Kodaikanal Observatory.

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A COMPARISON OF THE PERIODICITIES IN PROMINENCES AND SUNSPOTS.

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I have already[1] determined the amplitude of the 11 year period in prominences for comparison with the amplitudes of certain short periods, notably one of 13½ months, which were found to exist in the prominence observations at Kodaikanal and Catania. When it was found further, as will be detailed below, that the short periods in prominences had no counterpart in sunspots, it became very desirable to determine whether the well-established sunspot periodicities other than that of 11 years, existed or not, in prominences. I therefore undertook the investigation of periodicities up to 11 years, by the periodogram method of Schuster[2] with the best data which were available for the purpose.

The data used are those published in the Memorie della Società degli Spettroscopisti Italiani based upon observations made by the Italian observers of all prominences exceeding 30″ in height. These observations extend from 1871 onwards, now embracing over 3 eleven-year cycles, and are the most complete and uniform series of prominence observations at present available for so long an interval. They are therefore the most suitable for the investigation of long periodicities. The quarterly and half-yearly values of the mean daily frequencies as tabulated in the Memorie della Società degli Spettroscopisti Italiani were used to determine the intensities of periods from 2 to 13½ years. The work was carried out in a manner similar to that which Schuster has worked out[2] and applied to the investigation of sunspot periodicities[3]. The two Fourier co-efficients were first determined for each period and its first, and sometimes the second, sub-periods. The ordinate of the periodogram is then proportional to the product of the sum of the squares of the Fourier co-efficients and the time interval to which the analysis has been applied[2]. The data were arranged to give the phase at the time of first datum of 1881, *i.e.* at 1881·25 for periods determined from the half-yearly values, or at 1881·125 for those determined from the quarterly values. The ordinates of the periodogram (S), and the phases (ϕ) determined from half-yearly values are given in Table I and from quarterly values in Table II. The phase is 0° when a period has its maximum.

TABLE I.

Ordinates of the Periodogram (S) and Phases (ϕ) at 1881·25.

Period in years.	S	ϕ	Period in years	S.	ϕ	Period in years.	S.	ϕ	Period in years.	S.	ϕ
6 ...	5030	301°	7½ ...	8895	156°	10 ...	12970	128°	12½ ...	22200	43°
6¼ ...	1730	277°	8 ...	9870	128°	10½ .	21900	122°	13 ..	19830	32°
6½ ...	2675	235°	8½ ...	3667	113°	11 ...	28500	95°	13½ ...	16350	22°
6¾ ...	2560	226°	9 .	4350	133°	11½ .	32200	77°			
7 ...	8800	196°	9½ ..	7510	136°	12 ...	20250	64°			

TABLE II.

Ordinates of the Periodogram (S) and Phases (ϕ) at 1881·125

Period in years.	S.	ϕ	Period in years.	S.	ϕ	Period in years.	S.	ϕ	Period in years.	S.	ϕ
2 ...	808	114°	3⅛ ...	970	138°	4½ ...	2235	134°	6¼ ...	3090	269°
2⅛ ...	368	154°	3¼ ...	1640	81°	4⅝ ...	1127	84°	6½ ...	2840	255°
2¼ ...	579	358°	3⅜ ..	784	35°	4¾ ...	1680	119°	6¾ ...	8500	221°
2⅜ ...	44	162°	3½ ...	230	16°	4⅞ ...	1988	65°	7 .	7990	196°
2½ ...	208	142°	3¾ ...	440	70°	5 ...	2505	96°	7¼ ...	8900	178°
2⅝ ...	1113	31°	4 ...	383	338°	5¼ ...	3995	59°	7½ ..	9240	165°
2¾ ...	539	299°	4⅛ ...	1060	345°	5½ ...	3845	21°	7¾ ...	10400	146°
2⅞ ...	37	199°	4¼ ...	1145	203°	5¾ ...	4343	346°	8 ...	10650	133°
3 ...	172	203°	4⅜ ...	554	143°	6 ...	3645	308°	8¼ ..	7165	116°

[1] Royds, Kodaikanal Observatory Bulletin No. XXXIII.

