Quiet sun magnetic field evolution observed with Hinode SOT and IRIS

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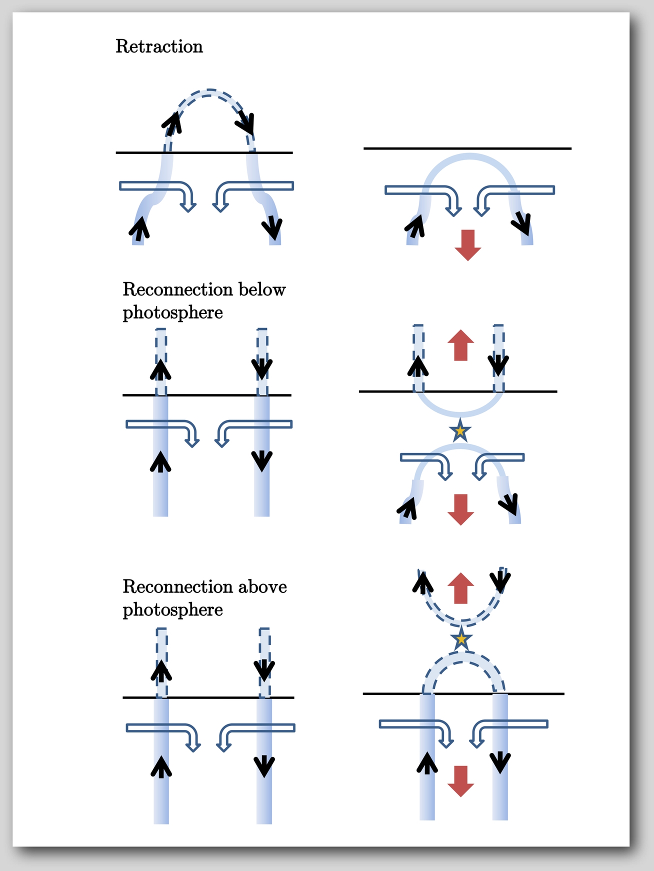
Flux Cancellation



Three possible flux removal processes

Three possible flux removal mechanisms according to Zwaan (1987). The left configuration sketches the configuration preceding the flux removal event on the right. The small black arrows indicate the magnetic field direction. The horizontal straight line represents the photosphere and the open arrows indicate the gas flow direction. The yellow star marks the location of the reconnection process and the filled red arrows indicate the travel direction of the loops.

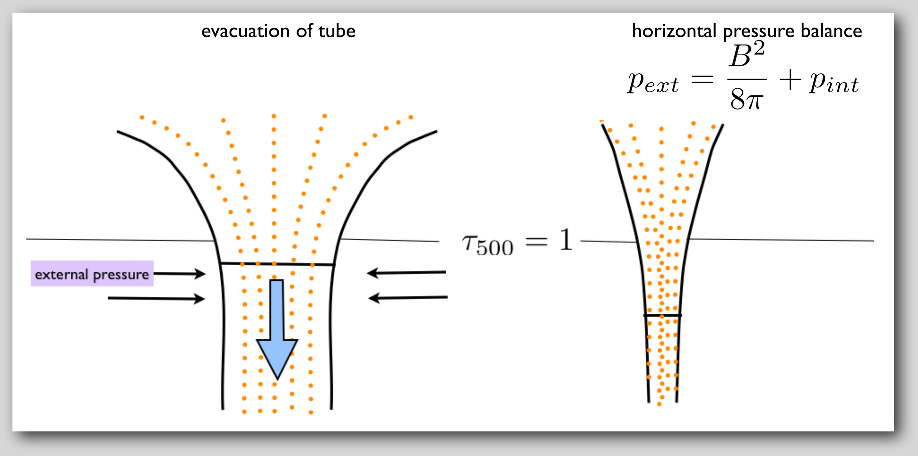
Observational signature

One expects to observe on the solar surface two opposite polarities in the longitudinal magnetic flux (B^L_{app}) with one, or both disappearing and a short-lived transverse magnetic flux (B^T_{app}) patch between the two polarities during the process. The observational signal on the solar surface is for all three cases the same, and one can not distinguish between these cases without additional, height-dependent information.

