RADIO ECHO OBSERVATIONS OF THE GIACOBINID METEORS 1946

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Summary

(1) Observations were made of the Giacobinid meteor shower 1946 on a wave-length of 4·2 m. A narrow beam directional aerial was constructed and used for this work.

(2) A continuous watch was maintained for 71 hours between 1946 October 8–11. The whole activity of the shower occurred between October 10^d 0^h–6^h U.T. The maximum was extremely sharp and occurred at 10^d 03^h $40^m \pm 3^m$, when the echo rate was 168 per minute for the equipment used.

(3) A method of obtaining the size distribution of these meteors is described, based on the theoretical work of Herlofson. For the range of meteor sizes studied the numbers of meteors were inversely proportional to the size.

(4) Coincident visual observations were obtained for twenty-one echoes. The correlations are similar to those obtained for the Perseid shower 1946. The number of electrons produced per cm. path for these meteors is calculated and shown to be in good agreement with Herlofson's theory.

(5) An experiment is described in which the aerial beam was directed into the radiant ; the number of echoes immediately decreased to about 4 per cent of their previous value.

(6) The height distribution, durations and amplitudes of the echoes are discussed. Changes in these indicate that the shower may have changed in character as it progressed.

1. *Introduction.*—This paper describes the use of the radio technique for the investigation of the Giacobinid shower of 1946. The previous work * had shown that the apparatus then used was not well adapted for astronomical observations and a large directional aerial array was therefore constructed and brought into use in the work on this shower. This apparatus (called A_3) is described in Section 2. An almost continuous watch was maintained from October 8^d 10^h 00^m U.T. to 11^d 9^h 30^m U.T., nearly all of which was carried out with A_3 except for a short period around maximum as specified in Table I when observations were made with half-wave dipoles (A_1). Throughout most of the watch A_3 was directed to a point 90° from the Giacobinid radiant, but during part of the rise to maximum, i. e. from October 10^d 2^h 40^m to 3^h 20^m U.T. it was directed towards the radiant for the experiment described in Section 5. Visual recording on the cathode ray tube was generally used, but during the peak period of activity, i. e. from 10^d 3^h 30^m to 3^h 50^m U.T. this was supplemented by a ciné film of the cathode ray tube working at 8 frames per sec. Over 1000 echoes have been analysed.

2. *Apparatus.*—With the exception of the aerial system the apparatus was identical with that used in the previous investigation.* The aerial system was

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* Prentice, Lovell and Banwell, *M.N.*, **107**, 155, 1947.

carried on an altazimuth mounting and produced a beam with the following characteristics :—

Azimuth beam width.	±6°·5 down to half intensity, with a side lobe of 7·5 per cent intensity at ±21° from the axis of the beam.
Elevation beam width.	±14° down to half intensity, with a side lobe of 3 per cent intensity at ±75° from the axis of the beam.
Power gain.	The theoretical free space power gain over a half wave dipole was 50, but due to uncorrected losses in the transmission line the actual overall free space gain during these observations was 33.

By means of a spark gap switching system the same aerial was used both for transmission and reception. The parameters of the apparatus were:—

Peak transmitter power	$P_0 = 1{\cdot}5 \times 10^5$ watts.
Wave-length	$\lambda = 420$ cm.
Minimum detectable input	$\epsilon_0 = 2{\cdot}0 \times 10^{-14}$ watts.
Power gain of aerial	$G = 33$

3. *Characteristics of the echoes.*

(a) *Rate of occurrence* (*hourly rate*).—Until October $9^d\ 21^h$ U.T. the rate was very low, usually 2 per hour and at no time exceeding 6 per hour. The first indication of the shower occurred between October $9^d\ 21^h\ 09^m$ and $21^h\ 40^m$ U.T., when seven echoes were obtained including three within a few seconds at $21^h\ 25^m$. The rate then returned to its previous low level and in the hour from October $9^d\ 23^h\ 01^m$ to $10^d\ 00^h\ 01^m$ only six echoes were seen. From $10^d\ 0^h$ the rate increased with great suddenness and in the succeeding hour 59 echoes were observed. Details of the rate of occurrence between October $10^d\ 0^h$ and 6^h are given in Table I and are plotted in Fig. 1 in which the rate is plotted on a logarithmic scale against time. The maximum of the shower was extremely sharp, the peak occurring at $3^h\ 40^m \pm 3^m$ U.T. when the ciné film analysis shows that 67 echoes occurred in 24 seconds, giving a rate of 168 per minute. Within ±5 minutes of this peak the rate was down to 50 per minute and within ±30 minutes it was down to 1 per minute. By $6^h\ 00^m$ the shower had apparently passed completely, the rate between $6^h\ 00^m$ and $7^h\ 00^m$ U.T. being only 5 per hour. From then until the end of the watch on October $11^d\ 9^h\ 30^m$ the maximum rate was 6 per hour. Thus in a period of 3 hours the echo rate observed with this apparatus increased by a factor of 5000.*

(b) *Height distribution.*—The height distribution of the echoes shortly before maximum ($0^h\ 14^m$ to $2^h\ 28^m$) and after maximum ($4^h\ 12^m{\cdot}5$ to $5^h\ 40^m$) is plotted in Fig. 2. These heights have been calculated from the measured range of the echo and the elevation of the aerial, assuming that the echo originates along the axis of the beam. The spread in the height distribution must therefore be attributed in

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* *Note added in proof.*—Subsequent experience has shown that the number of echoes found with this apparatus is very similar to the number of meteors seen by a visual observer. Although the sample is quite different, the greater sensitivity of the radio apparatus is just counter-balanced for this equipment by the observer's much greater cone of vision.

