SOLAR RADIO-NOISE OF 200 MC./S. AND ITS RELATION TO SOLAR OBSERVATIONS

C. W. Allen

(Communicated by the Commonwealth Astronomer)

(Received 1947 May 7)

Summary

The solar radio-noise observing programme on Mount Stromlo is described. Daily means of (*a*) steady flux, and (*b*) number of bursts per hour have been plotted against sunspot and geomagnetic data. Both flux level and burst frequency increase during a solar radio-noise storm, and both are closely related to the central meridian passage of sunspots. However, some large sunspot groups do not produce solar noise. No close relation has been found between the emission from the Sun of (*a*) radio-noise, and (*b*) those particles which produce geomagnetic storms.

No close correlation has been found between short period radio-noise phenomena and solar observations, but there are occasional outbursts of solar noise accompanying the commencements of flares. It is suggested that the noise source is located rather high in the corona. The observation of a noise outburst caused by a flare 37° from the main spot group can be explained if the source is more than 120,000 km. above the Sun's surface. Physical arguments lead to a similar height.

1. *Introduction.*—From the time it was announced that solar radiation in certain ultra-short wave radio was far more intense than black body radiation (**1**) at the accepted solar temperature (6000 deg. K.), and that increases were associated with sunspot activity (**2**) it was realized that a mass of important information would become available from extended and detailed solar radio intensity measurements at the appropriate wave-lengths. This paper describes the Commonwealth Observatory programme initiated in 1946 to investigate the relation between the incidence of the solar radio-noise (**3**) and other solar phenomena of the type that can be observed with optical instruments. Radio equipment for the purpose was prepared and erected by the Radiophysics Laboratory of the Council for Scientific and Industrial Research.

It was regarded as essential to have the radio and astronomical equipment in as close association as possible, so that the two sets of phenomena, both of which exhibit rapid changes, could be studied together. As the spectrohelioscope was thought to be the most promising astronomical tool for the purpose, the recorder of a 200 Mc./s. receiver was placed inside the spectrohelioscope hut on Mount Stromlo.

2. *Observations on 200 Mc./s. Solar Radio-noise.*—The receiving equipment, consisting of a 200 Mc./s. receiver and a four Yagi aerial array, has already been described by Pawsey, Payne-Scott and McCready (**4**). The receiver output is applied to an Esterline-Angus recording chart operating at three inches per hour. Full chart deflection is equivalent to 1000 microamps, and the set noise is normally adjusted by means of the gain to read 500 microamps. For this purpose the aerial system is turned to the sky at least 40° from the Sun and away from the

Galaxy. The solar radio-noise is superimposed on the set noise when the aerial is directed towards the Sun, and at normal quiet periods, the increase due to the Sun is of the order of 10 microamps and just detectable. The increase of the recorder deflection due to the Sun at periods of great activity may bring the needle to full scale deflection, and hence at such times the practice is to reduce the gain of the receiver. As power in the receiver is proportional to the square of the recorder current, the power ratio R of the solar component in terms of the set noise is $(d^2_{\text{sun}} - d^2_{\text{sky}})/d^2_{\text{sky}}$, where the d's are recorder deflections. The evaluation of the solar radio-noise flux depends on the noise factor of the set and the effective area of the aerial. The noise factor N (as defined by Pawsey, Payne-Scott and McCready (4)) is determined daily from a signal generator using a nomogram prepared by the Radiophysics Laboratory. It has varied between 7 and 30 since 1946 April. The Radiophysics Laboratory has also determined the effective area A of the aerial as 8·5 square metres. The flux of solar noise is then $8{\cdot}2 \times 10^{-15}\ RN/A$ watts metre^{-2} (Mc./s.)$^{-1}$. All values in this paper are reduced to the flux unit 10^{-15} watts metre^{-2} (Mc./s.)$^{-1} = 10^{-18}$ ergs/cm.^{2}.

The aerial is mounted on a manual polar axis, and is directed towards the Sun, or a few degrees ahead of the Sun, about every hour. The acceptance cone of the aerial is nearly 30°, and very little intensity is lost if the aerial is adjusted hourly.

Owing to the instability of the set, and to the fact that in normal times the measurement is of a very small difference, it is necessary to turn the aerial away from the Sun and back again at frequent intervals. In order to supplement the recorder on quiet days, the flux intensity is also determined visually on a backed-off microammeter by noting the variation as the aerial is turned on and off the Sun. This is done three times a day.

