STUDY OF ACTIVE REGION MAGNETIC FIELD STRUCTURES USING VLA RADIO, YOHKOH X-RAY AND MEES OPTICAL OBSERVATIONS

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Abstract

We report on the observation of compact magnetic flux tubes from the boundary between the umbra and penumbra of a large sunspot in AR 7135 on April 24, 1992. The structure and geometry of one such flux tube was determined using the coordinated observations obtained by the Very Large Array, the Yohkoh Soft X-ray Telescope and the Mees Solar Observatory. From radio observations we infer that the magnetic field of the flux tube at the spotside footpoint is $\sim$ 1300-1800 G.

1. Introduction

Transient brightenings of compact X-ray loops have been found to be very common in solar active regions by the Soft X-ray Telescope (SXT) aboard Yohkoh satellite (Shimizu, et al 1992). The transient brightenings involve an energy release much smaller than that in a typical sub-flare, and may be useful in evaluating the importance of microflares in coronal heating especially in active regions. Brightenings of similar time scale were also reported as EUV bursts in the neighborhood of active regions (see e.g., Porter et al, 1984). During a recent (April 24, 1992) coordinated observation of an active region by the the Very Large Array (VLA)[1] and the soft X-ray Telescope (SXT) aboard Yohkoh satellite, we observed several transient brightenings at radio and X-ray wavelengths. In this paper we discuss the magnetic field structures involved in transient brightenings. Preliminary results were also reported earlier in a poster paper (Gopalswamy et al, 1993) and in a dissertation (Payne, 1993).

1 The Very Large Array is a facility of the National Radio Astronomy Observatory, which is operated by Associated Universities, Inc., under co-operative agreement with the National Science Foundation

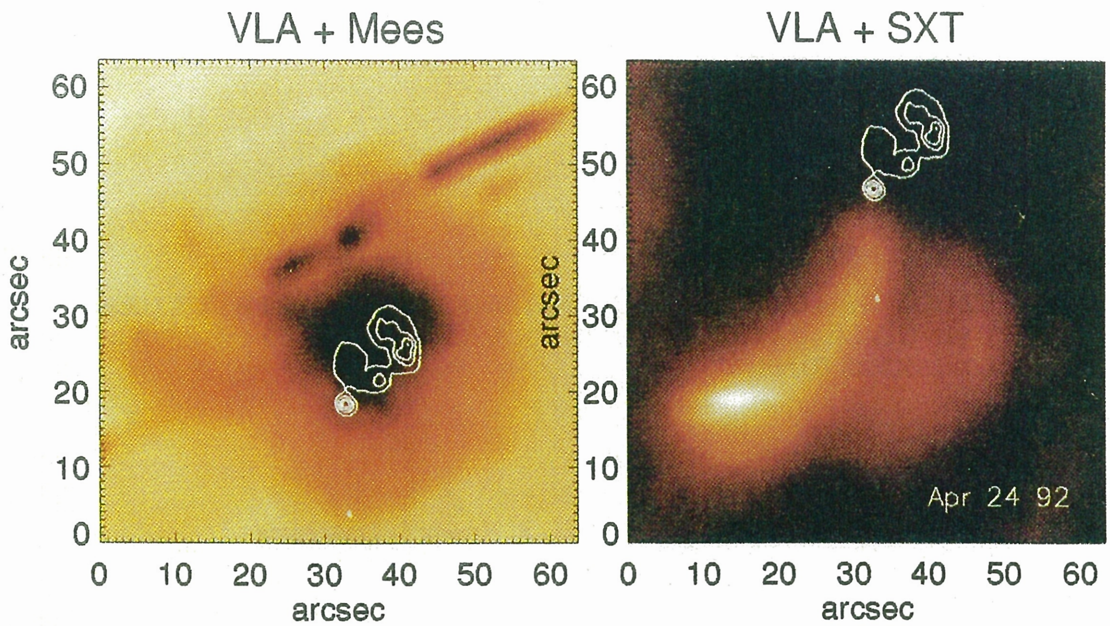

Fig. 1. VLA 2 cm contours superposed on Mees Solar Observatory's continuum image (left) and Yohkoh SXT image (right). The horse-shoe shaped extended contours are due to the sunspot associated microwave emission. The compact contours represent the Transient Microwave brightening. The contour levels in kilo kelvins are: 50,100,150,200,250,400,550. The elongated dark feature above the sunspot is and artifact.The cucumber shaped feature in the right figure is the transient in soft X-rays.

