SOLAR DECIMETRE RADIO BURSTS

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Summary

High resolution studies (2′ of arc beam) were made with the east-west arm of the Christiansen radio interferometer for about 50 21-cm solar burst events during 1958–1961. The burst sources were always closely associated in position with already existing radio plage regions of the Sun's slowly varying decimetre radiation. They had sizes of from 2 to 5′ of arc, never exceeded but often approached in size their parent plage region, and showed no major movements during their development. Brightness temperatures ranged up to 2×10^9 °K (mostly between 10^7 and 10^8 °K). More bursts were observed near the Sun's centre than near the limb, and more on the western than on the eastern half. There was also a curious "gap" of 30° longitude on the eastern half of the Sun with virtually no burst activity.

I. Introduction

A solar decimetre radio burst is part of a complex of simultaneous or closely successive events which may extend from optical to metre wavelengths in the electromagnetic spectrum, and sometimes involve the ejection of corpuscular streams. The characteristics of burst emission in different frequency ranges differ markedly. Further, in the same frequency range burst sources of different types may be distinguished. The basic observations required to delineate radio-frequency bursts comprise *dynamic spectra*, showing the variation in intensity of emission as a function of both frequency and time; and *high resolution studies* of the position, size, shape, movement, and brightness temperature of the emitting region. For metre wavelengths extensive results of both kinds have been obtained and a fairly well-defined classification of source types achieved. In the microwave range (centimetre and decimetre wavelengths) on the other hand, most observations have been by means of radiometers of low directivity operating at a single frequency. Hence studies of microwave bursts have so far been largely "morphological" in character, attempts being made to found a classification of burst types on the form of the total power record at a single frequency (e.g. Covington 1951; Kundu and Haddock 1961), account sometimes being taken also of the difference in the total power records on opposite polarizations. More recently synthetic dynamic spectra have been constructed with some success by combining simultaneous records from several radiometers operating at different fixed frequencies (Hachenburg and Wallis 1961; Takakura 1960; Takakura and Kai 1961).

Few high resolution observations have yet been obtained for centimetre and decimetre burst sources, though recently Kakinuma and Tanaka (1961) using eight-

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element interferometers operating at 9400 and 3750 Mc/s (both with beamwidth to half-power of 4·5′ of arc) have reported that the burst sources they observed were situated in the lower parts of coronal condensations, near the positions of the associated flares, had angular sizes of from 2 to 4′ of arc, and were almost stationary in position. Kundu (1959) found that most bursts at 3·23 cm wavelength had an extent of less than 2′ of arc.

Here we present the results of observations at 1420 Mc/s of about 50 burst events made during the years 1958–61 using the Christiansen grating interferometer (Christiansen *et al.* 1961) operated, on most occasions, to provide a fan beam with 2′ of arc resolution to half-power points in the east-west direction. The principal aim of the study is to determine typical physical characteristics of the decimetre burst sources: their sizes, positions, brightness temperatures, and movements. These results bear both on the physical nature of the burst sources and on questions of the possible classification of microwave bursts into distinct types (Kakinuma and Tanaka 1961; Takakura and Kai 1961).

In this latter regard it should be noted that the events described in the present paper form a crude sample, presented without any attempt at initial classification. In duration, the activity ranges from short events lasting only a few minutes to recurrent eruptions occupying a period of several hours. The peak emission intensities of the events range from less than twice the previous steady level up to several hundred times this value. The variation in intensity (as seen on a total power radiometer) may be quite smooth and gradual, or show rapid fluctuations; occasionally it was confined to a single, quite sharp spike. A few examples of total power records are shown in Figure 1. It is perhaps notable, in view of this extreme diversity in the morphology of the events, that the present high resolution study has shown on the whole no gross differences between the observed characteristics of different bursts, apart from those already apparent from the record of a broad-beam radiometer.

Eight of the burst events included in this paper are known to have been accompanied by metre wavelength type IV activity, and these have been described elsewhere (Krishnan and Mullaly 1961, 1962). The second of these papers contains fuller details than are given here of the method of reducing the records of burst events. Three rather small bursts, which were followed by apparently stimulated activity in distant parts of the Sun, have also been referred to in a previous publication (Mullaly 1961).

II. Equipment and Manner of Observing

The Christiansen crossed-grating interferometer (Christiansen *et al.* 1961) consists of two 32-element interferometers, one north-south and one east-west. They may be operated together as a cross to give a pencil beam, or separately to provide fan beams to scan the Sun from north to south or from east to west. In all cases the spacing of the fringes is greater than the Sun's angular diameter so that no ambiguity arises from the responses of multiple fringes. Almost all the observations discussed in this paper were obtained using the 32-element east-west arm alone to provide a fan beam with about 2′ of arc resolution to half-power points east-west, and broader than the Sun in the north-south direction. The Sun drifts through successive fringes so that repeated east-west scans are obtained at time intervals of about 4 min. In the absence of burst activity, the most notable features are the peaks due to slowly

