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ON THE STRUCTURE OF SMALL SUNSPOTS

By
Truls S. Ringnes

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Abstract

The smallest, and most short-lived sunspots are described differently at the observatories in Zürich and Greenwich.

These differences, which seem to originate both from the observing procedure and from the definitions of penumbra and umbra adopted, are further discussed.

Introduction

It is believed that all sunspots begin their lives as pores. At first a pore will not differ from other dark spaces between granulation elements. But it does not disappear after some minutes as a granule. The pore has a longer lifelength and increases in size and contrast to the surroundings, until the diameter is a couple of seconds of arc. The vast majority of pores never develop further, but sometimes a pore continues to grow in size and gains the character of a spot.

"One day spots", a term we shall use in what follows, is defined as: A spot observed on one day only; it does not belong to a revival group and its distance from the central meridian is less than 65 degrees.

In the following we shall compare the descriptions of the structure of one-day spots in Cycles 17^2-20, i.e. in the years 1938-76, given at the Swiss Federal Observatory in Zürich and the Greenwich Observatory.

<u>One-day spots observed in Zürich.</u>

Waldmeier uses the following definition of a spot: <u>A spot has a diameter of at least 3 seconds of arc and a lifelength of at least half an hour</u> [1]. In the Zürich sunspot statistics only spots of this category shall be incorporated.

In 1936 Waldmeier [2] introduced an 8-step scheme of classification of sunspot groups which takes into account magnetic polarity, appearence of penumbra and extent in heliographic longitude. The classification is based on the characteristic stages which a large spot group passes through during the course of its development and final decline. All groups observed in 1936 were classified according to this scheme. In 1937 a new class was added, and from 1938 all groups recorded in Zürich have obtained a classification letter between <u>A</u> and <u>J</u> (the letter <u>I</u> has been omitted) [3].

Only four classes need concern us here. The first three:

<u>A</u>: Single spot or group of spots, without penumbra and without bipolar structure

<u>B</u>: Group of spots without penumbra in bipolar pattern

<u>C</u>: Bipolar spot-group; one of the main spots is surrounded by a penumbra,

and the last one:

<u>J</u>: Unipolar spot with penumbra; heliozentric diameter $<2.5^{\circ}$.

The number of one-day spots recorded and classified in Zürich 1938-76 is given in Table I.

Table I. One-day spots recorded in Zürich.

Cycle	17^2 (1938-45)	18 (1944-54)	19 (1954-65)	20 (1964-76)	17^2-20 (1938-76)
Number	315	1068	990	848	3221
Type A	294 (93.3%)	992 (92.9%)	934 (94.3%)	738 (87.0%)	2958 (91.8%)
Type B	21 (6.7%)	66 (6.2%)	56 (5.7%)	109 (12.9%)	252 (7.8%)
Type C		10 (0.9%)			10 (0.3%)
Type J				1 (0.1%)	1 (0.03%)

One-day spots recorded in Greenwich

Information on one-day spots recorded in Greenwich is published in the "Photoheliographic Results" [4]. The areas of spots are given with one millionth of the solar hemisphere as unit. The smallest spots tabulated have an area of one unit, this corresponds to a circular spot with a diameter of 2.6 seconds of arc seen from a distance of 1 AU, or to a heliocentric diameter of 0.16 degrees.

