MORPHOLOGY OF THE 10 MILLION DEGREE PLASMA IN SOLAR FLARES AND THE FAILURE OF THE CHROMOSPHERIC EVAPORATION MODEL

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Abstract

The SXT images of over fifty C, M, and X type flares which occurred between October 1991 and February 1993 were analyzed. For each flare, the 10 million degree emitting region was typically found to be located at the loop top in the first well-exposed flare image recorded during the rise phase (within 1 to 2 minutes after flare onset), in images recorded near the intensity peak, and in images recorded during most of the decay phase. For the November 2 1992 limb flare, the loop top was bright for 24 hours. For a few flares, the brightness of the footpoints in the onset images was comparable to the brightness of the loop top, but the loop top brightness rapidly increased relative to the footpoints and remained intense for the duration of the flare. The brightest region at the loop top was very small throughout the flare, often as small as a single pixel (1800x1800 km). The conclusions are that the energy is deposited in a small volume at the top of the flaring loop structure, the heating mechanism acts over a period of up to tens of hours, and the hot plasma is confined at the top of the loop structure. These results are not explained by the traditional chromospheric evaporation model of solar flares.

Analysis of SXT Images

The most widely accepted flare model has been the chromospheric evaporation model (CEM). This model assumes that a sudden burst of energy is released by the annihilation of magnetic fields somewhere along a pre-existing coronal loop. The annihilation outburst produces beams of particles or conduction fronts that move within the loop boundary with velocities exceeding 500 km/sec toward the solar surface. Upon encountering the dense chromosphere, the chromospheric material is heated and expands up the legs of the loop.

As discussed in three recent papers, Yohkoh SXT and BCS observations of non-impulsive flares cannot be explained by the CEM (Feldman et al. 1994a and 1994b, and Acton et al. 1992). The SXT flare images recorded through the Be filter typically consist of one or at most a few flaring loops. In cases of multiple loops, the loops typically do not peak in brightness at the same time. For the duration of the event, the brightest part of the hot (ten million degree) emitting plasma is concentrated in a very small volume at loop tops and does not spread into the loop legs. The brightening at loop tops is seen in all well observed limb events. Even during the longer duration events, the bright region does not seem to move from its location at the top of the loop by more than one pixel (1800 km). In addition, the velocities derived from the BCS spectra during these flares are typically less than 100 km/sec. These findings are inconsistent with the predictions of the CEM.

These results are illustrated by the February 17 1992 flare. The H-alpha flare occurred at S16W81 beginning at time 15:37 UT. The BCS light curves rose at 15:38, peaked at 15:43 to 15:46, and declined thereafter. The SXT images shown in Fig. 1 were recorded through the Be filter at times 15:40:45, 15:45:05, 15:48:29, and 15:49:29. The footpoints were bright only in the earliest frame and quickly faded, while the loop top was bright throughout the flare, from the earliest to the latest frames.

The November 2 1992 flare originated in an active region that was approximately 5.5 degrees behind the west limb. The GOES light curves rose at 02:30 UT, peaked at 03:10, and decayed over the next 30 hours until 09:00 on November 3. Nine SXT images recorded at various times during the flare are shown in Fig. 2. White light images are superimposed on the first seven SXT images shown in Fig. 2, and the limb is visible in the last two SXT images. The first well-exposed SXT image through the Be filter was recorded at 03:07:30 (November 2) near flare maximum. This image consists of a bright emitting region at the top of a small number of loops. The appearance of this long duration flare changed very slowly. By 05:04:44, the bright emitting region consisted of perhaps three loops, each of which was bright at the top. By 08:50, only two of the loops were bright enough to be visible in the SXT images. The most prominent feature in the entire sequence of SXT images was the bright emitting region at the loop top at the time of the first image, and the loop top brightening is still clearly recognizable at 21:41. Over this period, the apparent height of this bright region above the solar limb increased from 25,000 km to 66,000 km or, allowing for the rotation of the active region, the height above the surface increased from 27,000 km to 90,000 km (a rate of approximately 1 km/sec). As the loop structure rose, the region of brightest emission remained at the top of the loop structure.

In the case of the November 2 1992 flare, the brightening at the loop top was visible for a period of 24 hours after flare onset. This implies that the energy was deposited at the top of the loop, the heating mechanism acted over a period of tens of hours, and the hot plasma was confined at the top of the loop. All of these findings contradict the CEM.

The nearly semicircular shape of the loop structures of the February 17 1992 and the November 2 1992 flares indicates that the flares were observed approximately along the normal to the plane of the loop structures. Thus the brightening at the loop top cannot be explained by the geometrical effect of emission from a long path length through the top of a loop structure viewed on edge. It is emphasized that the morphologies of the February 17 1992 and the November 2 1992 flares are not unusual, but are rather typical of the more than fifty flares that were studied in detail.