[2] Schuster, Proc. Roy. Soc. A., Vol. 77, page 136, 1906.

[3] Schuster, Phil. Trans. Roy. Soc , Vol. 206, page 69, 1906.

The periodogram is plotted in Figs. 1 and 2 below. Fig. 1 is the part from 5 to 13½ years and Fig. 2 shows the portion below 6½ years on an enlarged scale.

2. The predominant feature of the periodogram is, of course, the 11 year period, of which the first subperiod (5·56 years) but not the second, is well marked. Other features are the truncated peak from 6¾ to 8¼ years, which is probably composed of several periodicities, and small peaks at 4½ and 3¼ years.

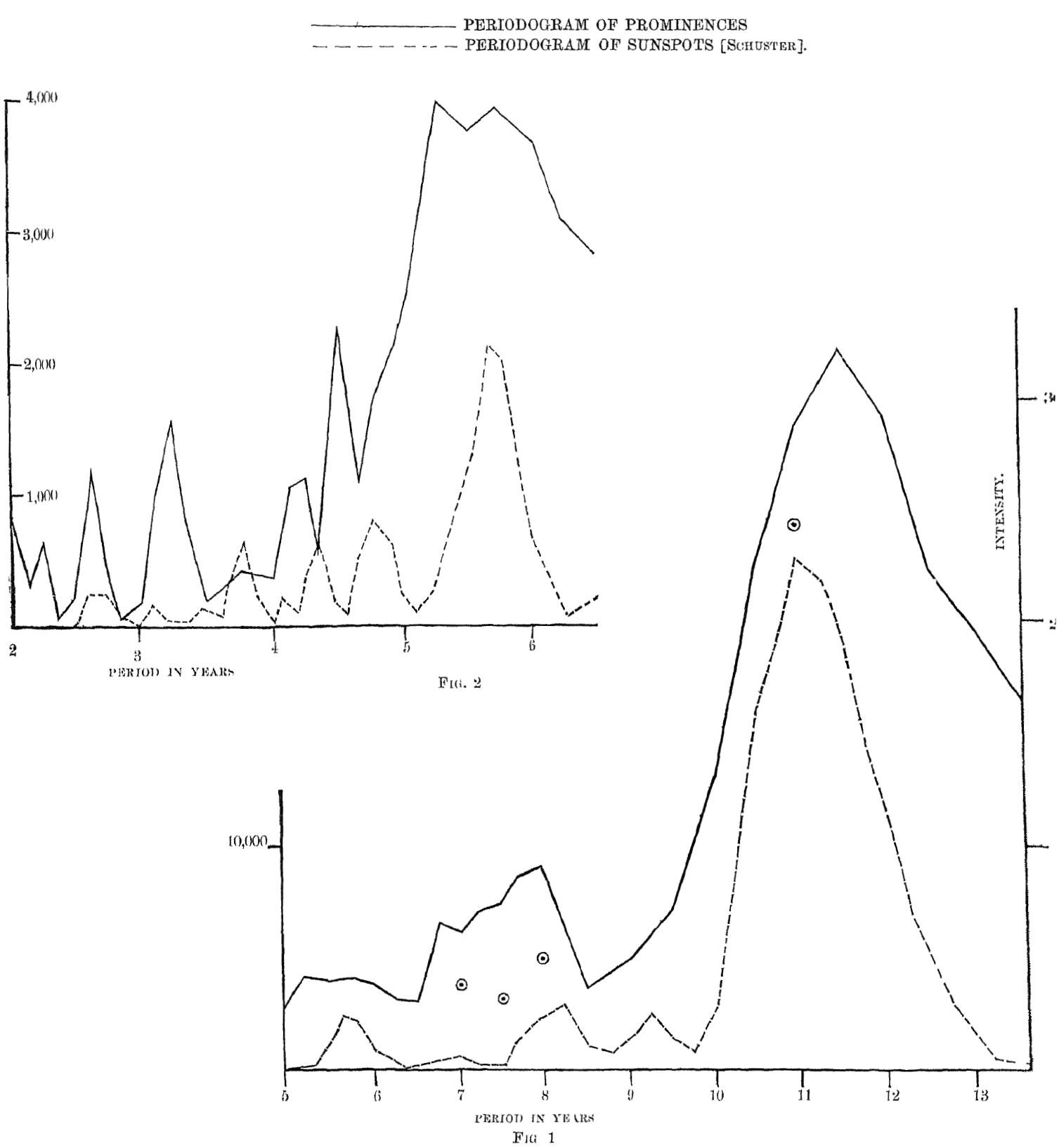

FIG. 2

FIG 1

In order to facilitate comparison of the periodograms of prominences and sunspots I have added to Figs 1 and 2, on a convenient scale, the sunspot periodogram as given by Schuster[1] for the years 1826–1900. This spot periodogram relates to a much longer time interval than that for which prominence observations are available, but this curve will serve for a general comparison. It is at once seen that the peaks of the 11 year period and its first sub-period are more pointed in the sunspot curve. This is of course due to the increase in what corresponds, in the optical analogy of the periodogram, to the resolving power brought about by the longer time interval and the greater reliability of spot data. It should here be mentioned that the slight dip at 5½ years in the band of the prominence periodogram due to the first sub-period of the 11 year period has no real significance. When so short a time interval as the present is being analysed, fictitious discontinuities are likely to be introduced in the presence of homogeneous periods, by the relatively large variations of the time interval into which the intensity is multiplied to give the ordinate of the periodogram.

3. We now turn to a discussion of the individual periods which have been established for sunspots.—

