HIGH-ENERGY FLARE EXPLOSIONS DRIVEN BY 3-DIMENSIONAL X-TYPE CURRENT LOOP COALESCENCE

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(Received 5 April, 1990; in revised form 18 March, 1991)

Abstract. We present a model for high-energy solar flare explosions driven by 3-dimensional X-type current loop coalescence. The 3-dimensional X-type current loop coalescence, where two crossed flux-tubes interact at one point, is a fundamentally new process as compared to the 1-D and 2-D cases studied earlier. This process is studied by a first-order approach of the relevant variables near the point of coalescence; it appears to yield reliable information in a sufficiently large area around this point. It is shown that, following a strong plasma collapse due to the pinch effect, a point-like plasma explosion can be driven while fast magnetosonic shock waves can also be excited. We found that the conditions in the area producing the remarkable flare bursts of 21 May, 1984 were indeed such that the many flare spikes could have been due to 3-D explosive X-type current loop coalescence. We also show, by studying the conditions of shock formation in a gamma ray flare, that the time delay of $\gamma$-rays from the impulsive phase could be the time needed for the shock formation in the flaring region.

We draw some general conclusions on the question why certain flares do emit $\gamma$-rays in the MeV energy range, and why other, apparently important and energetic flares, do not. We accentuate the fact that a well-developed high-energy flare has three phases of particle acceleration.

1. Introduction

The current loop coalescence model of solar flares (Gold and Hoyle, 1960; Tajima, Brunel, and Sakai, 1982; Tajima et al., 1987; for a review see Sakai and Ohsawa, 1987) provides keys to understanding many of the characteristics of solar flares such as explosive plasma heating, high-energy particle acceleration (for both protons and electrons), and quasi-periodic oscillation of electromagnetic emission. Recently it was shown (Sakai, 1989, 1990a; Sakai and de Jager, 1989a, b) that the loop coalescence processes may have different signatures, depending on the geometry of the region containing the two interacting current loops. The key parameters characterizing these different signatures are the scale $L$ along the loop current, which characterizes the length of the interacting region of two loops, and the radius $R$ of the current loop, as shown in Figure 1. As seen in Figure 1(a) where $L \gg R$, an almost one-dimensional current sheet can be induced in the interacting region by a quasi-parallel approach of two loops (Sakai and Ohsawa, 1987; Sakai, 1990a). In this situation the current loops coalesce with quasi-periodic oscillations when $B_p$ (magnetic field produced by the current) exceeds $B_t$ (magnetic field along the loop). During the coalescence electrons and protons...
Fig. 1. Schematic pictures showing three types of current loop coalescence: (a) 1-D coalescence, (b) 2-D coalescence, (c) 3-D X-type coalescence. $L$ is a characteristic length of the interacting region. $2R$ is the diameter of the loop with plasma current $j$ along the magnetic field, $B$. $B_p$ is the poloidal magnetic field produced by the plasma current.

can both be simultaneously accelerated to relativistic energies within one second (Sakai, 1990a). In contrast, when $B_p < B$, the loop coalescence proceeds, associated with motions causing plasma tilting without strong quasi-periodic oscillations.

When $L > R$, as seen in Figure 1(b), a flow of strong plasma jets can be driven by the plasma tilting motion around the magnetic reconnection point (Sakai, 1989a). This mechanism has been applied to explain coronal explosions (Sakai and de Jager, 1989b).

The third situation where $L \approx R$ (Figure 1(c)), is the case of 3-dimensional X-type current loop coalescence (Sakai and de Jager, 1989a), which we study in the present