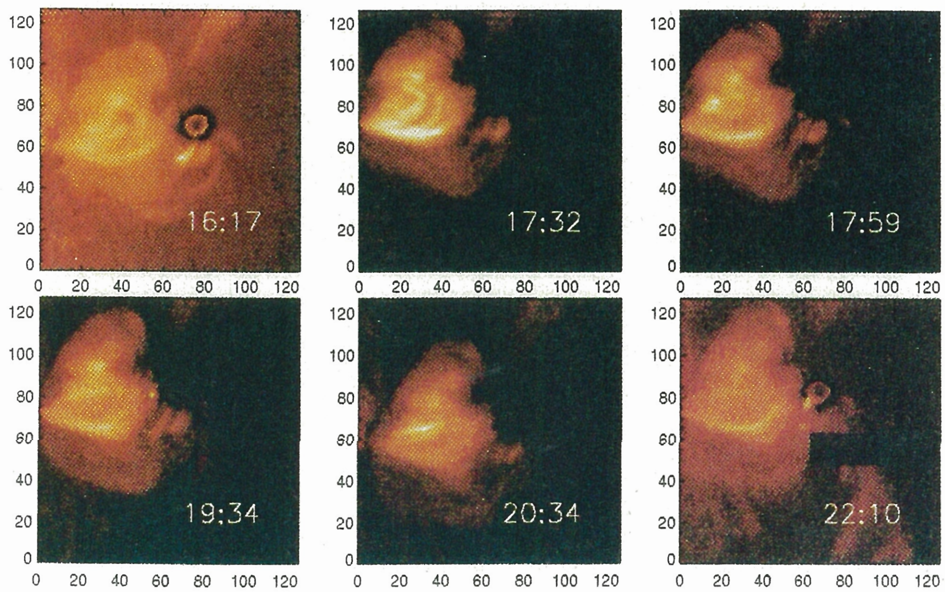

Fig. 2. Transient brightenings in soft X-rays at different times. For 16:17 and 22:10 UT, the images are superposed on white light data obtained by the SXT showing the transient brightenings relative to the sunspot in AR 7135. The bright feature within the sunspot is due to a wrap-around display.

2. Observational Results

The radio observations were made by the Very Large Array in its C-configuration, so that images could be made with a spatial resolution of ~1.5 arcsec at 2 cm wavelength. AR 7135 was observed for ~ 150 min in 10 intervals at 2 cm. During this period, about a dozen transient microwave brightenings (TMB) were observed as compact sources at discrete locations on the boundary between the umbra and penumbra. Fig. 1 shows the sunspot from continuum observations of Mees Solar Observatory. The sunspot was approximately symmetric with an umbral diameter of ~ 18 arcsec. The penumbra had a radial width of ~ 6 arcsec. The 2 cm radio emission consisted of an extended component of size ~ 12 arcsec associated with the umbra and the transient sources occurred at the periphery of the extended source (see superposed contours in Fig.1). The Yohkoh mission's Soft X-ray Telescope (SXT) was also pointed at the target AR 7135. The SXT makes full disk and partial frame images of the sun with a maximum spatial resolution of ~ 2.46 arcsec. The X-ray emission was confined to the coronal loops to the east of the sunspot. There was no significant soft X-ray emission from above the spot itself. Compact transient brightenings were also observed by the SXT at two locations near the big sunspot in AR 7135. Fig. 2 shows snap-shot images of some of the X-ray brightenings. The transients at 16:17 and 22:10 UT had temporal overlap with TMBs observed by the VLA. The spatial relationship between the X-ray and microwave brightenings at 16:17 UT can be seen in Fig. 1(right). We see that the radio source is clearly located at the foot point of the soft X-ray loop. The 22:10 UT brightening does not show a clear loop structure. However, examination of all the images for this transient showed a weak extension of the soft X-ray emission towards the southern footpoint of the 16:17 UT transient. The TMBs had a compact size of ~ 2 arcsec and occurred at several locations at the boundary between the umbra and penumbra of the sunspot. Fig. 3 shows a series 10 TMBs that occurred during our observations, many of repeatedly occurred in the same location. There were five locations along the southern half of the umbra-penumbra boundary. The time profiles of some of the TMBs in Fig. 4 show that the TMBs lasted for a few minutes with a rise time less than 30 s. TMBs with longer duration showed temporal structures suggesting the possibility of multiple brightenings. We need to use higher time resolution data to establish this point. (In the present study we used only 30 s time resolution). The total flux of the TMBs was ≤ 0.03 sfu, about two orders of magnitude smaller than the flux of typical flares at 2 cm. The peak brightness temperature of the TMBs was in the range of a few tens to a few hundred kilo kelvins. This corresponds to an increase by a factor of $\sim 4 - 50$ above the noise level. The TMBs had a high degree of circular polarization (70-100%) in the X-mode. In Fig. 5, we have co-registered the 16:20 transient in X-rays and microwaves with the longitudinal magnetogram from Mees Solar Observatory. We note that the X-ray brightening resembles a loop connecting the sunspot to a nearby region of opposite magnetic polarity. The microwave source is located at the spot-side footpoint of this loop. In logarithmic display of the X-ray images, we could see faint structures connecting to the southern end of the spot where the TMBs are located.

