DIVERGING MAGNETIC ARCADES AND ANTIPARALLEL CURRENTS

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ABSTRACT. X-ray images of the solar corona often show that magnetic arcades seen on the limb have a diverging shape. In this work we have compared X-soft pictures of the solar corona with images of the photosphere and with magnetograms in order to verify whether the diverging shape of some arcades might be imputable to the presence of antiparallel currents in close loops. Density current maps inferred by magnetograms show that inside a region characterized by the same magnetic polarity there are both sites of upward and downward current. Moreover, the field lines configuration obtained by force-free field extrapolation and its comparison with X-ray pictures indicate that the force-free parameter α changes its sign in the examined region.

1. Introduction

X-ray pictures of the solar corona often show loop systems characterized by a diverging or fan shape, which becomes particularly evident when these structures are observed on the limb (Ichimoto, 1995). Some authors (Levine, 1976; Sakurai, 1981) have suggested that the reason of this diverging structure should be the presence of currents flowing in antiparallel directions in close loops.

In this framework we recall that in the active regions of the solar atmosphere, the magnetic field configuration may be described by the force-free field approximation:

$$\nabla \times \mathbf{B} = \alpha \mathbf{B}$$  \hspace{1cm} (1)

where α is the force-free field parameter. Equation (1) implies that:

$$\mathbf{J} = \alpha \mathbf{B}$$  \hspace{1cm} (2)

indicating that in a force-free field currents flow parallel to the magnetic field. Equation (2) shows that J and B have the same sign (i.e. the current is parallel and in the same direction of B) when α is positive. On the contrary, when α is negative, the current is antiparallel to the magnetic field.

In this context, we considered very interesting to compare X-soft images of the solar corona obtained by the japanese satellite Yohkoh, with images of the photosphere taken at the Catania Astrophysical Observatory and with magnetograms taken at the Potsdam Sonnenobservatorium. The comparison between X-ray and white light pictures...
allows to get informations on the kind of photospheric motions which may give rise to the diverging loop phenomenon, while the comparison with magnetograms allows to confirm whether diverging loops are associated with antiparallel currents.

2. Description of the model

A force-free magnetic arcade may be described by the following equations:

\[
\begin{align*}
B_x &= \frac{\lambda}{k} B_0 [\cos(kx)e^{-\lambda z}] \\
B_y &= \frac{\alpha}{k} B_0 [\cos(kx)e^{-\lambda z}] \\
B_z &= B_0 [-\sin(kx)e^{-\lambda z}]
\end{align*}
\]  

(3)

where \( B_0 \) is the magnetic field strength at the edge of the arcade; \( B_x, B_y \) and \( B_z \) are the components of the magnetic field in the coordinate system where the plane \( z = 0 \) coincides with the photospheric level, and the \( y \) axis with the neutral line of the magnetic arcade. Moreover, \( k = \pi/(2h) \) (\( 2h \) is the width of the arcade at photospheric level), and \( \lambda \) is a parameter which depends on the shearing angle of the field lines with respect to the potential configuration (Zuccarello et al., 1987; Zappalá and Zuccarello, 1989; Zuccarello, 1992).

We assume that the arcade is sheared by a photospheric velocity field and we indicate with \( \Delta y \) the shearing of the field lines in a point of coordinate \( x \). The \( \alpha \) parameter may be expressed as a function of \( \Delta y \) as:

\[
\alpha = \frac{\Delta y}{\sqrt{\Delta y^2 + x^2}} k
\]

(4)

Therefore we can see that \( \alpha \) is negative when the shearing \( \Delta y \) is negative. This means that if in the same arcade of loops a region is subjected to photospheric motions in a certain direction and another region is subjected to motions in the opposed direction, there will be loops characterized by a positive \( \alpha \) and consequently by currents flowing parallel to \( \mathbf{B} \), and loops with negative \( \alpha \), where currents flow antiparallel to the magnetic field.

In synthesis, the presence of antiparallel currents in close loops may be due to footpoints motions in opposed directions at photospheric level.

In the hypothesis that loops may be approximated as simple wires, the presence of antiparallel currents may give rise to a repulsive force given by:

\[
F = \mu_0 \frac{I I'}{2\pi D L}
\]

(5)

where \( I \) is the current flowing in a loop, \( I' \) is the current flowing in the contiguous loop, \( D \) is the distance between the loops and \( L \) is their length. The result of this process is a bunch of loops which, even if anchored in nearby regions at photospheric level, are forced apart near their tops at coronal levels, giving rise to a diverging loop system, i.e. characterized by the fact that the planes where they lye are not perpendicular to the
solar surface, and in some cases the inclination angle is so small that they are almost parallel to the photosphere.

When in one of this arcades a flare takes place, Levine (1976) observed that loops that before the event where repelling each other, and were close to the solar surface, after the flare approached each other and tended to lye almost perpendicular to the solar surface.

Fig. 1 Soft X-ray picture of the active region NOAA 7500 (left) linked by interconnecting loops to NOAA 7496 (right). The image was taken on May 8, 1993 by Yohkoh.

3. Data Analysis and Conclusions

In order to verify whether the *diverging* morphology of some coronal loops may be due to the presence of currents antiparallel to the magnetic field, we examined a set of X-ray images of the solar corona obtained by the Japanese satellite Yohkoh.

We have found about 10 active regions characterized by diverging loops; between them, we have chosen the NOAA 7500, which shows a particularly complex structure and is linked by interconnecting loops to another active region, called NOAA 7496 (fig. 1). The NOAA 7500 is observed for the first time on the 5 May 1993 in the north-east quadrant (average latitude ~ 15 - 20 N) and disappears on the west limb on the 17 May.

Using the Potsdam magnetograph which allows to get magnetic field values from measurements in the line Fe I (5250.2 Å), it has been possible to get the magnetograms relatives to NOAA 7500. The region shows a large sunspot of north polarity N1 and two sunspots of south polarity S1 and S3, besides than two small sunspots n2 and s2 close to the neutral line.

The magnetic field values have then been used to determine the distribution of the vertical density current on the basis of the following expression:

\[
J_z = \left( \frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y} \right) / \mu_0
\]  

(6)

Using this procedure it has been possible to establish that in the largest sunspots both upward and downward currents are present.

This result is a first confirmation of the hypothesis that *diverging loops* may be due to currents which flow in a direction antiparallel to \( \mathbf{B} \) in some loops and parallel to \( \mathbf{B} \).
in contiguous loops.

Fig. 2 Force-free field lines extrapolations for $\alpha > 0$ (left) and $\alpha < 0$ (right) deduced by magnetograms relative to the active region NOAA 7500 on May 8, 1993.

The magnetic field values deduced by observations have then been used to infer the magnetic field lines configuration in three different approximations: potential field, force-free field with positive $\alpha$ and force-free field with negative $\alpha$.

The comparison between the X-ray images of the NOAA 7500 (fig. 1) with the force-free field extrapolation (fig. 2) indicates that both loops characterized by $\alpha > 0$ and $\alpha < 0$ are present (even if the extrapolation obtained in the force-free field approximation with negative $\alpha$ better approximates the morphology of the loops observed in X-ray), and this constitutes a further confirmation to our hypothesis.

Finally, the great number of flares (39 events in 10 days) observed in the region NOAA 7500, allow to conclude that this diverging configuration is able to store enough energy for the flares and is subjected to frequent instabilities which trigger flares.

References

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