QUESTIONS:

What is the predominant flux removal process?
Observations of a flux cancellation event by e.g. Chae et al., (2010) suggest that reconnection took place in the chromosphere. What is the observable chromospheric and transition region response?

Convective Collapse



QUESTIONS:

What is the cause of the oscillations observed in the CaIIH intensity, photosph. vlos and magnetic field strength in the newly formed strong magnetic field tube that have been observed (Fischer et al., 2009)?

Does the rebounce of downflowing material from cooler denser lower layers inside the tubes as observed (Bellot Rubio et al., 2001) and found in simulations (Takeuchi et al., 1999) induce shocks? Are these observed in the chromosphere?

Theoretical Convective Collapse Process

1. Start with magnetic flux tube in the intergranular lane at few hundred Gauss. It is strong enough to reduce convective heating, which will develop an adiabatic temperature gradient in its radiatively cooled atmosphere. The dotted lines represent the magnetic field and the horizontal line shows the τ = 1 level and the Wilson depression inside the flux tube.
2. The convective collapse process assumes an initial mass downflow, represented by the big blue arrow pointing downwards. The temperature of the downwards traveling mass increases adiabatically, whilst the surrounding atmosphere shows a much steeper temperature gradient. This leads to an enhancement of the downdraft. The flux tube is then evacuated.
3. The tube is forced to compress as the gas outside the flux tube, represented by the thin black arrows, is pressing horizontally against it. The limit of the compression is reached when the magnetic field pressure balances the outer gas pressure. The right side shows the compression of the flux tube, which leads to the intensification of the magnetic field strength.

Process according to Parker(1978), Spruit & Zweibel (1979)

The Data

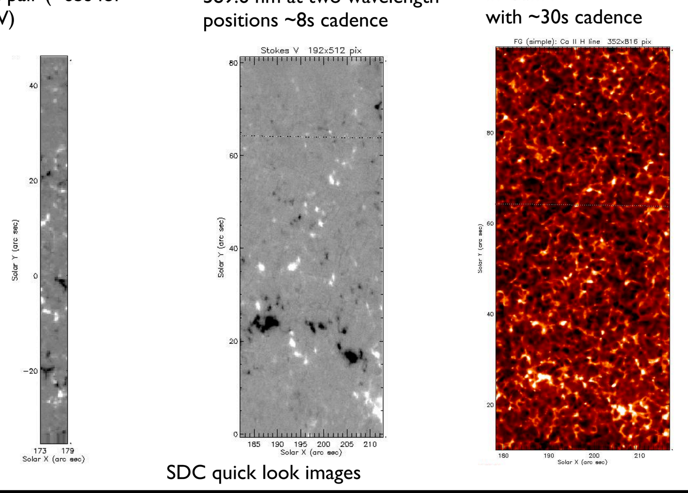
Hinode SOT Tsuneta et al. (2008)

~ 3 hours close to disk center co-temporal with IRIS

Spectropolarimeter (SP) full Stokes in the 630 nm line pair (~65s for full FOV)

Narrowband Filter Imager (NFI) filtergrams in Na 589.6 nm at two wavelength positions ~8s cadence

Broadband Filter Imager (BFI) recorded in CaIIH with ~30s cadence



SDC quick look images

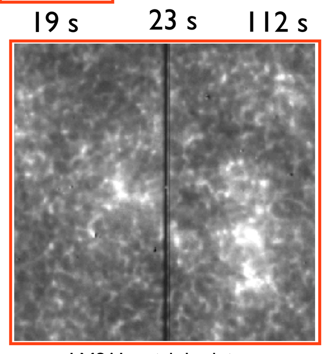
IRIS De Pontieu et al. (2014)

IRIS recorded in three passbands with the Slitjawimager and performed a 2-step raster with a 1 arcsec stepsize.