The general nature of 200 Mc./s. solar radio-noise records has already been described (4), and some examples are shown in Fig. 1. On the quietest days, there has always been a detectable amount of radiation which appears to be quite variable. Even on quiet days there are occasional sudden "bursts" of solar radio-noise which last for periods of the order of 1 sec. The peak intensity of bursts is usually between 1 and 10 flux units (i.e. $\times 10^{-15}$ watts metre^{-2} (Mc./s.)$^{-1}$). However, set instability and thunderstorms also provide occasional peaks which look like bursts, and it is not always possible to recognize the true bursts. During a radio-noise "storm" there is usually a high steady or slowly varying flux which has reached as high as 400 units. Furthermore, bursts are far more frequent during a storm and have sometimes reached the frequency of several per minute. Their intensity occasionally reaches the limit of the recorder at 50 units, and sometimes when the gain has been turned down have been observed over 100 units.

Besides steady noise and bursts, one can detect, rather rarely, sudden outbursts of radio noise, which last for a few minutes, fluctuating violently, and then disappear. In Section 5 we will see that such outbursts have a physical significance although they cannot be recognized with certainty from the records.

For tabulation purposes, the data can be described by (*a*) hourly values of steady flux, (*b*) hourly frequencies of bursts above a selected intensity, (*c*) time and intensity of the main bursts, and (*d*) time and maximum smoothed flux of all outbursts. The hourly values can also be averaged to give daily values of

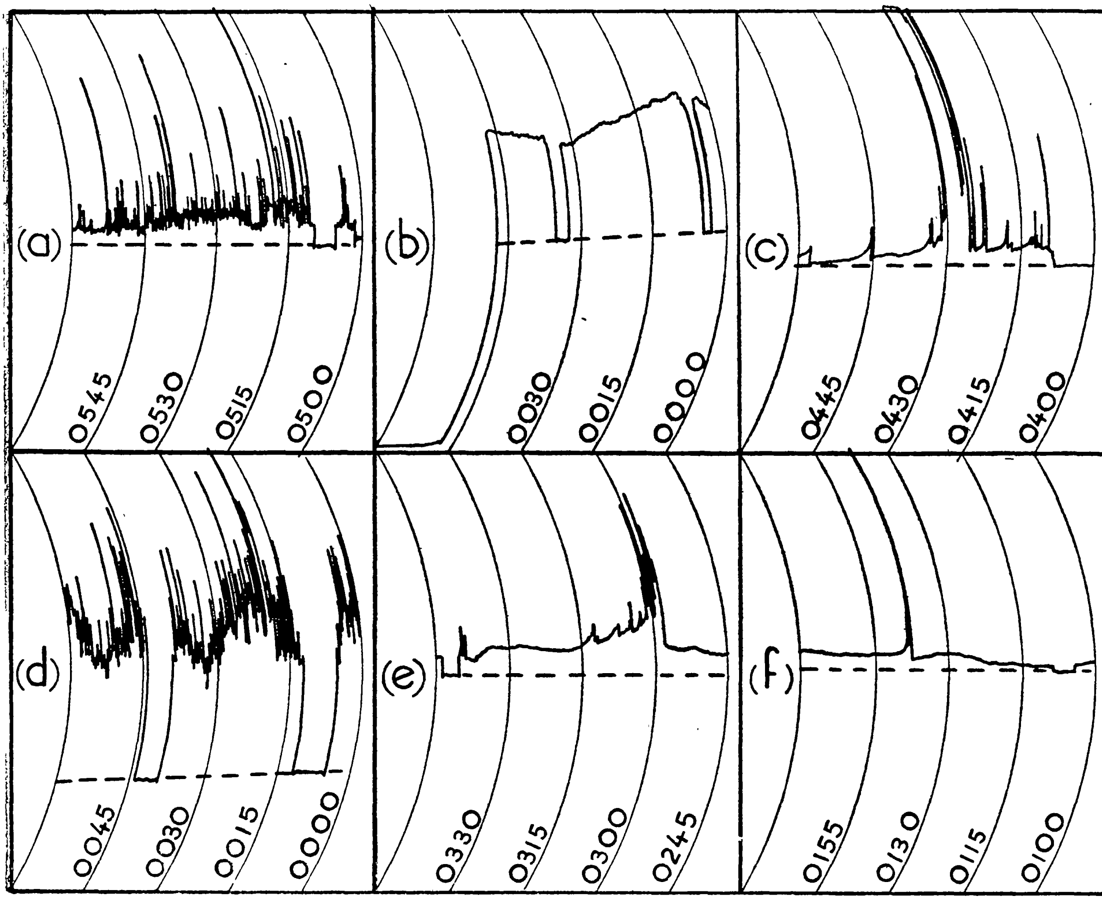

Fig. 1.—*Examples of solar radio-noise recordings. Set noise level is indicated by broken line. Note that timing is from right to left.*

