THE DECIMETRE WAVELENGTH RADIATION ASSOCIATED WITH TYPE IV SOLAR RADIO BURSTS*

By T. Krishnan† and R. F. Mullaly†

Summary

Results are presented of high-resolution studies made with the Christiansen grating interferometer of eight 21-cm burst events known to coincide with type IV metre-wavelength events. The decimetre wavelength sources remained in the lower corona in regions widely separated from the sources of simultaneous metre-wavelength emission. Physical measurements of the eight decimetre sources are also given : brightness temperatures (10^7 to 10^9 °K), apparent diameters (2 to 5' of arc) and heights (approximately 50,000 km above photosphere).

I. Introduction

Flares of importance two or more are often associated with intense bursts of radio emission over a very wide range of frequencies ; they have been observed from 1 cm wavelength to about 15 m. The study of this emission is of great importance for the understanding of the physical processes in the chromosphere and corona accompanying important flares. In the metre wavelength part of the spectrum, the radio spectrograph has led to the identification of some five types of radiation, and together with interferometer studies of the position and motion of the sources has suggested important ideas on the emission mechanism (Wild 1960). A particular type that is of great interest is the type IV radiation which is characterized by intense continuum emission in the metre wavelength spectrum, and the source of which is known on occasions to move out in the solar corona to distances of the order of two solar radii at velocities of the order of 1000 km/s (Boischot 1958 ; Wild, Sheridan, and Trent 1958). This type IV radiation is also known to be closely connected with geomagnetic disturbances (McLean 1959). Spectrographs are only just coming into use at decimetre and centimetre wavelengths, and our knowledge of the details of the burst emission in this range is correspondingly inadequate, though mention must be made of spectral models constructed by Japanese workers from total flux measurements at a number of fixed frequencies in the decimetre and centimetre spectrum (see e.g. Takakura 1960).

Takakura, in his spectral model, appears to suggest that the broad-banded component associated with centimetre and decimetre radiation is an extension of the type IV continuum to higher frequencies. It is desirable to investigate the physical features of the decimetre and centimetre radiation accompanying a metre wavelength type IV burst before accepting such a suggestion. Our investigation does not, in fact, support it.

Observations have been made in Sydney over the period 1958–60 with a highly directive interferometer operating at 1420 Mc/s, and in this period about 35 burst events have been recorded. Further, observations of burst spectra in the range 40–240 Mc/s, and of apparent position in the lower part of this range have also been made. This paper describes a study of eight of the 1420 Mc/s events which occurred at the same times as type IV bursts recorded on the metre wavelength equipment. It has been possible to derive important information on physical features of the decimetre radiation, such as the size, position, and brightness temperatures of the burst source. A comparison of the decimetre with the metre wavelength radiation is made, and the positions compared with the optical position of the accompanying flare, leading to a measure of under-standing of the association between the decimetre wavelength burst, the Hα flare, and the metre wavelength type IV radiation.

II. Equipment

The basic observations discussed were obtained using the 64-element crossed-grating interferometer at 1420 Mc/s operated at Fleurs, near Sydney (see Christiansen *et al.* 1961), which consists of two 32-element arrays in the north-south (N.-S.) and east-west (E.-W.) directions respectively.

While the instrument is normally used as a cross to obtain two-dimensional brightness distributions on the Sun, it is possible to use each array independently as a one-dimensional instrument. Most observations of bursts were obtained with the E.-W. array, which has a beamwidth in the E.-W. direction of 2′ of arc at the zenith, and is broader than the Sun in the N.-S. direction. The array produces multiple responses separated from each other by an angular distance greater than the diameter of the Sun, which can thus be scanned at time intervals of about 4 min with a fan beam. Figure 1 shows some typical records. The top curves show two adjacent scans when the Sun was undisturbed, the humps being due to scanning the " radio plages ", the bright areas that are the origin of the slowly varying component. In the absence of burst regions these traces are always closely identical. When there is an Hα flare there is a local enhancement of radio emission, as illustrated in the lower curves. Further, the position of this enhanced radiation closely coincides with that of the pre-existing radio plage. As can be seen from the figure the amplitude of the burst regions is highly variable from scan to scan. It is possible to obtain the position and size of the burst region accurately by subtracting on every scan the amplitude of the undisturbed Sun.

The array observations were supplemented by two other instruments :

(*a*) A total power radiometer, of low directivity, which gives a measure of the flux at 1420 Mc/s and its variation with time ; a typical record obtained from this instrument is shown in Figure 2.

