THE ASSOCIATION OF SOLAR RADIO BURSTS OF SPECTRAL TYPE III WITH CHROMOSPHERIC FLARES

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[*Manuscript received June* 11, 1957]

Summary

The relationship of radio bursts of spectral type III to solar flares is investigated by comparing simultaneous optical and radio observations. Over 300 flares are examined, 85 per cent. of which are microflares (class 1—). About 20 per cent. of the flares are associated with type III events, while more than 60 per cent. of the bursts recorded occur during the lifetime of a flare. These bursts tend to occur near the beginning of the flare or even to precede it slightly.

The degree of association varies markedly over a period of days. Flares occurring in certain activity regions show a high degree of correlation with bursts, while those occurring in other regions show little or no correlation. The probability of a burst accompanying a flare is greater for larger flares. It is essentially the same for flares on the eastern limb as for flares in the centre of the disk, implying a wide cone of escape for type III radiation. There is an apparent deficit for flares on the western hemisphere. The occurrence of a surge with a flare appears to increase somewhat the likelihood of an associated radio event.

I. Introduction

It has been known for many years that strong bursts of radio emission from the Sun often occur at the time of large solar flares. The work of previous investigators, based on single-frequency radio records, showed that not all flares are accompanied by bursts, but failed to reveal the factors controlling the association (cf. Hey, Parsons, and Phillips 1948; Dodson, Hedeman, and Owren 1953). Wild (1950) classified some bursts associated with flares as being of spectral type II; in bursts of this type the frequency of maximum intensity drifts slowly towards lower frequencies over a period of minutes. In a later investigation, Wild, Roberts, and Murray (1954) reported the occasional association of flares with large groups of bursts of spectral type III, in which the frequency of maximum intensity drifts rapidly towards lower frequencies over a period of seconds. The rapid frequency drift in these bursts has been attributed to the motion of disturbances moving outwards through the Sun's corona at nearly relativistic speeds. In view of the interest in these disturbances and their possible connexion with cosmic rays, it was felt that the relationship of type III bursts to flares required fuller investigation.

In the present paper we report the results of a joint observational programme undertaken for this purpose. Records from the radio spectroscope of the Radiophysics Laboratory have been compared with Hα films of the chromosphere taken simultaneously by the Division of Physics. Because the Sun was under continual optical observation during the period of the radio records the data

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obtained are more complete than those used in previous investigations. Over 300 flares were observed, about 85 per cent. of which were microflares. This may be contrasted with earlier studies which have dealt chiefly with flares of class 1 and greater.

It has been found that type III events, both isolated bursts and clusters, are often associated with the flares, although not all flares are accompanied by bursts and vice versa. The factors chiefly responsible for these differences have not been fully elucidated. Larger flares are more often accompanied by bursts and there is some evidence that the occurrence of a surge with a flare may increase the chance of a related type III event. Moreover it seems that the nature of the activity region in which the flare occurs affects the likelihood of a burst.

II. Observational Material

The cooperative programme of radio and optical observations was undertaken over the period November 1955 to July 1956. In all, simultaneous records are available for a total of 140 hr, recording the occurrence of 308 chromospheric flares and 204 distinctive type III radio events.

(a) *Chromospheric Observations*

The flare records used in this work were obtained with the Hα-patrol camera of the Division of Physics, Sydney (Bray *et al.* 1957) and consist of consecutive 16-mm diameter photographs of the solar disk taken at 30-sec intervals through a Lyot monochromator of bandwidth 0·7 Å. The reduction of the chromospheric records is undertaken by first making positive films of enhanced contrast from the original 35-mm negatives and then using a projection system to display on a screen an enlarged image of the solar disk some 12 in. in diameter. In scanning the film considerable care is taken to locate any chromospheric flares occurring within the period of observation. The apparent area of each flare is measured by comparison against standard figures of suitable shape and size.

