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DYNAMIC CORONAL HEATING BY MAGNETIC FLUX INTERACTION

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Abstract

The elements of a Converging Flux Model for heating X-ray bright points are here put forward which also accounts for the cancelling magnetic features that are usually observed to be present in the photosphere below bright points and the jets that are observed with Yohkoh. The model has three phases: a preinteraction phase in which two opposite polarity photospheric fragments are unconnected magnetically; an interaction phase when the fragments reconnect in the corona and create the bright point and x-ray jet; a cancellation phase when reconnection in the photosphere produces the cancelling magnetic feature. An analytical model is presented together with preliminary results of a numerical experiment and a three-dimensional modelling of particular bright points observed by the NIXT telescope. Furthermore, dynamic reconnection driven by footpoint motions in a bright point may represent an elementary heating event that could be heating coronal loops and coronal holes and not just bright points.

1. Introduction

A major unsolved problem in Solar Physics is: how is the solar corona heated to a few million degrees, presumably by the magnetic field? The corona has a three-fold structure of coronal holes, coronal loops and x-ray bright points, which was revealed by soft x-ray images from Skylab. In these pictures, the active regions above sunspot groups are rather fuzzy and the bright points are mainly just unresolved points of emission. However, recently, the remarkable NIXT photographs from rocket flights (at a temperature of 2-3 x 10^6K and with a five-times better spatial resolution of 500 km) have shown that active regions consist of many fine-scale loops and that bright points appear to include several interacting loops.

X-ray bright points (XBP) were discovered in 1970 from rocket images and were studied with Skylab by Golub et al (1974) and in the radio by Habbal et al (1986) and Kundu et al (1988). Important recent observations of them have been made by Yohkoh (Shibata et al, 1992; Nitta et al, 1992; Strong et al, 1992) and Nobeyama (Kundu, these proceedings). Bright points are uniformly distributed over the solar surface, and their lifetimes vary between 2 and 48 hours, with a mean value of 8 hours. They are situated above pairs of opposite polarity magnetic fragments in the photosphere.

It was natural to assume that the magnetic fragments represent emerging flux and this became the standard explanation for bright points (Heyvaerts et al, 1977; Forbes and Priest, 1984). However, Harvey (1984) showed that two-thirds of the bright points instead lie above so-called "cancelling magnetic features" (CMF), where pairs of photospheric magnetic fragments are approaching and cancelling (Martin, 1984).

So what is happening in an XBP/CMF event? It cannot be simple submergence of magnetic flux since this would not explain the brightening (which starts well before cancellation). Also, no chromospheric fibrils join the fragments and the fragments are initially widely separated (and therefore unconnected). We need to include the effect of the ambient magnetic field to which the fragments are initially connected.

2. Converging Flux Model

Together with Clare Parnell and Sara Martin, we are proposing a Converging Flux Model (Priest et al, 1993), which has three phases (Figure 1). In the Pre-interaction Phase a pair of oppositely directed magnetic fragments in the photosphere are unconnected and approach one another. They are separated by a channel of overlying flux, which is squeezed by the approach until a null point forms in the photosphere (Figure 1(ii)). In the Interaction Phase the null point moves upwards and coronal reconnection creates an x-ray bright point, whose structure consists of two newly reconnected and heated flux tubes, one a small loop linking the fragments and the other a large loop (as seen in NIXT and Yohkoh images) linking to distant locations. In the Cancellation Phase the fragments come into contact and cancel by photospheric reconnection. In the special case when the initial fragments are equal in magnitude the final state consists of two disconnected fields, one above the photosphere and one below.

A simple way of modelling the above processes is to represent the sources by poles of flux $\pm f$ at locations $z = \pm a$, where $z = x + iy$. The field components (B_x, B_y) due to such sources together with a uniform horizontal ambient field (B_o) may be written

$$B_y + iB_x = \frac{if/\pi}{z-a} - \frac{if/\pi}{z+a} + iB_o = iB_o \frac{z^2 - b^2}{z^2 - a^2} \tag{2.1}$$

where

$$b = (a^2 - ad)^{\frac{1}{2}} \tag{2.2}$$

is the half-width of the channel and $d = 2f/(\pi B_o)$ we refer to as the "interaction distance".

In the Pre-interaction Phase, the poles are assumed to approach at a speed much slower than the Alfven speed and to make the overlying field evolve through a series of potential states given by (2.1). As the source position (a) decreases, the half-width (b) of the channel decreases while its flux is conserved, until at the interaction distance (a=d) the null point forms at the origin. It is a second-order null point with $B_y + iB_x \approx -iB_o\, z^2/d^2$.

