X-615-65-342

NASA TM X-55327

OBSERVATIONS OF SOLAR RADIO BURSTS AT 26.3 MC/S

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AUGUST 1965

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GREENBELT, MARYLAND

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OBSERVATIONS OF TYPE III AND TYPE IV SOLAR RADIO BURSTS AT 26.3 MC/S*

ABSTRACT

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A source of Type III bursts in the solar corona was observed at 26.3 Mc/s (11.4 meters) with the Clark Lake antenna during the period July 31-August 12, 1963. The height of the source was found to be 2.4 solar radii from the center of the sun which presumably is the height of the plasma level for 26.3 Mc/s, corresponding to an electron density of $8.5 \times 10^{6}\ \mathrm{cm}^{-3}$. This height refers to the density in a coronal streamer over an active region and, together with determinations at frequencies of 1.5 to 201 Mc/s, corresponds to the density distribution with height of the van de Hulst model of the equatorial maximum corona, with all the densities multiplied by a factor of 10. No evidence was found for refraction in the corona.

A moving Type IV burst arising from a west limb flare in the same active region on August 11 was observed to travel out through the corona at an angle of 32° north of the radial direction to about 6.3 solar radii from the center of the disk with a velocity of about 1400 km/s. After reaching this height, the source moved inward with a velocity of 380 km/s to an altitude of 5.4 solar radii, where it remained until the end of the burst. The brightness distribution found for the source agrees with the "core and halo" model of Weiss and Sheridan for various types of bursts and the results of Erickson for Type III bursts. The observed properties of the burst are in reasonably good agreement with those found by other workers at frequencies of 40 to 169 Mc/s.

Author

I. INTRODUCTION

During the summer of 1963, high-resolution observations of radio emission from active regions in the solar corona were made at a frequency of 26.3 Mc/s with the Christiansen-type array at Clark Lake, California (Erickson, 1965). The lobes of the response pattern of the array are spaced $1\overset{\circ}{.}5$ apart in the east-west direction and are $10'$ wide to half power east-west and 3° wide north-south. A one-dimensional scan of the solar brightness distribution is obtained each time the sun crosses a lobe, which occurs at 6-minute intervals near local noon.

*Submitted for publication to the Astrophysical Journal.

II. TYPE III BURSTS

The study of Type III bursts that began with analysis of 1962 Clark Lake data (Erickson, 1963) has been continued. For Type III bursts, by far the greatest observable activity in our 1963 records coincided with the disk passage of McMath plages 6908 and 6909; specifically the period July 31-August 12. (Intense continuum radiation associated with the great activity in September made the observation of all but the strongest Type III bursts impossible.) Since these measurements were made at a single frequency, identification of the spectral type of the bursts was made by comparison with the data reported by the High Altitude Observatory in Boulder, Colorado (CRPL-F Part B, 1963) for frequencies from 7.6 to 41 Mc/s.

On the record shown in Figure 1, the periodicity in amplitude of the bursts is quite evident. The numbered vertical lines correspond in time to the passage of the center of the solar disk across each lobe of the antenna response pattern. Time increases from right to left, and the interval between lobe passages is approximately 6 minutes. It can be seen that the passages of the source of the Type III bursts are occurring earlier than the calculated times of passage of the center of the sun, and therefore that the source is west of the center of the disk, corresponding to the westward position of the active region for August 9. On this day, the array was phased to a declination of 17°22', close enough to the solar declination of 15°51' so that the sun passed through the pattern during the four hours centered on local noon. (The source Virgo A has a declination of 12°35'; the difference in declination was sufficient to make the source pass south of the pattern near transit, and through the pattern about 1-1/2 hours before and after transit. The positions marked for Virgo A in Figure 1 correspond to passage of the source through some of the lobes that lie well east of the meridian at the same time that the sun was passing through some of the western lobes.)

The bursts included in the study had intensities ranging from about the intensity of Virgo A to 4 or 5 times this value, or from about 5×10^{-23} watt meter^{-2} (cps)$^{-1}$ to about 2×10^{-22} watt meter^{-2} (cps)$^{-1}$. A large proportion of the bursts appeared to have durations less than or equal to 3.0 seconds, the time constant of the receiver. To insure that ionospheric refraction did not seriously affect the observed displacements of the radio source, the observed positions of Virgo A were compared with its calculated times of lobe passage.

In Figure 2a, the daily optical maps of the sun made and supplied by the Fraunhofer Institut and the 9.1-cm maps of Stanford University (from CRPL-F Part B, 1963) have been combined to show that the two plages were quite close together and constituted essentially the only active center on the disk during most of the 13-day period. This was a fortunate circumstance in that it led to the unambiguous identification of the optical feature with which the Type III bursts

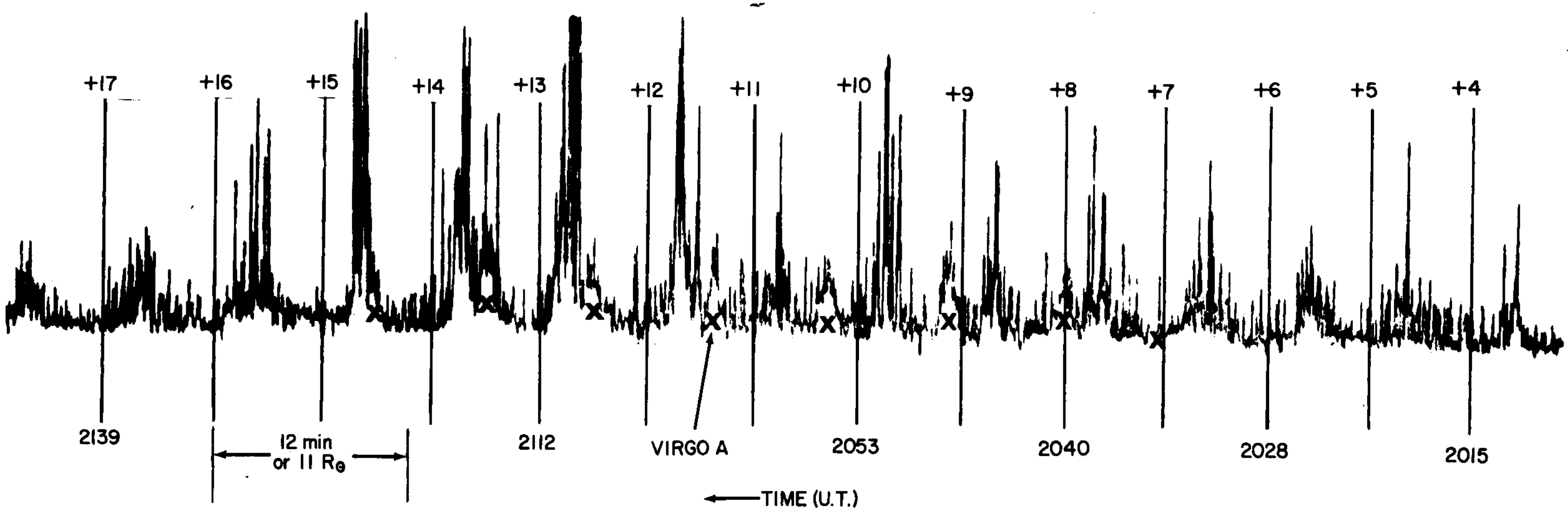

Figure 1–Part of the Clark Lake record for August 9, 1963 representing the passage of a source of Type III burst through some of the western lobes of the array. The numbered lines give the times of passage of the center of the sun through the lobes. Fringes due to the passage of Virgo A through some of the eastern lobes are indicated by X's.

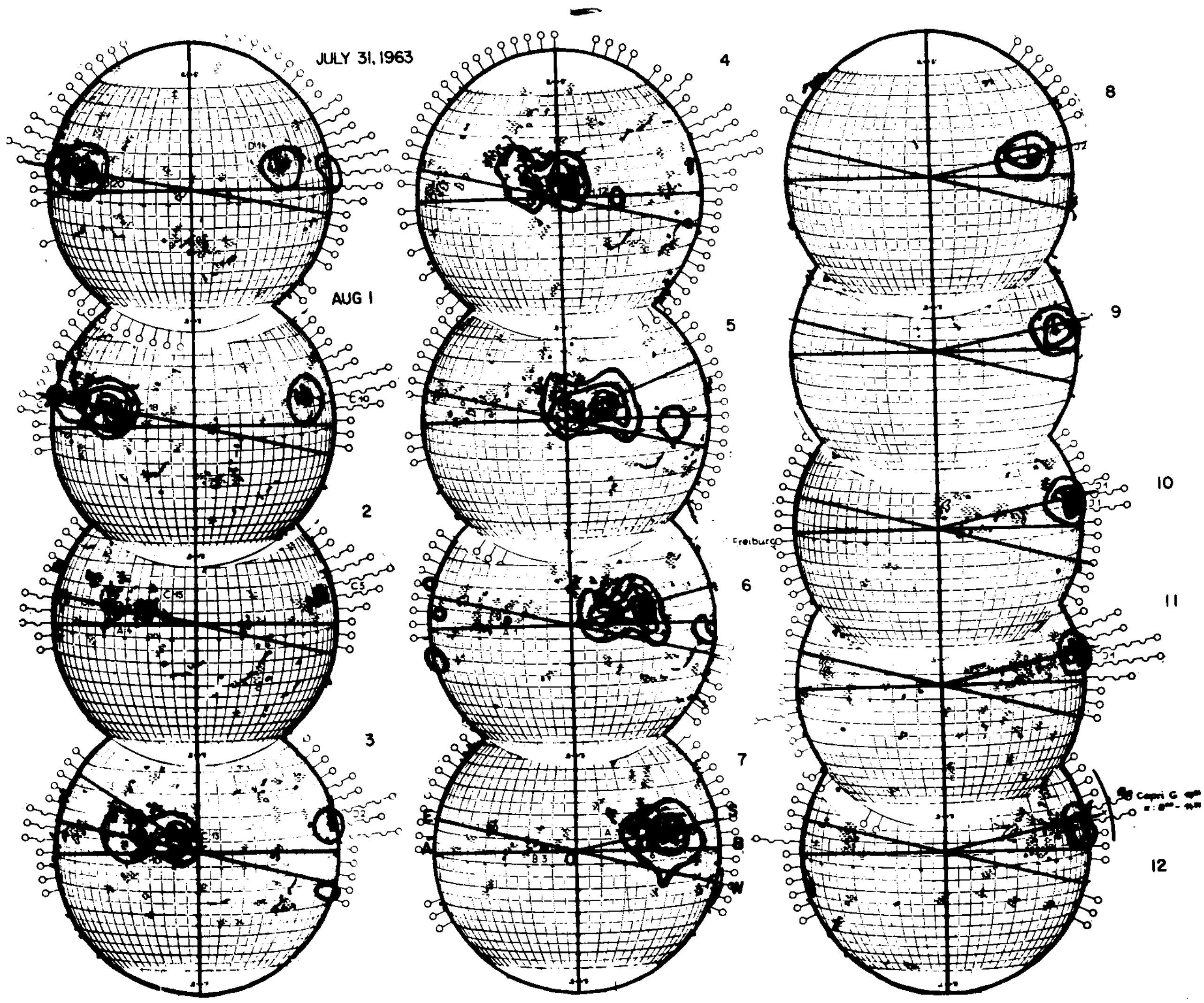

Figure 2(a)–The Fraunhofer Institut maps of the sun showing the positions of optical active regions. The contour lines represent the 9.1-cm Stanford maps which have been superimposed on the optical maps.