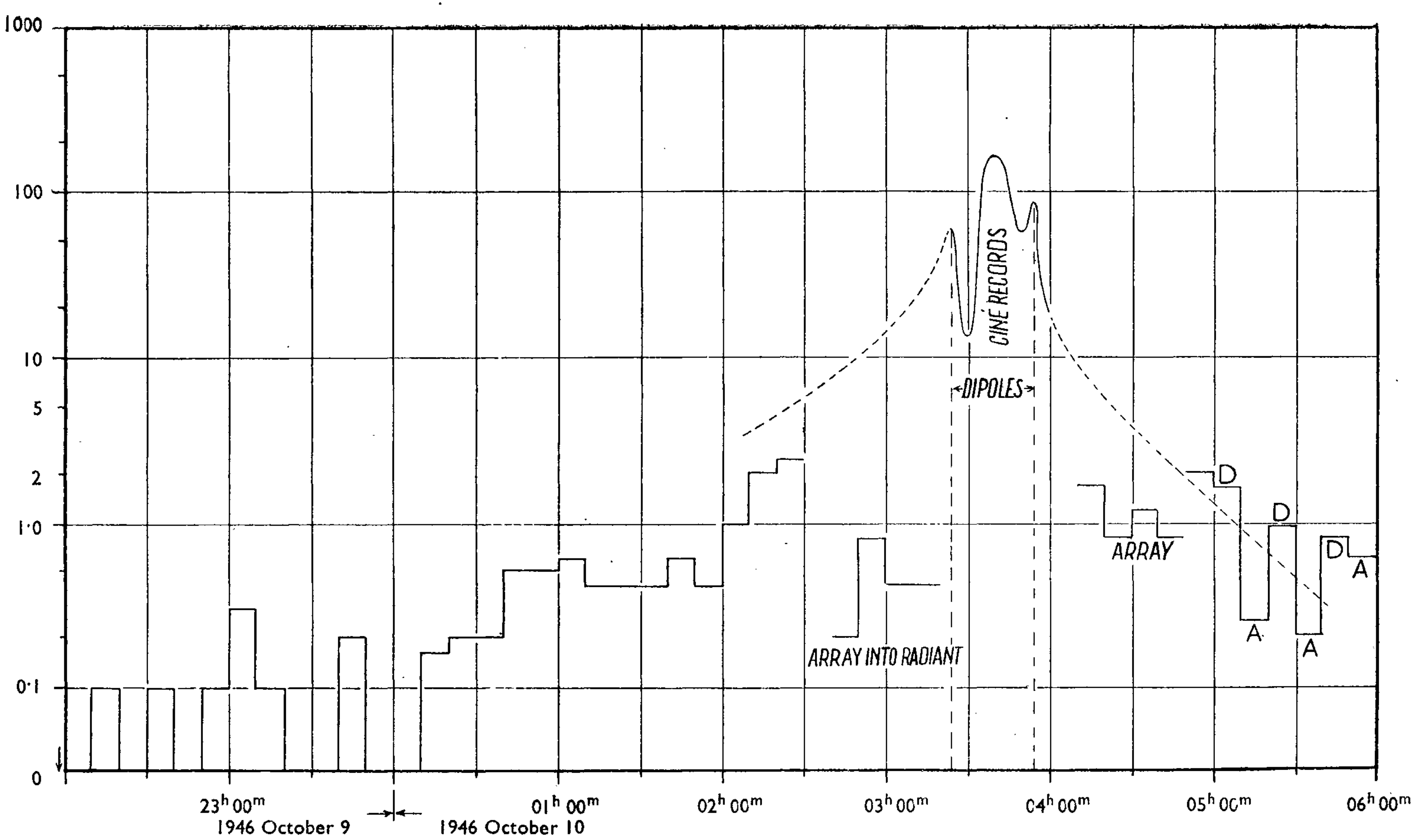

FIG. 1.—*Echo rates from Giacobinids* 1946 *October* 9–10. *Ordinates: Number of echoes per minute (Log. scale). Abscissae: Hours U.T.*

TABLE I

Mid-Watch U.T.	Dur-ation	No.	Rate per min.	Aerial
Oct. 9				
h m	m			
16 03	60	2	0·03	A_3
17 37	114	5	0·04	A_3
21 02	77	8	0·1	A_3
22 58	127	9	0·07	A_3
Oct. 10				
h m	m			
00 37	46	15	0·3	A_3
01 15	30	13	0·4	A_3
01 45	30	14	0·4	A_3
02 08	15	19	1·2	A_3
02 22	13	30	2·3	A_3
Interval, see *text Section* 5.				
h m	m			
03 31·3	13·2	210	*18·0	A_1
Oct. 10				
h m	m			
03 41·7	4·6	95	*19·0	A_1
03 49·5	5·0	87	*17·0	A_1
04 15	5	13	2·6	A_3
04 27·5	20	17	0·8	A_3
04 43·5	12	10	0·8	A_3
05 03	18	26	1·4	A_1
05 29	22	14	0·6	A_3
05 53	19	13	0·6	A_1
06 45	60	7	0·1	A_3
07 38	45	3	0·06	A_3
09 00	101	7	0·07	A_3
11 00	120	9	0·07	A_3

Column 1. *The time U.T. of mid-watch.*
2. *The duration of watch in minutes.*
3. *The number of echoes observed.*
4. *The rate per minute.*
5. *Aerial system used.*

* Note : *The above figures are from visual recording. At maximum, however, the rate was so high that the visual counts are merely minimum values. The rates plotted in Fig.* 1 *at maximum are the instantaneous rates taken from the ciné film.*

some measure to the width of the beam, but the difference between the two distributions cannot be attributed to this factor alone, since the elevation of the aerial was effectively the same in both cases, namely 60° before maximum, 70° after. This result may indicate some difference in the character of the shower before and after maximum or possibly in the conditions of the upper atmosphere (see also Sections 3 (c) and 4, below).