Spectra with ~19s cadence (9.6 s exposure at each slit position) in the following spectral windows:

1335.71	C II 1336
1355.60	O I 1356
1393.78	Si IV 1394
1402.77	Si IV 1403
2832.88	2832
2814.60	2814
2796.20	Mg II k 2796

2796 Å	1400 Å	2832 Å
19 s	23 s	112 s



LMSAL quick look image

Summary

We are in the process of finding and grouping the events according to the process phase they are in whilst being captured by the IRIS slit. Next we will perform frequency analysis of the chromospheric velocity oscillations with and without magnetic elements present. This will give a more complete picture of these quiet sun processes.

We see so far...

⇒ *Convective collapse event showing a substantial downflow (10 km/s) below the Mg II k3 formation height followed by continued velocity oscillations in the chromosphere.*

⇒ *Kilogauss magnetic element is repeatedly weakened below 1 kG and intensified to magnetic field values of above 1.5 kG which could be a sign of reoccurring convective collapse explaining the oscillation in the magnetic field parameter. Another strong magnetic element is in contrast weakened by flux cancellation.*

⇒ *Quasi-continuum increases increases by more than factor 2 during flux cancellation and larger k2v/k2r peak separation seen in Mg II k spectra*

References:

Bellot Rubio, L. R., Rodriguez Hidalgo, I., Collados, M. et al. , 2001, ApJ,560,1010
Chae, J., Goode, P. R., Ahn, K., et al. , 2010, ApJ, 713, L6
De Pontieu, B., Title, A. M., Lemen, J. R. et al. , 2014, Solar Physics 289, pp. 2733-2779
Fischer, C. E., de Wijn, A. G., Centeno, R. et al., 2009, A&A, 504, 583
Parker, E. N. 1978, ApJ, 221, 368
Spruit, H. C., & Zweibel, E. G. 1979, Sol. Phys., 62, 15
Takeuchi, A. 1999, ApJ, 522, 518
Tsuneta, S., Suematsu, Y., Ichimoto, K. et al. , 2008, Solar Physics 249, pp. 197-220
Zwaan, C. 1987, Annu. Rev. Astron. Astrophys., 25, 83