(*a*) 11 *year period*.—The interval of 3 cycles is not sufficient to determine as accurately as may be desired the exact period in the neighbourhood of 11 years, but there can be little doubt that the true period in prominences is coincident with that of sunspots which Schuster has fixed at 11·125 years. Before proceeding to discuss the phases of the 11 year period it may be mentioned here that Riccò has recently[2] published a discussion of the same data on which the periodogram I have constructed is based. He finds, *inter alia*, that the maxima of prominences occur 2 years later than sunspots in two cases and one year previously in the third. How far this is due to a delay in the 11 year maximum can now be determined from the phase of the 11 year period. Assuming the true period to be 11·125 years, we deduce from the phases given in Tables I and II the following times of maxima for that period and its first sub-period. The phases for sunspots according to Schuster are given for comparison :—

Period.	Dates of Maxima in Prominences.	Dates of Maxima in Sunspots.
11·125 years	1906·3 ± n. 11·125	1905·31 ± n. 11·125
5·56 „	1903·6 ± n 5·56	1903·75 ± n. 5·56

It is seen that the 11 year period has its maxima about one year later in prominences than in sunspots whilst the maxima of first sub-periods are practically coincident. Of course, it must be remembered that the 11 year periodicity in prominences is based on 3 cycles only and may therefore be considerably in error, but the phases are deduced from several neighbouring points in the band.

The effect of the greater retardation of the main period relative to the first sub-period is to flatten out the maximum of the 11 year cycle thus extending the duration of great activity of prominences. This retardation of the main period and the flattening out of the maximum is seen from Fig. 3, which shows the average growth and decay of prominences during the 11 year cycle, compared with the curve for Greenwich sunspot areas, on a convenient scale, for the same time interval.

