GALACTIC RADIATION AT RADIO FREQUENCIES

VI. LOW ALTITUDE SCINTILLATIONS OF THE DISCRETE SOURCES

By J. G. Bolton,* O. B. Slee,* and G. J. Stanley*

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Summary

A study has been made of the scintillations of four discrete sources at altitudes of from 0 to 10°. The observations cover the years 1947–1951 and were made at various frequencies in the range 40–300 Mc/s. It was found that the scintillation index, a measure of the amplitude of the scintillations, (1) increases with increasing wavelength, (2) decreases rapidly with increasing altitude, (3) shows seasonal and diurnal variations, the seasonal component having minima near the equinoxes and the diurnal component near dawn and sunset. The scintillation rate or the number of scintillations per minute (1) is different for sources of different declination, (2) is independent of wavelength. In the case of the Cygnus source, the data for which are the most extensive, the rate increases and the decline in the scintillation index with altitude is less rapid during the winter months.

A strong correlation is established between the occurrence of the scintillations and sporadic E. The difference in the scintillation rates for different sources can be explained in terms of variations in the size of irregularities and the effects of the winds in the E_s layer.

I. Introduction

In 1946, Hey, Parsons, and Phillips (1946) observed short period fluctuations in the intensity of galactic noise from a small region in the constellation of Cygnus. Later, Bolton and Stanley (1947) showed that these fluctuations came from what was effectively a point source and they discovered a number of other point sources. At first it was believed that the fluctuations were inherent in the sources, but since then spaced receiver observations have shown that the fluctuations are caused in some region of the Earth's atmosphere.

Observations with spaced receivers, one at Sydney and the other in New Zealand, were first made by the present writers in 1948. Sea interference technique was used at both sites for the observations of the source in Cygnus and the periods of observation overlapped for an hour each night. No correlation was found between the individual scintillations—as they are now generally called—and on some occasions no scintillations were observed at one site and violent scintillations at the other. Control observations were made of solar radiation during a period of high solar activity and almost 100 per cent. correlation was found between solar bursts and other short period fluctuations in the intensity of the solar radiation at the two sites.

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

From these observations it appeared certain that the greater part of the scintillation phenomena was due to atmospheric effects. There remained, however, the possibility of a small fluctuating component in the radiation from the source itself, and this was not discounted until the experiments of Lovell and Little (1950) and Smith (1950). These were carried out over much smaller base lines and with the source almost overhead. They showed that the correlation between individual scintillations at two sites disappeared for distances greater than about 5 km. A later but less extensive series of observations in Australia, some in conjunction with Mr. B. Y. Mills of this Laboratory (Mills and Thomas 1951), gave much the same result.

During the past 5 years about 2000 observations have been made of the four bright sources in Cygnus, Virgo, Taurus, and Centaurus. Each observation covers a period of about 2 hr from the rising of the source above the sea horizon. Most of the observations were made on a frequency of 100 Mc/s but a number were made at various frequencies in the range of 40–400 Mc/s. All observations subsequently described refer to a frequency of 100 Mc/s, unless stated otherwise. The first part of this paper gives a detailed account of the results of an analysis of this material and the second half establishes a correlation between the scintillations and sporadic *E*.

II. Scintillation Observations

(*a*) *Definition of Terms*

Before proceeding with a description of the scintillation phenomena it is necessary to define certain terms which will be used throughout the rest of this paper. It is believed that the flux densities of most of the discrete sources remain constant over long periods. On certain occasions, however, the amplitude of the signal received from the source fluctuates about a mean level with a period of about 1 min. Typical records of these fluctuations are shown in Figure 1. Here the slow variations in the signal are due to the interference method of observation. It can be seen that the amplitude and duration of the individual scintillations are by no means constant, so that any indices describing them are necessarily rough.

We shall define a *scintillation index* as the ratio of the mean peak to trough variations of the signal amplitude to its mean amplitude and express it as a percentage. For example, the scintillation index for the record of Figure 1 (*a*) approaches 200 per cent. at 1635 hr, and the mean index for the whole record is about 70 per cent.; the mean index for the record of Figure 1 (*b*) is between 30 and 40 per cent. Estimates by eye were used in assessing the records.

We shall define a *scintillation rate* as the number of peaks per minute. In determining scintillation rates from the records, where small scintillations of the order of fluctuations in the receiver noise occurred, every alternate small scintillation was counted.

(*b*) *Seasonal and Diurnal Variations in the Scintillation Index*

From 1947 to 1951 observations were made of the source in Cygnus at its rising almost every second day. Each record was assessed to give a daily scintillation index and the daily indices averaged to provide monthly means.

The values for the years 1948, 1949, and 1950 are shown in Figure 2 (*a*). The curves in this figure show a pronounced apparent seasonal variation in the scintillation index. It may be only apparent, as a diurnal variation could produce such a curve due to the change in the local time of observation of the source of 24 hr during the year.

All the available data for the four sources in Cygnus, Virgo, Taurus, and Centaurus are shown in Table 1. Some of the monthly means for the fainter sources are based on so few observations that the reliability of the mean index is

