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Effect of Superthermal Particles in the Quiet Sun Radio Emission

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Abstract. The bremsstrahlung emissivity and absorption coefficient, in the radiofrequencies range, are derived in the assumption that the electron population is not purely thermal, but presents a tail of high energy particles. This population is approximated by a bi-Maxwellian distribution. It is shown that, if the temperature ratio of the two Maxwellians is larger than 10, the absorption coefficient and the effective temperature depend only on the fraction R of particles in the highest temperature Maxwellian. The microwave radio spectrum is computed for some values of R, finding brightness temperatures lower than those computed with a pure thermal distribution. This fact could explain some inconsistencies found between radio and EUV observations.

Key words. Emission and absorption coefficients, Non thermal particles

1. Introduction

The upper layer of the solar atmosphere, transition region (TR) and Corona, can be investigated by means of the radiation emitted in the X-UV and radio domain. In the microwave range, where the refraction index can be safely assumed $n = 1$, the radio optical depth depends on temperature and on the differential emission measure: $DEM(T) = N_e^2 dh/dT$, where the temperature gradient is different from zero, and on the emission measure $EM(T) = \int N_e^2 dh$ in the corona where $T \sim constant$. These two quantities are also proportional to the EUV line intensities. However, very often radio and UV emissions do not agree with the same model of the solar atmosphere. (see, for instance, Zirin et al 1981; Noci, 2003). It has been recently shown by Chiuderi Drago and Landi (2003) (hereafter referred to as Paper I) that the observed average quiet sun brightness temperature, T_b, can be fitted by the following model:

- The DEM in the TR derived by matching the cell center model B of Vernazza, Avrett and Loeser (1981) (VAL) at $logT \leq 4.3$ with the DEM derived from EUV lines observed in the cells by SUMER and CDS instruments at $4.6 \leq logT \leq 6.1$
- The EM derived in the assumption of an homogeneous corona in hydrostatic equilibrium at $T = 1.2\ 10^6$, with a maximum electron density $N_e(0) = 2\ 10^8$.

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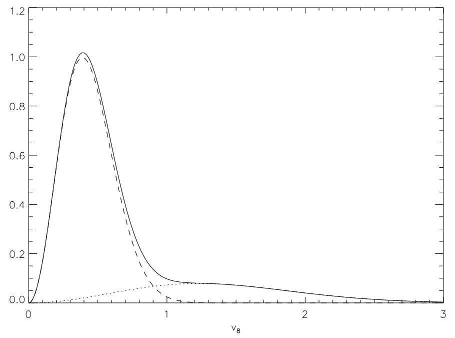

Fig. 1. Example of a bi-Maxwellian partcles distribution with $T_0 = 5.\ 10^4$, $T_1 = 5.\ 10^5$ and $R = N_1/N_{tot} = 0.2$.

It has been pointed out in Paper I that any contribution of the network emission added to the so obtained radio brightness temperature, will produce an excess of this latter with respect to the observations. In this paper we will show that an electron distribution consisting of a small tail of superthermal electrons added to a Maxwellian distribution produces a decrease of the computed T_b, thus permitting a more realistic scenario of the 'average' quiet sun radio emission, including cell and network contributions. In this first approach the assumed electron distribution will be approximated by two Maxwellians at temperature T_0 and T_1 with $T_1 > T_0$. An exemple of such distribution is shown in Fig. 1. The calculation of the emission and absorption coefficients for such a bi-Maxwellian distributions of electrons will be presented in the next Session. In Session 3 we will compute the microwave spectra, obtained with different amounts of high energy particles and we will compare them with the Zirin et al. (1991) and Borovik et al. (1992) observations.

2. Emission and absorption from a non-thermal distribution of electrons

The free-free radio emission per unit time from a single electron of velocity v in a plasma with an ion density N_i is given by:

$$\epsilon_\nu(v) = cost\frac{N_i}{v}ln(av^3/\nu) \tag{1}$$

where the logaritmic term comes from the ratio between the maximum and minimum collision parameters. In the radio frequencies range $a = m/4\pi Ze^2 = 3.15\ 10^{-10}$ The total emission j_ν and the absorption coefficient k_ν of a population of electrons $N_e(v)$ is therefore given by:

$$j_\nu = \int_0^\infty \epsilon_\nu(v)\ N_e(v)\ 4\pi v^2 dv$$

and

$$k_\nu = -\int_0^\infty \frac{dN_e(v)}{dv}\epsilon_\nu(v) 4\pi v^2 dv$$

(see for instance Wild et al., 1963) In case of a Maxwellian distribution at temperature T, the above integrals give the well known relations:

$$j_0(\nu) = C\frac{N_i N_e}{T^{1/2}}ln(\alpha T^{3/2}/\nu)$$

$$k_0(\nu) = C'\frac{N_i N_e}{\nu^2\ T^{3/2}}ln(\alpha T^{3/2}/\nu)$$

with $\alpha \simeq 5\ 10^7$ (Rohlfs and Wilson, 2000). In the assumption of a bi-Maxwellian distribution at T_0 and T_1 with $T_1 > T_0$, and assuming that a fraction R of the total number of particles belongs the hottest one, $R = N_1/N_{tot}$, we get the following expressions for the emissivity j_{2g} and the absorption coefficient, k_{2g}:

$$j_{2g} = j_0 \times (1-R)\left(1 + \frac{c_1}{c_0}\frac{R}{1-R}\left(\frac{T_0}{T_1}\right)^{0.5}\right)$$