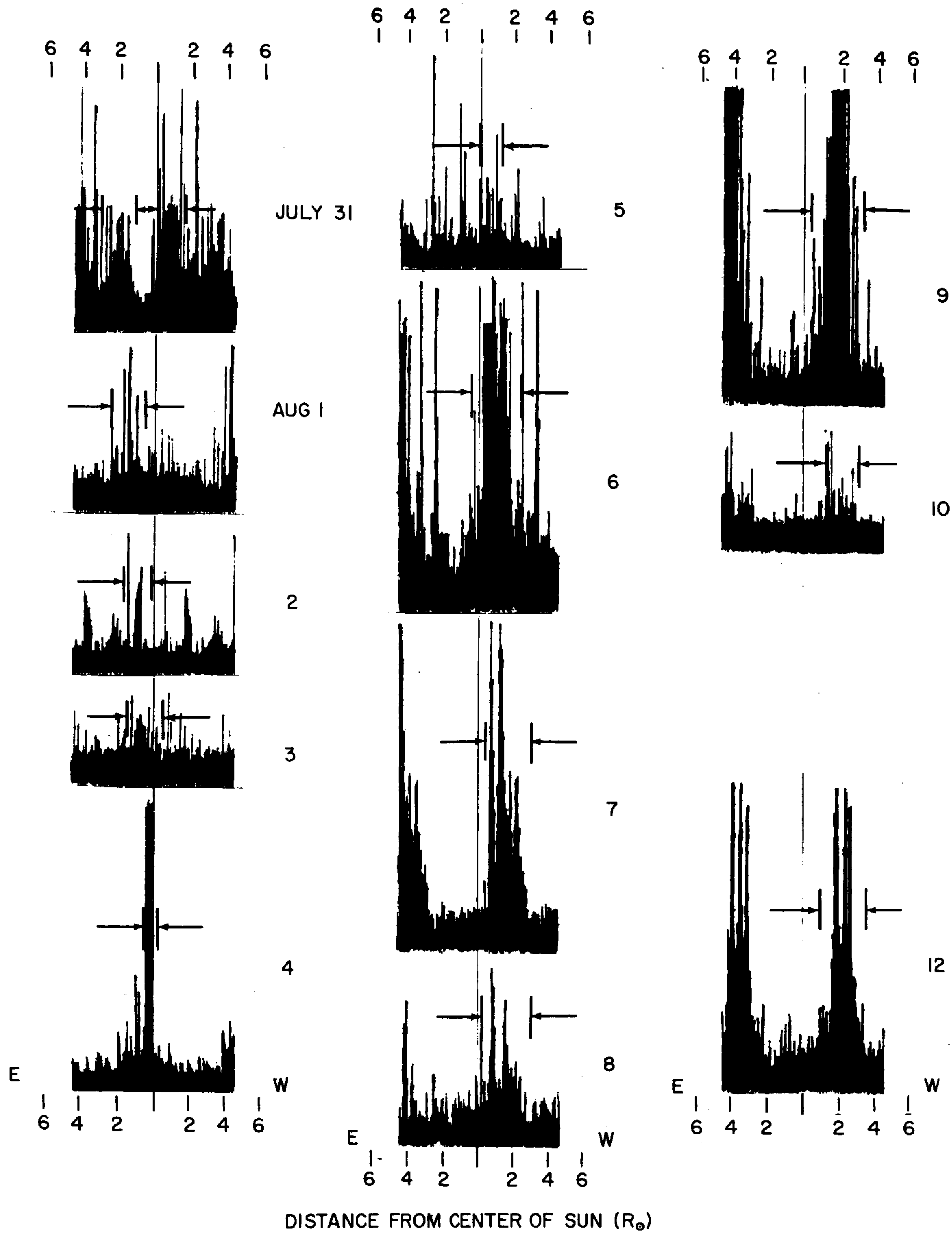

Figure 2(b)–Results obtained by superimposing the numbered vertical lines (see Figure 1) so that all the Type III bursts observed on a particular day are plotted as if they all occurred in one lobe of the array. The arrows indicate the bursts used in obtaining the positions of the Type III source(s).

were associated. It was then possible, by making the assumption that the source of the bursts was located radially above the optical (and 9.1-cm) active region, to correct the observed distances of the bursts for projection on the east-west line and obtain the radial distance of the source from the center of the sun. This method differs from the one used in most of the studies published to date (e.g., Shain and Higgins, 1959 and Morimoto and Kai, 1961) which are based on data obtained around the last solar maximum when there were always several active regions present on the visible solar disk. Consequently, the observed Type III bursts had to be related either to the region that had been most active during the preceding few hours, or to any chromospheric flares that were observed to occur at about the same time. The east-west displacement of the radio source was plotted against the east-west displacement of the optical source identified with it, for each observed burst. The slope of the line through these points gave the distance of the source from the center of the sun in solar radii. The large scatter of some of the points suggests that some of the optical identifications were in error. As an example of the method used in the present work, the Fraunhofer map for August 7 shows the east-west line EW, along which the scan is made; line AB, the intersection of the equatorial plane of the sun with the plane of the sky; and angle WOS, the angle between the direction of the source and line EW, used in correcting for projection on the east-west line.

Another difference between the Clark Lake data and those of other observers comes from the high sensitivity of the array. Rather than making a statistical study of isolated strong bursts observed on many different days, it was possible to observe many weak bursts during the few hours each day that the sun was in the beam. By superimposing the numbered vertical lines for each lobe-crossing of the center of the solar disk and recording the positions and heights of the individual bursts, the plots shown in Figure 2b were obtained and an average source position was found for each day. Taking as an example the plot for August 12, the arrows delineate the bursts that were used to measure the position of the source with respect to the center of the sun. The identical grouping of bursts on the left shows the ambiguity that comes from the spacing of the lobes about 6 solar radii apart. The plots for the other days indicate the variation in the number and intensity of bursts recorded during the period. On July 31, when there were apparently two regions producing Type III bursts (corresponding to the two regions for July 31 in Figure 2a), the plot is a bit complicated. Fortunately, the activity in the second region disappeared after July 31, making the position measurements easier and probably more accurate.

It is clear that the apparent halfwidth of the source was much larger than the 10' (or $2/3R_{\odot}$) halfwidth of the lobes. On most days the source halfwidth approached 2 solar radii and it occasionally exceeded this value. In the period covered by the 1962 Clark Lake data, there were days on which there were several times as many bursts per hour than were seen in the 1963 data (Erickson, 1963). Also, the average intensity of the bursts was greater, so that it was possible to compute the probability of occurrence of bursts above an intensity of 10^{-22} watt meter^{-2} (cps)$^{-1}$ for several days as a function of distance from the center of the solar disk. On the most active day (May 25, 1962) a symmetrical brightness distribution resulted from this averaging process, to which a gaussian curve was fitted. It was found that the central part of the brightness distribution was significantly too high, and that the sum of a wide gaussian ("halo") and a narrower distribution proportional to the shape of the lobes ("core") provided quite a satisfactory fit. This result agrees with the "core and halo" model proposed by Weiss and Sheridan (1962) who suggested the possibility that the core is formed by the radiation traveling directly from the source to the observer and that the halo comes from wide-angle emission from the source followed by scattering as the radiation emerges through the other parts of the corona. Of course, the result could also be explained by emission from a large number of individual sources of very small diameter varying in position in such a way that the shape and position of the observed source are produced. From the May 25, 1962 observations, the halfwidth of the halo was found to be 2.5 solar radii, a value consistent with the 1963 data, and the halfwidth of the core was equal to or less than the 10' beamwidth.

The measured positions for each day, corrected for projection on the east-west line, are shown in Figure 3. To within ±0.2 solar radii, or about 1/3 the beamwidth, they correspond to the positions that would be observed for a source radially above the optical active region at a distance of 2.4 solar radii from the center of the sun, rotating at the same angular rate as the active region. There is no apparent refraction of the 26.3 Mc/s rays as they come out through the solar corona toward the observer. A possible explanation for this was first suggested by Shain and Higgins (1959). It is known from optical observations that the corona is not spherically symmetrical, but contains regions of higher density (streamers) which tend to originate over active regions and extend more or less radially outward. Since radio bursts are strongly associated with active regions, it is reasonable to assume that the disturbances responsible for the Type III bursts travel out from active regions along their corresponding streamers. According to the ideas of Wild et al. (1954), Type III bursts originate at the level in the corona corresponding to the plasma level for the frequency of observation. In this case, therefore, the 26.3 Mc/s plasma level in a streamer would be at a considerably greater height in the corona than the plasma level for this frequency in the surrounding more or less spherically symmetrical corona. If the cross section of the streamer is not too large, the escaping radiation will emerge through a medium of comparatively low electron density and therefore will undergo very little refraction. If this is the case, the heights determined for Type III bursts will all refer to the height of the plasma level in streamers over active regions and not to the height in the so-called normal corona.

