

Current sheet of 4 November 2003 flares

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Reconnection current sheets are a central feature of models of solar flares and coronal mass ejections (CME) but they are still not understood. Ultraviolet spectra from the UVCS instrument aboard SOHO are combined with white light observations from MLSO to obtain the temperature, density, thickness and depth of the flare-CME current sheet that developed during the powerful flare on 4 November 2003. This paper summarizes the observations and the results. It was found that the thickness of the current sheet is far larger than expected from the Sweet-Parker picture of reconnection. It may be consistent with the region formed by slow-mode shocks in the Petschek picture, and it is probably consistent with models of reconnection in a turbulent layer such as that of Lazarian and Vishniac.

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1 Introduction

The solar flare at 19:45 hrs UT on 4 November 2003 was the largest in this solar cycle, and one of the largest ever recorded¹. The Ultraviolet Coronagraph Spectrometer (UVCS) aboard the SOHO satellite² was performing a long series of observations at a distance of 1.64 R_{SUN} from Sun center directly above the active region that produced the flare. Photons produced during the impulsive phase of the flare in the lines of O VI at $\lambda 1032$ and 1038 were scattered by O VI ions in the corona, making it possible to determine the flare luminosity at transition region temperatures where O VI is formed. In this paper, another aspect of the UVCS observations of this flare, the current sheet that forms between the flare loops and the core of the coronal mass ejection (CME) has been explored.

According to the standard picture of large flare/CME events^{3,4}, the rising CME core leaves behind a low pressure region in its wake. External magnetic pressure forces reconnection of the oppositely directed magnetic fields in this region, simultaneously helping to release and accelerate the CME and power the X-ray flare. Magnetic reconnection in the current sheet must proceed rapidly in order to account for the luminosity and the rapid rise of the X-ray emission.

In a modest number of events where the viewing geometry was favorable, it has been possible to determine physical parameters of the current sheet.

Yokoyama *et al.*⁵ measured the inflow rate into the current sheet from EUV images. UVCS observations have provided temperatures, densities and inflow rates^{6,9} which could be combined with outflow rates from white light images to estimate the Alfvén Mach number¹⁰.

The observations of the 4 November 2003 event are the best UVCS observations of a flare/CME current sheet to date in some ways, both because the event was so bright and because UVCS kept a constant pointing for many hours. In addition, MLSO white light coronagraph observations were available for much of the crucial period just after the impulsive phase. In this paper, the main physical parameters, the temperature, density and turbulent velocity of the current sheet have been summarized.

2 Observations

UVCS participated in the Max Millenium Flare Watch campaign for active region AR100486 during 2-5 November 2003. The UVCS slit was positioned at 1.66 R_{SUN} and a position angle of 262 degrees. A long series of 120 second exposures was obtained with the OVI channel. The grating position and detector mask allowed to observe the spectral lines O VI $\lambda\lambda 1032$, 1038 , Si XII $\lambda\lambda 499$, 521 , Ly λ , [Fe XVIII] $\lambda\lambda 974.5$ and C III $\lambda\lambda 977.0$. The combination of slit width and onboard binning in the spectral direction provided a resolution of about 90 km s⁻¹. The spatial binning in

the direction along the slit provided a spatial resolution of 42 arcsec or 3×10^9 cm.

Figure 1 shows the brightness of the lines detected by UVCS and the white light brightness from the Mauna Loa Solar Observatory (MLSO) Mark IV coronagraph. The horizontal axis shows the time in minutes, and the vertical axis shows the polar angle (PA) in degrees counter-clockwise from solar North. The vertical streaks in the UVCS [Fe XVIII], Si XII and C III data at about 150 minutes past 17:20 hrs UT correspond to a brief period of very high background due to X-rays from the flare. The vertical streak in the O VI data at slightly earlier times is due to O VI photons from the flare scattered in the corona.

The horizontal feature seen in [Fe XVIII], Si XII and white light is the current sheet, which is seen to last for many hours. It is initially broad and bright in [Fe XVIII], but faint in Si XII. As the current sheet cools, the Si XII/[Fe XVIII] ratio declines. The bright features seen in O VI and C III are located at PAs a little higher than the current sheet. They appear to be clouds of cool material ejected after the main event that are channelled by the magnetic field to move along close to current sheet. They are likely to be examples of 'streamer puffs' caused by the disturbance resulting from the main flare.

3 Results

A more quantitative picture of the fluxes in the emission lines is given in Fig. 2. The [Fe XVIII] intensity rises quickly, but not instantly, after the flare then declines gradually over the course of several hours.

The [Fe XVIII] line emissivity peaks at a temperature $\log(T) = 6.8$, while the Si XII emissivity peaks at $\log(T) = 6.3$. The ratio of the lines shows that the temperature declines from $\log(T) = 6.9$ to $\log(T) = 6.4$ during the course of the observations. The emission measure, $EM = n_e^2 L$, is obtained by dividing the [Fe XVIII] intensity by the line emissivity. The electron column density, $N_e = n_e L$, is obtained from the white light polarized brightness. The ratio of these two numbers gives the density, which then gives the line-of-sight depth, L .

