THE RATE OF AREAL DECREASE OF LONG-LIVED SUNSPOTS

A. Antalová and R. Mačura
Astronomical Institute of the Slovak Academy of Sciences,
059 60 Tatranská Lomnica, Czechoslovakia

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ABSTRACT: The analysis of 30 long-lived "naked" sunspots, observed in the years 1969 - 1976 (Tab. 1), and of 30 sunspots of the Zürich H-type, observed during the same period (Tab. 2), yielded the following results:

1. Long-lived "naked" sunspots occur in all size categories ranging from small (U = 20 millionths of the visible solar hemisphere) to large sunspots (U = 110 millionths of the visible solar hemisphere). The Zürich-type sunspots were of medium size (shown in Figs 4 -6). Both groups of sunspots represent the final stage of the evolution of an active region. These sunspots are unipolar and have the same magnetic polarity as their neighbourhood.

2. The rate of decrease of the area of umbras of long-lived "naked" sunspots per day can be expressed by Eq (1), for the Zürich H-type sunspots by Eq (3). Linear relations of the decrease of areas of whole sunspots W were determined for both groups of sunspots and are expressed by Eqs (2) and (4). They indicate that the larger the initial area U_0 of the sunspot, the larger the absolute value of the daily areal decrease of the sunspot.

3. The average daily relative rate of decay of the "naked" sunspots amounts to two hundredths of their initial area (Fig. 3). The average daily relative rate of areal decrease of the Zürich H-type sunspots is equal to two tenths of the area of the initial umbra (Fig. 6). The rate of decay of old unupolar sunspots, assuming they have the same area, depends on another parameters which can so far only be evaluated qualitatively. This parameter is the intensity of the sunspot´s interaction with its ambient medium. The interac-

tion mechanism is still not clear, but the "naked" sunspots form a group with an extremely low interaction intensity (Fig. 7).

СКОРОСТЬ УМЕНЬШЕНИЯ ПЛОЩАДИ ДОЛГОЖИВУЩИХ ПЯТЕН. Анализ произведен для 30 долгоживущих "накед" пятен (Таб. 1) и для 30 пятен цюришского класса H (Таб. 2), наблюдаемых с 1969 по 1976 год показал:

1. Долгоживущие "накед" пятна появляются во всех размерах, от малых (У = 20 миллионных частей видимого полушария Солнца - единица) по пятна крупных размеров (У = 110 единиц). Пятна цюришского класса H имели средние размеры (Рис. 4 - 6). Обе группы пятен являются заключительным этапом развития активной области. Обе группы пятен отмечаются униполярным магнитным полем и магнитная полярность этих пятен одинаковая с полярностью окружающей среды.

2. Скорость уменьшения площади умбры пятна за один день для "накед" пятен выражает Ур (1); для цюришского класса H Ур (3). Линеарные зависимости понижения площадей целых пятен двух групп выражают уравнения (2) и (4). Из установленных зависимостей вытекает, что абсолютное значение дневного понижения площади пятна тем больше, чем его начальные размеры ($У_0$) больше.

3. Средняя дневная относительная скорость распада "накед" пятна равняется двум сотых его начальной площади (Рис. 3). Значение того-же параметра для пятен цюришского класса H равно двум десатым начальной площади умбры (Рис. 6). Скорость распада старых униполярных пятен зависит не только от размеров пятна, но тоже от дальнейшей переменной величины, которую мы пока можем оценить только качественно и она отражает интенсивность интеракции пятна с окружающей средой. "Накед" пятна являются группой с крайне низким уровнем этой интеракции.

RÝCHLOSŤ POKLESU PLOCH DLHOŽIJÚCICH SLNEČNÝCH ŠKVŔN. Z analýzy 30 dlhotrvajúcich "naked" škvŕn, pozorovaných v r. 1969 - 1976 (Tab. 1) a 30 škvŕn zürišského typu H, pozorovaných v tom istom období, (Tab. 2) bolo zistené:

1. Dlhotrvajúce "naked" škvrny sa vyskytujú vo všetkých kategóriách veľkosti: od malých (U = 20 miliontín viditeľnej hemisféry Slnka) až po veľké škvrny (U = 110 jednotiek). Škvrny zürišského typu H mali strednú veľkosť (Obr. 4 - 6). Obe skupiny škvŕn predstavujú záverečné štádium vývoja aktívnej oblasti. Sú to škvrny unipolárne a majú tú istú magnetickú polaritu ako ich okolie.

2. Rýchlosť poklesu plochy umbier dlhotrvajúcich "naked" škvŕn za jeden deň je vyjadrená vzťahom (1). Pre škvrny zürišského typu H bola zistená závislosť (2). Lineárne závislosti poklesu plôch celých škvŕn W boli zistené pre obe skupiňy škvŕn a sú vyjadrené vzťahmi (2) a (4). Podľa zistených závislostí, čím má škvrna väčšiu počiatočnú plochu U_0, tým je väčšia absolútna hodnota denného poklesu plochy škvrny.

3. Priemerná denná relatívna rýchlosť rozpadu "naked" škvŕn je dve stotiny z ich počiatočných plôch (Obr.3). Pre škvrny zürišského typu H je priemerná denná relatívna rýchlosť poklesu plochy rovná dvom desatinám z ich počiatočnej umbry (Obr. 6). Rýchlosť rozpadu starých unipolárnych škvŕn závisí pri tej istej ploche od ďalšieho parametra, ktorým je intenzita interakcie škvrny

s jej okolím. Mechanizmus interakcie nie je zatiaľ známy, ale "naked" škvrny tvoria skupinu s extrémne nízkou intenzitou interakcie (Obr. 7).

