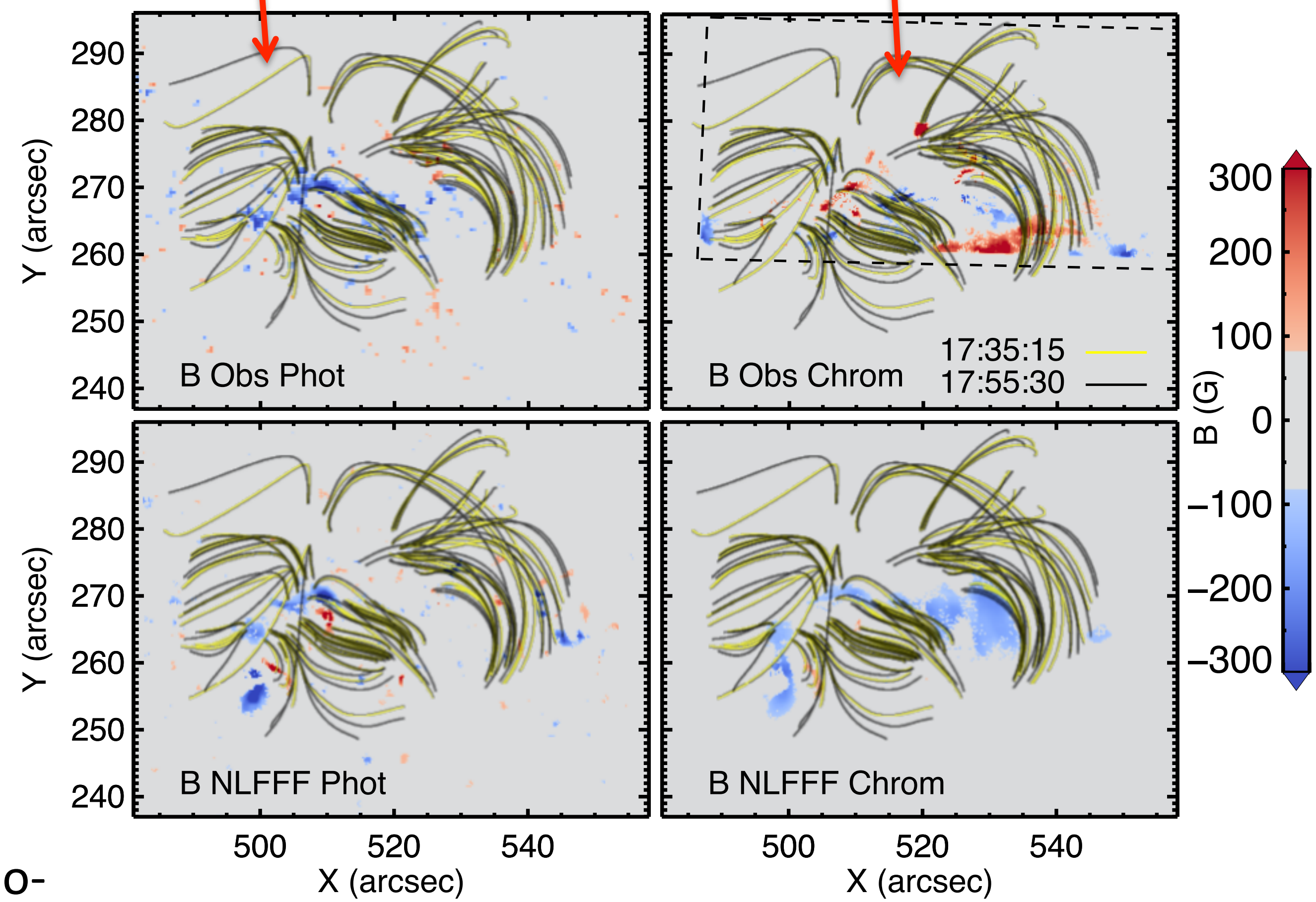
Comparison with NLFFF modeling

Photosphere agrees more or less, but not perfectly.

Chromosphere does not agree at all.

observations:

modeling:



Conclusion:
- not force-free?
- physics of chromo-sphere missing in model.

Statistics

What about other flares?

