

RESULTS OF MEASURES  
MADE AT THE  
ROYAL OBSERVATORY, GREENWICH  
UNDER THE DIRECTION OF  
SIR FRANK DYSON, M.A., LL.D., F.R.S.,  
ASTRONOMER ROYAL,  
OF  
PHOTOGRAPHS OF THE SUN  
TAKEN  
AT GREENWICH, AT THE CAPE, AND IN INDIA  
IN THE YEAR  
1921.

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# GREENWICH PHOTO-HELIOGRAPHIC RESULTS, 1921.

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## INTRODUCTION.

### § 1. *Positions and Areas of Sun Spots and Faculæ for each Day in the Year 1921.*

The photographs from which these measures were made were taken at the Royal Observatories of Greenwich or of the Cape ; at the Kodaikánal Observatory, Southern India ; or at Dehra Dún, North-West Provinces, India.

The photographs of the Sun obtained at Greenwich were taken with the Dallmeyer Photo-heliograph, of 4 inches aperture, usually stopped down to 2.9 inches, giving a solar image of about 10-centimetre radius.

The photographs from the Cape Observatory were taken under the superintendence of Mr. S. S. Hough, His Majesty's Astronomer at the Cape, and those from Kodaikánal under the superintendence of Mr. John Evershed, Director of that Observatory. The photographs from Dehra Dún, which have been forwarded by the Solar Physics Committee to fill the gaps in the combined series, were taken under the superintendence of the Deputy Surveyor-General, Trigonometrical Survey of India. At three of the observatories the instrument employed was a Dallmeyer Photo-heliograph giving an image of the Sun about 10 centimetres in radius ; at Kodaikánal a Cooke photo-visual object-glass of 6 inches aperture was used, the image of the Sun being on about the same 10-centimetre scale.

Photographs of the Sun were available for measurement upon each day in 1921, those finally selected for measurement being supplied by the different observatories as under :—

Greenwich	..	..	..	..	..	..	..	..	..	..	..	215
Cape	..	..	..	..	..	..	..	..	..	..	..	139
Kodaikánal	..	..	..	..	..	..	..	..	..	..	..	6
Dehra Dún	..	..	..	..	..	..	..	..	..	..	..	5
Total	..	..	..	..	..	..	..	..	..	..	..	365

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The names of those persons who measured the photographs for the year 1921 are as follows:—

H. W. Newton

Andrina M. Crommelin

H. Barton

H. F. Finch

At the principal focus of the Photo-heliographs, excepting that at Kodaikánal, two spider-lines are fixed by which the zero of position-angles on the photographs can be determined. These lines are respectively perpendicular and parallel to the equator in the Photo-heliographs at the Cape and at Dehra Dún, but are inclined to it at an angle of about  $45^\circ$  in that at Greenwich. In the Kodaikánal Photo-heliograph there is one wire fixed parallel to the equator.

The zero of position-angles for the Greenwich, Cape, and Kodaikánal Photo-heliographs has been determined by the measurement of plates which have been exposed twice, with an interval of about 100 seconds between the two exposures, the instrument being firmly clamped. Two images of the Sun, overlapping each other by about a fifth part of the Sun's diameter, were therefore produced upon the plates, and the exposures having been so given that the line joining the cusps passed approximately through the centre of the plates, the inclination of the wires of the photo-heliograph to this line was measured with the position-micrometer, and a small correction for the inclination of the Sun's path was then applied. The following tables give the correction for zero of position for the mean of the two wires as thus determined for the Greenwich and Cape Photo-heliographs.

The adjustment of the wires in the Dehra Dún Photo-heliograph was usually tested by stopping the driving clock immediately after a photograph had been taken and making a second exposure some two minutes after the first, a portion of a second image of the Sun, just intersecting the first, being thus obtained upon the plate.

At Greenwich, transits of the Sun were also taken over the two wires; the times of contact of the first and second limbs of the Sun with the two wires being noted. The ratio of the time taken by the Sun to pass over the NE—SW wire to that taken to pass over the SE—NW wire gives the tangent of the angle made by the Sun's path to the latter wire, the wires being assumed to be exactly at right angles to each other. From this angle, when corrected for the Sun's motion in declination, the correction for the zero of position of the wires can be inferred.

The zero-corrections used throughout the year 1921 in the reduction of the photographs taken at Greenwich were—

Jan. 1 to April 30, +  $2^\circ 45'$ ; May 1 to Aug. 31, +  $2^\circ 39'$ ; Sept. 1 to Dec. 31, +  $2^\circ 42'$ .

