Signatures of magnetic reconnection between small-scaled loops in the solar transition region

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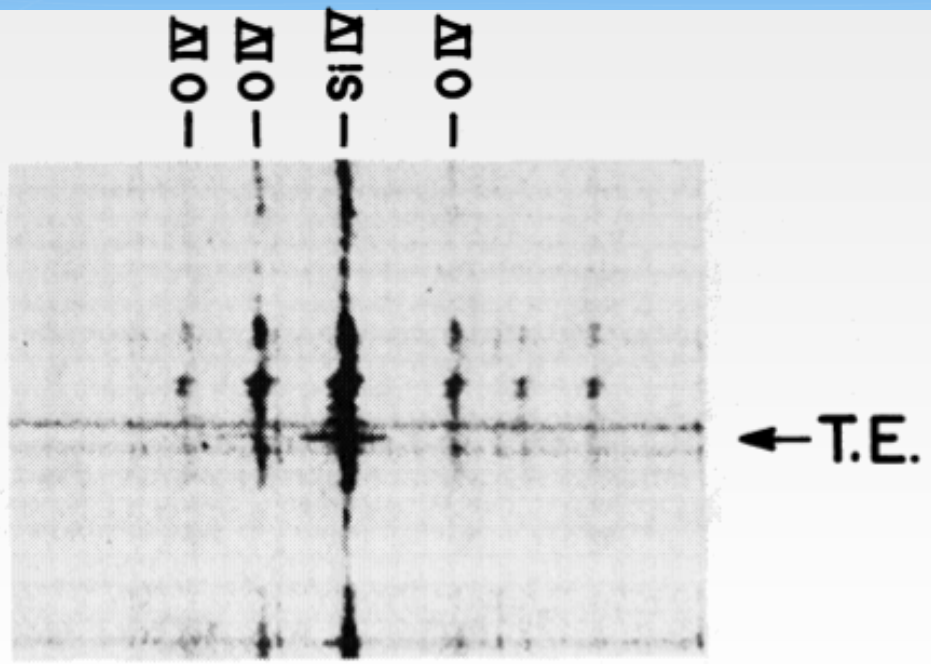
Transition region explosive events

- Bruckner & Bartoe (1983) – turbulent events identified by their non-Gaussian profiles - turbulent events and jets (HRST/NRL)
- Dere, Bartoe & Bruckner (1984) - introduced the term 'explosive events' or by-directional jets

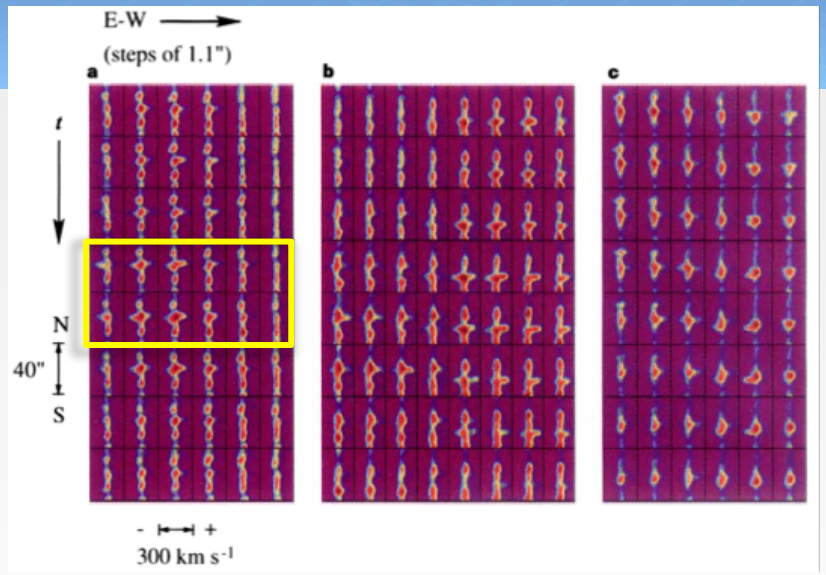


HRTS observations (Bruckner& Bartoe, 1983): “turbulent events and jets”

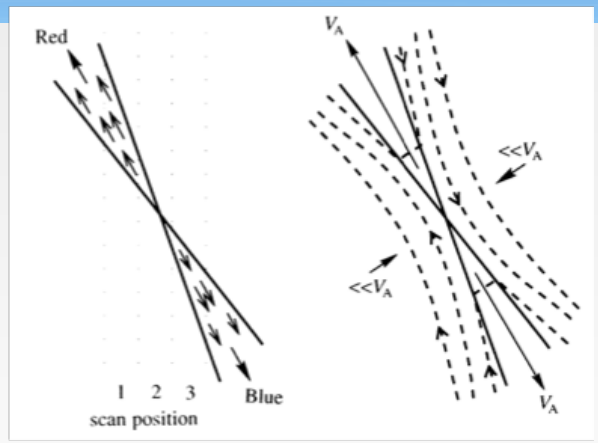
Explosive events (EEs): Some observational facts we have known

- They are normally found in the network region (Dere et al. 1989; Porter & Dere 1991; Madjarska & Doyle 2003; etc.);
- They are associated with regions of weak and mixed polarity fluxes (Brueckner et al. 1988; Dere et al. 1991; Chae et al. 1998a; Teriaca et al. 2004; Muglach 2008).
- Most of them are associated with magnetic cancellation (Chae et al. 1998a);
- They can represent hot plasma material flowing out of the magnetic diffuse region where chromospheric upflow events are also observed (Chae et al. 1998b);
- They have been found in chromospheric surge (Madjarska et al. 2009).