(no chromospheric data yet…)

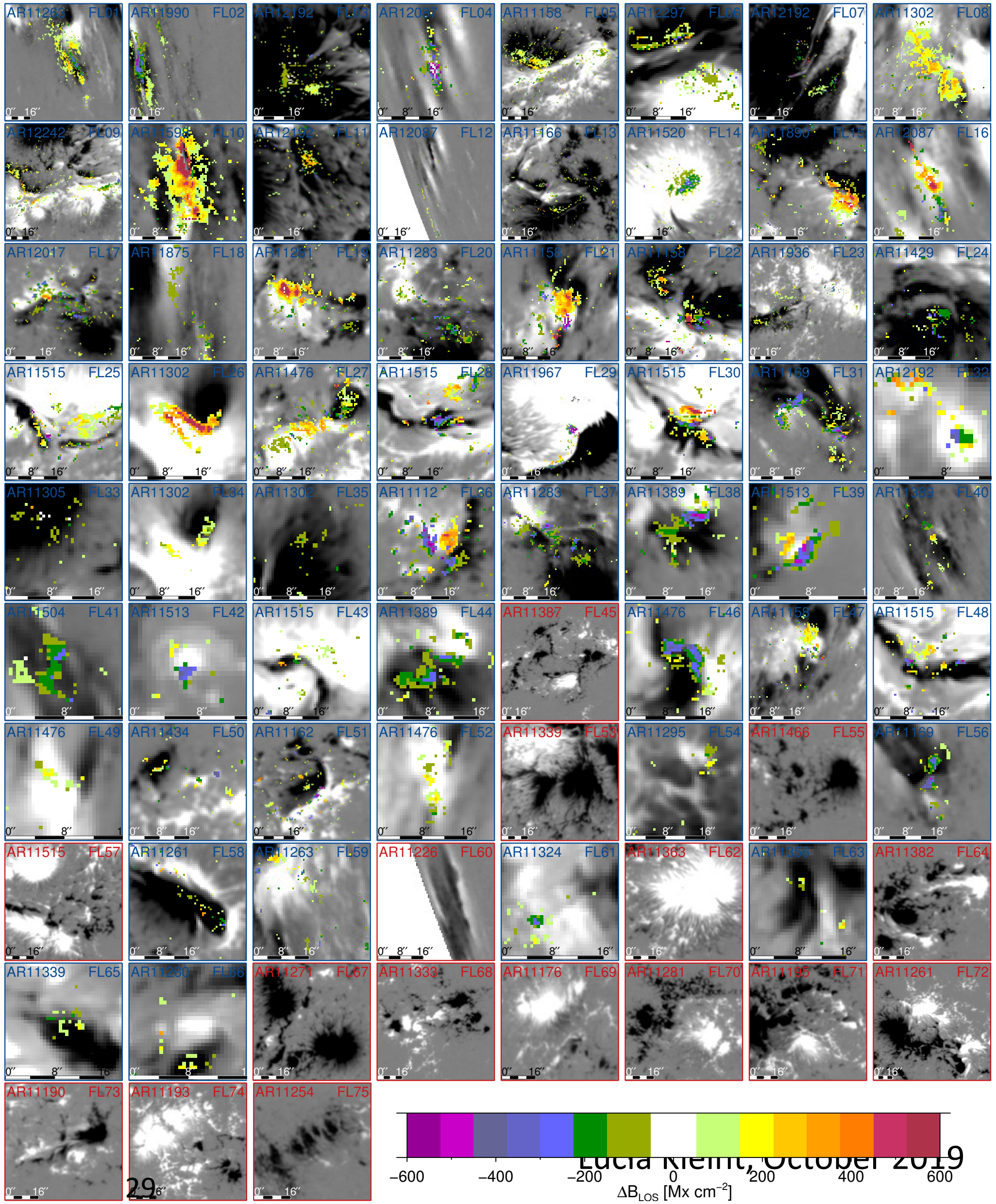
Castellanos Duran et al., ApJ 852, 25, 2018

Statistics: Occurrence

Statistics

- 75 flares analyzed, changes found in all >M1.6.
- Area of changes correlated to flare energy.
- Strong changes occur near the polarity inversion line.