3. Discussions

The high degree of polarization suggests that the TMB must be caused by either gyro-resonance emission or nonthermal gyrosynchrotron emission. Under coronal conditions, the third harmonic is relevant for gyroresonance emission. Detailed calculation shows that for the gyroresonance emission,we need a magnetic field of ~1800 G, a plasma temperature of $\sim 2\times 10^6$ K and a density of $\sim 1\times 10^{10} cm^{-3}$ at the 2 cm source in order to explain the observed polarization and brightness temperature. Analysis of the SXT data with different filters yielded a temperature of $\sim 6\times10^6$ K for the soft X-ray brightening at 16:20 UT. Thus we expect temperature gradient in the loop. For a nonthermal gyrosynchrotron mechanism,

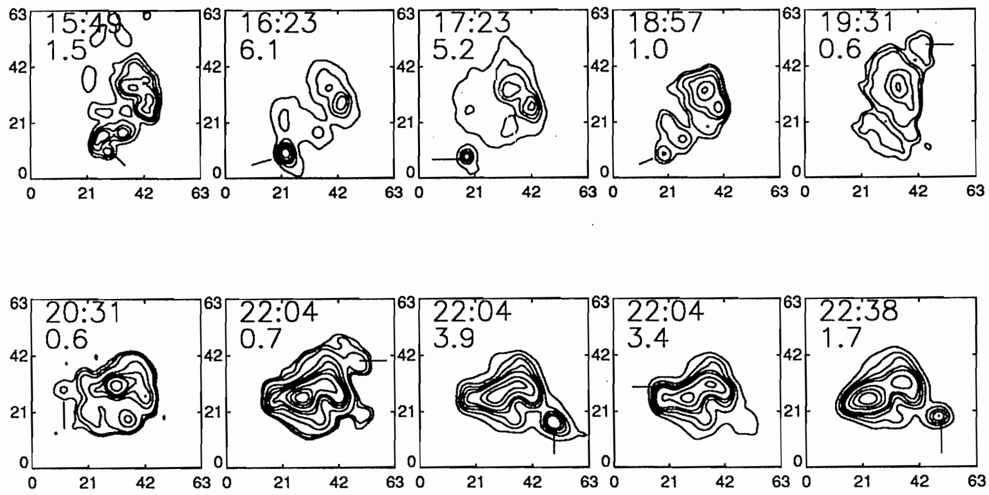

Fig. 3. Contour maps of all the transients that occurred in AR 7135 during our observations on April 24, 1992. The TMBs are marked by small straight lines. Note that the TMBs are located in five positions at the periphery of the extended sunspot emission.The UT time and the peak brightness temperature (in units of $10^5 K$) are given at the top left corner of each map.

