BRIGHT SOLAR ERUPTIONS AND RADIO FADINGS DURING THE YEARS 1935–36.

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1. During the past eighteen months attention has been drawn by various observers * to occasional coincidences between bright eruptions on the Sun and sudden fadings in short-wave wireless reception experienced over a large part of the Earth. During 1935 such coincidences were not obvious, but in 1936 as the Sun became increasingly active they were numerous enough to suggest a possible relation between the two phenomena. During the last solar minimum (1933·8) both phenomena appear to have been very infrequent. Previous to this minimum epoch, no data exist for the purposes of a statistical comparison. In the present paper comparative data obtained during 1935 and 1936 are discussed, in order to test the suggestion whether a solar-terrestrial relationship does in fact exist between these two phenomena, whose characteristics may first be briefly described.

2. *Bright Solar Eruptions.*—The first bright solar eruption ever recorded was that observed by Carrington and Hodgson on 1859 September 1. This unique eruption was visible in an ordinary telescope, and a repetition by this means has never been observed. The bright eruptions included in this paper are those which have been observed spectroscopically in monochromatic light, corresponding to $H\alpha$ (6563 A.) and to the lines of ionized calcium, H and K (3969 and 3934 A.).

In 1870 Young observed the form of a brilliant hydrogen eruption on the Sun's disc, by means of an ordinary solar spectroscope used with a widened slit. Brilliant reversals of $H\alpha$, which denote the presence of bright eruptions, have also been systematically observed by various observers but not published in detail. The spectroheliograph (perfected in 1892), working in H or in K (occasionally in $H\beta$) and later in $H\alpha$, depicted the appearance of bright eruptions when they were caught by chance on the daily spectroheliograms at one observatory or another. In 1926, however, Dr. G. E. Hale introduced his spectrohelioscope, which is admirably adapted for the visual search and observation of bright eruptions in $H\alpha$. The arrangement of an international programme of observations under the auspices of Commission No. 11 of the International Astronomical Union has recently led to a systematic search for their occurrence. Although in 1935 there were gaps in the observing programme, mainly between 21^h–0^h–9^h U.T., these have since been partly filled by new stations at work with spectro-

* Including Richardson, *P.A.S.P.*, **48**, 178 and 278, 1936. Newton and Barton, *Journal B.A.A.*, **46**, 196, 1936; Newton, *ibid.*, **47**, 109, 1937; *Nature*, **138**, 1017, 1936. Torreson, Scott and Stanton, *Terrestrial Magnetism*, **41**, 199, 1936. McNish, *Nature*, **139**, 244, 1937. A recent paper by J. H. Dellinger in *Terr. Mag.*, **42**, 49, 1937, will be referred to later; *see* also *Physical Review*, **50**, 1189, 1936.

helioscopes. Cloudy weather is, however, a severe hindrance at several of the participating observatories. Fig. 1 shows the observed monthly frequency of bright eruptions from 1935 to 1936 which may be compared with the sunspot curve given by the Zurich sunspot numbers, and also the frequency of radio fadings given in Tables II and IIA.

Bright solar eruptions have the following general characteristics :—

(1) They appear very suddenly, rise rapidly to a maximum, in 5 to 10 minutes, and die away less quickly. An hour after an eruption has first appeared, all traces of it may have disappeared.

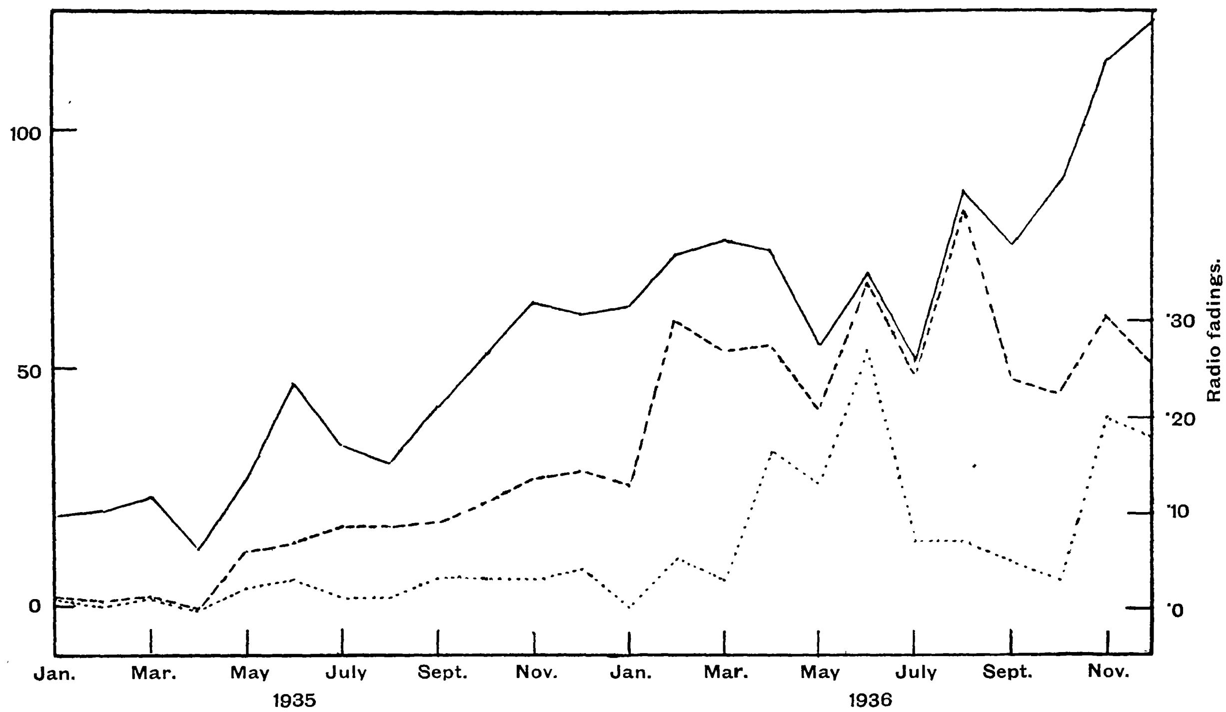

FIG. 1.—*Observed monthly frequency*, 1935–1936, *of*

Sunspots ——— *Bright Hα eruptions* - - - - - *Radio fadings* . . . . .

(2) Their average duration is from about 20 minutes, for those of lesser intensity, to 40 minutes, for those of greater intensity (1935–36 averages).

(3) In central intensity they sometimes equal or exceed that of the continuous spectrum adjacent to the line in the spectrum in which they are being observed.

(4) They are nearly always associated with sunspots.

(5) The photosphere, including the structure of sunspots, adjacent to the bright eruption appears unaffected.

