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MHD MODEL FOR LONG DISTANCE CORONAL LOOPS

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RESUMO. São estudadas as porções horizontais dos arcos coronais de longa distância. Admitindo-se hipóteses cuja verificação é accessível, mostra-se que a matéria encontra-se no estado isotérmico e estático. Portanto a função do aquecimento deve apenas compensar as perdas radiativas. A aplicação desse resultado a arcos em regime estacionário de diferentes tipos permite relacionar o aquecimento com dimensões e idades dos arcos. Uma outra aplicação às fases anterior e posterior a um aumento de emissão em raios X evidencia uma variação do aquecimento entre essas duas fases.

ABSTRACT. Horizontal parts of long distance coronal loops are studied. Under currently verifiable hypotheses, the conclusion is drawn that the matter is in isothermal and static state. Therefore the heating has only to balance the radiative loss. Applying this result to different types of steady state loops, the heating can be related to the loops' sizes and ages. Another application to both phases, before and after an enhancement of X-rays emission, reveals a change in the amount of heating.

Key words: CORONAL LOOP, HEATING

I. INTRODUCTION

Some coronal arches reach lengths comparable to the solar radius. They constitute the morphological class of long distance coronal loops. Two sub-classes can be distinguished with the following characteristics (Priest, 1982):

1) Interconnecting: $2\times10^9 \lesssim L \lesssim 7\times10^{10}$ cm; $2\times10^6 \lesssim T \lesssim 3\times10^6$K; $n \simeq 7\times10^8$ cm^{-3}

2) Quiet-region: $2\times10^{9} \lesssim L \lesssim 7\times10^{10}$ cm; $T \simeq 1{,}8\times10^{6}$K; $2\times10^{8} \lesssim n \lesssim 10^{9}$ cm^{-3}. L, n and T denote, respectively, the loop length, the electron density and the temperature.

Besides the descriptive ones, several works have been published on the MHD equilibrium and stability of such structures (Priest, 1982). In most of the previous MHD models, efforts have been made to describe the complete arch structure. On the other hand, the a priori imposition of: (a) currently unverifiable boundary conditions (pressure, temperature, heat flow) at the loop base and (b) arbitrary heat functions, might be a source of weakness to those models.

Here it is shown that an estimation of the amount of heating can be made under a set of reliably verifiable hypotheses.

II. ENERGY EQUATION

The specially long length of the arches suggests a fruitful modelling limited to the horizontal portions of the loops. Considering the photosphere spherical, ds is an arc element concentric to the Sun, along the horizontal portion of a loop. Solar rotation can be justifiedly neglected. Heat conduction will occur only along the magnetic field, to which the flow will be also aligned. So, assuming that the loop outlines the magnetic field, the problem can be treated one-dimensionally along the s coordinate. The loop cross section is assumed to be constant, in fairly good agreement with the observations. The material in the loop will be represented by a fully ionized hydrogen gas, but the radiative loss will take into account the other elements. Individual loops are usually recognized with almost a constant brightness during a time-scale of 10^{5} s $\simeq$ 1 day (Rosner et al., 1978). As the characteristic times for relevant processes are significantly shorter than 10^{5} s, the steady state approximation will be adopted.

Ruling out supersonic flows, it can be concluded that the kinetic pressure is nearly constant over the considered portions of the loop:

$$p = 2nkT \simeq p_0 \text{ (constant)} \tag{1}$$

where k is the Boltzmann constant. Two solutions are implied by the above equation, since v should be constant: if $v \neq 0$, $\frac{dT}{ds} = \frac{dn}{ds} = 0$; if $v = 0$, $\frac{dT}{ds} \neq 0$ and $\frac{dn}{ds} \neq 0$.

The general energy equation which gives the amount of heating H (erg cm^{-3} s^{-1}) does not depend on v:

$$H = \left(\frac{p_o}{2k}\right)^2 \frac{P(T)}{T^2} - \frac{d}{ds}\left(K \frac{dT}{ds}\right) \quad (2)$$

where K is the thermal conductivity along the magnetic field:

$$K = K_o \; T^{5/2} \quad (3)$$

with $K_o = 1{,}84\times10^{-6}$ (cgs). The first term on the right-hand side in (2) describes the radiative loss (erg cm^{-3} s^{-1}) and the function P(T) has been adjusted as

$$P(T) = \alpha T^{\beta} \quad (4)$$

where α and β are constants suitably defined over ranges of temperature (Rosner et al., 1978). If there is a non-null temperature gradient, the origin s = 0 can be ascribed to the cooler end with temperature T(0). The hotter end at s = L, with the maximum temperature T(L), defines the condition $\left.\frac{dT}{ds}\right|_L = 0$. According to these considerations it can be shown that the heat conduction term in equation (2) means always an energy loss, so that the radiative loss determines the minimum value of H. Temperature gradients calculated from the observational data are small enough, so that equation (2) can be approximated by the isothermal and static (v = 0) case:

$$H = \left(\frac{p_o}{2k}\right)^2 \frac{P(T)}{T^2} \quad (5)$$

Figure 1 displays H as a function of T for constant values of p_o. The shaded areas correspond to the observational data. Heating in quiet-region loops ranges between 3×10^{-6} and 10^{-4} erg cm^{-3} s^{-1}; on interconnecting loops, between 2.5×10^{-5} and 10^{-4} erg cm^{-3} s^{-1}.