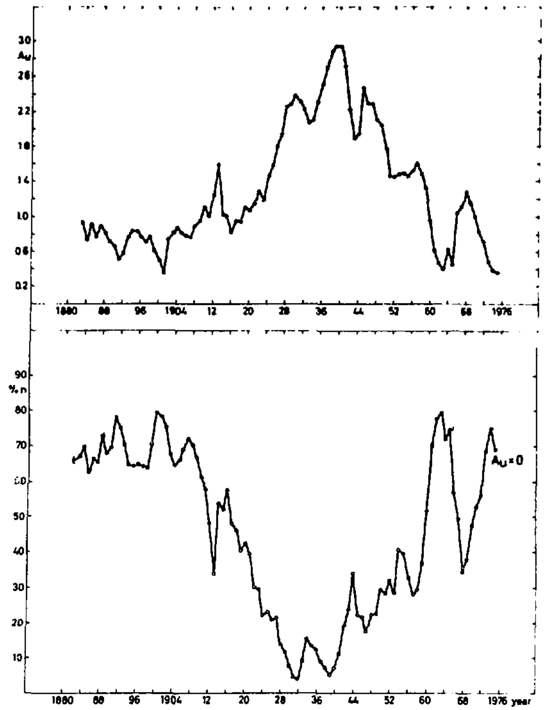

Fig.1. The top curve shows the sliding three-year mean of the umbra area of one-day spots. The lower curve gives the sliding three-year mean of the number of one-day spots with zero umbra area, in percent.

During the years 1880-1976 the umbra area (A_u) and also the ratio between the umbra area and the total area (A_p) of one-day spots ($1/q^2 = A_u/A_p$) have varied systematically with time as shown in Figures 1 and 2 [5].

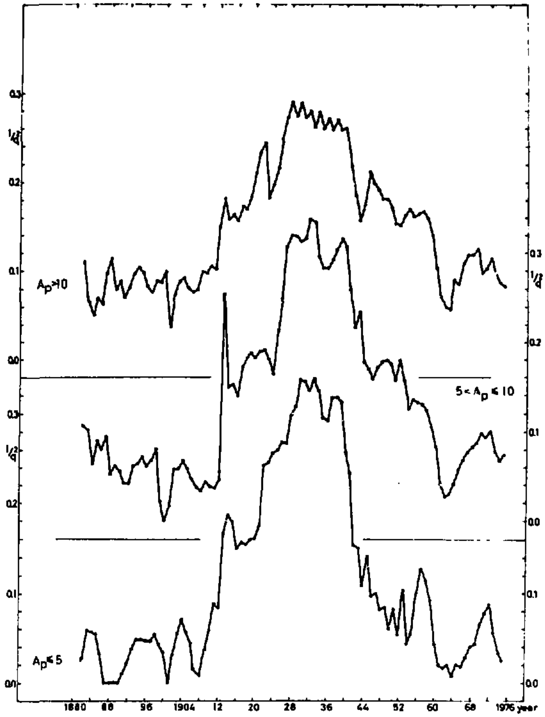

Fig.2. The sliding three-year mean of the ratio between the umbra and the total area ($1/q^2$) for given intervals of area.

The numbers and mean corrected areas of one-day spots recorded in Greenwich from Cycle 17[2] (the years after sunspot maximum, 1938-45) to and included Cycle 20 (1964-76) are given in Table II.

Table II. One-day spots recorded in Greenwich.

Cycle	17^2	18	19	20	17^2-20
Number	438	517	967	1210	3132
$\bar{A}_u$	2.78	1.96	1.19	0.95	1.45
$\bar{A}_p$	10.9	11.4	10.1	9.5	10.2
$1/q^2$	0.26	0.17	0.12	0.10	0.14

After 1915 the Greenwich Photoheliographic Results discontinued the differentation between the various types of sunspots seen on one day only, dismissing them with the remark that "these short-lived groups are usually composed of one or two very small spots". The Greenwich material thus only permits a study of the various types of one-day spots in Cycles 12, 13, 14 and the first part of Cycle 15. The results, as given in a previous paper [6], are the following: As might have been expected the single spots have the smallest mean total area. It is twice as large for double spots and about three times larger for multiple spots. There are pronounced parallel time-trends in the variation of the mean umbra area, the mean total area and the ratio between the umbra area and the total area of all types of one-day spots. Secular variations can not be explained only by a systematic variation in the frequency distribution of spots of different types.

A comparison between one-day spots recorded in Zürich and Greenwich.

