THE DAYLIGHT METEOR STREAMS OF 1947 MAY–AUGUST

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(Communicated by P. M. S. Blackett)

(Received 1948 March 9)

Summary

During the autumn and winter of 1946–1947 the well-known meteor showers were investigated by the radio echo technique on 4·2 m. wave-length. The results, both as regards activity and radiant areas, conformed closely to expectation from previous visual work. But during the investigation of the η Aquarids, which commenced on 1947 May 1 it was found that the well-known shower with its radiant near η Aquarii was not an isolated event, but merely the beginning of a great belt of meteoric activity extending towards the Sun observable only in daylight. Initially the main radiant of this new daylight shower was in Pisces, but the phenomena developed with great rapidity and by the end of June at least seven centres of considerable activity had been delineated, extending in the ecliptic up to $\alpha=90°$. This daylight activity continued throughout July and August, and comparison with the known major showers indicates that it is without precedent in extent and duration.

1. *Introduction.*—The evolution of the radio echo technique for the study of meteors has enabled a systematic survey to be made of meteoric activity, unhampered by cloud or daylight. In this work the daylight investigations are of particular interest, since they yield information about the meteor streams falling on the sunlit side of the Earth. During the summer of 1945 Hey and Stewart * delineated two daylight radiants between June 6 and 13 and during the daylight hours of 1946 May, June and July, Prentice, Lovell and Banwell † found a high general level of meteoric activity. The real significance of these results was not immediately apparent, since little evidence existed as to the relation between the number of radio echoes and the number of visible meteors. During the autumn and winter of 1946–47 a careful survey was made of the known meteor showers from which it was apparent that, with the radio wave-lengths and apparatus constants used in this work, a close relation existed between the number of radio echoes and the number of meteors seen by a visual observer. After discussing these relationships this paper describes the investigation of the daylight activity from 1947 May to August, which was of a most extensive and unexpected character.‡

2. *The Relation between Radio Echoes and Meteors.*—The short duration radio echoes originating in the neighbourhood of 100 km. above the Earth's surface have been studied since 1929, and it was demonstrated in the early days of this work by Skellett §, Schafer and Goodall || that meteors were, at least in part, responsible for these echoes.¶

* Hey, J. S. and Stewart, G. S., *Proc. Phys. Soc.*, **59**, 858, 1947.

† Prentice, J. P. M., Lovell, A. C. B. and Banwell, C. J., *M.N.*, **107**, 155, 1947.

‡ A preliminary announcement of the discovery of this daylight activity was made in *B.A.A. Circulars* Nos. 282 and 285, 1947.

§ Skellett, A. M., *Proc. Inst. Rad. Engr.*, **23**, 132, 1935.

|| Schafer, J. P. and Goodall, W. M., *Proc. Inst. Rad. Engr.*, **20**, 1131; **20**, 1941, 1932.

¶ A review of the work on the transient echoes has been given by Lovell, A. C. B., *Phys. Soc. Rep. Progr. Phys.*, **11**, 1948 (in the press).

Until the work of Hey and Stewart * on wave-lengths in the 4 m. to 5 m. region, all previous investigators used much longer wave-lengths (~10 m. or above) and the real significance of the work to astronomy was obscured by the complexity of the echo phenomena which appeared to bear little resemblance to the main features of meteoric activity hitherto known to the astronomers. The phenomena on these longer wave-lengths are not yet properly understood, but it is now well established that on wave-lengths shorter than 6 m. the radio echoes observed are due only to the meteors which are clearly associated with the meteor streams of the type known to the visual observers. Also on these shorter wave-lengths the main radio echo is obtained only when the meteor crosses the perpendicular from the receiving station to the direction of the trail. † This aspect sensitivity leads to methods for the determination of the radiant points of the meteors ‡, and it is evident that contemporary radio technique on these short wave-lengths provides a powerful method for the investigation of the activity and radiant points of meteor streams free from the effects of cloud, daylight and the complex radio echo phenomena on the longer wave-lengths.

3. *Apparatus.*—The essential features of the apparatus have been described elsewhere.§ The wave-length used was 4·2 m.; peak power in the transmitter pulse 50 kw.; pulse recurrence frequency 150 c.p.sec. and pulse width 8 μsec. The receiver sensitivity was such that a signal of 2 μV. at the receiver input doubled the signal/noise ratio. The large directional aerial system described previously || was used throughout this work. Observations were made visually on a cathode-ray tube display from which the range, duration and amplitude of the radio echoes were observed.

