OBSERVATIONAL EVIDENCE FOR MAGNETIC RECONNECTION IN MICROWAVE SOLAR BURSTS

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In this paper, we first discuss a set of 6 cm observations made with the NRAO Very Large Array (VLA) (spatial resolution ~ 2") that pertain to changes in the coronal magentic field configurations that took place before the onset of an impulsive burst observed on 14 May 1980. We also discuss a second set of 6 cm VLA observations (spatial resolution 18" arc) where several interacting loops were involved in triggering the onset of an impulsive burst observed on June 24, 1980, 19:57:00 UT. Both sets of observations are examples of magnetic reconnection process being involved in accelerating microwave emitting electrons.

In the first case, the burst appeared as a gradual component on which was superimposed a strong impulsive phase (duration ~ 2 minutes) in coincidence with a hard X-ray burst. Soft X-ray emission (1.6 - 25 Kev) was associated with the gradual 6 cm burst (before the impulsive burst), as is to be expected. There was a delay of hard X-ray emission (> 28 Kev) relative to 6 cm emission (~ 10 sec delay from 6 cm maximum to hard X-ray start and ~ 20 sec delay from 6 cm maximum to hard X-ray maximum.). The preflare region at 6 cm showed intense emission with peak $T_b \sim 1.3 \times 10^7$ K and degree of polarization p ~ 65% extended along a neutral line situated approximately in the east-west direction. A gradual burst source of intense emission with $T_b \sim 4 \times 10^7$ K and p ~ 50 - 80% appeared initially. The most remarkable feature of the 6 cm burst source evolution was that an intense emission ($T_b \sim 1.4 \times 10^8$ K; p ~ 60%) extending along the north-south neutral line (line of zero polarization at 6 cm), possibly due to reconnections, appeared, just before the impulsive burst occurred. This north-south neutral line must be indicative of the appearance of a new system of loops. In the 20 seconds preceding the impulsive peak ($T_b \sim 1.1 \times 10^9$ K; p ~ 40%) the arcade of loops (burst source) changed and ultimately developed into two strong bipolar regions or a quadrupole structure whose orientations were such that near the loop tops the field lines were opposed to each other. This quadrupole field configuration is reminiscent of the flare models in which a current sheet develops at the interface between two closed loops. The impulsive energy release must have occurred due to

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magnetic reconnection of the field lines connecting the two oppositely polarized bipolar regions (Kundu et al 1982; Velusamy and Kundu 1982). After the impulsive phase was over, the gradual burst still continued for another 10 minutes, with the magnetic field configuration being very similar to what existed in the gradual phase prior to the impulsive event. The important changes in the coronal field configuration, and hence magnetic field reconnections, are schematically represented in Figs. 1 and 2. The reconnection process accelerates electrons to energies of the order of 100 keV or higher, which are responsible for the microwave and possibly, the hard X-ray bursts. The delayed hard X-ray emission, assuming it to be nonthermal, must be attributed to the fact that not enough electrons of energy > 28 Kev were able to reach a thick target region to produce observable X-ray emission at the onset of 6 cm impulsive burst. The hard X-ray spectrum may be either thermal (exponential) or nonthermal (power law). In the thermal interpretation, impulsive phase plasma temperatures of 1-2 x 10^8 K and a plasma density of ~ 1 x 10^9 cm^{-3} are implied, if the X-ray emitting volume is comparable to the microwave emitting volume (Holman, this issue). The thermal interpretation implies delayed heating of the flare plasma to ~ 10^8 K.

