UVSP AND VLA OBSERVATIONS OF THE 24 JUNE 1980 FLARE: ASYMMETRIC OR ISOTROPIC BEAMING?

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Abstract. Observations of the 15:22 UT flare of 24 June 1980 were made using the Very Large Array (VLA) at 6 cm wavelength simultaneously with the Hard X-ray Imaging Spectrometer (HXIS) aboard the Solar Maximum Mission. It was found that at the peak of the impulsive phase, the brightest microwave point appeared to lie between the soft (3.6–8.0 keV) and hard (22–30 keV) X-ray maxima, which were themselves separated by ~20″ (Kundu *et al.*, 1984). Since the publication of these results, we have analyzed the imaging data from the Ultraviolet Spectrometer Polarimeter (UVSP) with the goal of narrowing the possible interpretations of the event. Like the VLA and HXIS, the UVSP observations provide information about the location of the primary electrons; the observations taken together suggest that the fast electrons were symmetrically distributed within the flare loop.

1. Introduction

Simultaneous spatially-resolved observations of the impulsive phase in hard X-rays and microwaves have shown that the primary electrons generating the X-ray and radio emission often, but not always, appear to be located in the same position in three-dimensional space (for a summary, see Kundu, 1984; another example was shown by Schmahl, Kundu, and Dennis, 1984). The flare of 24 June 1980 (15:22 UT) is a typical example of the complex forms that the spatial patterns of the high energy emission can take. In a study of hard X-ray images obtained by the Hard X-ray Imaging Spectrometer (HXIS) aboard the Solar Maximum Mission Satellite, Kundu *et al.* (1984) showed that the soft (3.6–8.0 keV) and hard (22–30 keV) X-ray maxima did not precisely coincide, the hard X-rays appearing ~20″ west of the soft X-rays. The VLA snapshots, on the other hand, showed that the peak emission at 6 cm occurred approximately midway between the soft and hard X-ray maxima.

Since these observations were published, we have analyzed some new data from the Ultraviolet Spectrometer/Polarimeter which provide some new insight into the geometry of the magnetic structure in the burst. Ultraviolet bursts have been shown to spatially coincide with the hardest (>20 keV) X-ray emissions (Cheng *et al.*, 1981; Cheng, Tandberg-Hanssen, and Orwig, 1984), and such observations can complement the microwaves and hard X-rays in providing information about the locations of the primary electrons.

The UVSP data provide the necessary ingredient for distinguishing between two possible interpretations of the Kundu *et al.* (1984) observations. One interpretation is

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that the magnetic structure is an asymmetric loop with a diffuse eastern foot where hard X-rays were emitted weakly and a concentrated western foot where hard X-rays predominated. An alternative interpretation is that the loop was fairly symmetric, but that the acceleration process was asymmetric, and this led to more beaming toward the western footpoint where harder X-rays were produced. We shall show that the UVSP data distinguish between these two interpretations, showing precisely where the energetic electrons were beamed.

2. Observations

The June 24, 15:23 UT flare was classified as SB in Hα and M1 in soft X-rays. The Hα flare onset was very abrupt, starting at 15:22 UT, peaking at 15:23 UT and fading away at 15:25 UT. The SMM instruments, including UVSP and HXIS, were pointed at this region throughout the flare.

