OBSERVATIONS OF THE GENERAL BACKGROUND AND DISCRETE SOURCES OF 18·3 Mc/s COSMIC NOISE

By C. A. Shain* and C. S. Higgins*

[*Manuscript received September* 14, 1953]

Summary

A survey of a broad strip of the sky, centred on Dec. —32°, has been made at a frequency of 18·3 Mc/s using an aerial with an overall beam width to half-power of 17°. Previous results concerning the background distribution of brightness have been confirmed and 37 discrete sources have been detected. The distribution of these sources shows some galactic concentration; it becomes homogeneous if sources within 18° of the galactic plane are excluded. From observations of source scintillations, it is concluded that some of the discrete sources have angular sizes of the order of 1°. No correlation was found between the occurrence of scintillations and published ionospheric data, but the observations are consistent with an origin of the scintillations in irregularities, of dimensions about 4 km, at a height of about 500 km.

I. Introduction

A previous paper (Shain 1951) described observations of 18·3 Mc/s cosmic noise which were made using an aerial with the direction of maximum sensitivity fixed vertically upwards in latitude 34 °S. The aerial thus received cosmic noise averaged over a rather wide strip of the sky centred on Dec. —34°. It was shown, by comparison with the results of Bolton and Westfold (1950), that the observed variations in intensity as the aerial scanned this strip (which included the centre and the south pole of the Galaxy) could be explained if contours of equal intensity at 18·3 Mc/s were of the same shape as at 100 Mc/s, the absolute intensity being much higher, and if, also, the ratio of the intensity at 18·3 Mc/s to the intensity at 100 Mc/s near the galactic centre were somewhat lower than the corresponding ratio away from the centre.

Although these observations gave some indication of the way in which the intensity of cosmic noise at 18·3 Mc/s would vary over the sky, it was apparent that a detailed survey should be made with an aerial of smaller beam width, at least over the important regions near the galactic centre and at some distance from the centre. Accordingly, an aerial was constructed, to operate at 18·3 Mc/s, with a beam width of 17° between half-power points, and for which the main lobe could be swung at least 20° north and south of the zenith.

The present paper describes the observations of cosmic noise made with this aerial, these observations being mainly concentrated in the range of declination from —12 to —52°. The intensities observed were of the same order as those previously reported. With the former aerial system it was thought that the effects of one or two discrete sources of radiation could be detected; with the

* Division of Radiophysics, C.S.I.R.O., University Grounds, Sydney.

greater aerial gain and better angular resolution of the equipment described in the present paper, 37 objects have been detected whose angular size is apparently considerably less than the aerial beam width. A number of these coincide in position, within the experimental uncertainty, with discrete sources listed by Mills (1952*a*). Some of the discrete sources fluctuate in intensity although others do not, and an attempt has been made to correlate the intensity of these fluctuations with the angular sizes of the sources and with various conditions of the ionosphere.

A second paper will describe comparisons between the observational results of this paper and those obtained by other authors at frequencies near 100 Mc/s. The earlier observations showed that useful information concerning ionospheric absorption could be obtained by studying the variations in the received intensity of cosmic noise from a region of the sky under different ionospheric conditions. In the course of the present work a more detailed investigation of the effects of the ionosphere on the intensity of cosmic noise has been made, but discussion of these effects will be reported elsewhere.

II. Equipment

The equipment was situated at Hornsby, near Sydney, N.S.W. (lat. 34 °S., long. 151 °E.). The aerial site was flat but sloped downwards to the north at an angle of 2°. It was surrounded by hills at a distance of about 1 km which subtended angles of less than 10° at the aerial.

(*a*) *Aerial*

The aerial consisted of an array of 30 horizontal half-wave dipoles 0·2 wavelengths above ground and arranged in plan as shown in Figure 1. It should be noted that the " north-south " rows of dipoles were actually in lines directed 4·7° west of north. (This " azimuth error " has been allowed for in all the observations.) The unequal spacing between rows in the east-west direction was adopted to reduce side lobes in this direction. It was expected that, since the array was fixed and of large physical size, it would be impracticable to make a complete measurement of the aerial sensitivity pattern and that this pattern would have to be obtained by calculation, assuming the currents in the dipoles to be known. Precautions were therefore taken to ensure that the currents in each dipole were of equal amplitude and of known phase.

For each dipole a separate coaxial feeder, with a Pawsey stub as balance-unbalance transformer, ran to a hut in the centre of the array. As the lengths of feeder were large, about 100 ft, the attenuations in the cables feeding each dipole were equalized as far as possible by making all the feeders from the north-south rows 2, 3, 4, and 5 (see Fig. 1) of the array the same length (five half wavelengths) and these from rows 1 and 6 one wavelength longer.

At the centre hut the feeders were first connected in threes, e.g. A1, A2, A3 ; B1, B2, B3 ; etc., and the impedance of each combination was matched, using a T-network, to the characteristic impedance of the cable used for the feeders. The outputs from the five matching networks in the western half of the aerial were then combined and the impedance of the combination again matched to the feeder characteristic impedance (see Fig. 2 (*a*)). Similarly, the feeders from the eastern half of the array were combined and two cables, one from the eastern half and one from the western half of the array, were taken to a hut outside the array which contained the receivers and recording equipment.

In order to direct the aerial beam to different declinations appropriate extra lengths of cable were inserted at the points indicated by small circles in Figure 2 (*a*).

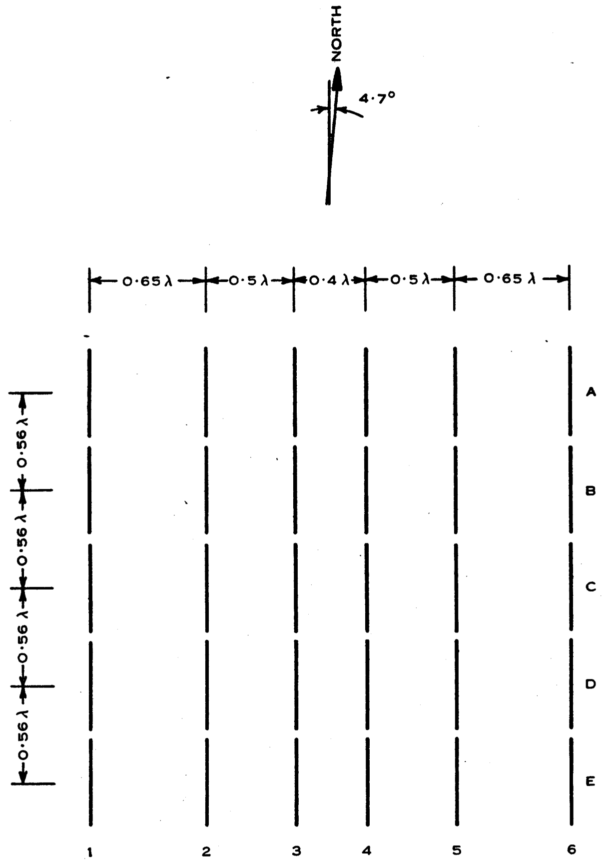

Fig. 1.—Plan of aerial array. The rows of dipoles are numbered and lettered for reference to individual dipoles.