(6) The eruptions do not appear to be areas of high temperature black-body radiation.*

(7) Occasionally two or more bright eruptions occur nearly simultaneously in widely separated groups of sunspots. Such occurrences are more frequent than can be ascribed to pure chance.†

* *Annual Report of the Mount Wilson Observatory*, 1935–36, p. 172.

† *Loc. cit.*, p. 171.

(8) The areas of the brilliant monochromatic emission range from tiny patches the size of a small sunspot (say 20 millionths of the Sun's hemisphere) to large patches or streaks equal in aggregate area to that of a large sunspot (say 500 millionths).

(9) The brilliant patches, which themselves usually possess no measurable outward velocity, are often closely associated with absorption markings possessing high radial velocity as great as 400–500 km./sec. Outward velocities are often followed by inward velocities indicating that part, at least, of the ejected cloud of gas is falling backwards to the Sun.

Table I gives the number of solar eruptions observed during 1934–36 extracted from the Zurich quarterly *Bulletin for Character Figures of Solar Phenomena* in which all observations made under the I.A.U. Scheme from contributing observatories are tabulated by M. d'Azambuja. The eruptions are arranged according to their observed intensity on an approximate scale of 1 (the smallest and least intense), 2, 3 (the largest and most intense).

Table I

Year	Number of Bright Solar Eruptions of Intensity			Total, including Unclassified Cases	Mean Sunspot Number
	1.	2.	3.		
1934	14	1	0	15	8·7
1935	137	18	2	161	36·1
1936	472	134	27	642	80·4

Table IA gives the number of bright eruptions (all classes) observed at a single observatory (Greenwich) with a spectrohelioscope systematically in operation through the last solar minimum. The observations indicate that the rapid rise in the observed frequency of bright eruptions during the last two years is largely real and is not merely due to the increasing number of observatories taking part in recording these eruptions.

Table IA

Year	1932	1933	1934	1935	1936
Number of bright eruptions	12	5	5	25	66 *
Mean sunspot number	11	6	9	36	80

* The instrument was being remounted in 1936 January and one month's observations were lost.

3. *Radio Fadings.*—The data of rapid fadings (experienced on short-wave radio transmission) used in this paper are derived from—

(*a*) A list prepared by the Secretary (Dr. Jouaust) of the French National Committee of the Union Radio Scientifique Internationale, and communicated to the Royal Observatory, Greenwich, by the President (Dr. Rayner) of Commission 1 of the Union. The data give the times of recorded fadings observed in France or in the French Colonies.

(*b*) A list of fadings, communicated to the Astronomer Royal by the Engineer-in-Chief, Cable and Wireless Ltd., London. These fadings are those recorded on channels operated by the Company from this country; the wave-lengths employed usually ranging from 16 to 25 metres according to circumstances.

The combined data (*a*) and (*b*) may be taken as being representative of fadings recorded on channels operating from Western Europe.

These radio fadings, which are to be distinguished from those recorded on channels traversing the ionosphere near the auroral zones when magnetic activity is present, have the following characteristics :—*

(1) The drop in signal strength occurs quite suddenly, being sensibly simultaneous on all routes affected.

(2) The duration of the excessive attenuation is approximately 10 to 45 minutes.†

(3) The recovery period is less definite, extending in some instances to one hour or more.

(4) The highest frequencies are in general affected to a lesser degree and for a shorter time.

(5) A sudden increase, on occasions, of noise field at the commencement of, or a minute or two prior to, the fade; the effect has been described as similar to that observed during charged rain storms, or "Fizzlies".

(6) The phenomenon is observed, in general, on those waves traversing a daylight path.

4. A comparison will now be made between these radio fadings and the data of solar eruptions. Table II contains the following information. (1) The date and time of the beginning and ending of the radio fading. In those cases in which the fading is reported from both sources the mean times are tabulated. The mean difference of time of commencement in 37 doubly observed cases is about 3 minutes. The ending of the phenomenon is less definite than the commencement, the mean difference in the doubly observed cases being 12 minutes. (2) Particulars of any solar eruption occurring within 30 minutes of the beginning or ending of each recorded fading are next listed as follows. The times during which the eruption was observed, the intensity of the eruption on a scale of 1 to 3 as previously defined, and the angular distance from the Sun's central meridian. Heavy type figures indicate that the actual beginning or end of the eruption was observed. Even in the most favourable circumstances the observed times of commencement are probably systematically late by one or two minutes, since the light intensity of the eruption has to rise above that of the normal bright flocculus to be distinguished by the observer as an eruption. In cases where no eruption appears recorded in the solar *Bulletin* it cannot be inferred from the published data whether the Sun was actually under observation (this information will in the future be available). In six cases, however, some information is available and is given on p. 607 of this paper. Cases marked "No scheduled observations" indicate that gaps occur in the observing programme as given in *Trans. I.A.U.*, **5**, 60, 1936.

* From information kindly supplied by the Engineer-in-Chief, Cable and Wireless, Ltd. See also a short article by R. Jouaust in *Onde Électrique*, **16**, 211, 1937.

† The mean duration given by those radio fadings in Table II is 23 minutes.

TABLE II

Comparative Data of Radio Fadings and Bright Solar Eruptions, 1935–36
(Radio Data : Union Radio Scientifique Internationale and Cable and Wireless, Ltd.)