It was found that the density is about $5 \times 10^7 \text{ cm}^{-3}$ and that L is about 10^{10} cm . These numbers imply that the actual thickness of the current sheet is comparable to its apparent thickness of more than $0.1 R_{\text{SUN}}$. That thickness is far larger than expected from classical models of reconnection current sheets. However, it is comparable to estimates based on other UVCS and

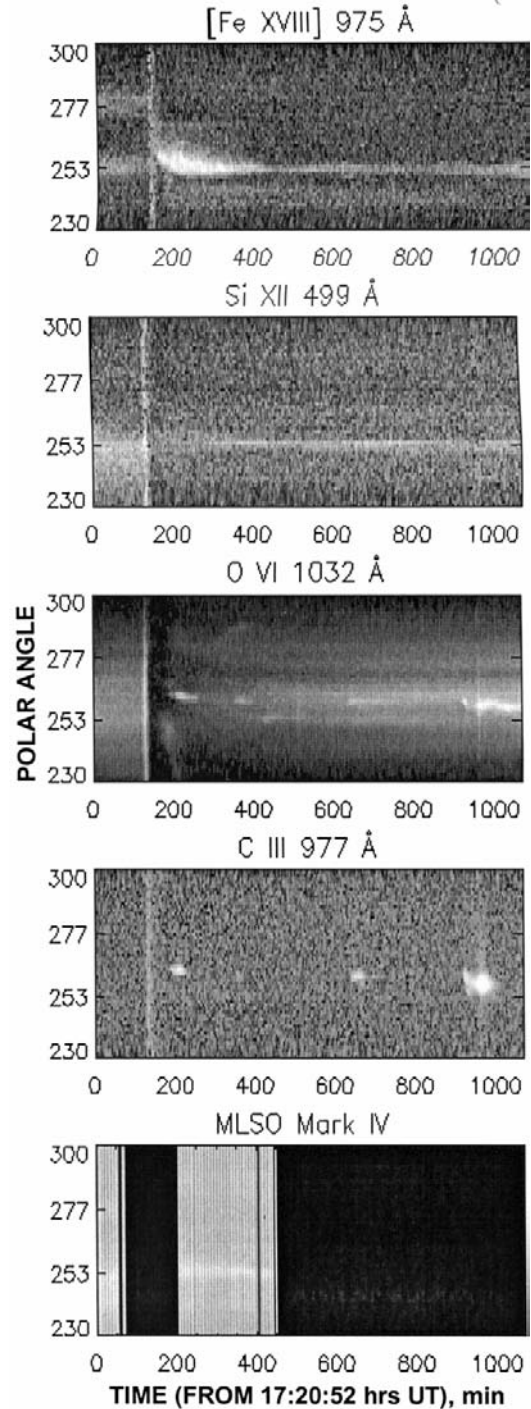


Fig. 1 — Intensities of several ultraviolet emission lines from UVCS and of the polarized brightness (pB) from MLSO extracted for positions corresponding to the UVCS slit. Vertical axis shows position angle, and the horizontal axis shows time. UV data are line intensities extracted from a series of 120 second exposures. MLSO pBs come from limb scans taken approximately 3 minutes apart. Vertical streaks in the UV images correspond to the high background due to flare X-rays, except for O VI, in which case real emission is seen due to flare O VI photons scattered by coronal O VI ions

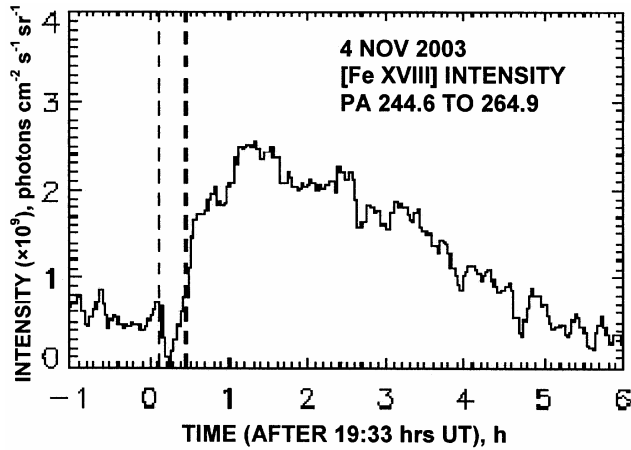


Fig. 2 — Plot of the intensity of [Fe XVIII] emission as a function of time. After the period of high background, [Fe XVIII] emission rises gradually for about half an hour, they decay over several hours

LASCO observations. It is somewhat higher than theoretical estimates based on turbulent reconnection, but those estimates are so far quite approximate.

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