(*b*) A dynamic spectroscope covering all frequencies between 40 and 240 Mc/s and a swept-frequency interferometer (range 45–60 Mc/s) operated at Dapto, N.S.W. (see Wild, Sheridan, and Neylan 1959) ; the latter instrument gives measures of the position of the metre wavelength source with time and frequency.
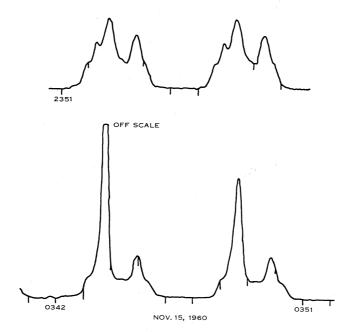
T. KRISHNAN AND R. F. MULLALY

Fig. 1.—Typical records of the Sun obtained with the 32-element east–west array providing a fan beam with 2′ of arc E.–W. resolution. Above are two successive scans of the undisturbed Sun, and below two scans during a period of burst activity.
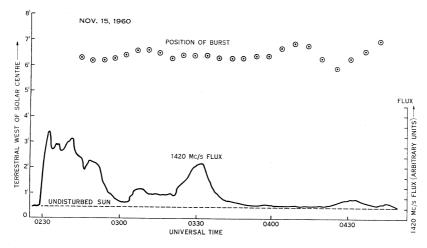

Fig. 2.—The variation in the total flux at 1420 Mc/s from the Sun during a period of burst activity (below), and the simultaneous small apparent east–west movements in the position of the burst source (above).

III. The Observations and Their Analysis

In order to avoid presenting a wealth of detail, we shall illustrate the method of analysis used with the typical observations obtained for one day, November 15, 1960.

(a) *The Position of 1420 Mc/s Burst Sources in Relation to that of the Chromospheric Flare*

The interferometer records were taken at intervals of four minutes almost from the start of the flare. The position of the centroid of the burst region can be estimated with an uncertainty of less than 20″ of arc. If this is done for a number of successive scans (Fig. 2) it is clear that no large-scale motion of the
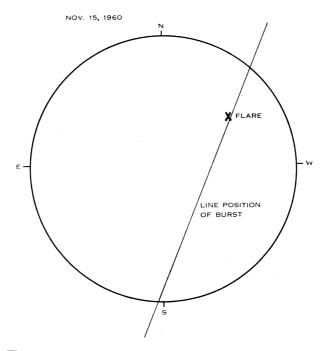

Fig. 3.—The position on the Sun's disk of the 21-cm radio burst and of the simultaneous Hα flare for November 15, 1960.

burst source occurs even at times when the total power record indicates great changes in the burst intensity. Plots of the position for the seven other days are closely similar. Small changes in position are sometimes noticed, but these never exceed 1′ of arc.

Figure 3 shows diagrammatically the position of the optical flares and the line on which the burst source was located. Burst sources have sometimes been observed on other occasions with the instrument operated in two dimensions, and there seems little doubt that the burst source is located very close to the flare region.

From the line position obtained for the burst (account being taken of the angle between the Sun's axis and the direction of scanning at the time of observa-

TABLE 1

Date	Position of Flare	Class	Duration	Metre Wavelength Activity	1420 Mc/s Source			
					Height over Flare (km)	±Error (km)	Average Size	Peak Obsd. Brightness Temp. T_b
7.vii.58	26 °N., 9 °W.	3+	0039–0324	III II IV	0	70 000	4'·0	$4·5 \times 10^7$ °K
29.vii.58	14 °S., 43 °W.	3	<0303– 0303–0359	II IV	20 000	12 000	4'·6	$2·0 \times 10^7$
22. x.58	5 °S., 22 °W.	2	2318 2333– >0006	II IV	29 000	24 000	2'·6	$6·4 \times 10^8$
30.iii.60				II IV			<2'·0	$>8·0 \times 10^7$
29.iv.60	12 °N., 19 °W.	2	0140– >0549	III IV	−12 000	24 000	<2'·0	$>5·0 \times 10^8$
11.xi.60				III II IV			2'·9	$2·0 \times 10^9$
14.xi.60	29 °N., 19 °W.	2	0246–0520	III IV	90 000	45 000	2'·7	$5·0 \times 10^8$
15.xi.60	26 °N., 35 °W.	3	0207–0427	II IV	6 000	24 000	3'·0	$3·0 \times 10^8$

tion), it is possible to derive the height of the burst region above the Hα flare, on the assumption that the burst lies radially above the flare. Figure 4 illustrates the method. If Y and X+Y respectively denote the perpendiculars from the centroid of the Hα flare, and from the centre of the Sun's disk to the line position of the burst, it is clear from the geometry that, if the burst is radially above the flare, the height of burst above flare is given by $h=R_\odot Y/X$ where $R_\odot$ is the solar radius. The position of the flare was taken as that given for the centroid in the Fraunhofer Institute maps. During the day, the scanning angle varies,
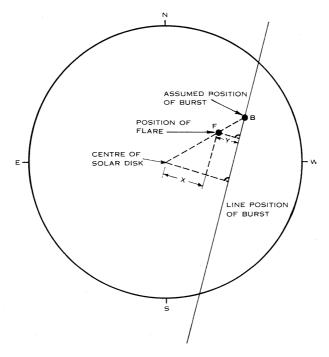