Date	Radio Fading		Bright Solar Eruption				Time-interval
	From U.T.	To U.T.	From U.T.	To U.T.	Intensity	Distance from C.M.	Fading – Eruption
1935	h m	h m	h m	h m		°	m
May 12	11 57	12 15	...	...	...	...	...
,, 30	12 30	...	...	...	...	...	...
June 14	17 00	...	...	...	...	...	...
,, 24	14 00	...	...	...	...	...	...
,, 26	18 00	...	...	...	...	...	...
July 6	14 07½	...	...	...	...	...	...
Oct. 15	19 30	...	...	...	...	...	...
,, 24	12 00	...	...	...	...	...	...
1936							
Feb. 6	15 20	16 10	...	...	...	...	...
,, 8	13 27½	14 30	**13 30**	14 00	1	72 E.	– **2½**
,, 14	15 17	15 50	15 30	16 00	2	0	– 13
Apr. 1	09 34	09 55	09 26	**10 40**	2	30 W.	+ 8
,, 1	12 00	12 20	...	...	...	...	...
,, 6	13 57	14 25	...	...	...	...	...
,, 8	16 49	17 16	16 45	17 03	2	10 W.	+ 4
			16 47	**18 30**	3	5 W.	+ **2**
,, 9	13 40	13 48	13 30	14 30	2	18 W.	+ 10
May 15	06 00	06 30	(07 04	**08 30**	3	27 E.	– 64) *
,, 25	12 34	12 47	...	...	...	...	...
,, 26	11 30½	11 43	**11 15**	12 03	2·5	41 W.	+ **15½**
,, 28	07 29	07 47	**07 15**	08 00	2	82 E.	+ **14**
,, 28	14 05½	14 19	...	...	...	...	...
,, 28	18 00	18 20	...	...	...	...	...
,, 29	10 24	10 35	Sun under observation : see p. 607				...
June 3	00 45	...	No scheduled observation				...
,, 3	16 35	16 55	16 29	17 00	1	0	+ 6
,, 4	11 54½	12 06	...	...	...	...	...
,, 9	14 25	14 57	14 24	14 32	1	79 W.	+ 1
,, 10	14 25	14 40	...	...	...	...	...
,, 10	20 55	21 20	...	...	...	...	...
,, 11	06 27½	06 42	...	...	...	...	...
,, 11	12 29	12 42	...	...	...	...	...
,, 16	13 30	13 37	13 25	**13 48**	2	75 E.	+ 5
			13 27	**13 42**	?	60 E.	+ **3**
,, 17	07 20	07 50	**06 52**	**07 14**	1	58 E.	+ **28**
			07 00	**07 15**	?	50 E.	+ 20
			07 27	**08 10**	1	62 E.	– 7
,, 17	12 48	12 54	...	...	...	...	...
,, 19	09 10	09 25	**09 00**	**11 00**	2	35 E.	+ **10**
,, 25	10 47½	11 13	10 51	11 40	1	62 E.	– 3½
			11 10	11 30	1	46 W.	– 22½
,, 25	11 15	11 25	10 51	11 40	1	62 E.	+ 24
			11 10	11 30	1	46 W.	+ 5

* See footnote on p. 599.

Date	Radio Fading		Bright Solar Eruption				Time-interval Fading − Eruption
	From U.T.	To U.T.	From U.T.	To U.T.	Intensity	Distance from C.M.	
1936	h m	h m	h m	h m		°	m
July 1	13 42	14 15	...	...	...	...	...
,, 15	05 05	05 15	No scheduled observation				...
,, 15	13 29	13 41	13 30	13 40	2	17 W.	− 1
,, 17	12 00	12 30	...	...	...	...	...
,, 30	13 40	13 50	...	...	...	...	...
,, 31	00 16	00 25	00 11	00 30	3	46 E.	+ 5
,, 31	09 30	09 50	...	...	...	...	...
Aug. 23	11 30	12 10	...	...	...	...	...
,, 25	18 35	18 58	18 58	19 22	3	66 E.	−23
,, 25	20 10	...	...	...	...	...	...
,, 28	09 30	10 02	09 20	11 30	3	32 E.	+10
Sept. 4	01 45	02 10	01 40	02 56	2	48 W.	+ 5
,, 4	12 38	12 50	...	...	...	...	...
,, 5	09 04	09 25	Sun under observation : see p. 607				...
,, 10	12 16	12 31	...	...	...	...	...
Oct. 9	14 32½	14 48	14 54	15 03	3	40 W.	−21½
,, 21	15 34	15 48	Sun under observation : see p. 607				...
Nov. 6	16 13½	16 35	16 24	16 50	1·5	37 W.	−10½
,, 7	14 50	15 18	...	...	...	...	...
,, 24	19 15	19 50	19 08	19 44	1	90 E.	+ 7
,, 25	04 40	05 15	...	...	...	...	...
,, 26	07 10	07 28	No scheduled observation				...
,, 26	09 00½	09 28	...	...	...	...	...
,, 26	17 55	18 18	17 49	18 28	3	36 E.	+ 6
			18 40	18 43	2	38 E.	−45
,, 27	07 50	08 20	No scheduled observation				...
,, 27	16 56	17 15	16 50	16 58	1	21 E.	+ 6
,, 28	15 10	15 45	...	...	...	...	...
,, 30	12 37½	13 08	...	...	...	...	...
Dec. 3	12 05	12 43	11 46	12 18	2+	55 W.	+19
			12 17	12 45	3	56 W.	−12
,, 9	13 12½	13 42	Sun under observation : see p. 607				...
,, 12	16 02	16 20	Sun under observation : see p. 607				...
,, 19	08 45	10 00	09 35	09 48	1	22 W.	−50
,, 22	13 05	13 15	...	...	...	...	...
,, 23	09 50	10 15	...	...	...	...	...
,, 25	08 55	09 10	Scheduled observation commences at 09^{h} 00^{m}				
,, 26	09 13	09 35	...	...	...	...	...
,, 28	10 57½	11 10	...	...	...	...	...
,, 29	08 21	08 41	Scheduled observation 08^{h} 00^{m} to 08^{h} 30^{m}				
,, 30	08 50½	09 10	(09 44	10 56	2	1 E.	−53½) *
,, 30	10 31	10 45	09 44	10 56	2	1 E.	+47
			10 53	12 50	3	56 W.	−22
,, 30	11 00	11 20	10 53	12 50	3	56 W.	+ 7
			11 00	11 05	1	48 E.	0
,, 31	13 00	14 12	Sun under observation : see p. 607				...
	13 50	14 15	13 45	14 20	2	12 W.	+ 5

* These two bright eruptions occurring just without the prescribed limit of time are entered here but are not included in the numerical data.

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(3) In the last column is given the time-interval—Time of fading *minus* time of solar eruption, the figures again being in heavy type in those cases for which the origin of the solar eruption was observed.

An examination of Table II, containing data of 79 fadings, brings out the following points:—

(1) During 1935 (two years after the last solar minimum) no association of bright eruptions with radio fadings is suggested by the few occurrences tabulated. It will be shown later, however, that two or three significant coincidences were recorded from other radio data.

(2) During 1936, a year of rapidly increasing solar activity, no fewer than 29 close associations of radio fadings with bright solar eruptions are shown in the table. In 8 cases the fading was recorded before the bright eruption was picked up by the observer, but it is clear from the solar record that in 6 of these 8 cases the eruption had begun before the observer first located it. In 21 cases there was a bright eruption on the Sun actually in progress when the radio fading commenced abruptly.

(3) Taking those cases of association in which the origin of the solar eruption was observed, the time-interval *Radio Fading* minus *Observed Origin of Solar Eruption* is 7 minutes, derived from 12 occurrences.

(4) The 29 cases of observed association include a high percentage of the more intense solar eruptions.

(5) The distribution of solar eruptions associated with the 29 radio fadings shows no preference for the central part of the disk.