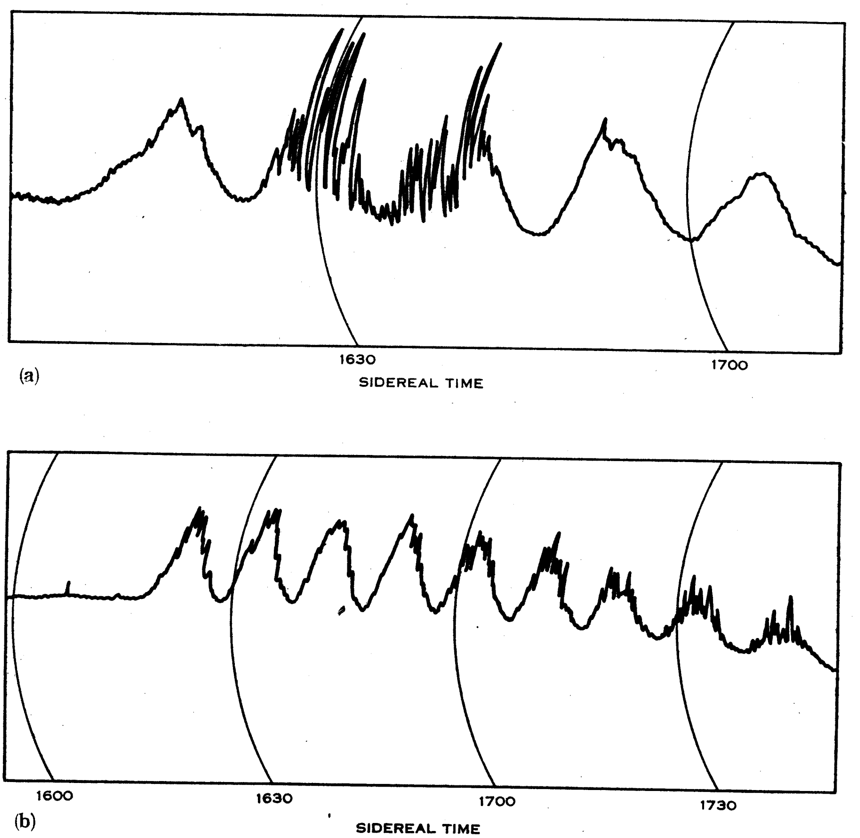


Fig. 1.—Typical records of the scintillations on interference patterns of the source in Cygnus at rising. (*a*) May 19, 1948; (*b*) June 11, 1949.

somewhat doubtful and these figures are shown in brackets. The values for the three northern sources* are plotted against the month and the local time of observation in Figures 2 (*b*) and (*c*); the heavy lines in each figure are the means of the other three curves. For the curves on a monthly basis, the local times of observation are spaced at intervals of approximately one-third of a day

* The declinations and mean azimuths of the four sources during the periods of observation are: Cygnus, 40° and 145°; Virgo, 12° and 110°; Taurus, 22° and 125°; and Centaurus, −43° and 40°.

(actually 0·28, 0·38, and 0·34 days). With such intervals, if the scintillation index contained only a diurnal component, this would appear in the mean of the curves of Figure 2 (*b*) greatly reduced in amplitude (by a factor of five or more). The amplitude of the mean curve of Figure 2 (*b*) is, however, comparable with those of the original curves and this indicates a definite seasonal

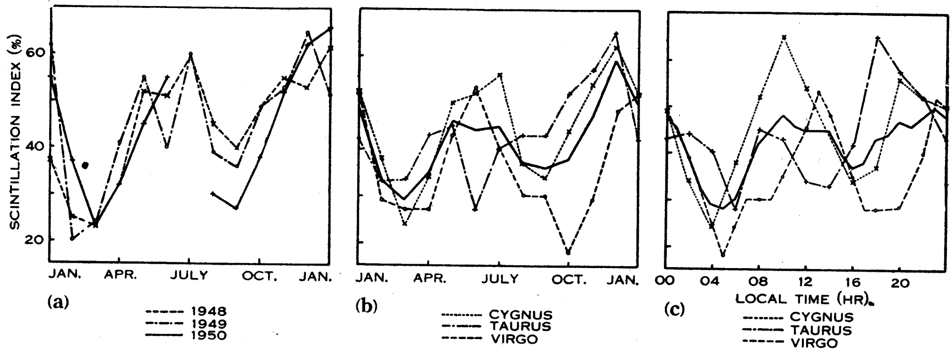


Fig. 2 (*a*).—Apparent seasonal variation in the mean monthly scintillation index for Cygnus for the 3 years 1948, 1949, and 1950.

Fig. 2 (*b*).—Mean monthly scintillation indices for Cygnus, Taurus, and Virgo plotted against the month of observation. Heavy line curve is the average of the other three and indicates the seasonal component in the variation of the indices.

Fig. 2 (*c*).—As in (*b*) but plotted against the local time of observation. Heavy line curve indicates the diurnal component in the variation of the indices.

Table 1

SCINTILLATION INDEX MONTHLY MEANS

Month	Cygnus-A		Virgo-A		Taurus-A		Centaurus-A	
	Number of Observations	Index	Number of Observations	Index	Number of Observations	Index	Number of Observations	Index
Jan. ..	45	52	17	52	10	42	7	54
Feb. ..	25	38	16	29	23	33	6	57
Mar. ..	57	24	28	27	35	34	16	37
Apr. ..	54	34	28	27	28	43	21	36
May ..	80	50	46	43	19	45	24	36
June ..	67	52	27	53	(3)	(27)	18	46
July ..	39	56	35	40	24	40	21	27
Aug. ..	50	37	21	30	7	43	—	—
Sept. ..	67	34	5	30	(3)	(43)	—	—
Oct. ..	66	44	15	18	(4)	(52)	(3)	(60)
Nov. ..	50	54	27	29	9	57	11	66
Dec. ..	49	65	22	48	12	65	6	73

component. Similarly, the mean curve of Figure 2 (*c*) indicates a true diurnal effect, as the effect of the seasonal component is almost eliminated by the displacement of it in the three original curves by intervals of one-third and two-thirds of a year. The two components have about the same amplitudes ;

the seasonal component has maxima about midsummer and midwinter with minima near the equinoxes, and the diurnal component has maxima near midday and midnight and minima near dawn and sunset.*

It can be seen from Table 1 that the monthly values of the scintillation index are different for Virgo and Centaurus, although the two sources are observed at about the same local time. This may possibly be due to the ray tracks of the two sources traversing the region of the atmosphere responsible for the scintillations at widely different latitudes. The ray paths for the sources through the E and F layers of the ionosphere are shown in Figure 9. The ray path for Centaurus is far to the south of those of the other three sources. It is not possible to suggest whether the seasonal or diurnal component of the scintillation index is more affected by latitude, as the Centaurus data are incomplete for several months of the year.

