of focus by moving the screen 3 or 4 cm. nearer to the lens, there appear two patches, one red the other green, which overlap one another, the part common to both being yellow. In the pulsative image the red and green become respectively blue-green and purple, while the overlapping portion is almost colourless. Possibly both the pulsative colours are less blue than they should be, with the result that their combination produces white or grey.

The difficulty of forming a satisfactory pulsative image from blue and violet is no doubt to be accounted for by the superior persistence of those colours. With stronger luminosity than can be obtained by the method of projection or by the use of pigments this difficulty is diminished, for then the greater part of the luminous impression vanishes more quickly.

Though the work of which an account is given in the present paper has occupied a large amount of time, it is obvious that the subject is far from being exhausted. Several doubtful points remain to be cleared up and apparent discrepancies reconciled, while of a number of remarkable phenomena which presented themselves no mention at all has been made. With more refined apparatus than that at present at my disposal, similar methods of experiment might be expected to yield important contributions to the theory of colour-vision.

"The Solar Activity 1833–1900." By WILLIAM J. S. LOCKYER, M.A., Ph.D., F.R.A.S., Assistant Director, Solar Physics Observatory, Kensington. Communicated by Sir NORMAN LOCKYER, K.C.B., F.R.S. Received April 29,—Read May 23, 1901.

Introduction.

A close examination of the curves representing the varying amount of spotted area on the Sun's surface, shows that no two successive cycles are alike either in form or area. The individuality of the cycles seems, on further inspection, to be repeated after a certain period of time, and this peculiarity, coupled with a like variation in the curves representing the variations of the magnetic elements, and with suspected cycles of change in various terrestrial phenomena, suggested a new investigation of the whole subject.

The object of this communication is to place before the Royal Society the first results which an examination of the various records has furnished.

Dr. Rudolf Wolf,* of Zürich, from a study of the sunspot observations made up to the end of 1875, drew attention to the facts, to use

* 'Mem. R. Astron. Soc.,' vol. 43, p. 200.

his own words, that "la fréquence des taches solaires persiste à changer périodiquement depuis leur découverte en 1610; que la longueur moyenne de la période est de $11\frac{1}{9}$ ans, et que cette même période satisfait aux changements de la variation magnétique, et même de la fréquence des aurores boréales."

Dr. Wolf was careful to point out that it was only the *mean length* of the solar period that covered a period of $11\frac{1}{9}$ years, and that the real length of any one period might differ from this value by as much as two years. The form in which he stated this result* was

$$T = 11{\cdot}111 \pm 2{,}030 \text{ (als Schwankung) } \pm 0{,}307 \text{ (als Unsicherheit)};$$

where T represented the length of the period, ± 2,030 the variation from the mean value, and ± 0,307 the probable error of the determination.

His attention was also drawn to the fact that the times of maxima did not occur a constant number of years after a preceding minimum, and he was led to determine the *mean* time of occurrence of the maximum after the preceding minimum and of the minimum after the preceding maximum, giving the *mean* intervals as 4·5 and 6·5 years respectively.

Further, he at first concluded that the total spotted area for each period was nearly constant, but, as he later remarks,† this view could not be held, as these quantities not only varied but indicated "eine bestimmte Gesetz-mässigkeit." The length of the period of this variation he gave as about 178 years, which covered practically sixteen ordinary sunspot periods. ("11,1111 × 16 = 177,7777.")

Somewhat later Dr. Wolf was led to suggest a shorter period of 55·5 years, which comprises about five ordinary eleven-year periods.

In a recent paper‡ Professor Simon Newcomb has published the results of his investigation of the irregularities in the successive sunspot periods, using as a basis Dr. Wolf's numbers up to the end of 1872, and the spot areas as derived from the Greenwich reduction of the solar photographs taken daily at Greenwich, Dehra Dun, and Mauritius.

The final conclusion at which he arrives is summed up in the following paragraph :—

"Underlying the periodic variations of spot-activity there is a uniform cycle unchanging from time to time and determining the general mean of the activity."

Professor Newcomb mentions, however, no length of period for this cycle, but speaking of its origin he remarks, "whether the cause of this cycle is to be sought in something external to the Sun or within

* 'Astron. Mittheil.,' Wolf, 187 ; p. 40.

† 'Astron. Mittheil.,' 1876, p. 47 *et seq.*

‡ 'The Astro-Physical Journal,' vol. 13, No. 1, 1901, p. 1.

it; whether, in fact, it is in the nature of a cycle of variations within the Sun, we have, at present, no way of deciding."