In the recording hut the two feeders were connected to a " feeder bridge " (Westcott 1948) as shown in Figure 2 (*b*), and two receivers were connected to the other corners of the bridge. The feature of this bridge is that the two receivers are quite independent of each other in operation, and one receiver (receiver 1 in Fig. 2 (*b*)) uses the aerial with the eastern and the western halves in phase while the other (receiver 2) has the two halves out of phase. The use of the two receivers simultaneously was helpful in recognizing some interfering signals and also permitted accurate direction-finding observations in some circumstances. The latter facility was used particularly in observations of solar noise to be described in another paper.

In setting up, each dipole was matched to its feeder with all other dipoles open-circuited. All feeders were then joined together and the whole array excited in phase. The impedance of each dipole was measured by observation of the standing waves in the appropriate feeder. This was done by inserting a special length of cable one wavelength long and comparing the relative amplitudes of the voltage in the line at three points spaced one-eighth of a wavelength apart. (A similar system has been described recently by Sutcliffe (1953).) It was found that mutual impedances had changed the dipole impedances slightly,

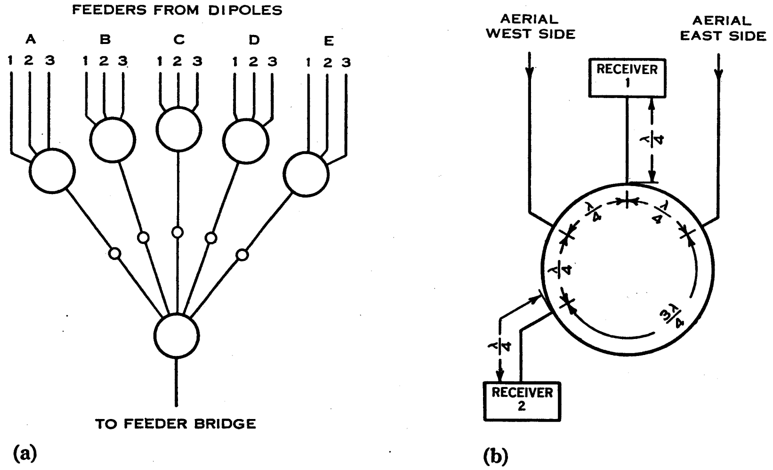

Fig. 2 (*a*).—Matching arrangements for feeders from the western half of the array. The large circles indicate the matching networks and the small circles the points where the extra lengths of cable were inserted for beam-swinging. Fig. 2 (*b*).—Arrangement of feeder bridge. All the feeders were of the same type of coaxial line, having a nominal impedance of 70 Ω, except the two quarter-wave sections at the receiver inputs which had a nominal impedance of 50 Ω.

but that all dipole impedances were very nearly the same. Finally, the feeders were connected in working order and the junction matching networks adjusted in turn. The aerial impedance measurements were repeated a number of times during the period of the observations.

An overall check of the equality of the feeders in the eastern and western halves of the array was obtained using a small oscillator attached to a balloon. Owing to the difficulty of controlling the balloon, this system could not be used to determine the detailed aerial polar diagram, but it was shown that the characteristics of the aerial which could be checked were as expected. A rough check of the positions of some side lobes and of the minima of the aerial diagram was also obtained during recordings of several intense solar disturbances.

Typical calculated aerial diagrams in the north-south plane are shown in Figure 3 (*a*) and the two diagrams for the east-west plane in Figure 3 (*b*). It should be noted that, because of the slope of the aerial site in the north-south plane, the aerial beam was directed to Dec. —32° rather than —34°, when no extra lengths of cable were inserted in the feeder system for beam swinging.

It was calculated that with the aerial beam in its normal position the proportion of power in the main lobe was 89 per cent., this proportion decreasing to 84 per cent. when the beam was swung through 20°.

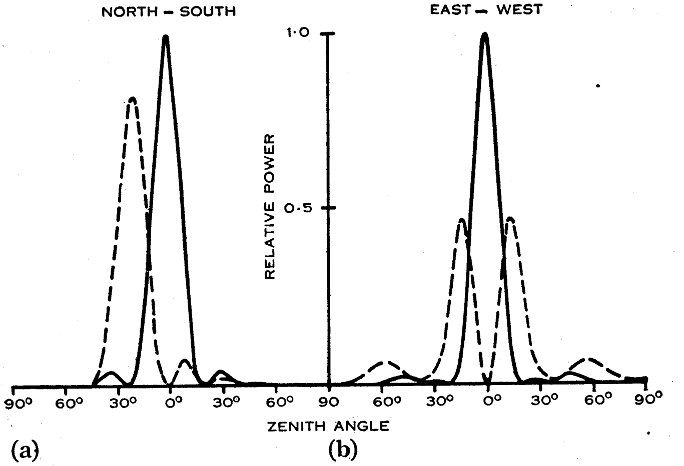

Fig. 3.—Aerial sensitivity. (*a*) North-south direction. Patterns are shown for the aerial directed to declinations —32° (full line) and —12° (dashed line). (*b*) East-west direction. The pattern used by receiver 1 (see Fig. 2 (*b*)) is indicated by the full line and that for receiver 2 by the dashed line.

(*b*) *Receivers and Calibration*

The two receivers were standard communication-type receivers with bandwidths of the order of 1 kc/s. As the intensity of the cosmic noise was always very high compared with the intensity of the noise generated in the receivers, no great care was taken to improve the receiver noise factors. Recording microammeters measured the detector current in each receiver.

Calibration of the received noise intensity was provided by a noise generator using a CV172 noise diode, the output impedance of the noise generator being adjusted to be equal to the impedance presented to the receiver by the aerial feeders.

(*c*) *Losses in the Aerial System*

The measured values of the noise power at the receivers were corrected for the power lost in the ground and in the aerial feeder system.

The power loss in the ground was calculated using appropriate values of conductivity and dielectric constant. The calculated loss, which does not depend critically on the values assumed for these constants, was 1·6 db.

The power loss in the feeder system was measured by observing the standing wave pattern in the feeder near the receivers when the dipole ends of the feeders were short-circuited. Also a direct measurement was made of the losses between the first matching networks and the receivers, using the noise generator. Allowing for the loss in the extra cable between the matching networks and the dipoles, this gave another estimate of the feeder losses which confirmed the first. The value adopted was 2·6 db.

Thus the total losses in the aerial system were estimated to be 4·2 db with an uncertainty of about $\pm 0 \cdot 3$ db (that is, about ± 7 per cent.).