4. *Observations of the Night-time Meteor Showers.*—The apparatus in the form described in Section 3 with the directional aerial system was first used during the Giacobinid shower of 1946 October 9–10. This work has been described previously ¶ and provided a very satisfactory proof that a high percentage of the radio echoes observed were associated with meteors from the major showers. Further experience on the well-known meteor showers also indicated that the hourly rate found on this particular apparatus was in reasonable agreement with the visual rate found by a single observer. Thus Table I shows the maximum hourly rate found by these radio echo observations compared with the maximum hourly rates predicted by Prentice ** for visual observers.

The duration of the above showers was also in good agreement with the durations predicted by Prentice. Further, when no showers are active, or when the aerial beam is directed away from its appropriate position at right angles to the direction of the radiant, the echo rate falls to approximately 1·5 per hour. It can therefore be assumed that the characteristics of new showers found by this apparatus under conditions not permitting visual observations (cloud or daylight) will be closely equivalent to the visual characteristics of the shower.

* *Loc. cit.*

† Hey and Stewart, *loc. cit.*; Lovell, A. C. B., Banwell, C. J. and Clegg, J. A., *M.N.*, **107**, 164, 1947.

‡ Hey and Stewart, *loc. cit.*; Clegg, J. A., in publication. (See footnote, p. 371).

§ Lovell, A. C. B., Banwell, C. J. and Clegg, J. A., *loc. cit.*; Prentice, J. P. M., Lovell, A. C. B. and Banwell, C. J., *loc. cit.*

|| Lovell, A. C. B., Banwell, C. J. and Clegg, J. A., *loc. cit.*

¶ Lovell, A. C. B., Banwell, C. J. and Clegg, J. A., *loc. cit.*

** *B.A.A. Handbooks*, 1946, 1947 and 1948.

TABLE I

	Radio Echo Maximum Hourly Rate 1946	1947	1948	Visual Rate at Maximum (after Prentice)	Duration of Visual Maximum (days)
" No shower " rate	1·5	1·5	1·5		
Quadrantids, Jan. 3	*	50	100	40	1
Lyrids, Apr. 21	*	15	*	7 to 12	2
Perseids, Aug. 10–13	30	30	*	55	4
Orionids, Oct. 18–23	7	10	*	8 to 10	6
Taurids, Nov. 3–10	5	8	*	5 to 6	8
Leonids, Nov. 16–17	10	3	*	8	2
Geminids, Dec. 11–13	50	60	*	60	3

* Observations not made.

5. *Investigation of the η Aquarids and discovery of the New Radiant in Pisces.*—The investigation of the η Aquarid meteor stream commenced on 1947 May 1. For this purpose the radiant position was taken to be $\alpha = 333°$; $\delta = \pm 0°$, as found from previous visual observation *, and the aerial system directed accordingly.† The method of delineating the radiant points of a stream has been described by Clegg.‡

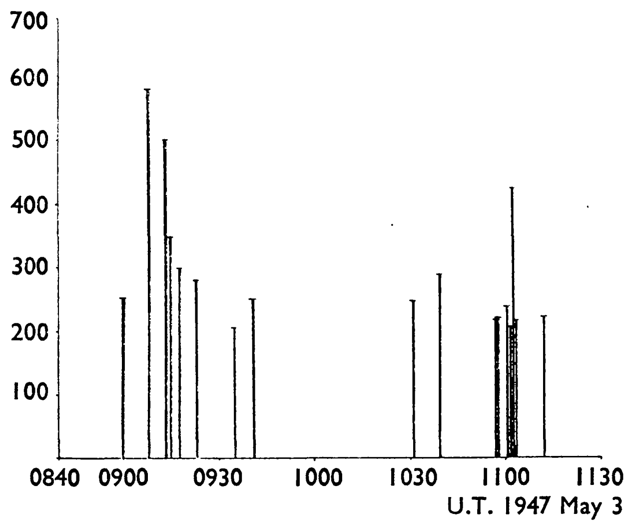

FIG. 1.—*Range/Time plots of echoes with aerial at azimuth* 110° *on* 1947 *May* 3. *Ordinates : Range in km.*

Fig. 1 shows the results obtained on 1947 May 3 between $8^h 40^m$ and $11^h 15^m$ with the aerial beam directed at azimuth § 110°. A single radiant corresponding to the η Aquarid stream passed through the beam between $9^h 00^m$

* Prentice, J. P. M., *B.A.A. Handbook*, 1948.