(6) The hourly distribution of the 79 radio fadings listed in Table II throughout the 24 hours U.T. shows a peak about noon, as given by the following tabulation:—

Hours U.T.	Number	Hours U.T.	Number
0–2	3	12–14	21
2–4	0	14–16	11
4–6	2	16–18	7
6–8	6	18–20	5
8–10	12	20–22	2
10–12	10	22–24	0

Since the emitting or receiving stations recording the radio fadings given in Table II are situated in terrestrial longitudes about which the Sun is on the meridian at about 12^h U.T., this distribution is in accordance with the characteristic already noted in paragraph 3, viz. that these radio fadings are observed, in general, on channels traversing a daylight path.*

Before stating the implication suggested by the above features, it is desirable to consider data of radio fadings derived from other sources. Whilst the present paper was being prepared, J. H. Dellinger published a paper on the same subject, entitled "Sudden Ionospheric Disturbances" (*Terrestrial Magnetism*, **42**, 49, 1937). Included in Dr. Dellinger's paper is a useful table (*loc. cit.*, Table I) giving a list of occurrences of fadings (reported from at least two sources) during 1934–36 which he has collected

* This statement will be found exemplified by data circularized by Dr. Jouaust on 1936 October 15. See also *Journal B.A.A.*, **47**, 100, 1937.

from various sources. From Dellinger's Table I we have compiled a supplementary table which contains 14 fadings during 1935 and 53 fadings during 1936 not listed in our Table II. (There are 31 fadings in our Table II not found in Dellinger's list.)

The diurnal distribution according to hours U.T. of these 67 fadings extracted from Dellinger's list is given by the dotted curve in fig. 2, the full curve being the distribution given by the European data in Table II. The data abstracted from Dellinger's list include a number of fadings recorded in the eastern half of the U.S.A., and he states that reports are relatively meagre from the Asiatic and Pacific regions. It will be seen in

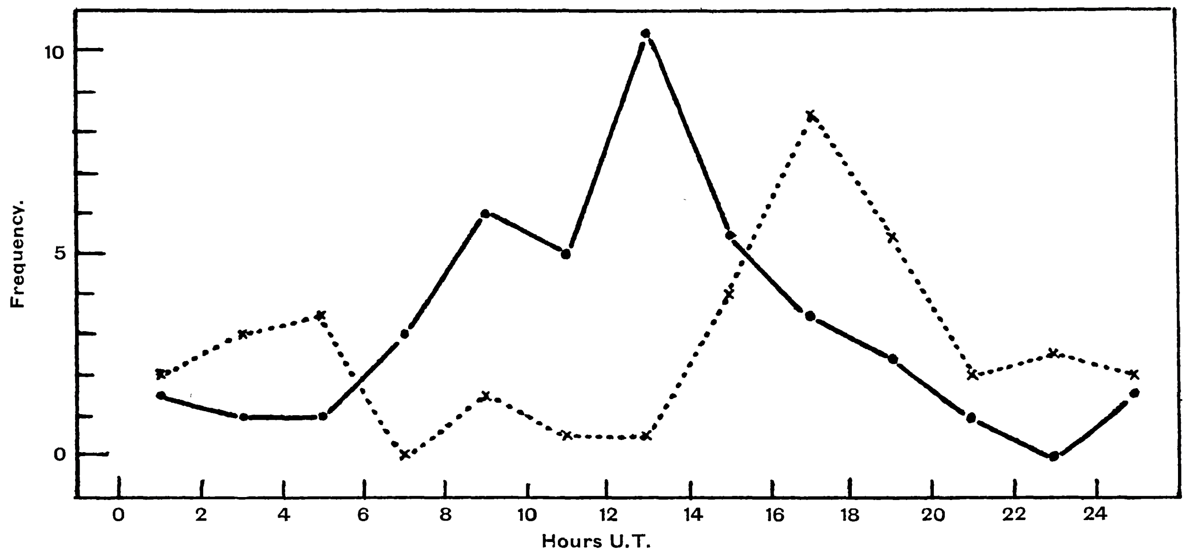

FIG. 2.—*Diurnal distribution of radio fadings (commencements) according to hours U.T. (2 hourly means).*

European data ——— *Extra-European data (Dellinger)* . . . . . .

fig. 2 that the peak shown in the diurnal distribution of fadings is displaced +4 hours from that given by data collected in our Table II.

The following table (Table IIA) is prepared in a similar way to Table II except that only joint occurrences (numbering 30 out of 67) of fadings and reported solar eruptions are listed. The durations of the fade-outs are also not available from the data to hand, but an average duration of 23 minutes derived from Table II has been used in making the comparison with the solar data.

5. *Discussion of Tables II and IIA.*—Combining the data in these two tables we have a total of 146 recorded radio fadings during 1935–36. In 59 cases there was recorded a bright solar eruption in close proximity, the mean interval—*beginning of fading* minus *time when solar eruption first seen*—being 4 minutes (the 20 best observed cases give 3 minutes).

This high degree of synchronization between the two phenomena may not, in itself, be significant, since owing to our prescribed limit of 30 minutes in associating a solar eruption with a radio fading, we should expect a small average time-interval to result. Taken, however, in conjunction with other features shown by the following analysis, the small time-interval of the order

TABLE IIA

(Supplementary to Table II)

Comparative Data of Radio Fadings (extra-European) and Bright Solar Eruptions, 1935–36, including only those Cases of a Joint Association (30 *out of* 67)