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DALLMEYER PHOTO-HELIOGRAPH, GREENWICH.

*Photographic Determination of the Zero of Position-Angles.*

Date. Greenwich Civil Time.	Correction for Zero.	Date. Greenwich Civil Time.	Correction for Zero.
d h	° '	d h	° '
1921 March 24. 11	+ 2. 48	1921 July 9. 9	+ 2. 27
" 24. 11	+ 2. 44	" 18. 11	+ 2. 54
April 20. 9	+ 2. 47	August 16. 9	+ 2. 37
May 2. 10	+ 2. 34	" 20. 9	+ 2. 36
" 22. 9	+ 2. 40	September 7. 11	+ 2. 43
June 17. 15	+ 2. 34	" 22. 9	+ 2. 34
" 24. 11	+ 2. 30		

*Visual Determination of the Zero of Position-Angles.*

Date. Greenwich Civil Time.	Correction for Zero.	Date. Greenwich Civil Time.	Correction for Zero.
d h	° '	d h	° '
1921 January 3. 12	+ 2. 47	1921 July 6. 9	+ 2. 36
" 15. 12	+ 2. 47	" 24. 10	+ 2. 39
February 1. 12	+ 2. 45	" 31. 16	+ 2. 42
" 20. 11	+ 2. 45	August 6. 11	+ 2. 43
March 10. 11	+ 2. 46	" 16. 9	+ 2. 38
" 17. 9	+ 2. 44	September 22. 9	+ 2. 42
" 24. 12	+ 2. 42	" 25. 9	+ 2. 45
April 4. 9	+ 2. 43	" 25. 12	+ 2. 46
" 8. 10	+ 2. 43	" 26. 15	+ 2. 45
" 20. 9	+ 2. 41	October 5. 12	+ 2. 44
" 30. 17	+ 2. 43	" 13. 10	+ 2. 42
May 2. 9	+ 2. 37	November 8. 12	+ 2. 46
" 10. 9	+ 2. 37	" 10. 10	+ 2. 43
" 22. 9	+ 2. 34	" 24. 12	+ 2. 44
June 7. 8	+ 2. 37	December 8. 11	+ 2. 45
" 25. 11	+ 2. 43		

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DALLMEYER PHOTO-HELIOGRAPH, CAPE OF GOOD HOPE.

*Photographic Determination of the Zero of Position-Angles.*

Date. Greenwich Civil Time.		Correction for Zero.	Date. Greenwich Civil Time.		Correction for Zero.
	d h	° '		d h	° '
1921 January	12. 8	— 0. 28	1921 July	16. 8	— 0. 32
February	2. 8	— 0. 43	August	3. 10	— 0. 32
"	18. 8	— 0. 30	"	18. 8	— 0. 24
March	4. 8	— 0. 22	September	3. 8	— 0. 34
"	18. 8	— 0. 26	"	17. 9	— 0. 27
April	5. 8	— 0. 25	October	4. 8	— 0. 44
"	20. 8	— 0. 30	"	19. 8	— 0. 24
May	4. 8	— 0. 29	November	4. 8	— 0. 37
"	20. 9	— 0. 29	"	18. 8	— 0. 40
June	3. 8	— 0. 32	December	2. 8	— 0. 37
"	17. 9	— 0. 21	"	17. 9	— 0. 36
July	2. 9	— 0. 30			

The zero-corrections used in the reductions of the photographs taken at the Cape Observatory were as follows:—

Jan. 1 to Oct. 31, — 0°.5; Nov. 1 to Dec. 31, — 0°.6.

The zero-correction adopted during the year 1921 for the Kodaikánal photographs was +0.3.

The measures of the photographs were made with a large position-micrometer constructed by Messrs. Troughton and Simms for the measurement of photographs of the Sun up to 12 inches in diameter. In this micrometer the photograph is held with its film-side uppermost on three pillars fixed on a circular plate, which can be turned through a small angle, about a pivot in its circumference, by means of a screw and antagonistic spring acting at the opposite extremity of the diameter. The pivot of this plate is mounted on the circumference of another circular plate, which can be turned by screw-action about a pivot in its circumference, 90° distant from that of the upper plate, this pivot being mounted on a circular plate with a position-circle which rotates about its centre. By this means small movements in two directions at right angles to each other can be readily given, and the photograph can be accurately centred with respect to the position-circle. When this has been done, a positive eyepiece, having at its focus a glass diaphragm ruled with cross-lines into squares, with sides of one-hundredth of an inch (for measurement of areas), is moved along a slide diametrically across the photograph, the diaphragm being nearly in contact with the photographic film, so that parallax is avoided. The distance of a spot or facula from the centre of the Sun is read off by means of a scale and vernier to 1-250th of an inch (corresponding to 0.001 of the Sun's radius for photographs having a solar diameter of 8 inches). The position-angle is read