III. Observations

(a) *Observational Procedure*

The equipment was run, almost continuously, during the period June 1950 to June 1951. The observations described in the present paper are largely based on a number of accurate records for which the receivers were run at a comparatively high gain, with part of the detector current backed off. While these records were being taken the receivers were monitored continuously and calibration signals were put on the records at intervals of less than 1 hr. These records were taken in several series at intervals of a few months and, during each series, records were taken on at least two nights with the aerial directed to each of the declinations −12, −22, −32, −42, and −52°. After each of these series of observations, readings of noise power were taken from the records at intervals of about 6 min and plotted as equivalent aerial temperatures against sidereal time.

At other times the receivers were left running with somewhat lower gain. At infrequent intervals the receivers were manually disconnected in turn from the feeder bridge and connected to the noise generator while a series of known noise intensities was put on the record. Between calibrations the receivers were usually unattended. Some interference was experienced from distant radio stations transmitting on the frequency to which the receiver was tuned (this was always within 25 kc/s of 18·3 Mc/s), and sometimes the record was lost during thunderstorms occurring within a radius of several hundred miles of the receiving site. However, these interfering signals could be recognized on the record and the recording time lost from these causes was small, so that records were obtained for practically every day during the year's observations. Having the two receivers tuned to slightly different frequencies often helped in deciding whether a peculiarity in the record was due to natural causes, for example solar noise, or to station interference.

(b) *Ionospheric Attenuation*

From experience in the earlier observations, it was expected that ionospheric absorption would be serious when the critical frequency of the F_2 region of the ionosphere was higher than 9 Mc/s, and with the improved recording technique it was thought that the highest critical frequency that could be tolerated would be somewhat less than 9 Mc/s. Absorption in the D region could be neglected since only records taken at night were used.

When records taken on different nights were compared, it was found that the equivalent aerial temperatures recorded for the same sidereal time were the

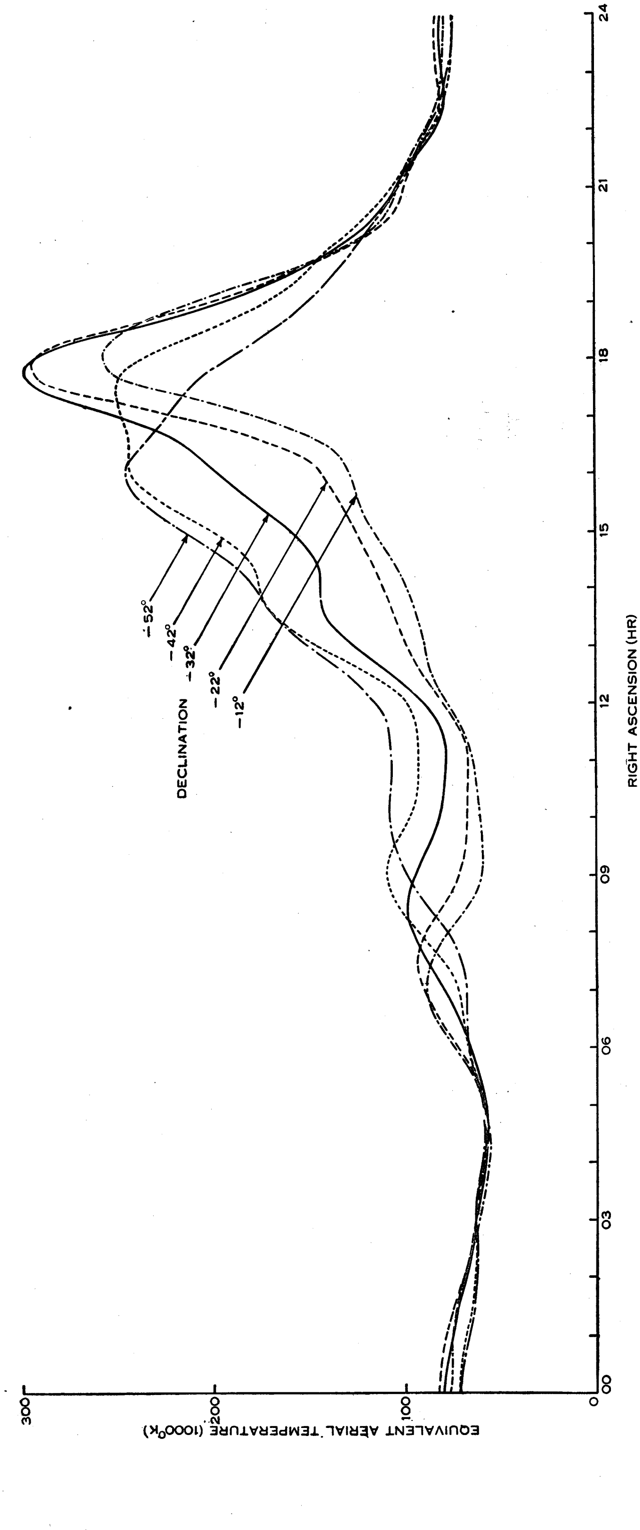

Fig. 4.—Observed equivalent aerial temperatures as functions of Right Ascension for the aerial beam directed to the five declinations indicated on the curves.

same within the experimental uncertainty so long as the critical frequency of the F_2 region was less than 5 Mc/s. Accordingly, only records taken under this condition were used in the main analysis and most of the zone of the sky observed could be covered with the more accurate records. The gaps in these records, during which the F_2 region critical frequency was greater than 5 Mc/s, were filled in using all the lower gain records for which the ionospheric conditions were suitable.

(c) *Results*

The results of these observations, as equivalent aerial temperatures plotted against Right Ascension for the five declinations, are shown in Figure 4. The estimated probable error in relative values of equivalent aerial temperature is about ± 2 per cent. and the probable error in the absolute values about ± 10 per cent. The results have been replotted in Figure 5 as contours of equal equivalent aerial temperature, using galactic coordinates.*

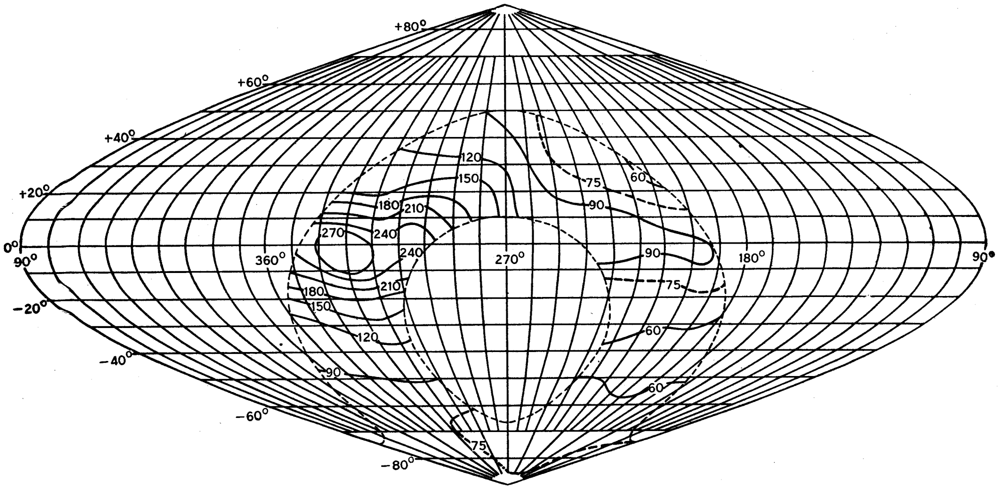

Fig. 5.—Contours of equivalent aerial temperature (in units of 1000 °K), plotted in galactic coordinates.

