ENERGY BALANCE IN PROMINENCE-CORONA TRANSITION REGIONS

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1. INTRODUCTION

Prominences are sheets of cold (< 10^4 K) plasma totally imbedded in the hot (> 10^6 K) coronal plasma. A Prominence-Corona Transition Region (PCTR) is therefore present all around it.

The PCTR can be analyzed using observed UV line intensities and brightness temperatures at μ-waves. Radio observations are usually performed on the disk (above filaments) while UV line intensities are measured at the limb. They therefore refer to the top and to the side PCTR, respectively.

It appears that PCTR models derived from UV and radio observations strongly disagree: in fact if we take the Differential Emission Measure ($DEM=p^2dz/dT$) derived from UV line intensities and compute the radio brightness temperature using the following relationship between T_b and DEM:

$$T_b(\nu) = \int_{T_o}^{T_c} T\, e^{-\tau}\, d\tau + T_c(1 - e^{-\tau_c})$$

$$d\tau(\nu) = \frac{\xi}{4\,k^2\nu^2}\,\frac{DEM}{T^{7/2}}\,dT \qquad \tau_c = \frac{\xi\; p^2}{4\,k^2\nu^2 T_c^{\;7/2}}\,\frac{H}{2}$$

with H = coronal scale height and $\xi = 0.2$, we get systematically much larger values than the observed one.

On the other hand, radio models of PCTR (Kundu et al., 1986, and references therein) require a gas pressure much lower than that consistent with optical and UV obvservations (Vial, 1989).

In all PCTR models, derived from both UV and radio data, the effect of the magnetic field on heat conduction has been so far neglected. Its inclusion can drastically change the results, especially for the top PCTR observed at radio wavelengths. In fact following Leroy (1989) the magnetic field in prominences lies in a plane parallel to the solar surface and in this plane forms an angle α with the prominence axis. α can vary from 0° to ~ 60°, and the most commonly observed value is 30°± 10° . Therefore when we observe the prominences from the top (filaments on the disk) at radio frequencies the angle θ between B and ∇T is

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$\theta \cong 90°$, while when the prominence is observed at the limb (UV lines) the angle can be $30° < \theta < 90°$ with the most probable value given by: $\theta = 60° \pm 10°$.

2. PCTR MODELS

We will now show that when the correct expression of the heat conduction is taken into account in deriving PCTR models, no discrepancy between UV and radio data exists.

Let us assume the z axis parallel to the temperature gradient ∇T, the energy balance in the static case is given by (Priest, 1982).

$$\frac{d}{dz}\left(k_{//} T^{5/2} + k_{\perp} T^{-5/2} \frac{dT}{dz}\right) = E_R - E_H \qquad (1)$$

where

$$k_{//} = c \cos^2\theta \quad ; \quad k_{\perp} = 2 \cdot 10^{-11} c \,\mathrm{sen}^2\theta \, \frac{p^2}{4 k^2 B^2} \quad ; \quad c = 1 \cdot 10^{-6} \quad ;$$

p is the pressure in dyn/cm^2 and B the magnetic field in G .

The specific radiated power, E_R has been approximated with a composite power law given by Rosner et al. (1978) for $T > 5 \cdot 10^4$ and by Poland (private communication) for $T < 5 \cdot 10^4$

$$E_R = p^2/4k^2 A_i \, T^{\alpha_i - 2}$$

The unknown heating function E_H has been parametrized as follows:

$$E_H = p^2/4k^2 \, f_H(T)$$

If $\theta \neq 90°$ and $d\theta/dz = 0$, eq. (1) becomes

$$k_{//} \frac{d}{dz} \left[T^{5/2}(1 + \varepsilon T^{-5}) \, dT/dz \right] = E_R - E_H \qquad (2)$$

where

$$\varepsilon = k_{\perp}/k_{//} = 2.6 \; 10^{20} \; p^2/B^2 \; \mathrm{tg}^2\theta \qquad \varepsilon T^{-5} > 1 \left\{ \begin{array}{l} \theta > 85° \\ T < 10^5 \end{array} \right.$$

assuming p = const. and defining:

$$\eta(T) = T^{5/2}(1 + \varepsilon T^{-5}) \, dT/dz$$

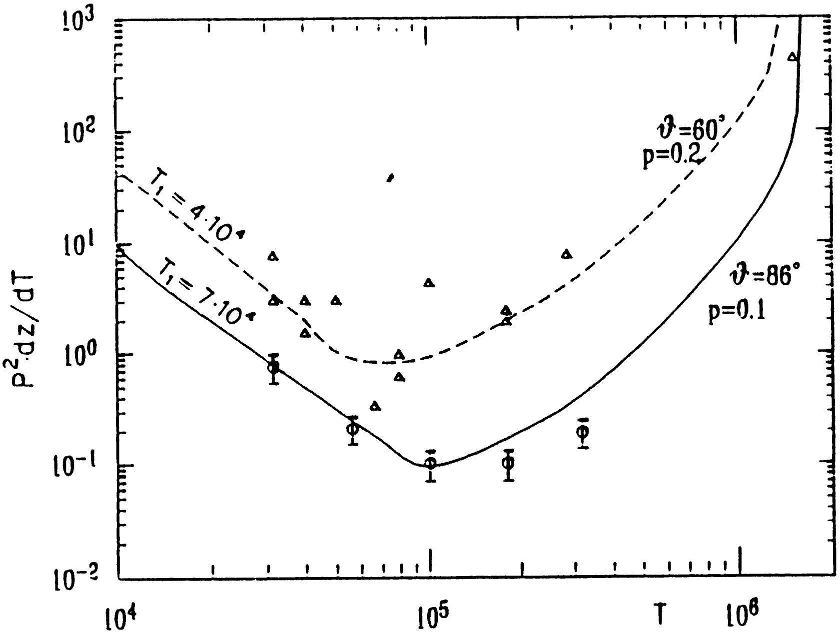
a first integral of eq. (1) is given by:

$$\eta^2(T) = \eta^2(T_o) + \frac{p^2}{4k^2 k_{//}} \int_{T_o}^{T} T^{5/2}(1 + \varepsilon T^{-5}) (A_i T_i^{\alpha_i - 2} - f_H(T)) \, dT \qquad (3)$$

