Solar and Astrophysical Dynamos and Magnetic Activity
Proceedings IAU Symposium No. 294, 2012
A.G. Kosovichev, E.M. de Gouveia Dal Pino, & Y. Yan, eds.

doi:10.1017/S174392131300241X

Evolution of magnetic field corresponding to X-ray brightening events in coronal holes and quiet Sun

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Abstract. We study the magnetic field structure and evolution for 26 X-ray brightening events in coronal holes and quiet Sun regions, including bright points and jets. We found that all brightening events are associated with bipolar regions and caused by magnetic flux emergence followed by cancellation. The emission fluctuations seen in the X-ray bright points are associated with reoccurring magnetic cancellation in the footpoints. An X-ray jet presents similar magnetic behaviour in the footpoints but its magnetic flux cancellation rate is much higher than in the bright point. Comparing coronal holes and the quiet Sun, we do not find differences in their corresponding magnetic field behavior.

Keywords. Sun: corona - Sun: chromosphere - Sun: evolution - magnetic fields

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X-ray brightening events, i.e. X-ray bright points (BPs) and X-ray jets are omnipresent in both coronal holes (CHs) and the quiet Sun (QS), and are suggested as one candidate of the source of the slow solar wind (Madjarska *et al.* 2012, and references therein). Coronal BPs are emission enhanced structures with size of $20''$–$30''$ and maximum lifetime of tens of hours observed in the solar corona. BPs show variations in their radiance lightcurves (Habbal & Withbroe 1981; Madjarska *et al.* 2003, etc.). The reason for these oscillations is still under debate. BPs are found to be associated with small bipolar regions, within which most are converging or cancelling (Golub *et al.* 1977; Webb *et al.* 1993). X-ray jets are dynamic phenomena which represent collimated plasma flows from coronal BPs (Doschek *et al.* 2010). They were first discovered in soft X-rays by Shibata *et al.* (1992) and are mostly associated with mixed polarity regions (Shimojo *et al.* 1998). Magnetic reconnection is believed to be the main mechanism of their formation (Yokoyama & Shibata 1995).

The observations include X-ray images taken by XRT (X-Ray Telescope, Golub *et al.* 2007), and chromospheric longitudinal magnetograms (Stokes V/I) taken by SOT (Solar Optical Telescope, Tsuneta *et al.* 2008) onboard Hinode. They include four datasets, whose details are listed in Table 1. After data reductions and coalignment, we sampled 22 events occurring in the CHs and six events in QS.

The evolution of the magnetic flux associated with a coronal transient brightening proceeds in a similar way for all events, including both BPs and X-ray jets. Magnetic evolution of events in CHs do not show difference compared to events in the QS. All brightening events identified in the X-ray images are caused by magnetic flux emergence and a follow-up cancellation with the pre-existing and/or newly emerging magnetic flux. The emergence is followed shortly after (a few tens of seconds) by cancellation. The emerging element can also surface at a distance away ($20''$ for instance) from the cancellation site. The newly emerged polarity then starts moving towards the stable centre often becoming larger with time by merging with a flux of the same sign. Once the

Table 1. Observations used in this study.

Date	Observing period (UT)	XRT sadence (s)	SOT cadence (s)	Observed region
2007-Nov-09	06:38 → 14:59	40	90	Coronal hole
2007-Nov-12	01:21 → 10:57	40	90	Coronal hole
2009-Jan-10	11:30 → 16:59	60	45	Quiet Sun
2009-Jan-13	11:22 → 17:34	60	45	Quiet Sun

magnetic polarities get close to each other and start cancelling, a brightening will appear in the X-ray image. Magnetic flux emergence is also important in maintaining the field strength of a magnetic element during its cancellation. Flux cancellation and emergence are often seen to happen simultaneously at the same location.

An X-ray jet occurred in our field-of-view and was studied in detail. By comparing magnetic evolutions of X-ray jet and BPs, we found that the magnetic field at the footpoints of X-ray jet evolves faster than that of BPs. Regarding magnetic cancellation rate, which is defined as $\Delta F/\Delta T$, where ΔF is the decrease of magnetic flux and ΔT is the time period of the decrease, we obtained 1.9×10^{14} Mx/s (positive polarity) and 6.5×10^{14} Mx/s (negative polarity) for the BP, and 3.0×10^{14} Mx/s (positive polarity) and 7.9×10^{14} Mx/s (negative polarity) for the X-ray jet. The flux cancellation rate of the positive polarity of the X-ray jet is about 60% higher than that of the BP. The magnetic flux cancellation rate of the negative polarities (dominant one in this CH) of the X-ray jet is only 20% higher with respect to the BP.

Our results show that all brightening events are associated with bipolar regions and caused by magnetic flux emergence followed by cancellation. A bipolar region is not formed by only two simple opposite magnetic polarities but each polarity is organised in many magnetic elements. The emission fluctuations seen in the X-ray BPs are associated with reoccurring magnetic cancellation in the footpoints. Magnetic cancellation remains much longer than the lifetime of the events seen in X-rays. This shows that transient brightenings can maintain high temperature plasma only during part of their lifetime. Although the magnetic field configuration and evolution in both the X-ray jet and BP are generally same, magnetic field evolves much faster in the footpoints of X-ray jets than that of BPs. This suggests that a fast magnetic cancellation can release energy in an explosive way seen as a jet in X-rays. However, this mechanism needs further investigation in both observation and modelling.

Research at Armagh Observatory is grant-aided by the N. Ireland Department of Culture, Arts and Leisure. Hinode is a Japanese mission in co-operation with international partners.

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