(a) 1946 *September* 14.	*Frequent bursts and low noise level.*
(b) 1946 *September* 20.	*No bursts and high noise level.*
(c) 1947 *March* 8.	*Large outburst.*
(d) 1947 *March* 10.	*Frequent bursts and high noise level.*
(e) 1947 *March* 14.	*Small outburst.*
(f) 1947 *March* 18.	*One burst and fairly quiet.*

the steady flux and the frequency of bursts per hour. We have divided the burst data into large bursts, over 5 units; and small bursts, from 1 to 5 units. Bursts smaller than one unit could not be detected with certainty on our records. The normal recording period on Mount Stromlo is 00.00 to 06.00 U.T.

It should be mentioned that recordings on frequencies other than 200 Mc./s. might not have the same characteristics, and that the form of tabulation here adopted may not be suitable for all solar radio-noise analyses.

3. *Daily Correlations.*—The solar radio-noise recorder commenced fairly regular daily operation in 1946 April, and the data for the twelve months 1946 April–1947 March, are plotted against sunspot and magnetic data in Figs. 2 and 3. The radio-noise values are plotted on a square root scale in order to compress the variations and keep them similar to the sunspot and magnetic data. All values above what may be regarded as the disturbance level are blocked in for emphasis. Both visual and recorded readings for the steady flux are included, although they cannot always be distinguished on the diagram. From 1946 April to August, values below 0·8 units could not be detected on the recorder,

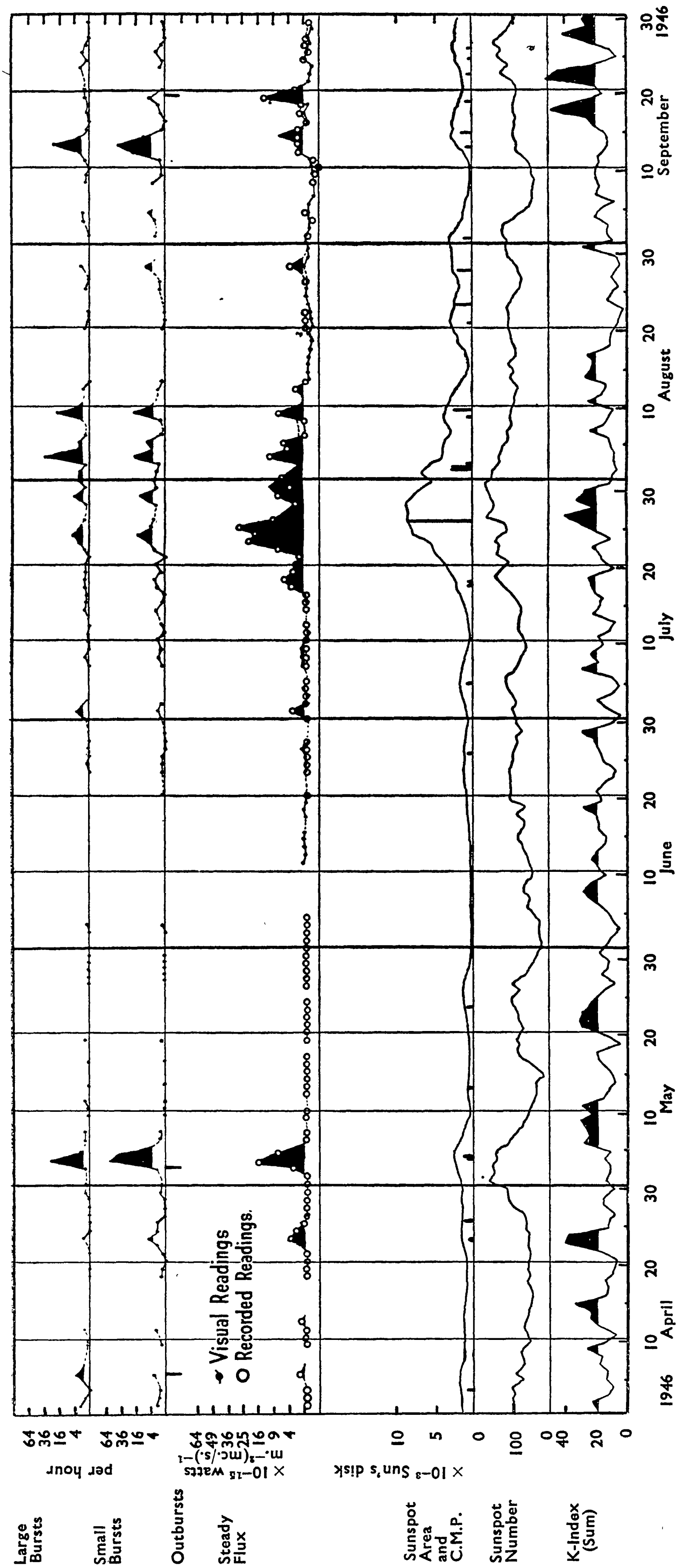

FIG. 2.—*Daily comparison of solar radio-noise with sunspot and geomagnetic data,* 1946 *April–September. From April to August recorded values below* 0·8 *units could not be detected, and such days are all plotted as* 0·8.