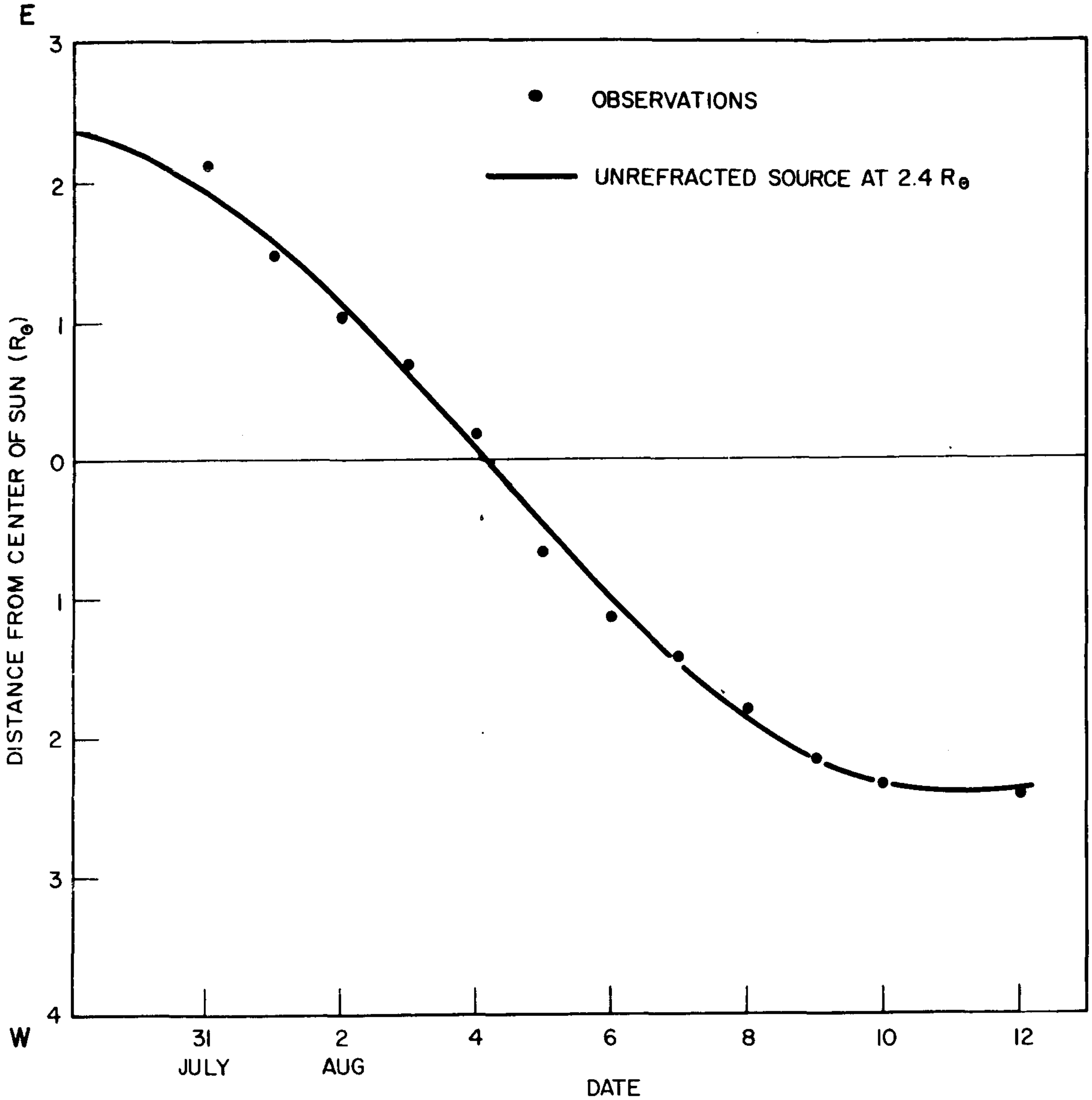

Figure 3–The positions of the Type III source for each day, determined from the plots in Figure 2, compared with the positions that would be found for a source radially above the optical active region at a constant height of 2.4 $R_\odot$ with no refraction of the rays as they emerge through the outer corona.

In Figure 4, an attempt has been made to summarize currently available observational data on the electron density distribution in the solar corona in order to compare it with the value obtained in the present study. Starting from the left side of the plot, the first two shaded areas result from the superposition of the various published results on the coronal electron distribution over the poles and over the equator of the sun, obtained from optical eclipse observations (Michard, 1954; Hepburn, 1955; von Klüber, 1958; Mogilevski et al., 1960; Ney et al., 1961). The three solid curves represent van de Hulst's (1950) models for

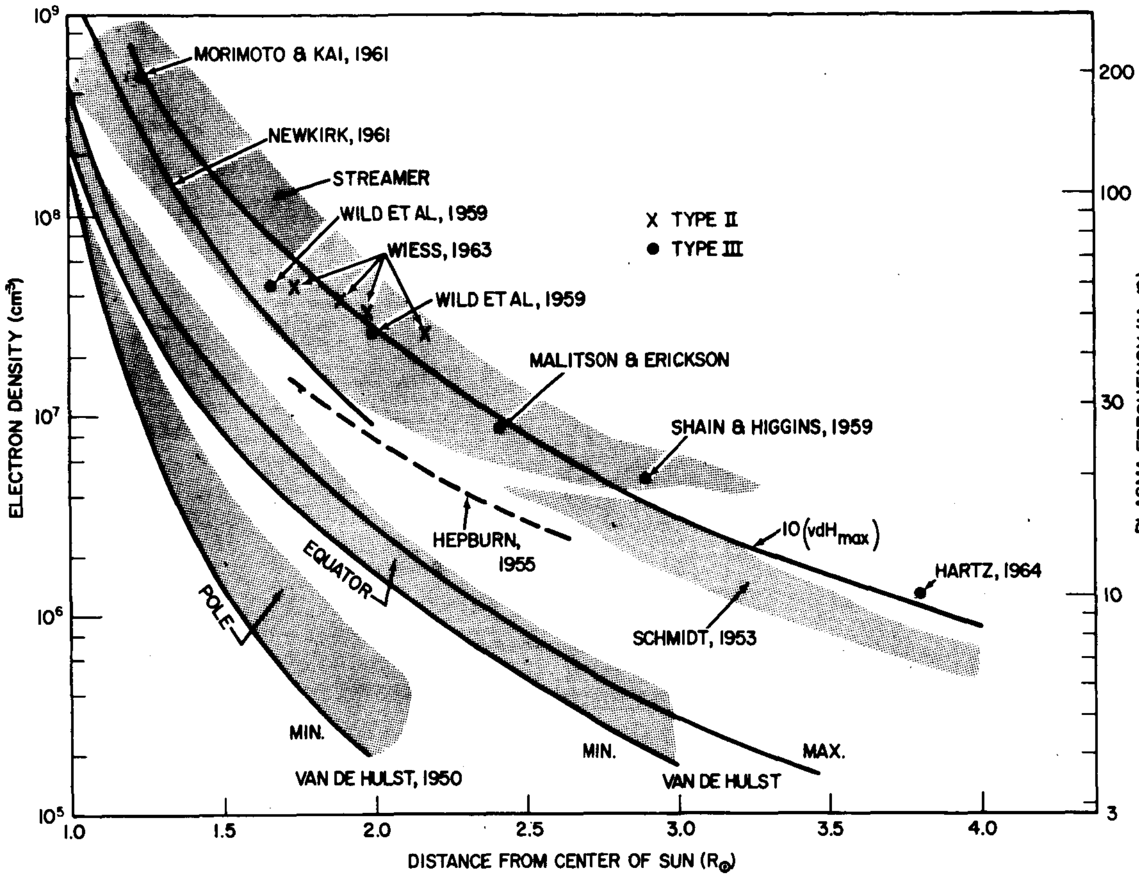

Figure 4—Estimates of the electron density distribution in the solar corona determined by various methods. The shaded areas for the polar and equatorial distributions represent results from optical eclipse observations. The solid curves are the models of van de Hulst. Optical results from streamers are shown by Newkirk's model (solid curve) and the results of Hepburn (dashed curve) and Schmidt (shaded area). The estimates from Type II and III bursts at frequencies of 10 to 201 Mc/s are shown by the crosses and dots and the large shaded area around them (to indicate the experimental error). The solid curve through this area is the equatorial maximum model of van de Hulst multiplied by a factor of 10.

the electron distribution over the poles, and over the equator at solar minimum and maximum. These models were derived from a study of eclipse photographs made over a period of forty years. The maximum curve can be obtained from the minimum curve by multiplying by the factor 1.78.

Optical measurements of the electron density in coronal streamers are represented by the work of Newkirk (1961), Hepburn (1955), and Schmidt (1953). Newkirk's model (the solid line) was derived from K-coronameter observations made outside of eclipse during the last solar maximum. Hepburn's curve was derived from 1952 eclipse plates and has only relative accuracy due to the lack of polarization measurements. The shaded area indicates the range of density distributions measured by Schmidt for 3 streamers on 1937 eclipse plates.

The wide shaded region near the top indicates coronal densities inferred from radio burst position determinations at various frequencies. The width represents a reasonable value of the experimental error involved, approximately $\pm 1/4 R_\odot$. The 26.3 Mc/s point obtained in the present study can be compared with the Type III observations of Morimoto and Kai (1961) at 201 Mc/s, Wild et al. (1959) at 60 and 45 Mc/s, Shain and Higgins (1959) at 19.7 Mc/s, and Hartz (1964) from 10 Mc/s to 1.5 Mc/s (only the point for 10 Mc/s is shown in the figure). It was assumed in all these determinations that the bursts observed were all fundamentals, and available observational evidence (Wild et al., 1959, and Shain and Higgins, 1959) supports the view that the fundamental is much stronger than the second harmonic in Type III bursts at these low frequencies. Since Type II bursts are also believed to originate at the plasma level corresponding to the frequency observed, the points of Weiss (1963a) for the fundamental bands of Type II bursts at frequencies between 60 and 45 Mc/s can also be included in the comparison. The radio burst observations fall very close to the solid curve, which represents the van de Hulst model for the equatorial corona at maximum, with all the electron densities increased by a factor of 10. Many of the published studies of solar bursts at metric and decametric wavelengths have used the Baumbach-Allen model (Allen, 1947) multiplied by the same factor. The two models (10 × van de Hulst and 10 × Baumbach-Allen) are almost identical out to about 2.5 solar radii, but 10 × van de Hulst comes closer to the 19.7 Mc/s point and was also found by Hartz (1964) to give more reasonable velocities of propagation of the disturbances responsible for Type III bursts over the range 10 to 1.5 Mc/s.

Looking at the general trend of the observations presented in Figure 4, it appears that the optically observed streamers (represented by Newkirk's model and observations by Hepburn and Schmidt) have electron densities that exceed those of van de Hulst's equatorial maximum model by a factor of about 5, and that an additional factor of 2 corresponds to the distribution found by observations of radio bursts. The optically observed coronal streamers may be thought of as typical, the kind that can be observed at any time during the solar cycle, although they are absent near the poles around solar minimum. Since a radio burst requires the presence of an active region for the production of the initiating disturbance, the radio measurements represent only streamers over active regions. It appears, then, that the densities in streamers over active regions tend to be roughly double those in ordinary streamers.