For the purposes of the present work a flare is defined as a distinctive temporary brightening of a chromospheric region ; brightness changes considered to be in the form of random fluctuations have not been catalogued as flares. Complex flares occurring simultaneously in the one bright hydrogen region have been regarded as a single flare. Detailed tests have shown that the flare identifications are reproducible by different observers working quite independently of one another. The measured times of flare commencement normally agree to within 1 min, but the finishing times may differ by several minutes as the final fading of a flare is often rather indefinite.

The detection of flares on the cinematographic records becomes increasingly difficult for smaller values of the apparent area. This effect is illustrated in Figure 1 (*a*), which shows the frequency of occurrence of flares of different areas.* As the apparent area becomes smaller the frequency of flares increases rapidly. The sharp drop for very small flares of areas below about 20 millionths of the visible hemisphere is instrumental and indicates the limit of reliable flare detection. It should be noted that the great majority of the flares are in fact micro-

* The relationship between flare area and importance class is given by Ellison (1954).

SOLAR RADIO BURSTS OF SPECTRAL TYPE III

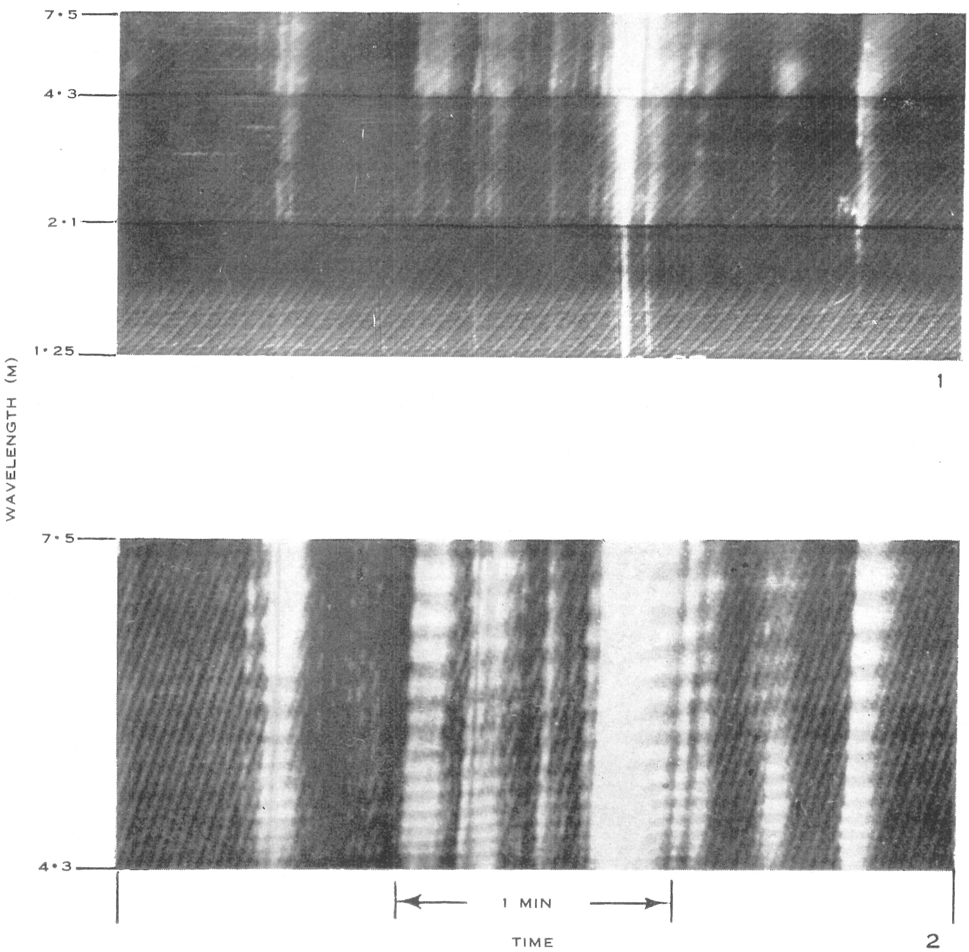
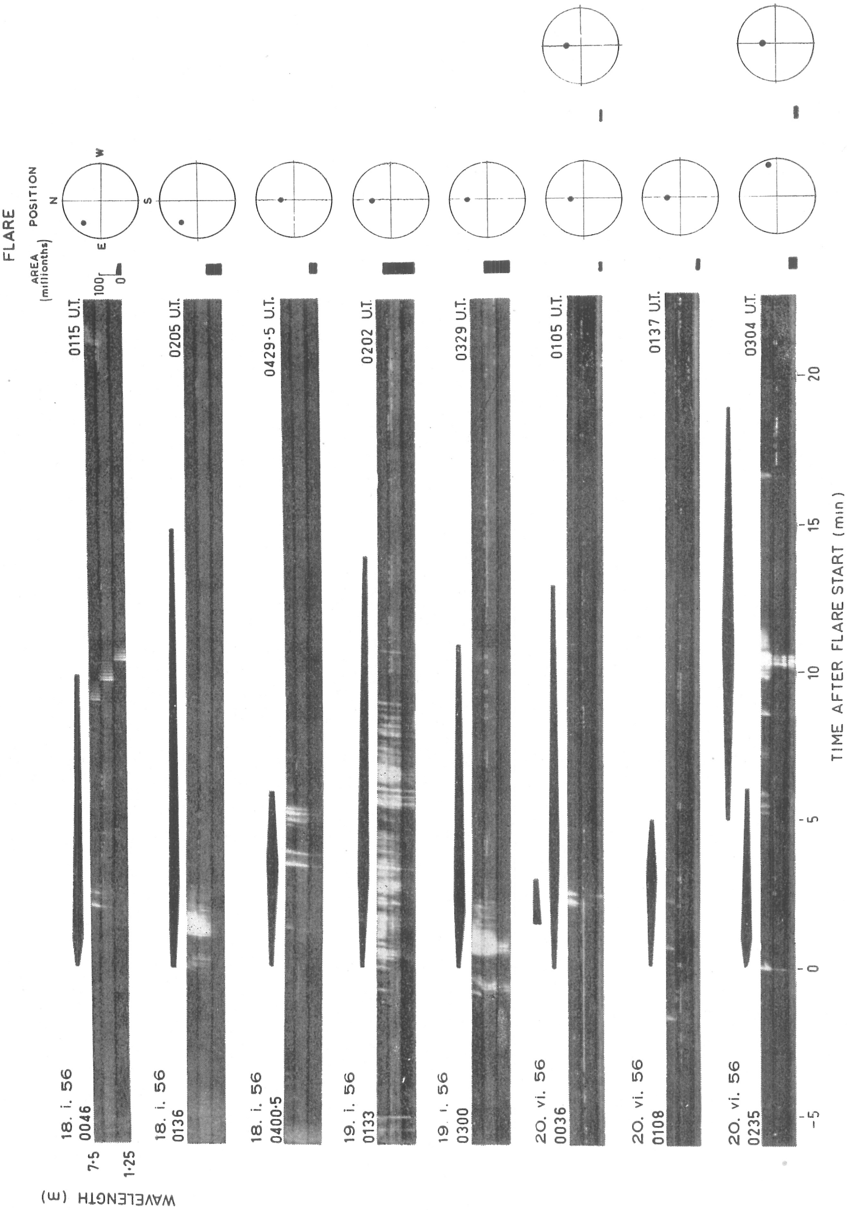


Fig. 1.—Spectrum record of a large group of type III bursts. November 9, 1955, 0223–0226 U.T.

Fig. 2.—Interferometer records of the same group of type III bursts. The minima appearing in the record of each burst are interference fringes, whose wavelengths determine the east-west coordinate of the burst.