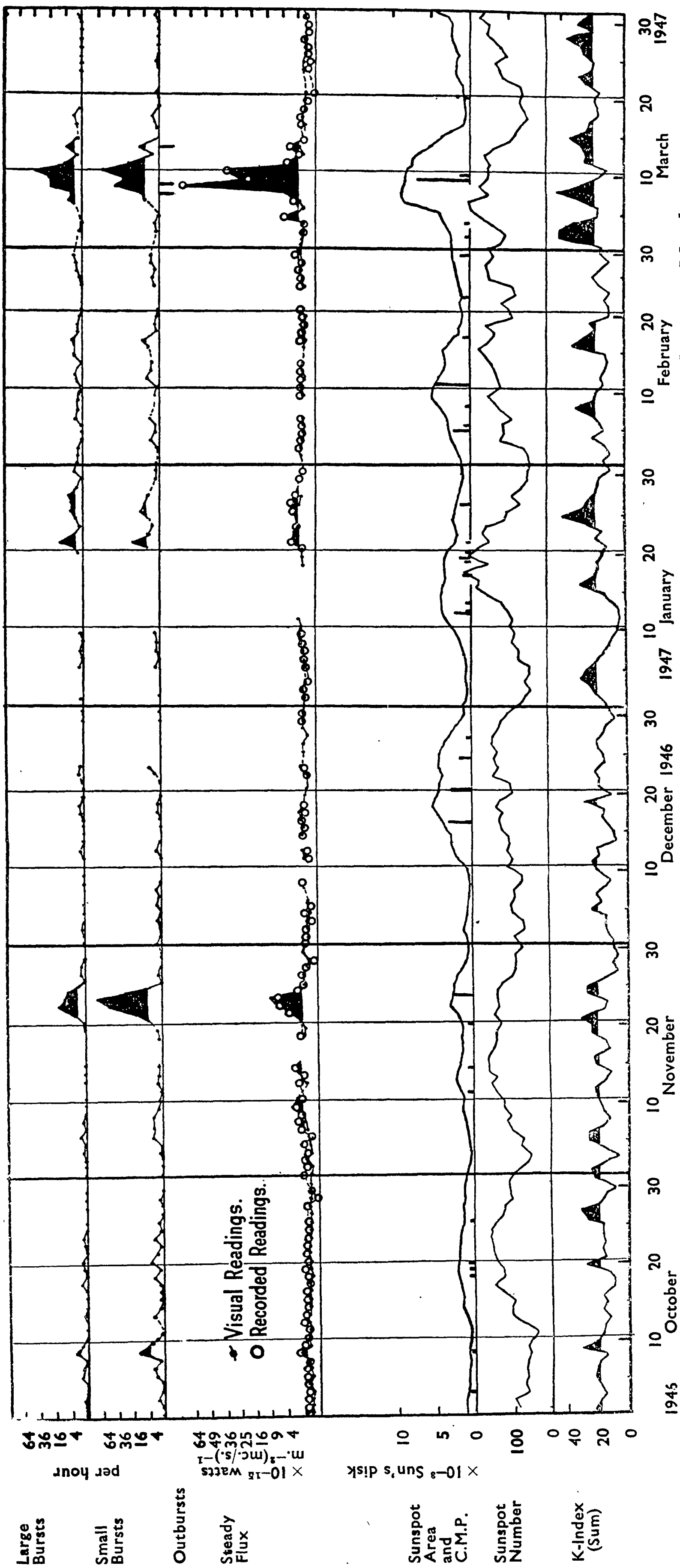

FIG. 3.—*Daily comparison of solar radio-noise with sunspot and geomagnetic data*, 1946 *October*-1947 *March*.

and all such days are plotted as 0·8. The visual readings are always more accurate than recorded readings for the low values.