In the investigations on periods of solar activity most workers have relied simply on Wolf's numbers, which are given by him back to the year 1749. Any one acquainted with these knows that from the time *systematic* observations of the Sun's surface were commenced by Hofrath Schwabe (1833), these numbers agree very closely with the actual facts; but before that date, the numbers are based, not on facts alone (which were not very numerous), but on a system of "meaning,"* suggested by the results of the observations from 1833 to 1876.

Although then Dr. Wolf was able to present us with a curve dealing with the spotted area from 1749, it was decided for the present communication to limit the discussion to those relative numbers which are based on the actual systematic observations since 1833. This necessarily restricted the investigation to a comparatively short number of years, namely, sixty-six (1833–1899), but it was thought that any variations detected, if greater than any which might be justifiably considered errors of observation, would be based on sound facts, and not on uncertain data.

The important magnetic results obtained from a discussion of the Greenwich Observations by Mr. William Ellis,† placed at my disposal a most valuable check on any variation that might be obtained from the sunspot curves, Mr. Ellis having shown that the curves for the magnetic elements are in almost exact accord with those of the sunspots obtained by Dr. Wolf. In this connection Mr. Ellis writes‡:

"Considering that the irregularities in the length of the sunspot period so entirely synchronise with similar irregularities in the magnetic period, and also that the elevation or depression of the maximum points of the sunspot curve is accompanied by similar elevations and depressions in the two magnetic curves, it would seem, in the face of such evidence, that the supposition that such agreement is probably only accidental coincidence can scarcely be maintained, and there would appear to be no escape from the conclusion that such close correspondence, both in period and activity, indicates a more or less direct relation between the two phenomena, or otherwise the existence of some common cause producing both. The sharp rise from minimum epoch to maximum epoch, and the more gradual fall from maximum epoch to minimum epoch, may be pointed out as characteristic of all three curves."

* For Wolf's method of "meaning" see 'Astronomische Mittheilungen,' von Rudolf Wolf, Zürich, 1876, p. 39 *et seq*.

† 'Roy. Soc. Proc.,' vol. 63, p. 64.

‡ *Ibid.*, p. 70.

The Sunspot and Magnetic Epochs employed.

As this paper deals mainly with the times of minima and maxima of both the sunspot and magnetic curves, it was necessary to utilise the results obtained from curves which had been "smoothed," as the original curves are of a subsidiary oscillatory character, especially at maximum.

The sunspot curves just referred to are reproduced in fig. 1. They are so arranged in order of date that each individual curve can be examined separately. The times of succeeding *minima* are arranged vertically under each other, so that any variation as regards acceleration or retardation of the following maxima, and any inequality in the length of the period minimum to minimum can be seen at a glance.

Up to the sunspot maximum of 1870·6 Dr. Wolf has published* the dates of these epochs, and these are utilised here. The more recent epochs have been brought together by Mr. Ellis,† and these complete the data available up to the last epoch, namely, the maximum of 1894·0.

Each of these epochs is indicated in fig. 1 by a short arrow with the corresponding dates. The magnetic epochs here used are those published by Mr. Ellis in the paper just mentioned, and obtained from curves smoothed similarly to those of the sunspot curves. Unfortunately the observations he discussed only commenced in the beginning of 1841, so that comparisons cannot be made previously to this date.

The smoothed curves obtained by Mr. Ellis are not here reproduced, but they will be found in his valuable paper‡ published in 1880.

The Sunspot Curves. Minimum to Maximum.