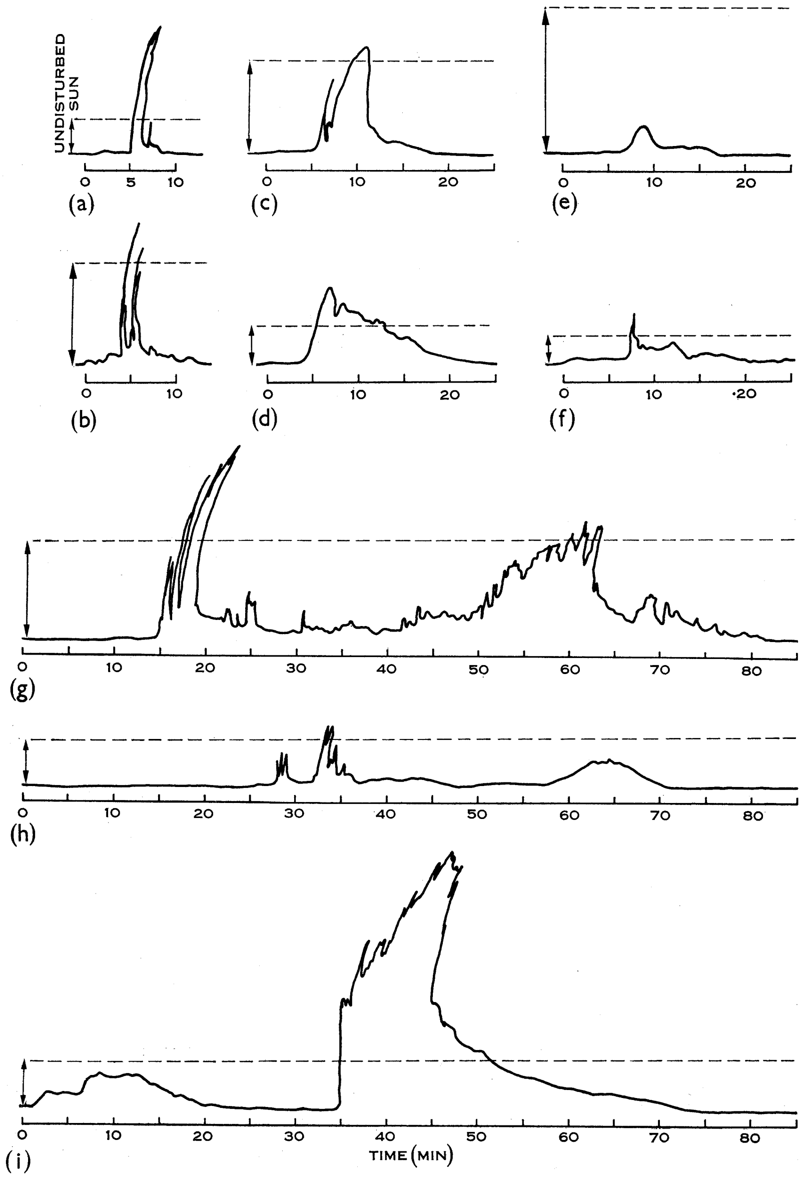

Fig. 1.—Total power radiometer records showing the progress of a number of more or less typical 1420 Mc/s bursts. Note the wide variety of types included in this sample.

varying regions of enhanced radiation ("radio plages"). These relatively stable emitting regions, which are associated with hydrogen plage regions visible optically, have a lifetime often of weeks. Any considerable variations normally show a time scale of at least a few days.

Bursts seem almost invariably to coincide closely in position with an already established radio plage region. On the record a burst is seen as an increase in the height of the peak indicating the radio plage. Because of the method of scanning, the burst is under observation only for a few seconds once every 4 min. With bursts which commence suddenly and reach a high intensity, this has not infrequently resulted in one or more scans being off scale, before the receiver gain was turned down sufficiently.

With the crossed interferometers, and with the north-south interferometer, the interval between successive observations of a point on the Sun's surface is normally much greater than 4 min, and these modes of operation have therefore rarely been used for investigating the progress of a burst.

III. Results

(a) *Position of Burst Centres*

The most noticeable feature in the location of the regions of 21-cm burst activity on the Sun's disk is the constant close coincidence in position of the bursts with already established radio plage regions of the Sun's slowly varying component. Typically the centroids of the burst source and radio plage coincide to within $0'{\cdot}5$ of arc in east-west position. Instances of worse agreement are usually associated with extended and complex plage structures. In no case were the centroids of the burst source and the radio plage found to be more than $1'{\cdot}5$ of arc apart east-west. On the few occasions when bursts were observed with a fan beam scanning the Sun from north to south, or using the interferometers crossed to give a pencil beam, the same degree of coincidence was found in the north-south direction.

The distribution in distance from the central meridian of the positions of the burst sources observed is shown in Figure 2(*a*). Noticeably more bursts are seen near the central meridian than near the limbs. Thus about half of the bursts observed occurred within $\pm 30°$ of the central meridian. A similar tendency has been noted for certain metre-wavelength events (Dodson and Hedeman 1958; Avignon, Boischot, and Simon 1959; Warwick and Warwick 1959; Kundu 1961; Suzuki 1961).