III. TYPE IV BURST

This burst occurred on August 11, 1963 when the same active region that produced the Type III bursts discussed above was on the west limb of the sun. The optical flare with which this burst has been associated was seen at the Lockheed Solar Observatory in Burbank, California from 1827 to 1850 U.T. (CRPL-F Part B, 1963). In Figure 5, the flare can be seen as a very small brightening

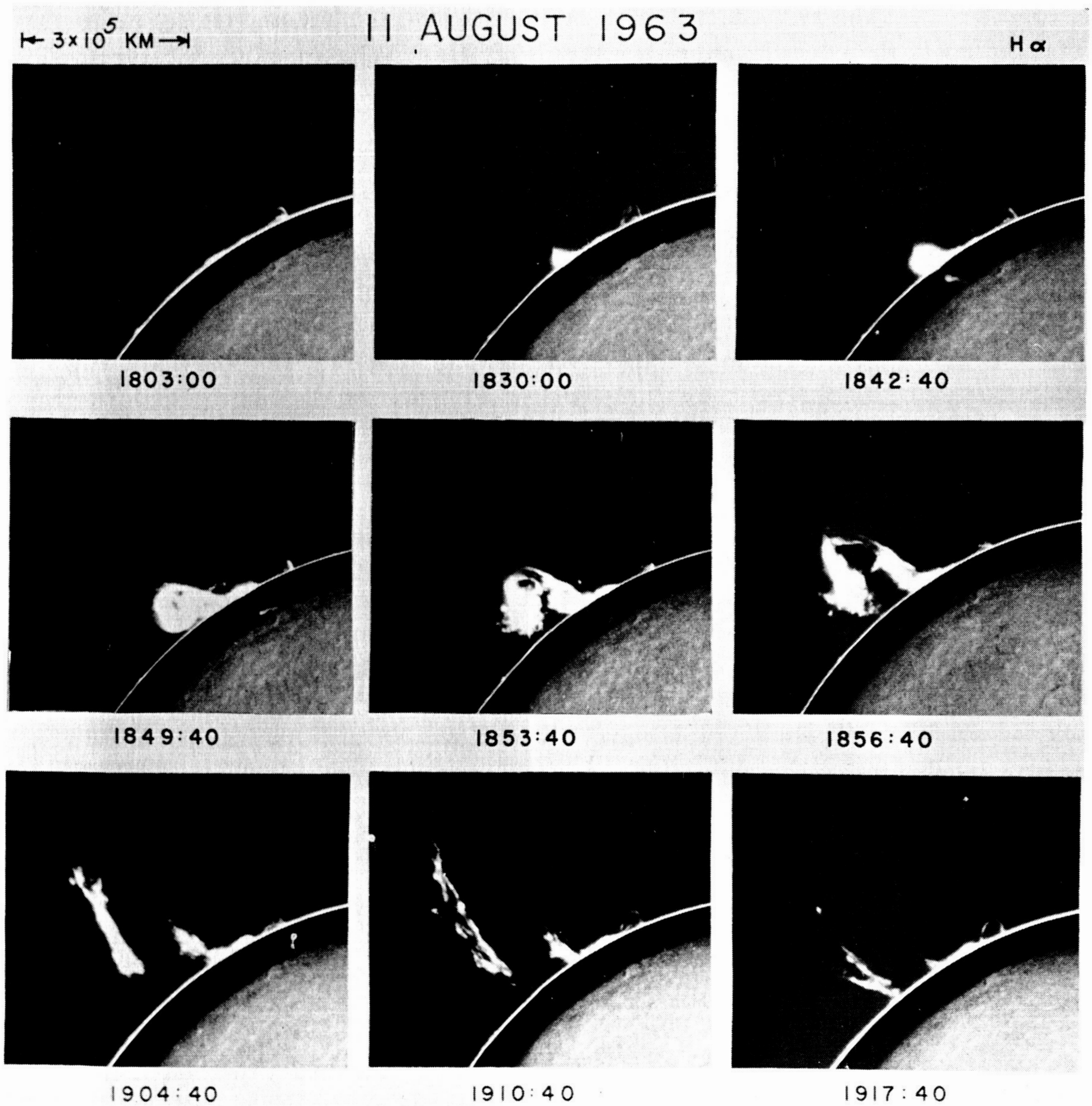

Figure 5—Lockheed Solar Observatory H-alpha photographs of the optical event associated with the Type IV burst of August 11, 1963. Times are U. T.

just above the solar disk. The H-alpha pictures presented here were made with a double optical system at the Lockheed Solar Observatory that photographs the disk and the limb of the sun simultaneously. The blowing off of an arch-type prominence from the limb is much more spectacular than the flare itself and this, together with the flare duration of 23 minutes and the accompanying radio bursts, points to the occurrence of a fairly large flare (classified by Lockheed as importance 2) most of which was probably located just over the limb on the invisible hemisphere of the sun. (Smith, 1964.)

Again, the identification of the spectral type of the burst was made by referring to the High Altitude Observatory sweep-frequency measurements. The HAO decametric record and H-alpha photographs of the August 11 event have been reproduced in Figure 14 of Warwick, 1965. Figure 6 shows our record, along with the occurrence of Type II, III and IV bursts observed at HAO, Type V observed at the Harvard Radio Astronomy Station at Fort Davis, Texas, and two flares reported by Lockheed (all from CRPL-F Part B, 1963). The record for Virgo A, which came through some of the eastern lobes of the pattern immediately after the solar event, is included to show that the observed times of lobe crossing were in fact close to the calculated times (marked by the vertical lines numbered from -19 to -1) indicating that ionospheric refraction was not an important source of error in the solar observations. Starting from the right (time runs from right to left on these records) there is a small "precursor" around 1858 U.T., coinciding with weak continuum radiation observed by the High Altitude Observatory from 1854 to 1905. Then at 1905 there is the abrupt onset of Types III, II, and IV almost simultaneously. By 1914 U.T. only Type IV remains. Comparing the actual positions of the fringes with the numbered lines for transit of the center of the sun across each lobe, the fringes seem to be occurring between the calculated central crossings. It is not immediately clear whether the source is appearing earlier (west) or later (east) than the sun's center. This ambiguity can be resolved by referring to the record from the phase-switched array at Clark Lake (Erickson, 1965) which has only one lobe corresponding to the central lobe in the total power array. Figure 7 shows several phase-switched records of solar transit, and the record for August 11 indicates clearly that the emitting region is about 3 solar radii west of the center of the sun.

Returning to Figure 6, the source at first (around 1912 U.T.) is about 2 minutes (or 2 solar radii) west of center but gradually moves westward until by 1950 U.T. it has reached a distance of about 3.4 solar radii from the center. The wide lobe at 2000 U.T. corresponds to an intense Type III burst observed at the High Altitude Observatory (and Type V seen at higher frequencies at Fort Davis) which makes it impossible to follow the development of the Type IV event for a few minutes). On the basis of this record, it is known only that the intensities of the strong Type III burst and of the first half of the Type IV burst were greater than about 1.5×10^{-22} watt meter^{-2} (cps)$^{-1}$. The record in Figure 8, corresponding to a

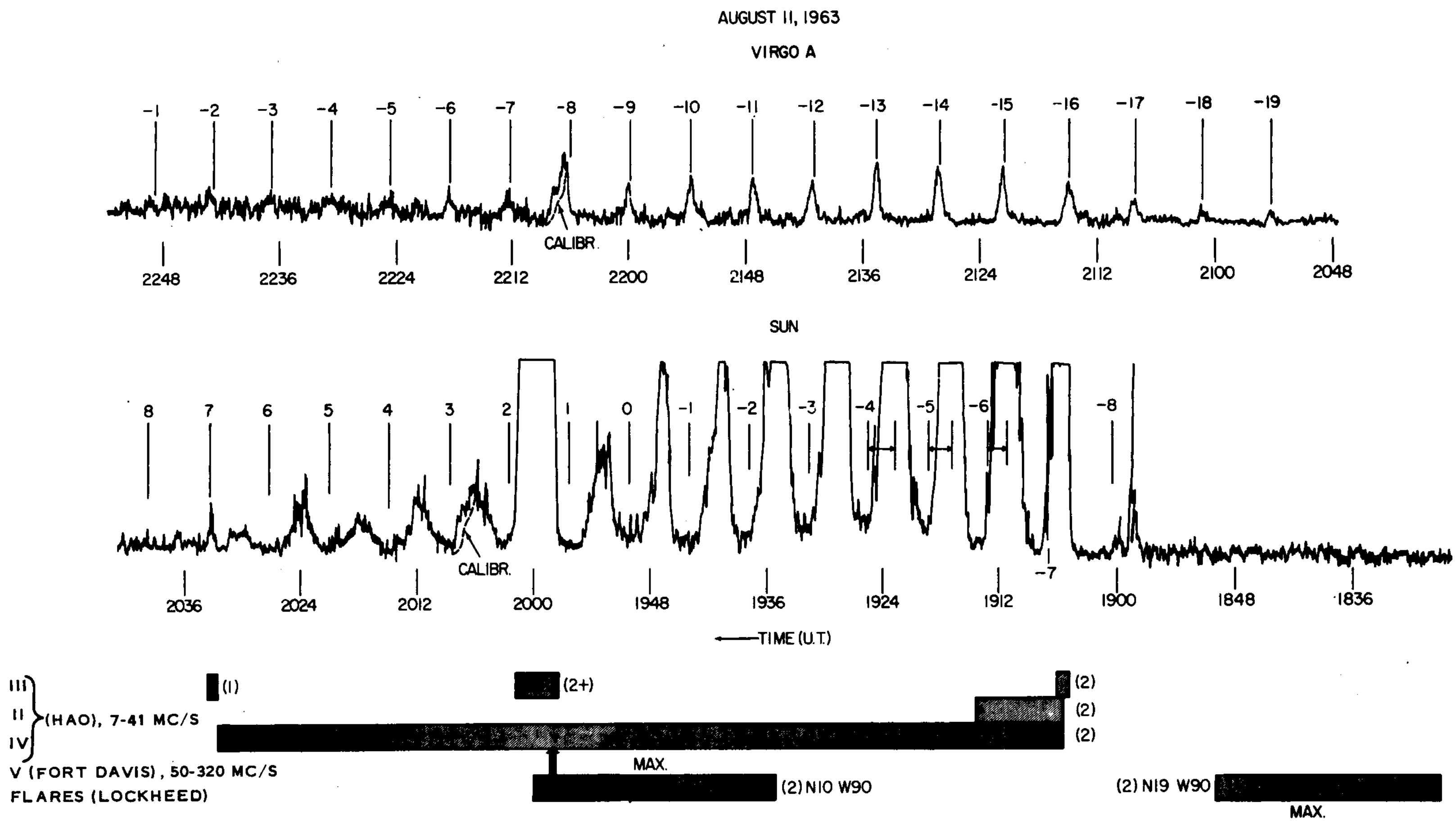

Figure 6–The Clark Lake high-sensitivity record of the bursts observed on August 11, 1963 and the times of the associated optical flares and of spectral radio observations by the High Altitude Observatory and the Harvard Radio Astronomy Station (Fort Davis). The numbers in parentheses indicate the importances of the flares and radio bursts. The record for Virgo A, made immediately after the Type IV event, is shown at the top.