Explosive events and magnetic reconnection



Innes et al., 1997, Nat., 386, 811

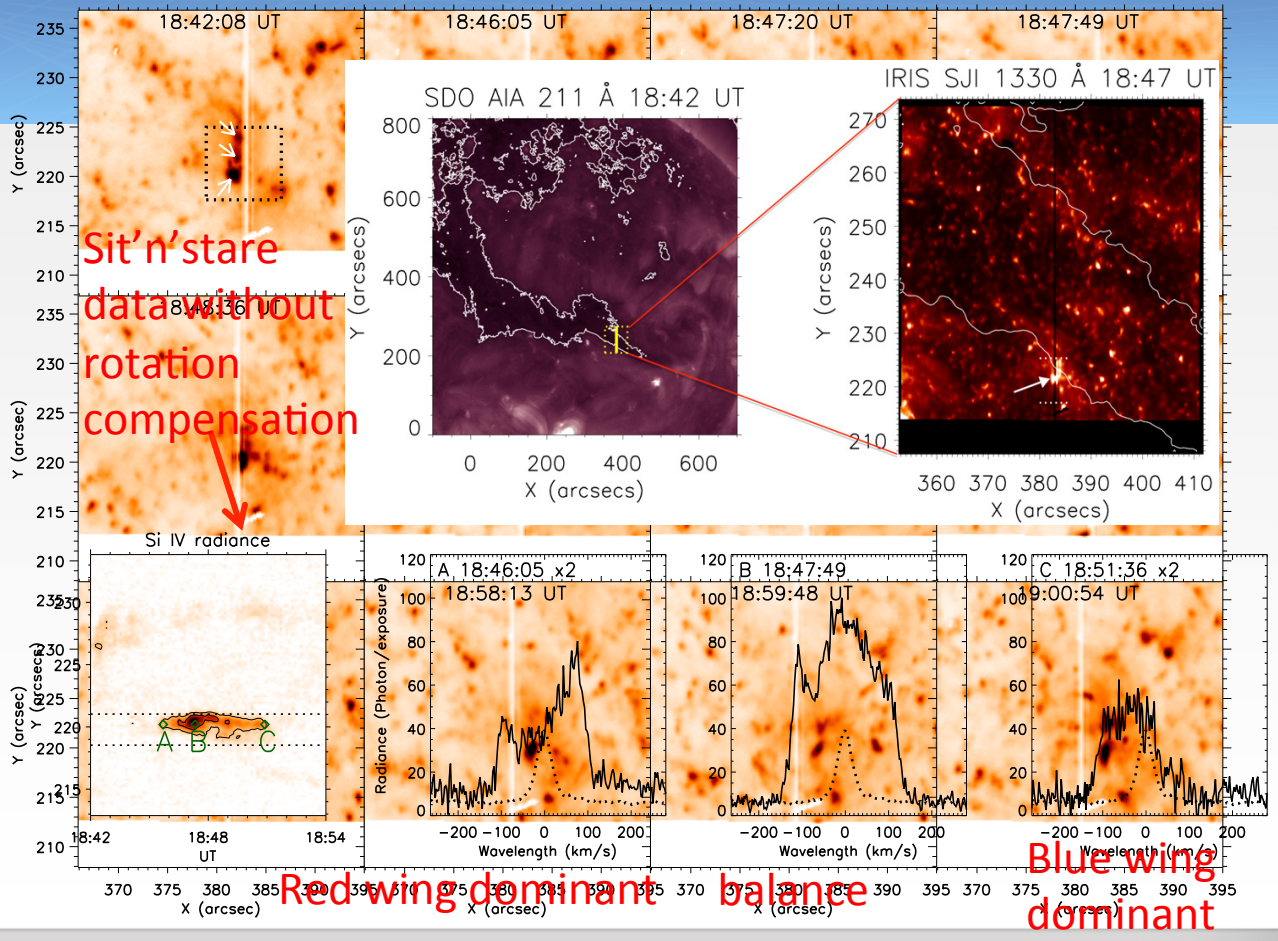


- Explosive events have been taken as signatures of bi-directional outflow generated by magnetic reconnection (Dere et al. 1989; Innes et al. 1997, 2015; etc.).
- Other interpretations: siphon flows in small scaled loops (Teriaca et al. 2004) and swirling jets (Curdt and Tian, 2011) have also been proposed as the phenomena causing explosive-event line profiles.

1. A case study of EE using IRIS observations

(Huang, Madjarska, Xia, et al., 2014, ApJ, 797, 88)

- The Si IV spectra show "red-wing-dominant→red-blue balance→blue-wing dominant" evolution.
- Multiple compact and dynamic bright dots (<1").
- Small jets (<2" length, ~0.35" width).



The case in AIA and HMI observations

- The event can be seen in AIA 193, 211 channels;
- Loops are rooted in the events seen in AIA 304, 171 channels;
- Magnetic cancellation in a small bipolar region.

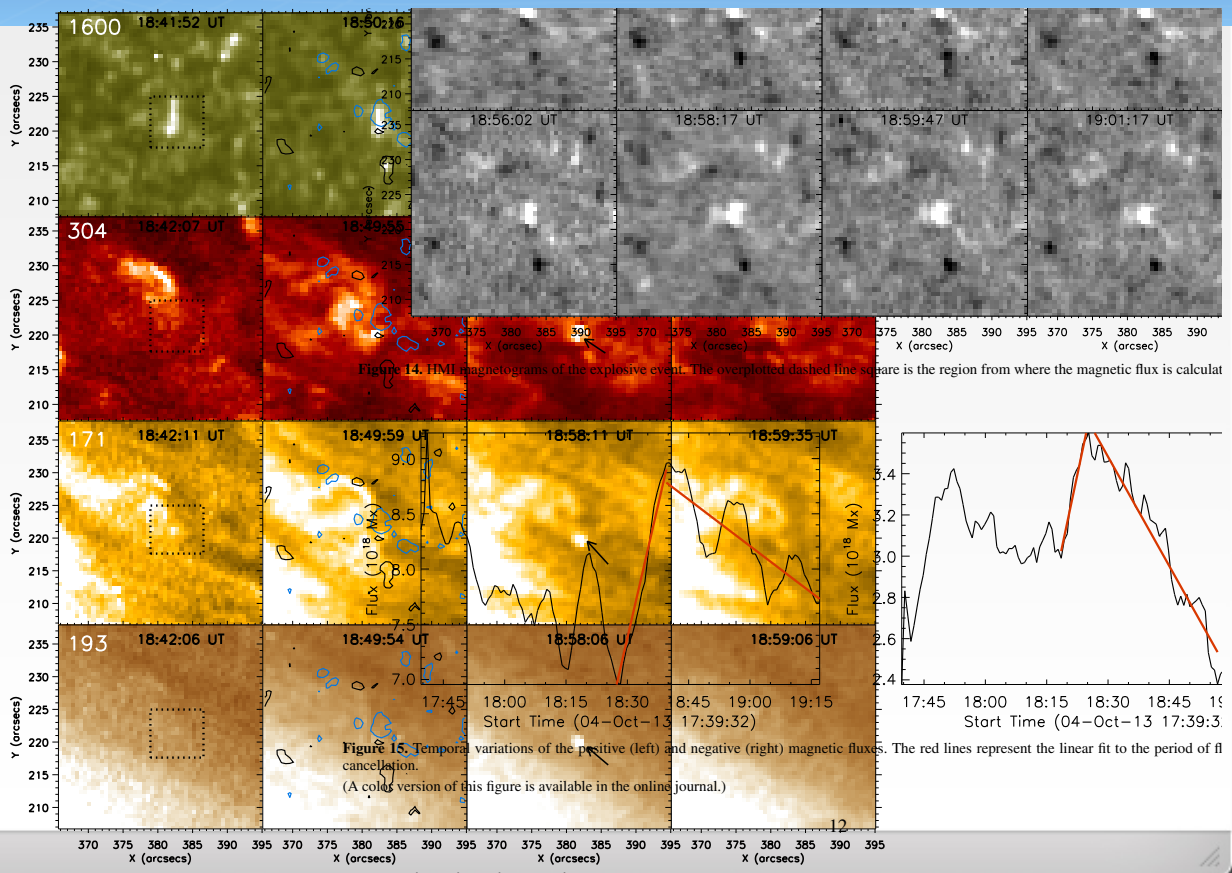
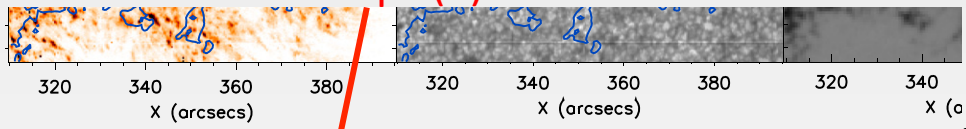