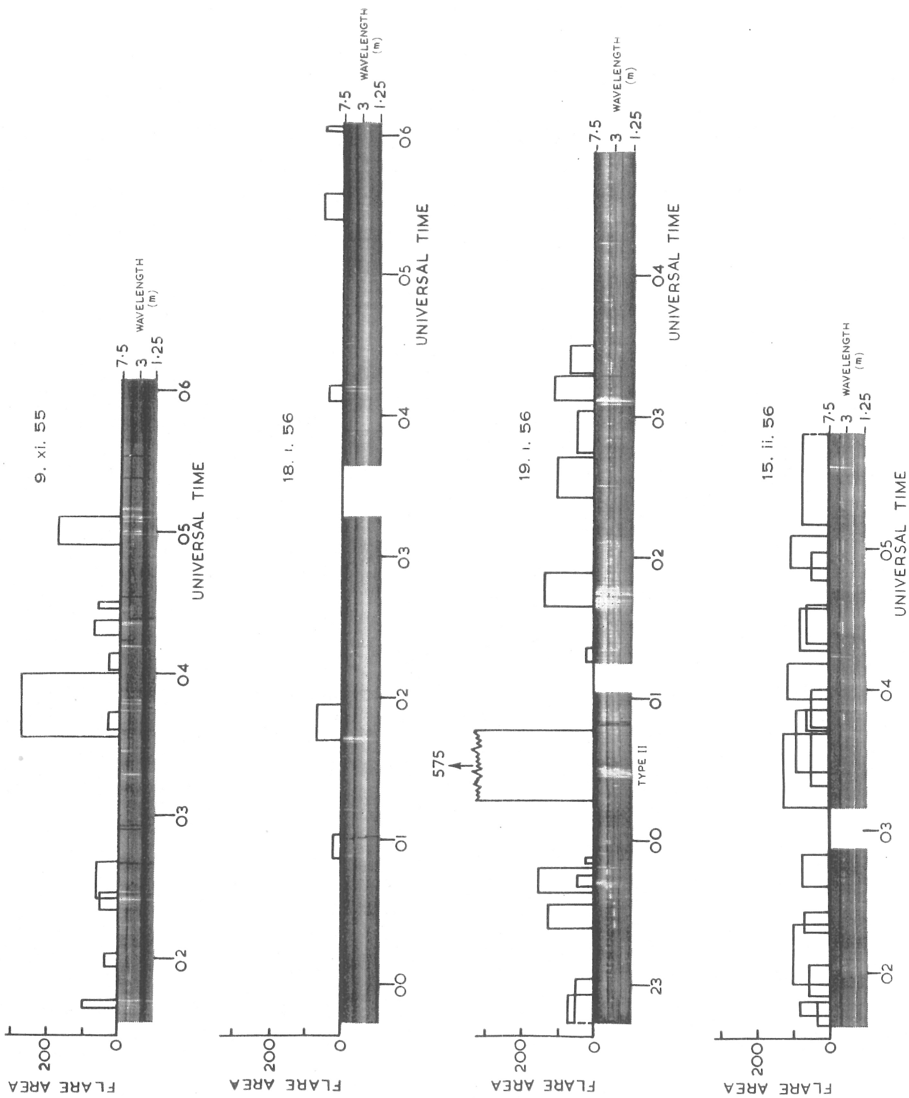
The oblique lines in these records are due to power line interference and should be disregarded.

