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ENERGETICS OF CHROMOSPHERIC-CORONAL ACTIVE REGIONS

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ABSTRACT. Observations performed by ATM (Skylab) and more recently by SXT (Yohkoh) and Soho confirm that footpoints of coronal loops may connect differently aged photospheric magnetic regions. It has been shown (Zappalá and Zuccarello, 1989; Zappalá and Zuccarello, 1991) that differences in the evolutionary stage of sunspot-groups give rise to differences in their relative velocity of the order of $3 - 3.5 \times 10^3 cm\, s^{-1}$ and we consider it extremely important both for continuos heating and for transients in closed loops magnetic regions. Using a linear α force-free field model, we have carried on an analysis to estimate the amount of stored magnetic energy in an arcade sheared by photospheric footpoint motions. We have found that the stored energy is sufficient both for heating and for transients. We propose, on the basis of a qualitative analysis between the storage and dissipative time scales, two possibilities : in the first continuous heating takes place, in the second the conditions for very energetics transients may take place.

1. Introduction

The question of chromospheric-coronal heating has ben studied by several authors: some of them have proposed mechanisms based on MHD waves dissipation (remote energy source) (Ionson, 1982; Heyvaerts and Priest, 1984), and others have proposed mechanisms related to magnetic energy dissipation via reconnection (in situ energy source) (Tanaka and Nakagawa, 1973; Low, 1982; Priest, 1997).

From the data obtained by ATM on board Skylab and lately confirmed by Yohkoh and Soho, it is possible to estimate that the amount of energy dissipated by MHD waves is two or three order of magnitude lower than that necessary to heat active region loops. Moreover these satellites have put into evidence that chromospheric-coronal layers are characterized by a total inhomogeneity and that parameters like temperature and density depend on the characteristics (topology and intensity) of the magnetic field. Therefore, it seems that magnetic dissipation takes place to heat active region loops, while the quiet corona would be heated via MHD waves. Obviously in both cases the magnetic field plays a fundamental role. Moreover, the behaviour of the magnetic field is the key to explain also impulsive events.

Even if, from one side, it is well known that the frozen-in conditions of the magnetic field in the plasma ensure that the open (coronal hole) or closed (quiet and active region) configurations are generated by the magnetic field and that the photospheric dynamics drive the loop behaviour, it is not yet clear what must be the characteristics of the photospheric velocity field in order to have continuous heating or flares.

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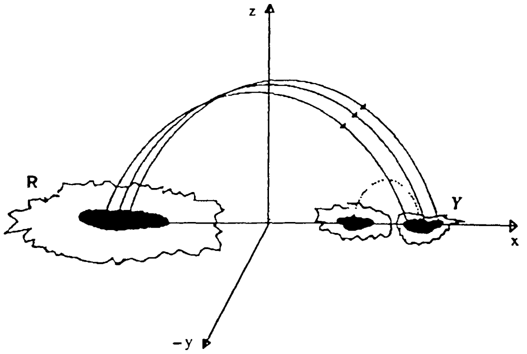

Fig. 1. Schematic picture of an arcade connecting two differently aged sunspot-groups: R is the recurrent sunspot-group and Y is the young one.

In a previous work we have put into evidence the decrease of the angular velocity with age of photospheric magnetic regions (Zappalá and Zuccarello, 1991). This braking, because of its connection with the solar differential rotation pattern, is not stochastic. Therefore, it seems worthwhile to investigate the possibility that this velocity field, via the conversion of kinetic energy into magnetic energy, is the primary engine for the energetics of chromospheric-coronal loops regions.

Taking into account this hypothesis, we have studied a model of a chromospheric-coronal arcade in which both slow dissipative mechanisms (heating) and explosive dissipative mechanisms (transients) find *in situ* the necessary energy.

2. Description of the model

We investigate the energy build-up phase in a linear force-free arcade sheared by a velocity field which is strictly related to the solar differential rotation pattern.

In a previous work (Zappalá and Zuccarello, 1991), using the Greenwich Photoheliographic Results sunspot-groups data collected during 1874-1976, we showed that the sunspot-group angular velocity is not invariant with time during the first 10 days of their life, showing a continuous deceleration. More precisely, 2-days old sunspot-groups have angular velocity which are on average 0.3 degrees day^{-1} higher than that of recurrent sunspots, and this difference decreases almost linearly with time.

Therefore an arcade interconnecting two differently aged sunspot-groups (for instance a two-days one and a recurrent one) might be subjected to a shearing motion due to the relative velocity at its footpoints. In the hypothesis that this motion builds up DC currents flowing parallel to the magnetic field, the amount of magnetic energy stored in a linear force-free field may be evaluated.