It is easily seen that if $\eta(T_o) = 0$, $\eta(T) \propto \frac{p}{\cos\theta}$ and $p^2 \frac{dz}{dT} \propto p \cos\theta$.

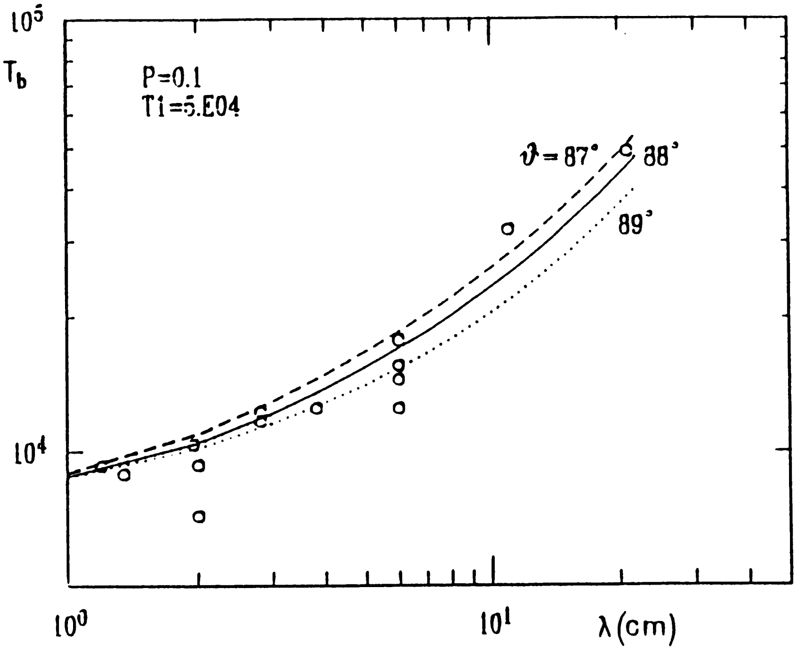
This means that an increase of the angle θ is equivalent to a decrease of the pressure.

We have first assumed that the heating function is given by



10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
$p^2 \cdot dz/dT$
$T_1 = 4 \cdot 10^4$
$T_1 = 7 \cdot 10^4$
$\vartheta = 60°$
p=0.2
$\vartheta = 86°$
p=0.1
10^4
10^5
T
10^6

Fig. 1



10^5
T_b
P=0.1
T1=5.E04
$\vartheta = 87°$
88°
89°
10^4
10^0
10^1
λ(cm)

Fig. 2

$$f_H(T) = A_x\, T^{a_x} \qquad \text{for} \qquad T_o \leq T \leq T_c \, .$$

A_x and a_x are determined assuming:

$$\eta(T_o) = 0 \qquad \left(\frac{d\eta}{dT}\right)_{T = T_o} = 0 \qquad \eta(T_c) = 0$$

$$T_o = 8\ 10^3$$

$$T_c = 1.5\ 10^6$$

In this way we have obtained very good fits of radio observations with $p \sim 0.2$ dyn/cm^2 and $\theta > 80°$ (Chiuderi Drago, 1989). Moreover we are able to explain in terms of different angles θ the discrepancy existing at high temperature between the DEM derived by Schmahl and Orral (1986) and by Engvold (1989).

However the heating function $f_H(T) = A_x T^a$ cannot reproduce the observed form of the DEM at $T < 10^5$ k.

The only way to fit the observed UV line intensity at low temperature is to assume an "ad hoc" heating function below a certain temperature $T_1 \cong 5\ 10^4$ K.

The second approach to the problem was therefore done by assuming:

$$E_{H_1} = E_R - \frac{p^2}{4\,k^2}\, A_1\, T^{1.5 - 2\alpha_1} \qquad T_o \leq T \leq T_1$$

$$E_{H_2} = \frac{p^2}{4\,k^2}\, A_2\, T^{\alpha_2} \qquad T_1 \leq T \leq T_c$$

where A_1, α_1 and T_1 are determined from a fit of the observed DEM in its decreasing part and A_2 and α_2 by the relationships:

$$E_{H_1}(T_1) = E_{H_2}(T_1) \quad ; \quad \eta(T_c) = 0$$

Assuming this form of the heating functions in eq. 1, the results shown in fig. 1 and 2 are obtained.

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DISCUSSION

KUNDU: After all these model computations that you have done using a sophisticated data base, can you tell us what is the thickness of the filament-corona transient sheath?

CHIUDERI-DRAGO: I cannot tell the thickness because we performed only a first integral (analytically) which gives dT/dz. However, since $dT/dz \sim pf(T)/\cos\theta$, I expect a much thinner transition region for large values of θ (radio) than for small values of θ(UV).