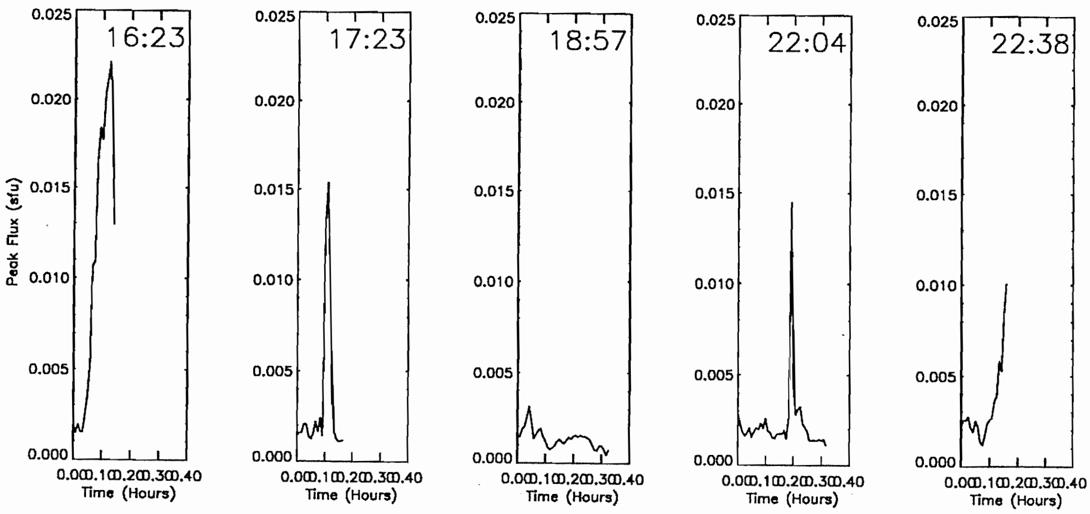

Fig. 4. Time profiles of five selected TMBs. Note that some of them show temporal structures indicating multiple TMBs.

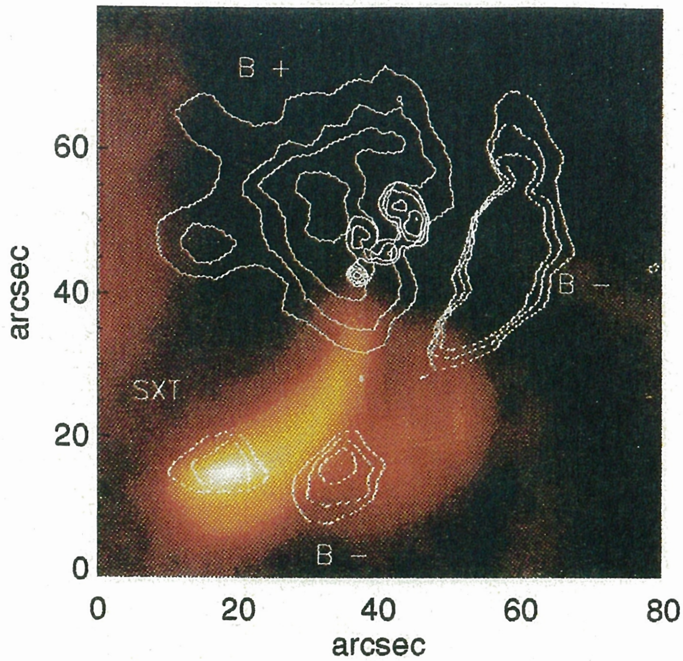

Fig. 5. Superposition of SXT and VLA contours of the 16:17 UT transient brightening on Mees longitudinal magnetogram. The wavy (dotted) contours represent positive (negative) magnetic polarity. Note that the SXT loop connects between the sunspot and the negative polarity patch to the south of the spot.

nonthermal electrons of energy $\sim$ 100 keV are needed with a number density of $\sim 4\times10^4 cm^{-3}$, in a magnetic field of $\sim$ 1200 G. There is no microwave emission from the other footpoint of the X-ray loop because the magnetic field is not high enough to support thermal gyroresonance or nonthermal gyrosynchrotron emission. Thus we conclude that the microwave emission originates from locations where the magnetic field is in the range 1200-1800 G in the lower corona. High values of photospheric magnetic field strength (2600-3000 G) reported in the Solar Geophysical Data are consistent with the implied high coronal values. The rate at which the TMBs occur is relatively high on this day. The VLA was pointed at the target region at 2 cm for only about 150 minutes and 11 TMBs occurred during this period. This corresponds to a rate of about 4 TMBs per hour. In addition there were 6 soft X-ray transient brightenings, two of which had temporal overlap with the TMBs. Thus we may conclude that the TMB is a frequent phenomenon at least on some days. We need to survey at other microwave frequencies to determine the actual occurrence rate and the importance of the TMBs for heating the active region corona.

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References

1. Gopalswamy, N. et. al., 1993, *EOS* **74**, 345.
2. Payne, T. W., 1993, *A multiwavelength Study of Solar Ellerman Bombs, Ph. D. Thesis, New Mexico State University.*
3. Shimizu, T. et. al., 1992, *Publ. Soc. Japan* **44**, L147.