Figure 14. HMI magnetograms of the explosive event. The overplotted dashed line square is the region from where the magnetic flux is calculat

Figure 15. Temporal variations of the positive (left) and negative (right) magnetic fluxes. The red lines represent the linear fit to the period of fl cancellation.
(A color version of this figure is available in the online journal.)

2. IRIS observations of an active region with loops

Loops (II)



Raster at Si IV

Raster at 2832 Å

Figure 2. Loop region viewed in *IRIS* Si IV 1402.8 Å (left, in reversed color table), a 2832 Å continuum image (middle), a
(right). The contours on the *IRIS* raster images correspond to HMI magnetic flux densities at −200 Mx cm^{-2} (blue) and 200 M
"B" (with dotted lines), and "C" (with dashed lines) denote the three loop regions.

4.1. Group A: Cool Transition Region Loop with One Active Footpoint

The FOV containing group A is enlarged in Figure 3. In this region, we visually identified 15 loops (see Figure 3) using the Si IV radiance image and the SJ images (see Figure 4 and the online animation). The identification is based on cross-checking both the Si IV radiance image and the SJ images. Please note that this region is occupied by bundles of loops, many of which are clearly visible in the SJ images, though relatively weak in the Si IV radiance image (e.g., loops in the area below loop 12). Most of these loops do not show clear footpoints in the spectral data. In the *IRIS* SJ images, however,

more loops with apparent plasm
animation attached to Figure 4
nearby a region of two small
panel). They appear to be root
spread around the strong sunspo
these loops are located in a mi
while the northern ends are ass
(positive) area. The apparent ler
10″ (~7000 km) to 40″ (~30,0(

The Si IV Dopplergram of the
Figure 3) clearly shows that
change from blueshifted (negati