Results

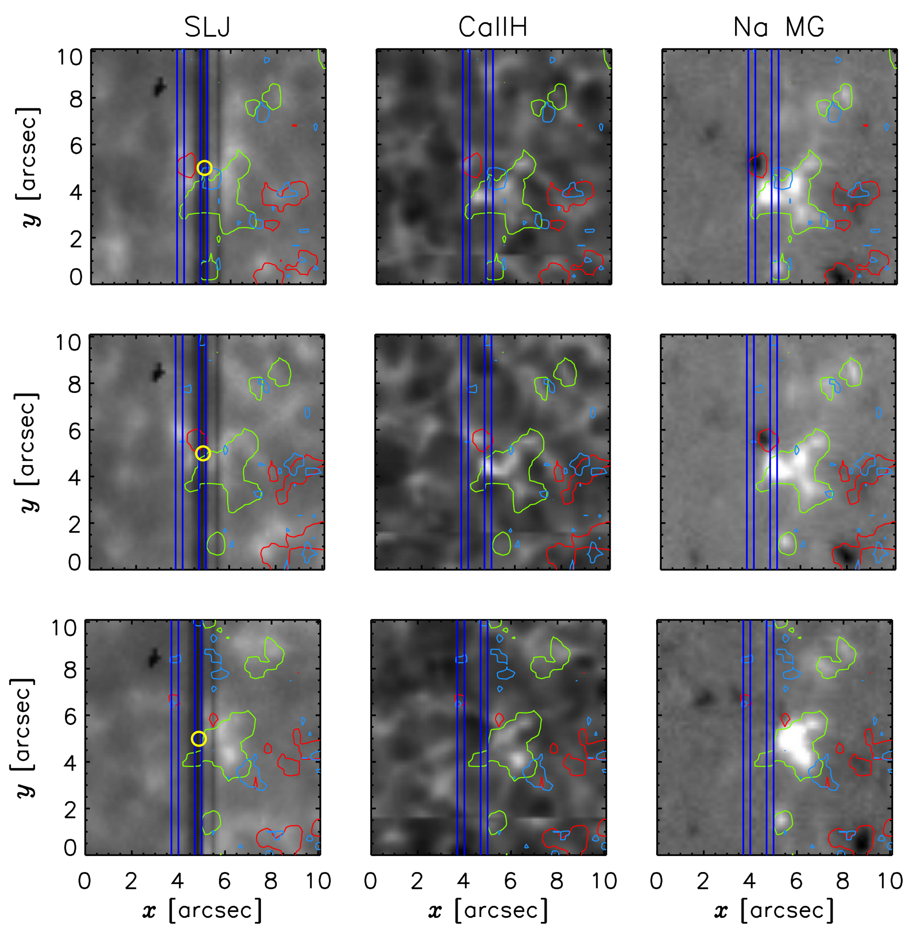
Data processing

The SOT NFI and BFI data was processed with the fg_prep.pro and the SOT SP data was processed with the sp_prep.pro routine provided by the HINODE SolarSoft instrument package. We constructed magnetograms and dopplergrams from the SOT NFI Na filtergrams and obtained MERLIN Stokes inversion results for the SOT SP data from the Community Spectro-polarimetric Analysis Center at the HAO. The IRIS data was downloaded as level 2 data from the LMSAL data center. All images were scaled to the IRIS slitjaw image scale. We then aligned the SOT NFI magnetograms with the SP magnetograms and to the SOT BFI CaIIH filtergrams. Finally the IRIS 2796 Å slitjaw images were aligned with the CaIIH broadband filtergrams and using the hairline in the slitjaw images and the slit spectrum we applied a correction for the residual shift. For the images shown below the data arrays were searched in each data cube for the closest image in time.

Flux cancellation event

The following panels show in each row the IRIS 2796 Å slitjaw image, followed by the SOT CAIIH image and lastly magnetograms constructed from SOT Na filtergrams. The two slit position of the IRIS raster are marked with blue vertical lines. The location of the slit spectra shown below is marked in the slitjaw images with a yellow circle. The green and red contours denote opposite polarity magnetic flux in the photospheric SOT SP magnetograms and the bright blue contours denote the transverse magnetic flux.

Event duration approx. 10 minutes



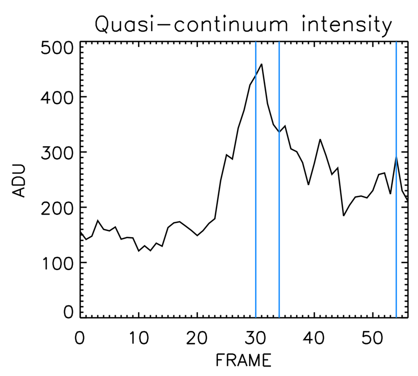
A magnetic element is pushed towards an opposite polarity group of magnetic elements.

A transversal magnetic flux patch appears possibly signifying the presence of a newly formed loop.

Continuation of flux cancellation takes place at slit position.

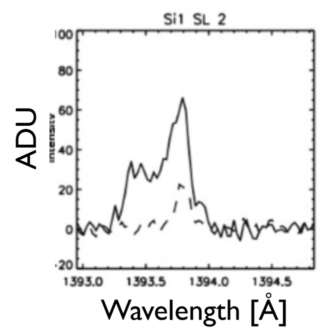
One of the footpoints has almost entirely disappeared.