IV. Analysis

(a) *Brightness Distribution*

Comparison of Figures 4 and 5 with corresponding figures in the earlier paper (Shain 1951) shows that the observed equivalent temperatures are of the same order but somewhat higher. The ratio of maximum to minimum for the present observations is greater than the ratio observed previously, owing to the narrower aerial beam used, but also the absolute intensities have been raised slightly, owing mainly to a better estimate of the aerial system losses.

* The values of Right Ascension and declination in Figure 4 are for the period of the observations. For the conversion to galactic coordinates (Fig. 5) the adopted position of the north galactic pole was R.A. 12 hr 40 min, Dec. +28° (1900).

A detailed comparison between the present observational results and those of Bolton and Westfold (1950) will be made in another paper. However, a rough comparison of Figure 5 with the contours of observed equivalent temperatures at 100 Mc/s given by Bolton and Westfold shows that at both frequencies there is the same general trend towards high intensities near the galactic centre and that the minimum intensities are in approximately the same position. Local differences in the shapes of the contours, for example in the regions near $l=280°$, $b=+20°$ and $l=305°$, $b=+5°$, are probably due to the effects of discrete sources.

Stanley and Slee (1950) have shown that the flux density from a number of discrete sources varies approximately in proportion to the wavelength, while the background brightness temperature varies approximately as the wavelength to the power $2 \cdot 5$, that is, the background brightness (flux per unit solid angle) varies as the wavelength to the power $0 \cdot 5$. Therefore, provided aerials of the same beam width are used, and this is approximately true when comparing the present observations with those of Bolton and Westfold, the relative increase in the received power due to discrete sources compared with the background power should vary approximately as the square root of the wavelength. Although it will be shown in the subsequent paper that, in the range of frequencies between 18·3 Mc/s and 100 Mc/s, the variation of source flux density with wavelength is somewhat different from that deduced by Stanley and Slee, it is in fact more rapid than the variation of background brightness with wavelength. This would result in a distortion of the contour lines as observed.

(*b*) *The Discrete Sources—Detection*

The irregularity in the contours of Figure 5 in the region near $l=280°$, $b=+20°$ corresponds to the increase shown near R.A. 13 hr 30 min on the curve of Figure 4 for Dec. $-42°$ and this agrees with the position of the discrete source Centaurus–A (Stanley and Slee 1950). A number of other similar increases could be detected easily. Since the objects giving rise to the localized increases in intensity must subtend an angle somewhat less than the beam width of the aerial and some at least correspond in position with discrete sources observed at higher frequencies, they have been called discrete sources; it should be remembered that they could have an angular size of several degrees. However, associated with some of these increases were short duration (order of 1 min) fluctuations in the received intensity and, as discussed later, this observation suggested that some at least of the discrete sources would subtend angles of the order of 1° or less.*

A careful check of the observational results was made for effects of discrete sources. The procedure, in the case of three of the weaker sources, is illustrated

* Evidence that the increase corresponding to the source Centaurus–A is due to a source of radiation having an angular size of the order of 1° was obtained during a short series of observations using the " sea interferometer " technique. Under suitable ionospheric conditions an interference pattern was obtained using an array of 12 half-wave dipoles erected near the top of a hill about 600 ft high and close to the sea. However, owing to the uncertain amount of ionospheric refraction and attenuation, these observations could not be used to improve the estimates of the position and intensity of the source obtained by other methods.

in Figure 6. In this figure the curves on which part of Figure 4 is based have been redrawn on a larger scale and with the curves for three declinations displaced vertically for clarity. The dotted sections of the curves correspond to the periods of the records during which fluctuations were observed. For each declination, records from observations on at least two separate days were averaged; the daily records were so similar that they could not be separated in the figure. Certain small " bumps " on the curves repeated themselves each

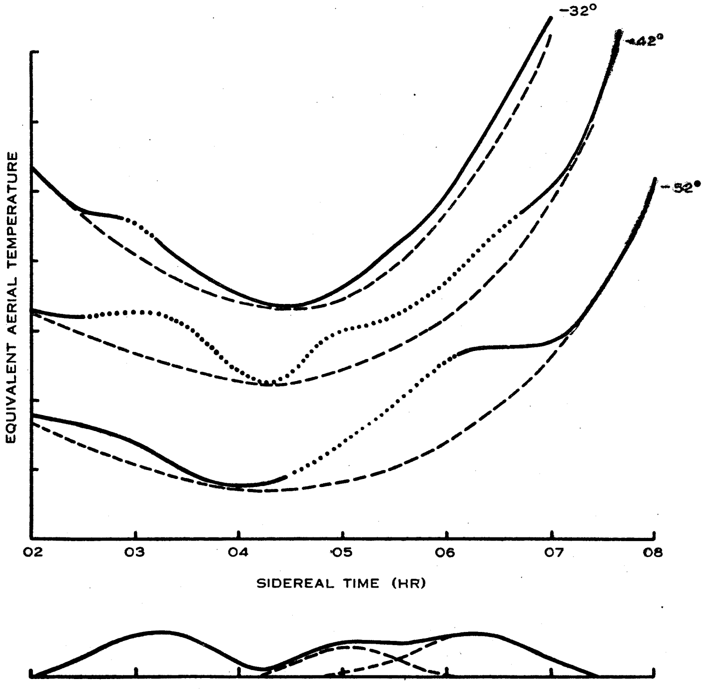

Fig. 6.—The detection of discrete sources. In the upper part of the figure are shown experimental curves (full and dotted lines) of equivalent aerial temperature versus sidereal time for declinations —32, —42, and —52°. The curves are displaced vertically for clarity (cf. Fig. 4). The dotted part of the curve indicates the periods during which fluctuations were observed and the dashed lines indicate the estimated variation of the general background temperature with sidereal time. The lower part of the figure shows the estimated discrete source contributions for Dec. —42°. The passage of three sources through the aerial beam is indicated (sources S03–4, S05–4, and S06–5 in Table 1).

day and there is apparently a progressive change with declination in the character of the records. These bumps, and the appearance of fluctuations, indicate the presence of several discrete sources and a rough indication of their position and intensity can be obtained directly from the figure. To obtain a better estimate of the positions and intensities, the estimated trend of the general background radiation was drawn for each declination (dashed lines in Fig. 6) and the differences between the observed temperatures and the estimated background

