Some Advances in 3D-Magnetic Field Topology: an Observed Case of a “Bald Patch” Flare

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Abstract.

The aim of this work is to bring observational evidences of the possible role of the “bald patch” topology in flaring events. A bald patch (or BP) is present along the photospheric inversion line where the field lines are curved-up, so when magnetic dips are present. The set of field lines associated to the BP define a separatrix where a current sheet may form. We find such configuration in AR 7722 where, on May 18, 1994, a sub-flare was observed in X-rays by Yohkoh/SXT and in Hα at NAOJ. Using the magnetohydrostatic equations derived by Low (1992), we model the magnetic field configuration by extrapolation of the Kitt Peak photospheric field, taking into account the effects of pressure and gravity. Hα flare kernels are shown to be located at the lower parts of the computed separatrices associated to bald patches (BPs). This is an evidence that BPs can be involved in flares, and that current sheets can be dissipated in low levels of the solar atmosphere.

1. Introduction

A classical view of magnetic reconnection is mainly based on the MHD physics of 2-D configurations with an X-type neutral point, or on the extension of it to 3-D, and it is thought to be accompanied by flux transport across separatrices (places where the field-line mapping is discontinuous). These magnetic configurations are characterized by the presence magnetic nulls and the associated separatrices. This class of configurations is however too restrictive in view of the various observed configurations where flares happen (Seehafer, 1985; Démoulin et al., 1994), then a broader definition of separatrices is required (Démoulin et al., 1996 and references there in). This requires the definition of so-called quasi-separatrix layers (QSLs) which are the generalization of separatrices to magnetic configurations with a non-vanishing magnetic field strength. By analysing several flares and an X-ray bright point, Mandrini et al. (1996), Démoulin et al. (1997), Schmieder et al. (1997), and Gaizauskas et al. (1998) have shown that Hα flare ribbons are located on the intersection of QSLs with the chromosphere and that they are connected by magnetic field lines where intense soft X-rays
Figure 1. Comparison of observations to the computed topology. (a) Yohkoh/SXT image, (b) Hα observation from Mitaka, (c) Hβ magnetogram taken at Huairou and (d) Kitt Peak magnetogram. (a), (b), (c) and (d) are coaligned, Solar north is up, and the unit of the axis shown on (c) and (d) is in Mm. On (c) and (d), thin full (dashed) lines represent isocontours of the longitudinal component of the magnetic field of 10, 50, 200 and 600 G positive (negative) values. BPs are shown by the thickest lines; the intersection of their respective separatrices with the photosphere is represented by thick lines. Arrows show the regions of bright flare ribbons. A fairly good correspondence is found between some observed brightenings and computed separatrices.

are emitted. In this contribution we rather concentrate on a special case which have so far mainly received theoretical attention.

2. Physics related Bald Patches

Apart from the presence of magnetic null in the corona, separatrices can only be present in a magnetic volume when some field lines are tangential to the boundary (i.e. the photosphere). This can happen on portions, named bald patches (or BPs), of the inversion line (for the field component normal to the boundary). Above a BP, the field lines are curved up and the magnetic field cross the inversion line from the negative to the positive polarity; just the opposite as for a simple arcade!

Seehafer (1985, 1986) was the first to look to the presence of BPs in magnetic configurations computed from magnetograms with a linear force-free field. He proposed that the BPs found may be at the origin of the homologous flares
observed in BP vicinity. Titov et al. (1993) and Bungey et al. (1996) derived the conditions needed for the presence of BPs in magnetic configurations typical of some active regions, and they showed that BPs exist for a wide range of parameters.

The continuous set of field lines starting at a BP forms a separatrix surface which separates three topological regions. It has been proven that strong currents can be generated at BP separatrices in the case of magnetic configurations invariant by translation (see e.g. Low & Wolfson, 1988; Vekstein et al., 1991; Aly & Amari, 1997). The ohmic dissipation of the electric currents (via magnetic reconnection) is expected to give, at least, plasma heating. Billingshurst et al. (1993) have studied the conditions of current sheet formation at BP separatrices. They found that the amount of current accumulated along the separatrix strongly depends on the applied horizontal footpoint motions. Contrary to Low & Wolfson (1988), they have found little evidence of vertical current sheet formation at the BP when photospheric shearing motions are present. However Aly & Amari (1997) showed that a vertical current sheet can still be present above the BP when a neutral X-point appears at the photospheric level (this can be the case, at least, when photospheric converging, or diverging, motions are applied).