(c) *Duration of the echoes.*—The distribution of durations before, during and after the maximum is given in Table II. The first and last periods are from visual observations of the cathode ray tube, but the distribution during maximum is taken from the ciné film.

The three periods differ only in the distribution of the long enduring echoes. The percentage of echoes lasting for longer than 5 sec. increased as the shower progressed. This is further evidence of the indication obtained in Section 3 (b) of a change in character of the shower or of the conditions in the upper atmosphere. The factors governing the duration of these transient echoes are not yet understood.

(d) *Life histories of echoes.*—A series of "life histories" of individual echoes was obtained during the period of maximum from a total of about 1600 separate frames exposed with the ciné camera in a series of groups. A selection from these is illustrated in Figs. 3 and 4 (Plates 3 and 4). Fig. 3 (Plate 3) shows five echoes, one at 145 km. range with a blurred appearance near its peak indicating a rapidly varying amplitude, also weak but definite echoes at 250, 230 and 300 km.

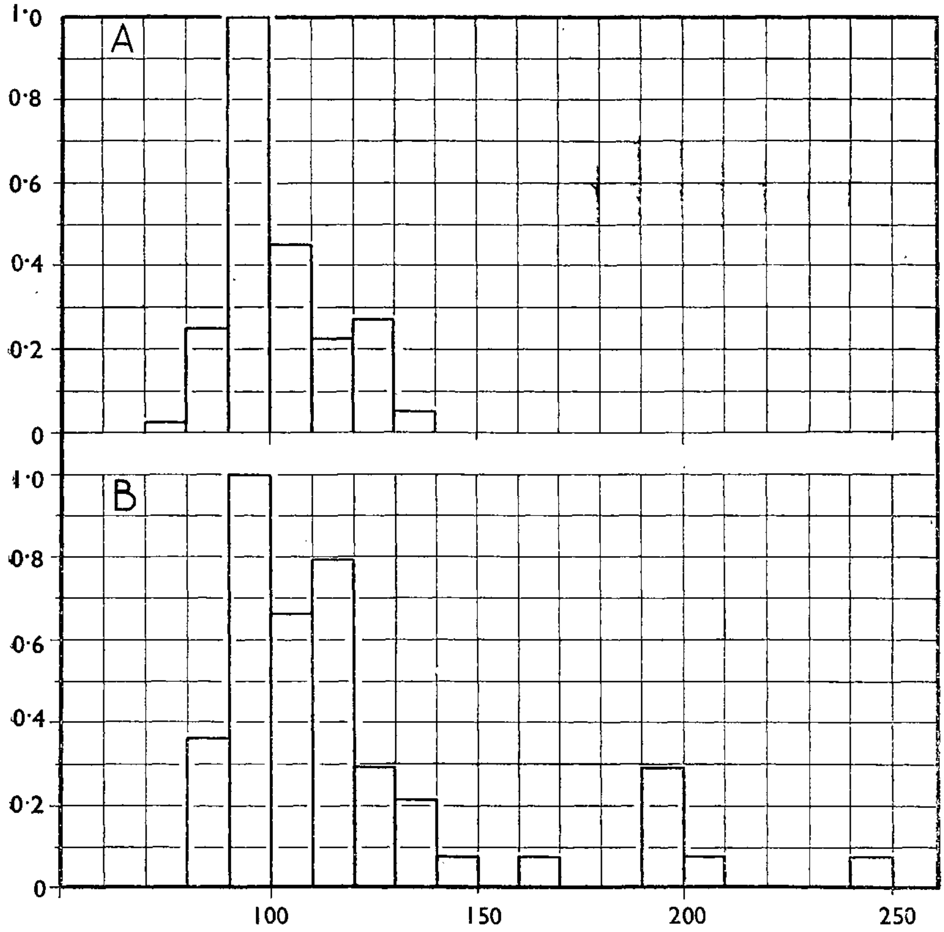

FIG. 2.—*Height distribution.*

A.—*Before maximum*: 00^h 14^m—02^h 28^m *U.T.*
Total number of echoes in sample: 91.

B.—*After maximum*: 04^h 12^m.30—05^h 40^m *U.T.*
Total number of echoes in sample: 54.

Ordinates: *Number of echoes in* 10 *km. intervals* (*normalized*).
Abscissae: *Height in km.*

TABLE II

Percentage Distribution of Durations (secs.)

Period	Limits U.T.	No. in sample	$<0·25$	$\geqslant 0·25$	$\geqslant 0·5$	$\geqslant 1·0$	$\geqslant 5·0$
	h m						
Before Peak	0 14 2 28	89	54	46	37	26	1·1
During Peak	3 30 3 50	233	60	40	32	24	7·7
After Peak	4 12 6 00	93	53	47	35	24	8·5

and an echo of nearly saturation amplitude at 405 km. The group photograph was started shortly after the appearance of this latter echo and continued for 92 frames (11·5 sec.) when the 405 km. echo disappeared. The very rapid