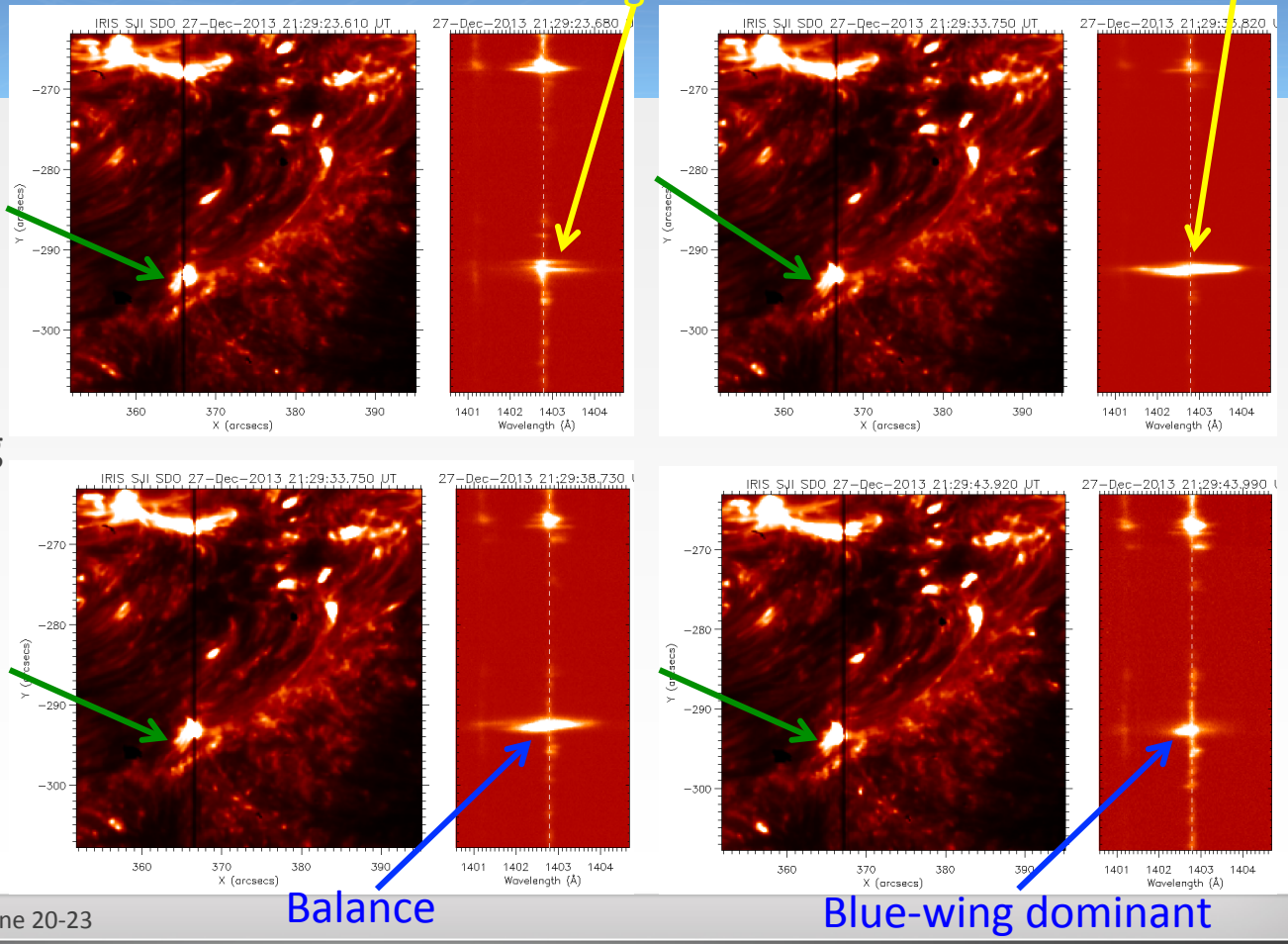
3

Loops (I)

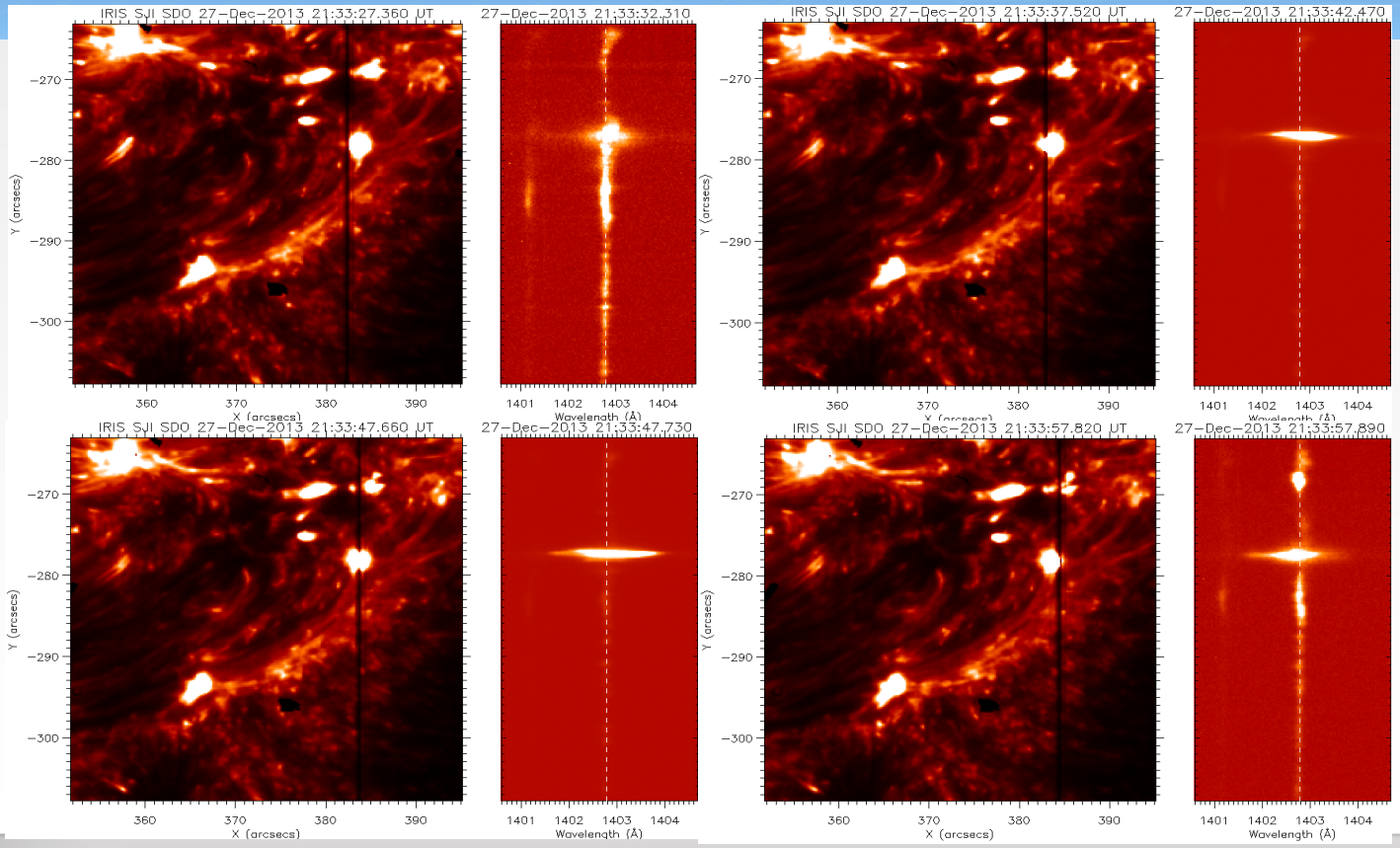
Huang, Xia, Li, Madjarska, 2015, ApJ, 810, 46

Si IV profiles in the footpoint of loops (I)

- When the spectral slit scans the footpoint from east to west, the Si IV spectra are turning red-wing dominant to blue-wing dominant. →signature of magnetic reconnection
- Multi-thread brightenings extended from the footpoint.