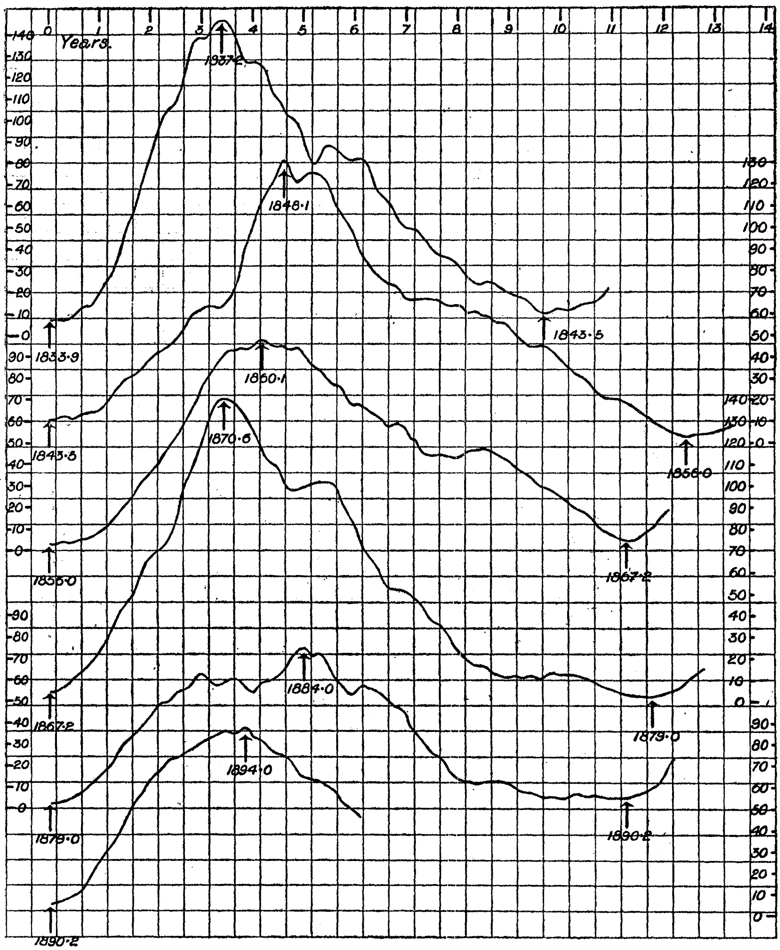
In the following table are brought together the dates of the epochs of maxima and minima:—

Sunspot epochs (Wolf).		Maximum *minus* minimum years.
Minimum.	Maximum.	
(1) 1833·9	1837·2	3·3
(2) 1843·5	1848·1	4·6
(3) 1856·0	1860·1	4·1
(4) 1867·2	1870·6	3·4
(5) 1879·0	1884·0	5·0
(6) 1890·2	1894·0	3·8
		Mean 4·03

* 'Mem. R. Astron. Soc.,' vol. 43, p. 202.
† 'Roy. Soc. Proc.,' vol. 63, p. 67.
‡ 'Phil. Trans.,' 1880, Part II, Plate 22.

If these figures in the last column be utilised as ordinates and the time element as abscissæ, the curve in fig. 2 (curve B) is produced. The peculiarity of this curve is that we have a very rapid rise to a maximum in 1843, and slow fall to the minimum in 1867. This is followed

FIG. 1.

