COOLING OF SOLAR FLARE PLASMAS

W. T. ZAUMEN and L. W. ACTON

Lockheed Palo Alto Research Laboratories, Palo Alto, Calif. 94304, U.S.A.

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Abstract. A simple model for the cooling of solar flare plasmas is considered. This model predicts that an increase in emission measure with decreasing temperature is a general feature of a cooling flare. The results are compared to solar flare data.

1. Introduction

The production of a plasma in which the electron temperature exceeds $10^7 \text{K}$ is characteristic of solar flares. The most effective means of studying these hot plasmas are by X-ray spectroscopy where both line and continuum measurements are useful. This paper deals with the interpretation of X-ray continuum observations of the cooling of solar flare plasmas.

Culhane et al. (1970) have treated this problem by examining three cooling processes: Coulomb collisions of hot electrons with lower temperature ions, conductive cooling, and radiative cooling. They conclude that the first process is unimportant and note that radiative cooling (which varies as the square of the electron density) is ineffective below particle densities of $10^{11} \text{cm}^{-3}$. Observations suggest that hot post-flare volumes frequently occupy the upper portions of loop structures in the low corona and in many cases can be expected to have densities significantly below this value. Culhane et al. discuss conductive cooling in terms of a model with a particular geometry. They allow conduction only along a horizontal tube of arbitrary length and uniform cross sectional area, and the energy conducted through the ends of the tube is treated as lost to the system. The variation of the emission measure during the cooling period of the plasma is not considered.

Strauss and Papagiannis (1971) have treated a more general problem and have attempted to reproduce the time profile of a thermal X-ray burst by solving the time dependent energy transport equations including both a source term due to heating by $80 \text{keV}$ electrons, and radiative and conductive loss terms. Their assumptions of a constant, uniform electron density within a tubular volume, and of conduction along the tube to a gas at absolute zero allows them to fit the subflare of 26 June 1968 with electron densities of $2 \times 10^{11} \text{cm}^{-3}$ or higher within the tube.

We wish to examine a simple conductive cooling model which allows for atmospheric readjustments and which is formulated so that the effects of conduction on the emission measure are evident. This is motivated by data in the form of electron temperature and emission measure profiles of solar flares during the cooling phase. These are the parameters typically determined by continuum X-ray spectroscopy in the 4–20 keV range.
2. Analysis

The conductive cooling model we consider deals with a column for which the area of a horizontal slice is $A$. This column contains a hot region, initially of vertical extent $L$, separated from a cool region immediately below it by a sharp boundary as shown in Figure 1. The hot region is at a temperature $T$ (initially $T_0$) given by the X-ray spectrum. The cool plasma, assumed fully ionized, is at the temperature $T_f$ of the corona. In actuality, the tube is expected to be arranged symmetrically in the form of a loop. The calculations, however should be valid for each half of the tube separately, provided that the interface between the hot and cold regions is well down in the legs of the loop.

For an ideal gas approximation to the plasma, energy conservation and conservation of particles implies that

$$ N = N_0 \frac{T_0 - T_f}{T - T_f}, $$

where $N$ is the number of electrons in the hot region at temperature $T$ and $N_0$ is the number of electrons in the hot region at some initial temperature $T_0$. Since the hot region is assumed isothermal, its electron density varies exponentially with scale height $H$ at temperature $T$ and scale height $H_0$ at temperature $T_0$.

![Diagram](image)

Fig. 1. Parameters and geometry of the conductive model. $T_0$ is the initial temperature of the hot region, $n_0$ and $n_f$ are the temperatures above and below the boundary between the hot and cold regions, respectively. $T_f$ is the temperature of the cool region. $D$ and $\Delta l$ are the initial length of the cool region and the change in its length during cooling of the hot region. $A$ is the area of the tube which confines the plasma.