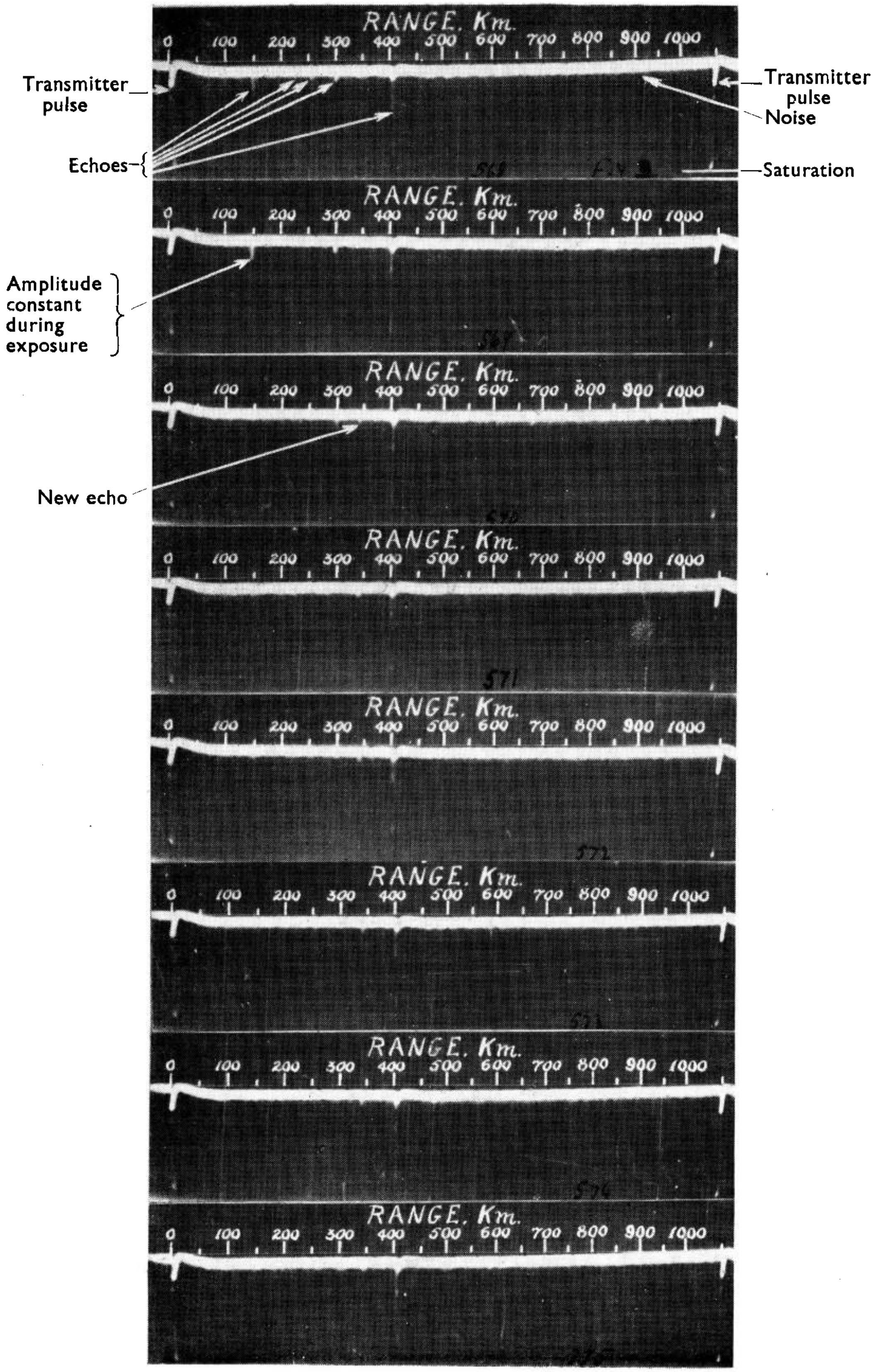

FIG. 3.