The observations of the second burst provides a good example of interacting loops (Kundu et al 1984). The 6 cm burst source was complex, consisting initially of two oppositely polarized bipolar sources separated E-W by ~ 1.'5 arc. The first brightening occurs in one component at 19:57:10 UT, located at the same position as the burst that occurred at 19:51:05 UT. The western component is much weaker at this time. It then brightens up at 19:58:05 UT, just at the onset of the impulsive rise of the burst and is accompanied by changes in its polarization structure. It then decays and by 19:59:05 UT, it appears to split into two weak sources separated E-W by ~ 12" arc. The eastern component brightens up at 19:58:15 UT and then decays until 20:00:15 UT. This brightening is accompanied by significant polarization changes, including reversal of polarization. A third component appears approximately midway between the eastern and western component at 19:58:45 UT during the peak of the associated hard x-ray burst (Figs. 3 and 4). The appearance of this source is again associated with polarization changes, in particular the clear appearance of several bipolar loops; its location overlaps two opposite polarities implying that it might be situated near the top of a loop. The third source reaches maximum intensity at 19:59:05 UT and by 19:59:15 UT it disappears. At the time of maximum intensity the burst source appears to lie at the interface between two oppositely polarized loops. Clearly, in this set of observations we are dealing with interaction between multiple loop structures and the resultant formation of current sheets between two oppositely polarized loop structures. The magnetic field reconnection process that ensues must be responsible for the acceleration of electrons responsible for impulsive microwave emission.

These two sets of observations provide the first observational evidence for magnetic reconnection in microwave flares.

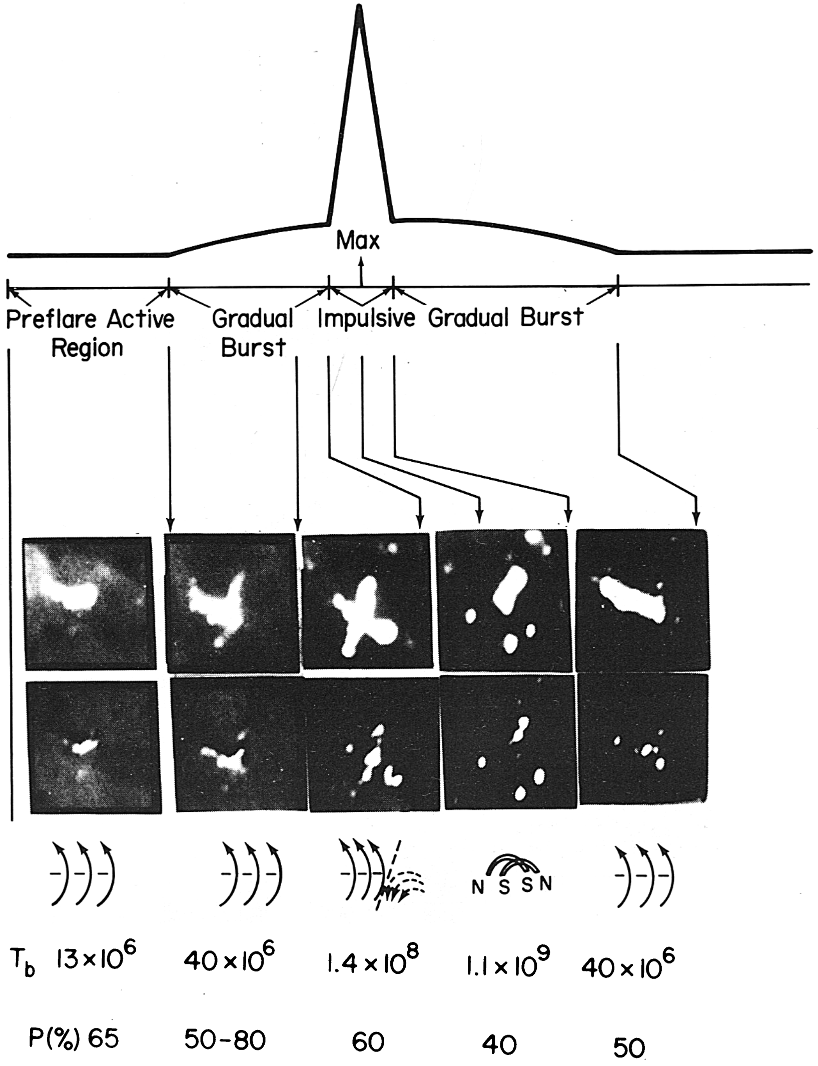

Fig. 1. Preflare active region and burst source maps for the 14 May 1980 burst at 6 cm. Each map was synthesized from data taken during a time interval appropriate to the observed 6 cm flux. Preflare 6 cm map 18:06-18:45 UT, $T_b(\max) \sim 13 \times 10^6$ K; gradual phase of burst, 18:59-19:14, $T_b(\max) \sim 40 \times 10^6$ K; last 5^m before impulsive phase, 19:14-19:19, $T_b(\max) \sim 1.4 \times 10^8$ K; peak of the impulsive phase 19:19:55-19:20:05, $T_b(\max) \sim 1100 \times 10^6$ K (Note the remarkable quadrupole structure); gradual phase of burst, 19:21-19:30, $T_b(\max) \sim 40 \times 10^6$ K.