In Figure 2(*b*), where the frequency of bursts is plotted against longitude on the Sun's disk, a measure of east-west asymmetry is apparent. This is more marked if events are included only for the three years 1958–59–60 immediately after sunspot maximum (Fig. 2(*c*)). For this period there are more than twice as many bursts (28) located to the west of the central meridan as there are to the east (13). When the east-west displacements from the central meridian are plotted for all the bursts (Fig. 2(*d*)), it is seen that there is also a large gap, corresponding to longitudes on the Sun's disk from just over 30° to just under 60° E., within which only two bursts in all were observed. If the evidence for asymmetry is substantiated, we would be led to think that the mechanism of decimetre burst emission must involve a polar diagram unsymmetrical in the east-west plane. The statistical significance of the asymmetry we have found is, however, no more than marginal: the probability that not more than 18 out of 46 events, randomly distributed in longitude, should lie in the eastern half of the Sun by chance is

$$\frac{1}{2^{46}}\sum_{r=0}^{18}\binom{46}{r} \simeq 0\cdot 08,$$

so that the significance is near the 10% level.

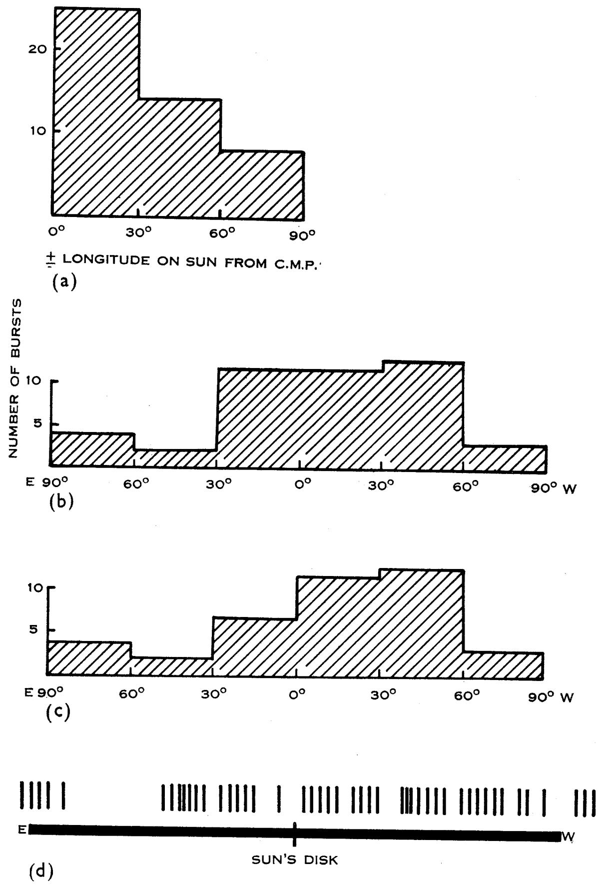

Fig. 2.—Distribution of bursts with longitude on the Sun's disk. (*a*) All bursts showing decreasing frequency towards limbs; (*b*) distribution in longitude for all bursts observed showing disparity between eastern and western bursts; (*c*) distribution of bursts observed during years 1958–59–60; (*d*) apparent east-west positions of individual bursts across Sun's disk.

The striking gap between 30 and 60° E. longitude (Fig. 2(*d*)), within which only two burst sources are located, has a higher significance. If the 46 bursts are distributed randomly in longitude, the probability of not more than two sources occurring within this 30° interval is

$$\sum_{r=0}^{2}\binom{46}{r}\left(\frac{5}{6}\right)^{46-r}\left(\frac{1}{6}\right)^{r} \simeq 0\cdot 02.$$

This probability remains fairly low even when it is considered that a few of the 46 events were associated (arising from the same active region on different days). The suggestion is that decimetre bursts typically have a polar diagram, with two lobes, asymmetrically disposed, as illustrated in Figure 3.

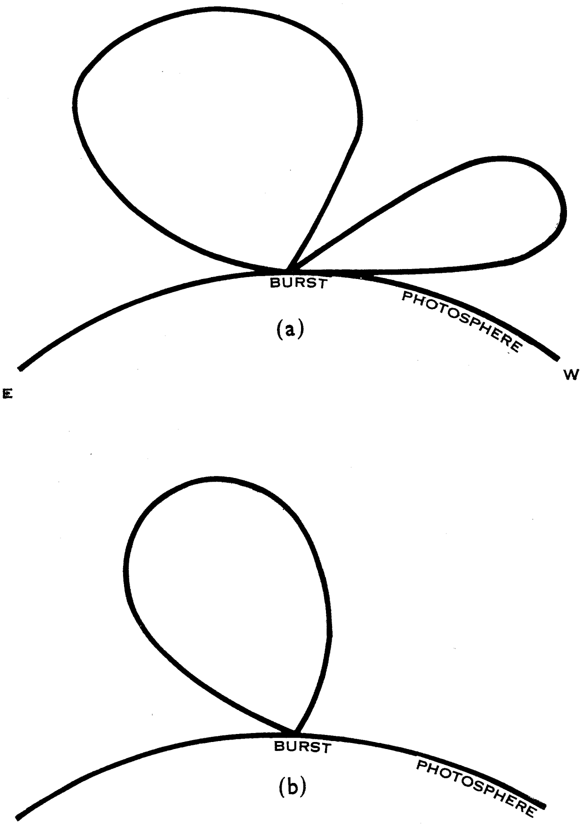

Fig. 3.—Suggested possible types of burst polar diagrams in the east-west plane. (*a*) A double-lobed polar diagram to account for the "gap" with no bursts seen between longitudes 30 and 60° E.; (*b*) a simple polar diagram inclined towards the east to account for the excess of bursts observed on the western half of the Sun.