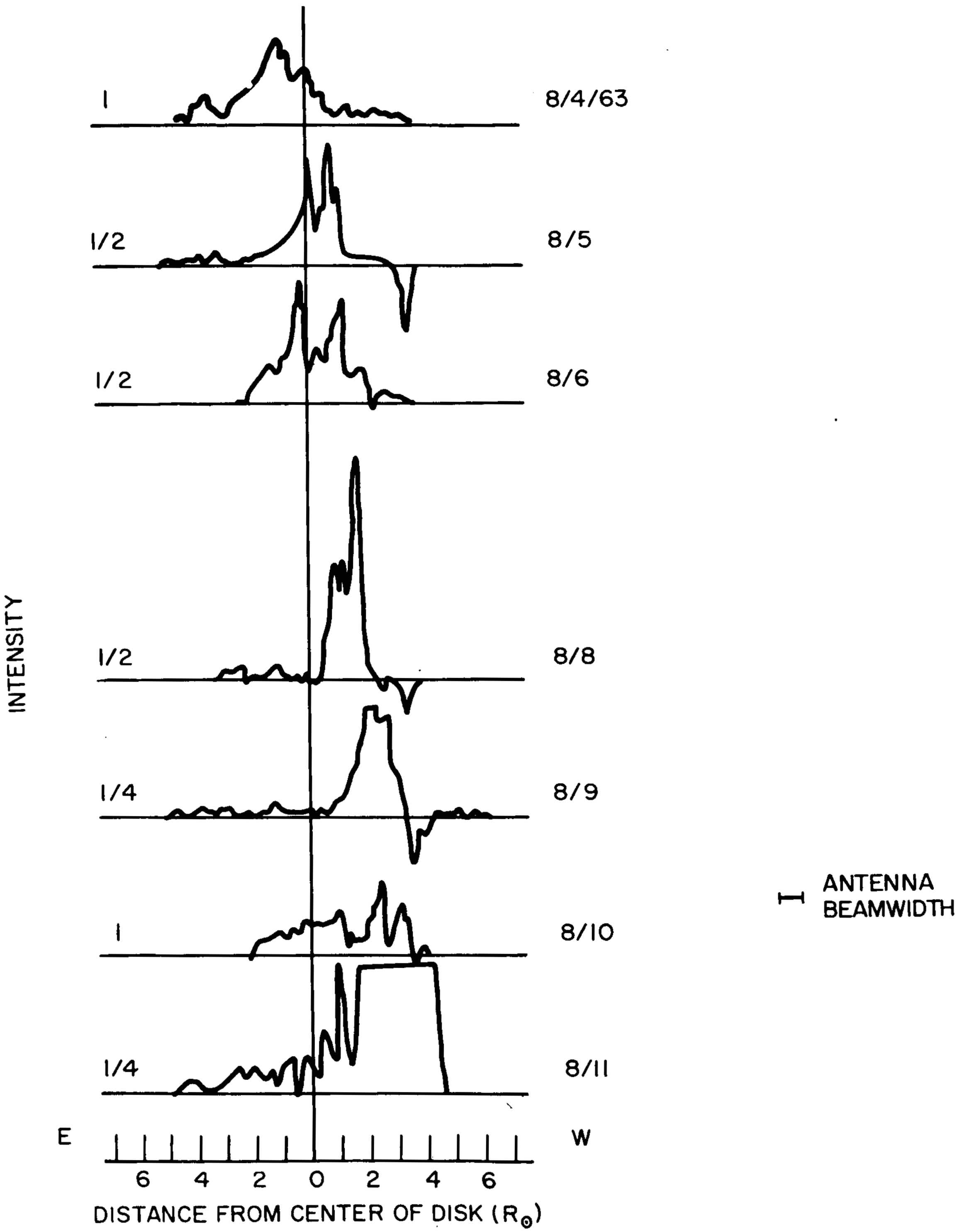

Figure 7—Records from the phase-switched array at Clark Lake for several days in August, 1963. As indicated, the intensity scales of some of the plots have been reduced to 1/2 or 1/4 that of the original records.

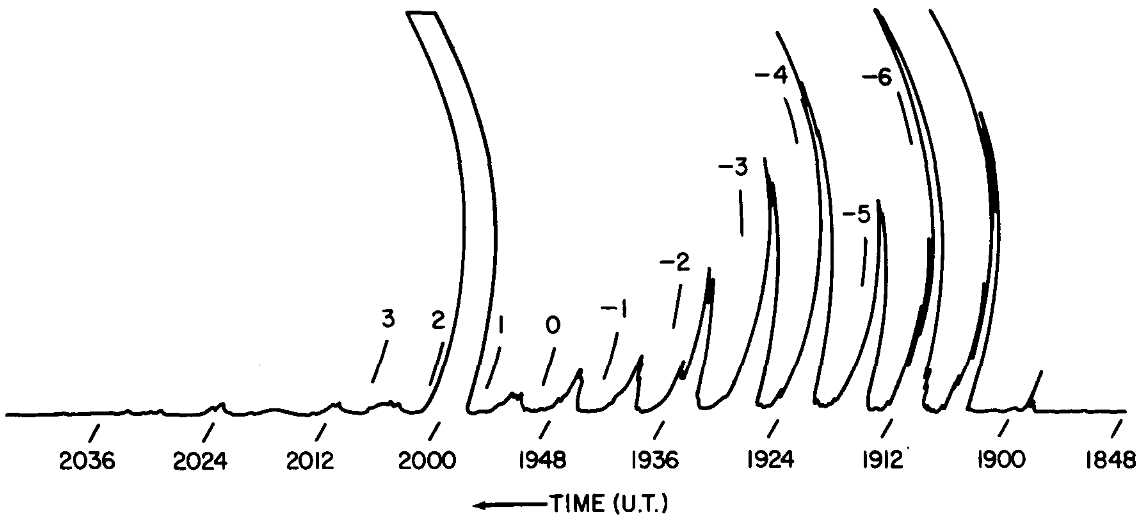

Figure 8—The Clark Lake low-sensitivity record of the bursts observed on August 11, 1963, with the times of lobe passage of the center of the sun indicated by the numbered lines.

sensitivity 10 times lower, shows that the highest intensity of the Type IV burst was not much greater than 1.5×10^{-21} watt meter^{-2} (cps)$^{-1}$ but that the strong Type III burst was probably many times more intense than this. Figure 9 gives the measured displacements of the Type IV source from the center of the sun and of Virgo A from its computed position. Judging from the data for Virgo A, there is a very slight westward displacement for a source east of the meridian which is the direction to be expected for ordinary spherical refraction in the ionosphere. However, the correction to the solar data would have been so small that it was neglected.

The measured displacements given in Figure 9 represent lower limits to the two-dimensional displacements which were projected on the east-west line. If the radio source had traveled out exactly radially from the flare, the direction of motion would be inclined at an angle of 31° to the east-west line (see Figure 10). Actually, the Lockheed Observatory reported that the optically observed ejected material (Figure 5) moved along a line that was north of radial (IGY Solar Activity Report No. 26, 1964) and therefore one might expect the angle to be even larger. Fortunately, this burst was also recorded at the High Altitude Observatory in Boulder, and we were able to make a preliminary examination of the data through the kindness of Dr. J. W. Warwick. By combining the displacements and fringe orientation deduced from the HAO record with ours, we find that the source apparently moved from the flare site to an altitude of 6.3 $R_\odot$ above the center of the sun along a straight line inclined at an angle of 32° north