A. C. B. Lovell, C. J. Banwell and J. A. Clegg, Radio Echo Observations of the Giacobinid Meteors **1946.**

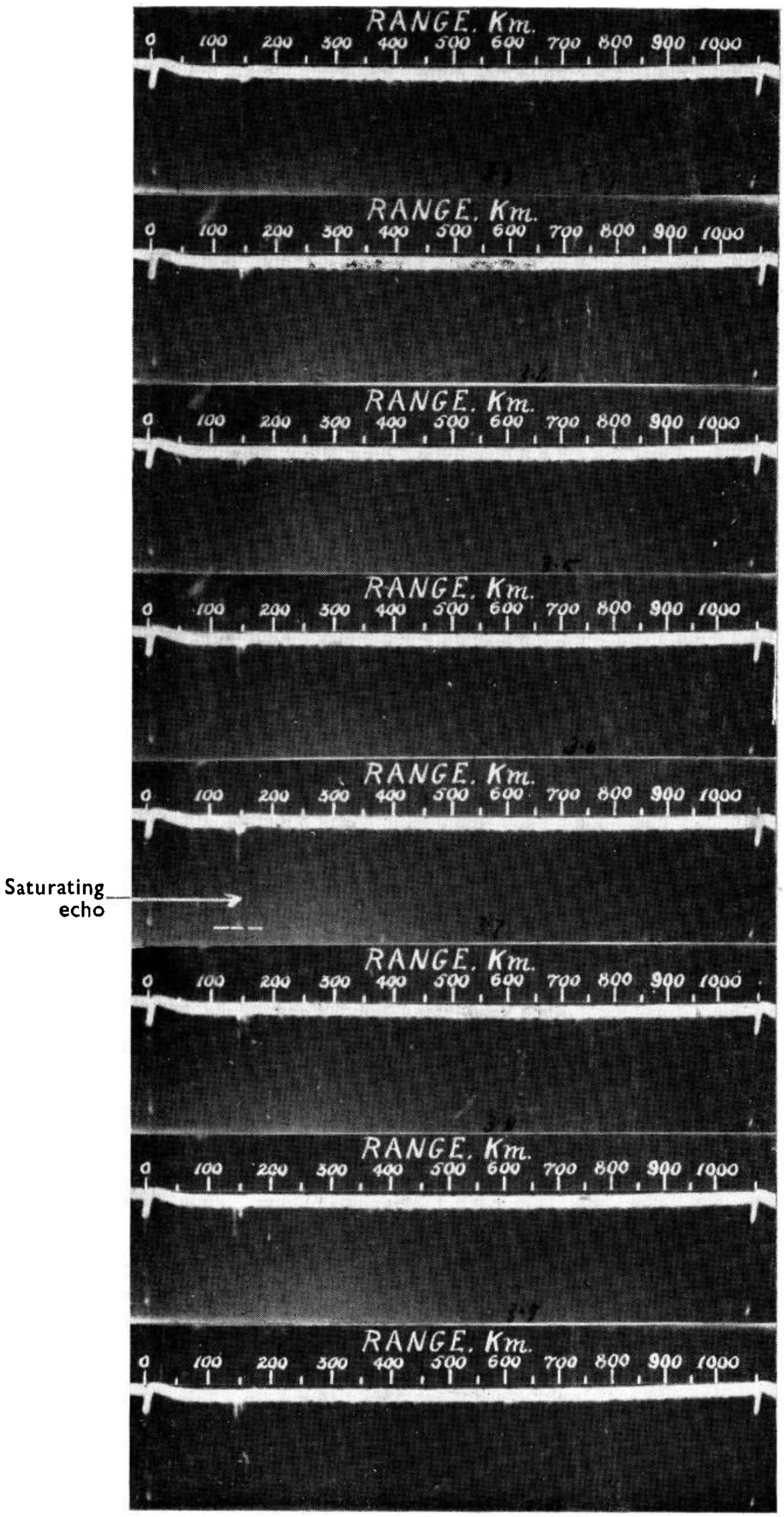

FIG. 4.

A. C. B. Lovell, C. J. Banwell and J. A. Clegg, Radio Echo Observations of the Giacobinid Meteors 1946.

disappearance and appearance of echoes will be seen from a comparison of successive frames, which represent $\frac{1}{8}$ sec. intervals. A number of the longer echoes show rapid variations in amplitude; for example those of the 145 km. echo * are plotted in Fig. 5 and show some sign of a fairly regular decay superimposed on the more

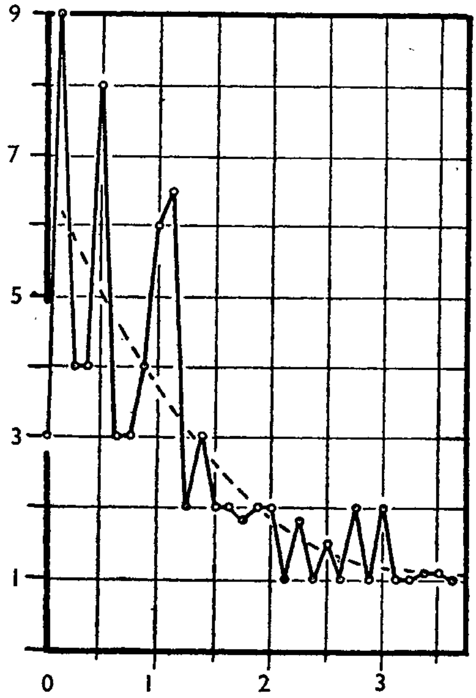

Fig. 5.—*Echo at* 145 *km. Rapid fluctuations apparent on film.* (*Photo: Plate* 3).
Ordinates: Signal-noise ratio.
Abscissae: Time in seconds.

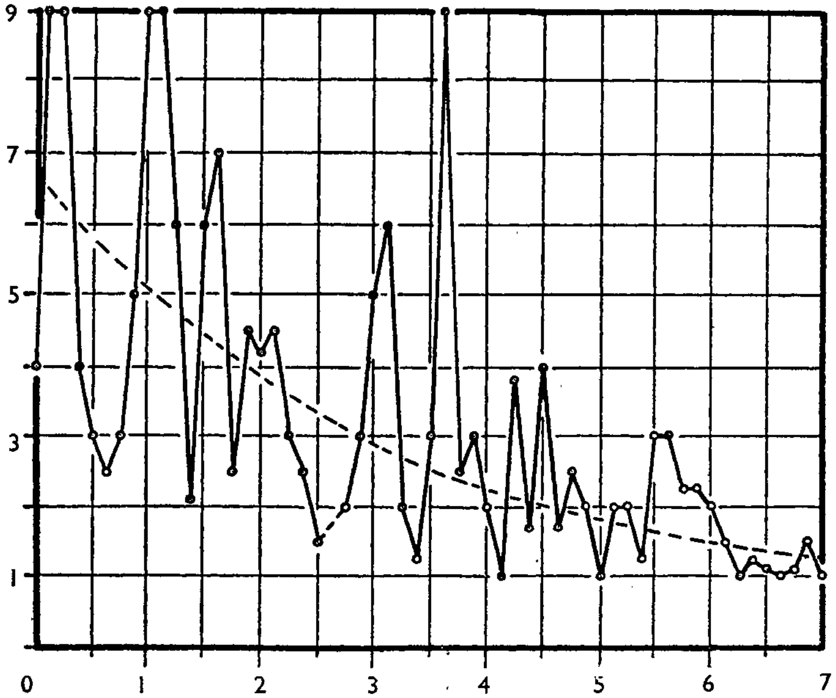

Fig. 6.—*Echo at* 140 *km. Rapid fluctuations apparent on film.* (*Photo: Plate* 4).
Ordinates: Signal-noise ratio.
Abscissae: Time in seconds.

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* Fig. 3 (Plate 3) shows only a small part of the history of this echo, near the end of its life.