Evidence for a two-lobe polar diagram for sources of enhanced radiation at metre wavelengths, has recently been reported by Bumba and Olmr (1960) who, observing individual sources, found an average separation of about 45° between the two maxima. The orientation of the polar diagram with respect to the radial direction on the Sun, was, they found, different for different sources.

(*b*) *Angular Sizes*

The half-widths (W) obtained from the east-west fan-beam scans of burst sources were all, with one possible exception mentioned below, somewhat greater than the half-width ($b = 2'$ of arc) of the aerial beam, indicating that the sources possessed finite extension in the east-west direction. Without knowledge of the true form of the source profiles it is not possible to calculate these extensions precisely. What was done was to find the half-widths (S) of an equivalent source of Gaussian profile. Since the beam is itself approximately Gaussian, S is given by

$$S = (W^2 - b^2)^{\frac{1}{2}}.$$

It is known that this formula gives a good approximation for small sources with non-Gaussian profiles.

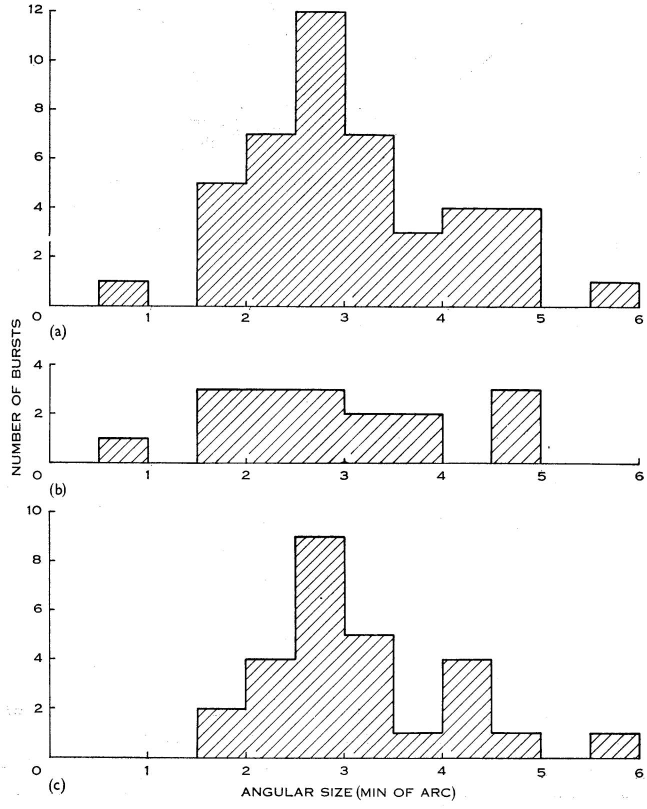

Fig. 4.—East-west angular size of burst sources. (*a*) All bursts; (*b*) bursts on eastern half of Sun; (*c*) bursts on western half of Sun.

In all cases, the half-width W, was measured after subtraction of the east-west profile of the undisturbed Sun. The Sun always returns to substantially the same profile after a burst as before, and this procedure serves to isolate the profile due to the burst source alone. In some cases when a large burst carried the recorder pen off scale, a process of extrapolation by triangulation was employed to estimate the half-width.

The angular sizes (S) obtained by these means are subject to experimental errors which may be estimated in typical cases to amount to from $\pm 0'\cdot 3$ to $\pm 0'\cdot 5$ of arc. In some instances the errors may be rather greater. In particular any large changes in the burst intensity during the few seconds needed for the beam to scan the burst source would invalidate any measurement of half-width. A few cases where this was suspected are excluded from the results given in this section.

The angular sizes found range up to about 6′ of arc, the mean for all events being 3′ of arc. A histogram showing the frequency distribution of the angular sizes for all the bursts measured is given in Figure 4(*a*). Figures 4(*b*) and 4(*c*) show the distributions for bursts respectively on the eastern and on the western half of the Sun.

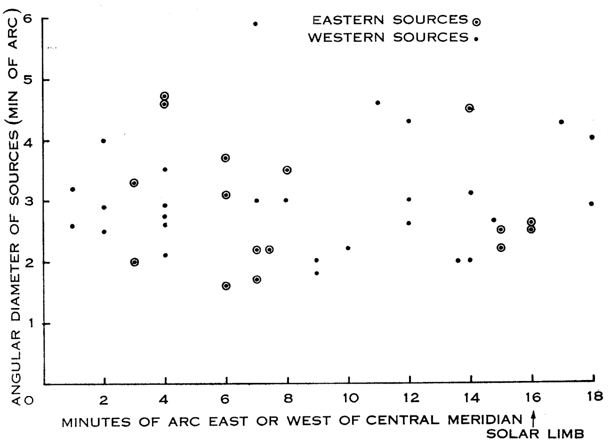

Fig. 5.—Angular size of burst sources plotted against distance from Sun's central meridian.