Date	Radio Fading (Commencement) U.T.	Bright Solar Eruption				Time-interval: Fading − Eruption
		From	To	Intensity	Distance from C.M.	
1935	h m	h m	h m		°	m
Aug. 30	23 20	**23 12**	23 30	2	3 E.	+ **8**
Sept. 13	16 30	**16 35**	**16 41**	?	?	− **5**
,, 27	12 48	12 00	12 30	1	62 W.	+48
Nov. 29	14 05	14 31	**14 45**	1	33 E.	−26
,, 30	18 55	17 51	18 30	2	19 E.	+64
Dec. 16	22 23	**22 10**	**22 38**	3	45 W.	+**13**
,, 17	16 15	16 09	...	3	62 W.	+ 6
,, 23	17 40	17 57	18 05	2	36 W.	−17
1936						
Feb. 16	15 50	16 30	17 00	1	25 W.	−40
Apr. 7	02 30	02 31	...	1	72 E.	− 1
,, 8	09 20	08 10	**10 00****	1	3 W.	+70
,, 25	14 27	**14 38**	14 45	2	45 W.	−**11**
,, 25	16 53	**16 15**	**16 30**	2	41 W.	+**38**
		16 25	16 50	1	30 W.	+28
		16 46	18 00	2	46 W.	+ 7
		16 49	18 00	1	35 W.	+ 4
May 30	17 30	15 42	18 00	1	44 E.	+108
June 9	15 55	15 30	17 00	1	80 W.	+25
,, 9	17 50	17 55	18 05	2	77 W.	− 5
,, 16	17 15	16 41	16 50	1	77 E.	+34
		18 01	**18 09**	2	70 E.	−**46**
,, 16	18 00	**18 01**	**18 09**	2	70 E.	− **1**
,, 19	16 20	**16 29**	**16 44**	1·3	35 E.	− **9**
,, 19	17 30	17 36	18 00	2	28 E.	− 6
,, 19	19 38	19 38	19 57	3	30 E.	0
,, 19	20 18	19 38	19 57	3	30 E.	+40
Aug. 4	17 27	**17 19**	**17 23**	1	33 W.	+ **8**
,, 5	16 07	15 36	16 00	1	30 W.	+31
		16 03	**16 48**	2·3	63 W.	+ **4**
Nov. 8	18 19	18 19	18 27	2	70 E.	0
,, 16	15 00	15 30	17 00	1	73 W.	−30
,, 25	19 25	18 40	**19 04**	1	50 E.	+45
,, 29	15 47	15 30	17 00	1	55 E.	+17
		15 55	16 37	1	10 W.	− 8
		16 08	16 14	3	3 W.	−21
Dec. 24	22 05	**22 00**	**22 18**	1	72 E.	+ **5**
		22 35	**22 53**	3	38 E.	−**30**
,, 24	23 50	**23 49**	23 58	2	72 E.	− **1**

* Three separate eruptions recorded between these times.

of a few minutes is probably of significance. It may be noted that a typical bright solar eruption takes from 5 to 10 minutes to reach its maximum intensity after the eruption first becomes visible (*The Observatory*, **59**, 295, 1936).

These 59 associated eruptions have the following distribution in their recorded intensities as shown in Table III. (In those cases where two or more solar eruptions are associated in Tables II and IIA with a radio fading the more intense eruption has been selected.) In the last column the number of eruptions so associated in each class is expressed as a percentage of the total number of eruptions of that class observed during 1935–36 (see Table I).

Table III

Solar Eruptions associated with Radio Fadings, 1935–36, *classified according to the Intensity of the Solar Eruption*

Intensity	Percentage Frequency	Number of Eruptions Associated with Fadings	Percentage of its Class
1	77	22	4
2	19	23	15
3	4	14	48

The high incidence of the larger and brighter solar eruptions (which themselves are infrequent relative to those of intensity 1) found in association with radio fadings is very marked and suggests the reality of a relationship between the two phenomena.

We have now to consider that, on account of the relative frequency of solar eruptions (all classes taken together) during 1935–36, there is to be expected a number of chance coincidences with radio fadings, even if the two phenomena were entirely unrelated. The observed number of solar eruptions given in Table I probably requires correction by a factor of nearly 2, in order to allow for gaps in the international solar programme and for cloudy weather experienced frequently at some of the observing stations. The radio data, undisturbed by cloudy weather, probably requires a smaller correction on account of lack of continuity of observation, though at least three or four observing centres distributed in longitude around the Earth would appear to be required to ensure fully representative data.

In Table IV are tabulated the observed number (59) of radio fadings and associated solar eruptions during 1935–36 together with the expected number (n) of chance coincidences, computed by the following approximate formula:—

$$n = N \times f \times d,$$

where N = total number of radio fadings (22 in 1935 and 124 in 1936), f = mean daily frequency (corrected) of solar eruptions, d = mean duration of eruptions expressed as a fraction of a day.

Table IV brings out the fact that the observed number of coincidences between the two phenomena in question is far in excess of the number

Table IV

Coincidences of 59 Radio Fadings and Solar Eruptions

1935–36 Year	(a) Observed Number. All Eruptions Intensity 1, 2 and 3	Major Eruptions Intensity 2 and 3	(b) Expected Chance Coincidences All Eruptions Intensity 1, 2 and 3	Major Eruptions Intensity 2 and 3
1935	8	5	0·4	0·06
1936	51	32	9·1	2·7

which would be expected if they were unrelated. This is especially marked in the cases of observed associations in which the solar eruptions were of major importance. It seems probable that a continuous solar record would considerably increase the number of observed coincidences.

Control Data.—In order to estimate further the extent to which chance coincidences may affect the result, two further tests on the data have been made. Firstly, we have taken the above 59 cases of association, and in each case have abstracted from the Zurich *Bulletin* the solar eruption and its intensity that was nearest in time to that already selected as occurring within the prescribed limit of 30 minutes. The average difference in time of these newly selected eruptions from the radio fadings is $\pm$ 7·6 hours, and the mean intensity of the eruptions 1·4, as compared with the corresponding values given by the original selection, namely, $\pm$ 0·1 hour : mean intensity 1·9.

Secondly, we have again taken the above 59 cases of associations and carried through afresh the comparison between the solar data and the radio fadings for the following epochs reckoned from 0^h = the time of each radio fading :—

$$-3^h, \quad +3^h, \quad -24^h, \quad +24^h, \quad -48^h, \quad +48^h.$$

The numbers of associated solar eruptions thus found within the prescribed limit of 30 minutes at each of these epochs were then tabulated, as before, according to their intensity, 1, 2 or 3. The results are given in Table V. In fig. 3 the numbers of associations found in each class of intensity are expressed as percentages of the total number of associations found in each class throughout the epochs, as defined above.

Table V

Number of Bright Solar Eruptions, according to their Intensity, occurring within 30 Minutes of Epochs 0^h, -3^h, $+3^h$, -24^h, $+24^h$, -48^h *and* $+48^h$, *where* 0^h = *Time of Radio Fading*

Solar Eruption of Intensity	Epoch from Radio Fading = 0^h: -48^h	-24^h	-3^h	0^h	$+3^h$	$+24^h$	$+48^h$
1	15	17	18	22	14	20	10
2	3	6	15	23	6	4	1
3	0	1	1	14	3	0	3

The results show clearly a peak at 0^h in the case of the larger and brighter eruptions (intensities 2 and 3). [Incidentally, Table V suggests that within 2 days of the radio fadings there is a tendency for solar eruptions to rise above normal frequency.]

