PROPAGATION OF ELECTRONS EMITTING WEAK TYPE III BURSTS IN CORONAL STREAMERS

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Abstract. We report the observations of weak type III bursts at 73.8, 57.5, 50.0, and 38.5 MHz from Clark Lake Radio Observatory on four days and discuss their characteristics. In addition to Clark Lake data, the magnetogram and sunspot/active region data and the coronal streamer data obtained by HAO's Coronagraph/Polarimeter aboard SMM satellite are used to study the location of the burst sources with respect to the coronal streamers emanating from active regions. It is shown that the bursts occur within or close to the edge of dense coronal streamers implying that the coronal streamers contain open magnetic field lines along which the electrons generating the bursts propagate. The positional analysis of the bursts is used to estimate the variation of coronal electron density with radial distance.

1. Introduction

The observations of X-ray microflares (Lin *et al.*, 1984) and Clark Lake microbursts and weak type III bursts (Kundu *et al.*, 1983a; Kundu and Stone, 1984; Kundu *et al.*, 1986; White *et al.*, 1987a, b) demonstrate the existence of small-scale, yet nonthermal releases of energy on the Sun. It is of interest to know the location of these weak burst sources and the nature of the instability responsible for burst generation. The Clark Lake multifrequency radioheliograph provides the burst positions with respect to the quiet Sun which can be compared with the location of active regions on the disk and the active region streamers. In this paper we make this comparison and show that the weak type III bursts occur within or close to the edge of the active region streamers. From the study of kilometric type III's, it is known that the brightness temperatures range from as high as 10^{15} K (Evans *et al.*, 1971) down to 6×10^7 K (Bougeret *et al.*, 1970). The Culgoora Spectroheliograph observations of many weak type III bursts indicate that the type III spectrum extends down to $\approx 10^7$ K (Dulk and Suzuki, 1980). We observed many weak type III bursts in this range and thus they provide an extension of the type III spectrum by more than one order of magnitude. The observations of the weak type III bursts not only broaden the observational data on type III bursts but also provide clues to a better understanding of the type III phenomenon as a whole (White *et al.*, 1987a).

If the weak type III bursts are generated by electron beams, then it is of interest to study the propagation paths of these electrons. The type III characteristics would imply that the electrons must propagate along open magnetic field lines. Using Clark Lake data at a single frequency (73.8 MHz), Kundu *et al.* (1983a) have shown that the type III electrons propagate along magnetic field lines adjacent to neutral sheet in coronal streamers. In this paper, we make use of Clark Lake data at four frequencies on four

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days along with the magnetograms and sunspot group/active region data (*Solar Geophysical Data*) and High Altitude Observatory's Coronagraph/Polarimeter data to study the region of occurrence of weak type III bursts in the coronal streamers associated with active regions. We also discuss the characteristics of these bursts and their interpretation in terms of radiation at fundamental and harmonic plasma frequencies.

In Section 2, we report further observations from Clark Lake Radio Observatory. The association of the bursts with active regions and their locations relative to the coronal streamers are discussed in Section 3, and the conclusions are summarized in Section 4.

2. Observations

The bursts were observed by the Clark Lake multifrequency radioheliograph (Kundu *et al.*, 1983b). The radioheliograph operates at selected interference free-frequency bands between 25 and 110 MHz. For these observations the frequencies 38.5, 50, and 73.8 MHz were used. In two events, in addition to the above three frequencies, 57.5 MHz was also used.

We present here five events that were observed on July 27, 28, 1985, and September 12, 17, 1985 (DOY 208, 209, 255, and 260). The total duration of the burst activity ranges from 16s to 166s (Table I). In events of longer duration such as the one on DOY 260, probably groups of bursts are involved. Since the actual time between successive maps at a single frequency is longer than the typical duration of a type III burst, the successive maps may or may not be the continuation of the same burst. In other words, we can only find the position of the burst in a given event which correspond to the projected plasma level corresponding to the fundamental or harmonic radiation. There was one event on each day except 17 September, 1985, when there were two events. These two events are designated as 260(1) and 260(2).