SOLAR RADIO BURSTS OF SPECTRAL TYPE III



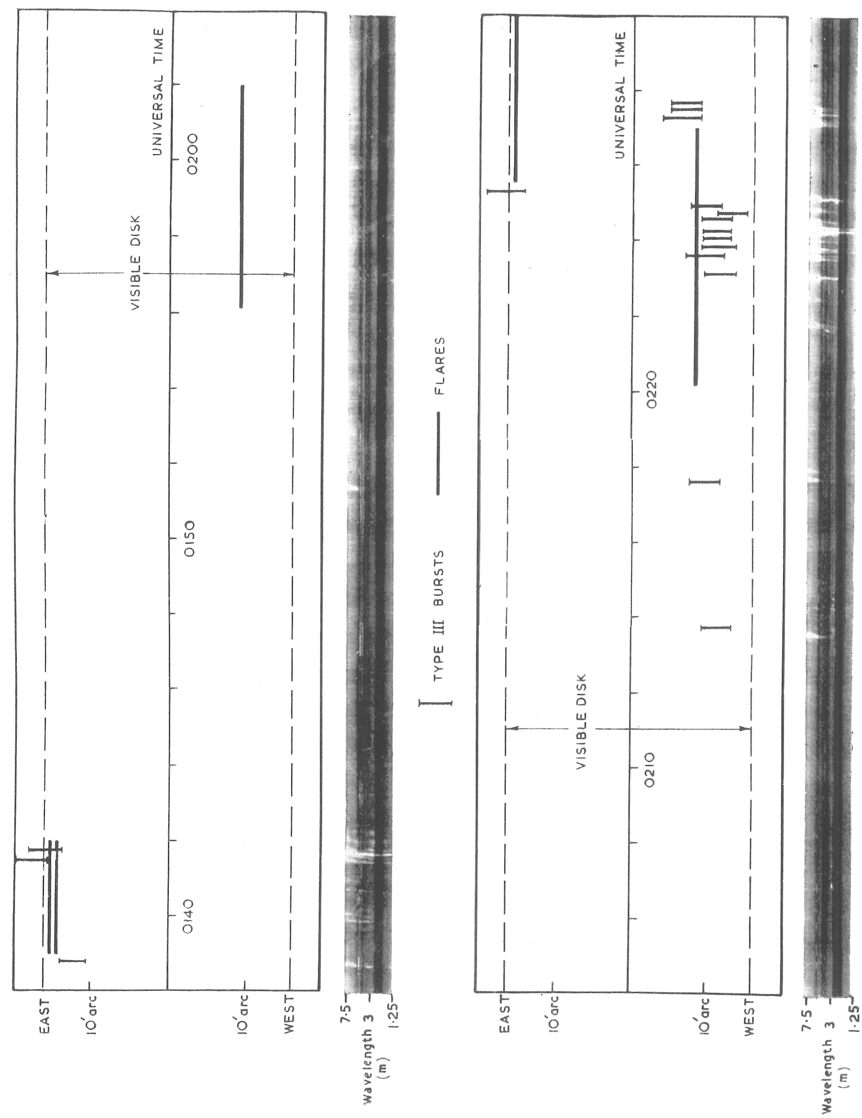
Some convincing examples of associated type III bursts and flares. The duration and time of maximum brightness of the flare are indicated diagrammatically above each radio spectral record. In the spectral records bright lines parallel to the time axis are due to interfering signals and should be disregarded. The brightening near 0102 on January 18, 1956 is an intensity calibration.

SOLAR RADIO BURSTS OF SPECTRAL TYPE III



Intercomparison of optical and radio spectroscopic data.

SOLAR RADIO BURSTS OF SPECTRAL TYPE III



A comparison of the position on the solar disk of the type III bursts and chromospheric flares recorded in the period 0138–0230 U.T. on November 9, 1955. With the interferometer available only the east-west coordinates of the radio bursts could be determined.

flares, whose area, corrected for foreshortening, is less than 100 millionths. Another histogram, shown in Figure 1 (*b*), gives the distribution of flare lifetimes and illustrates the short duration of most of the flares.

(*b*) *Radio Spectrum Observations*

The records of the radio spectroscope (Wild, Murray, and Rowe 1954) are in the form of a succession of radio spectra photographed on continuously moving 35-mm film at intervals of 0·5 sec. Each spectrum covers the frequency range 40–240 Mc/s (1·3–7·5 m) with a bandwidth of 0·5 Mc/s. The sensitivity of the equipment is such that bursts are observed if their flux density (in one plane of polarization) exceeds about 5×10^{-21} W m^{-2} (c/s)$^{-1}$. The quiet Sun is not detected.