(c) *Scintillations of a Number of Sources on the Same Day*

As might be expected from the seasonal component in the scintillation index, there is fair correlation between the scintillations of sources on the same day. This has been observed in " round the clock " observations on 10 or more sources. With few exceptions all sources show some or no scintillation activity during the same period, and active or inactive periods may last for several days. The condition of the atmosphere responsible for the scintillations must therefore be widespread and must persist for several days at a time.

(d) *Variation of the Scintillation Index with Frequency*

In 1950 a series of observations were made of the Cygnus source on frequencies between 40 and 400 Mc/s. Each record was assessed for a scintillation index and the ratio of that index to the index for the 100 Mc/s record of the same day determined. This procedure was necessary as only a few observations were made at each frequency and the observations at the various frequencies were made at different times of the day and year. Difficulties due to seasonal and diurnal variations and day-to-day changes are thus removed by relating the observations to those on the base frequency. The complete series of results is shown in Figure 3 (*a*). Owing to the difficulty of assessing some of the higher frequency records where there is a low signal-to-noise ratio, the increase in the ratio beyond 200 Mc/s is questionable. More reliance can be placed on the curve of Figure 3 (*b*) where only records on active days, when the index on both frequencies exceeded 30 per cent., have been used.†

* This result is different from that of Ryle and Hewish (1950) or Hewish (1952) from observations at much higher angles of incidence in the northern hemisphere. They find a principal diurnal component in the variation of the scintillation index with a single maximum at about 01 hr. There is a slight change in the shape of the diurnal variation during the year and it has the lowest amplitude near the equinoxes.

† Hewish (1952), from observations over a 2 : 1 range of frequencies, suggests that the index is approximately proportional to the square of the wavelength. This is in fair agreement with the low frequency section of Figure 3 (*b*).

(e) Variation in the Scintillation Index with the Altitude of the Source

The scintillation index, on the average, shows a marked decline with increasing altitude of the source. This change is difficult to demonstrate from a single record or even a short series of records, as the scintillation index sometimes changes appreciably in a period of minutes. On our records the change in altitude is divided into intervals of 1° by the effect of the interference fringes. In order to reduce the labour involved in analysis we have examined only

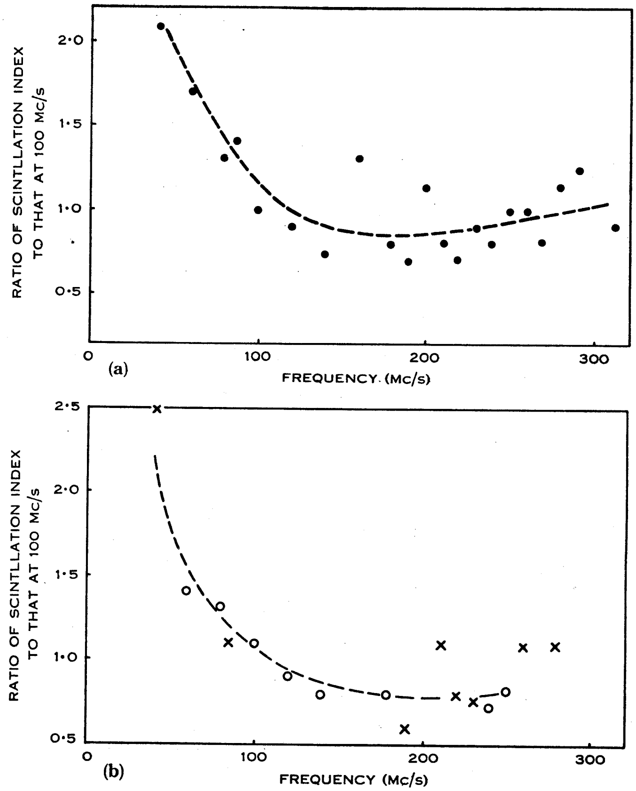


Fig. 3.—Curves showing the variation of the Cygnus scintillation index with frequency. (*a*) Includes all available records; (*b*) only records on which the scintillation index at both frequencies was greater than 30 per cent.
Circles are means of more than and crosses means of less than four readings.

the distribution of fringes in which the scintillations are particularly severe. The fringes (which for short we shall call X-fringes) are those for which the index is almost 200 per cent. Histograms of the distribution of X-fringes against altitude for the four sources are shown in Figure 4. They show a marked decline in the number of X-fringes with altitude and reflect the general decrease in scintillation activity with the altitude of the source. These histograms should possibly tail off a little more slowly, as the eighth and ninth fringes are missing on some records and are difficult to judge on others. It is stressed that the histograms do not arise from a number of records with X-fringes from 0 to 10°, a number with X-fringes from 0 to 9°, and so on, but merely indicate that the probability of observing an X-fringe decreases with increasing altitude. The number of observations of Cygnus for which the first fringe is an X-fringe (140) is quite a small fraction of the total of observations (about 800), but the histograms are considered to be a reliable indication of the behaviour of the scintillations with altitude. The same data of Figure 4 for Cygnus are presented in Figure 5 (*a*) on a monthly basis ; they have been normalized by multiplying