Fig. 4.—Illustrating the method of obtaining the height of a burst source above the Hα flare, assuming the burst is radially above the flare.

but no large changes were found in the apparent height. The mean height for each day is shown in Table 1, with the estimated limits of error. These errors are large and arise from the experimental uncertainty in the position of the burst centroid, from the finite extent of the Hα flare, and from the possibility that the burst may be situated not quite radially above the flare. As illustrated in Figure 5, when Y is plotted against X, all the heights obtained seem to be less than 35,000 km except for one day when the active region was close to the central meridian where the method gives an insensitive measure of the height. Despite the comparatively large uncertainties, we can conclude with certainty that the regions of origin of 1420 Mc/s bursts are situated in the lower solar atmosphere and not in the upper corona.

(b) The Sizes and Brightness Temperatures of the Burst Sources

Knowing the beamwidth b of the fan beam to be 2' of arc in the E.-W. direction it is possible from the halfwidth W of the burst source to estimate its size. The formula

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

is exact for sources of Gaussian profile scanned with a Gaussian beam, and is known to give a good approximation for *small* sources of other profiles.

No substantial change in size is found throughout the whole event for any of the 8 days. The average sizes obtained are shown in Table 1.

In calculating the halfwidths of the burst region, the responses due to the underlying radio plage regions have been subtracted. In cases where the deflection of the pen-recorder carried the trace off scale a method of extrapolation
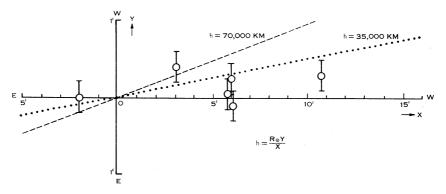

Fig. 5.—The heights of 21-cm burst sources above the associated Hα flares for six events. The vertical lines indicated the assigned limits of error.

by triangulation was employed with an error margin which we estimate as $\pm 10\%$ (from trials on burst peaks which were on scale). In all cases of doubt every attempt was made to err on the side of larger sizes so that *lower* limits of brightness temperatures might result.

In two instances the source was not resolved by the 2' of arc beam, and here again lower bounds of brightness temperatures were derived. As we have pointed out, the decimetre emission at 1420 Mc/s accompanying the continuum phase of metre wavelength activity is the main interest of this study. We have therefore chosen the scan at 1420 Mc/s which has the largest burst amplitude, concurrently with the metre wavelength continuum, to estimate the peak observed brightness temperature.

In calculating the brightness temperatures the assumption was made that the burst regions were circular in shape, with the sizes derived from E.-W. observations. Occasional observations taken with the N.-S. interferometer showed that their extent in the N.-S. plane was not dissimilar from their E.-W. size, so that this assumption seems reasonable.

Table 1 shows for each burst the peak brightness temperatures obtained from the relation

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

The values of flux (F) taken for this purpose were derived as follows. Sydney 1420 Mc/s total power records were used to obtain the proportional increase in flux, due to the burst at its greatest amplitude, over the flux from the undisturbed Sun before the burst. Since the calibration of the Sydney radiometer was unreliable, the values used for the 1420 Mc/s flux were corrected using 1500 Mc/s values for the undisturbed Sun (published by the Heinrich Hertz Institute) assuming the flux to be linearly proportional to frequency. These 1500 Mc/s values were taken as a good long-term measure of the total flux. They have been used in a similar fashion to correct 1420 Mc/s flux values in other work published from this laboratory (Labrum 1960 ; Krishnan and Labrum 1961).

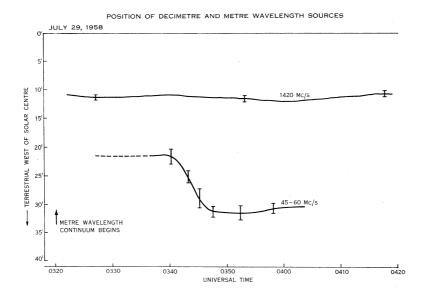### (c) Comparison with Metre Wavelength Positions

Directional observations of the metre wavelength continuum radiation have shown that at times there is a large-scale movement of the source of the radiation at an early phase in the development of the continuum (Wild, Sheridan, and Trent 1958). Boischot (1958) has observed similar movements at 169 Mc/s, typically outwards from the Sun to about two solar radii. It has been suggested that this type IV radiation might be of the synchrotron type.
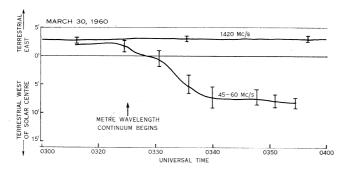
In order to see whether such movement might be present at decimetre wavelengths, we compared the positions of decimetre sources with the metre wavelength positions. This comparison was possible only for three of the days when complete interferometer records, covering the early phase of the type IV event, were available on both frequency ranges.