† In the following observations the elevation of the aerial beam was maintained constant at approximately 15°.

‡ Clegg, J. A. (in publication). The method is briefly as follows :—If the aerial azimuth is 90°, the first echoes from a given radiant will be received when this is on the meridian, owing to the aspect sensitivity of the trails. It can be shown that if the aerial is at a low elevation these initial echoes will appear at long range and that the ranges will steadily decrease as the radiant moves westwards, finally disappearing as the appropriate echo-region moves out of the beam. This gives the right ascension of the radiant, and in order to determine the declination the beam is then rotated through an angle θ to the south so that it is again in advance of the echo-region and the observations repeated. From the time interval between the first appearance of the long-range echoes in the two cases the declination can be calculated.

§ In this paper azimuth is taken as a bearing east of north.

and $10^h 00^m$. During the next hour only two echoes were obtained (corresponding to the "no shower" rate) but between $10^h 55^m$ and $11^h 15^m$ a group of seven echoes appeared. This was the first indication that appreciable activity might exist well following the η Aquarid radiant. During the succeeding days this activity increased rapidly and the results with the aerial directed at 90° on May 7 between $7^h 20^m$ and $13^h 20^m$ are shown in Fig. 2. The η Aquarids transited

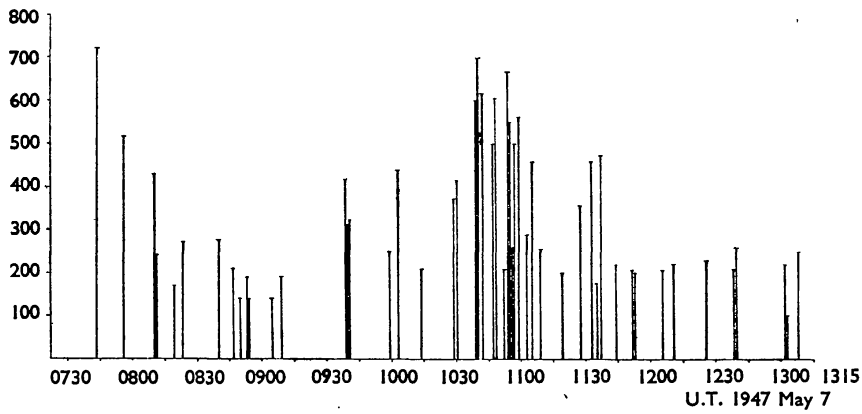

FIG. 2.—*Range/Time plots of echoes with aerial directed at azimuth* 90° *on* 1947 *May* 7. *Ordinates : Range in km.*

at $7^h 40^m$, and after some scattered activity another clearly defined radiant passed through the beam at $10^h 40^m$. It can be seen from Fig. 2 that the activity of this new radiant at this stage was 13 per hour, or twice the activity of the η Aquarids. The times of transit enable the right ascension of these radiants to be placed. The first is at $\alpha = 335° \pm 3°$ corresponding to the η Aquarid radiant and the new radiant at $\alpha = 20° \pm 2°$. Later observations on a different aerial azimuth enabled the declination of these radiants to be placed at $\delta = 0° \pm 3°$ and $\delta = +20° \pm 2°$. The first is thus verified to be the radiant in Aquarius already established by visual observation and the second to be a hitherto unknown radiant lying in the constellation Pisces. By twilight on this date a radiant in this position is just rising and hence cannot be seen visually.