Figure 1 shows a typical weak type III event which was observed on 28 July, 1985. It shows a fast enhancement from the quiet Sun level, reaching peak brightness and then slowly decaying to the pre-burst quiet Sun level. The top row shows the quiet Sun maps for the three frequencies. (The quiet Sun map at 73.8 MHz is unreliable as the 'dirty' map contains side lobe effects.) Notice that the brightening has already started in the 38.5, 50, and 57.5 MHz maps as seen from the time of the map and brightness temperature marked on the maps. This indicates that the onset is somewhere between 18 : 41 : 20 and 18 : 41 : 21 UT. The last map in each column represents the post burst quiet Sun level. It is evident that the quiet Sun level is returned earlier at higher frequencies and progressively later at the lower frequencies, implying that the duration of the bursts progressively increases at lower frequencies. The apparent source sizes considerably increase at lower frequencies as evident from each row. At a given frequency, the source position is remarkably stable throughout the duration of the burst. All these characteristics are typical of type III bursts. In addition, since there are four frequency observations one can roughly follow the bursts at various frequencies. We estimate the drift rate as 3–8 MHz s^{-1}, which lies in the range of type III drift rates

TABLE I

Parameters of burst sources

Date	DOY	Burst duration (s)	Source height ($R_\odot$)				Source size				Peak T_b (10^6 K)			
			73.8	57.5 (MHz)	50	38.5	73.8	57.5 (MHz)	50	38.5	73.8	57.5 (MHz)	50	38.5
07/27/85	208	22	1.81	1.94	2.07	2.17	4.′3	6.′5	6.′1	13.′2	2.16	1.18	5.51	5.06
07/27/85	209	16	0.55	0.63	0.73	0.87	3.′6	5.′9	7.′0	13.′2	10.06	28.25	31.21	27.43
09/12/85	255	37	1.59	–	1.80	1.96	5.′3	–	11.′2	15.′6	0.67	–	10.23	6.23
09/17/85	260(1)	31	1.57	–	1.80	2.0	3.′9	–	7.′0	15.′5	11.67	–	25.03	30.84[a]
09/17/85	260(2)	166	1.36	–	1.47	1.48	4.′7	–	13.′1	18.′9	16.61	–	31.86[a]	20.20
			0.72	–	1.0	1.44	5.′9	–	13.′7	17.′1				

[a] Saturation occurred.

