INVESTIGATION OF NON-UNIFORM HEATING DURING THE DECAY PHASE OF SOLAR FLARES

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Abstract. We have analysed X-ray spectra of 13 solar flares as obtained by the Bent Crystal Spectrometer (BCS) on the Solar Maximum Mission. In particular, we have examined the observed ratio of $T_{Fe}/T_{Ca}$, where $T_{Fe}$ and $T_{Ca}$ are the temperatures obtained from the Fe XXV and Ca XIX spectra, respectively. In order to simplify the investigation we have analysed only flares which reach quasi-steady-state during the decay. It turned out that the observed ratios cannot be explained by a model consisting of a single, uniformly heated loop, with a constant or variable cross-sectional area. We propose that this problem may be solved by introducing some distribution of the heating function across the flaring loop. This model has been tested by detailed calculations.

1. The Analysis

We have analysed soft X-ray spectra of 13 solar flares observed by the BCS instrument on the Solar Maximum Mission satellite (see Table I). In particular, we have examined the observed ratios of $T_{Fe}/T_{Ca}$, where $T_{Fe}$ and $T_{Ca}$ are the electron temperatures of an iron and calcium emitting plasma. These temperatures are determined from the intensity ratios of the resonance line $w$ to the lithium-like dielectronic satellite $j$ in Fe XXIV ion and the satellite $k$ in Ca XIX ion, respectively (in notation of Gabriel, 1972). The intensity ratios of dielectronic satellite $j$ or $k$ to the resonance line $w$ are independent of the electron density and the ionization balance; they depend only on the electron temperature for a Maxwellian plasma and are commonly used now to estimate plasma temperature from high-resolution X-ray spectra (Lemen et al., 1984).

It is well known that the intensity $F_i$ of an X-ray line for an optically thin plasma can be written as

$$ F_i = \int f_i(T)\varphi(T)\,dT, $$

where $f_i(T)$ is the emission function (i.e., the line intensity for unit emission measure of plasma at temperature $T$, as predicted by theory), and $\varphi(T)$ is called the differential emission measure distribution ($\varphi(T) = N_e^2\,dV/dT$).

The emission function $f_i(T)$ contains all the temperature dependent factors connected with the line-formation processes including the excitation rate coefficient and the ionization balance. In the present paper, we have used the emission functions calculated

by Lemen et al. (1984), based on the excitation rate coefficients from Bely-Dubau et al. (1982) and the ionization balance from Jacobs et al. (1977).

We assume that the flare emission occurs in a single loop. In order to further simplify the investigation, we have analysed only the long-lasting quasi-steady-state (QSS) phase of the flare evolution (Jakimiec et al., 1986), when the variations of the physical conditions in the loop are slow. During this phase, the energy input (heating) is balanced by the radiative and conductive losses in any plasma volume, with convective transport playing a negligible role (plasma motions are not important to the energy balance).

Identification of the QSS phase was made for the 13 flares based on the so-called Diagnostic Diagrams as suggested by Jakimiec et al. (1987). An example of such a diagram is presented in Figure 1 for the flare of 29 June, 1980 (10:41 UT). For this flare, the QSS phase is reached 1.4 min after the first observation indicated. After this time, the evolution proceeds along a path indicated by the dashed line. This line shows the theoretical steady-state relationship between the maximum temperature and the emission measure for a constant volume coronal loop (Jakimiec et al., 1987). During the QSS phase, it might be expected that the differential emission measure (DEM) distribution corresponds to the steady-state loop model approximation. For such a model it is possible to calculate the theoretical values of $T_{\text{Ca}}$ and $T_{\text{Fe}}$ according to Equation (1). In the present investigation, the DEM distributions have been calculated based on the numerical modelling of a single, uniformly heated, quasi-static loop, with varying cross-

![Fig. 1. Diagnostic diagram for the flare of 29 June, 1980 (18:42 UT). The QSS phase corresponds to this portion of the diagram which may be approximated by the straight line with inclination predicted by the so-called scaling law. The temperature $T_{\text{Fe}}$ is derived based on the BCS Channel No. 4 iron spectrum, while the emission measure is derived from the BCS Channel No. 1 line fluxes. For details of the analysis of the spectra, see Lemen et al. (1984).](image-url)