When a<d, we have the Interaction Phase with reconnection driven at the null point by the motion of the sources. As a preparation for performing a numerical experiment on such reconnection, a simple model may be set up for continuing evolution through potential states. In equation (2.1) b^2 now becomes negative and so the field vanishes at an X-point on the y-axis at a height $\mid b \mid = (ad - a^2)$, which rises as a decreases to a maximum of $\frac{1}{2}d$ when $a = \frac{1}{2}d$ and then decreases to zero as the sources approach the origin.

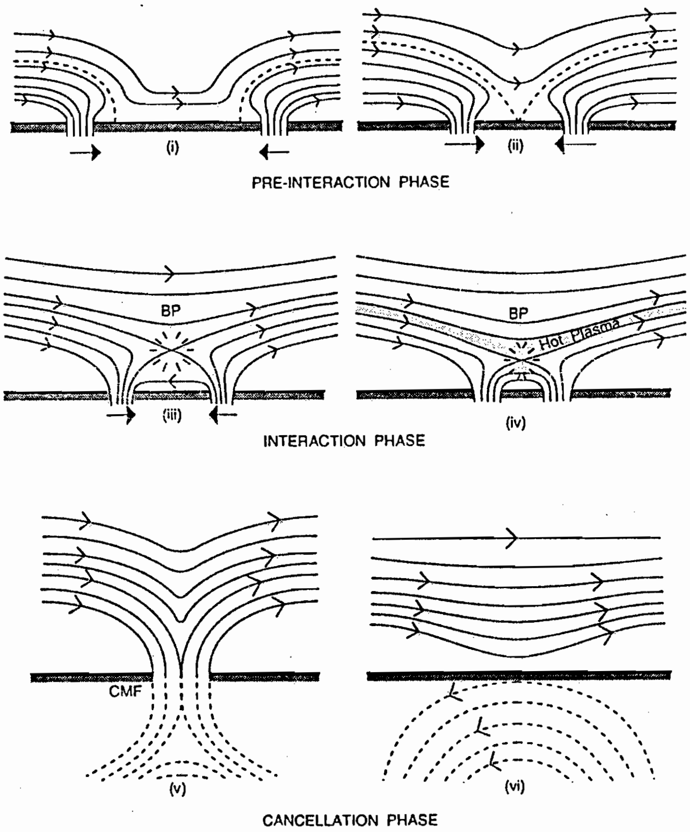

Fig. 1. The magnetic field lines for the Converging Flux Model, showing: the Pre-interaction, Interaction and Cancellation Phases.

If instead there is no reconnection, the topology is preserved and a current sheet forms so that the magnetic energy (W) exceeds the energy (W_o) of the potential state by an amount that can be released by reconnection to give the bright point. The field is given by

$$B_y + iB_x = \frac{iB_o(z^2 + h^2)^{\frac{1}{2}} z}{z^2 - a^2}, \tag{2.3}$$

which tends to a uniform field iB_o at infinity and has a cut (the current sheet) stretching along the y-axis from the origin to $z = ih$. The condition that the flux above the sheet is preserved gives the length of the sheet as $h = (d^2 - a^2)^{\frac{1}{2}}$, which increases from zero to d as a decreases from d to zero.

The energy (W) may be calculated and is of order the observed values between 3.10^{20} and 3.10^{21}J (3.10^{27}-3.10^{28} erg) for d = 5-10 Mm.

We have just started a numerical experiment on slow reconnection in the Converging Flux Model. Figure 2 shows the left half of the initial magnetic field due to four sources. The right-hand boundary is an axis of symmetry with an X-point about one-third of the way up it. The left-hand source on the base is held fixed and the compressible, resistive MHD evolution is studied in response to the motion of the right-hand source to the right, so driving reconnection at the X-point. The code is an explicit one, Lax-Wendrof for density and velocity and ADI for the magnetic field. Initially, we have run it with 80 x 80 grid points, a global magnetic Reynolds number of 10^3, a plasma beta of 10^{-2} and an Alfven Mach number for the speed of