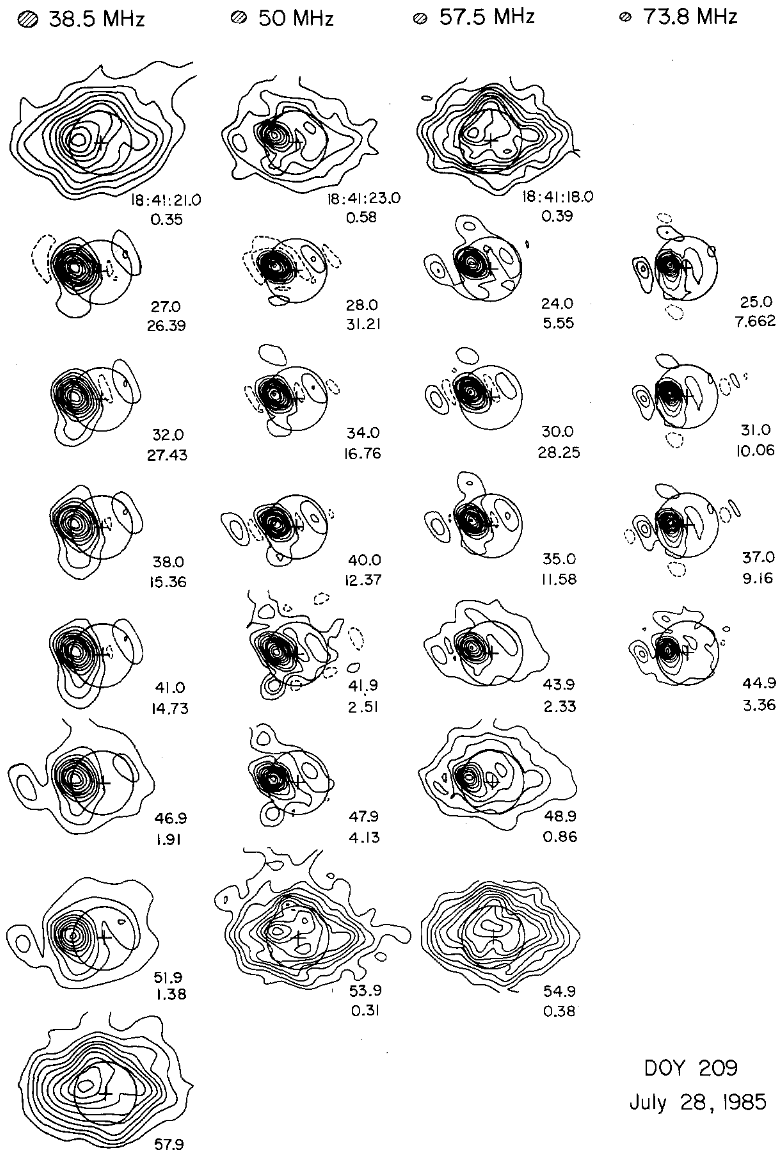

Fig. 1. The weak type III burst event of 28 July, 1985 (DOY 209), at four frequencies: 38.5, 50, 57.5, and 73.8 MHz. Top and bottom maps at each frequency corresponds to the quiet Sun level. The quiet Sun maps for 73.8 MHz are not presented because they are unreliable due to side lobe effect. Increase in burst duration and source size towards lower frequencies are clearly seen. The UT and brightness temperature (in units of 10^6 K) are marked on each map. From second row onwards, the hours and minutes in UT which are the same as in top row, are omitted. The beam size at each frequency is shown at the top.

at low frequencies. For example, the empirical formula for the drift rate, $df/dt = -10^{-2} f^{1.8}$ at an observing frequency f (MHz) gives ≈ 7 MHz s^{-1} at $f = 38.5$ MHz (Melrose, 1980).

Table I summarizes the projected source heights and apparent source sizes of all five bursts. The projected source heights lie within the values obtained by Dulk and Suzuki (1980). The apparent source sizes seem to be somewhat smaller than the average value of type III bursts derived by Dulk and Suzuki (1980) where an average source size of 11′ at 80 MHz and 20′ at 43 MHz were estimated. However, their distribution shows many bursts whose source sizes are of the same order as that observed by us. It is interesting to note that the source heights lie very close to the corresponding plasma levels as determined from Newkirk's (1967) electron density model above an active region. This is in contrast with the earlier observations of Dulk and Suzuki (1980) and may be evidence for the ineffectiveness of ducting and other propagation effects (Duncan, 1979) under conditions in which the weak bursts occur. Another interesting observation is that the event 260(2) on 17 September, 1985, shows two distinct source positions which brighten and decay at least twice at 50 and 73.8 MHz frequencies. One can rule out ionospheric refraction to cause the source to appear at two different locations. This is clearly seen by comparing the outermost contours which are close to the quiet Sun level. Te two distinct sources are barely visible at the lowest frequency 38.5 MHz, probably due to the poorer angular resolution at lower frequencies. Figure 2 shows two sets of maps showing the two distinct positions. The inner and outer sources appear to lie at approximately the projected heights (from the disk center) of fundamental (F) and harmonic (H) plasma levels. Of course, one cannot rule out the possibility that the source positions correspond to two different bursts occurring at two different locations. The duration of this event is quite long, about 3 min and the event could consist of a group of bursts. Although two pictures are shown at each frequency, the entire event consisting of ~ 20 pictures, show the same trend.

The rather long 'dead' time in the sequential observing at different frequencies does not permit us to identify any fundamental-harmonic emissions, and they may indeed correspond to different bursts. As mentioned above, if wave ducting effects are neglected (Suzuki and Sheridan, 1982), then the bursts appear to be close to the appropriate F and H plasma levels. The event 260(2) is the only one which occurred close to the disk center whereas all the other events were close to the limb. The fundamental and harmonic emission are believed to lie within about 50° of the central meridian of the Sun (Dulk and Suzuki, 1980; Suzuki and Sheridan, 1982). Therefore, our observations are consistent with the suggestion that only in the case where the emission is close to the disk center does one observe the fundamental. We should note that second harmonic emission was considered to be more plausible on the basis of source size requirements (Kundu *et al.*, 1983a) and fundamental emission was used to test whether conventional threshold dependent emission mechanisms would apply for microbursts (White *et al.*, 1987a, b). It is clear that one needs further observations especially close to the central meridian to clarify this point.