6. *The Development and Radiants of the New Daylight Streams.*—After 1947 May 7, the daylight activity developed with great rapidity and became extremely complex. The events during the months of May to August were so unexpected and the general level of activity over a period of many weeks was so great compared with any previous events, that it became impossible with the single directional aerial to maintain a complete record. For example the situation on 1947 June 18 with the aerial directed at 90° is shown in Fig. 3. Compared with the results for May 7, illustrated in Fig. 2, it is evident that a stream of high activity transits similarly at $10^h 30^m$ but in addition there is considerable scattered activity preceding and a series of new radiants extending on the following side for $3^h 30^m$ in right ascension. Plots similar to those illustrated in Figs. 1–3 were obtained daily throughout May and June and check observations were then made until the commencement of work on the Perseid stream on 1947 August 1. The results of the analysis of this information are given in Table II. Columns 2, 3 and 4 of this table give the limits and duration of observation and the total numbers of echoes observed, and column 5 the principal radiants determined. The activity of ths streams cannot be directly derived from columns

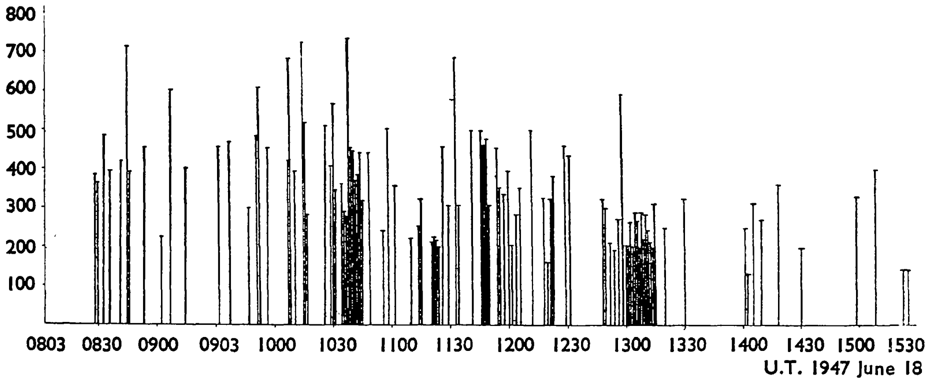

FIG. 3.—*Range/Time plots of echoes with aerial directed at azimuth* 90° *on* 1947 *June* 18. *Ordinates : Range in km.*

3 and 4 owing to the techniques used by which the aerial beam is set in advance of the radiant in order to observe the initial long-range echoes.* Entries in column 5 have been made only for the days on which marked radiants can be determined. Absence of entries does not necessarily imply that a particular radiant was not active but merely that the information obtained was either too confused or inadequate for a satisfactory delineation. Fig. 4 shows the areas of most intense activity on a Mercator projection of the heavens. (A B C D E F G corresponds to the tabulated radiants in Table II). During the latter part of July and August the situation became complicated by the presence of circumpolar radiants, and although the main streams of daylight activity still continued we are unable to delineate the radiant points with any precision. For example Fig. 5 shows the range-time plots for 1947 August 4 with the aerial directed at 90°. Two main daylight streams are still seen to be in transit at $10^h 20^m$ and $11^h 20^m$, but these are followed between $12^h 00^m$ and $14^h 30^m$ by an extensive series of echoes of gradually increasing range which corresponds with the lower culmination of a radiant in Lacerta. Similar range-time plots for August 26 are shown in Fig. 6. The activity was negligible until $10^h 50^m$ when a single radiant passed through the beam. After this date the daylight activity rapidly disappeared.

7. *The Activity of the Daylight Streams.*—Owing to the difficulties of resolution it is not possible to give the daily rates for each individual radiant. Fig. 7 shows the approximate mean daily rate per radiant. As shown in Table II a number of active radiants passed through the beam in succession on the majority of days. The equivalent overall visual rate would therefore have been determined by the sum of the activity for the individual radiants and hence would be considerably greater than the rates plotted in Fig. 7.

8. *Discussion.*—It is evident from the comparison of Tables I and II and Fig. 7 that the daylight meteor activity during 1947 May–August was of a different order from that of the regular night-time showers. The activity appears to have been caused by a number of very active radiants closely grouped in right ascension and declination and moving regularly in increasing longitude throughout the period. The phenomena were of great complexity and from the observations made it is only possible to describe the main features of the events as follows :—

(*a*) The η Aquarid stream (A in Table II and Fig. 4) conformed closely to predictions from previous visual observations. It existed from May 1 to 10

* See footnote, p. 371.