The sunspot and magnetic data are taken, where possible, from *Terrestrial Magnetism* and after 1946 October are either from the Interservice Radio Propagation Laboratory publications or from observations made in Australia. Projected sunspot areas are used, measured from the Observatory spot sketches. As the K-indices are summed for Greenwich days, the points are located on the centre of each day. Other data are located at the time to which the observations actually refer. Any systematic lags detectable in the diagram should therefore be real. The central meridian passages and maximum areas of all spots whose projected areas exceeded 500×10^{-6} of the visible disk are shown beneath the spot area curve.

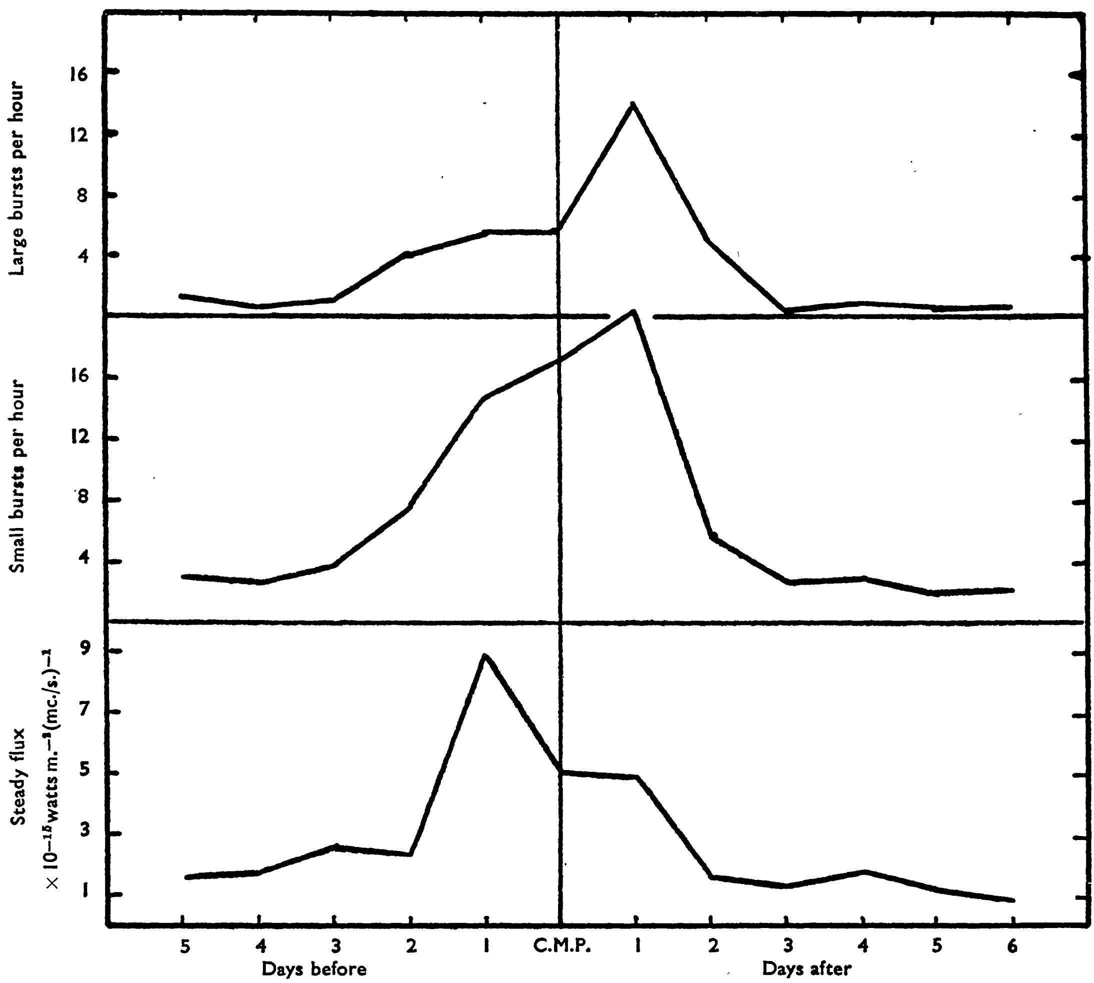

FIG. 4.—*Variation of solar radio-noise as large sunspots pass the central meridian.*

The general relation between solar radio-noise and sunspots is clearly demonstrated. The sunspot area is seen to be a better correlation index than sunspot number, and a still better index is the central meridian passage of the great sunspots. However, as Hey has remarked (5), there is no strict proportionality between spot area and noise flux. All solar noise storms or periods of activity in Figs. 2 and 3 coincide with near meridian passage of spots (possible exception on 1946 July 2), but the meridian passage of large spot groups is not necessarily accompanied by an appreciable noise increase.