CURVES OF GROWTH AND DECAY DURING 11 YEAR CYCLE

A PROMINENCES 1880—1912

B SUNSPOTS 1879—1911

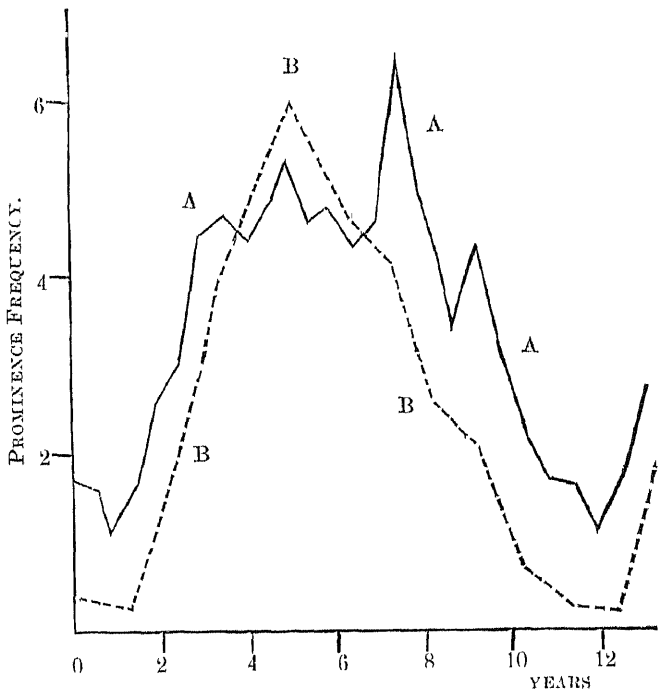

FIG. 3.

[1] Schuster, Phil. Trans. 206. 69 1906. Table IV, column IV, and Table V.

[2] Riccò, Mem. Spett. It., Ser II. Vol. II, page 147, 1913.

(*b*) *Periods of* 4·80, 8·36, 4·38 *years*.—None of these periods established for sunspots can be identified with certainty in the prominence periodogram. This is due in the more important cases to their being hidden, if present at all, in the broad bands due to other periods. The most persistent spot period, 4·80 years, for instance would be hidden in the band at $5\frac{1}{2}$, and the 8·36 period in the band from $6\frac{3}{4}$ to $8\frac{1}{4}$ years. The less certain spot period of 4·38 years, may be identical with the peak at $4\frac{1}{2}$ years in the prominence periodogram. If this is really so, the maxima in prominences occur at $1896{\cdot}4 \pm$ n. 4·38, rather earlier than in sunspots, where they are at $1897{\cdot}00 \pm$ n. 4·38 years. This comparison of phase is however hardly warranted in view of the uncertainty of the assumed identity of the periods in spots and prominences.

4. There are other periods in the prominence periodogram which have no counterpart in Schuster's curve for sunspots. The most important are those periods which are not distinctly resolved in the band from $6\frac{3}{4}$ to $8\frac{1}{4}$ years. The intensities of these periods are too large to be accidental, being indeed, after the 11 year period the most marked feature of the periodogram. Although the 8 year period may be affected by the spot period of 8·36 years the rest of the band is totally absent from the sunspot periodogram. It seems therefore, as though there was here a real difference in the periodicities in sunspots and in prominences. This conclusion is not warranted, however, until these periods are shown to be absent from sunspots in the time interval 1880—1912 for which the prominences are analysed; for it is possible that they might have been present in spots also for so short an interval but absent at other times, thus giving a small average intensity over the long interval 1826—1900 to which the spot periodogram relates. I have therefore determined the intensity of the periods of 7, $7\frac{1}{2}$, and 8 years from the yearly values of the Greenwich daily sunspot areas from 1880—1911, and the relative intensities are given below, the points being marked thus O in Fig. 1, on a scale to show their true importance compared with the 11 year period. The values are given below together with those for prominences for comparison :—

Period.	Relative intensity.		Phases in spots at 1881·125.	Phases in prominences at 1881·125.
	In spots.	In prominences.		
11 years	1	1	...	..
8 ,,	0·19	0·38	135°	133°
$7\frac{1}{2}$,,	0·12	0 32	149°	165°
7 ,,	0·16	0·28	217°	196°

From the table we see that there can be no doubt in consideration of the agreement of phases (which, since they refer to the same time interval, are strictly comparable whatever the true periods may be) that identical periodicities exist in both sunspots and prominences, although their relative intensities are doubled in prominences.

