Magnetic flux emergence followed by magnetic flux cancellation in the quiet-sun observed with the Interferometric BIdimensional Spectrometer (IBIS)

C. E. Fischer [1] and R. Rezaei [2,3]

1 Kiepenheuer Institut für Sonnenphysik, Schöneckstrasse 6, 79104 Freiburg, Germany; Email: cfischer @leibniz-kis.de
2 Instituto de Astrofísica de Canarias, Avda Vía Láctea S/N, La Laguna 38200, Tenerife, Spain
3 Departamento de Astrofísica, Universidad de La Laguna, 38205 La Laguna (Tenerife), Spain

1. INTRODUCTION

Magnetic flux removal is constantly observed in longitudinal magnetograms in the photosphere: opposite polarity magnetic flux density patches approach each other, show a steady loss of magnetic flux and, finally, one or even both patches will disappear. Zwaan (1987) described three possible ways of removing magnetic flux from the solar surface (see Fig. 1):

(1) simple retraction with an opposite-polarity pair connected through a loop being dragged into the convection zone without any reconnection taking place.

In the second and third scenario the opposite polarities are at first not connected. They are convectively forced together and reconnection takes place either above or below the solar surface. In both cases two new loops have formed.

(2) in the case of reconnection below the surface the newly formed U-loop travels upward, causing a transverse magnetic field signal when passing the surface.

(3) Whereas, if reconnection takes place above the photosphere, an Ω-loop is formed and consequently submerges.

In all three cases (1) - (3), the signature in photospheric magnetograms consists of two mutually approaching patches of opposite polarity, followed by a transient transverse magnetic field due to the passage of the apex of the newly formed loop. One cannot distinguish between these cases without additional, height-dependent information. Several authors have attempted to obtain information on the magnetic field topology during the cancellation process.

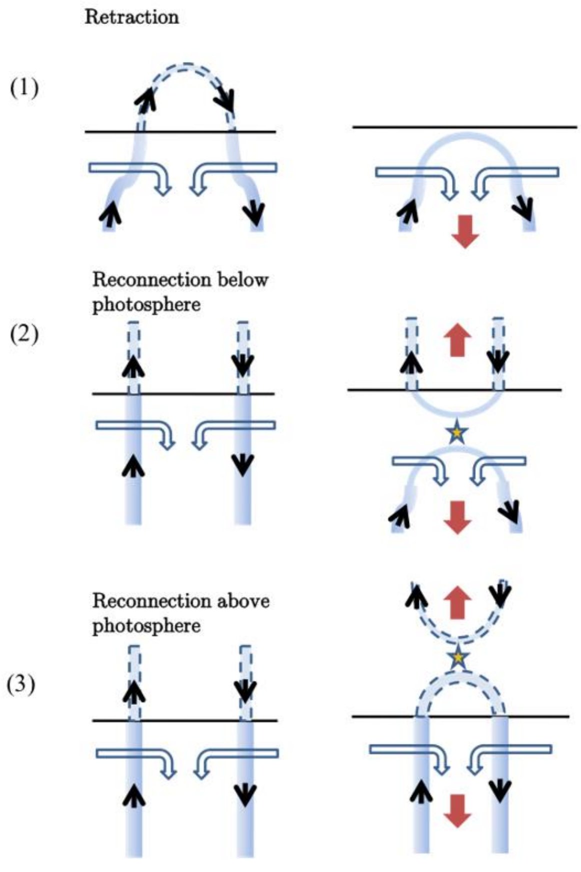

Figure 1: Cartoon showing three possible cases of flux cancellation. (after a cartoon in Schrijver & Zwaan (2000)). The solid blue loops denote magnetic field, with the parts above the solar surface (black line) outlined with a dashed blue line. The white arrows, outlined with a solid blue line, signify the gas flows. The red arrows show the magnetic loop travel direction and yellow stars are locations of magnetic reconnection.