Table I also gives the peak brightness temperatures for each event at various

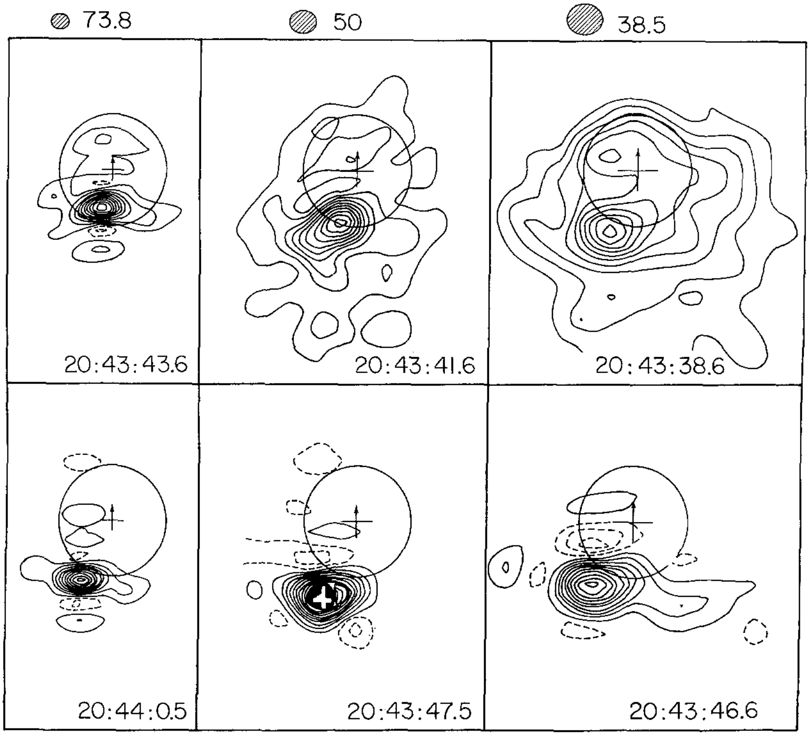

Fig. 2. (a) The inner (fundamental) source and (b) outer (harmonic) source of the complex event of 17 September, 1985 (DOY 260) at three frequencies 38.5, 50.0, and 75.8 MHz. The beam sizes are shown in the top of the figure.

frequencies. The brightness temperature varies from quiet Sun level to the instrument saturation level ($\approx 10^8$ K). The peak brightness temperature tends to be higher at lower frequencies (there is some uncertainty about the exact peak T_b at any frequency since the telescope could be observing at other frequencies at the time of the peak). This is also in agreement with the statistical analysis of Dulk and Suzuki (1980) who found that at lower frequencies (43 MHz) the brightness temperature was 4 to 5 times higher than at 80 MHz. Further, Table I clearly shows that the weak type III bursts occur as an extension of the lower limit of the usual type III brightness temperature spectrum.

3. Association with Active Regions and Active Region Streamers

The sources of type III bursts are believed to be associated with active regions (Kundu *et al.*, 1983a). Here we present further evidence in support of this association, and relate burst positions to coronal streamers using the HAO SMM Coronagraph/Polarimeter

(C/P) images and the extended quiet Sun features in the Clark Lake radio maps. Since the coronal streamers are associated with the active regions, the weak type III bursts could occur on open magnetic field lines of the streamers.

We find that all the five events are associated with active regions, most of which contained sunspot groups. Figures 3–5 show the association of the bursts with the Stanford magnetograms, and the Boulder/Holloman sunspot maps; in these figures we have also plotted the outer brightness temperature contours of the weak type III bursts at the three frequencies 73.8, 50.0, and 38.5 MHz. We have not included the frequency 57.5 MHz in these plots since it is available for only two events and the features are close to the 50 MHz contours. In each case the magnetogram and sunspot observations were taken within a few hours of the times of the bursts as marked on the figures. Since there was no sunspot on DOY 255, we give only the magnetogram in association with the bursts and have indicated the location of the active region (AR). Similarly, we give only the magnetogram for the event 260(1) which is associated with the spotless AR 4693 at S19 W75.