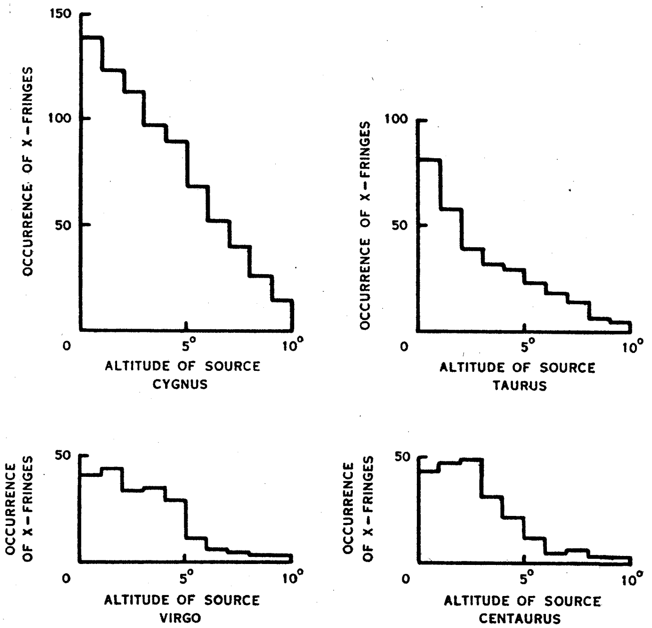


Fig. 4.—Histograms showing the number of occasions on which the scintillation index reached 200 per cent. for successive intervals of 1° altitude (X-fringes). The observations refer to four sources after their rising. The histograms reflect the decrease in scintillation activity with increasing altitude.

the number of X-fringes by the ratio of the average number of observations in each month to the actual number of observations in that month. As a general rule the scintillations decrease rapidly with increasing altitude. However, this decrease is less rapid during the winter months.

It can be seen from Figure 5 (*a*) that the incidence of X-fringes reflects the apparent seasonal variation in the scintillation index.

(*f*) *Scintillation Rates for Four Sources*

To determine the mean scintillation rate for each source a group of scintillations in an interval of 5–10 min was counted on each record. The place chosen corresponded to an interval of between 2 and 4° in the altitude of the source.

This ensured that the scintillations were of sufficiently large amplitude to make an accurate count and yet avoided peculiar effects that sometimes occur near grazing incidence. The data obtained are presented in Table 2 and Figure 6, the latter showing the distribution of scintillation rates among the days of observation.

In the case of Cygnus, sufficient data were available to study the variation of scintillation rate throughout the year. The results are presented as histograms in Figure 5 (*b*), along with the histograms showing the variation in the incidence of scintillations with altitude. The scintillation rate increases appreciably in May and June, the 4-year averages being 1·28 and 1·40 against the yearly mean of 1·15 per minute. This feature has shown up even in the individual years, the monthly values for June and October being 1·40 and 1·14 for 1948, 1·34 and 1·12 for 1949, and 1·60 and 1·06 for 1950 from about 10 observations in each month.

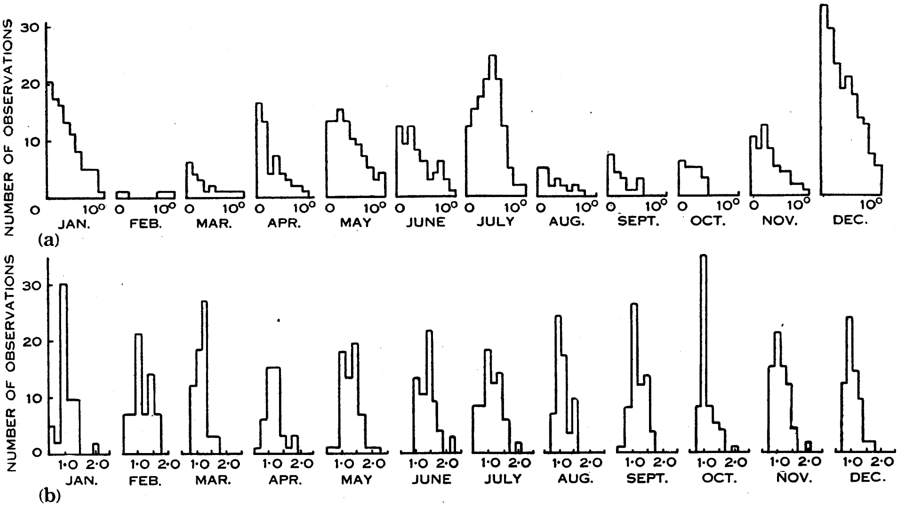


Fig. 5 (*a*).—Incidence of scintillations with altitude for Cygnus. The data of Figure 4 on a monthly basis. Note the change in distribution of the X-fringes with altitude in the winter months, indicating a slower decline in the scintillation activity with altitude.
Fig. 5 (*b*).—Seasonal variation of scintillation rate for Cygnus. The data of Figure 6 on a monthly basis. Note the higher average scintillation rates in May and June.

(*g*) *Variation of the Scintillation Rate with Altitude*

It was not possible to make any accurate estimate of the change of scintillation rate with altitude. A considerable section of each day's record was used in the foregoing analysis. In a similar section of the records at an appreciably greater altitude (say 7°) the smaller amplitude of the scintillations does not permit accurate counting. Visual inspection of the records does not suggest any marked change in the rate between altitudes of 1 and 10°.

(*h*) *Variation of the Scintillation Rate with Frequency*

The same records as were used in the analysis of Section II (*d*) were examined to find out whether there was any change in the scintillation rate with frequency.