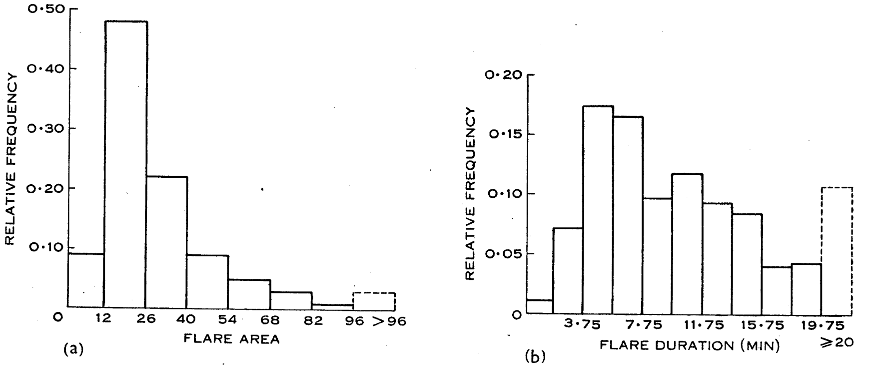


Fig. 1 (*a*).—Histogram showing flare occurrence as a function of apparent area. Areas are measured in millionths of the visible hemisphere.

Fig. 1 (*b*).—Histogram showing flare occurrence as a function of duration.

Bursts of spectral type III may occur isolated, in groups with durations of seconds or minutes, or in storms lasting hours. In Figure 1 of Plate 1 a sample record is given which shows a large group of bursts. All bursts or groups occurring in isolation have been catalogued, but in periods of storm only strong bursts or groups have been listed separately.

(*c*) *Radio Position Measurements*

On three days during the period of the investigation, observations of the position of the radio source were made with a swept-frequency interferometer operating over the range 40–70 Mc/s (4·3–7·5 m) (Wild and Roberts 1956). The interferometer base line is 1 km along an east-west line. Figure 2 of Plate 1 shows the interferometer record of the group of type III bursts whose spectrum is shown in Plate 1, Figure 1. Measurement of the wavelengths of the interferometer fringes allows one coordinate of the burst position to be measured with an estimated accuracy of about ±4 min of arc.

III. Type III Bursts and Flares

An intercomparison of the optical and radio records reveals many cases of a clear association between a flare and a type III radio event. Some convincing examples of this behaviour are shown in Plate 2.

However, there are numerous cases of flares which are not accompanied by bursts and vice versa. This inconsistent behaviour is well illustrated by the sample daily records given in Plate 3. In the first three cases there are many examples of a fairly clear-cut association, but in the fourth case many flares were recorded during a period marked by the almost complete absence of any distinctive radio events. Another striking example of this lack of correlation occurred on June 15, 1956, when 25 flares were recorded over a period of about 4 hr, during which time the only radio event recorded was a single weak burst of unclassified spectral type.

Because of the high rate of occurrence of flares and bursts the association between them can be discussed quantitatively only by adopting some criterion for deciding when a flare and a burst are related. In the present analysis a coincidence has been counted only if the radio event occurs within the flare period ± 2 min. This is a more stringent condition than that used by previous investigators. By comparison Dodson, Hedeman, and Owren (1953) used limits of ± 30 min.

With this definition 30 per cent. of the flares were accompanied by type III bursts. However, this total includes cases where two or more physically distinct flares occurred at the time of the same radio event. By counting such cases as only one association a minimum estimate is obtained for the percentage of associated flares ; this figure is 23 per cent.

If one considers not the proportion of flares which are accompanied by bursts but instead the proportion of bursts accompanied by flares, the percentage of associations is appreciably higher. Both isolated bursts and groups of bursts, irrespective of their intensity, are associated with flares to about the same degree, namely, in 60–70 per cent. of all cases. This tendency for bursts to occur within the lifetimes of flares is statistically very significant, as the total number of coincidences exceeds that for bursts occurring randomly in time by about 10 times the standard deviation.