off on the large position-circle which rotates with the photographic plate. The photograph is illuminated by diffused light reflected from white paper placed at an angle of  $45^\circ$  between the photograph and the plate below.

All photographs are measured independently by two persons, and the means taken.

In the case of large or complex groups of spots, the positions of the chief components are measured individually, and also for groups so near the east or west limbs of the Sun that the effects of foreshortening are appreciable. In other cases the position of the centre of a group is estimated in the micrometer. In this respect a difference has been made in the practice during years previous to 1916, where in this section components of groups are given separately and combined into groups in the Ledgers.

When required, corrections are applied to the measured distances and position-angles for differential refraction. The formula is given in the *Introduction* for 1909. It is seldom necessary, however, to apply this correction except to a few photographs taken at Greenwich in mid-winter.

The calculations of heliographic longitude and latitude are made by use of the formulæ given in "Researches on Solar Physics: Heliographical Positions and Areas of Sun Spots observed with the Kew Photo-heliograph during the years 1862 and 1863" by W. De La Rue, B. Stewart, and B. Loewy. *Phil. Trans.*, 1869. If  $r$  be the measured distance of a spot from the centre of the Sun's apparent disc,  $R$  the measured radius of the Sun on the photograph, ( $R$ ) the tabular semi-diameter of the Sun in arc, and  $\rho$ ,  $\rho'$  the angular distances of a spot from the centre of the apparent disc as viewed from the Sun's centre and from the Earth respectively,  $\rho$  is obtained from the equations:—

$$\rho' = \frac{r}{R}(R); \text{ and } \sin(\rho + \rho') = \frac{r}{R}.$$

If  $D$  and  $\phi$  are the heliographic latitudes of the Earth and the spot respectively, referred to the Sun's equator, and  $l$  the heliographic longitude of the spot from the solar meridian passing through the centre of the disc, longitudes west of the centre being reckoned as positive, and  $z$  the position-angle from the Sun's axis,

$$\begin{aligned} \sin \phi &= \cos \rho \sin D + \sin \rho \cos D \cos z \\ \sin l &= -\sin z \sin \rho \sec \phi. \end{aligned}$$

The position-angle  $z$  is found from the position-angle from the North Point by subtracting  $P$ , the position-angle of the N end of the Sun's axis, measured eastward from the North Point of the disc. The heliographic longitude of the spot is  $l+L$ ,

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where  $L$  is the heliographic longitude of the centre of the disc. The three quantities  $P$ ,  $D$ , and  $L$  for the time of the exposure of each photograph are derived from the Ephemeris for Physical Observations of the Sun given on p. 506 of the *Nautical Almanac* for 1921.

The inclination of the Sun's axis to the ecliptic is assumed to be  $82^{\circ} 45'$ , the longitude of the ascending node for 1921.0 to be  $74^{\circ} 39'.5$ , and the period of the Sun's sidereal rotation to be 25.38 days; the meridian which passed through the ascending node 1854 January 1, Greenwich Mean Noon, being taken as the zero meridian.

§ 2. *General Catalogue of Groups of Sun Spots for 1921.*

The Catalogue contains every group of spots which lasted for two or more days, and the group numbers are in continuation of those given in 1920 and previous years. Groups seen only once are not included, but appear in the Daily Results with a distinctive numeration.

During the year 1921, a number of groups of spots have been noted in the Catalogue as "Revivals." These have been tabulated in series in a table following the Catalogue. The respective groups of each series are in the same heliographic position, and are seen in consecutive rotations but with definite breaks in their history between each rotation. The latter feature excludes them from being classed as "Recurrent" groups; they differ from "Intermittent" groups in their being of long period intermittency. When a "Recurrent" series forms part of a "Revival" series, a reference is made in the last column of the table. Other groups which are given in detail in Ledger II are also indicated.

