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OBSERVATIONS OF ENHANCED CORONAL HEATING IN SHEARED MAGNETIC FIELDS

R. T. Moore [1], J. Poreter [1], G. Roumeliotis [2], S. Tsuneta [3], T. Shimizu [3],
P. A. Sturrock [4], and L. W. Acton [5]

[1] *Space Science Laboratory, NASA Marshall Space Flight Center, Huntsville, AL 35812, U.S.A.*
[2] *Center for Space Science and Astrophysics, Stanford University, Stanford, CA 94305, U.S.A.*
[3] *Institute of Astronomy, The University of Tokyo, Mitaka, Tokyo 181, JAPAN*
[4] *Center for Space Science and Astrophysics, Stanford University, Stanford, CA 94305, U.S.A.*
[5] *Department of Physics, Montana State University, Bozeman, MT 59717, U.S.A.*

Abstract

From superposition of Yohkoh SXT images on MSFC vector magnetograms of two active regions, we find: (1) coronal heating is enhanced at sites of strong magnetic shear, and (2) this heating is produced by microflares.

To explore coronal heating in relation to magnetic shear in active regions, we selected two active regions (AR 6982 on 26 December 1991 and AR 7070 on 28 February 1992) in which (1) classic magnetic shear was obvious in vector magnetograms from the Marshall Space Flight Center (MSFC) Solar Vector Magnetograph and (2) the location, structure, and variability of bright coronal X-ray features were well observed by the Yohkoh SXT. The first active region is shown in Figures 1 and 2, and the second one is shown in Figures 3 and 4. The Figures show the location, form, and configuration of the sunspots, magnetic polarity inversion lines, and magnetic shear, and the corresponding location, form, and fluctuation of the bright X-ray coronal plasma.

In both active regions, magnetic shear is concentrated along the boundary between impacted sunspots of opposite polarity (that is, along the polarity inversion line in a delta sunspot). This form of nonpotential magnetic structure is common in delta sunspots and along other inversion lines in active regions (Moore and Rabin 1985). The field near an inversion line is deemed strongly sheared if it runs along the inversion line rather than going right across the inversion line as it would if it were a nearly potential field (Hagyard, Moore, and Emslie 1984). The magnetic shear in the first active region is more extreme and more extensive than in the second active region. The first active region has four shear sites, each of different extent, field strength, and degree of shear; in the second active region, the field strength and degree of shear change markedly along the inversion line through the delta sunspot. From this small but diverse sample of shear conditions we draw the following conclusions:

1. The X-ray brightness, and hence the coronal heating, in active regions is enhanced at sites of strong magnetic shear.
2. The enhanced heating continually varies on time scales of a few minutes. That is, the heating is not steady, but continually fluctuates in the manner of an irregular sequence of microflares. This finding of microflaring on magnetic inversion lines is compatible with Solar Maximum Mission UV and X-ray observations of microflaring on inversion lines in active regions (Porter, Toomre, and Gebbie 1984; Porter, Fontenla, and Simnett 1993).
3. Within and among sites of obvious magnetic shear, most of the time the heating is stronger where the magnetic shear is stronger, but places of weaker shear can flare up and briefly be the brightest.
4. The magnetic shear helps the heating, but does not do the heating all by itself. Because the heating is bursty, but on average is stronger where the field shear is greater, we infer that the heating is caused by the shear acting together with "something else," some further condition or process at the inversion line. For this "something else," we suggest slowly-driven reconnection (or "tether cutting") that accompanies flux cancellation at the inversion line and that triggers microflares in the sheared field. This is the same process as that proposed by Moore and Roumeliotis (1992) and Roumeliotis and Moore (1993) for the triggering of full-blown eruptive flares in sheared field configurations of this same form. Thus we expect that, as in larger confined eruptive flares (Moore 1988), our microflare heating events are driven by confined eruptive action of the sheared field. In our view, these localized confined eruptions are triggered in the sheared field by underlying flux cancellation. This idea is also consistent with chromospheric activity that has been observed with flux cancellation: photospheric flux cancellation is accompanied by eruptive microflaring in the overlying chromosphere (Roy and Michalitsanos 1974; Martin, Livi, and Wang 1985).
5. Similar microflaring was observed at one site of no appreciable shear in our vector magnetogram. This suggests the presence of miniature sheared configurations similar in form to that seen in the delta sunspots but so small that they are below the spatial resolution of our magnetograph (2.7 arcsec pixels).