There is a strong tendency for radio-noise to be received from the Sun only when the spot is not more than one day from the central meridian. This tendency had already been noticed in the observations made in Sydney (4) and is now well confirmed by independent data. For the 24 spot groups whose areas exceeded 1000×10^{-6} of the Sun's visible disk, the mean noise flux and burst frequency from five days before to six days after central meridian passage of the spots is shown in Fig. 4. The concentration of solar noise as the spot passes the meridian implies that the noise is emitted in an approximately radial beam. Noise has been received from the greatest spots when four days or more from the central meridian, but such noise has always been weaker than near the meridian.

Fig. 4 demonstrates some tendency for the steady noise to precede, and the bursts to follow, the central meridian passage of spots, but this tendency may be changed as more data becomes available.

A close relation between frequency of bursts and flux of steady noise is readily seen in Figs. 2 and 3, but some radio-noise storms, e.g. 1946 September 14, consist mainly of bursts, while others, e.g. 1946 September 20, are mainly high steady noise. On September 14, the main spot group was developing rather rapidly, while on September 20, the main spot group—mostly small spots was on the decline. A search through the data gives some support for the generalization that bursts are relatively more frequent in the early stages of sunspot development and steady noise in the later stage.

No significant difference between the distribution of large bursts and small bursts has been detected.

There is a good general correlation between noise and geomagnetic activity, as might have been expected, since both are associated with great sunspots. However, the details of the correlation do not suggest that radio-noise and geomagnetic particles are necessarily emitted from a sunspot at the same time. The lag between radio-noise emission and the apparently associated magnetic storm varies between 0 and 3 days.

4. *Short Period Correlations.*—Since solar radio-noise and spectrohelioscope features both vary with periods much shorter than a day, it was hoped that the daily correlation just mentioned would be amplified by detailed correlation of some of the more rapid features. A visual observing programme, particularly aimed at detecting such relations, has been carried out since 1946 April.

As was expected, no solar features whatever could be detected with periods of the order of 1 sec., and hence correlation with individual bursts, when frequent, was at once ruled out.

The next attempt was to search for any features in the spectrohelioscope or spectroscope which might vary in a systematic fashion with the coming and going of solar radio-noise. The following features were studied visually: (*a*) bright $H\alpha$ flocculi, (*b*) dark $H\alpha$ flocculi, (*c*) dark flocculi with high sight-line velocities, (*d*) flares, (*e*) changing width of $H\alpha$ in flares, (*f*) general appearance in spectrohelioscope, (*g*) appearance of $H\alpha$ in spectroscope, (*h*) bright $H\alpha$ "bombs", (*i*) incidence and density of the D3 line of *He*, (*j*) incidence and brightness of emission in 5169 A. of Fe^{+}. Generally, the procedure was to become familiar with these features on normal days, and then to seek for anything unusual during periods when solar radio-noise was being received. Nearly all the features were found to vary so closely with the size and general activity of sunspot groups that they gave no new information. *We could find no chromospheric or photo-*

spheric features which appeared to have an invariable physical connection, or high short period correlation, with the solar radio-noise.

This rather disappointing result has led us to suspect that the location of the noise source was not near the photosphere or chromosphere, but probably high in the corona. This suggestion has been made elsewhere (**6, 7**), and is supported by an observation in Section 5.

It should be remarked that a search for a correlation between radio-noise and visible features might be confused by the geometrical conditions affecting the direction of the solar noise beam. The fact that nearly all noise is received when a sunspot is within a day of the meridian, shows that there is a directional control which concentrates the radiation in an approximately radial direction. However, the exact direction of the beam might well depend on equidensity contours of the corona and this would cause a variation in the received noise which would be rather independent of the actual emission.

The situation with regard to flares differs from other chromospheric observations, in that, while there is no general correlation, there are occasions when there appears to be a physical connection between an outburst of noise and the onset of a flare.

5. *Flares and Outbursts of Radio-noise.*—Interest in the association of flares and solar radio-noise was first aroused by Appleton's remark (**1**) that "the noise . . . . was often the precursor of a catastrophic fade-out associated with a bright eruption (flare) on the Sun". Hey (**5**) and Ellison (**8**) have described the coincidence of an outburst of radio-noise with the onset of a great flare on 1946 July 25, and similar observations are mentioned in the report by Reber and Greenstein (**7**).