Castellanos Duran et al, ApJ 852, 25, 2018



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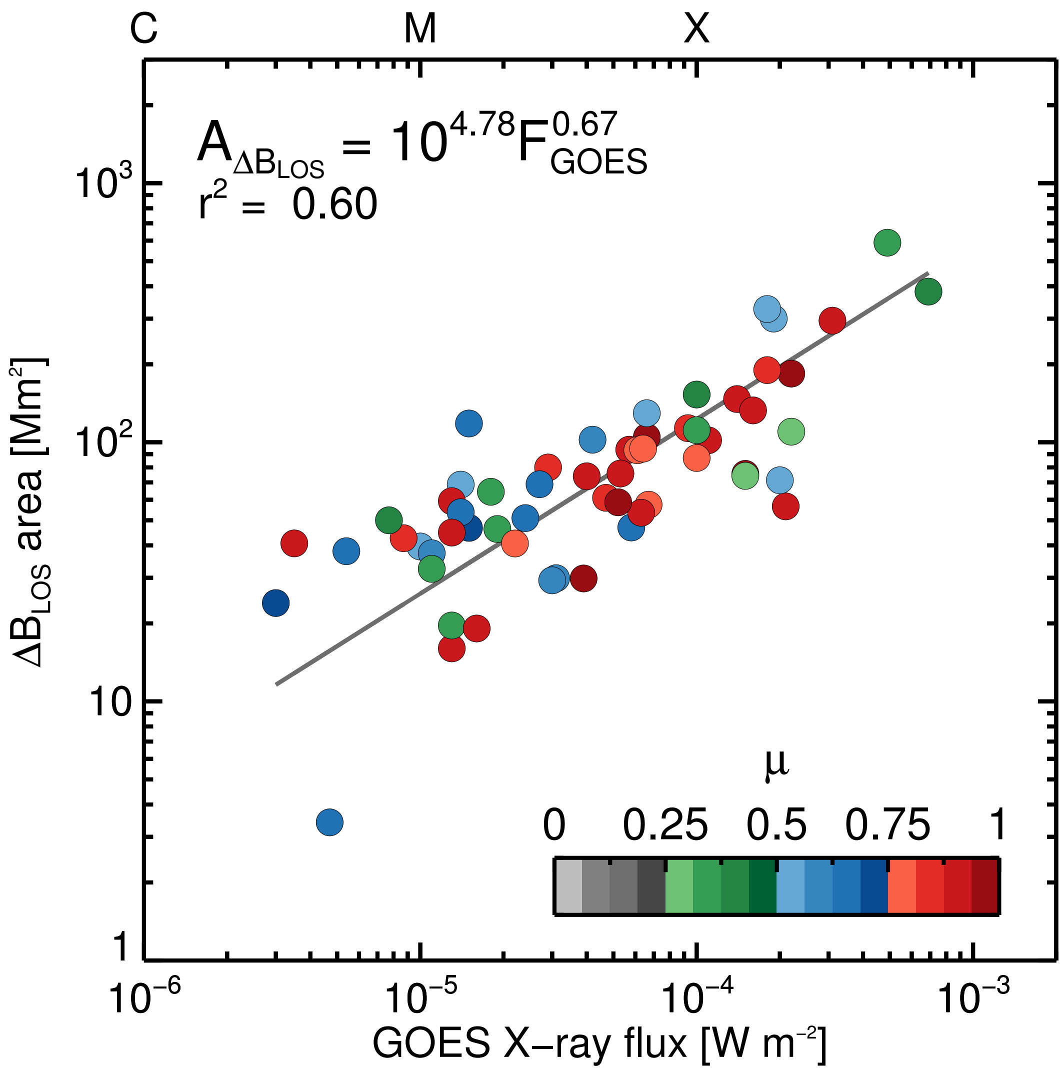
Statistics: Areas of photospheric B-changes

Statistics

- The (detected) B-change area depends on the flare strength.