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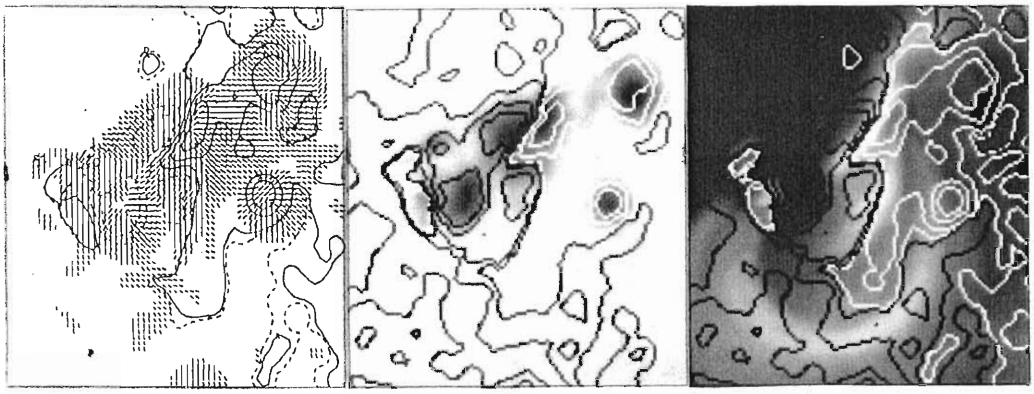

Fig. 1. Enhanced coronal X-ray brightness at sites of strongly sheared magnetic field in an active region having a delta sunspot. The active region is AR 6982 at S 10°, W 15° on 26 December 1991. Solar north is up and west is to the right. The distance between the centers of the two round leading sunspots is about 50,000 km. Middle panel: MSFC line-of-sight magnetogram superposed on SXT photospheric image, showing locus of polarity inversion lines through and around the sunspots (10, 100, 500, and 1000 gauss contours, white for positive flux, black for negative). Left panel: MSFC vector magnetogram showing strong magnetic shear along the polarity inversion line through the delta sunspot, less extreme shear along the southern extension of this inversion line, and two points of strong shear along the western edge of the bifurcated island of positive flux on the southeast edge of the negative sunspots. The line-of-sight component of the field is mapped by the contours (10, 500, 1000 gauss contours, continuous for positive, dashed for negative); the direction of the transverse component is mapped by the distributed dashes wherever the strength of this component is 250 gauss or more. Right panel: SXT coronal image superposed on MSFC line-of-sight magnetogram, showing magnetic location of coronal enhancements. Each of the four sites of strong magnetic shear is marked by an enhancement in the overlying low corona. The brightest strand traces the inversion line through the delta sunspot, showing that the brightest coronal plasma is embedded in the most strongly sheared magnetic field in the active region.

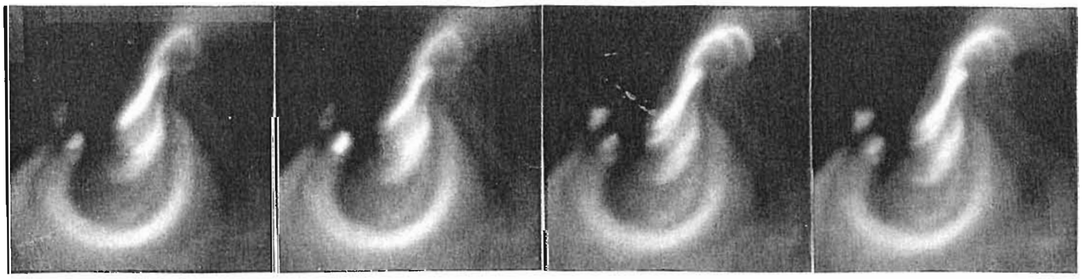

Fig. 2. Fluctuations of X-ray brightness in the sheared-field sites of enhanced coronal heating in the active region of Figure 1. Times of these frames are 18:31:40, 18:37:48, 18:52:28, and 18:57:24 UT. Of the four shear sites, the one with both the strongest shear and the stongest field (the channel of sheared field through the delta sunspot) is noticeably the brightest in the first, third, and fourth frames; in the second frame, the southern leg of the main inversion line and one of the two shear points on the west side of the positive-polarity island are about as bright as this channel of strongest shear. The coronal enhancement at each of the four shear sites changes discernibly from frame to frame in brightness, size, and shape; the coronal changes at each site appear to be random and independent of the changes at the other sites. The first frame is the same coronal image as in the right panel of Figure 1; each frame is of the same exposure and filter (668 ms, AlMg).