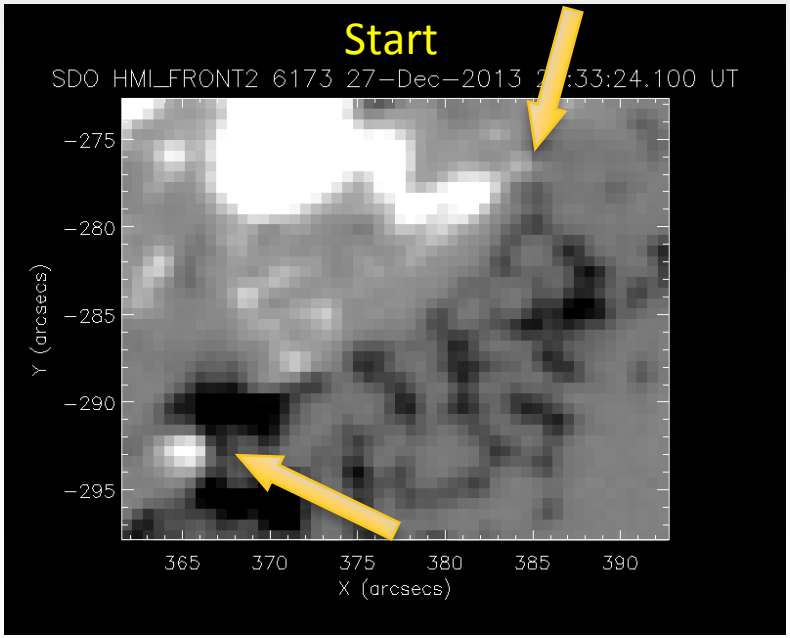


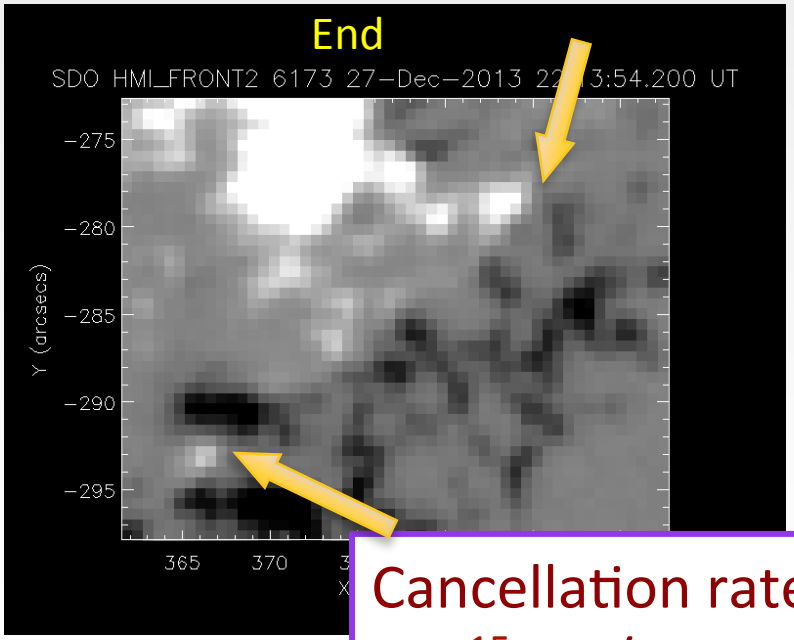
Si IV profiles in the other footpoint



- The same phenomenon is seen in Si IV spectra of the other footpoint.

Significant flux cancellation at the footpoints: another evidence of magnetic reconnection

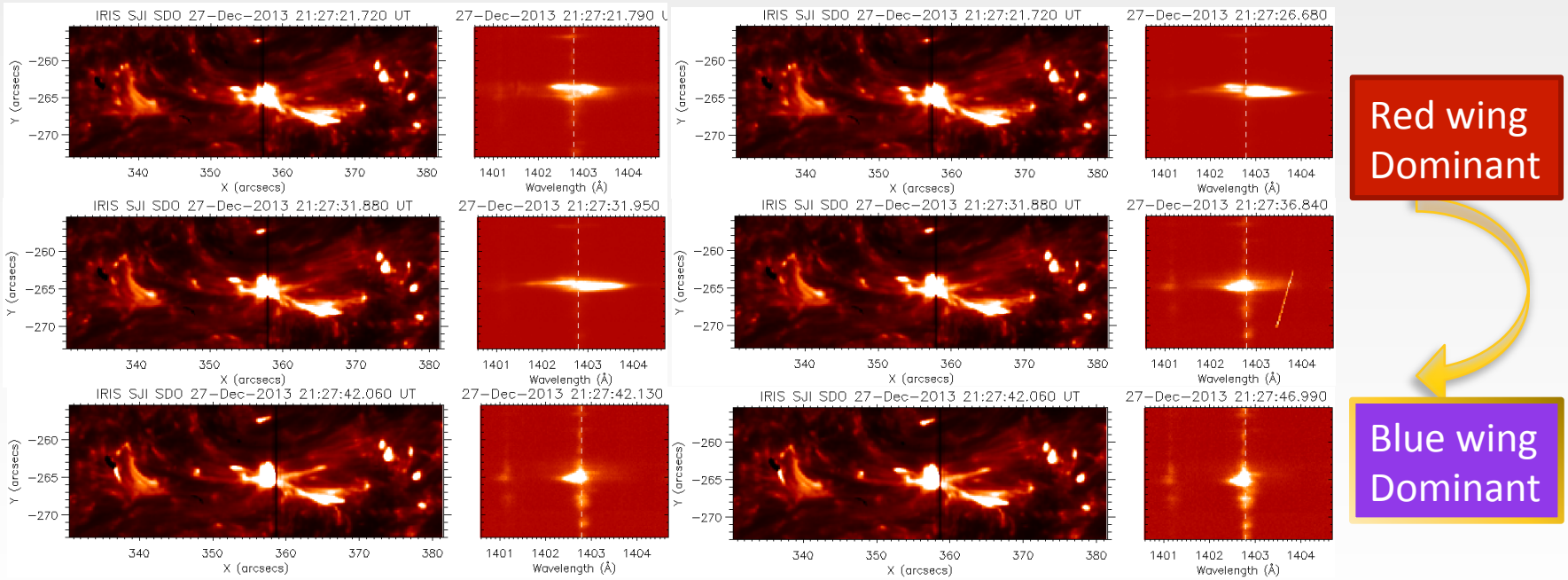




Cancellation rate : ~10^{15} Mx/s

Huang, Xia, Li, Madjarska, 2015, ApJ, 810, 46

Evolution of Si IV profiles in loops II



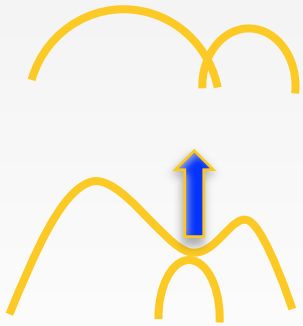
- Spectroscopic signature of magnetic reconnection occurring between transition region loops