TABLE 1

LIST OF DISCRETE SOURCES OBSERVED AT 18·3 Mc/s

Number	R.A. (hr min)	Dec. (deg)	l (deg)	b (deg)	Flux Density (S) (10^{-25}W m^{-2} (c/s)$^{-1}$)	Level ($L=25+\log_{10}S$)	Notes
S							
00—1	00 23	—19	65	—81	1500	3·2	
01—2	01 34	—20	150	—75	1100	3·0	
03—4	03 24	—41	211	—54	350	2·5	
04—2	04 22	—21	185	—39	700	2·8	
05—4	05 12	—45	217	—35	350	2·5	
06—1	06 05	—18	192	—16	1000	3·0	
06—3	06 22	—33	209	—18	300	2·5	
06—5	06 21	—51	227	—24	850	2·9	
07—1	07 10	—18	199	— 2	1200	3·1	
08—4	08 20	—43	228	— 3	700	2·8	
09—1	09 23	—12	214	+28	400	2·6	
09—3	09 20	—34	230	+12	700	2·8	
09—5	09 55	—53	246	+ 2	800	2·9	
10+1	10 45	+16	199	+61	1300	3·1	
10—1	10 20	—10	224	+39	800	2·9	
12+1	12 30	+11	262	+73	1100	3·0	
12—0	12 53	— 1	277	+61	4100	3·6	(1)
12—1	12 24	—14	263	+47	1500	3·2	
13—2	13 20	—22	284	+40	2000	3·3	
13—3	13 44	—33	285	+27	650	2·8	
13—4	13 25	—43	279	+18	5300	3·7	(2)
13—5	13 00	—58	273	+ 5	3300	3·5	(3)
14—4	14 45	—42	294	+15	5300	3·7	
15—1	15 21	—16	317	+31	1000	3·0	
15—6	15 35	—61	290	— 5	6300	3·8	(3)
16—3	16 02	—39	308	+ 8	3800	3·6	
18—2	18 20	—28	332	— 9	5700	3·8	
19+0	19 30	+ 2	8	—10	1100	3·0	
19—2	19 40	—20	349	—23	650	2·8	
20+x	20 02	+ x			(66000)	(4·8)	(4)
20—4	20 06	—47	320	—34	350	2·5	
21—1	21 20	—15	5	—42	1400	3·1	
21—2	21 50	—25	354	—52	500	2·7	
21—3	21 05	—30	344	—44	800	2·9	
21—5	21 56	—52	311	—51	250	2·4	
23—2	23 20	—25	5	—72	1550	3·2	
23—5	23 30	—51	295	—64	250	2·4	

(1) Intensity uncertain owing to confusion with S12—1.

(2) Centaurus–A. Probable error in position ±2 min in Right Ascension, ±1° in declination.

(3) Uncertainty in declination. Intensity depends on adopted position.

(4) A small increase observed with the aerial beam in furthest north position. No means of obtaining declination with any accuracy but consistent with suggestion that the increase is due to the source Cygnus–A. Intensity estimated assuming Dec. +40°.

were plotted against sidereal time as in the lower part of Figure 6. This curve represents the variations in equivalent aerial temperature at Dec. $-42°$ due to the passage through the aerial beam of the sources only. Knowing the relative aerial sensitivities, the relative amplitudes of the estimated source contributions at the different declinations provided a check on the consistency of the estimates of the background trend. In some cases, as on the right side of Figure 6, the source bump was of much longer duration than expected from the aerial beam width and is clearly due to the effect of two neighbouring sources.

A similar procedure was followed for all the records. Sometimes, when the rate of change of the background temperatures with Right Ascension was high, clearer indications of sources were obtained by plotting equivalent aerial temperatures against declination or against galactic latitude. In all, 31 sources could be detected in the zone bounded by declinations -4 and $-60°$ (corresponding to the lines swept out by the half-power points of the aerial beam during the main survey). In addition, records were available for two other positions of the aerial beam and, although the aerial gain was lower in these positions, a further six sources could be detected.

In general, for all the sources, positions could be assigned only roughly, with an estimated probable error of up to 5° for the weaker sources, although the uncertainty was somewhat lower for the stronger sources.* Similarly, the estimated probable errors in the intensities vary from about ± 20 per cent. for the strongest to a factor of 2 for a few of the weakest sources.

A list of the sources detected is given in Table 1. The sources have been numbered according to the system used by Mills (1952*a*). In this system the hour of Right Ascension is followed by the sign and tens of degrees of the declination, so that the designation of a source gives some indication of its position. To avoid confusion with the sources in Mills's list, the numbers of the sources in Table 1 will be prefixed by " S " (e.g. S05–4).

Also in accordance with the suggestion of Mills, the " level ", L, of a source is defined by $L = \log_{10}(S \times 10^{25})$, where S is the flux density of the source (total for two planes of polarization) in units (W m^{-2} $(c/s)^{-1}$).

A map of the sources, using galactic coordinates, is given in Figure 7. Each source is represented by a symbol which gives an indication of its level. Also shown in Figure 7 are open circles showing the positions of all the sources detected by Mills within the regions of the sky of interest. It is seen that a number of the sources listed in Table 1 have positions close to sources listed by Mills and, taking into account the uncertainties in the positions of the sources, dashed lines have been drawn round the symbols which it is thought probably represent observations of the same object at the two frequencies.

* The position of the source Centaurus–A was obtained more accurately, with a probable error of about ± 1 min in Right Ascension and $\pm 1°$ in declination, by comparing the amplitudes of fluctuations in intensity as observed simultaneously with the two receivers, using different aerial diagrams as shown in Figure 3 (*b*).

(*c*) *Distribution of the Discrete Sources*

The distribution of the sources detected in the range of declinations from −4 to −60° has been analysed by a method similar to that used by Mills. The logarithm of the number of sources with level L or greater is considered as a function of L. If there is a random distribution of a large number of sources, this function should be a straight line having a slope −1·5. Figure 8 shows the ogive for the sources observed at 18·3 Mc/s. The points corresponding to levels 2·6 or less are probably not very reliable since the numbers of sources observed having these levels will be less than the true numbers owing to confusion with sources of greater intensity. It is seen that the points are fitted by a line