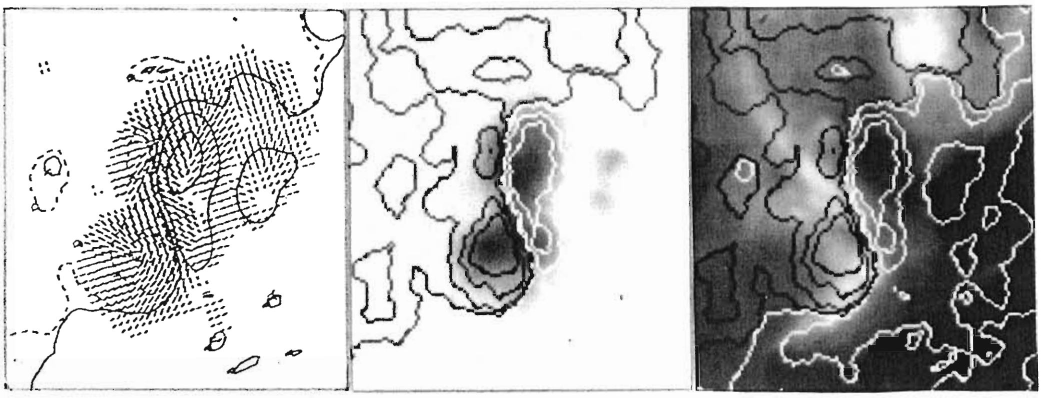

Fig. 3. Enhanced coronal X-ray brightness at sites of strongly sheared magnetic field in an active region having a delta sunspot. The active region is AR 6982 at S 10°, W 15° on 26 December 1991. Solar north is up and west is to the right. The distance between the centers of the two round leading sunspots is about 50,000 km. Middle panel: MSFC line-of-sight magnetogram superposed on SXT photospheric image, showing locus of polarity inversion lines through and around the sunspots (10, 100, 500, and 1000 gauss contours, white for positive flux, black for negative). Left panel: MSFC vector magnetogram showing strong magnetic shear along the polarity inversion line through the delta sunspot, less extreme shear along the southern extension of this inversion line, and two points of strong shear along the western edge of the bifurcated island of positive flux on the southeast edge of the negative sunspots. The line-of-sight component of the field is mapped by the contours (10, 500, 1000 gauss contours, continuous for positive, dashed for negative); the direction of the transverse component is mapped by the distributed dashes wherever the strength of this component is 250 gauss or more. Right panel: SXT coronal image superposed on MSFC line-of-sight magnetogram, showing magnetic location of coronal enhancements. Each of the four sites of strong magnetic shear is marked by an enhancement in the overlying low corona. The brightest strand traces the inversion line through the delta sunspot, showing that the brightest coronal plasma is embedded in the most strongly sheared magnetic field in the active region.

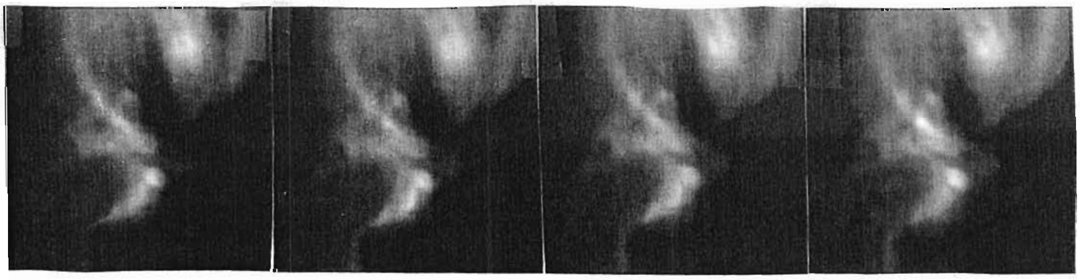

Fig. 4. Fluctuations of X-ray brightness in the sheared-field core of enhanced coronal heating in the delta-sunspot active region of Figure 3. Times of these frames are 13:54:55, 13:57:37, 13:59:45, and 14:05:05 UT. These snapshots illustrate that the high-shear eastern end of the inversion line was usually the brightest part; the last frame shows an exception when a structure stemming from the moderate-shear central portion of the inversion line was briefly the brightest. The coronal enhancement all along the sheared extent of the inversion line shows substructure that changes from frame to frame; separate substructures change randomly and independently in brightness, size, and shape on time scales of minutes, suggesting microflaring. The coronal enhancement southwest of the delta sunspot shows similar flickering substructure. The first frame is the same coronal image as in the right panel of Figure 3; each frame is of the same exposure and filter (948 ms, AlMg).