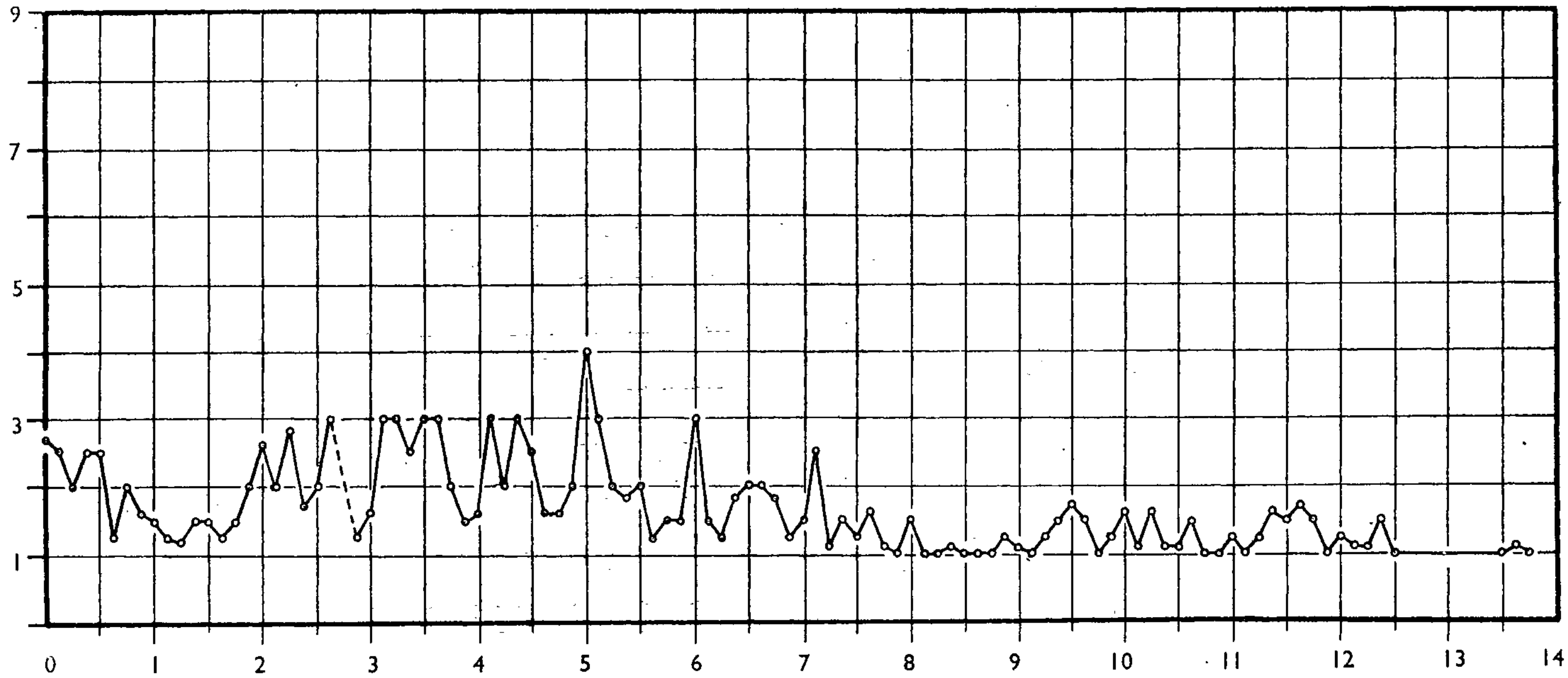

FIG. 7.—*Echo at 455 km. Rapid fluctuations apparent on film.*
Ordinates: Signal-noise ratio.
Abscissae: Time in seconds.

rapid fluctuations. Fig. 4 (Plate 4) shows part of the life history of a pair of echoes of variable amplitude at 140 and 150 km., the amplitudes of the 140 km. echo being plotted in Fig. 6. Again the amplitude shows some indications of a steady decay superimposed on the variations. This regular decay, however, is not nearly so evident in other cases; an example of an echo without marked decay is plotted in Fig. 7. Because of the rapid changes in amplitude that are evidently taking place even during a single exposure the individual points plotted in Figs. 5 to 7 must be considered to be unrelated, and the lines joining them merely indicate their sequence. On the other hand a few echoes do not show these rapid fluctuations in amplitude; one of these is illustrated in Fig. 8 which shows a fairly well-defined periodic fluctuation and a superimposed decay. This very rapid fluctuation in amplitude is a new feature of the transient echoes found from the film analysis. The causes of these fluctuations and the various factors influencing the rate of disappearance of the echo need further study.

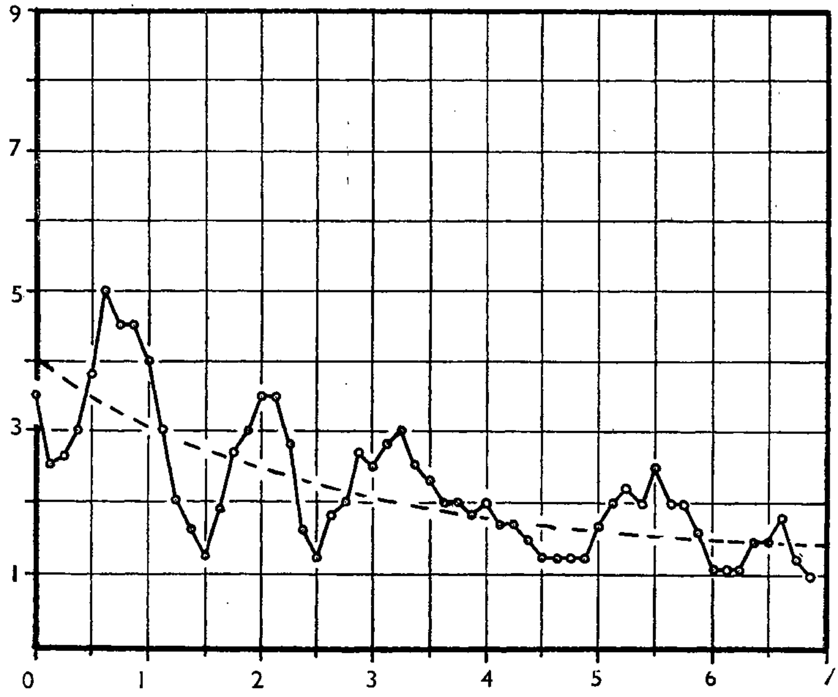

FIG. 8.—*Echo at 115 km. Rapid fluctuations absent on film.*
Ordinates: Signal-noise ratio.
Abscissae: Time in seconds.