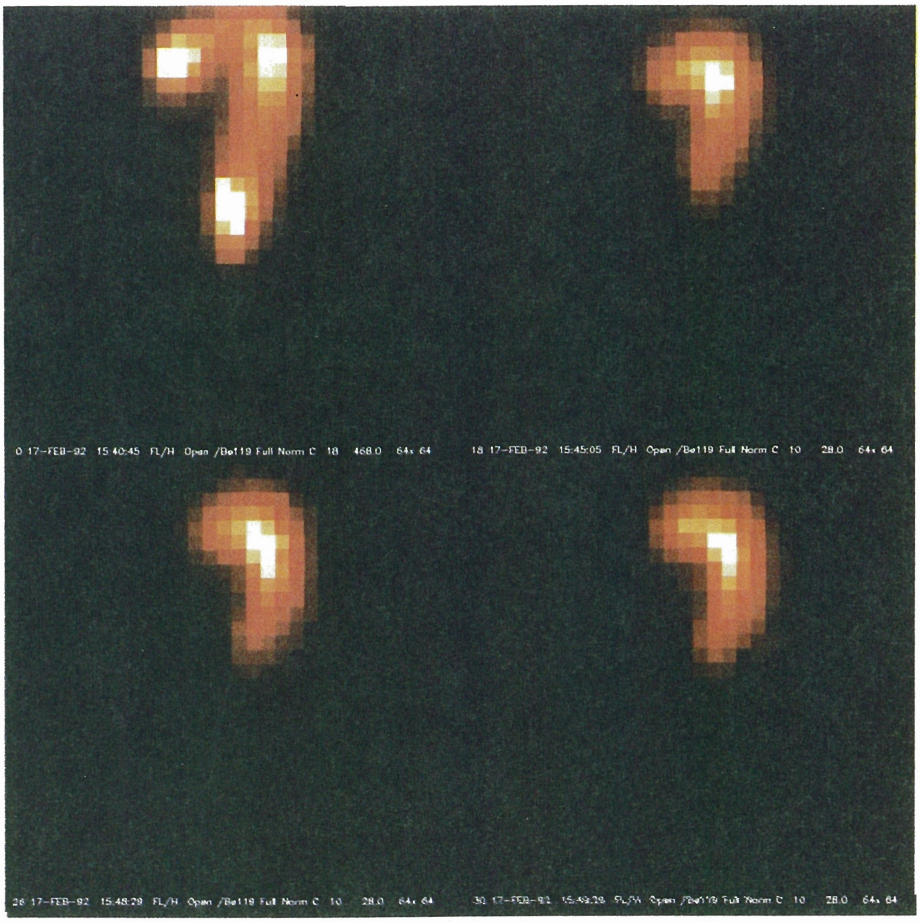

Fig. 1. SXT images of the February 17 1992 flare.

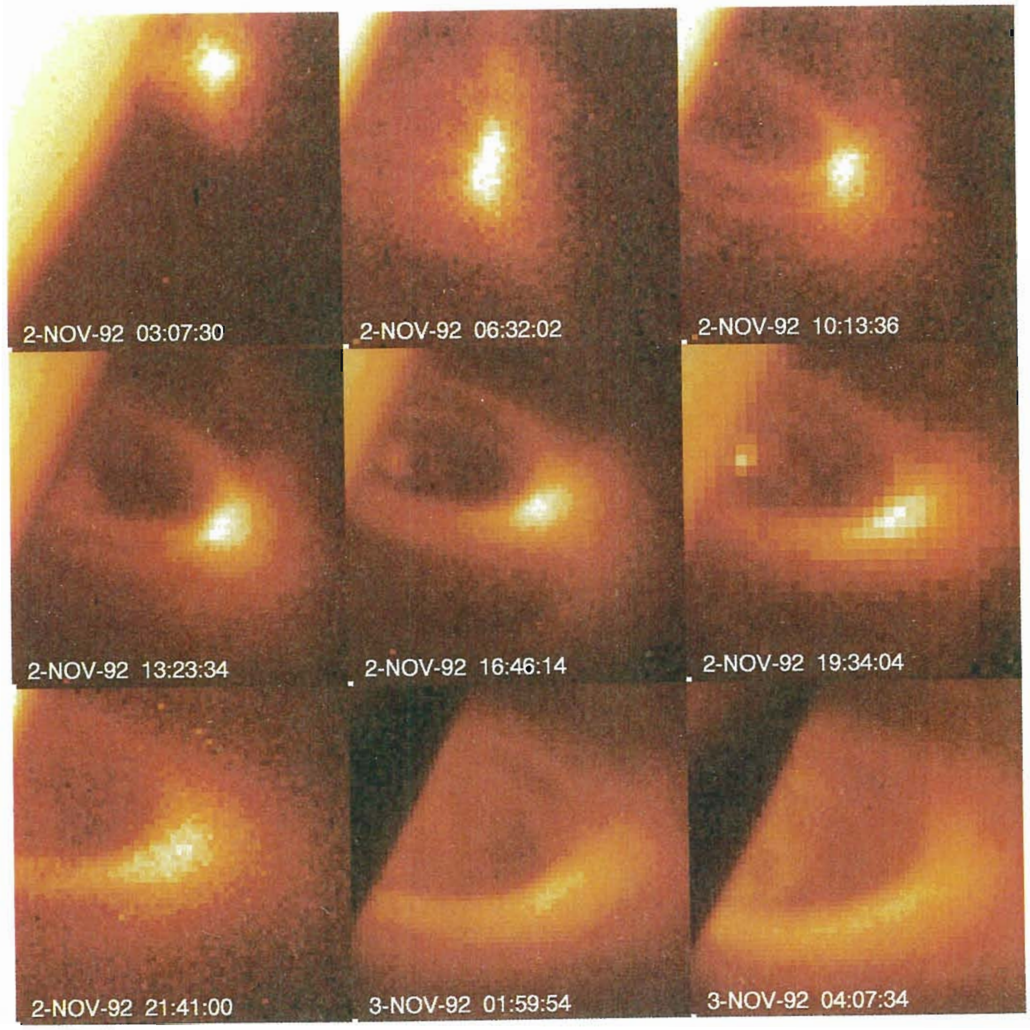

Fig. 2. SXT images of the November 2 1992 flare.

References

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