Harvey et al. (1999) suggested that reconnection takes place primarily above the photosphere with subsequent submergence of Ω-loops as they observed that chromospheric magnetic flux disappeared prior to photospheric cancellation. Kubo et al. (2010) analysed Hinode spectropolarimetric data and found only 1 in 5 events showing a transverse magnetic flux signal indicating the presence of a loop apex.

In Fischer et al. (2011) we carried out statistics on Hinode spectropolarimetric data of a higher temporal resolution and found 27 of 33 events showing transverse magnetic flux during the event. We therefore confirmed the model picture of the cancellation process, yet, we could not distinguish between submerging/emerging loops.

The magnetic flux cancellation process is capable of reconfiguring the magnetic field topology by which magnetic energy can be converted to kinetic and thermal energy leading to observable atmospheric changes. Traces of case (3) can be, for example, high velocities (reconnection jets), local heating, loop brightening, or waves generated by the energy release. Borrero et al. (2010) found supersonic upflows close to opposite polarities, which they interpreted as jets caused by flux emergence interacting with pre-existing fields.

Fischer et al. (2016) observed heating events with the Interface Region Imaging Spectrograph (IRIS) at sites of magnetic flux cancellation which indicates events with reconnection taking place above the solar surface.

Our aim in this work is to characterize the flux removal process using multiwavelengths high-resolution data of the IBIS instrument. Thanks to data obtained for two spectral lines with different formation regions in the solar atmosphere we are able to follow the temporal evolution with height.

2. OBSERVATIONS

We obtained service mode data in October 2016 from the IBIS instrument which was installed at the Dunn Solar Telescope. The target was the very quiet-sun at disk center and we analyzed a time series of around 80-minute with a 32 s cadence. The Field-of-view was 40 arcsec to 90 arcsec with a pixel size of 0.097 arcsec/pixel. The seeing was variable ranging from medium to very good.

The spectral lines Fe I 617.3 nm and Na I 589.6 nm were observed in spectropolarimetric mode with 20 and 10 wavelength points, respectively, and in H-alpha 656.3 nm in spectroscopic mode with 14 spectral points.

The National Solar Observatory provided a calibration package which took care of the dark-and flatfielding of the data, as well as the blueshift correction which needed to be applied due to the collimated mount of the instrument. In addition, a destretch algorithm reduces seeing-induced effects. The polarization package calculated the Stokes I,Q,U, and V profiles correcting for telescope and instrumental induced polarization. Finally, we performed a crosstalk-correction for contributions from Stokes I to Stokes Q,U,V.

After the data reduction we aligned the narrowband data spatially through cross-correlation of the continuum images of the spectral lines.

We integrated the Stokes V profiles to obtain the total circular polarization (Eq. 1).

$$CP_{tot} = \frac{\int_{\lambda 1}^{\lambda 2} V(\lambda) d\lambda}{I_c d\lambda} \quad (1)$$

The signal in the linear polarization was mainly below the noise for this very quiet sun data set.

3. RESULTS

The event takes place in a quiet-sun internetwork region and the temporal evolution is shown in Figure 2. We observe a positive polarity element as seen in the circular polarization maps of Fig. 2 in the first row at around x/y = [9,10] (within red circle). This patch will eventually collide with a negative polarity element seen at x/y = [12,5]. The duration of the event is around 40 minutes with the negative polarity finally disappearing (see last row).

At T = 40 minutes (first row) we detect a positive polarity patch in the Fe I 617.3 nm diagnostics. It is difficult to observe the matching negative polarity of this newly appearing magnetic flux. We suggest that the negative polarity patch at x/y ~ [12,5] consists of actually two distinct longitudinal magnetic flux density foot points, one of which is associated with the newly appearing positive polarity patch. In the total circular polarization maps in Na I 589.6 nm we do not find the emerging/newly appearing positive polarity patch (empty red circle). This indicates, that we might be observing an emerging magnetic loop in the lower photosphere which has not reached the formation height of the Na I 589.6 nm spectral line which is formed in the high photosphere. This is reconfirmed when looking at the total circular polarization maps in Na I 589.6 nm where the negative polarity patch seems smaller and might only be associated with the pre-existing magnetic field. In the following sequence the positive polarity patch becomes also shortly visible in the Na I 589.6 nm diagnostics.