Here again, owing to day-to-day variations in the rate and the small number of observations at each frequency, it was necessary to relate the scintillation rate at a particular frequency to that of the base frequency of 100 Mc/s on the same day. The results for six observations at each of five frequencies are presented

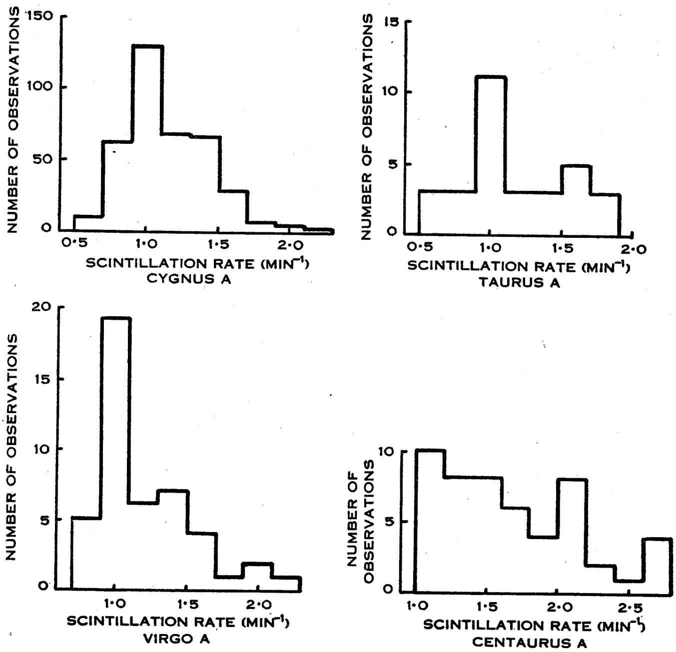


Fig. 6.—Histograms showing the distribution of scintillation rates for four sources. Each observation refers to an individual night and is the average rate during a period of 5–10 min when the altitude of the source is between 2 and 4°.

TABLE 2

MEAN SCINTILLATION RATES OF FOUR SOURCES

Source	Mean Scintillation Rate (min^{-1})	No. of Records Used	Approx. No. of Scintillations Counted
Cygnus	1·14	390	2400
Virgo	1·18	45	270
Taurus	1·24	38	200
Centaurus	1·80	51	400

in Table 3 where the differences are not greater than the experimental uncertainty. It is believed that the scintillation rate is independent of frequency over this range.* Owing to the interference method of observation and the rapid change of the scintillation index with frequency, it is generally difficult to study the

* A similar result is reported by Hewish (1952) over a 2 : 1 frequency range.

TABLE 3

VARIATION OF SCINTILLATION RATE WITH FREQUENCY

Frequency (Mc/s)	60	100	120	140	180	240
Ratio of scintillation rate to that at 100 Mc/s	0·89	1·00	0·91	0·96	0·92	1·02

correlation of individual scintillations over a range of frequencies. However, when this is possible, some similarity can be seen between groups of scintillations over a range of two to one in frequency.

(*i*) *Relation between the Scintillation Rate and Index*

Owing to the slow recorder speed of 6 in/hr used in most of the observations, it is difficult to study the relation between the scintillation rate and index. However, a small number of observations were made in New Zealand in 1948

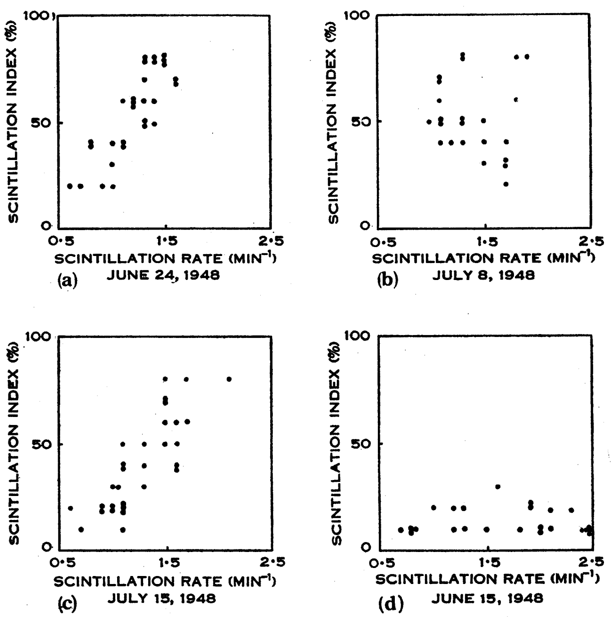


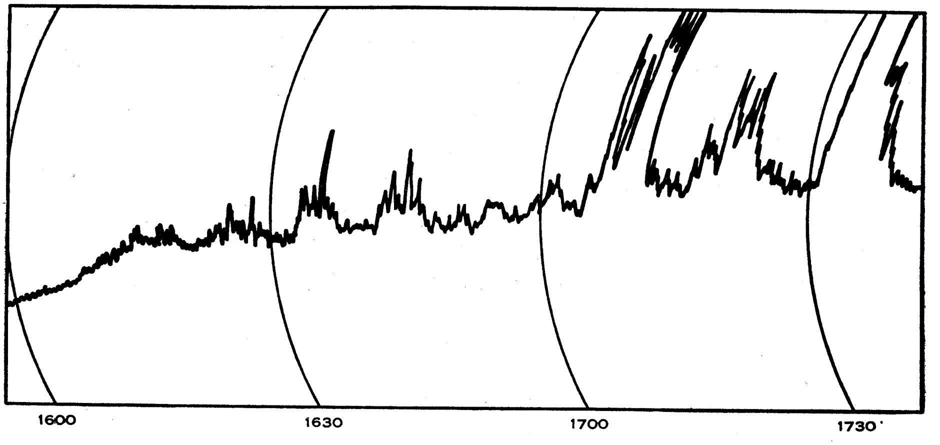
Fig. 7.—Correlation diagrams of the scintillation indices and rates for 4 nights' observation of Cygnus. Each point represents an interval of 4 min.

using a much higher recorder speed.* On most nights the rate and index showed large independent variations or one quantity remained constant while the other varied, but on about one-third of the nights there appeared to be some

* From the limited number of observations no change was found in the average scintillation rate with altitude. On occasions violent scintillations were observed up to altitudes of 14°. This is in agreement with the Sydney observations for the winter months (Section II (*e*) and Fig. 5 (*a*)).

association between the variations in the two quantities. The results for four of the nights are shown in Figure 7, each dot representing the mean value for a period of about 4 min.