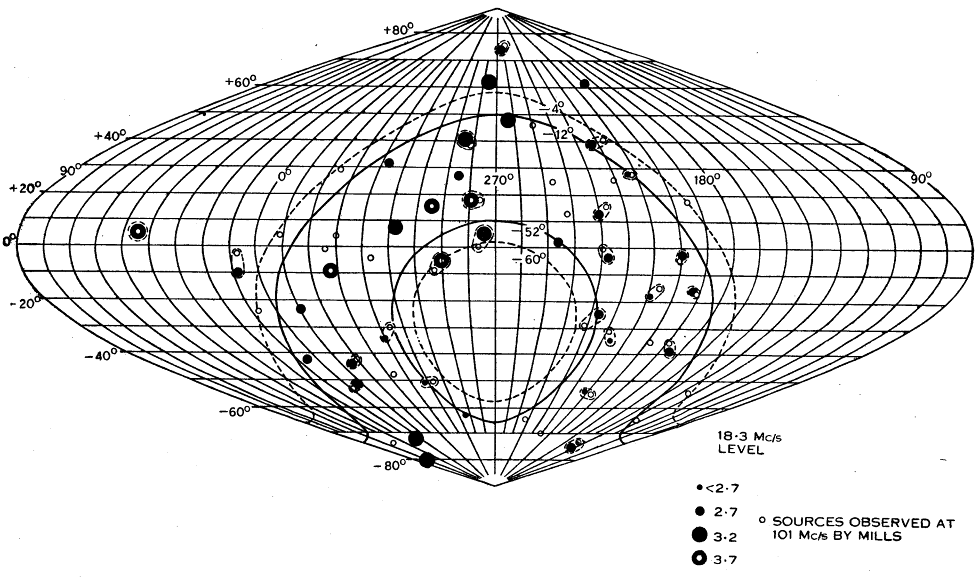

Fig. 7.—Map of the discrete sources observed at 18·3 Mc/s (galactic coordinates). Intensities are indicated by different symbols as shown. The full and dotted curves show the limits of the aerial maximum and half-power points in the main survey. Open circles give the positions of sources observed by Mills ; dashed lines have been drawn round the symbols which probably indicate observations of the same source.

having a slope of about −1·1 rather than −1·5. This result is similar to that obtained by Mills. Mills then considered separate ogives for the sources within ±12° of the galactic plane and for the remainder. He found that the sources near the galactic plane gave an ogive slope of −0·75 while the remaining sources gave a slope of nearly −1·5, a result consistent with the hypothesis that the latter sources comprised a homogeneous distribution.

Although, when analyzed in the same manner, the 18·3 Mc/s sources gave a similar result, it was thought that, with the smaller number of sources available for discussion, a different method of presentation, involving the largest possible number of sources at each step, should be adopted. First, the least squares solution for the slope of the number-level ogive was calculated, omitting sources with level 2·6 or less. Then the three sources in the band around the equator from latitudes −3 to +3° were removed and the slope of the ogive for the remaining sources was calculated. This procedure was repeated as the band around the equator containing the discarded sources was widened in small steps until the number of sources left became small. (For latitude limits 0, 18, and 27° the numbers of sources used were respectively 24, 14, and 11.) The results of these calculations are shown in Figure 9 where the points represent the slope of the ogive neglecting the sources in a band around the equator extending to the appropriate latitude limit. It is seen that the magnitudes of the slopes are about 1·3 or less until the ogive is restricted to sources outside a range of 18° from the galactic plane and then increases sharply to at least 1·5. This suggests that the sources outside that range of latitude are distributed homogeneously

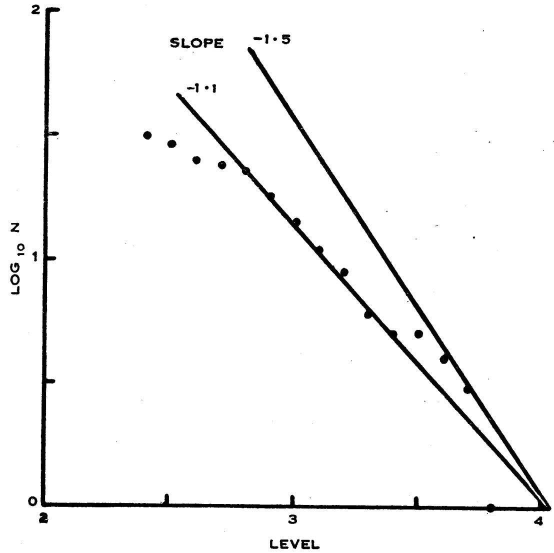

Fig. 8.—Number-level ogive for all sources with declinations between —4 and —60°. N is the number of sources with level L or greater.

whereas the sources within ±18° of the galactic plane include some other class of source. This agrees with Mills's conclusions. Similar calculations to the above were made for the sources in Mills's list (omitting sources with levels less than 1·0) and these gave the slopes indicated by the crosses in Figure 9. The 18·3 Mc/s and 101 Mc/s results are in very good agreement.

A check was made to see whether the density of sources was greater in the northern galactic hemisphere than in the southern hemisphere. It was found that there was no significant difference, but the comparatively small area of the northern hemisphere covered in the survey did not allow a very sensitive test to be made.

(*d*) *Source Scintillations*

(i) *Observations*.—Soon after recording began it was noticed that there were often irregular fluctuations in intensity at times when it appeared that a discrete source was passing through the aerial beam, although there were some sources which were rarely, if ever, seen to fluctuate in intensity. It was thought that the presence or absence of scintillations might be a property of a source. However, Ryle and Hewish (1950) have found a diurnal variation in the amplitude of these " scintillations " of sources observed at high angles while Bolton, Slee, and Stanley (1953) found both annual and diurnal variations for their low angle observations and it was therefore necessary to check whether the lack of scintillations for some sources was not merely an effect of the times of observation. Unfortunately there are no sources for which observations extend over more than a few months (corresponding to a few hours' variation in local time of observation), but a number of sources were chosen for study of their scintillations so that there were observations covering all hours of the day and a large part of the year.

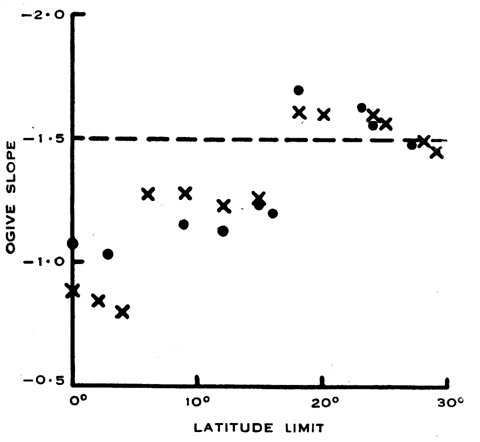

Fig. 9.—Slope of the number-level ogive for sources outside a band around the galactic equator having the width specified by the appropriate latitude limit.

• 18·3 Mc/s: sources between —4 and —60° declination with levels 2·7 or greater.

× 101 Mc/s: all sources with level 1·0 or greater.

The average amplitude of the scintillations for a record of a particular source was estimated in terms of the amplitude of the inherent noise fluctuations of the trace. For all the observations the bandwidth of the receiver was kept constant and similar recorders were used. Then, although the records were made with various settings of the receiver gain, the width of the trace on the record corresponded to a constant fraction of the total noise intensity at the time of observation. The estimates of the amplitude of the scintillations could then be converted to the units in which the intensity of the source was expressed. A scintillation index for observations of a source during a particular month was calculated as one-half the monthly average of the estimated daily averages of the amplitude of the scintillations divided by the intensity of the source. This index should then be comparable with that used by Ryle and Hewish. Although the method of estimation is rather rough, it is sufficiently reliable for comparison between different sources and for correlations of scintillations with ionospheric phenomena.