At T = 59.73 minutes a clearly visible brightening appears in the H-alpha core images (within black circle, last image, second row). It is located within 1-2 arcsec proximity to the magnetic flux emergence site. We also detect a dark cloud in the H-alpha core images (green circle). This dark cloud indicates cooler denser gas within the hotter environment. Following the time development of the cloud it expands in size and appears even darker with time (see rows three and four in Figure 2). At 60.27 minutes we detect at the former lo-

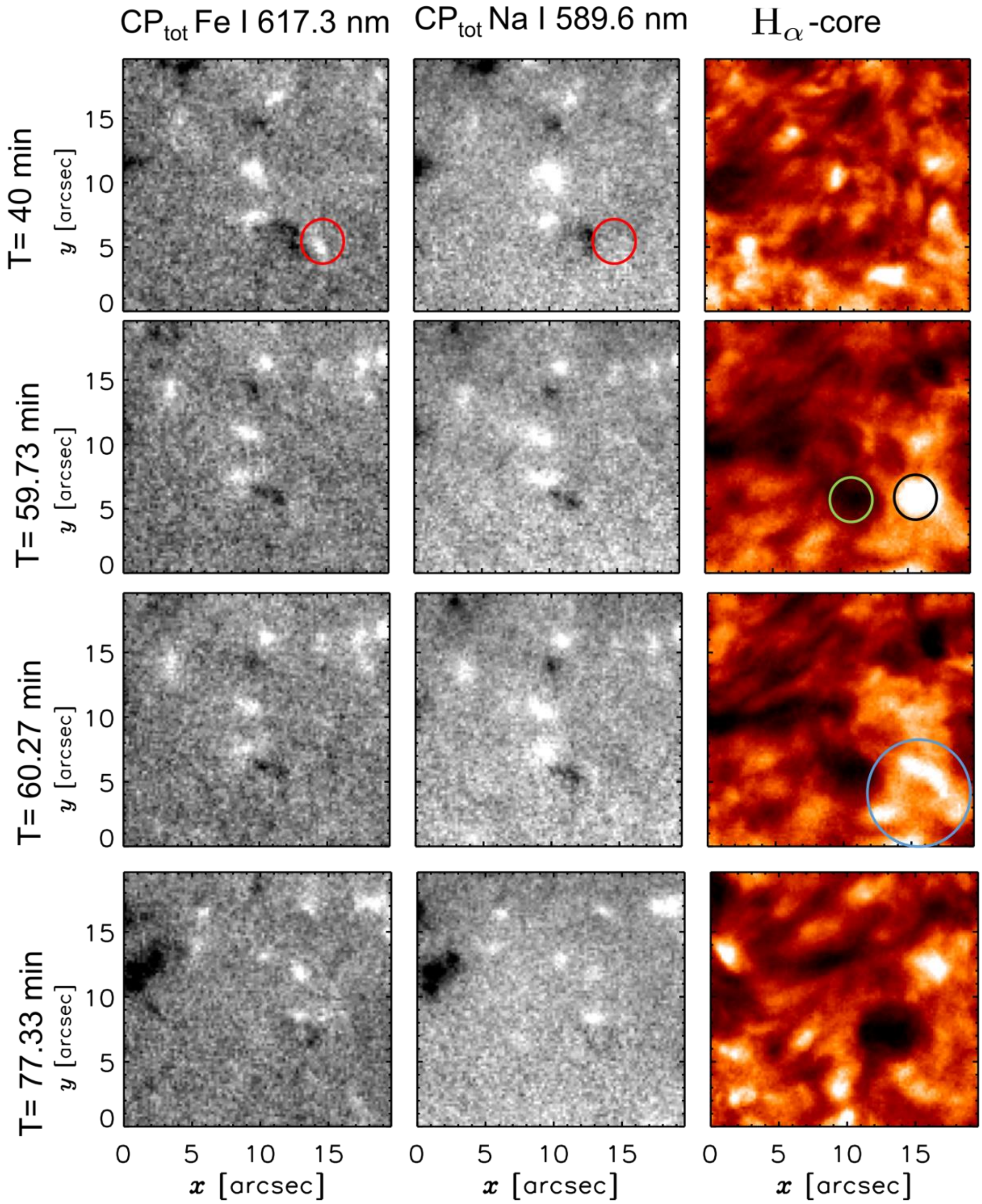

Figure 2: Magnetic flux emergence followed by magnetic flux cancellation. The columns show the total circular polarization maps for the Stokes V profiles in the Fe I 617.3 nm line, followed by the total circular polarization maps for the Na I 589.6 nm line, and finally, the H-alpha line core images (in data units). Top to Bottom: the panels depict the scene at 4 different times (written on the left side). The colored circles signify locations of interest referenced in the text.

cation of the brightening a bright loop like structure (within blue circle, third row).

A possible interpretation of the described events is the following scenario: a magnetic loop emerges from the low photosphere into higher layers. During its ascent it collides with the pre-existing magnetic field and magnetic reconnection takes place in the chromosphere evidenced by the increase in radiation in the H-alpha line core. The magnetic loops are reconfigured, leaving a post-reconnection loop, analog to what is observed during large-scale magnetic reconnection in flares.

In Chae et al. (2010) a similar event was found in a quiet sun region. They analyzed H-alpha images recorded with the New Solar Telescope (now Goode Solar Telescope) and obtained magnetograms from the Michelson Doppler Imager as context data. They had no further information on the magnetic field topology, however, they were able to follow their event describing the morphology with high spatial resolution H-alpha images. They interpreted the observations of a brightened shrinking loop in their H-alpha core images accompanying the flux cancellation event as a post-reconnection loop. They also observe the eruption of a small cloud.