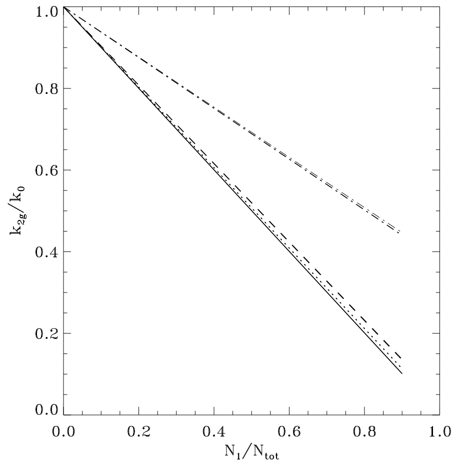

Fig. 2. Ratio of the absorption coefficients k_{2g}/k_0 plotted as a function of R for the following values of T_0/T_1: 0.5(dotted-dashed), 0.1 (dashed), 0.05 (dotted), 0.01 (full). Each curve is plotted for $T_0 = 5.\ 10^4$ and $T_0 = 5.\ 10^5$, but they are not distinguishable

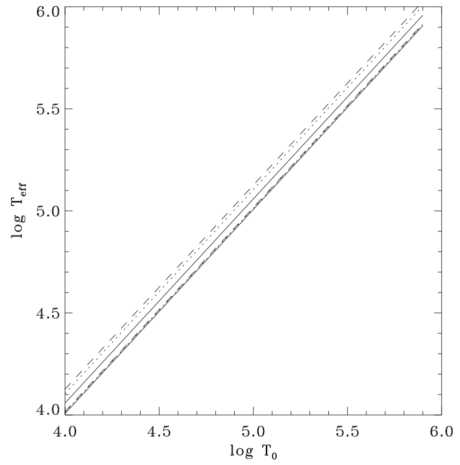

Fig. 3. T_{eff} vs T_0. Lower lines: R=0.1, T_1/T_0=0.01 (full line), 0.05 (dotted), 0.1 (dashed). Upper lines: R=0.5, same ratios of temperatures

$$k_{2g} = k_0 \times (1-R)\left(1 + \frac{c_1}{c_0}\frac{R}{1-R}\left(\frac{T_0}{T_1}\right)^{1.5}\right)$$

In the above equations $c_{0,1} = 1.5\ lnT_{0,1} - 4.6$ are the logaritmic terms present in Eq. 1, computed for $\nu = 5GHz$ and $T = T_0$ and T_1 respectively. From the ratio j_{2g}/k_{2g}, we derive the source function and the effctive temperature:

$$T_{eff} = T_0 \times \frac{1 + \frac{c_1}{c_0}\frac{R}{1-R}\left(\frac{T_0}{T_1}\right)^{0.5}}{1 + \frac{c_1}{c_0}\frac{R}{1-R}\left(\frac{T_0}{T_1}\right)^{1.5}}$$

Plots of k_{2g}/k_0 as a function of R for $T_0 = 5.\ 10^4$ and $5.\ 10^5$ and different values of the ratio T_0/T_1 are shown in Fig. 2. It is interesting to notice that, the k-ratio is practically independent of the temperature T_0 and, for $T_0/T_1 < 0.1$, also of the temperature ratio. The effective temperature is plotted in Fig. 3 as a function of T_0 for R=0.1 and 0.5 and three values of the ratio T_1/T_0 .The plot shows that T_{eff} is strictly proportional to T_0

3. Comparison with observations

The two quantities shown in the figures enter the radio transfer equation:

$$T_b = \int T_{eff} e^{-\tau} d\tau \tag{2}$$

where, in case of thermodynamic equilibrium $T_{eff} = T_0$ and $d\tau = k_0 ds$

Since both the ratios k_{2g}/k_0 and and T_{eff}/T_0 are independent of the local temperature T_0 and depend only on R, if we assume that the fraction of particles in the hottest maxwellian is constant along the TR, we may easily integrate Eq. 1, by multiplying k_0 and T_0 by the above ratios.

We have used the model mentioned in the Introduction to compute the microwave spectrum in the assumption of thermodynamic equilibrium. We have then changed k_0 and T_0 into k_{2g} and T_{eff} obtained assuming $T_1/T_0 = 10$ with R=0.2 and R=0.25. The resulting radio T_b are plotted in Figure 4. Notice that the dotted line

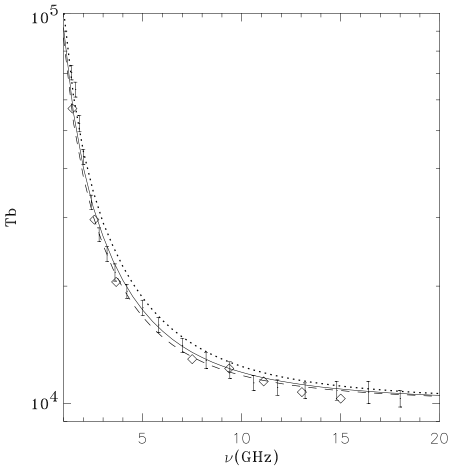

Fig. 4. Brightness temperature spectrum obtained by a Maxwellian distribution (dotted line), by a bi-Maxwellian distribution with $T_0/T_1 = 0.1$ and R=0.2 (full line) and R=0.25 (dashed line). Points with error bars are from Zirin et al. (1991), diamonds from Borovik et al. (1992)

is the same as that plotted in Figure 3 of Paper I It appears from the figure that the presence of a number of superthermal particles equal to about 20 % of the total number of electrons in the TR plasma, decreases the computed T_b from ~ 10 to ~ 2 % going from the lowest to the highest frequencies. We plan to repeat the above calculations with the following distributions of electrons:

a) a Maxwellian distribution to which a small tail of particles following a power law distribution is added.

b) a Kappa function.

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