(ii) *Results.*—Scintillation indices were calculated, for all months for which observations were available, for 12 sources. In Figure 10 (*a*) these indices are plotted against the month of observation and in Figure 10 (*b*) against time of

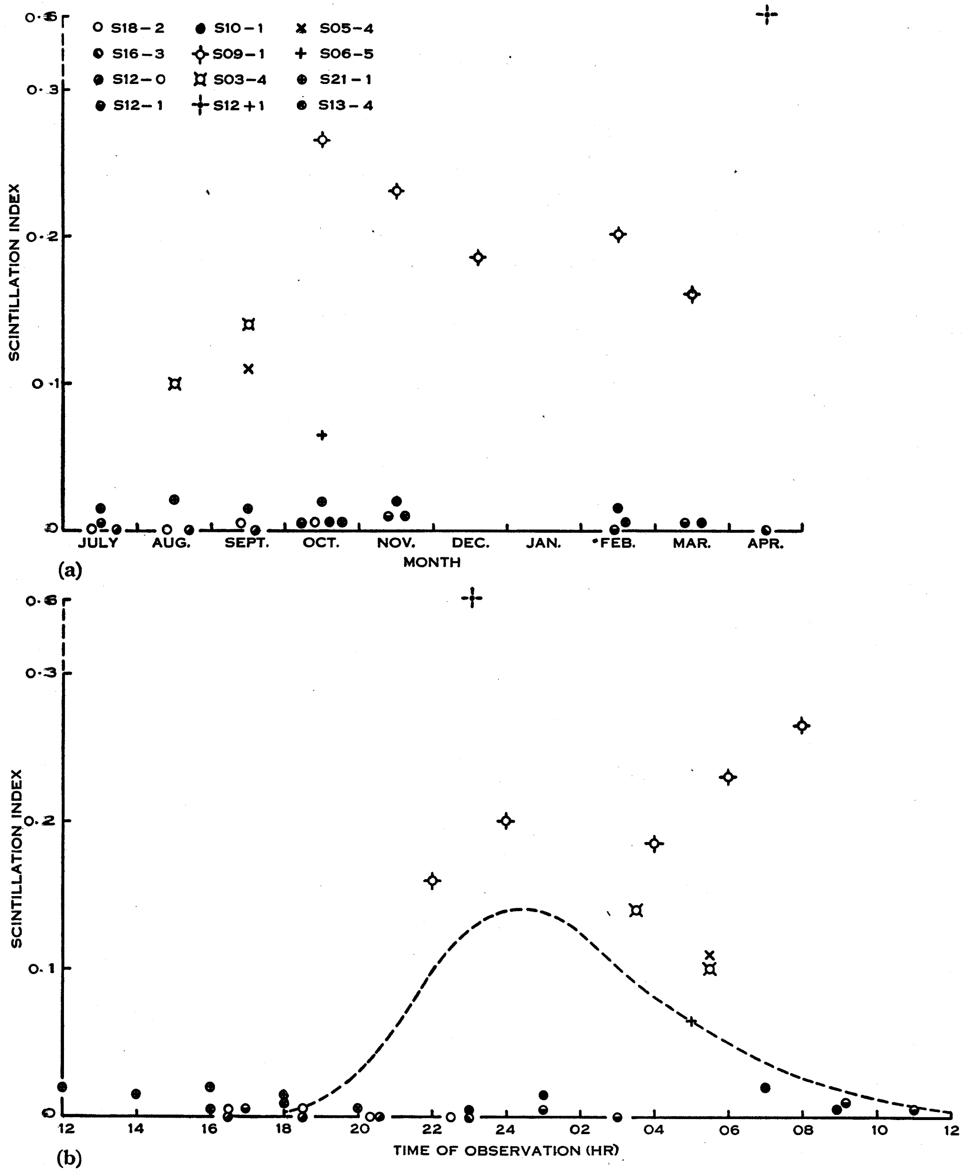

Fig. 10.—Scintillation indices for 12 sources (each represented by a symbol as shown) plotted against (*a*) month of observation, (*b*) time of day. The dashed curve in (*b*) shows the diurnal variation of scintillation index observed by Ryle and Hewish (1950).

day. The dashed curve in Figure 10 (*b*) represents the diurnal variation of scintillation index reported by Ryle and Hewish from their observations of four northern sources. Both figures show a considerable scatter in the values of scintillation index. Although high values of scintillation index have not been observed during the winter nor during the midday and afternoon hours, this does not imply marked diurnal and seasonal variations since the sources with high scintillation indices have not been observed at these times. In fact no significant trends can be deduced from these data, but Figures 10 (*a*) and 10 (*b*) together bring out the fact that there are wide differences in the scintillation indices for different sources, even when observed at approximately the same time of day in the same season. This can be seen in the differences between the sources S09–1, S10–1, and S12–1, but the most striking illustration is the difference between the sources S12+1 and S12–0.

These two sources appear on some records as one clear increase (bump) somewhat lengthened with respect to the aerial beam width (see Fig. 11). On

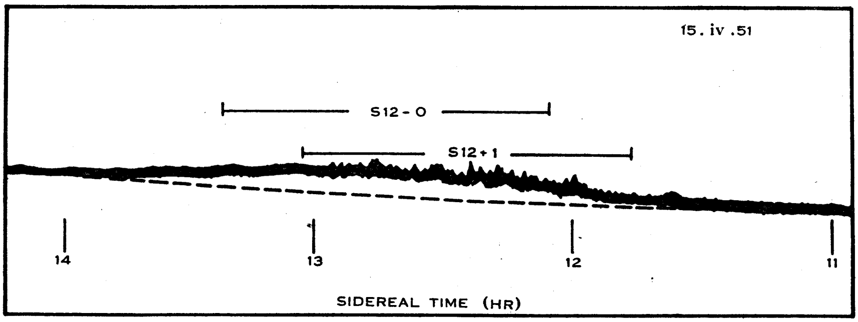

Fig. 11.—A record showing the " bump " as the sources S12+1 and S12—0 pass through the aerial beam. The source S12+1 which transits earlier shows marked scintillations, whereas there are few, if any, scintillations on the later portion of the bump, due to the source S12—0. The lines above the trace show the half-power points for the two sources ; the dashed line indicates the background radiation.

this bump fluctuations in intensity were often observed for a time which would correspond to the passage of a single source through the aerial beam, but the maximum of the fluctuations was clearly displaced from the maximum of the smoothed bump. Thus, of the two sources observed under practically the same conditions, one shows considerable scintillations whereas the other shows none.*

The suggested explanation of this difference is to be found in the different angular sizes of the sources. Previous work (e.g. Little and Maxwell 1951) has suggested that the scintillations are due to diffraction by irregularities in the *F* region of the ionosphere, the irregularities having such a size as to subtend an angle of about $0 \cdot 5$–$1 \cdot 0°$ at the Earth's surface. Then, for constant observing conditions, a source will have a high or low scintillation index depending on whether its angular size is much less or greater than about $0 \cdot 5°$. The sources considered in Figure 10 may be roughly divided, according to scintillation indices, into the classes shown in Table 2, corresponding to scintillation indices

* The source S12+1, together with S09—1, is also distinguished by the more rapid rate of scintillation (up to several peaks per minute) in comparison with the other sources (one peak every few minutes).