As we have seen the minimum size of one-day spots tabulated in Zürich and Greenwich are about the same. One should then expect that the number of spots recorded at the two observatories were nearly equal. However, this is not the case. It is not only due to a systematic difference; the ratio between the numbers as well varies irregularily with time. This has been studied by Kopecký et al. [7] and others, and will not be discussed here.

As the lifelength of most of the one-day spots is fairly short and the observations at Greenwich and Zürich are performed at different times, many of them are seen at one observatory only. Spots recorded both in Zürich and Greenwich are given in Table III. Here the number (N), mean umbra area (A_u), mean total area (A_p) and the ratio between these areas (I/q^2) are tabulated for the different types.

Table III. The area (Greenwich) and type (Zürich) of one-day spots recorded both in Greenwich and Zürich.

Cycle	Zürich Type A				Zürich Type B				Zürich Type C				Zürich Type J				Zürich Type A,B,C,J			
	N_A	$\bar{A}_u$	$\bar{A}_p$	$1/q^2$	N_B	$\bar{A}_u$	$\bar{A}_p$	$1/q^2$	N_C	$\bar{A}_u$	$\bar{A}_p$	$1/q^2$	N_J	$\bar{A}_u$	$\bar{A}_p$	$1/q^2$	N	$\bar{A}_u$	$\bar{A}_p$	$1/q^2$
17^2	57	3.42	11.88	0.29	3	5.00	16.33	0.31									60	3.50	12.10	0.29
18	83	1.93	10.27	0.19	11	3.09	15.64	0.20	3	5.00	24.33	0.21					97	1.97	10.55	0.19
19	178	1.21	9.70	0.12	18	2.11	11.94	0.18									196	1.29	9.91	0.13
20	230	1.15	9.00	0.13	50	1.98	13.04	0.15					1	2.00	14.00	0.14	281	1.31	9.77	0.13
17^2-20	548	1.52	9.72	0.16	82	2.27	13.27	0.17	3	5.00	24.33	0.21	1	2.00	14.00	0.14	634	1.64	10.25	0.16

In Table IV other data are given for the Type A spots, and in Table V for the Type B spots.

Table IV. One-day spots of Type A recorded both in Greenwich and Zürich.

Cycle	Years	Percent of N						$A_u/A_p = 1/q^2$				N
		$A_u = 0$	$0 < A_u \leq 2$	$A_u > 2$	$A_p \leq 5$	$5 < A_p \leq 10$	$A_p > 10$	$A_p \leq 5$	$5 < A_p \leq 10$	$A_p > 10$	All one-day spots	
17^2	1938-45	0.0	31.6	68.4	12.3	33.3	54.4	0.394	0.342	0.264	0.288	57
18	1944-54	19.3	55.4	25.3	19.3	49.4	31.3	0.123	0.170	0.210	0.188	83
19	1954-65	36.5	48.3	15.2	29.2	37.6	33.1	0.095	0.127	0.129	0.124	178
20	1964-76	40.9	43.5	15.6	35.7	33.0	31.3	0.078	0.109	0.151	0.128	230
17^2-20	1938-76	31.9	45.6	22.4	28.6	37.0	34.3	0.105	0.150	0.170	0.157	548

Table V. One-day spots of Type B recorded both in Greenwich and Zürich.

Cycle	Years	Percent of N						$A_u/A_p = 1/q^2$				N
		$A_u = 0$	$0 < A_u \leq 2$	$A_u > 2$	$A_p \leq 5$	$5 < A_p \leq 10$	$A_p > 10$	$A_p \leq 5$	$5 < A_p \leq 10$	$A_p > 10$	All one-day spots	
17^2	1938-45	0.0	0.0	100.0	0.0	0.0	100.0	0.00	0.00	0.306	0.306	3
18	1944-54	27.3	9.1	63.6	18.2	18.2	63.6	0.00	0.118	0.212	0.198	11
19	1954-65	16.7	50.0	33.3	22.2	27.8	50.0	0.154	0.171	0.180	0.177	18
20	1964-76	20.0	50.0	30.0	18.0	32.0	50.0	0.179	0.104	0.162	0.152	50
17^2-20	1938-76	19.5	42.7	37.8	18.3	28.0	53.7	0.156	0.120	0.183	0.171	82