References

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Velusamy, T. and Kundu, M. R.: 1982, Astrophys. J., 258, 388.

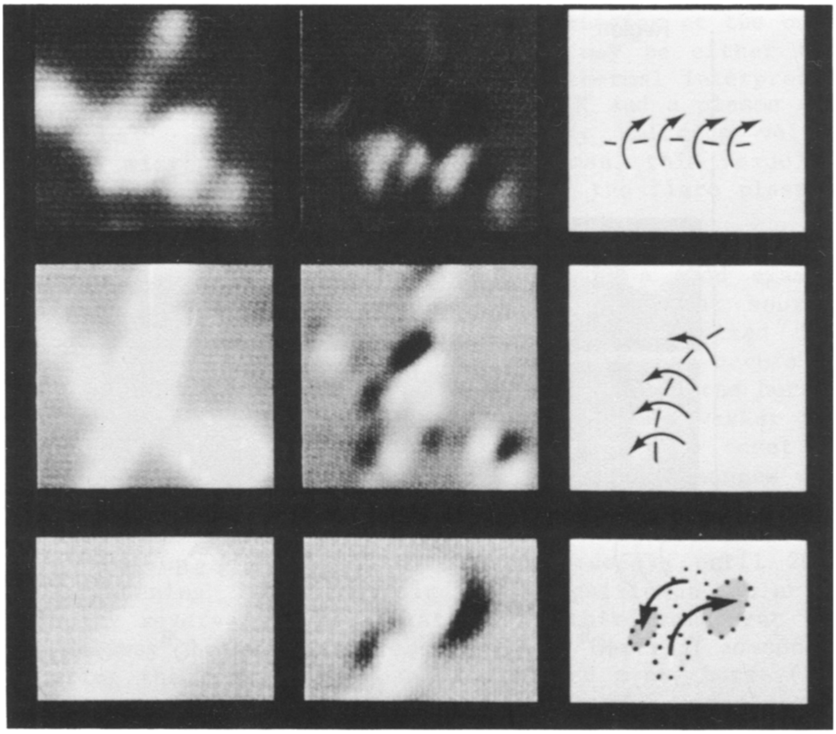

Fig. 2 Total intensity (left) and polarization (middle) maps at three selected periods (from top to bottom) - gradual phase, just before onset and at peak of impulsive phase burst shown in Fig. 1. The inferred magnetic field lines are also shown (right).

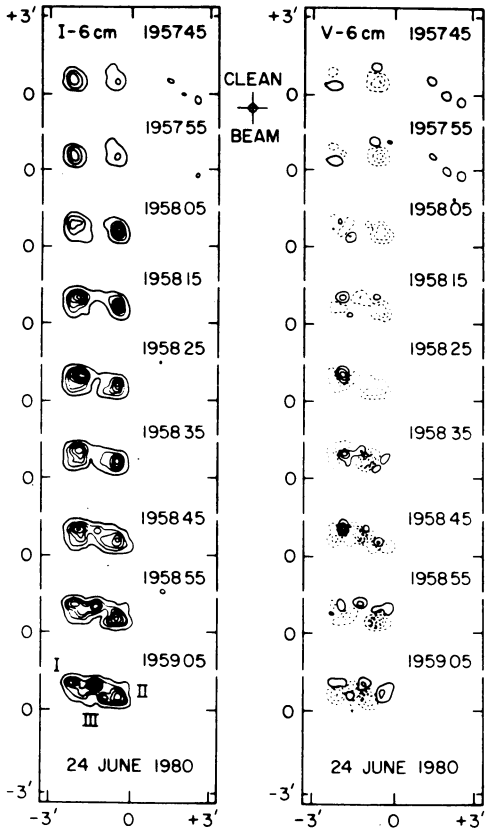

Fig. 4 Sample VLA snapshot maps for the 19:59 UT burst. Clean beam size is 18". I-contours: 0.3 x 10^6 K to 11.8 x 10^6 K in steps of 1.21 x 10^6 K; V-contours: ± 0.15 x 10^6 to ± 1.96 x 10^6 K in steps of 0.45 x 10^6 K.