15.2.2016
There was an error in the continuum locating. In the proceedings contribution we average 5 continuum points between 2795 and 2795.3 Å.
The qualitative development does not change however.



The left image shows the MgIIk quasi-continuum intensity versus time.
The blue vertical tick marks mark the time at which the above panels have been taken.
During the flux cancellation the entire spectral range has increased in intensity.
The peak separation of k2v and k2r increases as well (not shown in plot).

Other events:

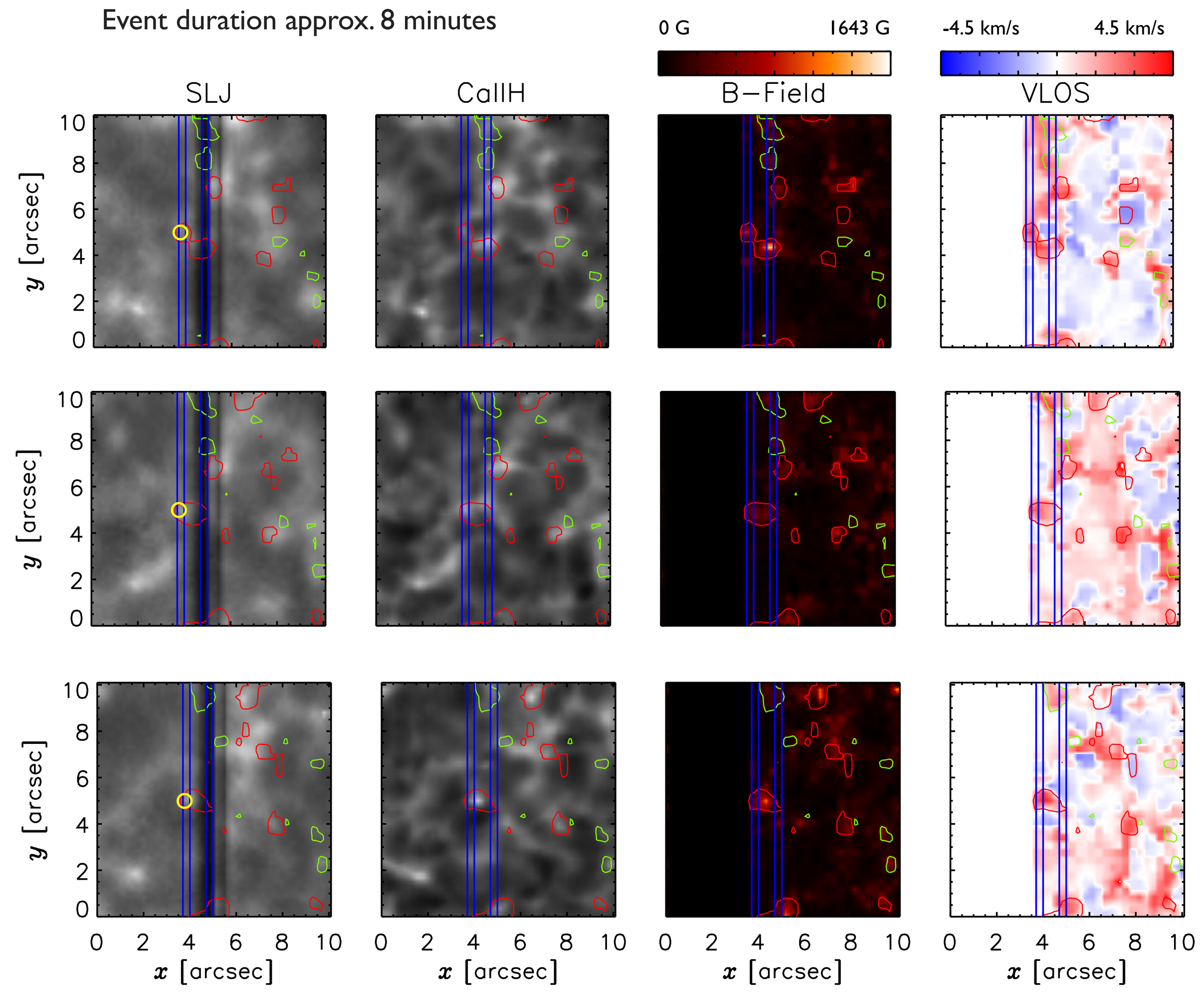


Another flux cancellation event takes place when an emerging loop moves towards a pre-existing accumulation of opposite polarity magnetic elements. Above this group we find besides a chromospheric response also a response in the Si IV 1394 and 1403 transition region lines. There seem to be two components present which could indicate a bi-directional flow. The dashed profile is taken at the beginning of the flux cancellation event.

Convective collapse event

The following panels show in each row the IRIS 2796 Å slitjaw image, followed by the SOT CAIIH image and the last two panels are the magnetic field and velocity derived from the SOT SP profiles by Stokes inversion. The FOV in the SP data is reduced as the raster did not cover the entire area recorded by the BFI/NFI. The contours and lines represent the same items as in the flux cancellation event to the left.