4. *The size (mass) distribution of the meteors.*—Formulae have been given in a previous paper* for ϵ the strength of the received echo from a meteor which produces α electrons per cm. path, namely

$$\epsilon = 3{\cdot}3 \times 10^{-28} \frac{\alpha^2\lambda^3}{R^3} P_0 G^2 \text{ watts}, \tag{1}$$

$$\alpha = 5{\cdot}5 \times 10^{13} \frac{1}{G} \sqrt{\frac{\epsilon R^3}{P_0 \lambda^3}}, \tag{2}$$

where λ is the wave-length in cm., R the range in cm., P_0 the peak power of the transmitter in watts and G the power gain of the aerial system, and where the

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* Prentice, Lovell and Banwell, *loc. cit.*

conditions are as stated.* Now from the ciné film records taken during the period of maximum it is possible to measure with greater accuracy than previously the amplitude of the echo (and hence to obtain ϵ from the receiver calibration) and the range R. Measurements were restricted to those echoes which occurred at ranges less than 200 km., so that a value for G could be assumed which is sensibly constant. This excludes meteors at low elevations where G departs appreciably from its value on the axis of the beam. P_0 and λ are known, and hence α can be calculated. The results of these calculations are plotted in Fig. 9, which shows the percentage of echoes between October $10^d 3^h 25^m$ and $3^h 55^m$ U.T.

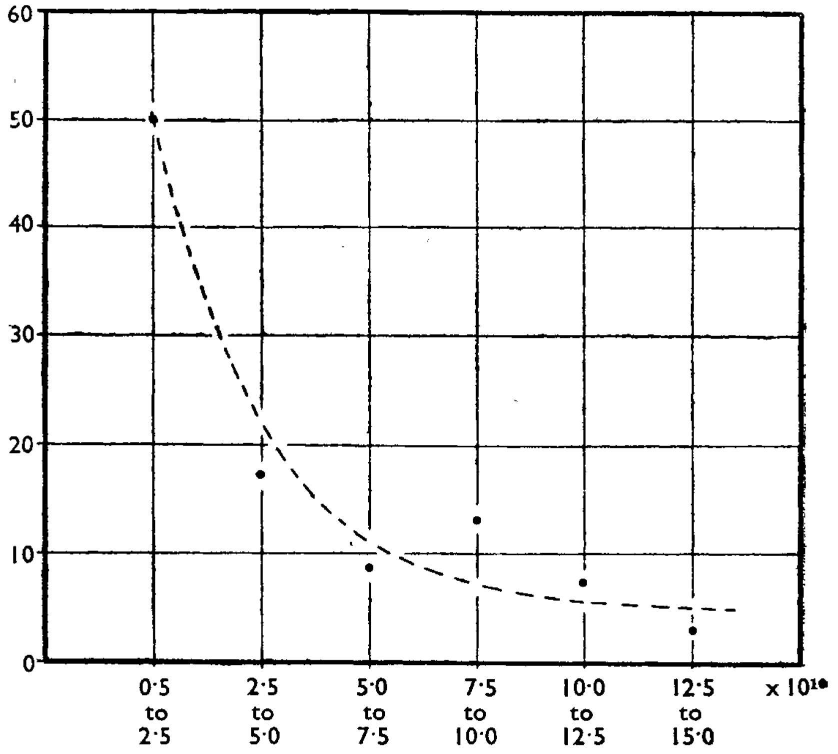

FIG. 9.—*Size (mass) distribution of meteors during period of maximum.*
Ordinates: Percentage of total echoes.
Abscissae: α; number of electrons per cm.

producing a given number of electrons per cm. path. A meteor producing 5×10^9 electrons/cm. at a range of 100 km. was just detectable by the apparatus; one producing 8×10^{10} electrons/cm. at 100 km. saturated the receiver output.†

A statistical analysis of the data from which Fig. 9 is plotted shows that the distribution of strength of ionization obeys an inverse power law with an exponent $0{\cdot}9 \pm 0{\cdot}2$. The theory of meteor ionization developed by Herlofson ‡ shows that for a given velocity the number of electrons produced per cm. path is proportional to the size of the meteor. We may infer both on *a priori* grounds and from the fact that the meteors form a compact group that the velocities of the meteors in the stream are sensibly constant. In this case it follows as a further consequence of the theory that the measurements of ionization also give the distribution in masses of

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* Prentice, Lovell and Banwell, *loc. cit.*

† These values differ from those in Table III because the investigation of sizes was done with A_1 and the work on coincidences with A_3.

‡ Herlofson, in the press; see also *Rep. Prog. Phys.*, **11**, 1948.

the meteors. Thus in the Giacobinid shower at maximum the size distribution was inversely proportional to the size of the meteors for the range of ionization measured by the apparatus used. The present development of the theory does not justify the derivation of absolute sizes, but a preliminary application indicates that the sizes of the meteors in this range of ionization are of the order of:—

$$r = 10^{-2}\ \text{cm.}$$

It is not possible to derive a size distribution similarly for the period outside maximum because the observations of amplitude were made visually and are not considered to be sufficiently accurate for this purpose. These observations show however a difference in the amplitudes of the echoes before and after maximum. In the period before maximum ($0^h\ 14^m$ to $2^h\ 28^m$) 40 per cent of the echoes scattered back a received power greater than $4{\cdot}9 \times 10^{-13}$ watts, but after maximum ($4^h\ 12^m$ to $6^h\ 00^m$) only 13 per cent scattered back a power greater than this amount. This data may be compared with the indications in Sections 3 (b) and 3 (c) that the characteristics of the stream changed during its progress or that a change occurred in the conditions in the upper atmosphere.