The burst of 27 July, 1985 (DOY 208) seems to be associated with AR's 4680 and 4681, close to the eastern limb. The bursts occur closer to AR 4681 (S 10 E 70). Brightness enhancements in the region above both AR's are quite clear in the quiet Sun

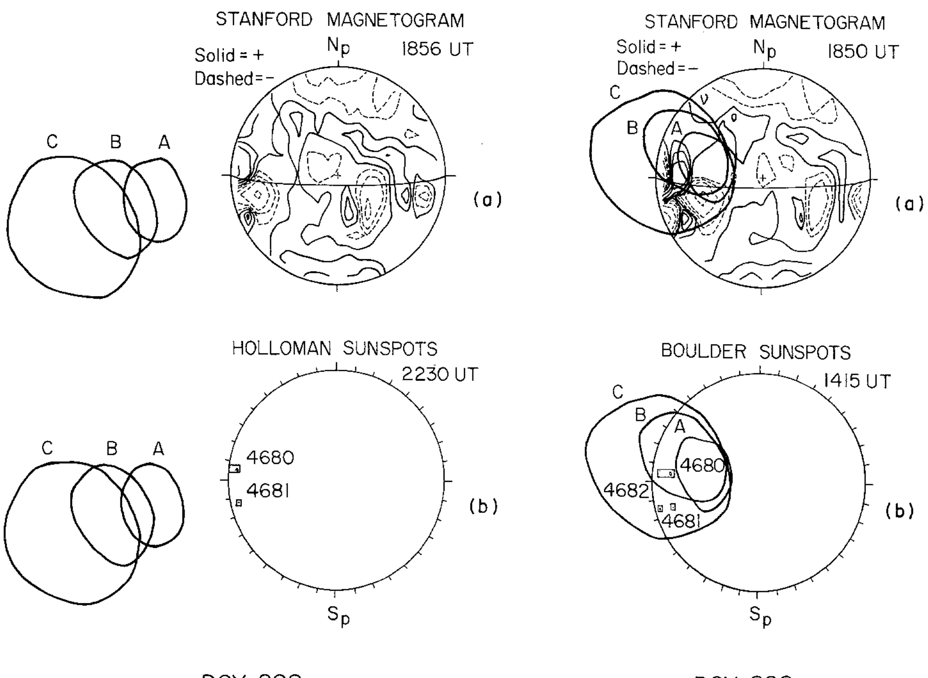

Fig. 3. Superposition of outer contours of burst maps at three frequencies (A: 73.8, B: 50.0, and C: 38.5 MHz) on Stanford magnetogram (a) and Holloman/Boulder sunspot (b). *Left*: bursts of 27 July, 1985 (DOY 208) at 21 : 04 : 38.8 UT. *Right*: bursts of 28 July, 1985 (DOY 209) at 18 : 04 : 18 UT.

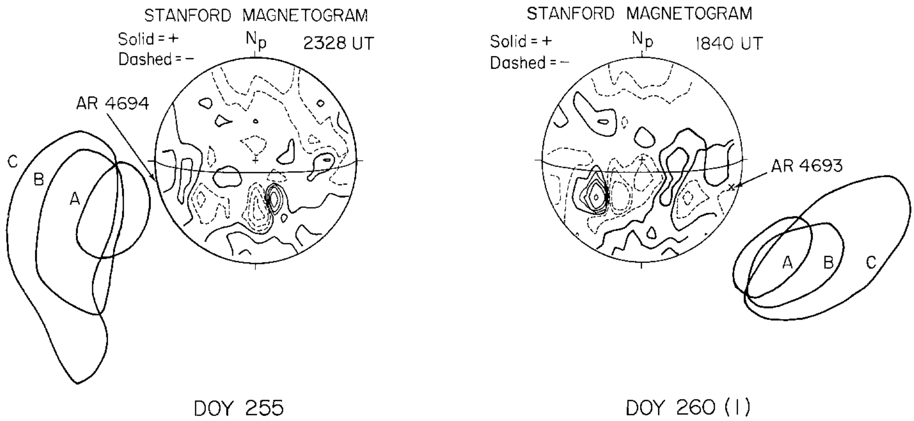

Fig. 4. Same as Figure 3, only Stanford magnetograms are used. Active regions of interest are marked. *Left*: bursts of September 12, 1985 (DOY 255) at 18 : 30 : 31.2 UT. *Right*: bursts of 17 September, 1985 (DOY 260) at 17 : 10 : 32.6 UT.