We describe a linear α force-free magnetic arcade by using the following equations :

$$\begin{aligned} B_x &= \frac{\lambda}{k} B_0 [cos(kx) e^{-\lambda z}] \\ B_y &= \frac{\alpha}{k} B_0 [cos(kx) e^{-\lambda z}] \\ B_z &= -B_0 [sin(kx) e^{-\lambda z}] \end{aligned} \qquad (1)$$

where B_0 is the magnetic field strength at the edge of the system; B_x, B_y and B_z are the components of the magnetic field in the coordinate system shown in fig. 1. The plane $z = 0$ is the photospheric level, and the y axis coincides with the neutral line of the magnetic arcade. Moreover, $k = \pi/(2h)$ ($2h$ is the width of the arcade at photospheric level), and λ 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).

In fig. 1 the greater sunspot named R stands for the recurrent sunspot-group, while the bipolar group called Y stands for the young sunspot-group.
We assume that the arcade is sheared by a photospheric velocity field given by :
$\mathbf{v} = v_y\ \mathbf{e}_y$ which, after a time which we call shearing time τ_{sh}, produces a shearing Δy_h of the field lines at the edge of the arcade characterized by $x = h$. The α parameter may be expressed as a function of Δy as :

$$\alpha = \frac{\Delta y}{\sqrt{\Delta y^2 + x^2}} k \tag{2}$$

The total amount of magnetic energy W_s stored in the time τ_{sh} is given by the difference between the magnetic energy content of the force-free field, and the magnetic energy W_p of the arcade when the field is potential ($\alpha = 0$) :

$$W_s = \frac{B_0^2 L}{\mu_0 \pi} h^2 \left(\sqrt{1 + \left(\frac{\Delta y_h}{h} \right)^2} - 1 \right) \tag{3}$$

Therefore the total amount of stored magnetic energy W_s is a function of the displacement Δy_h of the magnetic field lines and taking into account that $\Delta y_h = v_y\ \tau_{sh}$, we can deduce the dependence of W_s directly from the photospheric velocity field $\mathbf{v}$.

We have calculated the amount of stored magnetic energy for different values of h, L, τ_{sh}, and Δv. The results are reported in Table 1.

Tab. 1 - Energy stored in a magnetic arcade with $B_0 = 2 \times 10^3 G$

$h(cm)$	$L(cm)$	$\tau_{sh}(s)$	$\Delta v(cms^{-1})$	$W_s(erg)$
6×10^9	6×10^8	8.64×10^4	3.47×10^3	2.73×10^{30}
6×10^9	6×10^8	1.72×10^5	3.23×10^3	1.88×10^{31}
6×10^9	6×10^8	2.60×10^5	2.94×10^3	1.53×10^{32}
1.6×10^{10}	4×10^9	8.64×10^4	3.47×10^3	1.82×10^{31}
1.6×10^{10}	4×10^9	1.72×10^5	3.23×10^3	1.26×10^{32}
1.6×10^{10}	4×10^9	2.60×10^5	2.94×10^3	1.05×10^{33}

We can see that the values of the stored magnetic energy range between $\sim 2.73 \times 10^{30}$ to 1.05×10^{33} erg depending on the dimension of the arcade and on the footpoints velocity. Therefore we may conclude that the velocity field related to differences in the angular velocity of differently aged sunspot-groups is adequate to store in a continuous way an amount of energy sufficient for loops heating and for flares.

3. Discussion

This work gives a contribution to the widely accepted scenario that loops heating process is strictly related to the shearing of the magnetic field and that the energy dissipated during a flare is previously stored in a non-potential configuration of the magnetic field. In other words, kinetic energy is converted in magnetic energy during an initial storage phase. Then, due to a dissipative mechanism, magnetic energy is converted in other kind of energy. In this regard, it is our opinione that heating or flares may occurr depending on the ratio between the storage timescale and the dissipation timescale. More precisely, if energy is stored during a storage timescale (τ_{st}) of the same order of magnitude of the dissipation timescale (τ_{diss}) related to a certain dissipation mechanism, heating will take place. If the energy is stored during a timescale τ_{st} during which no dissipation mechanism takes place and then suddenly, when a new magnetic topology or a certain treshold is reached, a flare will take place.

Therefore, from an energetic point of view, we propose the following scheme: assuming a unique source of energy (both for heating and flaring) characterized by a mechanism which converts kinetic energy into magnetic energy, and that an amount of energy ΔE_{Tot} is available for dissipation, a (non-specified) dissipative mechanism may take away this energy and contribute to the "normal" and continuous heating of the active region, in order to have :

$$\Delta E_{Tot} = E_{Diss} + E_{Res} \qquad (4)$$

where E_{Res} is the residual magnetic energy which is not taken away by the dissipative mechanism. We may have a situation where : $E_{Diss} << E_{Res}$ that is, the energy dissipated is lower than the residual one, in this case the surplus of energy may be suddenly dissipated in a more energetic event and, depending on the value of ΔE_{Tot} or on $\frac{\partial \Delta E_{Tot}}{\partial t}$, we may have a microflare, or a large flare. On the contrary, when $E_{Diss} >> E_{Res}$, the possibility to get a flare should be reduced.

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