Further evidence of an association between bursts and simultaneously occurring flares is provided by positional information obtained from radio interferometer observations. Plate 4 shows the positions on the disk of flares and radio bursts for a period of one hour on November 9, 1955. When comparing the occurrence of flares and bursts reference should also be made to the spectrum records included in the plate, as not all bursts have been shown in the positional chart. This evidence suggests that active centres on the Sun may produce flares and type III bursts simultaneously, or may produce one or the other separately.

IV. Analysis of Factors Influencing the Association of Bursts and Flares

In this section we study the influence of some physical factors on the relationship between radio bursts and flares. A quantitative discussion is given on the basis of the definition of coincidence stated in Section III. The ambiguous cases which arise when a radio event occurs during the lifetimes of two or more physically distinct flares have generally been excluded. However, one association is counted in those cases where no ambiguity is involved for the particular parameter under consideration.

(*a*) *Dependence on Flare Area*

The dependence of the degree of association on flare area is illustrated by Figure 2 which shows that the probability of a burst is markedly greater for larger flares. This conclusion is similar to that of Hey, Parsons, and Phillips (1948), who found that for flares of class 1 and greater the proportion of flares accompanied by bursts at 4·1 m wavelength increases with the importance of the flare.

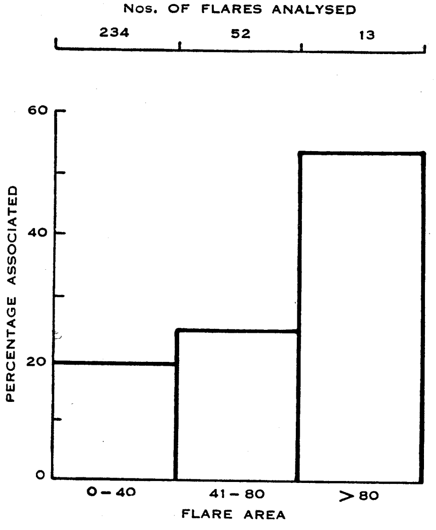


Fig. 2.—Histogram showing the dependence of association on apparent flare area. Areas are measured in millionths of the visible hemisphere.

(*b*) *Dependence on Disk Longitude*

The variation of the degree of association with disk longitude is given in Figure 3. It is evident that the association is independent of the position of the flare on the disk, apart from an apparent deficit for flares on the western hemisphere more than 30° from the central meridian. The occurrence of type III bursts over a wide range of disk longitude implies a wide cone of emission of type III radiation. It is not highly directional as is thought to be the case for type I (noise storm) radiation (Machin and O'Brien 1954).

Hey, Parsons, and Phillips (1948) and Hey and Hughes (1955) have reported an east-west asymmetry for outbursts detected on single-frequency receivers. The western deficit shown in Figure 3 agrees with these earlier results. For the present sample the probability of the results occurring by chance, if the distribution were actually statistically uniform, is of the order of a few per cent.

(*c*) *Temporal Relation of Bursts and Flares*

To avoid ambiguities consideration is restricted to the type III events occurring within the flare period ± 2 min, for flares which are separated in time from other flares by at least 4 min. Of these bursts, 50 per cent. commenced within ± 2 min of the start of the flare. The average duration of the flares is about 8 min, so that type III bursts tend to occur in the early stages of the flare, or even to precede it slightly.