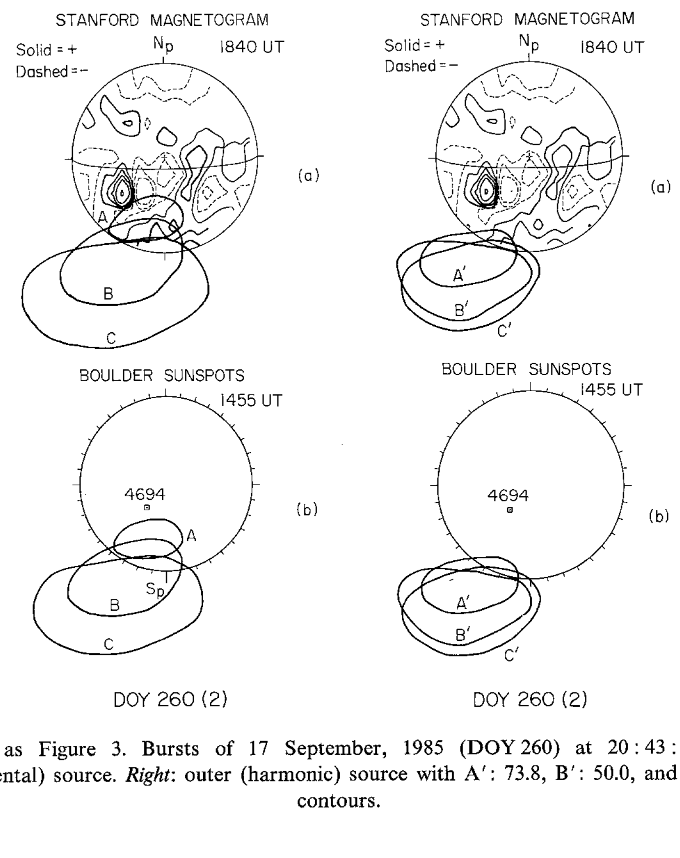

Fig. 5. Same as Figure 3. Bursts of 17 September, 1985 (DOY 260) at 20 : 43 : 27.6 UT. *Left*: inner (fundamental) source. *Right*: outer (harmonic) source with A′: 73.8, B′: 50.0, and C′: 38.5 MHz contours.

maps at the end of the bursts. Stanford magnetograms indicate that the leading polarity of the magnetic field in the region 4681 is negative and the field lines emanate from the trailing edge of the AR. The magnetic field of the associated spot group is quite strong (1600–2000 G).

The next day (DOY 209, July 28, 1985) the bursts again occurred above the same active regions 4680 and 4681 with an additional group 4682 appearing on the eastern limb. On this day the bursts appear to be situated obliquely with respect to AR 4680 (N 07 E 70). The fact that the active region has moved towards the disk center is responsible for a shorter projected height of the bursts compared to those occurring on DOY 208.

There were no spots visible on 12 September, 1985 (DOY 255) but there were several B level X-ray flares and a small flare on the eastern limb. In fact, an X-ray B5.7 flare occurred at the time of the burst (18 : 30–18 : 31 UT) on the east limb (S 14 E 90) which started at 18 : 21 UT, peaked at 18 : 33 UT and ended at 18 : UT. The bursts on this day seem to be associated with the region 4694 which appeared on the eastern limb the next day (13 September, 1985) at S 14 E 81. This implies that the region 4694 was just close to the limb during the time of the burst. This region was not present during the optical observations which were about 4 hours earlier than the time of our observations.

There were two region 4693 and 4694 on 17 September, 1985 (DOY 260) at S 19 W 75 and S 11 E 10, respectively. The first type III burst (260(1)) event which occurred at 17 : 10 UT seems to be above AR 4693 because the burst is seen on the SW limb and this is the only active region present on the western hemisphere. The region is spotless. The more complex event (260(2)) occurred a few hours later at 20 : 43 UT above the spotted region 4694 at S 11 E 10.