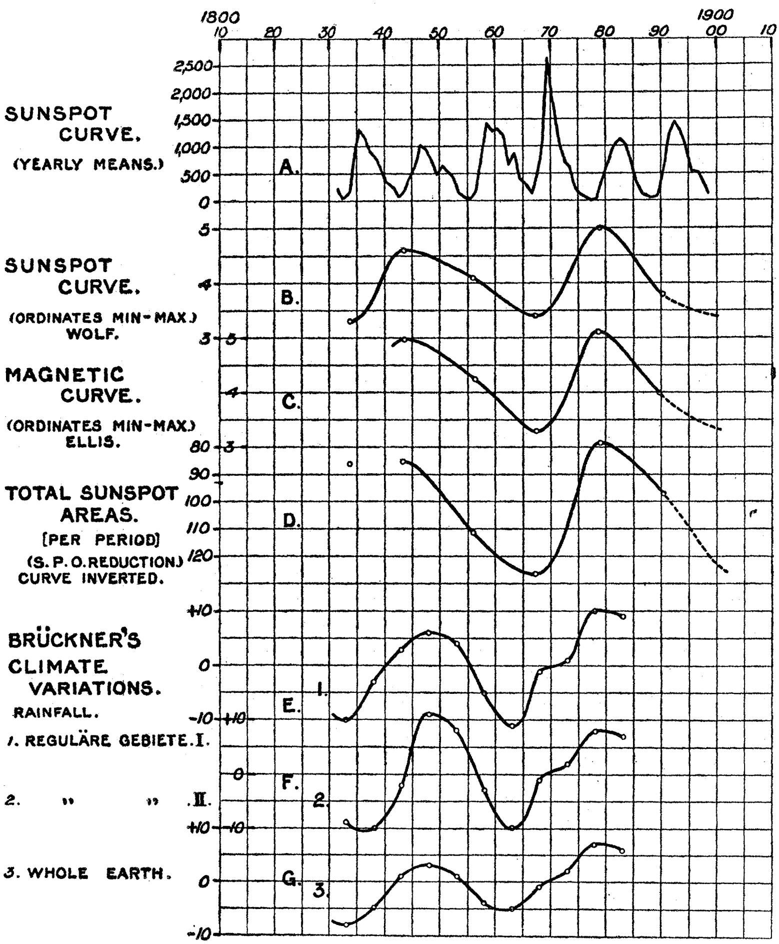


by a similar rapid rise to the next maximum in 1879 and a gradual fall as far as observations at present indicate.

The curve thus indicates that there is some law at work which introduces a secular variation by retarding the sunspot maxima in relation to the preceding minima.

The period of this retardation can be deduced by taking the interval between the times of maxima or minima of this secular variation curve. By considering the minima, *i.e.*, from 1833·9 to 1867·2, we have a period of 33·3 years, and if we take the maxima

Fig. 2.



at 1843·5 and 1879·0 we obtain 35·5 years. The mean of these two values gives a period of 34·4 years.

The Magnetic Curves. Minimum to Maximum.

Mr. Ellis's values for the dates of the magnetic epochs were investigated in exactly the same way as the sunspot epochs were examined.

It may be again mentioned that as the observations he reduced only begin in the year 1841, no comparison can be made with the epochs of 1833·9 and 1837·2.

Forming the table of maximum *minus* minimum as before and adding in the last column the values of maximum *minus* minimum of the sunspot curves from the previous table for the sake of comparison, we have as follows :—

Magnetic epochs (Ellis).		Maximum *minus* minimum.	
Minimum.	Maximum.	Magnetic.	Sunspots.
(1) —	—	—	3·3
(2) 1843·60	1848·55	4·95	4·6
(3) 1856·15	1860·40	4·25	4·1
(4) 1867·55	1870·85	3·30	3·4
(5) 1878·85	1883·90	5·05	5·0
(6) 1889·75	1893·75	4·00	3·8

The nearly complete parallelism of the numbers in the last two columns indicates their strict accord with each other.

The curve showing this magnetic variation is given in fig. 2 (curve C), and it is practically a counterpart of curve B.

The value for the length of the period, as gathered from the interval between the two maxima of this curve at 1843·60 and 1878·85, is 35·25 years, which does not differ very much from the value deduced from the maxima of the corresponding sunspot curve, namely, 35·5 years.

Sunspot and Magnetic Curves Combined. Minimum to Maximum.

By combining the values of the intervals (minimum to maximum) from both the sunspot and magnetic curves, their mean values can be determined as shown in the last column of the following table, the general mean for the whole period being added below :—

From minimum occurring about	Mean of sunspot and magnetic intervals in years.
(1) 1833	3·3
(2) 1843	4·77
(3) 1856	4·17
(4) 1867	3·35
(5) 1879	5·25
(6) 1890	3·90
	Mean .. 4·12

Since these numbers cover more than a complete cycle, they may be combined so that mean values for the intervals minimum—maximum may be obtained for those epochs when the intervals have their largest, intermediate, and smallest values. Thus in the years 1843 and 1879 the maxima followed the minima in 4·77 and 5·25 years respectively, the mean interval thus being 4·91 years. For the intermediate stage (combining (3) and (6)) a value of 4·03 years is found, while for the minimum interval combining (1) and (4) this value 3·32 years.

The actual epoch of maximum relative to the preceding minimum oscillates about the mean value, its greatest amplitude being in the mean 0·8 *year.*

The Total Sunspot Areas. Minimum to Minimum.

The great divergence in the amount of spotted area during consecutive eleven-year cycles suggested that perhaps this periodical retardation of the maxima with respect to the each preceding minimum might be accompanied by variations following the same law. It was observed that when a maximum occurred comparatively soon after a minimum, the tendency of the whole spotted area for that sunspot period was to be increased.