Figure 6 shows the results for the three days. The displacement of the burst source from the middle of the Sun along the scanning direction is plotted against time. The observation of the position at metre-wavelengths was made at four different frequencies (45, 50, 55, and 60 Mc/s) and we have plotted the mean positions. No systematic difference between positions derived at these differing frequencies was noted. The vertical lines indicate the spread over the frequency range at any time. The positions of the metre and decimetre wavelength sources are seen to differ substantially.

Apparent large-scale movement of the metre wavelength source ($\sim$10′ of arc) can be clearly seen on two of the days—July 29, 1958 and March 30, 1960. However, such movement is not invariably observed, as is shown by the plot for November 15, 1960.

On the two days when large-scale movement is observed, no such movement is to be seen at all at the decimetre wavelength of 1420 Mc/s. It is not possible to state unambiguously that *no* source moves outward from the Sun at decimetre wavelengths ; the limit is set by the masking effect of the main burst seen in the side lobes of the instrument (estimated at about 2–3 %). If the brightness temperatures calculated for these days as shown in the table are taken into account, and the size of any escaping source is taken to be the same as that of
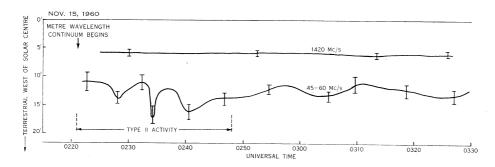
Fig. 6.—The east–west positions of 21-cm and of simultaneous metre wavelength burst sources for three events.

the parent source, it can be said that no source with a brightness temperature greater than about 10^6 °K is seen to move out at 1420 Mc/s. In fact, in none of the 35 burst events observed is there any evidence for a decimetre wavelength source in the high corona.

IV. Conclusion

The brightness temperature of the 21-cm burst sources concurrent with type IV events are typically 10^8–10^9 °K. Owing to the tendency for the opacity to decrease with increasing temperature, these brightness temperatures, if the emission is of thermal origin, would require considerably higher electron temperatures. The thermal generation of such temperatures seems unlikely in the chromosphere : *some non-thermal mechanism is suggested.*

The 21-cm bursts have their origin in the chromosphere or lower corona ; simultaneously metre wavelength sources are often observed at much greater heights. No large-scale movement of the 21-cm burst sources is found to correspond with the rapid outward motion of some metre wavelength type IV sources. *The decimetre and metre wavelength emissions are therefore produced simultaneously in widely separated regions of the solar atmosphere.*

If any sources of 21-cm radiation at the position of the metre wavelength sources *do* exist, their brightness temperature must be less than 10^6 °K. Since Boischot (1958) quotes typical brightness temperatures of 10^{10} °K for a moving type IV source at 169 Mc/s, it would appear that, *if metre wavelength type IV emission is synchrotron in origin, the high-frequency cut-off of this emission is situated well below 1420 Mc/s.*

It is clear that the decimetre radiation, which is known to be broad-banded, cannot be described simply as an extension of the metre wavelength type IV continuum.

V. Acknowledgments

The authors wish to thank Mr. J. P. Wild for placing some of his observational material at their disposal and for valuable discussions.

Dr. Pawsey's consistent encouragement and advice were invaluable.

Our thanks are also due to Miss J. Todd and Mr. J. Healey, who did much of the computing work with cheerful efficiency.

VI. References

BOISCHOT, A. (1958).—" Paris Symposium on Radio Astronomy." (Ed. R. N. Bracewell.) p. 186. (Stanford Univ. Press, 1959.)

CHRISTIANSEN, W. N., LABRUM, N. R., MCALISTER, K. R., and MATHEWSON, D. S. (1961).—*Proc. Inst. Elect. Engrs.* **108B** : 48.

KRISHNAN, T., and LABRUM, N. R. (1961).—*Aust. J. Phys.* **14** : 3.

LABRUM, N. R. (1960).—*Aust. J. Phys.* **13** : 700.

MCLEAN, D. J. (1959).—*Aust. J. Phys.* **12** : 404.

TAKAKURA, T. (1960).—*Proc. Astr. Soc. Japan* **12** : 55.

WILD, J. P. (1960).—Solar radio spectroscopy. *Nuovo Cim.* (In press.)

WILD, J. P., SHERIDAN, K. V., and NEYLAN, A. A. (1959).—*Aust. J. Phys.* **12** : 369.

WILD, J. P., SHERIDAN, K. V., and TRENT, G. H. (1958).—" Paris Symposium on Radio Astronomy." (Ed. R. N. Bracewell.) p. 176. (Stanford Univ. Press, 1959.)