The physics of current accumulation and dissipation is expected to be significantly different at BP locations than in the corona, mainly due to the high density of the plasma at the photospheric/chromospheric level. One of the known effects is to reduce the validity of line-tying at the BP (Karpen et al., 1991). This effect is expected to broaden the BP separatrice, forming a QSL. The possible formation of a current layer in such configurations is still under debate, though Démoulin et al. (1996) have given some positive arguments for current accumulation at QSLs, and, Billingshurst et al. (1993) show that the current layer may be thin enough (for a fast dissipation).

3. An observed case of Bald Patches

We have investigated the magnetic topology of a sub-flare in the active region AR 7722. The release of energy is detected in Hα as well as in X-rays (Fig. 1). They are of small intensity, in particular they are not detectable by the GOES satellite. They have the characteristics of X-ray bright points or/sub-flares. In the following we use the terminology "sub-flares", but the reader may keep in mind also the terminology "X-ray bright points" since we believe that the physics of these phenomena is basically the same (see references above).

We used the linear magnetohydrostatic extrapolation (lmhs) method developed by Low (1992); this method introduces the plasma effects (pressure and gravity) on the magnetic field. The boundary conditions for the magnetic field have been given by a photospheric magnetogram from Kitt Peak (see Aulanier et al., 1998 for further information). The confrontation of the computed magnetic configuration with the observations brings new lights on the origin of the sub-flares.

The computation of BPs and their associated separatrices, in the region of the strongest emission observed in soft X-rays and Hα (see Fig. 1), reveals the presence of three BPs. One, BP1, lies on the local magnetic inversion line
Figure 2. 3-D view of the field lines forming the separatrix of BP1. A multiplicative factor of 8 for vertical extension of the field lines is used for a better viewing of the configuration. The separatrix is formed by two asymmetric lobes. The drawing convention is the same than in Fig. 1.

between N2 and P2, and we will call it BP1 (see Fig. 1d). One of the intersection of its associated separatrix with the z = 0 plane has a half-circle shape, which partially encloses N2. The other intersection has an elongated shape at the North of P2 (this portion is the brightest in soft X-rays and in Hα). Both intersections with the photosphere of the separatrix curve associated to BP1 as well as BP1 itself, have bright observational counterparts (on Fig. 1, arrow a1). A 3-D view of the BP1 topology is shown on Fig. 2. The BP1 separatrix curve shows two asymmetric lobes, the largest one joining the BP1 to the long northern ribbon which crosses N1.

Yohkoh/SXT shows flare activity in the region of the largest lobe of BP1 (see saturation on Fig. 1a), which implies that most of the energy was released there. A weaker X-ray emission is observed above the other separatrix lobe. This is likely due to its low altitude above the photosphere. Hα observations also show that the flare ribbon is the brightest at the larger lobe location (see Fig. 1b). This result suggests that as P2 emerges and moves, its magnetic flux impacts on very low lying field lines coming from the side of N2. Consequently, a current sheet is formed along the BP1 separatrix, and then dissipated. It can be said that by this process, the BP is “activated”. Thus, this event can then be considered as a “bald patch flare”.

Burgy et al. (1996) have proven that in some cases, a separator can join two BPs. In the present observed case, some parts of the BP separatrices are close (less than 3 Mm), so that if the observed polarities were slightly modified, they could cross each other, forming a separator (see Fig. 1). A possible reason for the absence of separator is the underestimation of the flux of N2, because of averaging with positive polarities on the spatial resolution size of the Kitt Peak
magnetogram. It is only by a further study of others cases that the requirement of a separator can (or cannot) be demonstrated. What this study indeed show is the direct link between the energy release location and the BP separatrices.

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References


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