Scintillations of the type represented by Figures 7 (*a*) and (*c*) have been occasionally observed in groups lasting 10–30 min on otherwise inactive days.



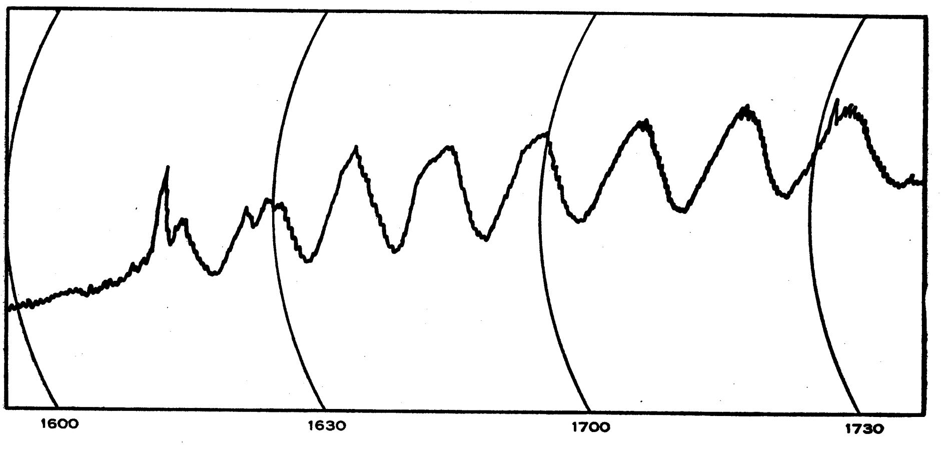


Fig. 8.—The upper record shows strong absorption and a very high scintillation rate for Cygnus at rising. The lower record, obtained the previous day, is typical for March.

The activity commences with low amplitude scintillations of long duration, and builds up to high amplitude scintillations of short duration. The reverse occurs as the activity declines. It may be that the mechanism responsible for the scintillations is different from the usual one in these cases.

(j) Other Phenomena

No association has been observed between the scintillation activity and the atmospheric conditions at ground level, so that the troposphere is unlikely to be the source of the scintillations.

No obvious long- or short-term connexion has been found between the scintillations and solar activity; no change is observed in the scintillations at sunrise; the long series of Cygnus observations has been examined for periods of the order of 27 days without results and the average scintillation activity between 1948 and 1950 (cf. Fig. 2) has remained practically constant while the sunspot numbers declined appreciably. The average sunspot numbers for the three years were 135, 135, and 85.

Possible exceptions to the foregoing are three unusual records out of a total of about 2000. One of these is illustrated in Figure 8. The lower record is typical for Cygnus in March, rising just before dawn. The unusual one (upper record) shows strong absorption of the signal and an abnormally high scintillation rate. Some of the scintillations are too fast for accurate reproduction. On two of the three occasions when such records were obtained, a visible aurora* was reported from southern Australia at about the time of observation. On the third occasion no aurora was reported but high level radio emission was received from the Sun on the preceding day.

III. Scintillations and their Association with Sporadic E

(a) Summary of Experimental Evidence

Before discussing the scintillations and their association with ionospheric phenomena the main points of the experimental evidence may be summarized as follows.

The scintillation index

(1) Shows both seasonal and diurnal variations.
(2) Decreases with decreasing wavelength.
(3) Decreases rapidly with increasing altitude. For Cygnus this decrease is less rapid in the winter months.

The scintillation rate

(1) Is independent of wavelength.
(2) Is different for sources of different declination. For Cygnus the rate is higher during the winter months.

(b) Correlation with Ionospheric Phenomena

Some difficulty is inevitably encountered in attempting to correlate the low altitude scintillations with local ionospheric phenomena. This is illustrated in Figure 9 which shows the ray tracks of the four sources in the E and F layers of the ionosphere during the periods of observation in relation to the ionospheric recording stations. There are considerable distances between the ray tracks and the nearest stations but the ionospheric condition responsible for the scintillations might, however, be expected to be fairly widespread (Section II (*e*)). We have

* A similar association of high scintillation rate and auroral phenomena is reported by Little and Maxwell (1951) and with magnetic disturbances by Hewish (1952).

therefore sought correlation between the scintillations of the three northern sources and ionospheric data from Brisbane and between scintillations of Centaurus and data from Hobart and Macquarie Island. We have used the hourly values given in the Ionospheric Predictions, Series D, of the Ionospheric Prediction Service of the Commonwealth Observatory. In assessing any indices the hourly value nearest to the time of observation and the two values on either side have been considered.

(c) *Correlation with Spread* F

Ryle and Hewish (1950), Little and Maxwell (1951), and Mills and Thomas (1951) have suggested that the scintillations are associated with disturbances in the F layer, in particular with the condition known as spread F. Such an association with the low altitude scintillations appears unlikely as the incidence

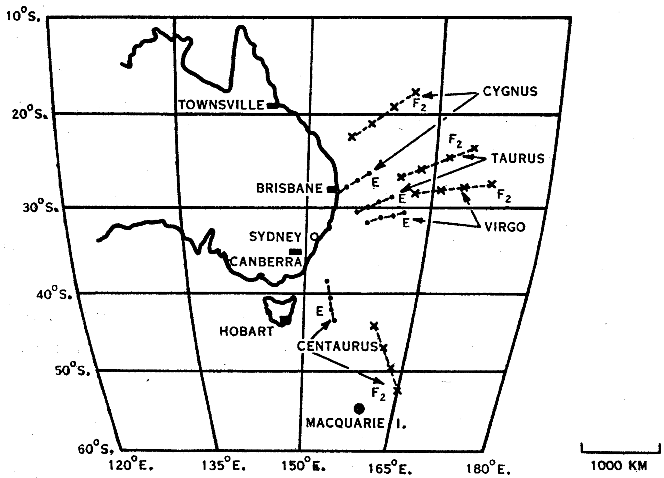


Fig. 9.—Sketch showing sections of the ray tracks of the four sources through the E and F_2 layers (at 100 and 400 km) of the ionosphere. These sections refer to the maximum period of observation of the sources each day and correspond to a range of altitude of 0 to 12° ; the dots and crosses are at intervals of 4° altitude. The positions of the ionospheric recording stations on the east Australian coast are also shown.