Loop raising from the conjunction region → evidence of magnetic reconnection in imaging data

near a small sunspot while their northern legs are associated with a single magnetic polarity. Possible siphon flows in these loops are suggested by the Si IV 1402.8 Å Doppler velocities that are gradually changing from about 10 km s^{-1} blueshifts in the southern legs to about 20 km s^{-1} redshifts in the northern ones. The nonthermal velocities in the major sections of the loops vary from 15 to 25 km s^{-1}, but increase in the southern ends. We concluded that these loops can not be heated by a steady energy release process and impulsive heating mechanism is required. The energy is possibly deposited in their southern ends where magnetic cancellation with a rate of 10^{15} Mx s^{-1} indicates the release of significant magnetic energy. The magnetic energy is likely to be released impulsively by magnetic reconnection, and it is redistributed by the enthalpy flux carried by the siphon flows.

Si IV 1402.8 Å. Both footpoints
regions. Small-scale magnetic rec
the footpoints, which are witne
profiles with enhanced wings
shifts and magnetic cancellati
10^{15} Mx s^{-1}. These loops are p
by small magnetic reconnecti
transition region. Doppler veloc
that blue and red Doppler-sl
12 km s^{-1} alternate along the loc
vary from 10 to 25 km s^{-1}. Th
images show finer strands in whi
flows might be present.

Group C is an excellent exam
loop systems that have two en



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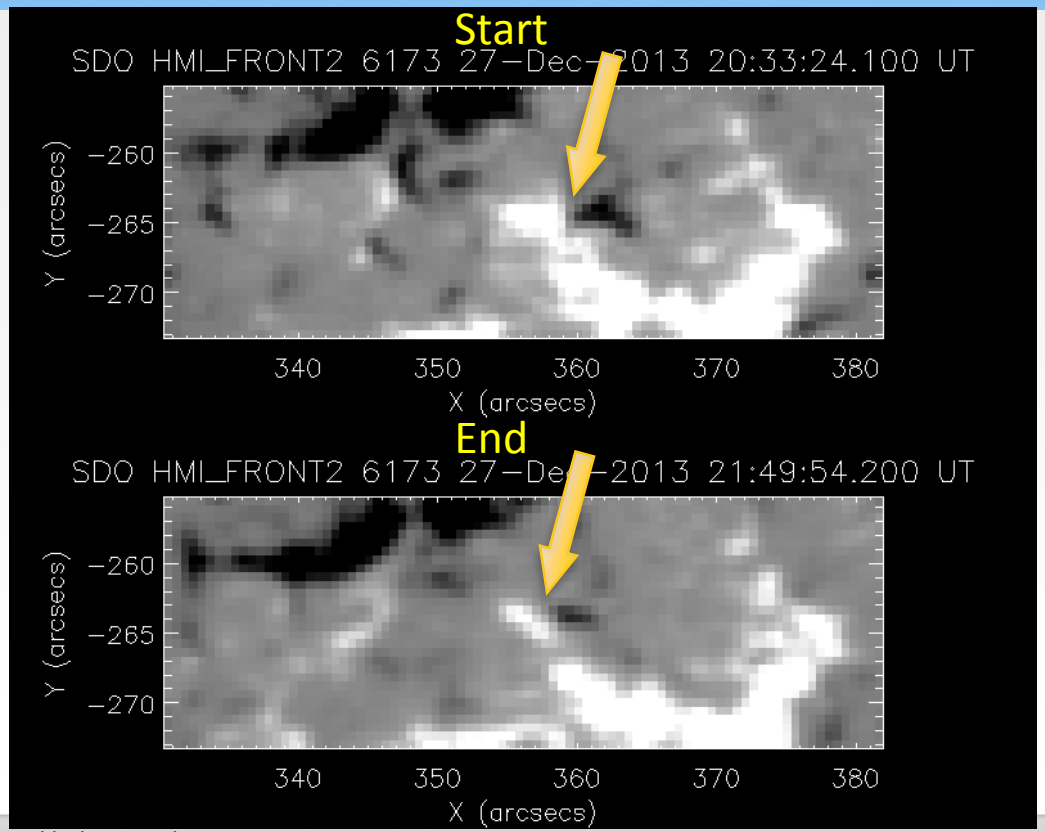
Huang, Xia, Li, Madjarska, 2015, ApJ, 810, 46