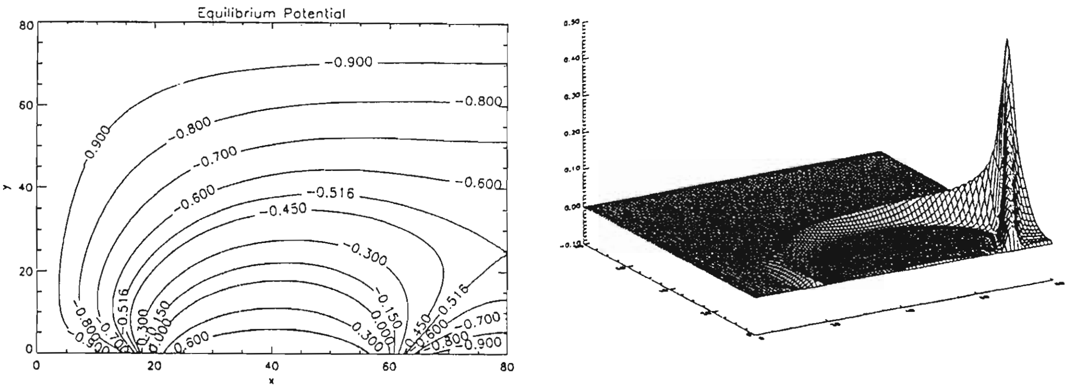

Fig. 2. A numerical experiment on converging flux showing the initial magnetic field and the resulting current density.

the source of 10^{-3}. On the top and left-hand boundary the normal magnetic field and plasma velocity are set equal to zero, while on the base the horizontal velocity is specified, the normal velocity is set to zero and the second vertical derivative of the density vanishes. Unit length is about one-sixth of the base, while density and magnetic field are measured relative to the initial (uniform) density and the field at roughly unit distance from the left-hand source.

The resulting current density shows an intense spike at the X-point and a strong current everywhere along the separatrix. In response to a relatively small motion of the source (moving one-twelfth of the way along the base) the energy in the domain rises by 5%, with most of that being a rise in magnetic energy associated with the presence of the currents, and 3% of it being liberated as ohmic heating.

3. Application to Specific Bright Points

We have considered particular bright points that were observed on the NIXT flight of July 11, 1991 in Fe XVI at 2-3 x 10^6K. In the full disc image there is an active region surrounded by a collection of 5 bright points. The photospheric magnetogram below one of them shows four discrete sources of flux which we have represented by poles, two being of positive polarity and two negative. The resulting field lines in the photospheric plane (Figure 3a) show that the plane is split into four topologically different regions by four separatrix field lines which intersect at two X-type neutral points. Each region contains only field lines that link two particular poles. When the central source moves to the right, flux is transferred between the regions and the field lines that have reconnected brighten to give shapes that compare well with the bright point. In three dimensions the separatrix field lines become dome-like surfaces and these surfaces intersect in a separator field line that links the two photospheric neutral points. Two field lines before and after reconnection show that, during the process of reconnection in three dimensions, the field lines approach the separator and then reconnect at the two null points before moving away from it (Figure 3b).

4. Conclusion

We are proposing a Converging Flux Model for x-ray bright points and cancelling magnetic features. It includes a Preinteraction Phase, an Interaction Phase when coronal re-

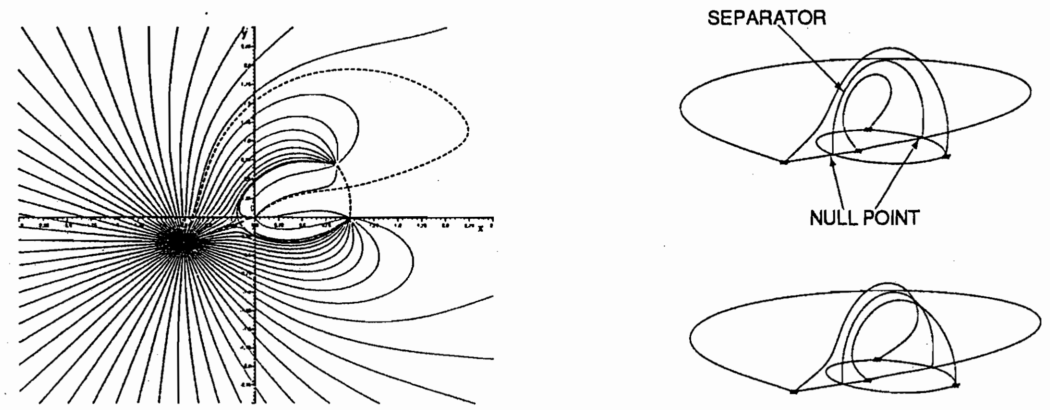

Fig. 3. (a) Field lines in the photosphere due to four flux sources below a bright point. (b) Field lines before and after reconnection.

connection creates the bright point, and a Cancellation Phase when photospheric reconnection produces the cancelling magnetic feature. Indeed, coronal reconnection driven by footpoint motion may produce the restructuring events seen by Tsuneta et al (1992). It may also represent an elementary heating event that could heat not just bright points but also other coronal loops and even coronal holes such as the nanoflares of Parker, Sturrock and Poletto and Kopp (these proceedings). I hope too that some of the ideas may be useful for future Yohkoh and Nobeyama studies of bright points.

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