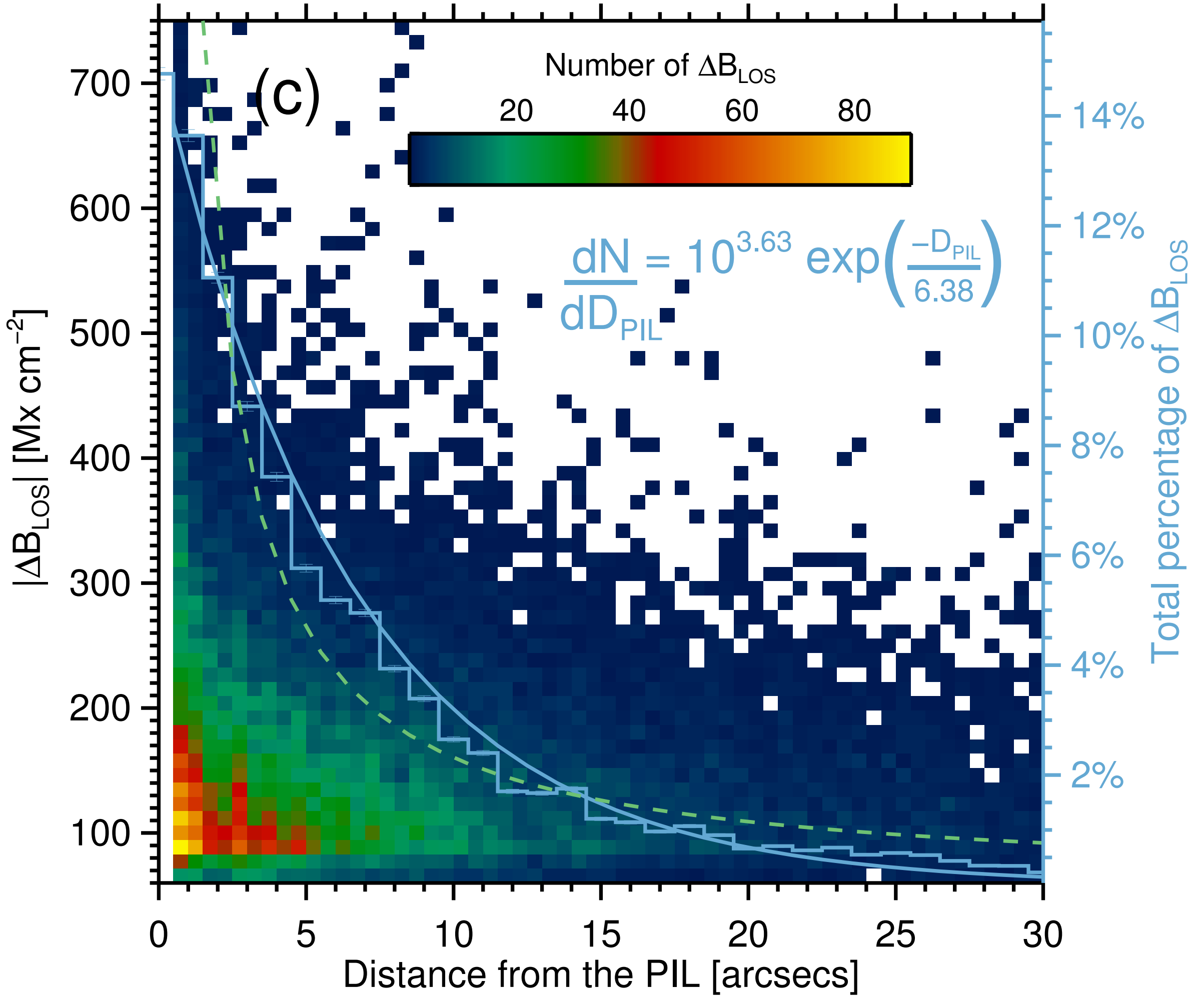
- area corrected for foreshortening. No dependence on limb distance



Statistics: location of photospheric B-changes

Statistics

- The strongest B-changes occur near the polarity inversion line (exponential decay with distance)
- Example: 90% of changes > 250 G are within 9” of PIL.