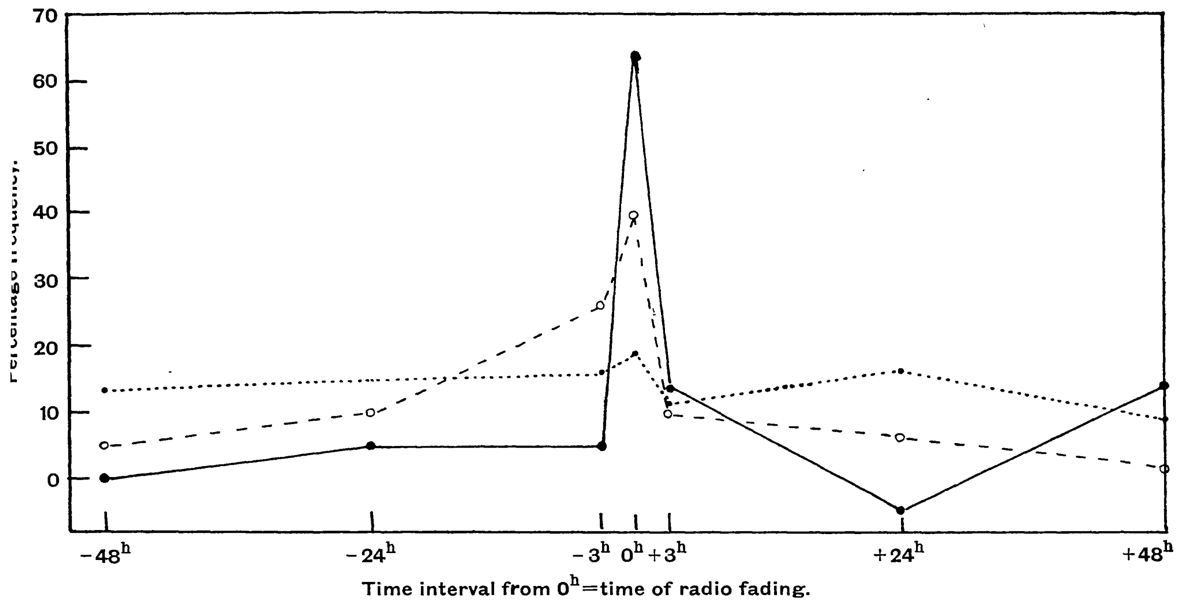

FIG. 3.—*Solar eruption intensity*

——— 3 (*Greatest*). - - - - - 2. . . . . . 1 (*Least*).

The distribution on the Sun's disk according to angular distance from the central meridian for the 59 solar eruptions associated with radio fadings may next be noted, as follows :—

TABLE VI

Longitude from Sun's Central Meridian	Number
0°–29°	14
30°–59°	27
60°–90°	17
Unclassified	1

Taking the evidence presented by Tables III–VI it may be concluded that there exists a close relationship between the observed radio fadings *

* It has been pointed out by R. Bureau and J. Maire (*Comptes rendus*, **203**, 1275, 1935 ; *Nature*, **139**, 110, 1937) that sudden fadings on short waves are often accompanied by improved reception on long waves (7500–11,000 metres). Their results are based on the automatic reception at Paris, Rabat and Tunis of atmospherics originating from a distant terrestrial source. In a memorandum circularized by the French Committee of Scientific Radiotelegraphy, there are listed, during the year 1936, 109 occurrences of a sudden increase in the number of atmospherics of which 47 occurrences (43 per cent.) correspond closely in time with the sudden fadings in short-wave transmission listed in Table II of our paper ; 4 other occurrences correspond with fadings given in Table IIA. In 6 additional cases, not coincident with reported short-wave fadings, there were bright solar eruptions in progress. Although it is not proposed in this paper to extend the comparison of long-wave radio data and associated bright solar eruptions, it is noted that the former will provide useful and independent data for future discussion.

(implying disturbance in the ionosphere) and bright eruptions on the Sun. The observations indicate an agency travelling out radially in all directions, from localized patches of enhanced emission in the Sun's chromosphere, with approximately the speed of light. The more extensive bright solar eruptions appear to be most effective in this relationship.

It seems desirable to extend the astronomical observations in the following ways:—

(1) A more extensive record of bright solar eruptions, and any associated phenomena, in $H\alpha$ and in other absorption lines of the solar spectrum.

(2) A record to be kept at each contributing observatory of the times under which the Sun is actually under observation. This suggestion has been put into operation during the last few months, and the collective information assembled by M. d'Azambuja at the Meudon Observatory should eventually supply answers to the following questions.

(*a*) Can large solar eruptions observed in $H\alpha$ or in K occur on the Sun without affecting the ionosphere?

(*b*) Can appreciable disturbances in the ionosphere occur and no unusual disturbance be located with certainty on the Sun?

(3) An improved scale of estimating the intensity of solar eruptions, such as one based on photometry coupled with measurement of the area

Table VII

Solar Eruptions of Intensity 3 having (to date) no Reported Associated Radio Fadings, 1935–36.

Date	Time U.T. From	Time U.T. To	Distance from Central Meridian	Observatory
1936	h m	h m	°	
Feb. 16	03 25	...	23 W.	K.
Mar. 16	16 24	...	8 E.	C.
May 15 *	07 04	**08 30**	27 E.	M. and Z.
June 2	16 31	18 00	45 W.	C.
,, 5	15 40	16 26	22 W.	W. and G.
,, 26	16 58	18 00	61 W.	C.
July 9	16 46	16 50	60 W.	C.
,, 12	16 25	17 40	23 E.	C.
,, 28	17 52	18 00	75 W.	C.
,, 30 *	**10 41**	**11 30**	48 E.	G.
Aug. 3	05 03	...	2 W.	K.
,, 5	**22 17**	**22 21**	49 W.	Mt. W.
,, 15	**07 46**	**08 20**	1 W.	Z.
,, 30	02 35	...	5 E.	K.
Sept. 25	04 18	...	5 E.	K.
,, 26	02 23	...	0	K.

K. = Kodaikanal; C. = (Wynne Cook) Swarthmore or Wynnewood; M. = Meudon; W. = (Newbegin) Worthing; G. = Greenwich; Mt. W. = Mount Wilson; Z. = Zurich.

* On May 15 and July 30 Cable and Wireless, Ltd., report that conditions were somewhat erratic, particularly on the most northerly routes, as a result of magnetic disturbances.

of the enhanced emission. Whenever obtainable, an observed intensity curve of a bright eruption caught in its initial stages may be extrapolated backwards to derive the time of origin of the disturbance with greater precision than can otherwise be usually attained.

A table is appended giving a list of 16 large solar eruptions (intensity 3) observed during 1935–36 for which no associated radio fading has as yet been reported. During 1935 there were only two eruptions of intensity 3 observed; both of these were associated with radio fadings given in Table IIA.

It may be noted that the mean time difference of these 16 eruptions from Greenwich noon (12^h U.T.) is 6·0 hours.

