MAGNETIC TOPOLOGY IN NOVEMBER 5, 1998 TWO-RIBBON FLARE AS INFERRED FROM GROUND-BASED OBSERVATIONS AND LINEAR FORCE-FREE FIELD MODELING

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ABSTRACT

We analyzed the 3D structure of the linear force-free magnetic field. A longitudinal magnetogram of the AR NOAA 8375 has been used as the photospheric boundary condition. Nov 5, 1998 2B/M8.4 two-ribbon flare can be explained in the framework of quadrupolar reconnection theory; the interaction of two closed magnetic loops which have a small spatial angle. The revealed magnetic configuration allows us to understand the observed location and evolution of the flare ribbons and the additional energy released during the gradual phase of the flare, as well. Besides, reconnection of closed magnetic loops can logically explain the connection between a two-ribbon flare and a giant X-ray post-flare arch which usually is observed after the flare onset. We emphasize that unlike the Kopp and Pneuman configuration, the model discussed here, doesn’t necessarily need destabilization and opening of the magnetic field.

Key words: Sun: flares, magnetic field, linear force-free field modeling

1. INTRODUCTION

It is generally accepted that a two-ribbon flare (TRF) is due to a reconnection process which happens in previously open magnetic field (Sturrock 1968, Hirayama 1974, Kopp and Pneuman 1976). It suggests that rising prominences and/or fast expanding coronal loops are trigger of the TRF. After the filament destabilization and eruption, the stretched magnetic field lines become open and reconnect. This process is accompanied by type III and IV radio bursts.

On the other hand, it has also been shown that there is no direct link between filament eruption and TRF (Forbes 1992). Out of 16 studied two-ribbon flares with pre-existing dark filament, in 10 cases filaments erupted and 5 filaments remained undisturbed (Hirayama 1974). In an earlier study by Smith and Ramsey (1964), about half of the major flares were found to be associated with active region filaments and preceded by their sudden eruption.

Any flare model must explain not only how and where magnetic energy is released, but also a location (shape?) and a topological link between all flare ribbons and remote brightenings seen in the course of a two ribbon flare.

The Hard X-ray Imaging Spectrometer aboard the SMM mission discovered extensive post-flare coronal arches (Švestka et al., 1982). The arches appeared to be connected to the occurrence of two-ribbon flares. Simberová et al. (1993) also showed that a giant post-flare arch was formed by interactions of large-scale loops present above the flaring active region. This result doesn’t seem to support the Kopp and Pneuman (1976) model which invokes the reconnection of the open magnetic field lines. To the contrary, the co-existence of a giant X-ray post-flare arch and a post-flare loops system can be a sign of a single reconnection event in a simple magnetic system of closed coronal loops.

For the famous, well-studied May 16, 1981 two-ribbon flare, Vršnak et al. (1987) established that the site of energy release was located at the loop top in a closed magnetic configuration. They also conjectured that, in the studied flare, a process of driven reconnection between neighboring loops took place.

Many studies have shown that chromospheric Hα kernels were found to be on the intersection of the separatrices (surfaces that separate volumes of different magnetic connectivity) with the photosphere. But only relatively few ones studied in detail the magnetic topology in two-ribbon flares (Gorbachev and Somov 1988, Demoulin et al., 1994a, Mandrini et al., 1995, Yurchishin 1997). Both the magnetic configuration and the Hα brightenings are found to be qualitatively different and more complex than ones proposed in models with open magnetic field. They concluded that the flares under consideration result from the interaction of closed large-scale magnetic structures, and not from an internal instability happening within a twisted flux tube.
2. OBSERVATIONAL DATA AND MAGNETIC FIELD RECONSTRUCTION

BBSO observations completely covered the Nov 5, 1998 flare which occurred in AR NOAA 8375 (Yurchyshyn et al. 2000). We also used the AII filter YOHOKH soft X-ray data.

Figure 1 shows GOES soft X-ray 1-8 Å flux plot of the flare as a function of time. It is interesting to note that the two-ribbon flare was not provoked by filament eruption, in fact, no filament was present in this AR. Figures 2 and 3 show Hα images obtained at the center and at the red wing of the spectral line. The post-flare loop system connected flare ribbons B and C and showed apparent growth.

To reconstruct coronal magnetic field we used a numerical method for the LFSS calculation proposed by Abramenko and Yurchishin (1996). We used the BBSO line-of-sight magnetogram as the photospheric boundary condition. The magnetogram was recorded at 18:18 UT, before the flare onset. We obtained a set of numerical solutions with different α parameter and then, using high resolution BBSO Hα images as well as soft X-ray images from YOHOKH we chose the numerical solution (α = 0.013 arcsec$^{-1}$) which best fits the observed magnetic configuration before the flare.

3. RESULTS

We used a simple method which allowed us to define magnetic links between the flare ribbons in this two-ribbon flare. First, we calculated, the lines of force which originate within the leading spot. Then, considering each line, we located both its footpoints. Doing so, we could distinguish three different magnetic flux tubes. All the lines of force which originate in the area marked with a have their ends at the flare ribbon marked with B (line 1, Figure 4). All the field-lines starting from the area b ended at the flare ribbon A (lines 2, 3, Figure 4) while field-lines coming...
out from the area c went south-eastward and ended at the Hα brightening D (Figure 5). Any two closest magnetic field lines originated correspondingly in areas a and b, nearby to the border between them, have their second ends separated and rooted in different distant magnetic elements of northern polarity. Thus, the boundaries of these a, b, c areas are the intersection of separatrices with the photosphere. In other words, following the definition by Demoulin et al. (1996), these boundaries are places where a drastic change in the field-line linkage occurs. Discontinuities in the field-line linkage at the boundary are at the origin of the formation of current sheets. It has been found that observed flare kernels are located at these discontinuities (Demoulin et al., 1996 and references therein). Our calculation show that in case of the Nov 5, 1998 flare, Hα brightenings are also located at places where rapid changes in the field-linkage above the photosphere take place. According to this, we are able to clear up the magnetic configuration in the two-ribbon flare as well as indicate magnetic fluxes which took part in energy release process.