It is seen therefore that there are within the region 7 to 8 years periods of considerable intensity n sunspots for the time interval 1880—1911, but since their average intensity during the interval 1826—1900 is small we must conclude that these periods are not permanently active. So far then as the periods between $6\frac{3}{4}$ and $8\frac{1}{4}$ are concerned there is no marked real difference between the sunspot and prominence periodograms, since if the spots and prominences are analysed for the same time interval, the same periodicities are found in each.

The period of $3\frac{1}{4}$ years which is also absent from the spot periodogram cannot, in view of its small intensity, be regarded as certain. We must conclude therefore that all the periodicities which can be established in prominences are present also in sunspots.

5. It is very evident from an inspection of spot and prominence data, that at the times of minimum solar activity, the activity of spots sinks much lower than that of prominences. In the following table are given the relative amplitudes of the periods which have been found, expressed as a percentage of the average value of the daily prominence frequency over the whole time interval, and compared with the corresponding data for spots :—

Period.	Amplitude in Prominences. (Average daily frequency 3·73.)	Amplitude in spots. (Average daily area 562.)
11·125 years	44% of average frequency.	73% of average area.
5·56 „	18% „ „	17% „ „
4·5 „	13% „ „	....
$6\frac{1}{4}$ to $8\frac{1}{2}$ „	28% „ „	33% of average area.

Short Periods.

6. Periodicities between 4 and 19 months have already been investigated in the prominence observations made at Kodaikanal during the years 1905 to 1912[1]. It is convenient here to summarise our knowledge of the existence of short periods in prominences. In the Kodaikanal observations was found a period of $13\frac{1}{3}$ months with an amplitude about $\frac{1}{3}$ that of the 11 year period as well as two others, less certain, of $7\frac{1}{2}$ and $6\frac{1}{3}$ of amplitudes each about $\frac{1}{4}$. The $6\frac{1}{3}$ month period may be partly due to the sub-period of $13\frac{1}{3}$ months. If we take the Catania prominence observations for the same interval, we find that the first two periods have amplitudes of about $\frac{1}{6}$ of the 11 year period, but the $6\frac{1}{3}$ month period is absent. The phases are not in good agreement, but the Catania observations are not so complete as those made at Kodaikanal where prominences below 30″ are taken into account. When we consider the longer interval of Italian observations 1880—1912, the average amplitudes are then small although the phases agree well with those derived from Kodaikanal observations. It appears, therefore, that the short periods mentioned are not permanent, but are in evidence only a comparatively short time.