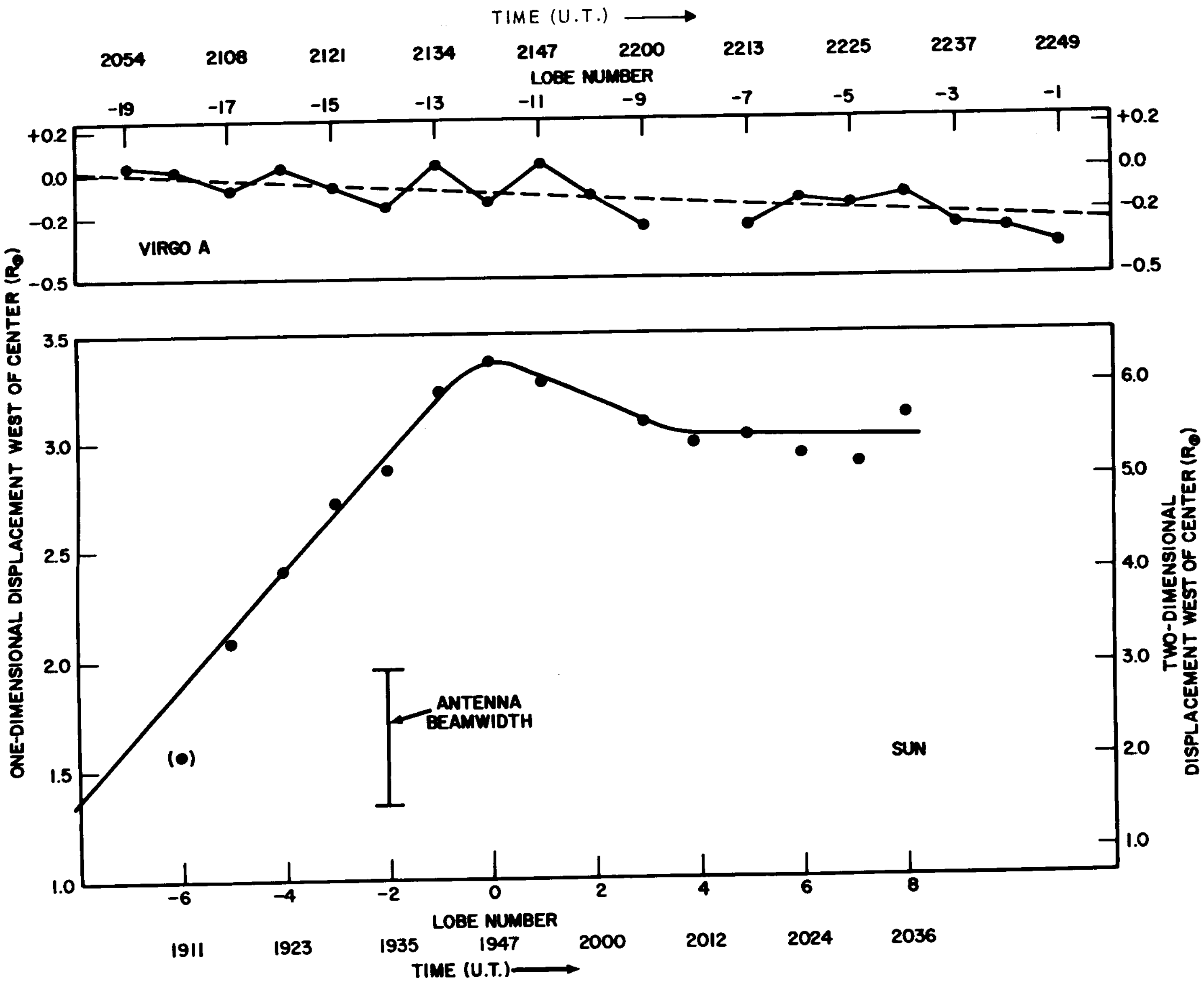

Figure 9—The measured displacements of the Type IV source from the center of the sun. The vertical scale on the left gives the displacement measured along the east-west line at Clark Lake and the scale on the right shows the displacement determined from comparison of the Clark Lake and Boulder data. The east-west displacements of Virgo A from its computed positions are indicated at the top.

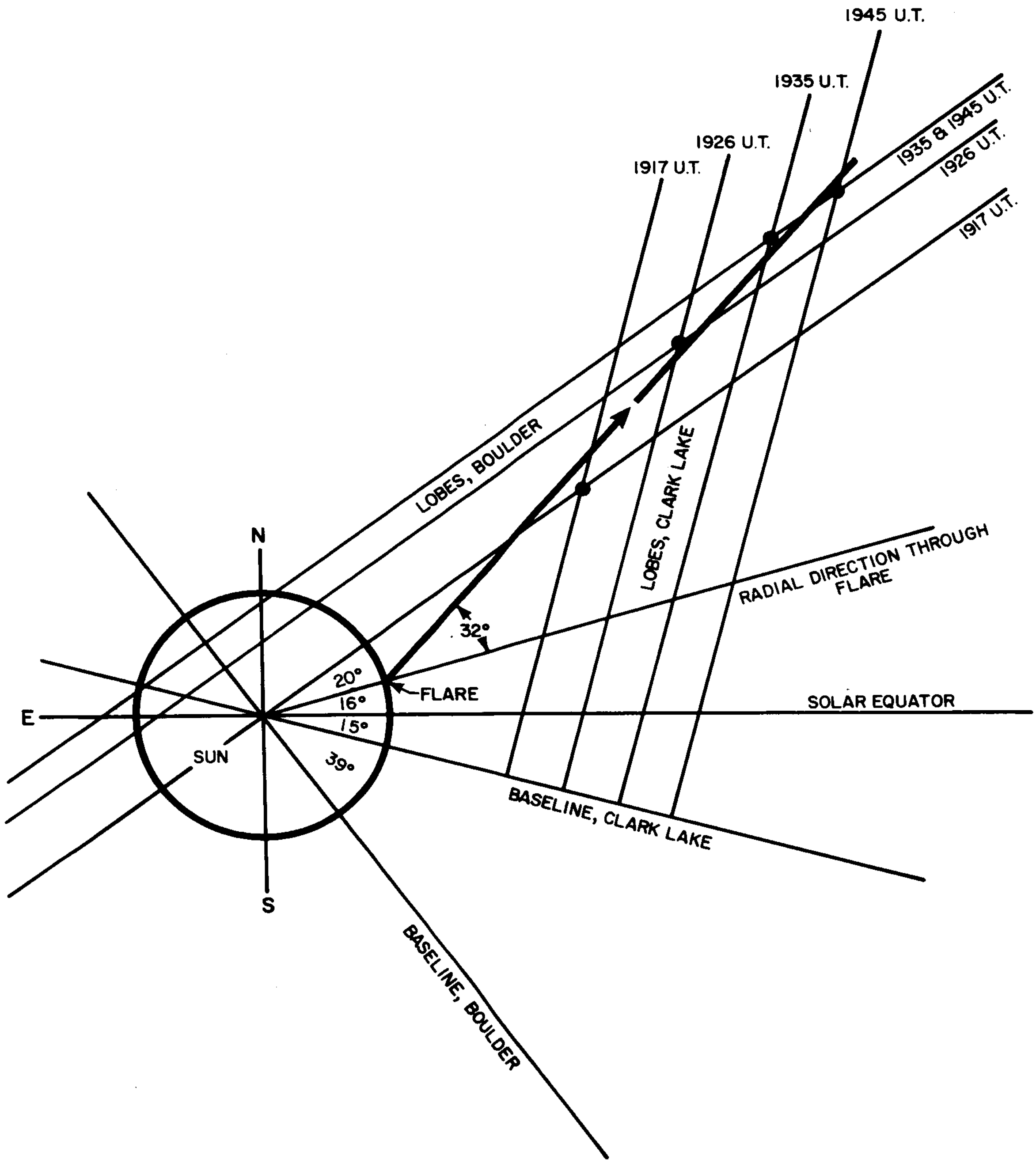

Figure 10–Diagram showing the orientation of the lobes of the Clark Lake and Boulder arrays with respect to the solar equator and the position of the optical flare. The two-dimensional positions of the Type IV source are indicated by the dots at the intersections of the Clark Lake and Boulder lobes.

of the radial direction. A comparison between this direction and the direction of motion of the optically observed material is of interest. According to information supplied by the Lockheed Observatory (Smith, 1965), the angle is $40° \pm 2°$ north of the radial direction through the flare. The agreement is good considering the errors inherent in each type of measurement, and indicates that the optically observed motion is closely connected to the motion of the Type IV source. However, the velocities measured for the optical material are considerably lower. Warwick (1965) has measured a maximum velocity of about 400 km/s from the H-alpha patrol photographs taken at the High Altitude Observatory. If the vertical scale in Figure 9 is changed to convert the measured displacements into what we believe are true two-dimensional displacements, the outward velocity of the source calculated from the slope of a straight line drawn through the observed points is 1400 km/s. After the initial rapid motion, the source appeared to move slowly inward at a velocity of about 380 km/s and finally came to rest at a distance of about 5.4 solar radii from the center of the disk.

Comparing these results with observations at other frequencies, we find many similarities and some differences. Of the 12 Type IV bursts studied by Weiss (1963b) at frequencies from 70 to 40 Mc/s for which he had data from the start of the burst, only 4 had "systematic rapid movements." For each of these bursts the initial rapid motion was away from the center of the sun and lasted from 5 to 20 minutes (this stage lasted about 35 minutes in our burst). Three of the 4 bursts (the fourth was not observed long enough) had a second stage consisting of a comparatively slow inward motion and, finally, there was stabilization at a distance closer to the center of the disk than the maximum displacement attained at the end of the first stage. By making the assumption of radial motion from the flare site, Weiss derived some rough approximations to the true two-dimensional velocities involved. They are compared with our values in Table 1.

Table 1

Date	Two-Dimensional Velocities (km/s)	
	Out	In
26 June 1958	2200	-
7 July 1958	4400	500
29 July 1958	3300	1300
27 June 1960	2200	100
11 August 1963	1400	380

Boischot (1958) observed Type IV bursts at 169 Mc/s with the Nançay interferometer and found velocities of Type IV bursts from several hundred to more than 1000 km/s, measuring east-west displacements from the center of the disk and assuming the source to move out radially. The maximum altitudes varied greatly from burst to burst, and ranged between 1.3 and 6 solar radii from the center of the disk. The rapid ascent followed by a slower descent and stabilization of position were observed in several cases. Kundu and Firor (1961) found one-dimensional velocities of the order of 1000 km/s for Type IV bursts at 87 Mc/s, and maximum east-west altitudes up to 7.6 solar radii. From his observations of the Type IV event of March 30, 1960 with a phase-switched interferometer at frequencies from 13 to 23 Mc/s, Philip (1964) deduced a one-dimensional velocity of the order of 10,000 km/s (a two-dimensional velocity of 14,000 km/s), and a maximum altitude over 11 (or 15) solar radii from the center of the disk. On the basis of these values, Philip suggested that the properties of Type IV bursts seen at frequencies around 20 Mc/s may differ radically from the same bursts observed at frequencies 2 or 3 times as high. Our results from the August 11, 1963 event and observations of a number of bursts at decametric wavelengths by Warwick (1965) do not support this view. Boischot (at 169 Mc/s) and Kundu and Firor (at 87 Mc/s) found the angular sizes of the sources to be greater than 10'. In contrast to these low-frequency observations, bursts observed at 340 Mc/s by Kundu and Firor (1961) and at 201 Mc/s by Morimoto (1961) had motions of only a few minutes of arc at most and positions much lower in the solar atmosphere, at heights near the plasma levels corresponding to the higher frequencies. The angular sizes of the sources were usually smaller than 4'.

The brightness distribution of the August 11 Type IV burst was observed to be similar to that observed for Type III by Erickson (1963) and for Type II, III, and IV bursts by Weiss and Sheridan (1962); i.e., the observed source has a shape that can be approximated by the sum of a wide gaussian halo and a narrow core with a distribution proportional to the shape of each lobe of the array. Figure 11 gives the shape of 3 of the fringes taken from the low-sensitivity record (Figure 8). The solid curves represent the observed fringe shapes; the dotted curves give the wide gaussian distributions and narrow lobe-shaped distributions chosen to give the best fit to the observed curves; and the dashed curves are the sums of the wide and narrow distributions for each case. There is a hint of asymmetry in the shape of each observed curve, which recalls the suggestion of Weiss and Sheridan (1962) that a Type IV burst observed by them with a two-component interferometer at two spacings, had a slight asymmetry. However, the largest separation of the centers of the core and halo amounted in our case to less than 4' and can not be considered significant, keeping in mind that the beamwidth was 10' and that the shapes of the fringes in several cases were found to be distorted by the passage of at least one weak discrete source through one of the outer lobes of the array at the same time that the Type IV source was in one of the inner lobes.