A scatter diagram of angular size against distance of the source from the Sun's central meridian has been plotted in Figure 5. There is no appreciable difference between the angular sizes of bursts near the Sun's centre and those situated near the limb. If the burst emission originated from a thin plate-like region in the solar atmosphere, we would expect bursts located near the limb, which would be seen edge-on, to have smaller east-west sizes than those near the centre. Similarly, emitting regions in the form of tall columns would have greater east-west extent when seen near the limb. Thus burst radiation would seem to originate from regions with very roughly the same radial as lateral extent. This conclusion, however, can apply only to those burst sources whose polar diagrams permit them to be seen when near the limb.

The smallest angular diameter of a burst source was the value $S = 0'\cdot5 \pm 0'\cdot5$ of arc obtained for a short-lived, fairly intense burst observed near the east limb at about 0055 UT on July 19, 1959. This may, therefore, possibly have been something quite small, almost a point source. On the other hand, since the upper limit on the size was 1′ it may merely have been an unusually small burst source, similar in type to the rest. This event, however, was unusual in another respect: it was the only burst observed which was not clearly associated in position with a radio plage region.

(c) *Changes in Angular Size during the Course of a Burst*

In general, apart from variation in the intensity of emission, burst sources show little change during their lifetime. There have occasionally appeared to be small changes, of the order of $0' \cdot 5$ of arc, in the angular size, but these may, at least sometimes, have been spurious and due to rapid changes in the intensity of the burst emission during the time taken to scan the source. A few instances, however, appear to have been genuine changes in source size. The most notable example was a burst commencing about 0230 UT on April 29, 1960 (Fig. 6). The source initially had an

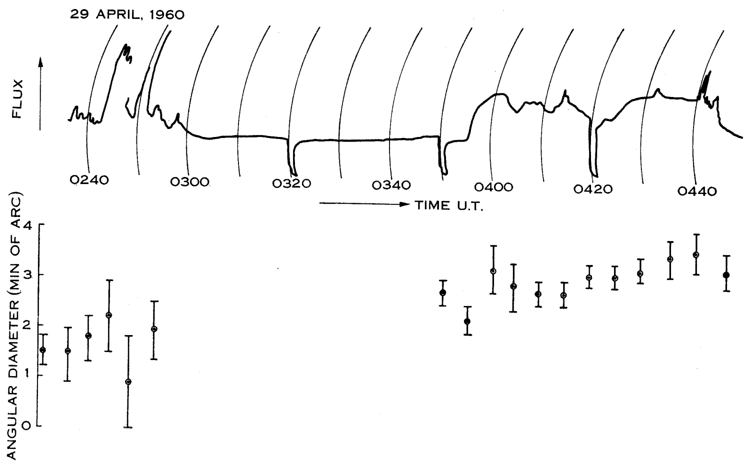

Fig. 6.—Changes in measured angular diameter on successive scans of a burst source observed on April 29, 1960. A rare instance in which there is some evidence of change of size during the progress of burst activity.

angular size a little less than $2'$ of arc. Between 0300 and 0350 UT the eruption was quiescent; about 0350 the activity recommenced, the angular size on the next few scans being variable over the range 2–3$'$ approximately. Then on successive scans the size increased steadily from just under $3'$ to about $3' \cdot 5$. This was quite an intense burst, accompanied by a type IV metre-wavelength event. It was situated about $40°$ west of the central meridian. On one or two other occasions, there is evidence that the size decreased as the event progressed. Thus a very intense burst on July 14, 1959 had an initial stage of very strong emission with an angular size of about $4'$ or $4' \cdot 5$ of arc, followed by a long period of weaker emission during which the size appeared to be about $3'$. There is no evidence of a source initially expanding in size. This may mean that the whole area brightens simultaneously. On the other hand, we have observations only at 4 min intervals, and if there is a *rapid* initial expansion stage (say much less than 1 min in duration) it might have escaped observation on every occasion. Since an average source has a diameter of about $3'$ of arc, or 150 000 km on the Sun's surface, the bright region would have to expand, during such a hypothetical initial phase, at a rate of at least 5000 km/s.

(*d*) *Movements*

No major changes were ever observed in the position of burst sources. Occasionally small movements of the order of 0′·5 or even 1′ of arc were seen. Sometimes these occurred when the intensity of the burst was fluctuating and the movements might consequently be attributed to a change in the centroid of radiation originating partly from the burst source and partly from the underlying radio plage, rather than to a real movement in the source of the burst radiation. On other occasions such an explanation was difficult to sustain and there appeared to be a real

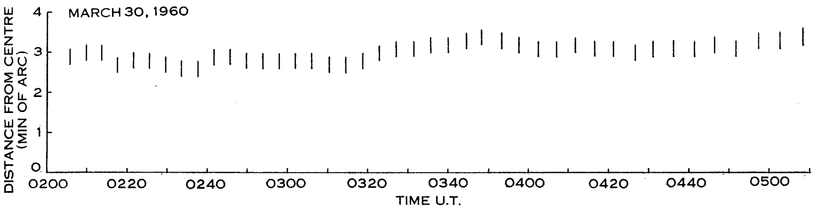

Fig. 7.—Apparent small movements in the centroid of emission during progress of a burst (March 30, 1960). (The values plotted are running means for three successive scans.)