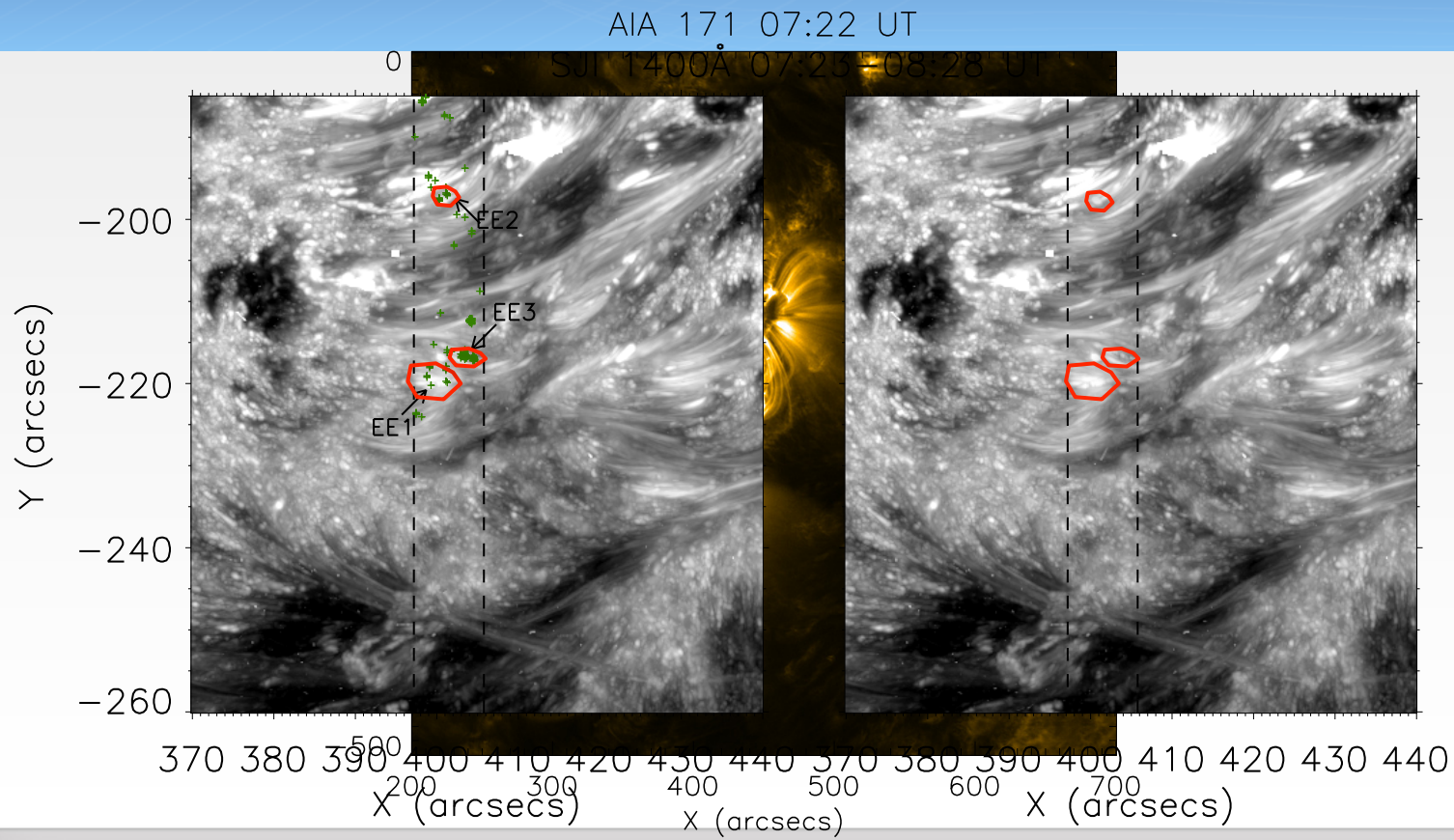
Flux cancellation → evidence of magnetic reconnection in magnetic field data



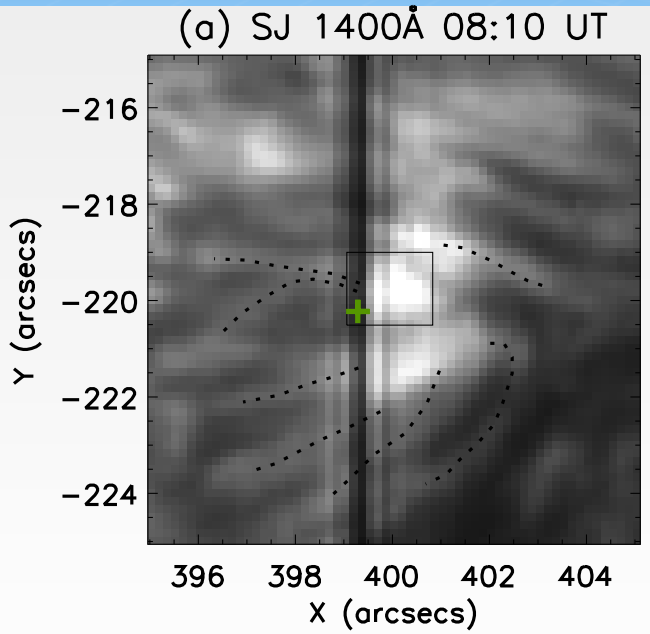
Huang, Xia, Li, Madjarska, 2015, ApJ, 810, 46