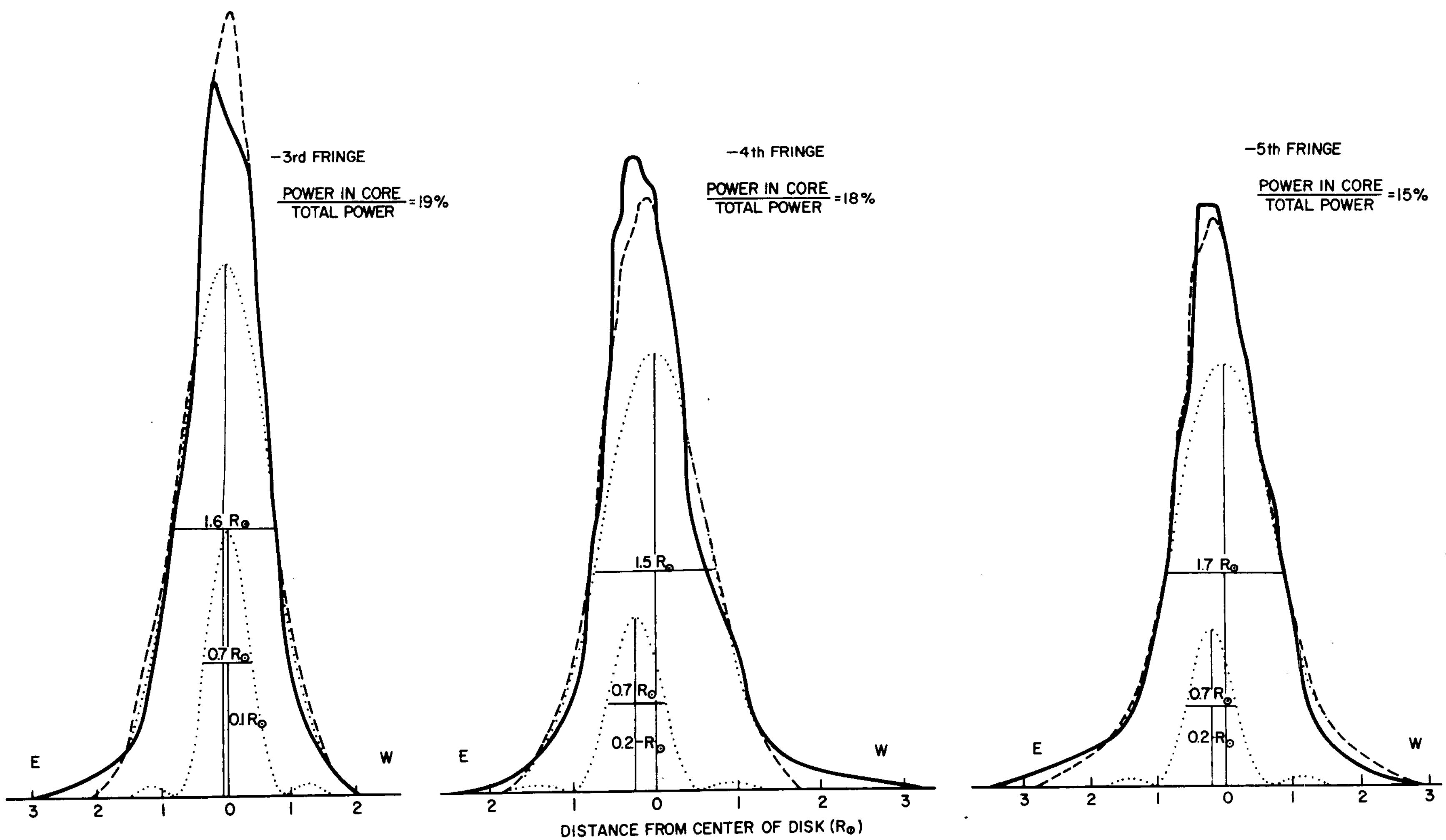

Figure 11–The observed shapes of 3 fringes (solid curves) and approximations to the shapes (dashed curves), each of which is the sum of a wide gaussian distribution and a narrow lobe-shaped distribution (dotted curves).

Weiss and Sheridan reported on the brightness distribution in only one Type IV burst, the one that followed the 3+ flare of November 15, 1960. The visibility of the burst was measured repeatedly at two spacings during a 45-minute period starting about 1/2 hour after the start of the flare. No motion of the source was detected during this time. In Table 2 the data on this burst at 60 and 40 Mc/s are compared with our 26.3 Mc/s data on the August 11, 1963 burst. We cannot make a good estimate of the width of the core, being limited by our 10' beamwidth. The halfwidth of the halo is found to be considerably narrower than the 48' assumed by Weiss and Sheridan in their model in which the brightness distribution depends on frequency, but somewhat wider than the 20' that emerges from their data in the model where the brightness distribution is independent of frequency. If, as Weiss and Sheridan have suggested, the halo is due to scattering, it should be wider at 40 than at 60 Mc/s, and still wider at 26.3 Mc/s. Moreover, the ratio of power in the halo to the total power in the measured brightness distribution should increase as the square of the wavelength. To be consistent with the 26.3 Mc/s ratio of 81%, we would expect the values at 60 and 40 Mc/s to be 16% and 35%, approximately the reverse of what has been reported. Since scattering should be greater for sources low in the corona, the fringe shapes should be examined for any change as the source travels outward. Unfortunately, the earliest fringes cannot be used because of our inability to separate out the effects of the Type II and III bursts. The first fringe thought to consist entirely of Type IV radiation is the -5th one which coincided in time with a displacement of approximately 3.2 $R_\odot$ from the center of the disk. This is considerably above the 26.3 Mc/s plasma level in the normal corona (roughly 1.6 $R_\odot$ for the van de Hulst or Baumbach-Allen models or 1.8 $R_\odot$ for the Newkirk model) so that any effect would be expected to be small. We find in fact (see Figure 11) that the ratio of power in the core to total power is 15% for the -5th fringe, while it is close to 19% for the other 3 fringes for which we have good profiles (-4th, 18%, -3rd, 19%, 0th – from the high-sensitivity record – 21%).

Table 2

Frequency	60 Mc/s	40 Mc/s	26.3 Mc/s
Halfwidth of Core	2!7 [quoted as 6' by Weiss (1963b)]	4!0	$\leq$10'
Halfwidth of Halo	48'	48'	26'
$\frac{\text{Power in Halo}}{\text{Total Power}}$	36%	20%	81%

IV. SUMMARY

Type III bursts from a source associated with McMath plages 6908 and 6909 were observed during the four hours around local noon at Clark Lake for each day from July 31 through August 12, 1963. The displacement of the source from the center of the solar disk was measured for each day and projection effects were accounted for by assuming that the source was radially above the associated optical and 9.1-cm active region. In this way, the height of the source in the corona was found to be 2.4 solar radii from the center of the sun. According to the generally accepted idea of the production of Type III bursts at the plasma level, the height found from 26.3 Mc/s observations should correspond to an electron density of 8.5×10^6 cm^{-3}. The height of 2.4 $R_\odot$ refers to the level in a coronal streamer above an active region where the density has decreased to this value and is considerably farther out than the 26.3 Mc/s plasma level in the normal or ambient corona. Presumably this is the reason for the lack of evidence for refraction in the measured positions of the Type III source. Comparison of our results with those obtained for Type III and Type II bursts at other frequencies, ranging from 1.5 to 201 Mc/s, indicates that the electron density distribution in coronal streamers over active regions is close to that of the van de Hulst model of the equatorial maximum corona multiplied by a factor of 10. These densities are about a factor of 2 higher than for optically observed streamers.

A moving Type IV burst was observed on August 11; it was associated with a west limb flare in the same active region that produced the Type III bursts. This event was observed both at Clark Lake and at HAO Boulder, with fringe orientations that differed by about 39°. By combining observations, the two-dimensional position and velocity of the source could be estimated throughout the whole event. The source appeared to move out at a velocity of 1400 km/s along essentially a straight line inclined at an angle of 32° north of the solar radius through the position of the flare. It reached a maximum altitude of 6.3 $R_\odot$ above the center of the sun, then moved inward at a velocity of 380 km/s to 5.4 $R_\odot$, where it stabilized and remained until the end of the event. The motion and maximum altitude correspond well with those of several Type IV sources studied by Weiss at 40 to 70 Mc/s and also with events observed by Kundu and Firor at 87 Mc/s. The brightness distribution in the observed source can be approximated by the sum of a wide gaussian halo and a narrower core with the shape of the lobes of the array. This result agrees with the findings of Weiss and Sheridan for Type II, III, and IV bursts and of Erickson for Type III bursts.

We should like to acknowledge the careful work of Mr. J. R. Hubbard who obtained the data on which this study was based. Thanks are due also to Mr. J. K. Alexander for helpful criticisms, and particularly to Dr. J. W. Warwick for making his data on the August 11, 1963 event available to us and assisting in their interpretation. This work was supported in part by National Science Foundation Contract No. NSF-GP-3393.

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OBSERVATIONS OF SOLAR CONTINUUM EMISSION AT 26.3 MC/S

DURING THE PERIOD 18-25 SEPTEMBER 1963*

These are observations obtained with the Christiansen-type array at Clark Lake, California (Erickson, 1965). The lobes of the antenna response pattern are spaced 1°.5 apart in the east-west direction and are 10' wide between half-power points. A one dimensional scan of the solar brightness distribution is obtained each time the sun crosses a lobe (this occurs at 6-minute intervals near local noon.)

During the latter part of September 1963 the array was phased to a declination of +7°23', while the declination of the sun varied from +1° 55' on September 18 to -0° 48' on September 25. Therefore, the sun crossed the pattern roughly two hours before and two hours after local noon. In Table 3 are listed the times when the sun was in the beam.