though small movement in the centroid of the source of burst emission. Two of the more notable examples are shown in Figures 7 and 8. (See also Krishnan and Mullaly 1962.) The position typically moves to and fro rather than showing a definite and permanent change from one location to another. Such movements are therefore perhaps due to the brightening or darkening of one part of the burst source relative

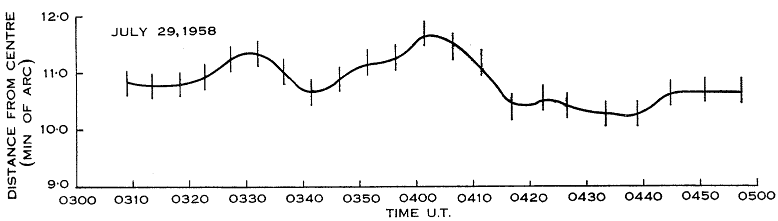

Fig. 8.—Apparent small movements in the centroid of emission during progress of a burst (July 29, 1958). (Running means over three successive scans.)

to another, rather than to a bodily movement in the source region as a whole. Since the burst of March 30, 1960 (Fig. 7) was situated only 3′ of arc from the Sun's central meridian, the movement in this case is not likely to be due to changes in the *height* of the source. The burst on July 29, 1958 (Fig. 8) is much nearer the limb and height changes may more plausibly be suggested here. If this explanation were accepted it would mean that the burst source rose and fell through a height range of about 100 000 km. For what it is worth, the maximum east-west component of velocity thus derived is of the order of 100 km/s.

(*e*) *Brightness Temperatures*

To calculate the brightness temperature (T_b) the sources were assumed to be uniform in brightness and circular in shape, with the angular diameter (S) obtained from the east-west observations. In a few cases when it was not possible to measure S, the mean value for all bursts ($\bar{S} = 3'$ of arc) was employed. The flux (F) due to the burst was obtained either from the Sydney 1420 Mc/s total power radiometer which gave the increase in solar emission due to the burst over the emission of the undisturbed Sun or, for small bursts, by measuring with a planimeter the areas of east-west scans of the Sun before and during the bursts. The flux value for the undisturbed Sun itself was occasionally taken from the Sydney radiometer, but more usually from the 1500 Mc/s flux figures published by the Heinrich Hertz Institute, which were considered more reliable. These values were corrected to 1420 Mc/s, assuming flux to be linearly proportional to frequency. The brightness temperature T_b was calculated from the relation

$$F = 1\cdot 88\times 10^{-27}(S/32\lambda)^2 T_b \quad \mathrm{Wm^{-2}(c/s)^{-1}},$$

where F is the flux density, S the size in minutes of arc, and λ the wavelength in meters.

The peak brightness temperatures obtained for almost 50 events are displayed in the histograms of Figure 9. The lowest peak brightness temperature recorded was 10^6 °K and the highest 2×10^9 °K. Almost two-thirds of the bursts had peak values of T_b within the range from 10^7 to 10^8 °K. Only three events had peak values of T_b less than 4×10^6 °K and only four above 3×10^8 °K. There is little indication in the histograms of Figures 9(*b*) and 9(*c*) of much difference between the eastern and western halves of the Sun, except perhaps for a slight excess in the proportions of eastern bursts with peak values of T_b in the range 10^6–10^7 °K, and of western bursts with values in the range 10^7–10^8 °K. The mean peak T_b for all western bursts ($1\cdot 7\times 10^8$ °K) is, however, almost twice that (9×10^7 °K) for eastern bursts.

No bursts were observed with peak brightness temperatures below 10^6 °K. This apparent cut-off, and the form of the distribution just above it, may be somewhat affected by observational selection: those events with very low values of T_b tend often to be of short duration, and some may have occurred entirely between successive east-west scans, so escaping observation. Neither are small bursts (responsible for increasing the level of the Sun's total 1420 Mc/s emission by less than 1%) easily detected on the records of the total-power radiometer. Not all small bursts are of very short duration, however. Of the two smallest bursts in our sample (each with $T_b = 10^6$ °K), one lasted for over 20 min. The other seems to have been very short-lived; it was seen on only one scan, on which it showed a sharp rise followed by an exponential decay; the inference is that its total duration was only about 10 s.*

Bursts with angular diameters of 2′ of arc or more, could be detected with brightness temperatures of only a few hundred thousand degrees. It seems then that there may be a cut-off and that bursts with peak brightness temperatures much below

* It was impossible to measure the angular size of this burst. The value $T_b = 10^6$ °K was calculated using $S = 3'$ of arc, the mean for all bursts.

10^6 °K do not occur or occur infrequently. On the other hand, such bursts may escape observation by being of very short duration or unusually small angular size. The question of a cut-off is of interest for the discussion of possible mechanisms of production of burst radiation.