The times of the 87 radio fadings unassociated with recorded bright solar eruptions have been compared with the Greenwich register of times of observations with the spectrohelioscope. In only 3 cases the Sun was being observed at Greenwich at the times of the respective fadings, viz. 1936 May 29^d 10^h 24^m, June 17^d 09^h 08^m * and Sept. 5^d 09^h 04^m. Although no bright eruption was registered, there was in each case appreciable or unusual activity observed at or near the time of fading, as follows :—

May 29.—The disappearance at some time between 11^h on May 29 and 10^h on May 30 of a long absorption marking extending over 30° of solar latitude.

June 17.—Two small patches of enhanced emission near a sunspot, not definite enough to be classified by the observer as a bright eruption; a measured component of radial velocity of $+65$ km./sec. of an associated absorption marking. Another velocity ranging from -30 to $+50$ km./sec. in an adjacent part of the disk.

September 5.—An absorption marking near a sunspot with a component of radial velocity of -130 km./sec. The marking projected about $1\frac{1}{2}'$ beyond the limb as a prominence.

M. d'Azambuja has kindly communicated the information that during the occurrence of four other fadings commencing 1936 Oct. 21^d 15^h 34^m, Dec. 9^d 13^h $12\frac{1}{2}^m$, Dec. 12^d 16^h 02^m and Dec. 31^d 13^h 00^m respectively, the Sun was being observed at one of the collaborating stations. It is not known at present whether unusual solar activity occurred at or near these times, in the apparent absence of bright eruptions. A frequent record of the whole solar disk, taken with a self-recording spectroheliograph as recently installed at the Mount Wilson Observatory, would be of great use in these and similar cases.

6. Before summarising the results of this paper there are two points for inquiry that present themselves. (*a*) A tendency or absence of tendency for fadings to occur at intervals of 27 days, corresponding to the Sun's synodic rotation. (*b*) The association or otherwise of terrestrial magnetic phenomena at, or near, the time of solar eruptions accompanied by radio fadings.

* This fading is given in Dellinger's list in *Terrestrial Magnetism*, **42**, 49, 1937.

(*a*) *Test for Recurrence Tendency of Radio Fadings in 27 or 54 Days*

The graph (fig. 4) has been derived in the following manner. Taking in turn each fading recorded either in Table II or IIA, an entry had been made on any day between the initial day $=0$ and day $=60$ when a fading is listed. The sums for each of the days 0 to 60 are then taken and expressed as percentages of the total for day 0 and plotted. The analysis has not been carried beyond 1936 November 1, since data for the requisite overlap into 1937 are not yet available. No extra weight has been given to those days on which two or more radio fadings are recorded.

Fig. 4 shows a very irregular curve * following the initial day of disturbance. Although a peak is shown at day $=28$, there are similar peaks at days 6 and 36. There is also a broader peak centred at about day 52. The reality of these peaks appears doubtful, although, owing to the Sun's rotation in about 27 days, active sunspot regions producing bright eruptions and brought again on to the visible hemisphere by the Sun's rotation might be expected to produce a broad peak centred at 27 days (given a relationship between bright eruptions and radio fadings).

(*b*) *Associated Magnetic Phenomena*

Taking those cases of associated fadings and bright eruptions given in Table II, the magnetic traces of the Greenwich Magnetic Station at Abinger were examined for each of the occurrences. Out of 29 cases there were only 3 definite cases in which a small but possibly significant deflection of the H.F. trace occurred within a minute or two of the reported fading. The dates and times are 1936 April 8^d 16^h 49^m, May 28^d 07^h 29^m and Aug. 28^d 09^h 30^m. The ranges are quite small, of the order of $10\,\gamma$. On April 8 between 16^h 46^m and 16^h 51^m the horizontal force as registered at Huancayo (Lat. $12°$ $3'$ S., Long. $75°$ $20'$ W.) suddenly increased by $108\,\gamma$ and then decreased $139\,\gamma$ between 16^h 51^m and 17^h 28^m.†

Of the remaining 26 cases no deflections were recorded on the traces in 18 cases, while the remaining 8 cases were indeterminate owing to general unsteadiness or disturbance (including two small magnetic storms) that was prevailing at the time.

Next, the ranges in H.F. in 24 hours for the intervals, -48 hours, -24, $+24$, $+48$ . . . $+120$ hours, immediately preceding and following the time of the recorded beginning of each of these 29 cases were measured and tabulated in Table VIII. The mean ranges are given for

(*a*) All the 29 cases.

(*b*) Excluding the 2 cases when small magnetic storms were occurring.

(*c*) Eighteen cases (excluding one case when a magnetic storm was occurring) for which the associated solar eruption was within 4 days' time of the transit of the Sun's central meridian.

* This may be compared with the diagram given by Greaves and Newton in *M.N.*, **89**, 642, 1929, which shows a 27-day period in the recurrence of the *lesser* magnetic storms.

† *Terrestrial Magnetism*, **41**, 199, 1936.