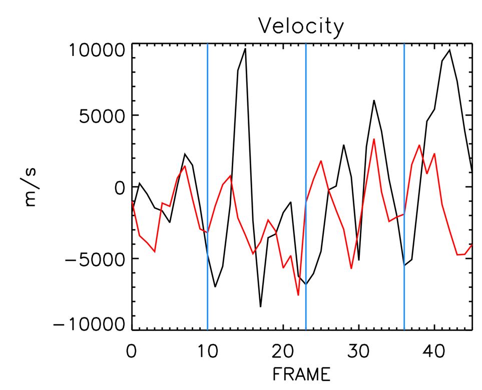
Event duration approx. 8 minutes



After a convective collapse the magnetic field strength in the magnetic element is above 1 kG. The strong magnetic field element is co-spatial with a CaIIH bright point.

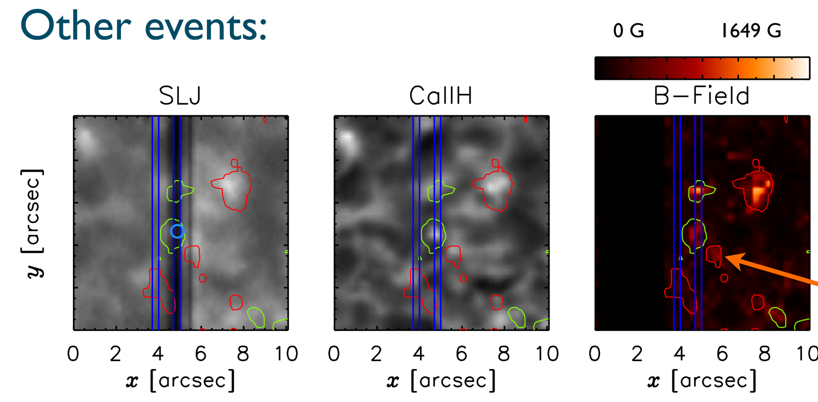
The magnetic field drops below 1 kG.

After another episode of photospheric downflow the magnetic field is increased again above 1.5 kG. A bright point appears in the Ca II H.



We show the inverse of the Centre-of-gravity velocity derived from the Mg II k spectra (black line), which is also a good indicator of the k2v/k2r peak intensity ratio and therefore the average velocity above the k2 formation height. Positive values denote downflows. The red line is the velocity derived from the k3 minima.
The strong downflow is not seen in the high chromosphere. The time of the images shown in the panels above is marked with a blue vertical line.

Other events:



The presence of another strong magnetic element element having undergone a convective collapse has a similar effect on the chromospheric velocity pattern as shown above. This magnetic element is ultimately weakened by flux cancellation with an approaching opposite polarity element.