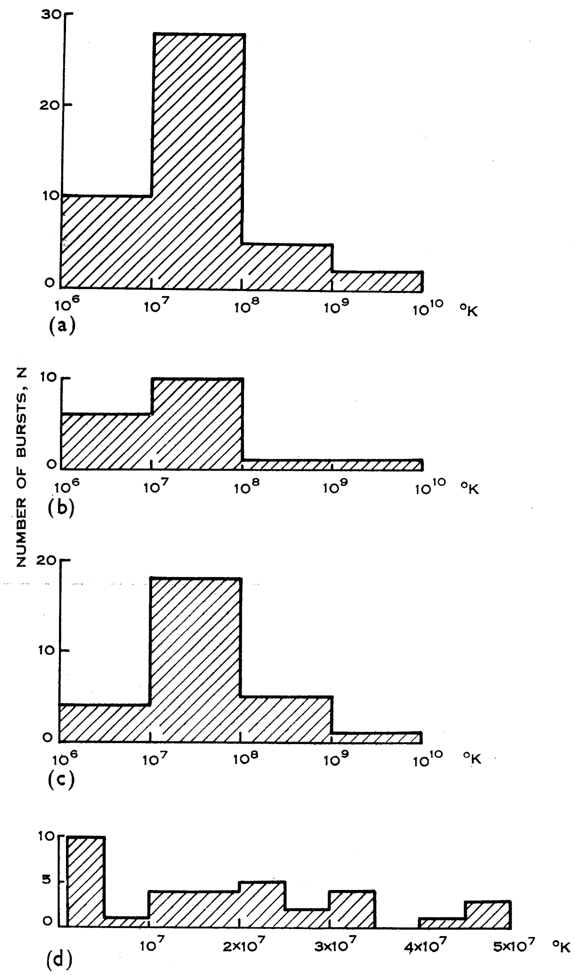

Fig. 9.—Distribution of peak brightness temperatures of bursts observed. (*a*) All bursts; (*b*) bursts located to east of the central meridian; (*c*) bursts to west; (*d*) bursts with $T_b < 5\times10^7$ °K plotted with T_b on a linear scale.

(*f*) *Burst Sources and Radio Plages*

Bursts always, or almost always, occur in the close vicinity of radio plages of the slowly varying component of solar radiation. All radio plages do not, however, produce a burst; a few give rise to several bursts during their lifetime.

Both east-west strip scans and pencil-beam maps of the solar radio brightness were used to measure the diameters for all radio plage regions on which bursts were observed. Such diameters are not always easy to determine at the epoch of sunspot maximum, when a considerable proportion of the Sun's disk is covered by a number of complex and almost touching radio plage regions. In Figure 10 a scatter diagram is plotted showing the relation between the angular diameters of radio plages and of the corresponding bursts. Clearly there is no exact dependence of the dimensions of the burst source on the dimensions of the parent plage region. A considerable number of the burst sources are of about the same size as their parent plages; while the others are smaller. The striking feature, however, is that *none of the burst sources substantially exceed their associated plages in size.*

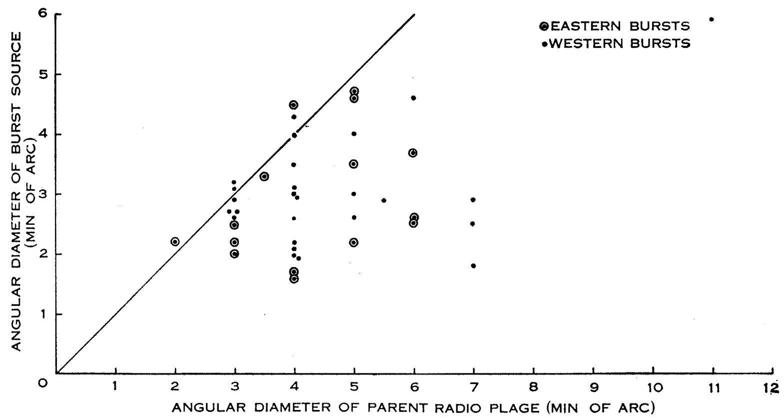

Fig. 10.—Angular diameters of burst sources and angular diameters of their parent radio plage regions. Note that the burst source never substantially exceeds its parent plage in size.

(*g*) *Heights*

In our study of the eight bursts known to be accompanied by metre-wavelength type IV activity (Krishnan and Mullaly 1962) we estimated the heights of the decimetre burst sources above the photosphere on the assumption that they were situated radially above the optical flares. The heights obtained were subject to large uncertainties, but all lay in the range from 0 to 70 000 km above the photosphere—the approximate range of heights within which the radio plages themselves lie (Christiansen and Mathewson 1959; Mullaly and Rome, unpublished data).

The maximum east-west distance found for the centroid of a burst source from the central meridian was 18′ of arc (two cases). This corresponds to a height of 10^5 km above the photosphere (not allowing for refraction effects).

In addition we have taken the 10 burst sources nearest the limb (all within 35° of the limb) and measured their displacement from the position of the parent radio plage. Six coincided with their radio plages within $\pm 0' \cdot 3$ (the approximate limit of measurement), one was displaced towards the central meridian by $0' \cdot 5 \pm 0' \cdot 3$, and three displaced away from the central meridian by about $0' \cdot 7 \pm 0' \cdot 3$. This indicates that the burst sources coincide in height with their parent plages normally within 20 000 km or less, with a slight suggestion that some bursts are higher than their plages by a few tens of thousands of km.