We suggest that there were at least two large-scale events of energy release. The first and major energy release event happened about 19:35 UT (Figure 1). The Hα image taken at 19:43:35 UT (Figure 2) shows three well developed flare ribbons also marked on Figure 5 with letters A, B, C. We suppose that this energy release was due to the reconnection of two magnetic fluxes during which the connectivity of magnetic field was exchanged between four loop foot-points without a significant change in the longitu-

Figure 5. Hα + 0.75Å image taken at 20:56:35 UT. Dark loops at upper right – growing post-flare loops system (PFL). Solid lines denote calculated field-lines connecting the area b with the flare ribbon A. Dashed lines – calculated field lines (α = 0.013 arcsec⁻¹) which connect the area c with the flare ribbon D.

Figure 6. Greyscale Hα + 0.75Å image overlapped by a soft X-ray YOHKOH image shows the magnetic configuration after the flare. The resolution configuration consists of the low-lying post-flare loops system (dark loops) and the overlaying giant X-ray post-flare arch. The crosses denote the hottest parts of Hα and X-ray loops and might locate the site of the reconnection.

nal field. Analysis of the longitudinal magnetograms supports this theoretical assumption since no large-scale magnetic flux cancellations at, or around, the flare site were observed. The first magnetic flux is represented by a line i which connects the area a and the flare ribbon B and shown in Figure 4. The second one is magnetic flux which leaves the leading sunspot in the area b and goes to the flare ribbon A (lines of 2, 3). The reconnection will create new magnetic loops systems. The first one, the Hα post-flare loop system connects the area b and the flare ribbon B (Figure 4), while the second one, a large scale loop system, connects the area a and the flare ribbon A. This large-scale loop might corresponds to a well-known giant X-ray post-flare arch (Śvestka et al., 1982). Figure 6 shows the off-band Hα image (the same as in Figure 3) with an overlapped SXT/YOHKOH image. One clearly sees the presence of both the low-lying Hα post-flare loop system (dark loops) and the overlaying hot X-ray giant coronal arch (a white loop with contours at the right top corner). The Hα loop are located just below the hot X-ray loop with their top being almost tangential. The post flare loop system connects the leading sunspot and the flare ribbon B and the large scale X-ray arch has its footpoints at the sunspot and the flare ribbon A. This kind of magnetic connection corresponds to that predicted by the model.

Both, the post flare loops system and the giant X-ray post-flare arch exhibit apparent growth (Poletto
and Švestka 1992, Schmieder et al., 1995) as the flare is in progress. Thus, due to the evolution of newly formed loops, a disturbance of the pre-existing overlaying magnetic field will take place. This, in turn, might provoke the subsequent reconnection of the newly formed loops with the loops system which connects the area c and the flare ribbon D (Figure 5). If we are correct, this second-step reconnection should start a bit later than the main phase of the energy release. This might be seen in Hα images taken at 19:43 UT and 20:29 UT (Figure 2). One may see that when the eastern ribbon (marked with A in Figures 2) has faded, the south-east ribbon (marked with D) became brighter. Also, according to SGD (Figure 1), at 20:30 UT, after the X-ray flux reached its maximum, the GOES light curve has broken its gradual decrease and has formed plateau which might imply that an additional source of energy has turned on. This second reconnection event creates a new loop system connecting the area c with the flare ribbon A and b with D (Figure 5) and explains the evolution of the flare ribbons.

4. DISCUSSION AND CONCLUSION

As inferred from LFFF modeling, the two-ribbon flare was a product of multiple reconnection process between interacting loops which make a small angle in space. The calculations explore only the large-scale magnetic field structure in the AR. However, taking into account a possible filamentation of the solar magnetic field, this flare could be considered as a superposition of many small-scale reconnection events. In this case, one would expect a variety of angles between small-scale magnetic fluxes which would bring up the additional energy for the flare (Anschwanden et al., 1999). Another possible scenario is that the self-organized criticality model could be realized with the avalanche process of small-scale energy releases (Lu and Hamilton 1991).

The magnetic configuration, revealed here, naturally explains the location and the shape of the flare ribbons, the location of the post flare loop system, as well as the magnetic connection between the Hα brightenings. Multiple magnetic reconnection also allows us to explain the evolution of the flare ribbons and the additional energy release during the gradual phase of the flare. The interaction of closed magnetic loops in two-ribbon flare can also explain the origin of the giant X-ray coronal arch observed after the two ribbon flare onset (Švestka et al., 1982). This result also meets the Šimebrova et al. (1993)’s conclusion that the giant arch is the result of progressive reconnection of elementary flux tubes of two (or more) interacting loops.

We would like to emphasize that unlike the Kopp&Pneuman configuration, the model discussed here does not necessarily need destabilization and eruption of the active region filament. The filament eruption, even if it accompanies a two-ribbon flare, could be a one of many equal possibilities to trigger a solar flare.

REFERENCES


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