Since 1946 July, 130 flares or fade-outs have been observed in Australia at times when the radio-noise set was in operation. Most of these showed no influence at all on the noise record, whether noise was being emitted at the time or not. For only 31 of them was there any evidence of change in the solar noise record that might possibly be attributed to the flare, and for only five of them could one be reasonably sure of a physical connection between the flare and the noise change. The conditions for the five occasions were as follows:

(1) On 1946 August 29, a flare of importance 1 in a spot group at lat. 30° S., long. 22° E., was seen to commence at 01.38 U.T. and finish at 01.58. The intensity was greatest at 01.40, at which time the $H\alpha$ emission was somewhat broader than normal—the flare could be seen at $\pm 1 \cdot 0$ A. from the centre of $H\alpha$. At 01.41, the recorder showed a burst of about 20 units (the highest for the day). After the burst the steady flux decreased a little, until about 02.01 when, with a small burst, it returned to the earlier value—about 1 unit.

(2) An active flare was seen in lat. 11° N., long. 29° E. at 04.40, 1947 March 8. It was decreasing when first noticed and gone by 04.50. A fade-out was observed on the ionospheric recorder at 04.30, and strongly suggests that this flare started rather violently about that time. From 04.26 to 04.30 there was a very remarkable outburst of solar noise, exceeding the recorder limit of 68 units (see Fig. 1). The noise then returned to normal while the flare was still in progress.

(3) On 1947 March 9, at 05.13, a rush of noise was heard in the loud speaker attached to the noise recorder. The flux had been steady at about 26 units, but without bursts, for about an hour. A rapid scan of the Sun with the spectrohelioscope revealed that a flare of importance 2 was commencing at lat. 14° N.,

long. 11° E. The *Hα* line was fairly wide, about ±1·0 A., during the first few minutes. In the period 05.13–05.16 there were two bursts and an increase of flux, which we have listed as an outburst although not very typical. The radio noise then decreased to about 19 units, until the flare was over at 05.29, after which there was an increase to 33 units.

(4) On 1947 March 9, at 06.57, a flare of importance 2 was seen to commence at 26° S., 15° E. It developed very rapidly in the first five minutes, during which time *Hα* extended to 2·4 A. to red and 2·0 A. to violet. The solar noise had been fairly steady at about 24 units for over an hour. With the incidence of the flare the steady noise remained the same, but a series of bursts commenced rather suddenly and continued for a half hour during the intense part of the flare. There was some evidence of outbursts at 06.59 and 07.02, when two different sections of the flare were at their widest in *Hα*.

(5) At 04.00 on 1947 March 14, a flare was found to be in progress at 25° S. and 58° W., and continued until 04.35. The flare was rated importance 1, but from the glowing appearance in the spectrohelioscope it was judged to be the end of a flare of importance 2 or 3. There was an outburst from 02.58 to 03.02 (see Fig. 1), followed by a rather quiet period. Bursts and steady noise increased again at about 04.15. Three ionospheric stations reported fades beginning between 02.45 and 03.00, but all reported a maximum fade intensity at 03.00, in good synchronization with the outburst.

If we ignore the fourth case this information suggests that a normal accompaniment of a vigorous flare is an outburst of noise during the initial stages when *Hα* is wide, followed by a small decrease in flux during the life of the flare. Individual flares, however, differ widely in detail.

It is this correlation between flares and outbursts that shows that an outburst has a particular physical significance. Outbursts cannot be recognized with certainty on the noise records, but a list of occasions which appear to be genuine outbursts has been extracted from our recordings, as in Table I.

TABLE I

List of Outbursts from 1946 *April*—1947 *March*

Time	Date	Maximum Flux
05.15 U.T.	1946 April 6	8 units
06.30 ,,	,, May 3	11 ,,
07.26 ,,	,, Sept. 20	28 ,,
04.28 ,,	1947 March 8	68 ,,
05.14 ,,	,, March 9	32 ,,
03.00 ,,	,; March 14	26 ,,

The outbursts are shown in Figs. 2 and 3, but they are not sufficiently complete or numerous for correlating with other phenomena. They may prove to have a connection with magnetic storms.

It is important to notice that only a small percentage of solar radio-noise is associated with flare commencement, and that, therefore, flares are not a necessary part of the physical mechanism that produces the radio noise. The conditions that obtain in the corona might be rather delicately balanced, so that the corona could be stimulated into noise production by the ultra-violet radiation from a flare. Whether or not a flare would be accompanied by a noise outburst would then depend on whether (*a*) the corona was already in the condition to emit noise, (*b*) the flare was sufficiently vigorous, and (*c*) the radio-noise beam was directed towards the Earth.