The description of the structure of these small sunspots thus is totally different in Greenwich and Zürich. In Zürich 99.4 percent are classified as A or B, i.e. spots without penumbra. In the Greenwich-records, on the contrary, 100 percent are with penumbra - of these more than 30 percent without umbra. In Greenwich then, most of the one-day spots would have been classified as "Single spot or group of spots, with penumbra but without bipolar structure" - a class which do not exist in the Zürich scheme. Such a class would be partly covered by the last class in the sequence, J. One single case is found where a one-day spot has been classified as J in Zürich (No. 13, Rotation 1611; February 1974) - however, this may be a misprint.

Concluding remarks

The fourth flight of the Soviet Solar Stratospheric Observatory (SSO) in 1973, provided some photographs of high spatial resolution ($0\overset{''}{.}24$-$0\overset{''}{.}30$) of small sunspots and pores, which have been analysed by Krat and Vyalshin [8]. Their investigations shows that there is no direct relationship between the size of a pore and its brightness. One of the smallest pores observed belongs to the darkest ones. There exists also a number of "grey" pores (I/I_p greater than 0.8).

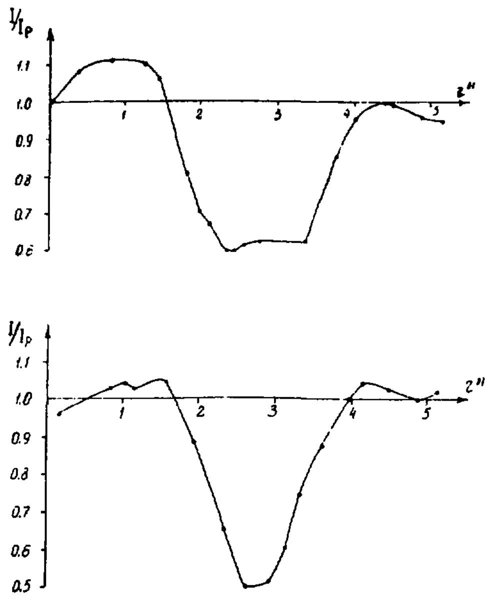

Fig. 3. Photometric scans of two large pores (Krat and Vyalshin).

From photometric scans of two large pores (small sunspots), which are reproduced as Figure 3, it is seen that the brightness changes continuosly from the border towards the center, but tends to have a constant value in the central part, thus mimicking a penumbra and an umbra.

It is important to point out that the observational methods are different in Greenwich and Zürich. The Greenwich measurements are based on daily photographic records of sunspots, supplemented by photographs obtained at other observatories. The Zürich sunspot maps and tables are based on daily drawings of spots, using a projected solar image. To cover the gaps in the Zürich records, visual observations from other observatories have been used. This may imply that the effects of stray light etc. will lead to different detection thresholds of the umbrae of one day spots.

This together with an apparent different use of the concepts "umbra" and "penumbra", may be the explanation of the differences described.

The Zürich classification scheme is thought to represent the sequence of evolution of a large sunspot group. When this scheme has been applied it is tempting to believe that new small groups orginating on the solar disk, under routine measurement, as a rule, automatically will be assigned to one of the two first classes. In this connection one interesting aspect is to be mentioned. At the time when the Zürich classification scheme was introduced, in 1937, the Greenwich records show the largest umbra area and the highest ratio between the umbra and total area (Figures 1 and 2, Tables III and IV). At that particular epoch the agreement between the two descriptions thus was better than ever since.

The discrepancy pointed out in this paper will apparently not be definitively resolved before observations from space of sufficient resolution including intensity measurements become available.

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