I have been permitted for this inquiry to utilise the values which have quite recently been obtained at the Solar Physics Observatory from a new reduction of the curve representing the solar spotted area, and these values, representing the total spotted area in millionths of the Sun's visible hemisphere from minimum to minimum, are given in the last column of the following table :—

Sunspot period from		Total spotted area.
From minimum	to minimum.	
1833·9	1843·5	86 003
1843·5	1856·0	85 201
1856·0	1867·2	111 514
1867·2	1879·0	126 188
1879·0	1890·2	78 353
1890·2	1901· +	96 734 +

The figures in the last column show a similar but inverted sequence to those in the previous tables. Thus from minimum 1867·2 to the following maximum 1870·6 we have a short interval of time; the spotted area for that period is greatest. If the above values in the last column be graphically shown, and the curve inverted, we have a remarkable similarity (fig. 2, Curve D) to the two curves B and C

previously described. Special attention is called to the slow fall from 1843 to the minimum at 1867·2, and the rapid rise to 1879·0.

It may be remarked that the value for the total spotted area for the period 1833·9 to 1843·5, the earliest value in point of time dealt with, is not quite in harmony with the other values. It is probable that although at this period the time of maximum and minimum could be accurately determined, the values may be too small owing to the fact that Schwabe's observations were not made at that period quite on a uniform plan. Mr. Warren de la Rue and Professor Balfour Stewart* on this point wrote :—

"By the commencement of 1832 Schwabe had matured his system to such an extent as to give, no doubt with considerable precision, the shape and area of each group; although it was not until the commencement of 1840 that he finally fixed upon the system of delineation, which he henceforth pursued up to the time when he discontinued his observations."

The above suggestion seems to be borne out by the reduction of sunspot photographs secured at the Wilna Observatory, where it was found that the maximum of 1870 was of about the same order as that of 1836. The Report of the Wilna Observatory for the year 1871 refers to this point in the following terms† :—

"The curve traced from our observations about the last maximum period of spots (1870) is one and a-half times as high as that of the three most recent periods, *i.e.*, the total sum of the areas of the spots about the maximum period of 1870 was one and a-half times larger than during the last thirty-six years. This marked difference obliged us to enter upon a double verification of our calculations, but we did not discover any appreciable errors."

With reference to the value given in the last line of the last column of the table, although this is probably very near the truth, it is yet impossible to state the date of the present minimum (1901·2 probably). All the areas recorded since the minimum of 1890 and up to the beginning of 1900 have been employed; this value is, however, only slightly below the real one, so that a + sign has been printed against it.

If, therefore, these two facts be kept in mind, it will be seen that the inverted total sunspot-area curve can be considered practically an exact counterpart of the other two curves.

The Total Area of the Magnetic Curves. From Minimum to Minimum.

The remarkable similarity between the magnetic and sunspot curves, especially in the later years when such observations are naturally more

* 'Report of the Committee on Solar Physics, 1882.' Appendix B, p. 77.

† *Ibid.*, Appendix D, p. 154.

accurate, made it unnecessary to discuss the variation (as shown in the case of the sunspot areas) regarding the total areas of the curves from minimum to minimum. This variation seems to be more pronounced in the curve representing the horizontal force than in that representing declination.

Length of the Period of Variation thus determined.

In summing up the values obtained for the length of the secular period of variation under discussion, we form the following table :—

	Maximum to maximum. Years.	Minimum to minimum. Years.
Sunspot curve	35·5	33·3
Magnetic „	35·25	—
Total spotted area for period	35·5	—
Means	35·41	33·3
Combined mean	34·89	

The observations thus lead to the conclusion that *underlying the ordinary sunspot period of about eleven years there is another cycle of greater length, namely, about thirty-five years.*

This cycle not only alters the time of occurrence of the maxima in relation to the preceding minima, but causes changes in the total spotted area of the sun from one eleven-year period to another.

The Variation in the Length of the Interval Minimum to Minimum.

Having found a definite variation in the length of the interval minimum to maximum, the curves show a further variation when the interval—minimum to minimum—was considered. An attempt was therefore made to see if any law could be traced, but the inquiry only led to a negative result.

The following table contains the values for the periods—minimum to minimum—and the differences from the mean, for both the sunspot and magnetic curves individually and combined. It will be seen that the alternation of signs in the columns showing the sunspot differences is not corroborated by the magnetic differences, but when the combined values are used this oscillation for consecutive periods is still *en evidence* :—

Minimum beginning in the year	Sunspots.		Magnetics.		Combination.	
	Minimum to minimum.	Differences from mean.	Minimum to minimum.	Differences from mean.	Minimum to minimum.	Differences from mean.
	Years.	Years.	Years.	Years.	Years.	Years.
1833–1843	9·6	−1·7	..	..	9·6	−1·7
1843–1856	12·5	+1·2	12·55	+1·0	12·52	+1·32
1856–1867	11·2	−0·1	11·40	−0·14	11·30	+0·10
1867–1879	11·8	+0·5	11·30	−0·24	11·55	+0·35
1879–1890	11·2	−0·1	10·90	−0·64	11·05	−0·15
Means..	11·3	—	11·54	—	11·20	—

Although there is a suspected variation in the length of both the magnetic and sunspot periods (reckoning from minimum to minimum), which increases and decreases in *alternate* eleven-year periods from a mean value, the observations do not extend over a sufficient interval of time to allow a more definite conclusion to be drawn.