of spread F increases rapidly with geographic or magnetic latitude. It can be seen from Figure 9 that the ray track of the Centaurus source lies between magnetic latitudes of 50 and 60 °S., whereas the ray tracks of the northern sources are near latitude 20 °S. in the F_2 layer, yet the mean scintillation indices for the whole year are practically the same for all the sources. In spite of this, correlation was sought between the Centaurus scintillations and spread F at Macquarie Island and Hobart but with no result. A negative result was also obtained between the scintillations of Cygnus and spread F at Brisbane. However, when the analysis was restricted to the three winter months a small correlation was found. (Mills and Thomas's observations were mainly concerned with winter months.)

(*d*) *Correlation with Sporadic* E

The seasonal and diurnal components in the scintillation index suggest an association with sporadic *E* (see McNicol and Gipps 1951). A day-to-day correlation of the two phenomena was examined on the following basis. The daily scintillation index was divided into three classes:

H, high: index 60 per cent. or greater.
M, medium: index between 30 and 60 per cent.
L, low: index 30 per cent. or less.

Similar classifications were assigned to the sporadic *E* recorded at Brisbane (or Hobart in the case of Centaurus):

H, high: critical frequency high for the month concerned.
M, medium: echoes present only part of the time, or critical frequency low for the month concerned, or both.
L, no echoes observed.

TABLE 4

CORRELATION BETWEEN CYGNUS SCINTILLATION INDEX AND SPORADIC *E* AT BRISBANE

Sporadic *E* at Brisbane	Cygnus Index		
	High (*H*)	Medium (*M*)	Low (*L*)
High (*H*)	57	18	28
Medium (*M*)	35	31	41
Low (*L*)	27	34	92

The results of the analysis of the Cygnus and Brisbane data for the years 1949 and 1950 are shown in Table 4. The number of correlations is 180 or 50 per cent. of the total, the number of partial correlations is 128 or 35 per cent. of the total, and the number of anti-correlations 55 or 15 per cent. of the total. The percentages that would result from pure chance are 34, 40, and 26 respectively. If we restrict the analysis to the very definite cases of high or low indices, thus neglecting cases in which the sporadic *E* is probably patchy, we obtain the results in Table 5 for the four sources. In this table the figures that would result from pure chance are shown in brackets. In each case there are more than 20 per cent. more correlations than would be expected on the basis of pure chance.* The probabilities against the observed results occurring by chance are less than 1 in 15,000 for Cygnus, 1 in 360 for Virgo, 1 in 25 for Taurus, and 1 in 12 for Centaurus, the lower values being due to the smaller number of observations. The high significance of the number of correlations indicates a strong connexion between the low altitude scintillations and sporadic *E*.

* These figures are the same (or better if partial correlations are included) as those obtained between scintillations at high angles of incidence and spread *F* by observers in the northern hemisphere (Ryle and Hewish 1950; Little and Maxwell 1951). The data for Cygnus were examined in periods of 3 months but the percentage of correlations was not found to vary with the time of year.

(*e*) *The Scintillation Index and the Critical Frequency of Sporadic* E

A comparison between the mean monthly scintillation index for Cygnus and two indices describing sporadic *E* at the time of observation of the source is shown in Figure 10. These two indices are the percentage of days in each month when sporadic *E* was observed and the mean critical frequency of the sporadic echoes on the days observed. The results are averages for the years 1949 and 1950. It will be seen that, although the form of the three curves is similar, the critical frequency of the echoes is lower in midwinter than midsummer, and the two maxima of the scintillation index curve are about equal. The reason for the difference in the relative heights of the maxima is probably to be found in the seasonal characteristics of the sporadic *E*. Sporadic *E* at Brisbane has been studied extensively by McNicol and Gipps (1951). They

TABLE 5

CORRELATION BETWEEN SCINTILLATION INDICES OF FOUR SOURCES AND SPORADIC *E* AT NEAREST IONOSPHERIC STATIONS

Sporadic *E* at Brisbane	Cygnus Index		Sporadic *E* at Brisbane	Virgo Index	
	H	*L*		*H*	*L*
H	57	28	*H*	27	22
	(34)	(50)		(16)	(33)
L	27	92	*L*	9	53
	(50)	(70)		(20)	(42)
Sporadic *E* at Brisbane	Taurus Index		Sporadic *E* at Hobart	Centaurus Index	
	H	*L*		*H*	*L*
H	18	7	*H*	8	6
	(12)	(13)		(5)	(9)
L	7	20	*L*	2	13
	(13)	(14)		(5)	(10)

give an overall picture of the incidence of sporadic *E* as showing both seasonal and diurnal components, the former with minima near the equinoxes and the latter with minima near dawn and sunset, that is, the same as is found for the scintillations of the northern sources. They find two distinct types of sporadic *E*; one, predominant in summer, has high critical frequencies and strongly blankets the upper layers of the ionosphere, and the other, predominant in winter, has lower critical frequencies but does not blanket the upper layers. The summer type is present most of the year but only occurs on about one day in four in winter and for shorter periods. As there is no blanketing by the winter type it must have pronounced lateral irregularities. It is suggested that if one of the factors involved in the production of scintillations is the relative retardation of two adjacent rays through the E_s layer, the winter type with its lower electron concentration and more pronounced lateral irregularity might be just as effective as the summer type with a more uniform but higher electron concentration.