(*d*) *Dependence on Flare Surges*

The chromospheric records used in this work have been analysed by Dr. R. G. Giovanelli in a study of the surges which sometimes accompany chromospheric flares. He has kindly made these results available for an investigation of the relationship between the occurrence of bursts and surges. Of the 48 flares

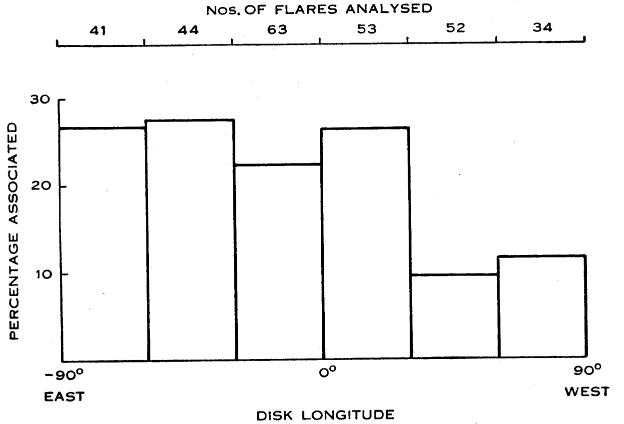


Fig. 3.—Histogram showing the dependence on disk longitude of the association of type III bursts and flares.

accompanied by a visible surge 29 per cent. were associated with a type III event. This is to be compared with an 18 per cent. association for the 246 flares which were not accompanied by a visible surge. These figures suggest that the occurrence of a surge with a flare somewhat increases the likelihood of an associated radio event.

This is evidently not another aspect of the dependence on flare area (see Section IV (*a*) above), as the fraction of the flares accompanied by surges was found to be essentially independent of the area of the flare.

Further work in this direction is clearly desirable.

(*e*) *Dependence on Activity Region*

There is a strong indication that the association of flares and type III radio events depends in some way on the development of the activity region in which the flare occurs. During the period covered by these observations, flares occurring in certain activity regions showed a high degree of correlation with bursts, while those occurring in other regions showed no correlation at all. The result of this is evident in Plate 3, where the association is seen to be very high on some days and very low on others.

Perhaps the most interesting region examined is the one which appeared on the east limb on about June 14, 1956. Of the 12 flares observed in this area prior to June 19 none showed any association with type III events. But on June 19 and 20 about half the flares seen were associated with radio emission. Further flares detected on subsequent days again were not accompanied by radio events.

(*f*) *Relation of Flares to Other Types of Radio Bursts*

During the common observing period many storms of weak type I bursts were recorded. There were five periods during these storms when the activity was strong, and, in addition, there were eight isolated groups of strong type I bursts. Only two of these strong events occurred at the time of flares. Furthermore, in one of these cases (Plate 3, January 19, 1956, 0045–0207 U.T.) the flares were clearly associated with groups of type III bursts, which were far more outstanding than the type I storm. As can be seen from the plate this enhancement in fact follows a type II burst and accompanying class 2 flare, and is apparently related to them. Other examples of such a delayed association are also known.

Earlier evidence has shown that flares often accompany bursts of spectral type II. Of the two bursts of this type recorded during the present investigation, one was associated with a class 2 flare (Plate 3), but the other was not accompanied by a visible flare. This burst was strong and quite typical of the type II class.

V. Conclusion

The radio bursts on metre wavelengths which are associated with chromospheric flares are found to be mainly of spectral type III. Of the present sample more than 60 per cent. of the type III bursts coincide with flares. Bursts of spectral type II are also known to be accompanied by flares, but these bursts are relatively infrequent. Activity of spectral type I does not commonly increase at the time of microflares.

Approximately 20 per cent. of microflares are accompanied by type III bursts, the proportion rising to about 60 per cent. for flares of class 1 and greater. The distribution of associations with disk longitude implies a wide cone of emission of type III radiation. It seems that flares accompanied by a visible surge are somewhat more likely to be associated with a type III radio event, and there is evidence that the likelihood of an association is influenced by the nature of the flare activity region.

VI. Acknowledgments

This investigation has been made possible by the work of many members of the Divisions of Physics and Radiophysics of the Australian Commonwealth Scientific and Industrial Research Organization. Our thanks are due to Mr. G. McMahon, Mr. M. Komesaroff, and Mr. J. Joisce for assistance in the observational programme, and to Mrs. P. Hodgson, Miss P. Williams, and Mr. J. Connolly for their considerable contribution to the reduction of the records.

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