Relation of the Sunspot Curve to the Light Curve of η Aquilæ.

It is generally conceded that the spots on the surface of the Sun are the result of greater activity in the circulation in the solar atmosphere, and therefore indicate greater heat and, therefore, light. This being so, the curve representing the spotted area may be regarded as a light curve of the Sun.

The Sun may thus be considered a variable star (1) the light of which (reckoning from minimum to minimum) is variable, with a mean value of about 11·1 years; (2) the epoch of maximum does not occur a constant number of years after the preceding minimum, but varies regularly, the cycle of variations covering about 35 years.

It is interesting therefore to inquire whether there be any other known star or stars which exhibit variations similar in kind to those given above.

In the year 1896 I undertook the investigation of all the observations, whether published or not, of the variable star η Aquilæ * which had been made between the years 1840 to 1894, numbering in all 12,000.

For the present inquiry the light curve of this star is of great interest, as its chief peculiarities are similar to those I have indicated in connection with the sunspot curve.

Not only are the more rapid rise to maximum and slow fall to

* 'Resultate aus den Beobachtungen des veränderlichen Sternes η Aquilæ,' Inaugural-Dissertation, Universit. Göttingen, 1897 (Dulau and Co., London).

minimum distinct features of the curve, but the periods (reckoning from minimum) vary slightly in length in the course of many *mean* periods. More important still, the time of occurrence of the maximum in relation to the preceding minimum varies to a comparatively *large* extent in the course of *few* mean periods. The facts arranged in tabular form sum up the information with regard both to the sunspot curve and that of η Aquilæ.

To facilitate the comparison, the different intervals of time converted into fractions and multiples of the sunspot (Q) and η Aquilæ (P) periods are given in separate columns.

		Light curve of			
		Sun.		η Aquilæ.	
Minimum to minimum.	Mean value	Years. 11·20	= Q	$7^d\ 4^h\ 14^m\ 4$	= P
	Period of variation	Unknown	?	—	2400 P
	Maximum variation from mean	± >1·4	± >0·12 Q	$\pm 3^h$	0·017 P
Minimum to maximum.	Mean value	4·12 (about)	0·37 Q	$2^d\ 5$	0·31 P
	Period of variation	34·8 "	3·10 Q	—	400 P
	Maximum variation from mean	±0·8 "	±0·07 Q	$\pm 5^h$	±0·03 P

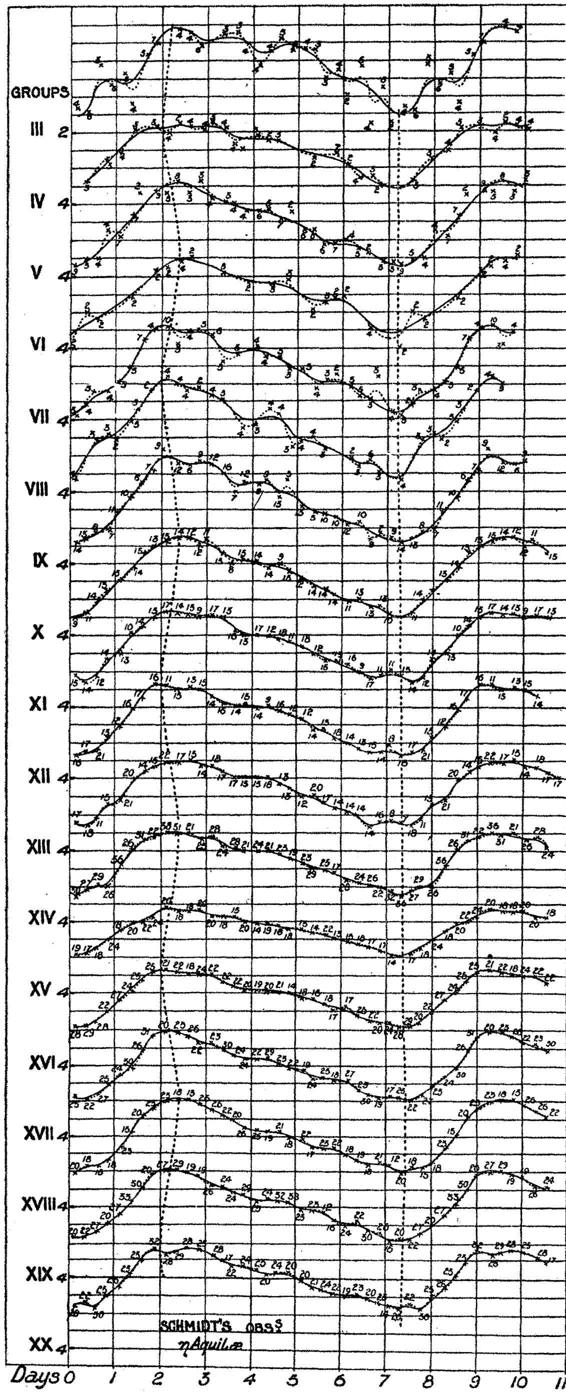
Fig. 3 is a reproduction of a set of light curves of the star η Aquilæ, in which the dotted line and the two vertical wavy and oblique dotted lines passing through the points of maxima and minima indicate the variations of the times of maxima and minima.