TABLE II

Date (1947)	Limits of Observation (U.T.)		Number of Hours	Number of Echoes	Principal Radiants* (α±δ)		
	h m	h m			A		
May 1	08 43	09 43	1·0	4			
2	09 30	10 30	1·0	12	**332±0**		
3	08 00	15 45	5·3	52	**341±0**		C
4	05 50	15 40	8·4	67		*7+20*	*34+25*
5	03 04	13 25	8·0	45	**339±0**		**20+20**
						B	
6	02 26	15 15	10·3	87		**354+5**	**21+20**
7	05 30	15 40	9·6	88	**337±0**		**22+20** to **41+20**
8	07 15	15 48	8·0	39			
9	05 38	16 20	10·4	130		**357+5**	**27+20** to α=**38**
10	05 25	16 25	10·6	132	**343±0**		**28+29**
11	08 44	14 37	5·5	50			**29+30** to α=**36**
12	05 20	11 12	5·4	55			**30+30** to **45+25**
13	04 33	15 40	10·5	133		**1+5**	**31+24**
14	08 05	13 50	5·5	51			**32+28**
15	07 03	12 08	5·1	52	*α=335*	**1+5**	
16	08 39	11 13	2·6	26			
17	08 20	10 30	2·0	14	*α=17, 47, 62*		
18	01 43	16 03	13·9	109			
19	08 23	13 21	5·0	22	*α=37, 68*		
20	08 13	16 11	6·1	64	*α= 0, 9*		
21	07 55	14 15	6·1	62	*α=354, 19, 31*		*51+30*
22	09 07	10 37	1·5	29			
23	08 09	14 05	6·6	96	*43+15, 50+20*		
24	07 33	13 00	4·2	53	*α=44, 51*		
25	09 40	14 06	4·4	46	*62+35*		
26	06 14	08 51	2·6	16			
27	09 03	13 30	4·1	31			
28	08 32	14 00	4·8	38	*α=35, 51*		
					D		
29	08 32	14 20	5·7	59			*36+30*
30	06 33	13 30	6·4	54	**45+35**		*37+30*
						E	
31	...	...	...	...			
June 1	...	...	...	...			
2	08 00	15 52	7·6	88	**45+25**	**52+15**	*39+30*
3	08 00	13 36	4·9	40	**47+25**	**53+15**	
4	07 08	14 16	6·6	134	**47+25**	**54+15**	
5	07 20	14 56	7·5	98	**47+25**	**54+15**	
6	07 02	15 34	8·4	162	**48+30**	**57+15**	
7	11 40	16 16	4·5	50			
8	09 55	14 07	4·1	86	**49+28**		
9	07 54	15 15	7·2	149			
10	07 30	14 35	7·1	53	**51+28**		
11	07 18	14 10	6·6	110	**51+33**	**60+15**	
12	08 23	14 00	5·5	51	**53+30**	**61+15**	
13	07 10	14 00	6·7	118	**52+30**	**62+15**	
14	07 14	08 31	1·3	27	**53+35**		

TABLE II (*cont.*)

Date (1947)	Limits of Observation (U.T.)		Number of Hours	Number of Echoes	Principal Radiants* (α±δ)		
	h m	h m			**D**	**E**	
June 15	11 00	13 11	2·1	40			
16	07 17	16 00	7·0	89			
17	07 53	14 00	3·9	141	**α=53 to 67, δ=+25 to +35**		
18	07 21	15 40	8·3	126			
19	07 44	16 00	8·2	88			
							G
20	07 24	15 28	8·0	111			**80+20**
21	12 05	16 00	3·9	37			**79+30**
					F		
22	11 04	12 04	1·0	34			
23	07 35	15 57	5·7	122	**68+35**		
24	07 25	16 08	7·6	163	**68+40**		
25	07 26	15 30	6·4	85	**68+35**		**83+25**
26	07 20	15 15	8·6	107	**66+30, 67+35,**		**84+25**
27	08 12	16 30	6·3	73	**68+30**		**85+25**
28	09 30	12 00	2·5	56			
29	11 02	13 41	2·7	44			
30	08 36	15 07	6·1	101			
July 1	08 36	16 00	7·4	100			
2	08 45	15 30	6·7	86	*α=87*	*88+10*	
3	07 57	14 15	6·2	88			
4	09 52	14 00	4·1	72	*α=74*		
5	10 40	13 20	2·6	45		*93+10*	
7	09 15	12 20	3·1	31	*α=81*		
8	09 31	10 33	1·0	13	*α=82*		
10	09 17	11 20	2·1	26	*α=71, 85*		
11	11 15	12 15	1·0	8	*α=100*		
12	10 40	12 35	1·9	28			
14	09 06	14 12	4·9	46			
17	09 29	14 20	4·9	58	*α=100, 112, 127*		
21	08 37	15 18	6·4	77			
23	08 45	14 30	5·8	81			
25	10 52	13 00	2·1	33			
28	09 19	11 30	2·2	24			
30	11 00	12 30	1·5	26			
31	10 00	13 31	3·4	46			