§ 3. *Ledgers of the Areas and Heliographic Positions of Groups of Sun Spots for 1921.*

*Ledger I.—Recurrent Groups.*—This Ledger supersedes the Catalogue of Recurrent Groups of Sun Spots given in years previous to 1916 of the *Greenwich Photo-Heliographic Results*, and the reference numbers of the series are in continuation of those given therein. The groups forming this Ledger have been abstracted from a general Ledger of all spot groups seen throughout the year, and were selected upon the following plan, reference being made to the General Catalogue:—If any spot group when first seen was  $60^{\circ}$  or more to the east of the Central Meridian, then the Catalogue, and, if necessary, the Daily Results also, were searched some fifteen or sixteen days earlier, to ascertain whether a spot group of similar heliographic longitude and latitude was then near the west limb of the Sun. Similarly, if any spot group when last seen was  $60^{\circ}$  or more to the west of the Central Meridian, then the Catalogue was searched some fifteen or sixteen days

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later, to ascertain whether a spot group of similar heliographic longitude and latitude was then near the east limb of the Sun. Both the search forward and the search backward have been made in the case of every spot group that was observed close to both the east and west limbs, in order that no possible case of identity might be overlooked. When there appeared to be a case of probable identity between spot groups observed in two consecutive rotations of the Sun, the character of the second group has been carefully compared with that of the first in each of the three elements—area, longitude, and latitude. In cases where the evidence appeared to render probable the continued existence of the spot, it has been numbered in the Ledger, and where there has been some uncertainty a note has been added. If, on the other hand, the evidence appeared to go in the other direction, but was not quite decisive, the series has been printed in the Ledger but a separate number has not been given it. It has been distinguished by the number of the preceding series, placed in brackets and marked with an asterisk. In cases where a well-defined series has been recorded, there have sometimes been included in brackets spot groups undoubtedly belonging to the same general disturbance, but for which the evidence of continuity was not sufficient.

Besides the Ledgers of the groups, there have been printed in a similar manner important components of the principal groups. This has been done in all cases where it appeared probable that an individual component lasted to the second or third rotation after its first appearance.

*Ledger II.—Non-Recurrent Groups.*—This Ledger contains the most important of those groups which do not last to a second rotation. Individual components are also given after their respective groups, where they are large and distinctive.

§ 4. *Total Areas of Sun Spots and Faculæ for each day, and Mean Areas and Mean Heliographic Latitude of Sun Spots and Faculæ for each Rotation of the Sun, and for the year 1921.*

Particulars relating to this section are given in the headings on pages D 63–69.

F. W. DYSON.

*Royal Observatory, Greenwich,  
1924, February 1.*



ROYAL OBSERVATORY, GREENWICH.

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POSITIONS AND AREAS

OF

SUN SPOTS AND FACULÆ.

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FOR EACH DAY IN THE YEAR

1921.

POSITIONS and AREAS of SUN SPOTS and FACULÆ for EACH DAY in the YEAR 1921.

- Col. 1. (1) Time when photograph was taken expressed in days and decimals of a day reckoning from midnight at commencement of year. (2) Place of observatory—Greenwich (G), Cape of Good Hope (C), Kodaikánal (K), Dehra Dûn (D). (3) Date of photograph (Civil reckoning).
- Col. 2. Number of Spot Group in order of appearance and in continuation of the Group-numbers given in previous years. Groups seen on one day only are distinguished by the number of the Rotation during which they were observed and by a letter given in the order of their appearance. When there is no number in the second column, it is to be understood that there is a Facula unaccompanied by a Spot.
- Col. 3. Distance of Spot Group or Faculæ from Sun's centre in terms of the Sun's radius.
- Col. 4. Position Angle of Spot Group or Faculæ measured from the North pole of the Sun's axis in the direction N., E., S., W., N.
- Col. 5. Heliographic Longitude of the Spot Group derived from the measures.
- Col. 6. Heliographic Latitude of the Spot Group similarly derived.
- Col. 7. Area of Umbræ corrected for foreshortening in millionths of the Sun's visible hemisphere.
- Col. 8. Area of Whole Spots composing the Group similarly expressed.
- Col. 9. Area of each group of Faculæ similarly expressed. The positions of Faculæ relative to the Spots with which they are associated are indicated by the letters *n, s, p, f, c*, denoting respectively north, south, preceding, following, concentric.
- In line with the date of each day is given in brackets the position angle of the Sun's axis from the North point: the heliographic longitude and latitude of the centre of the disc; the total areas of Spots and Faculæ for the day.