The curve for each group is the result of a combination of the observations made over a period equal in length to 100 mean periods (mean period = $172^h{\cdot}2344$) of the star. This whole set of curves is the result of a discussion which I made of all the observations of η Aquilæ made by one observer, Herr Julius Schmidt.

Other Cycles of about Thirty-five Years.

Having found that, in addition to the well-known eleven-year period of sunspot frequency, there is another cycle which extends over about thirty-five years, and which is indicated clearly, as has been shown, both by the changes in the times of the occurrence of the epochs of maxima and in the variations in area included in consecutive eleven-year periods of both sunspot and magnetic curves, it is only natural to suppose that this long-period variation is the effect of a cycle of disturbances in the Sun's atmosphere itself.

FIG. 3.


GROUPS
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
XVI
XVII
XVIII
XIX
XX
SCHMIDT'S OBSS
η Aquilæ
Days 0 1 2 3 4 5 6 7 8 9 10 11

Such a cycle, if of sufficient intensity, should cause a variation from the normal circulation of the Earth's atmosphere, and should be indicated in all meteorological and like phenomena.

It is not intended to go into any detail as regards such terrestrial variations, but it may be noted that much important work has been done on the investigation of changes in climates by Professor Eduard Brückner,* who expended immense labour during many years in the promotion of the inquiry. Professor Brückner did not restrict his discussion to observations made over a small area or for a short interval of time, but utilised those made in nearly every part of the civilised world, and extending as far back in point of time as possible. Further, he did not restrict himself to the discussion of the observations of one or two meteorological phenomena, but examined critically all likely sources from which such changes as he expected could be detected. Thus he sought variations in the observations of the height of the waters in inland seas, lakes, and rivers; in the observations of rainfall, pressure, and temperature; in the movements of glaciers; in the frequency of cold winters; growth of vines, &c.

The result of the whole of the investigation led him to the conclusion that there is a *periodical variation in the climates over the whole earth, the mean length of this period being* 34·8 ± 0·7 *years.*

It may be of interest to remark, that so convinced was Professor Brückner of the undoubted climate variations that he deduced, and so certain was he that such variations could only be caused by an external influence, that he investigated Wolf's sunspot numbers to see whether such a cycle was indicated.

Misled by the long period of variation of sunspots of fifty-five years as suggested by Wolf, he was led to conclude that his climate variation was independent of the frequency of sunspots. He sums up his conclusion in the following words† :—

"Die Klimaschwankungen vollziehen sich unabhängig von den Schwankungen der Sonnenflecken-Häufigkeit; eine 55-jährige Periode der Witterung, wie sie der letzteren entsprechen würde, ist in unseren Zusammenstellungen nicht zu erkennen."

Nevertheless, he was led to make the bold suggestion, that such a variation as he sought must really exist in the Sun, but might possibly be independent of sunspots. He finally concluded that the climate variations are the first symptom of a long period variation in the Sun, which probably will be discovered later.