It is interesting to note that McNicol and Gipps suggest a possible correlation between the incidence of spread echoes from the E_s and F layers during the winter nights. This may explain the slight correlation between the incidence of Cygnus scintillations and spread F at Brisbane found for winter nights (Section III (*c*)).

(*f*) *The Size of the Irregularities in the* E *Layer*

Other writers have provided fairly satisfactory explanations of the scintillation phenomena in terms of a diffraction screen formed by irregularities in the relevant layer of the ionosphere. Hewish (1952) has shown that the phase deviation of the wave emergent from the screen governs both the amplitude and scale of the diffraction pattern on the ground. Determination of the size of the

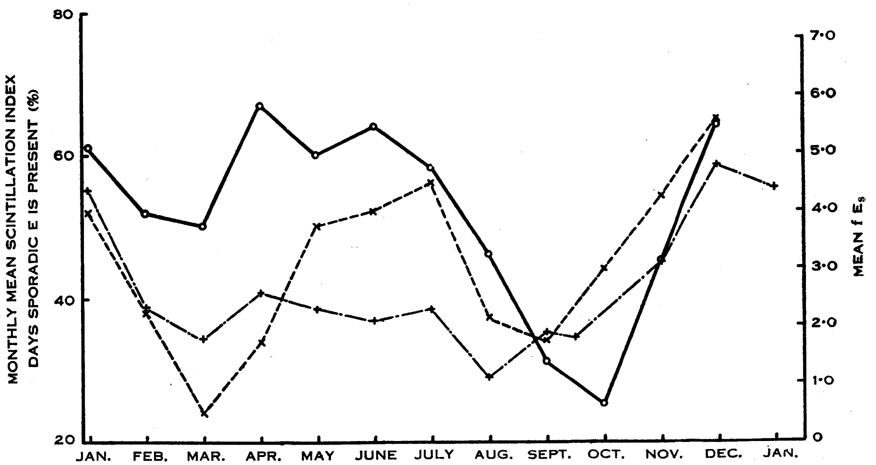


Fig. 10.—The annual variation in the mean monthly scintillation index for Cygnus (× ——— ×), the percentage of days during the month on which sporadic E is observed at the time of the Cygnus observation (o——o) and the mean critical frequency (+—·—+) on those days. Ionospheric datum is for Brisbane and all data are averages for the years 1949 and 1950.

irregularities in the screen requires in general a knowledge of the lateral extent of the phase and amplitude deviations on the ground. For phase deviations at the screen of less than 1 radn the scale of the diffraction pattern on the ground is the same as that of the irregularities in the screen, but for deviations greater than 1 radn the scale of the ground pattern is smaller. In the latter case the scale decreases as the wavelength increases.*

The scintillations result from the relative motion of the ray track of the source and the diffraction screen. In our case, as the scintillation rate is independent of wavelength between wavelengths of 1 and 5 m, we can assume

* Little (1951) suggests that the diffraction patterns on the ground are similar for a range of wavelengths if at the longest wavelength the area over which there is correlation on the ground is larger than the size of the first Fresnel zone at the screen. In such a case the scale of the pattern on the ground is the same as that of the irregularity of the screen.

that the phase deviation at the screen is less than 1 radn over this range. Hence if the diffraction theory is applicable to our case the apparent size of the irregularities can be deduced from the scintillation rate and the velocity of the ray track through the E layer (assumed stationary). The relevant data are given in Table 6. The fifth column, obtained by dividing the velocity of the ray track by the scintillation rate, gives the apparent size of the irregularities. These sizes are much greater than those found by other ionospheric measurements and are more of the order of individual clouds of sporadic E.

It is reasonable to assume that over the relatively small distances between the ray tracks of the three northern sources (of Fig. 9) the true sizes of the irregularities would not change by the amounts indicated in Table 6. The differences in the apparent sizes can be explained by postulating irregularities which are elongated in an east-west direction, or by taking ionospheric winds into account, or both. Munro (1950) finds that near Sydney winds of the order of 3 to 4 km/min exist in the E layer ; their directions are towards the north-west

TABLE 6

RAY TRACKS OF SOURCES AND SCINTILLATION RATES

Source	Velocity of Ray Track		Scintillation Rate (min^{-1})	$\frac{\text{Velocity}}{\text{Rate}}$ (km) (*Apparent* Size of Irregularities)
	Speed (km/min)	Direction of Travel of Ray Track		
Cygnus	4·1	30° S. of W.	1·14	3·6
Taurus	7·2	20° S. of W.	1·24	5·8
Virgo	8·0	10° S. of W.	1·18	6·8
Centaurus	6·1	75° N. of W.	1·80	3·3

in summer but more towards the north in winter. A wind of 3·5 km/min towards the north-west would reduce the discrepancies of Table 6, giving the sizes as 3·8 km for Cygnus, 4·9 km for Taurus, and 5·3 km for Virgo. In addition, the change of wind direction towards the north in winter would explain the higher scintillation rate observed at that time for Cygnus. However, the discrepancy between Centaurus and the other three would be further increased by such winds but it is likely that both the size of the irregularities and the winds are different in the part of the E region crossed by the ray track of Centaurus.

If the irregularities were in the F layer and Munro's wind characteristics for this layer adopted, the size of the irregularities would average 17 km for the three northern sources, that is, much greater than the sizes indicated by spaced receiver observations.

(g) *The Decrease of Scintillations with Altitude*

The observed decrease in the scintillation index with altitude is much greater than would be expected merely on the basis of the change in the path length through the E layer. A similar result has been obtained by Little and

Maxwell (1951) and Hewish (1952). On the diffraction theory they suggest that up to a certain distance the index would increase with the distance from the screen. In our case the change in distance is 2 : 1 during the period of observation.

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