5. *The effect of the direction of the aerial beam with respect to the radiant.*—The high rate of occurrence of the Giacobinids near maximum provided an opportunity for a statistical test of the assumption made in all previous work that an echo is generally obtained only when the beam is perpendicular to the ionized track. At $2^h\ 34^m$ the aerial was moved from its standard direction at 90° from the Giacobinid radiant and until $3^h\ 15^m$ it was directed into the radiant. The rate immediately decreased abruptly, as shown in Fig. 1, only 9 echoes being obtained in these 41 minutes, whereas it can be estimated from the extrapolation of the curve in Fig. 1 that at least 250 echoes would have been observed during this period if the original direction of the aerial had been maintained.

This experiment therefore shows that at least 96 per cent of the meteors observed with an apparatus of this sensitivity can be detected only when their ionized track is at right-angles to the direction of the axis of the aerial beam. With regard to the other 4 per cent, we may infer that at most one half were due to non-shower meteors, and it appears therefore that a small percentage of meteors may scatter back sufficient energy to be detected even under these unfavourable conditions. Confirmation is given by one visual coincidence obtained during this period, in which the visual meteor was seen to be travelling approximately down the axis of the beam.

6. *Correlation with visual observations.*—Between $0^h\ 14^m$ and $1^h\ 07^m$ and between $1^h\ 34^m$ and $2^h\ 28^m$ the sky was clear and it was possible to make simultaneous echo and visual observations. Details of the coincidences obtained are given in Table III and of the correlations in Table IV.

Of the 79 echoes observed during the visual watch 26 per cent were coincident with visual meteors, but if we restrict the analysis to echoes which lasted longer than 0·5 sec. the coincidences were 50 per cent. This latter result is identical with the visual correlations during the Perseid epoch 1946.* There is a better correlation for the Giacobinid echoes of duration less than 0·5 sec., 16 per cent for the Giacobinids as compared with 5 per cent for the Perseids.

These meteors having been seen visually can be used to test the correctness of Herlofson's theory of meteor ionization. According to this a meteor which

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* Prentice, Lovell and Banwell, *loc. cit.*

TABLE III

Coincidences

No.	U.T.	R	H_0	ϵ	α^* $\times 10^9$	D	Mag.
	h m s						
1	0 17 45	115	100	6·5	4·5	0·5	4
2	34 00	105	91	10·0	6·2	2·5	3
3	0 55 30	107	93	>68·0	>14·9	2·0	4
4	1 02 15	100	86	6·5	2·3	0·25	2
5	04 45	95	82	17·0	6·1	0·5	...
6	1 34 15	110	95	>68·0	>15·2	2·0	...
7	40 35	115	100	>68·0	>16·2	1·0	2
8	49 14	115	100	>68·0	>16·2	1·2	...
9	1 54 20	145	125	17·0	11·8	0·25	4
10	2 00 00	95	82	>68·0	>12·6	0·1	...
11	2 01 05	115	100	>68·0	>16·2	3·0	3
12	05 20	117	101	>68·0	>17·1	4·0	3
13	09 05	120	104	>68·0	>17·6	0·1	3
14	10 40	113	98	>68·0	>16·2	1·0	...
15	14 45	105	91	2·0	2·4	0·1	3
16	2 15 20	115	100	>68·0	>16·2	8·0	3
17	20 00	140	121	49·0	18·6	?	...
18	20 08	132	114	17·0	10·0	11·0	...
19	23 20	100	86	>68·0	13·6	1·0	...
20	27 00	110	95	?	?	0·2	...
21	2 27 00	100	86	2·0	2·3	0·25	...

Column 1. *Serial number.*
2. *Time,* 1946 *October* 10.
3. *Range, km.*
4. *Height, km., assuming that echo occurred on axis of the beam.*
5. *Received power, in units of* 10^{-14} *watt.*
6. *Number of electrons per cm. path.*
7. *Duration of echo, seconds.*
8. *Visual magnitude.*

* These values are for A_3 with which the coincidences with visual work were obtained. The calculations of the size distribution in the text refer to A_1.

TABLE IV

Correlations

	=0·1*	=0·2*	>0·2 ⩽0·5	>0·5 ⩽1·0	>1·0	Total
Number of Echoes	21	22·0	14	9	13·0	79
Visual Coincidences	3	1·0	5	3	8·0	20†
Percentage Visual/Total	14	4·5	36	33	61·5	
	16			50		

* *Durations estimated.* † *Plus one, duration unknown.*

produces approximately 10^{10} electrons/cm. path will be on the limit of naked eye visibility. The corresponding values of the electron density of the 21 visual coincidences, calculated from equation (2), are given in column 6 of Table III. These range from $2 \cdot 3 \times 10^9$ to $> 1 \cdot 8 \times 10^{10}$ electrons/cm. path, but these must be taken as minimum values, firstly because it has been assumed throughout that all echoes originated so near to the axis of the beam that the power gain G can be taken at its maximum value 33, and secondly because eleven of the echoes were of sufficient power to saturate the receiver. The general agreement between observation and theory is therefore satisfactory.

7. *Acknowledgments.*—The authors' thanks are due to Mr N. Herlofson and Mr D. R. H. Forsyth (Physical Laboratories, Manchester) and to Mr G. G. Yates (Solar Physics Observatory, Cambridge) for help in taking the observations and to Mr J. P. M. Prentice for supplying information on the Giacobinid radiant which made the investigation possible.

Physical Laboratories,
University, Manchester:
1947 *January* 7.