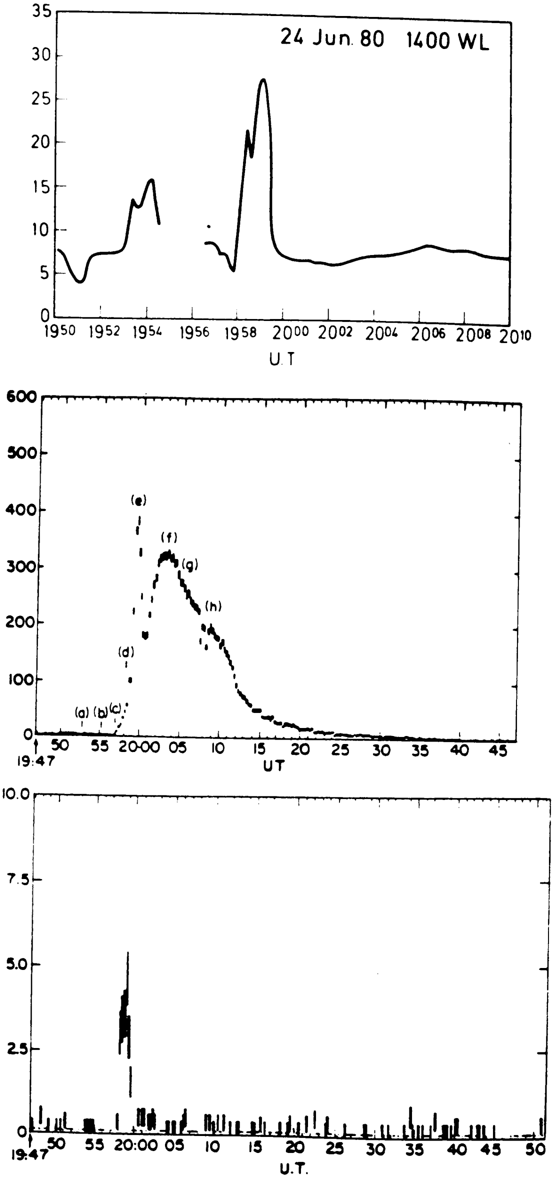

Fig. 3 Top: Amplitude (in units of sfu, 1 sfu = 10^{-22} w m^{-2} Hz^{-1}) vs. time of 24 June 1980, 19:50 and 19:59 UT bursts at 6 cm; (middle and botton): total emission light curves (in cts s^{-1}) of the same events in soft (3.5 -8.0. Kev) and hard (22.0 -30.0 Kev) X-rays.

DISCUSSION

Bratenahl: Is there a photospheric magnetogram available? The photospheric magnetic field should not change very much on a time scale of seconds.

Kundu: Yes, we do have photospheric magnetograms for the region in which the flare occurred. They of course do not change on time scales of seconds, but then we do not have photospheric magnetograms during the flare.

Mullan: You have shown examples of reconnection during flares. Do you see examples of reconnection <u>outside</u> flares? In other words, do you see non-thermal emission associated with "normal coronal heating"? Can you distinguish between coronal heating and flaring?

Kundu: I believe we may see reconnections outside flares, but they may not be easy to detect, because they may occur over a long time scale. We have evidence for the existence of non-thermal particles in non-flaring active regions, because we see brightness temperatures as high as 10 million degrees in active regions before flares. However, it is not clear how we can relate such non-thermal particles to coronal heating.

Krishan: Flares can occur in single loops as well as in interacting loops. The spatial position of the flaring region, i.e., the position of magnetic reconnection, will be very different. In fact, one should see at least three flaring regions simultaneously, at the points of interaction as well as at the neutral line of the individual loops.

Kundu: I believe that when flares occur as a result of interacting loops, we shall see mainly one flaring region, namely at the region of interaction. If two loops flare up simultaneously we may observe two regions near their tops, but whether or not we shall see the third region will depend on how strong the interaction is.