The HAO SMM-C/P produces images of the white light corona. We have chosen the images closest to the time of our observations and presented them in Figure 6. Solar north, accurate to a few minutes of arc is indicated by the small arrow in the center of the occulting disc ($\sim 1.6\ R_\odot$). The dot in the center of the circle at the end of the arrow indicates the Sun center. The white light coronal streamers are clearly visible, some of them having multiple structures. A comparison of these streamers with the active regions shown in Figures 3–5 indicate that these streamers lie above the active regions. Superimposed on these images are the CLRO maps of the bursts at three frequencies, viz., 38.5, 50.0, and 73.8 MHz for the four events 208, 255, 260(1), and 260(2). The event 209 could not be superimposed because the projected height of the bursts was within the occulting disk. But the general direction of the bursts appears to coincide with the streamers very well. Figure 6 shows that all the bursts occur on the edge of the streamers. Notice that the lower frequency bursts occur at greater heights on the streamer. This result provides further support for the earlier conclusion of Kundu *et al.* (1983a, b) who studied the association of type III bursts with the white light streamers using the Solwind coronagraph images from the P78–1 satellite.

We estimate the coronal electron density variation with radial distance using the position measurements of the type III bursts. We chose three events (208, 255, 260(1)) where the bursts occurred above the limb, so that the measured radial distances of the

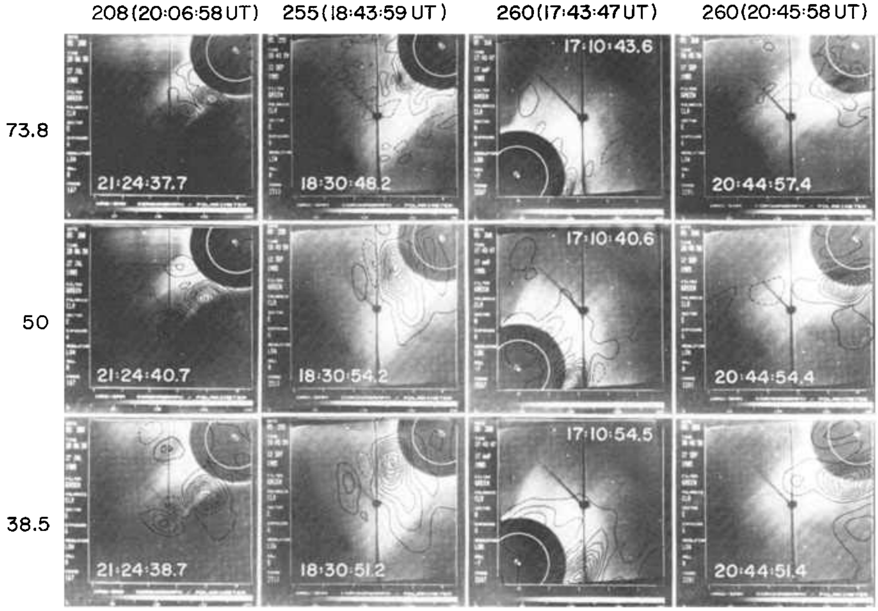

Fig. 6. Superposition of type III bursts at 73.8, 50.0, and 38.5 MHz on HAO–C/P picture of coronal streamers for DOY 208, 255, and 260. The time of C/P picture is indicated on each column. The time of the type III burst is indicated in the corners of the figures.

centroids are likely to be close to the actual source heights. We estimated the electron density using both fundamental and harmonic plasma emissions. The radial dependence of density is plotted in Figures 7(a)–(c), for the three cases. On the same plots, we have shown electron densities estimated from radial scans of column density obtained from HAO SMM–C/P observations and assuming that the full soruce depth along the line of sight is equal to half the measured source size. The error bars indicated are from maximum possible errors in the column density scans (Hildner, private communication). These figures show good agreement between the estimates obtained by using both methods. The density values are different on different days, which may be expected (Newkirk, 1967). The somewhat lower values obtained from the column density scans in Figures 7(a)–(c) could be due to an overestimate of the source depths along the line-of-sight if the emission occurs at the fundamental whereas they agree well if the emission is at the harmonic plasma frequency. Smaller depths along line-of-sight could result if the streamer is fan shaped; however, the C/P data do not show evidence of such structures in the plane of sky. Scattering could also cause the observed source size to be bigger than the true source size.