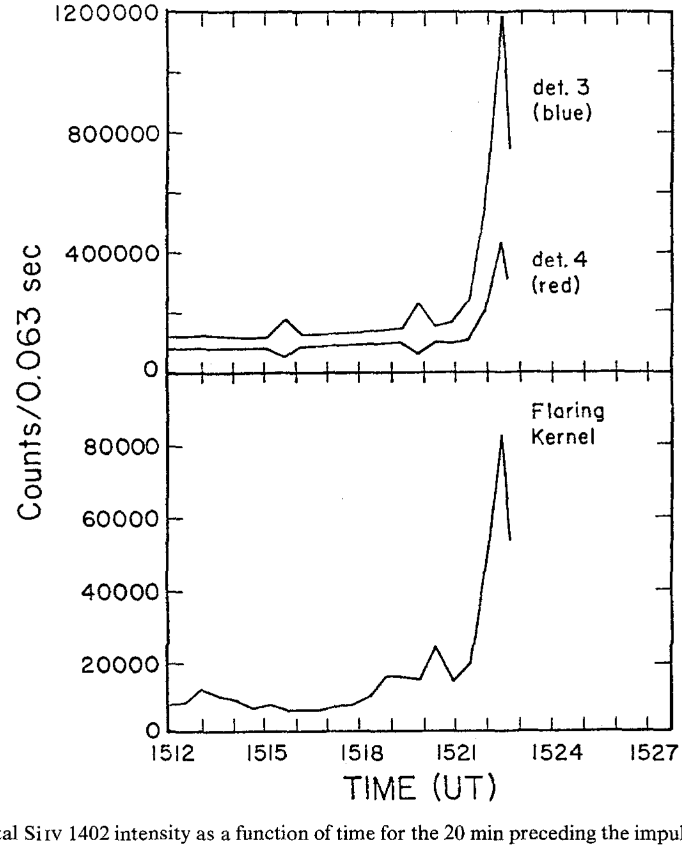

Fig. 1. (a) Total Si IV 1402 intensity as a function of time for the 20 min preceding the impulsive maximum of the flare. Detector 3 recorded the blue side of the Dopplergram while detector 4 recorded the red side of the Dopplergram. The two small variations at ~15:15 and 15:20 UT were due to calibration shift of the Dopplergram position. (b) Intensity of the kernel as a function of time for the same period as above.

2.1. The UVSP Burst

The 24 June flare was observed in the Si IV 1402 Å line by the UVSP instrument. The observation was done in a Dopplergram mode with a field of view (FOV) of 60″ × 60″ and a pixel size of 3″ × 3″. The time cadence of the raster observation was 31 s. Figure 1 shows the light curves obtained by the two detectors covering the red and blue sides of the Si IV line as well as all the pixels in the raster (upper panel). The lower panel of Figure 1 shows the light curve of the flaring kernel (see Figure 2). Unfortunately the detectors were saturated at 15:22 UT, when the impulsive hard X-ray burst was approaching its peak (HXIS), and the UVSP observations were terminated. However, there was good spatial and temporal coverage of the onset phase of the burst, and this will be compared with the VLA observations.

Figure 2 shows the time sequence of raster images observed in Si IV. The left contour maps are for the summed intensity of the two UVSP detectors. The right contour maps

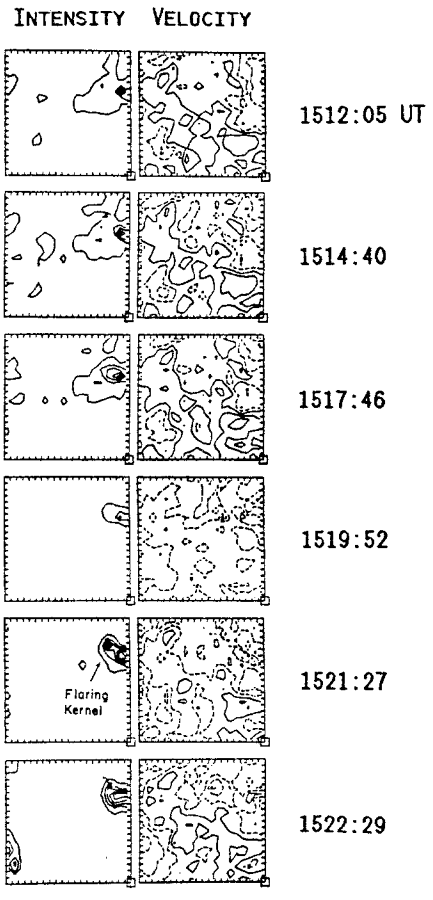

Fig. 2. Rasters of intensity and velocity in the Si IV line for the 15:12:05–15:22:29 period. The velocity maps have a poorly calibrated zero level, which was selected to make the mean velocity of the entire map equal to zero.

show the velocity distribution derived from the Dopplergram observations (cf. Henze, 1984). Since we do not have absolute calibration of the wavelength position, the derived velocity value can only be taken as a rough estimate of the relative mass motion velocity. The figure shows that the Si IV flare was located in a bright kernel in the SW (15:21 UT). In fact, this flaring kernel was already the dominating feature in the UVSP FOV at the beginning of the observation at 15:12 UT. Examination of the total light curve of the kernel (Figure 1) shows that the Si IV intensity there starts to increase rapidly at about 15:19 UT. The raster images show that the flaring kernel was the pre-existing bright point. The intensity at the kernel increased more than an order of magnitude at the time of the flare. Previous observations in the transition region lines have shown that many initially bright points in the active region become the impulsive flaring sites, although many do not.