IV. Discussion

We have found the ranges in values of several of the physical properties connected with decimetre burst sources: angular size, position, and brightness temperature. A burst originates from a volume typically 100 or 200×10^3 km in

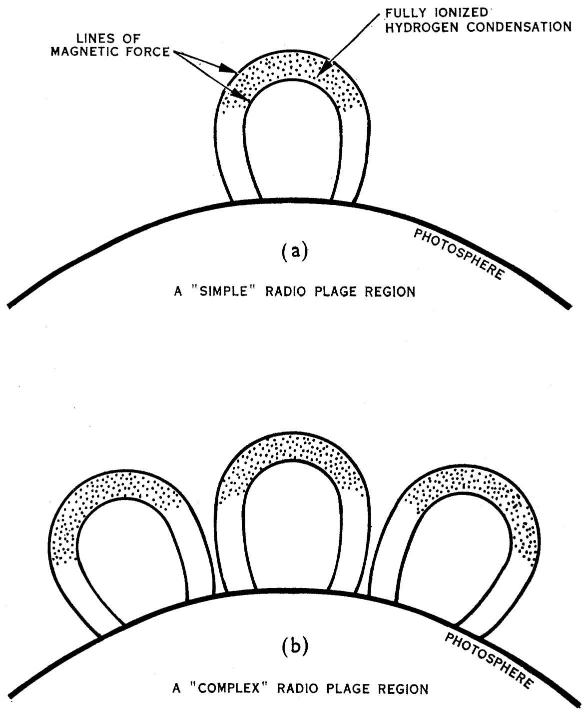

Fig. 11.—Diagrammatic cross sections of radio plage structures with the ionized gas confined by (*a*) one and (*b*) more than one arched magnetic field. It is suggested that a decimetre burst originates from high energy electrons confined by one magnetic arch; so that the burst source cannot be substantially larger in extent than the radio plage, but, if the plage is "complex", it may be smaller.

diameter, and of very roughly the same thickness,* whose centre is situated about 50 or 100×10^3 km above the photosphere. The burst sources coincide closely in position with radio plage regions. A burst source during its lifetime shows no major changes in size or position.

* However, it is necessary to take into account that the sample is inhomogeneous. More bursts are seen near the central meridian than near the limb, and it is possible that thin plate-like regions, which are invisible when situated near the limb, form a subclass which our data ignore.

The close coincidence in position and size of decimetre burst sources with stable radio plage regions is remarkable. The east-west angular diameter of a burst source was never found to exceed the diameter of the associated radio plage by more than the error of measurement. Many bursts appeared to be considerably smaller than their plages, but we should remember that a radio plage, especially in the years near sunspot maximum, is often a complex structure. It consists of condensations of fully ionized hydrogen confined, no doubt, by strong magnetic fields. A "simple" radio plage might be thought of as a single arched field configuration confining ionized gas (Fig. 11(*a*)). If two or more "simple" plages are in close juxtaposition (Fig. 11(*b*)) we have a "complex" radio plage. Electrons trapped in one arch of such a complex plage would be virtually isolated from the adjacent arches, since the conductivity across the field is very low. On the basis of this picture, admittedly oversimplified, it may be suggested that the volume from which burst radiation is emitted coincides with one arch of a radio plage. The emitting electrons, whether the plage electrons in a more energetic state or additional injected electrons, would be confined by exactly the same field as limits the radio plage itself.*

There is naturally no evidence as to the polar diagrams of individual bursts, but this statistical study suggests that, on the average, the burst radiation has a definite directional pattern. Thus radiation might be concentrated into a cone, the axis of which is tilted to the east, so that more bursts on the western half of the Sun are seen (cf. Fig. 2(*b*)). There is also the very curious gap in sources on the Sun's disk between 30 and 60° E. longitude, which appears to be statistically significant. This might require a polar diagram with two lobes (Fig. 2(*a*)). These features, if substantiated, await explanation in terms of the mechanism of burst emission.

The high brightness temperatures that are observed at times are of interest. It is difficult to account for temperatures of the order of 10^8 °K on the basis of thermal emission alone.

Two mechanisms of decimetre burst emission have been suggested, classical radiation from high energy electrons ("synchrotron" radiation) (Takakura 1960) and thermal or quasi-thermal radiation with bands of weak synchrotron radiation superimposed (Hachenburg and Wallis 1961). The dissimilarity between the properties of radio plages, where the burst emission originates, and those of the bursts is striking: the temperatures of the latter are much higher and their polar diagrams complicated. It seems therefore that there must be a basic difference in the mechanism of emission between bursts and radio plages. It is not possible to distinguish between the two mechanisms of burst emission from our results, but it is clear that the existence and configuration of a magnetic field plays an important part in the generation of burst emission at 21-cm wavelength.

* In the attractive theory of the origin of flares and bursts proposed by Gold and Hoyle (1959) the magnetic field should change at precisely the time of a burst event. Since, however, a radio plage is almost always exactly the same in appearance before and after the occurrence of a burst, such a modification of the field, if it happens, cannot cause any major redistribution of the electron condensation.

V. Acknowledgments

The observation of these bursts over several years has involved many colleagues. In particular, we would like to thank Mr. C. Turrall, who not only maintained the equipment throughout this period but was also responsible for many of the observations. Dr. Pawsey has always given us the benefit of his interest and critical advice. Mr. J. P. Wild and Mr. N. R. Labrum read the manuscript. Mr. Labrum was also actively associated with this work throughout.

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VI. References

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