4. Summary and Conclusions

We have presented observations of weak type III bursts at three frequencies on four days and have shown that their brightness temperatures are extensions of the lower edge of

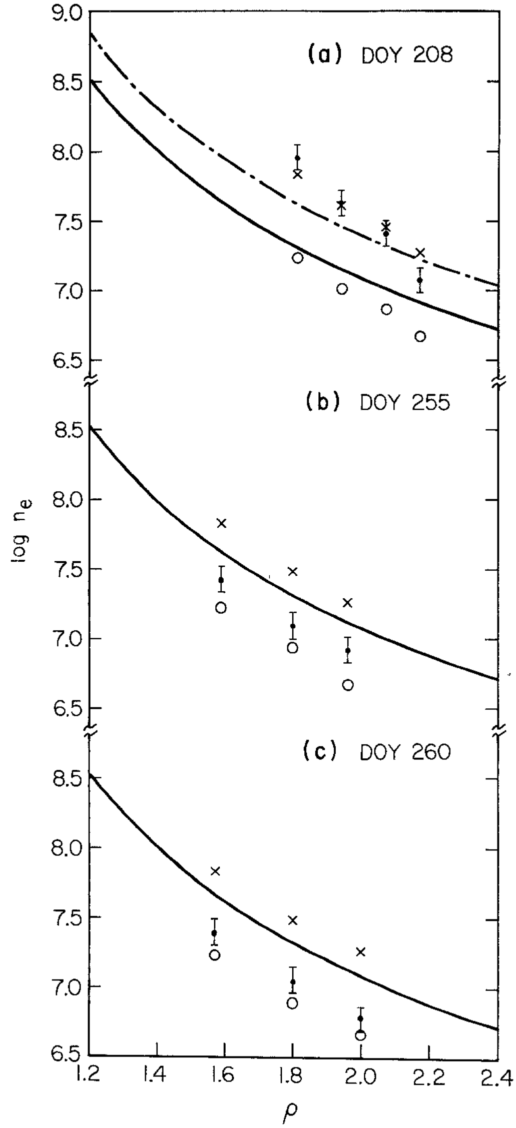

Fig. 7. The plot of coronal electron density (n_e) as a function of radial distance ρ (in units of solar radius) for (a) DOY 208, (b) DOY 255, and (c) DOY 260. The solid and dot-dashed curves are due to Newkirk's streamer and 2 × Newkirk's streamer models, respectively. × and O correspond to electron densities obtained by assuming fundamental and harmonic plasma emission, respectively. ⧲ represent electron density obtained from HAO SMM–C/P.

the brightness temperature spectrum of the usual type III bursts. The characteristics of the bursts can be summarized as follows:

(1) The bursts have short rise times and slower decay times; the single frequency duration is $\lesssim 37$ s. Events showing longer duration contain groups of bursts.

(2) The bursts drift from higher to lower frequencies and the drift rate lies in the range of 3–8 MHz s^{-1} in agreement with empirical models.

(3) The source sizes increase from higher to lower frequencies.

(4) Bursts are stationary at any given frequency in consecutive maps, confirming the plasma radiation interpretation of such weak bursts.

(5) The emission occurs at both fundamental and harmonic plasma frequencies if the bursts occur closer to the central meridian. It must be emphasized that our statistics are not sufficient (we have only one event 260(2)) to draw definite conclusions regarding the occurrence of fundamental and harmonic emissions close to the central meridian. However, our observations are in agreement with the statistical result that fundamental emission occurs within 50° of the central meridian (Suzuki and Sheridan, 1982). More observations are needed to establish this point in the case of weak bursts.

(6) The position measurements of the bursts could be used to determine the coronal electron density variation with height. The results are in good agreement with existing models. As the events used for density determination are limb events, the fundamental emission for weak type III's will contradict the conclusion of Suzuki and Sheridan (1982). This would then imply that the weak type III's differ from the usual ones in the details of scattering of plasma waves (White *et al.*, 1987a).

(7) The bursts occur in the elongated structures of the quiet Sun which are the radio counterparts of coronal streamers. The bursts seem to occur at the edge of active region coronal streamers. Thus the streamers must contain open magnetic field lines along which energetic electrons propagate, generating type III bursts along their way.

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