The scale of our bright loop feature is similar to the findings of Chae et al. (2010). We also detect a dark cloud as seen in the H-alpha core images, which might be signifying an ejection of cool material from the reconnection site. In our case the dark cloud appears also next to the location of brightening and seems to expand with time as well.

4. SUMMARY

Thanks to the multiwavelength spectropolarimetric observations we are able to draw conclusion on the sequence of events during the emergence of a magnetic flux into a pre-existing magnetic system. We observe a brightening in H-alpha next to the emergence site as well as expulsion of a dark cool material blob. This is shortly afterward accompanied by a magnetic flux cancellation. A possible interpretation is magnetic reconnection between established magnetic loops and an emerging magnetic field taking place in the chromosphere followed by the submergence of an Ω-loop.

Acknowledgements

We would like to thank the Dunn Solar Telescope team and pipeline developers for providing us with service mode data and software. This research is funded by the German Science Foundation (DFG) under grant agreement FI 2059/1-1. C.E.Fischer thanks the organizers of the NSPM24 meeting for the invitation.

REFERENCES

Chae, J., Goode, P. R., Ahn, K., et al. 2010, ApJ, 713, L6
Borrero, J. M., Martínez-Pillet, V., Schlichenmaier, R., et al. 2010, ApJ, 723, L144
Fischer, C. E. 2011, PhD thesis, Universiteit Utrecht, The Netherlands
Fischer, C. E., Bello González, N., & Rezaei, R. 2016, in ASPC, Vol. 504, 19
Harvey, K. L., Jones, H. P., Schrijver, C. J., & Penn, M. J. 1999, Sol. Phys., 190, 35
Kubo, M., Low, B. C., & Lites, B. W. 2010, ApJ, 712, 1321
Schrijver, C., & Zwaan, C. 2000, Solar and Stellar Magnetic Activity, Cambridge astrophysics series (Cambridge University Press)
Zwaan, C. 1987, ARA&A, 25, 83