0·01 or less, 0·02, 0·1, and greater than 0·2. Then, if the critical angular size for the sources to show marked scintillations is 0·5°, the classes in Table 2 would correspond to angular sizes of sources 1° or greater, 0·5–1·0°, about 0·5°, and less than 0·5° respectively. Although there may be some doubt as to the absolute scale of sizes, the table should give a good indication of relative angular sizes.

The source S12+1 corresponds to the source observed by Mills (1952*a*) and designated 12+1 (Virgo–A). This source has been shown (Mills 1952*b*) to have an equivalent angular size of about 0·1° at 101 Mc/s, and in recent observations Mills (personal communication), using a new technique, has detected a source close to the position of S12−0 which has an angular size greater than 1°. Assuming the source sizes at 101 Mc/s are comparable to those at 18·3 Mc/s, Mills's observations agree with the values deduced from Table 2 and confirm the suggested explanation for the differences in scintillation indices.

TABLE 2

OBSERVED SCINTILLATION INDEX (A ROUGH INDICATION OF ANGULAR SIZE)

<0·01	0·02	0·1	>0·2
S12—0 S12—1 S16—3 S18—2	S10—1 S13—4 S21—1	S03—4 S05—4 S06—5	S09—1 S12+1

(iii) *Correlation between Scintillation Amplitude and Ionospheric Data.*—The daily amplitude of the scintillations of the sources S09−1 and S13−4 were compared with fE_s (the highest frequency on which "sporadic E" echoes are observed) and with the occurrence of "spread F" echoes, from the records of the Canberra station of the Ionospheric Prediction Service of the Commonwealth Department of the Interior.

For correlation with fE_s, the scintillation amplitudes were divided into several ranges and the average was found of the values of fE_s recorded during the observations of scintillations in a certain range. No correlation was obtained between fE_s and amplitude of scintillations. Also, using a similar method, no correlation was found with magnetic K-index.

During the period of interest, there were very few occasions on which spread F echoes were reported and on these occasions the amplitude of the scintillations was neither unusually high nor low. Nevertheless it is possible that the occurrence of scintillations is connected with the occurrence of spread F echoes as the amount of "spread" in critical frequency of the irregularities required to produce scintillations at 18·3 Mc/s is probably so small (see, e.g. Little 1951) that it would not be noted in routine ionospheric recording.

(iv) *The Height of the Irregularities causing the Scintillations.*—Provided the lateral dimensions of the irregularities causing the scintillations are greater than the dimensions of the first Fresnel zone at the height concerned, for radiation of the lowest frequency considered, the scintillation index would be expected to vary as the square of the wavelength. Such a variation was found by Hewish (1952) and also by Bolton, Slee, and Stanley (1953) for frequencies near 100 Mc/s. However, it will be seen from Figure 10 (*b*) that the scintillation index for the smallest (angular size) sources observed at 18·3 Mc/s is not much more than the index for sources observed at 81 Mc/s by Ryle and Hewish (1950), indicating a very slow variation with wavelength. The possible explanation of this is that when the frequency is reduced to 18·3 Mc/s, the size of the irregularities, assumed the same at all frequencies, is of the order of magnitude of the first Fresnel zone.

Several authors (e.g. Little and Maxwell 1951) have shown that the lateral dimensions of the irregularities are about 4 km. This would be the diameter of the first Fresnel zone for 18·3 Mc/s at a height of about 500 km, which is consistent with the height of the irregularities deduced by Hewish (1952). On the basis of the arguments of this Section, such a height would be an upper limit. A lower limit cannot be set definitely. For example, if the irregularities causing scintillations were in the *E* region (at a height of about 120 km), a size of 4 km would be only about twice the diameter of the first Fresnel zone, so that this height could not be excluded.

Of course these arguments break down if the irregularities causing the scintillations at higher frequencies are different from those affecting the 18·3 Mc/s radiation.

V. Conclusion

Although, for different frequencies there are important differences both in absolute intensities and in the distributions of brightness over the sky, these observations have confirmed earlier conclusions that the variation with frequency of the characteristics of cosmic noise is smooth, so that useful comparisons can be made between observations at comparatively widely-spaced frequencies. The observations described in the present paper should be useful for such detailed comparisons. In particular, the aerial diagram of the array used for this work bears a close similarity to that of the aerial used by Bolton and Westfold (1950) and, with some minor corrections, these two surveys can be compared directly. Such a comparison will be considered in a subsequent paper. That paper will also discuss the information that can be obtained from a comparison of the flux densities of the discrete sources given in this paper and as measured by Mills (1952*a*).

These observations were made using the pencil-beam technique, even though the resolution was not very high. They have confirmed the suggestion that a fairly large number of the discrete sources subtends considerable angles, certainly much greater than the angles subtended by visual stars, and they have also confirmed the conclusions of Mills concerning the distribution of the discrete sources over the sky. The observations of scintillation phenomena have been shown to be consistent with the deductions of previous workers from observations of the scintillations at higher frequencies.

VI. References

Bolton, J. G., Slee, O. B., and Stanley, G. J. (1953).—*Aust. J. Phys.* **6**: 434–51.

Bolton, J. G., and Westfold, K. C. (1950).—*Aust. J. Sci. Res.* A **3**: 19-33.

Hewish, A. (1952).—*Proc. Roy. Soc.* A **214**: 494-514.

Little, C. G. (1951).—*Mon. Not. R. Astr. Soc.* **111**: 289.

Little, C. G., and Maxwell, A. (1951).—*Phil. Mag.* **42**: 267-78.

Mills, B. Y. (1952*a*).—*Aust. J. Sci. Res.* A **5**: 266-87.

Mills, B. Y. (1952*b*).—*Nature* **170**: 1063.

Ryle, M., and Hewish, A. (1950).—*Mon. Not. R. Astr. Soc.* **110**: 381.

Shain, C. A. (1951).—*Aust. J. Sci. Res.* A **4**: 258-67.

Stanley, G. J., and Slee, O. B. (1950).—*Aust. J. Sci. Res.* A **3**: 234-50.

Sutcliffe, H. (1953).—*Wireless Engr.* **30**: 180-1.

Westcott, C. H. (1948).—*Wireless Engr.* **25**: 215-20.