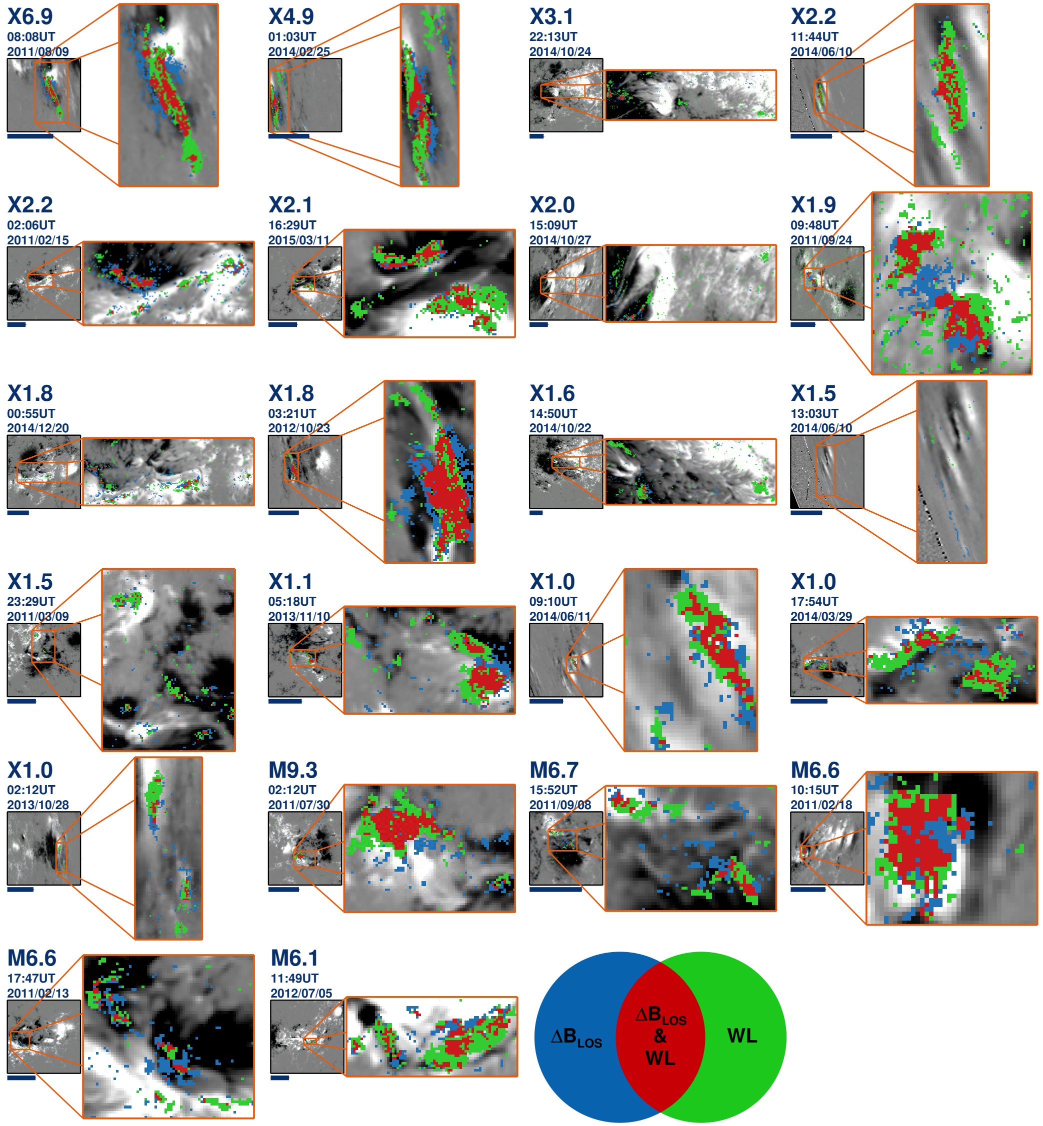
Castellanos Duran et al, ApJ 852, 25, 2018

Are B-changes related to white light emission?

Statistics

- WL & B-changes often overlap, but are not identical.
- In 64% of the cases the B-change area is larger than the WL area.

Castellanos Duran et al, to be submitted, 2019



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Outlook

We do not yet have statistics for chromospheric magnetic field changes.

-> GREGOR, DKIST

Summary: 2014-03-29 flare

independent?

Photosphere ⟷ **Chromosphere**

Photosphere

- HMI ΔB_{LOS}: <320 G
- Changes close to polarity inversion line.

Chromosphere

- Stronger (<640 G) and bigger areas
- Changes close to loop footpoints.
- Not reproduced by NLFFF.
- More statistics desired.

- Not compatible to shrinking loops. Compatible to increasing loop sizes or untwisting loops.