In the light of the present communication Professor Brückner's conclusions are of great interest, because not only does the length of

* 'Geographische Abhandlungen Wien,' Band 4, Heft 2, p. 155, 1890. "Klima-Schwankungen seit 1700 nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit."

† 'Klimaschwankungen,' Brückner, p. 242.

the period, but the critical epochs of his cycle, completely harmonise with those found in the present discussion of the sunspot and magnetic curves.

To illustrate more fully this connection, and to take only one case, namely, rainfall, the three rainfall curves* are reproduced in fig. 2 (curves E, F, G).

E and F represent the secular variations for what Professor Brückner calls "Reguläre Gebiete I und II,"† while curve E is the mean for the whole set of observations he has employed, and represents the secular variation of rainfall over the whole earth as far as can be determined.

The comparison of these curves with those representing the sunspot and magnetic results given above them, shows that when the epoch of maximum spotted area (curve B) follows late after the preceding epoch of minimum (1843, 1878), or when the spotted area from minimum to minimum is least (curve D), the long-period rainfall curve is at its maximum or we have a wet cycle.

When on the other hand the maximum (curve B) follows soon after the preceding minimum (1867), and the spotted area for this cycle is at a maximum (curve D), the rainfall curve is at a minimum or a dry cycle is in progress.

It may also be observed that in a detailed investigation of the movements of glaciers, Professor Ed. Richter finds a cycle of thirty-five years. In his 'History of the Variations of Alpine Glaciers,'‡ he sums up his results as follows:—"Die Gletschervorstösse wiederholen sich in Perioden, deren Länge zwischen 20 und 45 Jahren schwankt, und im Mittel der drei letzten Jahrhunderte genau 35 Jahre betrug."

Further he pointed out that the variations agreed generally with Brückner's climate variations, the glacier movement being accelerated during the wet and cool periods.

Another very interesting investigation to which reference must be made is that which we owe to Mr. Charles Egeson, who published his researches§ in solar and terrestrial meteorology just a few months before the appearence of Professor Brückner's volume. Mr. Egeson not only finds a secular period of about thirty-three to thirty-four years in the occurrence of rainfall, thunderstorms, and westerly winds in the month of April for Sydney, but the epochs of maxima of the two latter harmonise well with the epochs of the thirty-five yearly period deduced in the present paper for sunspots.

Thus he finds that the yearly numbers of days of thunderstorm

* Brückner, *ibid.*, p. 171.

† Brückner, *ibid.*, p. 170.

‡ 'Zeit. d. Deuts.-Oesterr. Alpen-Vereins,' 1891, Band 12.

§ Egeson's 'Weather System of Sunspot Causality.' Sydney, 1889.

attain their maxima values in 1839 and 1873, and those of the westerly winds in April in 1837 and 1869. As the secular variations of the sunspots have their maxima in 1837·2 and 1870·8, the agreement is in close accord.

There seems little doubt that, during the interval of time covered by the present investigation, the meteorological phenomena, number of auroræ, and magnetic storms, show secular variations of a period of about thirty-five years, the epochs of which harmonise with those of the secular variation of sunspots.

As we are now approaching another maximum of sunspots which should correspond with that of 1870·8, it will be interesting to observe whether all the solar, meteorological, and magnetic phenomena of that period will be repeated.

Conclusion.

1. There is an *alternate* increase and decrease in the length of a sunspot period reckoning from minimum to minimum.

2. The epoch of maximum varies *regularly* with respect to the preceding minimum.

The amplitude of this variation about the mean position is about ± 0·8 year.

The cycle of this variation is about thirty-five years.

3. The total spotted area included between any two consecutive minima varies regularly.

The cycle of this variation is about thirty-five years.

4. There is no indication of the fifty-five-year period as suggested by Dr. Wolf.

5. The climate variations indicated by Professor Brückner are generally in accordance with the thirty-five-year period.

6. The frequency of auroræ and magnetic storms since 1833 show indications of a secular period of thirty-five years.

"On the Variation in Gradation of a Developed Photographic Image when impressed by Monochromatic Light of Different Wave-lengths." By Sir WILLIAM DE W. ABNEY, K.C.B., D.C.L., D.Sc., F.R.S. Received March 26,—Read May 2, 1901.

Introductory.

When a series of small spaces on a photographic plate are exposed to a constant light for geometrically increasing times, or for a constant time to geometrically increasing intensity of illumination, the spaces so exposed will on development show deposits of silver of different