Table 3

Date, September 1963	U. T. When Sun Was in Beam
18	1715-1751, 2127-2203
19	1712-1745, 2133-2206
20	1707-1739, 2139-2211
21	1703-1735, 2141-2213
22	1658-1729, 2147-2218
23	1654-1726, 2150-2222
24	1649-1719, 2155-2225
25	1647-1715, 2159-2227
(Note: Record began at 1715 each day.)	

For each day, there are observations of 26.3 Mc/s radiation associated with McMath plage region 6964. It was possible to determine the east-west position of the radio source with respect to the center of the solar disk by finding the time difference between the calculated lobe passage of the center of the disk and the observed passage of the source.

*Submitted for publication in the Information Bulletin of Solar Radio Observatories

Ionospheric effects, which are difficult to assess, undoubtedly constituted the major source of error in the position measurements. Comparison of the observed positions with the calculated ray paths (see below) indicated that the error at times was as large at $\pm 0.25R_{\odot}$. To eliminate regular spherical refraction from the results as much as possible, an average position was found from the usable lobe crossings two hours before noon (considerably fewer in number) and one for those after noon, and the two were then averaged. The crossings after noon on September 22 showed a large eastward displacement that increased with time, due in all probability to a strong geomagnetic disturbance that was reaching its peak at about that time (2100-2300 U.T.). For this reason only the morning measurements were used in deriving a position for September 22. By comparing the measured positions with the sunspot positions and assuming that the radio source was radially above the sunspot group, corrections were made for projection on the east-west line. Table 4 gives the corrected east-west displacement of the source from the center of the solar disk, the measured halfwidth, the approximate flux, and the intensity assigned by the High Altitude Observatory in Boulder, Colorado (CRPL-F Part B, October 1963) for the continuum emission observed with sweep-frequency equipment from 7.6 to 41 Mc/s on each day.

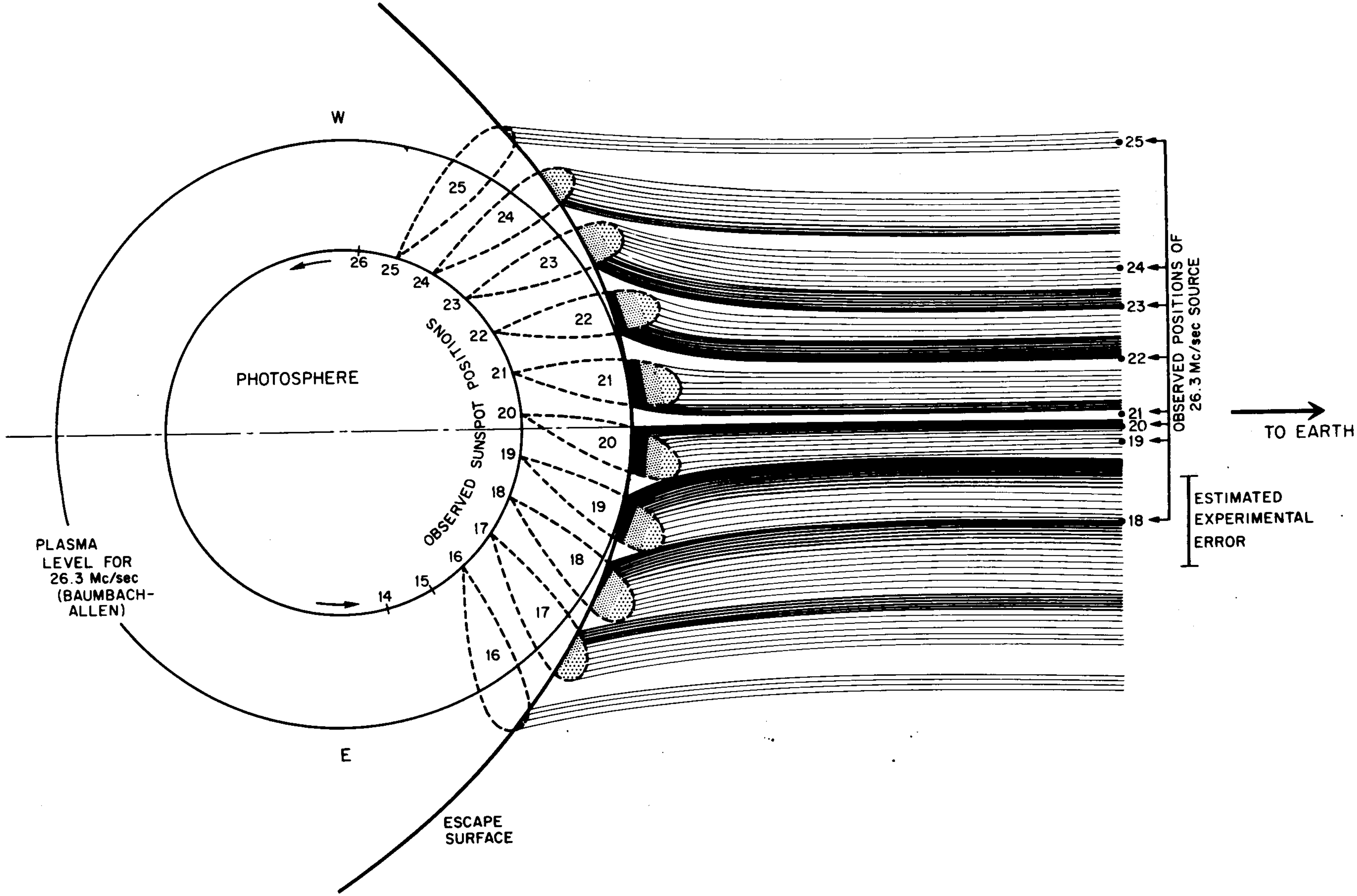
Table 4

Date, September 1963	Displacement ($R_{\odot}$)	Halfwidth ($R_{\odot}$)	Flux $\left[10^{-22}\ w.m^{-2}.(c/s)^{-1}\right]$	HAO Intensity
15	–	–	–	Not detectable
16	–	–	–	1+ (mean)
17	–	–	–	2
18	0.59 E	1.53	> 8.0	2
19	0.16 E	1.52	> 8.2	2
20	0.06 E	1.60	> 8.2	2
21	0.00	1.51	> 8.2	2
22	0.31 W	1.46	> 7.6	2
23	0.60 W	1.44	> 7.7	1+
24	0.80 W	1.30	2.8	1
25	1.50 W	1.23	1.7	1-
26	–	–	Not detectable	Not detectable

The observed positions were all within 1.50 solar radii of the center of the disk and were strongly concentrated to the center. Also, the apparent weakening and final disappearance of the source as its angular distance from the central meridian of the sun became large, required an explanation. An attempt was made to construct a model using the 26.3 Mc/s positions, the spectral data from the High Altitude Observatory, sunspot positions from the solar maps furnished by the Fraunhofer Institut in Germany, and ray paths for 26.3 Mc/s in a Baumbach-Allen corona (Allen, 1947). During the disk passage of the associated optical active region, the High Altitude Observatory recorded continuum emission for essentially the whole observing day from September 16 through September 25, and we rely on the spectral observations for the identification of the emission that we observed on only one frequency. In Figure 12, the source of continuum radiation is depicted as the upper end of a high-density column that originates just above the sunspot group and extends out through the chromosphere and corona to a height of 1.9 solar radii above the center of the sun. The electron density in the column decreases outward, but is always considerably higher than that of the surrounding solar atmosphere. The emission of the continuum radiation is assumed to fall off steeply with height. The solar radius drawn through the top of the column is 11° east of the radius through the corresponding sunspot group, i.e., the column rotates at the same rate as the sunspot group but lags behind.

The width of the column is arbitrarily taken to be about 1/4 solar radius, or 4'. The observed halfwidth of about 1.5 solar radii is due presumably to scattering of the radiation as it travelled through the outer parts of the corona on its way to the earth (scattering is not shown in the figure.) The shapes of the fringes are consistent with this idea in that they appear to be composed of an intense narrow core ($\leq$ the 10' beamwidth of the array) and a fainter, wide halo. This shape appears to be characteristic of most types of solar radio emission at metric and decametric wavelengths (Weiss and Sheridan, 1962; Erickson, 1963; Malitson and Erickson, 1965). The core apparently represents direct radiation from the original source and the halo is formed by the radiation scattered away from the direct path.

The results of observation of the continuum source of September 1963 agree well with those of Le Squeren (1963) from her study of a large sample of noise storms at 169 Mc/s using the Nançay interferometer. To explain the variation of apparent altitude and intensity of the source with displacement from the central meridian of the sun, she also postulated coronal structures that decrease in emissivity with altitude. The directivity of the emission shown by the disappearance of the sources as their associated optical active regions approached the limb was explained, as in our case, by the inability of radiation originating below the escape surface to travel outward and be observed at the earth. In addition, an average eastward tilt of the coronal structures of 10° was deduced from an east-west asymmetry in the intensity of the sources. This is surprisingly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OBSERVED SUNSPOT POSITIONS
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PLASMA LEVEL FOR 26.3 Mc/sec (BAUMBACH-ALLEN)
ESCAPE SURFACE
OBSERVED POSITIONS OF 26.3 Mc/sec SOURCE
ESTIMATED EXPERIMENTAL ERROR
TO EARTH

Figure 12

close to the 11° we found from the time of central meridian passage of the 26.3 Mc/s source compared to that of the associated spot group as well as the times when the source was no longer detectable.

According to the well-known theory concerning propagation of radio waves in ionized media, there should be two rays from each point on an observable radio source to the point of observation. There is a direct ray that is only slightly refracted in its passage outward through the corona, as in our model, and there is a reflected ray that first proceeds inward and is reflected at the reflection surface (identical with the escape surface out to angles of about 60° from the central meridian) and then travels outward through the corona. The deviation of the latter ray is much greater, of course, than that of the direct ray. Le Squeren at first attempted to account for the large observed displacements of the radio sources toward the central meridian by considering only the direct rays, which should strongly predominate in the observed source due to much greater optical depth over the paths of the reflected rays. She found that the densities in the corona would have to be increased by more than an order of magnitude to account for the displacements. This is far larger than anything observed optically, even in coronal streamers, and also leads to an escape surface that would make it impossible to receive radiation from sources fairly low in the corona as close to the limb as they are actually observed. On the other hand, the reflected rays could account for the displacement but there is the difficulty of explaining away the expected predominance of the direct ray unless some kind of preferential inward emission is invoked. The model that is shown in Figure 12 uses only the direct rays and attempts to account for the displacements by the propagation to the earth of rays coming from different parts of the column on different days, depending on its position with respect to the central meridian.

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