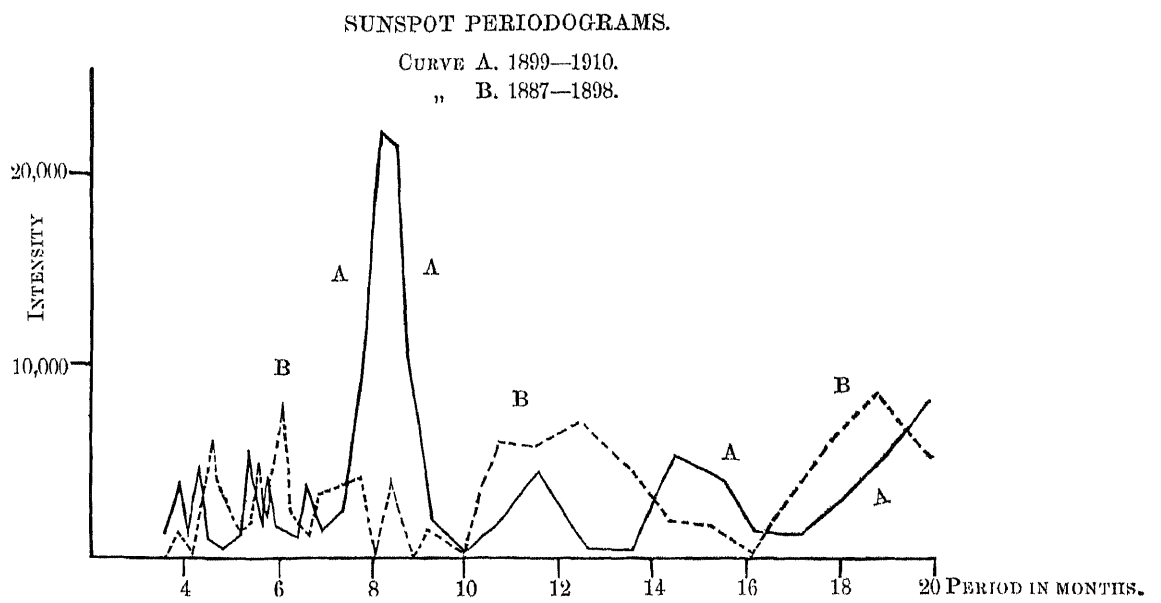

Fig. 4.

7. For the purpose of comparing these periodicities with those in sunspots, Mr. A. A. Narayana Ayyar, B.A., of this Observatory, has analysed sunspot data for short periodicities. The Greenwich data for each rotation of the sun were divided into intervals of about 12 years, the last of which, 1899—1910 includes the interval for which Kodaikanal prominence observations have been analysed. The periodogram for 1899 to 1910 was constructed first, and it was found that the 13 month period of prominences was entirely absent but a new one of just over 8 months was intense, having an average amplitude during these thirteen years of about $\frac{1}{3}$ that of the 11 year period. On passing to the previous twelve years 1887—1898 however the intensity of the 8 months period was practically zero and also small during the interval 1874—1886. The periodograms of the two first mentioned intervals are given in Fig. 4 above. It was found on closer

[1] Royds, Kodaikanal Observatory Bulletin No. XXXIII.

investigation that this period of about $8\frac{1}{4}$ months was present from 1892—1896 and reappeared again from 1903 to 1910 with the same phase as before. From the years 1874 to 1892 its appearance in proper phase has not been detected.

With regard to existence of the 13 month period in spots even when the interval 1905 to 1911 was analysed separately its amplitude was still not large. We see then that so far as these short periods are concerned, they are not simultaneously present in both spot and prominences; they appear in each for a short time only and then disappear and perhaps reappear again.

SUMMARY.

A.—Long Periods.

1. The prominence periodogram is very similar to that of spots for the same time interval. Between 2 years and 11 years there are no periodicities present in prominences which can be proved to be absent from sunspots, and *vice versâ*.

2. The 11 year period is the predominant feature of the prominence periodogram, and its maximá occur about one year later than in sunspots. The maxima of its first sub-period, 5·56 years, are not delayed in prominences.

3. Periods between 7 and 8 years of considerable intensity in prominences have been shown to be present also in spots, but they are not permanently active.

B.—Short Periods.

1. A period of 13 months in prominences from 1905—1912 is not present in spots and one of $8\frac{1}{4}$ months in sunspots is absent from prominences. These periodicities are not permanent but the spot period of $8\frac{1}{4}$ months has been shown to disappear for a time and reappear again later.

I wish to express my obligations to Mr. A. A. Narayana Ayyar, B.A., Third Assistant of this Observatory for his careful determination of short periodicities in sunspot data.

Kodaikanal Observatory,
November 13th, 1913.

T. ROYDS,
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9. The similarity of the two periodograms seems to us to confirm the reality of the chief features of the periodogram in the total areas of prominences, for we know of no *a priori* reason except that stated in the second paragraph of section 6, why the percentage number on one limb should be dependent on the total. The confirmation is the more remarkable since the total prominence area per day depends on the number of days of observation, which introduces an element of uncertainty from which the percentage observed in the eastern limb is free, as the number of days of observation does not in this case come into consideration.

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KODAIKANAL OBSERVATORY,
15*th November* 1913.

S. SITARAMA AYYAR,
First Assistant.