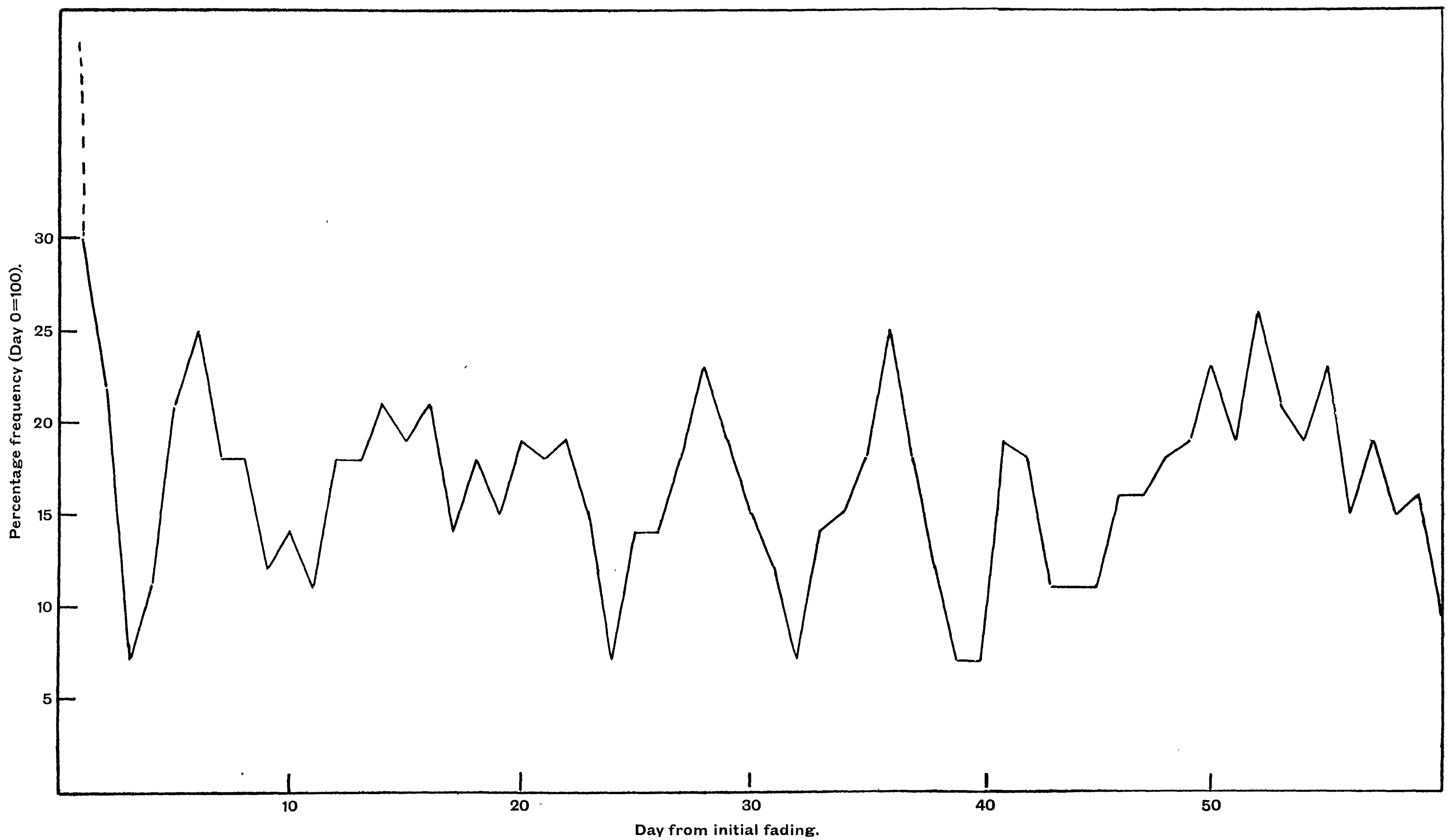
Percentage frequency (Day 0=100).
30
25
20
15
10
5
10
20
30
40
50
Day from initial fading.

FIG. 4.

TABLE VIII

Measured Ranges in H.F. (Abinger) Before and After Radio Fadings associated with Solar Eruptions, 1935–36

	-48^h	-24^h	$+24^h$	$+48^h$	$+72^h$	$+96^h$	$+120^h$
(*a*)	68γ	71γ	70γ	71γ	81γ	62γ	67γ
(*b*)	70	62	66	62	67	59	60
(*c*)	67	61	63	68	75	61	63

The mean of the daily extreme ranges for the year 1936 is 68γ.

It may be said that the above examination of magnetic conditions at Abinger at about the time of radio fadings observed from W. Europe during 1935–36 gives no definite indication that any associated disturbance took place in the Earth's magnetic field either at the time of the joint occurrence of solar eruption and radio fading or within 120 hours afterwards. The data, however, are insufficient to draw any definite conclusion. It is of interest to tabulate some similar magnetic data for the Earth as a whole given by the de Bilt magnetic character figures. The following tabulation shown in Table IX has been prepared by writing down the mean character figures for days −3, −2, −1, 0, +1, +2 . . . +6 for each of the radio fadings tabulated in Tables II and IIA for 1935 and 1936 September 30 up to which date the de Bilt circulars have been received.

TABLE IX

Mean de Bilt Magnetic Character Figures corresponding to the Epochs of 37 *Radio Fadings* 1935–36 *September* 30

	Day of radio fading = 0									
Day	−3	−2	−1	0	+1	+2	+3	+4	+5	+6
Mean of character figures	·61	·56	·69	·84	·71	·65	·64	·52	·67	·60

In this case also no definite conclusion can be inferred from Table IX, but the trend of the figures suggests a slight rise in magnetic activity for the Earth as a whole on those days on which a radio fading occurred during 1935–36. There is no indication of a peak about two days after the radio fading.

It may be recalled that from the infrequent records since 1892 of bright solar eruptions of the greatest intensity there is shown a tendency for the eruption to be followed by a terrestrial magnetic storm about 26 hours later.* It is probable, however, that so far during the present 11-year cycle, no bright eruption equal in intensity to these very great eruptions has as yet been observed.

Attention has been drawn by various spectroscopic observers to the occasional occurrence of characteristic deflections shown in magnetic traces

* Hale, *Astrophysical Journal*, **73**, 379, 1931 ; (H. W. N.), *Monthly Notices*, **90**, 824, 1930.

synchronous with the observed time of great chromospheric outbursts at the Sun's limb.* Extended data based on the observations of bright solar eruptions and of disturbances in the ionosphere promise to throw light on these problems.

7. *Summary*.—The present paper makes a preliminary comparison between sudden radio fadings (implying disturbances in the ionosphere) and bright eruptions observed on the Sun in hydrogen light ($H\alpha$) or in that of ionized calcium (K). Certain characteristics of the radio fadings themselves suggest that they are related in some way to radiation effects proceeding from the Sun. The comparison made with the solar eruptions leaves little doubt that a close relationship exists between the two phenomena, especially in the case of the largest eruptions, and implies a solar agency, travelling from limited parts of the Sun's chromosphere (and indicated visually by bright $H\alpha$ eruptions) with approximately the speed of light.

The question of a tendency for radio fadings to recur in 27 days or 54 days is examined, as well as the possibility of terrestrial magnetic effects being shown when radio fadings occur. The results given by the present limited data are not conclusive enough to be stated with confidence.

It is obvious that the comparison between the bright solar eruptions and radio fadings should be continued during the present solar cycle. A future discussion should include definitive radio data as given by radio soundings of the ionosphere based on Professor Appleton's methods. A few suggestions are made in which the solar observations might be extended, but chiefly a continuous solar record, as far as weather conditions will allow, as well as an improved scale to define the intensity of the solar eruptions are required for furthering the present investigation.

In conclusion we wish to thank the Astronomer Royal for his suggestion that a comparison should be made between the solar and radio data put at our disposal.

We are also indebted to Mr. W. M. H. Greaves for some helpful criticism and advice when concluding this preliminary investigation, which in essentials follows the procedure which he used some years ago in a discussion † (with one of us) between sunspots and terrestrial magnetic storms. The latter relationship, as is well known, implies a corpuscular agency from the Sun.

Royal Observatory, Greenwich :
1937 *June* 1.

* C. A. Young, *The Sun*, p. 156, 1888 ; C. Michie Smith, *M.N.*, **70**, 23, 1909. The eruption referred to in this paper was on the disk but near the limb. A. Fowler, *The Observatory*, **56**, 43, 1933.

† *M.N.*, **88**, 556, 1928 ; **89**, 84, 1928 ; 641, 1929.