After July 31 the programme was interrupted by work on the Perseids, and the only subsequent observations obtained were as follows :—

Aug. 1	11 00	12 00	1·0	11	
4	08 45	15 00	6·3	64	*α=103, 120*
8	10 50	11 45	0·9	7	
19	10 13	11 43	1·5	12	
26	09 31	12 45	3·2	17	*α=134*
		Total	427·1	5298	

* The seven principal streams are indicated in heavy fount and lettered A to G corresponding with Fig. 4.

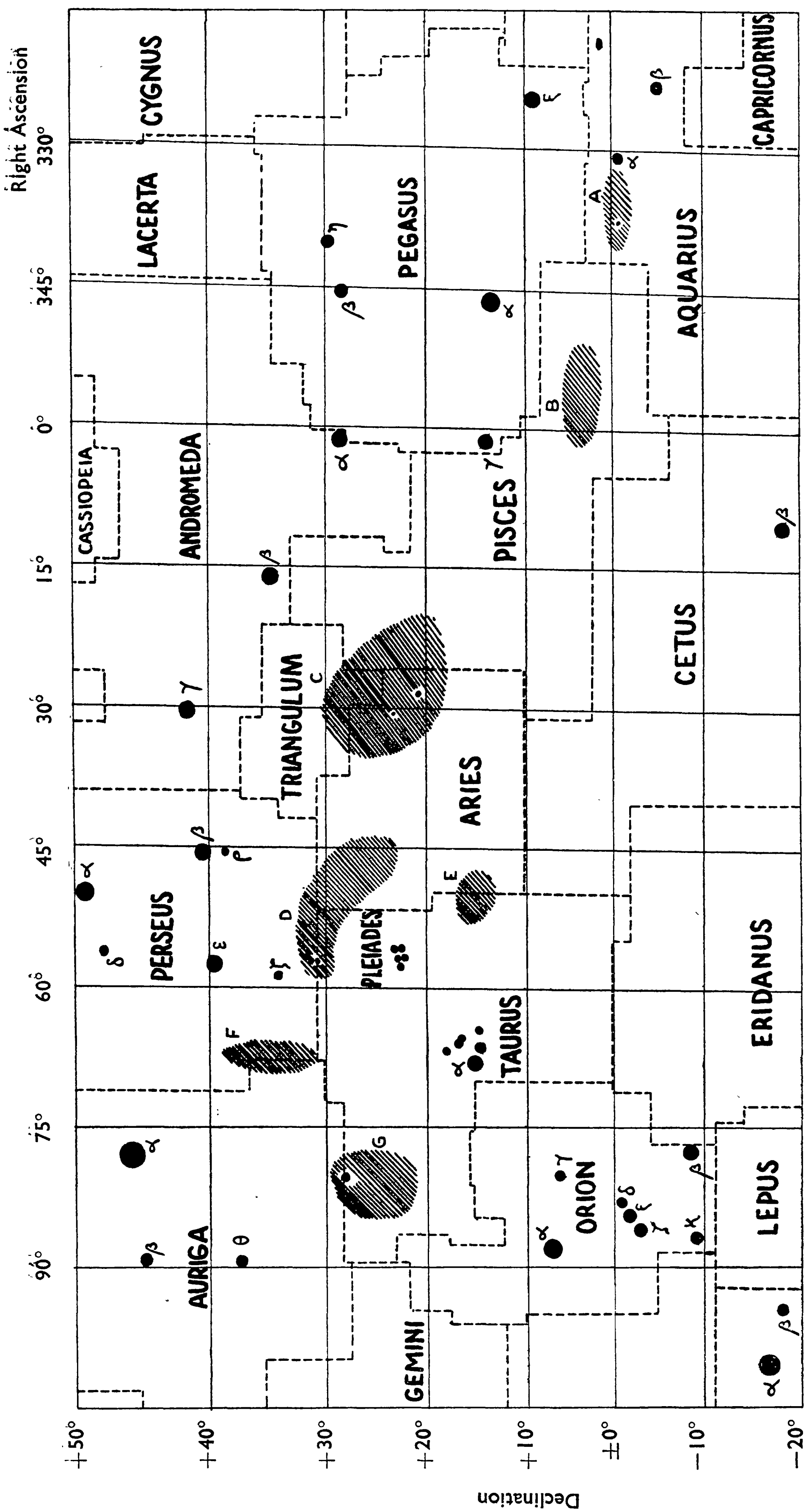

FIG. 4.—*Main Areas of Daylight Activity (Mercator Projection).*

Principal Periods of Activity :

A. *May* 1–10. B. *May* 6–15.
C. *May* 3–15. D. *May* 30–*June* 17.
E. *June* 2–13. F. *June* 23→ ?
G. *June* 20→ ?

A, B, C, D, E, F, G *correspond to Table* II.

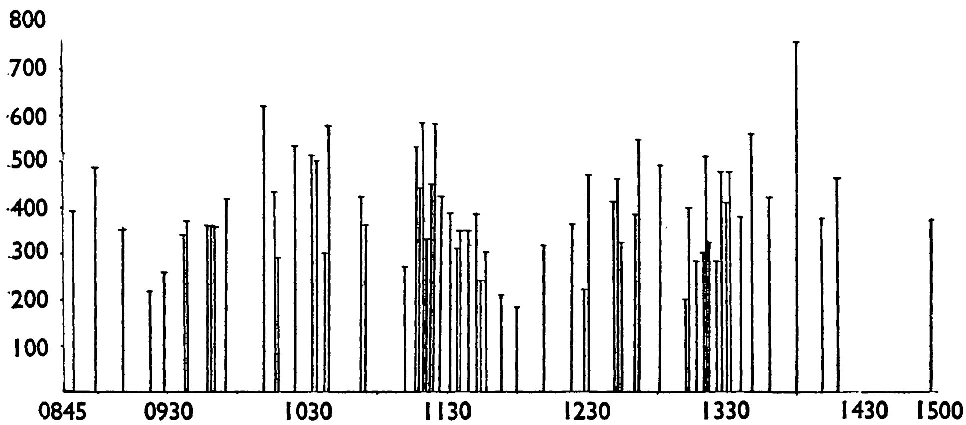

FIG. 5.—*Range/Time plots of echoes with aerial directed at azimuth 90° on 1947 August 4. Ordinates : Range in km.*

and possibly later; radiant $\alpha = 339°$, $\delta = \pm 0°$, hourly rate $\simeq 12$. Overlapping in date, there was a near following stream (B) with radiant approximately $\alpha = 355°$ to $5°$, $\delta = +5°$, hourly rate $\simeq 13$.

(*b*) Simultaneously with the appearance of the η Aquarids, three more radiants were observed following these centres. The main new Piscid radiant (C in Table II and Fig. 4) at $\alpha = 20°$ to $32°$, $\delta = +20°$ to $+30°$, with hourly rate $\simeq 20$ to 25, and minor radiants preceding and following.

(*c*) The radiant in Pisces and the two minor radiants were clearly delineated until May 15; then followed a period of confused activity. After May 29 even more active radiants, north preceding and south preceding the Pleiades, appeared at $\alpha = 45°$ to $55°$, $\delta = +25°$ to $+35°$, hourly rate 20 to 25 (D), and $\alpha = 52°$ to $62°$, $\delta = +15°$, hourly rate 20 to 40 (E).

(*d*) On June 20 the series was joined by a new centre of great activity near β Tauri at $\alpha = 80°$ to $85°$, $\delta = +20°$ to $+30°$, hourly rate 20 to 30 (G).