Figure 3(a) shows the co-alignment of the UVSP raster with the off-band Hα filtergram, together with comparisons between Hα, hard X-ray, and VLA observations (from Kundu *et al.*, 1984). The co-alignment between the UVSP and the Hα observations was done by using the known pointing position of the UVSP raster on the solar disk and then locating on the whole disk Hα picture. We estimate that the accuracy of the co-alignment is about 5″ to 10″, which is adequate for our purpose. The figure shows that the Si IV flaring kernel is co-spatial with the centroid of the HXIS contour in the soft (3.5–8 keV) band, and just to the west of the VLA intensity center. Since the smaller FOV of the UVSP observation did not cover the entire flare region, we have no information on the UV emission at the other bright hard X-ray spot to the right, which was conspicuous in the 22–30 keV band (see Figure 3(b)). Comparison between impulsive HXR and UV bursts in flares (Cheng *et al.*, 1981; and Cheng, Tandberg-Hanssen, and Orwig, 1984) have shown that the sites of flaring UV kernels are also strong sources of hard X-rays. It is reasonable to assume that a UV bright kernel would be observed at the hard X-ray spot, if the UVSP had a larger FOV at the time of the 24 June flare. The co-alignment of observations in the various wavelength bands strongly suggests that the bright spots in Si IV and in hard X-rays are the footpoints of a flaring loop. We also note that there was a small Si IV bright point showing up at the time when the impulsive burst was in the rise phase (Figure 2) to the left of the main Si IV flaring kernel. The intensity at this minor Si IV point is a factor of ~ 50 less than that at the main kernel. Considering the complicated morphology of the flare as shown in Hα and hard X-rays, it is entirely possible that the whole complex of loops in the active regions were affected, and the minor Si IV point may represent the footpoint of one of them.

2.2. 6 cm VLA BURST

Figure 4 shows a sequence of VLA snapshot maps at 6 cm in total intensity (I) and circular polarization (V) during the rise phase of this flare. We have mapped the 6′.0 × 6′.0 field with a resolution of 28″. Each map was made using a 10 s integration which was the best time resolution that was available for VLA mapping at the time. The six sets of I, V maps shown in Figure 4 are a representative sample from the 32 sets of snapshot maps which we made for this burst between 15:19:45 and 15:26:45 UT on

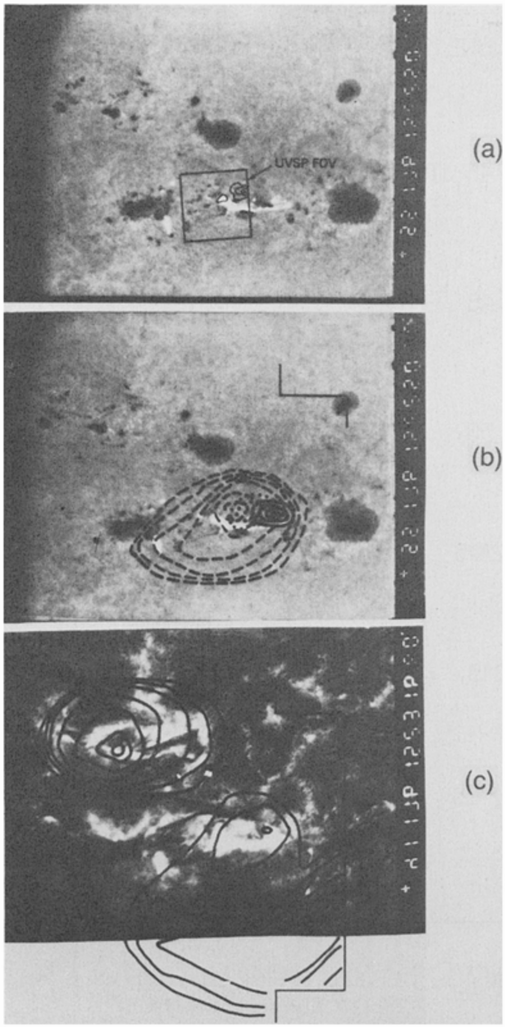

Fig. 3. (a) UVSP raster (15:22:29 UT) overlain on an off-band Hα filtergram at 15:22:20 UT. (b) 15:18:24 UT HXIS soft (dashed) and hard (full) X-ray images together with the VLA map of the impulsive phase (dotted). (c) 15:53:44 soft X-ray contours on the line center Hα image. The Hα photographs are courtesy of V. Gaizauskas (ORSO).