III. DISCUSSIONS

The criterium for the radiative stability (Priest, 1982) can be properly applied to the model:

$$L \lessgtr L_{max} = \frac{2k}{p_o}\left(\frac{K_o}{\alpha} T^{11/2-\beta}\right)^{1/2} \quad (6)$$

Loci for several values of L_{max} are also indicated in Figure 1. The observational range of L and the range of L_{max} displayed in the Figure 1 are

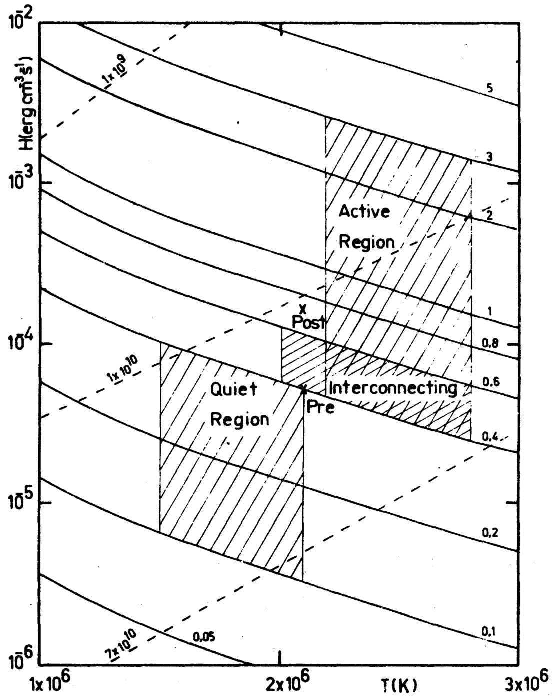
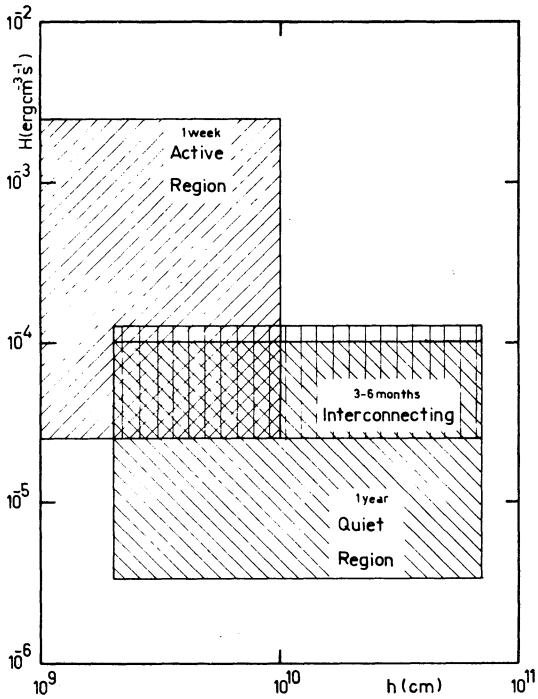


Fig. 1. Heating function versus temperature for constant values of the kinetic pressure. Shaded areas correspond to the observations of different types of loops. Dashed lines represent the loci for constant L_{max}. The two points refer to flaring loop reported by Svestka et al. (1977).

coincident. This seems to indicate that the length of the long distance loops are close to L_{max}.

Among the several magnetic structures observed in X-rays and EUV, the active region loops are seemingly good candidates for the application of the model. The physical parameters are: $10^9 < L < 10^{10}$ cm; $2.2\times10^6 < T < 2.8\times10^6$K; $5\times10^8 < n < 5\times10^9$ cm^{-3} (Priest, 1982). The lower parts of the respective shaded area in Figure 1 overshoot the line for $L_{max} = 10^{10}$ cm. Overlooking this fact, a conclusion can be drawn that H in average decreases with the height, h, of the loop, since $L \sim h$ (Figure 2). H ranges between 3×10^{-6} and 2.5×10^{-3} erg cm^{-2} s^{-1}. If the heating energy enters the loop through its feet, the product Hh is an estimate of the input flux. It is in average 7×10^6 erg cm^{-2} s^{-1} for loops of active-regions, 3×10^6 erg cm^{-2} s^{-1} for interconnecting loops, and 2×10^6 erg cm^{-2} s^{-1} for quiet-region loops. It should be pointed out that H decreases as the loop gets older. Typical age of the structure is also indicated in Figure 2.



ig. 2. Amount of heating as a function of the height. Typical ages are ndicated for each type of loop.

Application of equation (5) to the initial and final states of an nterconnecting loop which flared in soft X-rays for about 4 hours (Svestka t al., 1977) reveals that the final level of the heating was three times the nitial one. This change is shown in Figure 1. Since an increase on H is ssociated to a decrease on L_{max}, the final state could imply a reconnection f the magnetic field lines shortening the loop.

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