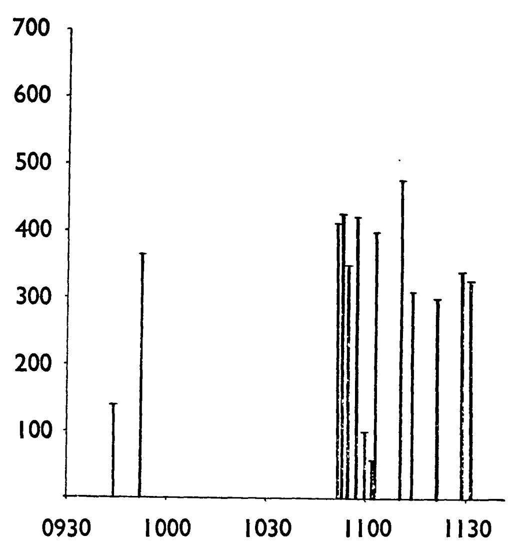

FIG. 6.—*Range/Time plots of echoes with aerial directed at 90° on 1947 August 26. Ordinates : Range in km.*

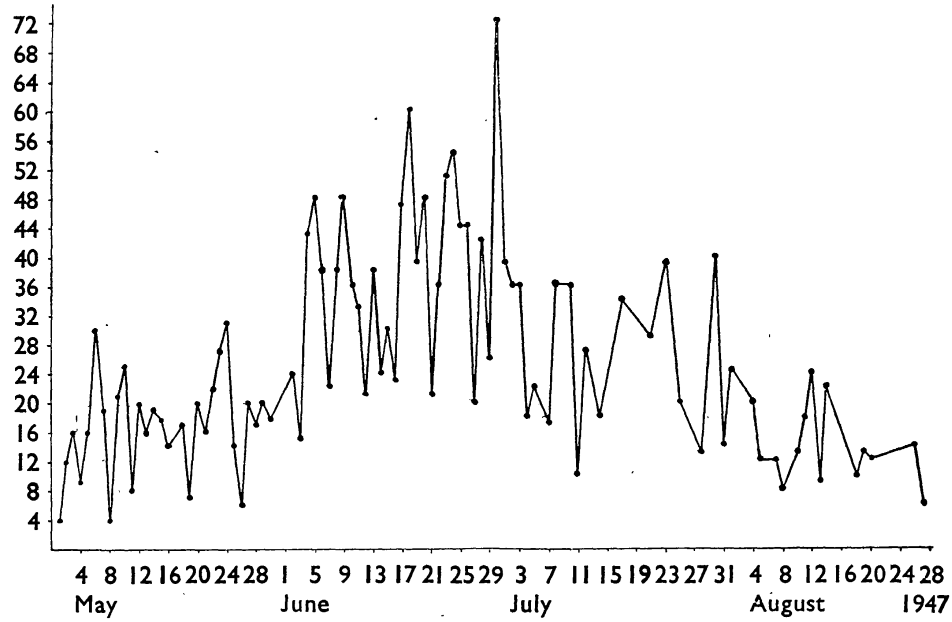

FIG. 7.—*Mean hourly rate per radiant* 1947 *May-August.*
Ordinates : Number of echoes/hour.

(*e*) On June 23 a further prominent stream near 54 Persei was observed at $\alpha = 66°$ to $68°$, $\delta = +30°$ to $+40°$, hourly rate 20 to 45 (F).

(*f*) During July and August the observations were insufficient to delineate the radiants accurately but the indications are that the new radiants in Taurus and Perseus were mainly responsible for the activity during these months.

(*g*) The above analysis given in Table II refers only to the principal radiants. The situation was not always clearly defined and on many days the whole area between the main centres showed considerable activity.

In retrospect it seems justifiable to assume that the high daylight rate found by Prentice, Lovell and Banwell * in 1946 June–July must have been due to the above radiants. Thus there are good grounds for believing that the events detailed in this paper may be a recurrent phenomenon and that future observations will make it possible to give a more comprehensive account.

9. *Acknowledgments.*—The work described in this paper involved the recording of 5298 echoes during 427 hours of observation in 1947 May, June and July. This task could not have been accomplished without the willing help of our colleagues at the Jodrell Bank Experimental Station of the University of Manchester, and we wish to acknowledge our indebtedness to C. J. Banwell, J. G. Davies, C. D. Ellyett, D. R. H. Forsyth and F. Moran. We also desire to thank J. P. M. Prentice for his constant interest and for his help and advice in presenting these results.

Physical Laboratories,
University of Manchester :
1948 *March* 8.

* *Loc. cit.*