In the above list of examples, the flares of 1947 March 8 and 9, are of special interest, since they took place in a spot that was 37° from the great spot. The close relation between noise and great sunspots suggests that the noise source in this case was in the region of the great spot. If the noise was stimulated by radiation emitted from the Sun's surface near the small spot, it can readily be seen from Fig. 5 that the source of the radio-noise must have been at least

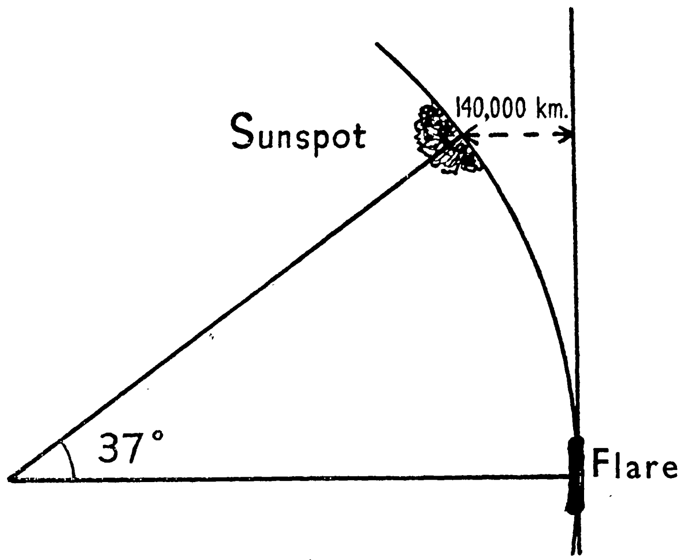

FIG. 5.—*Illumination of sunspot neighbourhood by a flare.*

140,000 km. from the centre of the great spot, and at a height of at least 120,000 km. above the Sun's surface.

Such a height is reasonably consistent with Appleton's theory of reflection and absorption in ionized layers (**9**) for 200 Mc./s. waves, particularly if, as Martyn has shown (**10**), the radiation is the extraordinary polarized ray. In that case the height of the reflection layer is dependent on the electron concentration in the corona and the magnetic field from the spot. Using Baumbach's electron concentrations (**11**), Martyn's method of analysis (**12**), and reasonable values for the spot field, the 200 Mc./s. extraordinary reflection layer is at a height of 130,000 km., in good agreement with that deduced from Fig. 5. For lower frequencies, the height would be greater.

Since the bursts at different wave-lengths show very little detailed agreement (**13**), it might further be inferred that they are not produced at the same level. Presumably, the lower frequencies would be produced at a higher level. Rather definite information on the heights of the sources would be provided if a flare from a distant spot group were to produce a noise outburst at one frequency and fail to produce an outburst at a higher frequency.

Routine observations such as those described in this paper, if made at more than one frequency, should settle such questions in due course.

Acknowledgments

The observations described were made at the Commonwealth Observatory. The radio equipment was prepared and erected by the Radiophysics Laboratory of the Council for Scientific and Industrial Research, Sydney; and operated by Mr L. H. Heisler and Mr R. O. Errey of the Radio Research Board, also of the Council for Scientific and Industrial Research, Sydney. Solar observations were made by Miss F. J. Daly and the author. The author is indebted to Drs R. v. d. R. Woolley, D. F. Martyn and J. L. Pawsey for helpful discussion.

Addendum, 1948 *March*

More recent checks on the constants of the aerial and receiver show the system to be 6 D.B. less sensitive than formerly estimated. As a result all noise levels quoted in the paper should be increased by a factor of 4, and the flux unit becomes 4×10^{-15} watts metre^{-2} (Mc./s.)$^{-1}$.

Commonwealth Observatory,
Mount Stromlo,
Canberra, A.C.T.:
1947 *May* 2.

References

(1) Appleton, E. V., *Nature*, **156,** 534, 1945.
(2) Pawsey, J. L., Payne-Scott, R., and McCready, L. L., *Nature*, **157,** 158, 1946.
(3) As the radiation appears as an increase of noise level in a radio receiver, it will often be referred to in this paper as solar radio-noise.
(4) Pawsey, J. L., Payne-Scott, R., and Mc Cready, L. L., *Proc. Roy. Soc.*, A., **190**, 357, 1947.
(5) Hey, J. S., *Observatory*, **66,** 360, 1946.
(6) Martyn, D. F., *Nature*, **158,** 632, 1946.
(7) Reber, G., and Greenstein, J. L., *Observatory*, **67,** 15, 1947.
(8) Ellison, M. A., *M.N.*, **106**, 500, 1946.
(9) Appleton, E. V., and Builder, G., *Proc. Phys. Soc.*, **45,** 208, 1933.
(10) Martyn, D. F., *Nature*, **158,** 308, 1946.
(11) Baumbach, S., *A.N.*, **263,** 121, 1937.
(12) Martyn, D. F., Private communication.
(13) Unpublished observations from the Radiophysics Laboratory.