24 June, 1980. This time interval includes the impulsive rise of burst intensity. The impulsive rise occurs from 15:21:50 to 15:22:50, spanning the first apearance of Hα brightening at 15:22:08. The first Hα brightenings, however, are 10″–20″ W of the burst. The 6 cm brightness reaches maximum intensity at 15:22:55 UT and decays during the remainder of the maps. With the resolution of 28″ the burst structure appears simple (unresolved) and its position is constant for all maps. The burst source in Figure 4 is centered approximately 10″ north of the small bulge on the right-hand side

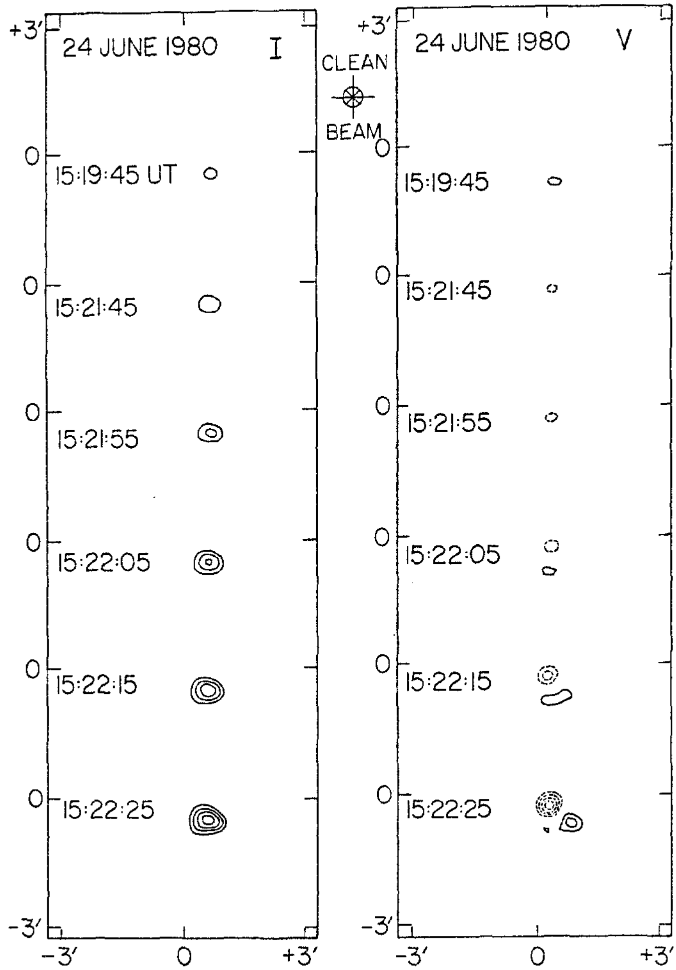

Fig. 4. VLA snapshot (10 s) maps for the 6 cm burst. Clean beam size is 28″. *I*-contours: 2.5×10^6 K to 7.18×10^6 K in steps of 0.31×10^6 K.

of the flare kernel in Figure 3. The filtergram of 15:22:50 UT shows that this bulge is actually resolved into two Hα ribbons separated N–S by about 5″. The circular polarization maps for the burst at 6 cm show a simple bipolar structure with the left circularly polarized (LCP) component located about 34″ northeast of the right circularly polarized (RCP) component. The RCP component is coincident with the southern-most Hα ribbon at the eastern edge of the Hα flare shown in Figure 3. Near the time of the burst peak the predominant polarization is LCP (see Figure 4).

3. Interpretation

Since the 22–30 keV HXIS emission appears to the west of the VLA 6 cm peak and the UVSP maximum appears to the east of the 6 cm peak, we conclude that there was energy transport to both east and west in the loop structures. We must note, however, that the VLA synthesized beam was quite large (28 arc sec) and, therefore, it is not inconceivable that the 6 cm position was much closer to the hard X-ray source than it appears to be (Alissandrakis, Schadee, and Kundu, 1988). The simplest interpretation seems to be that the microwaves were emitted from the top part of the leg of a magnetic loop, UV emission appeared from the eastern footpoint, and hard X-rays were radiated from the western footpoint. The 6 cm *V*-maps show bipolarity along a NE–SW axis. UV emission may have also been emitted from the western footpoint, but it was outside the UVSP field of view. The failure of hard X-rays to appear on the eastern leg of the loop may be due to limited sensitivity, since it is hard to imagine a process that would produce impulsive UV radiation, but not hard X-rays. Presumably the western footpoint not observed by UVSP was far brighter in UV than the eastern footpoint, as suggested by the HXIS footpoint disparity.

None of the UV, X-ray or microwave peaks coincided with the Hα ribbons. Some of the displacement might be caused by projection effects; this would require that the magnetic loops lay well out of the vertical plane. The 6 cm *V*-maps show some bipolarity along a NE–SW axis, not the E–W direction expected by the simplest interpretation given above. The magnetic structure may be a highly sheared arcade, with mainly E–W lines of force, but a polarity which is also partially N–S. This is consistent with the Hα displacement as well as the circular polarization and the UV/microwave/HXR displacements.

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