SPACE AND TIME DISTRIBUTION OF HARD X-RAY EMISSION IN A LOOP AT THE BEGINNING OF A FLARE

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Abstract. Using a new 1D hybrid model of the electron bombardment in flare loops, we study not only the evolution of densities, plasma velocities and temperatures in the loop, but also the temporal and spatial evolution of hard X-ray emission. In the present paper a continuous bombardment by electrons isotropically accelerated at the top of flare loop with a power-law injection distribution function is considered. The computations include the effects of the return-current that reduces significantly the depth of the chromospheric layer which is evaporated. The present modelling is made with superthermal electron parameters corresponding to the classical resistivity regime for an input energy flux of superthermal electrons of $10^8$ erg cm$^{-2}$ s$^{-1}$. It was found that due to the electron bombardment the two chromospheric evaporation waves are generated at both feet of the loop and they propagate up to the top, where they collide and cause temporary density and hard X-ray enhancements.

Key words: Flares – X-Rays

1. Model

The hybrid model made consists of two parts: (a) the hydrodynamic part, describing a 1D semi-circular flare loop along its axis, and (b) the particle representation of superthermal electrons. Both these parts are synchronized in time.

In the hydrodynamic part, we have used the standard set of 1D hydrodynamic equations (Karlický, 1990). In the particle part of this model the superthermal electrons are represented by a large number of numerical particles ($10^5$). In present simulations an isotropic and continuous flux of superthermal electrons was generated. These electrons were injected at the top of the loop with the power-law distribution function. The trajectories of all the numerical electrons in the loop were computed. The energy and pitch angle changes of every individual electron in every particle time step were then computed as the sum of the collisional and return-current effects, using Monte Carlo method (see Bai, 1982; Karlický, 1990; Karlický et al., 1990). For the initial state, a semi-circular loop with the length 10,440 km in hydrostatic equilibrium
with a temperature profile of the chromosphere-transition region taken from the VAL model (Vernazza et al., 1981) was used. The density in the chromospheric part of loop was taken 10 times greater than in the VAL model and the temperature at the loop apex was chosen equal to $2 \times 10^5$ K. Knowing at every time the instantaneous distribution function of superthermal electrons in the flare loop, the hard X-ray emission and its positional dependence were calculated.

2. Results

All computations were made for an isotropic and continuous flux of superthermal electrons, with a power-law distribution function, having a spectral index $\delta = 3$. The superthermal electrons start to propagate from the apex of the loop, where they are injected. The energy input flux through input plane into one hemisphere was chosen as equal to $1 \times 10^9$ erg cm$^{-2}$ s$^{-1}$. Due to the electron bombardment the evaporation density waves at both feet of loop were generated and after some time ($\approx 15$ s) they collide, forming a density enhancement at the top of the loop (Fig. 1). Simultaneously with the hydrodynamic computations, we calculated the evolution of the position and of the spectrum of the hard X-ray emission in the loop (Fig. 2). Positions are expressed along a semi-circular loop.

![Graph](image)

Figure 1. The density profile in the flare loop during the isotropic and continuous bombardment at 16.80 s (dashed line), and 19.68 s (dashed and dotted line).

At the beginning of the evaporation, the hard X-ray is emitted mainly from the feet of the loop. At the top of loop we can see a small hard X-ray enhancement, which
is caused by the fact that the injection of electrons takes place at this position and that the electrons with pitch angles close to 90° spend a relatively long time there. Due to the decrease of return current losses, the energy of electrons entering the dense chromospheric layers is increasing in the following times, which increases the intensity of hard X-ray emission from the loop feet. Simultaneously with the upwards motion of evaporation waves into the corona the hard X-ray sources are prolonged in the same direction, and at 16.80 s, i.e., at time of the collision of evaporation waves, the hard X-ray radiation from the loop top is enhanced (Fig. 2).

![Graph](image)

**Figure 2.** The positional and energy distribution of hard X-ray emission at 16.80 s. The intensity of hard X-ray is expressed by superposition of low-level (+), middle-level (x) and high-level (○) emissivities. The corresponding hard X-ray emissivity levels are respectively 0.6, 6 and 20 photons cm⁻³ s⁻¹ keV⁻¹.

**Acknowledgements.** One author (M. K.) would like to acknowledge the support from the grant CIPA3510PL921464 of Commision of the European Communities.

**References**


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