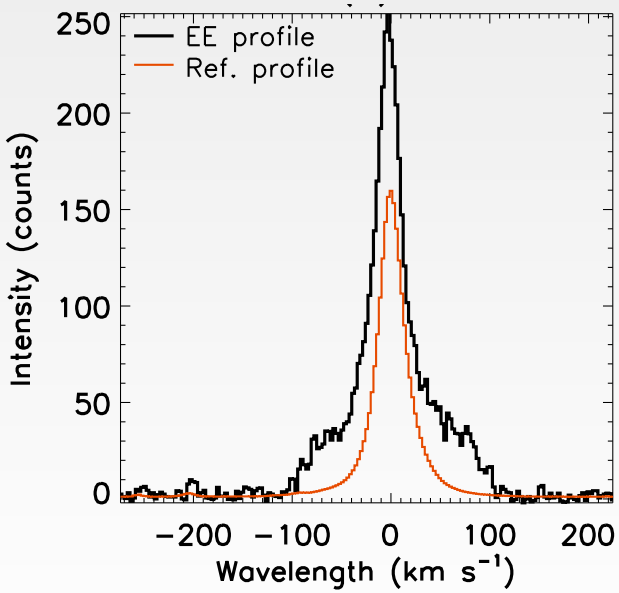
Cancellation rate : ~3×10^{15} Mx/s

3. Explosive events are also associated with brightenings along loops



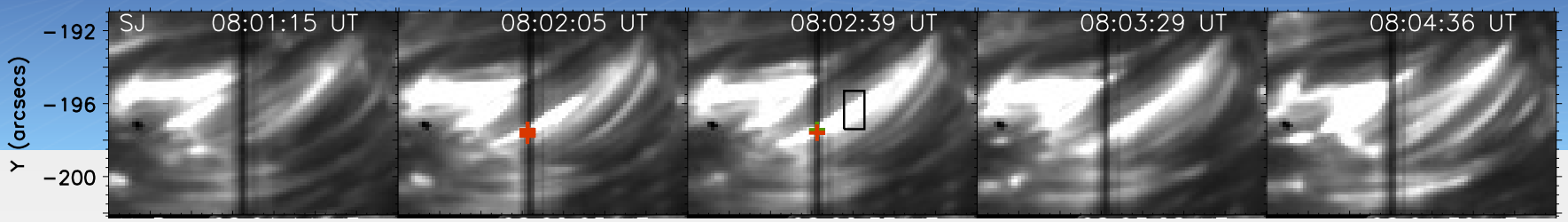
EE1

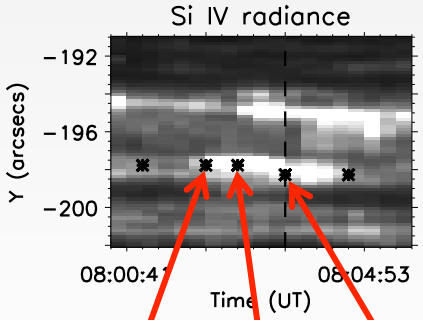


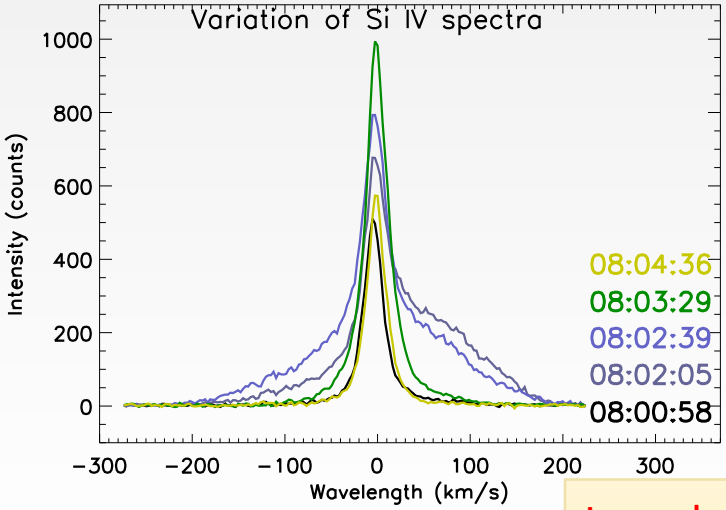


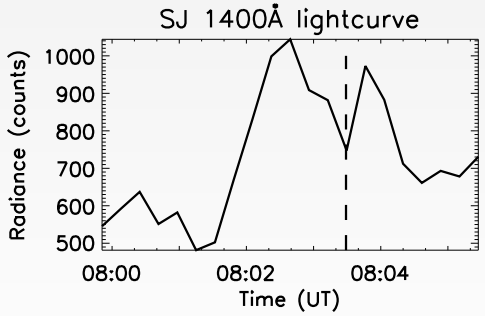
- EE1 occurred in a conjunction region of multiple loop footpoints.

EE2: brightenings along loops









Explosive events

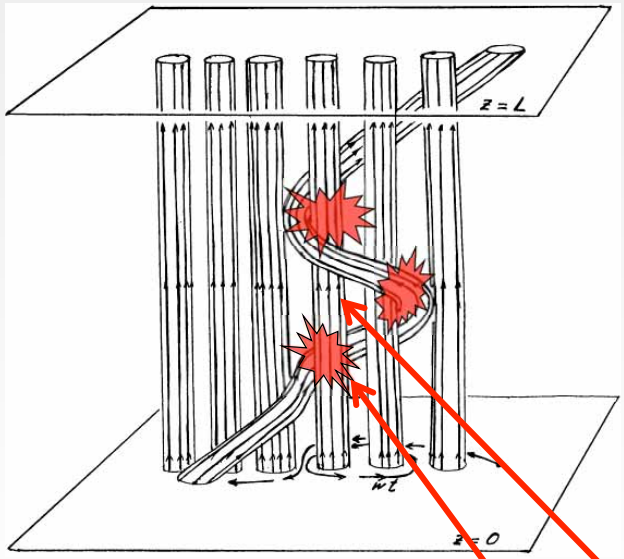
Not Explosive events

Loop brightenings after 08:03:29 do not produce explosive events. Why?

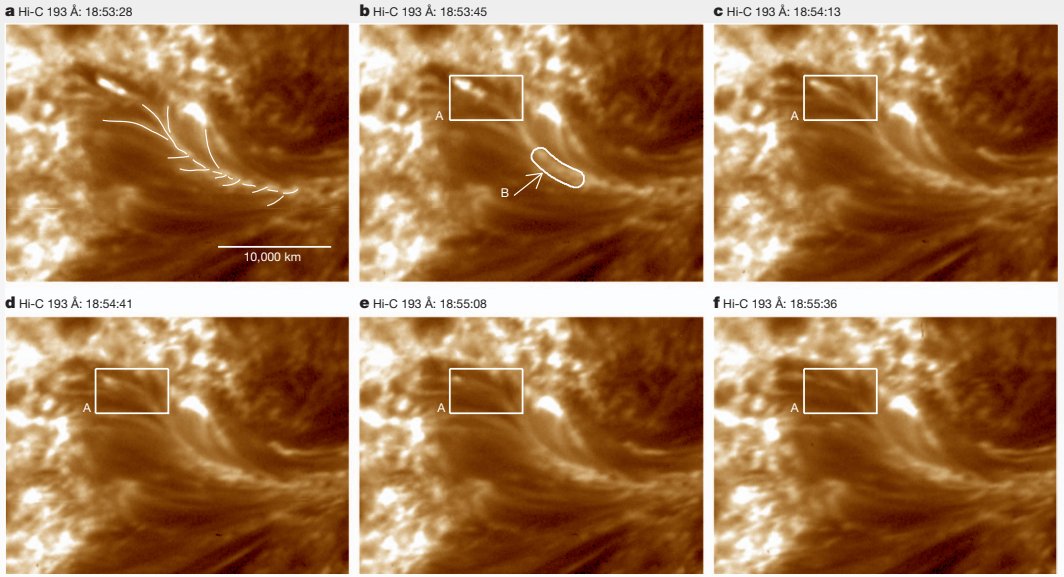
EE3: propagating loop brightening

18 km/s

Reconnection in braidings of loops?



Parker, 1972, ApJ



Cirtain et al., 2013, Nature

No reconnection

Reconnection

Summary

- With IRIS observations, we found
  - An explosive event in quiet-Sun is associated with multiple bright dots in a complex loop system;
  - In active region, explosive events are found to be evidences of magnetic reconnection occurring in the conjunction region of transition region loop footpoints;
  - In active region, brightenings along transition region loops can also produce explosive events, which might relate to magnetic reconnection occurring in loop braids;
  - Explosive events are one important signature of reconnection events that heat the transition region plasma.