1. INTRODUCTION

The generation, structure, evolution and decay of local magnetic fields on the Sun represents a partial problem in understanding solar magnetism as whole. This problem crystallized as a result of the discovery of extensive macrostructural magnetic fields on the Sun and their cyclic variations with the phase of the 11-year cycle. Babcock´s model (1961) mainly tried to explain the properties, then already known, of the 22-year magnetic cycle of activity (Spörer´s and Hale´s laws). According to his model, a bipolar active region is generated by the emergence of a magnetic tube in the shape of a loop from the convective layer to the solar surface. This model explains the large-scale magnetic fields mainly in the neighbourhood of the solar poles by the dissipation of the magnetic fields of following sunspots of the bipolar regions.

Two approaches now exist to explaining the magnetic field of sunspots. The first is based on Babcock´s model. Buoyancy lifts the magnetic tube in the shape of a loop from the convective layer to the solar surface. This involves elements of the toroidal magnetic field of the Sun. The phenomenological manifestations of these new local magnetic regions, associated with the generation of arch filaments, were described by Waldmeier (1955), Bruzek (1967, 1969) and Weart and Zirin (1969). Zirin (1971) introduced the term "emerging flux region" (EFR), because spectroscopic observations of the velocities of arch filaments indicated that they moved upwards. The rate of emergence of the EFR´s depends on the activity in its neighbourhood (Liggett and Zirin, 1985). The relation of the EFR´s to the subsurface magnetic tubes of toroidal flux is not defined in more detail in the referenced papers. The buoyancy phenomenon itself has its problems as well (Parker, 1984). The concept of emerging magnetic tubes is the basis of the studies and models of sunspots presented by Piddington (1975) and Zwaan (1978).

Convective motions as a possible mechanism of intensification and concentration of thin magnetic elements into more extensive formations represent the fundamental idea of the second approach to explaining the origin of local magnetic fields. Bumba and Howard (1965) found that a developing active region follows the supergranular nework as it increases its size. Harvey (1977), Stenflo (1977) and Harvey and Stenflo (1985), drawing on observations of magnetic fields on the Sun, came to the conclusion that the basic element of the magnetic field in the solar photosphere is an extremely thin (tens of km) and, therefore, as yet indistinguishable magnetic tube in which the magnetic induction amounts to several hundreds mT. All the other magnetic structures, which can be observed by currently available instruments, are composed of these elementary tubes.

The mechanism of decay of sunspots, formations with the largest concentration of magnetic induction on the Sun, is related to the problems of the essence of the large-scale magnetic fields on the Sun. Current opinions claim that the large-scale magnetic fields are generated autonomously. In a number of cases, a large-scale field was observed to emerge first at a particular locality on the Sun, only later followed by the local magnetic field. It is now no longer possible to explain the generation of a large-scale field just by the dissipation of a local field for a number of reasons. Let us define our problem more precisely in the form of a question: How does a local magnetic field decay? A number of mechanisms is probably involed. Wallenhorst and Howard (1982), Wallenhorst and Topka (1982) and Gaizauskas et al. (1983) found that most of the magnetic flux of a bipolar active region is fragmented. The new term submergence of a magnetic tube was introduced for the cases in which the magnetic field in an active region evidently did not dissipate (Zirin, 1985; Rabin et al., 1984). The morphological condition for the submergence of a magnetic tube below the Sun´s surface should be a convincing observation that opposite polarities approach each other in the course of the submergence. This condition is based on analogy with the generation of a local field in the course of which the opposite polarities move away from one another. The submergence of weak bipolar fields was studied by Martin (1983) and Martin et al. (1984). The theoretical problems of the mechanisms of decay of local magnetic fields were treated by Parker (1984).

So-called "naked spots" are a suitable object for studying the decay mechanism of local magnetic fields. These are unipolar isolated spots which keep to the remnants of old active regions. They were called "naked" because of the absence of H-alpha brightening which usually accompanies sunspots. There is no opposite polarity in the neighbourhood of these spots and this is probably why the chromospheric structure is absent. Liggett and Zirin (1983) give the definition of "naked" spots and their relation to coronal voids. According to this study the differential velocity of rotation of the "naked" spots does not differ from the velocity of average spots (Newton and Nunn, 1951).

The purpose of this paper is to compare the rates of decrease of the areas of two groups of unipolar isolated sunspots: the "naked" spots and H-type spots according to the Zürich classification. The Zürich type H spots, which were analyzed in this paper, were observed only during one solar rotation.

2. OBSERVATIONAL MATERIAL AND METHOD OF TREATMENT

The data on the daily values of the areas of umbras and whole sunspots, observed in the years 1969 - 1976, were taken from the Royal Observatory Annals, Greenwich Photoheliographic Results. Using the mentioned H-alpha and magnetic criteria, a total of 30 "naked" spots and 30 Zürich H-type spots were selected. Only sunspots whose identification was quite unambiguous were taken from the Annals. Table 1 contains the data on the "naked" spots and Tab. 2 the data related to the Zürich H-type spots. Table 1 is arranged as follows: Column 1 - the current number of the spot in our list.

Column 2 - the number of the spot in the General Catalogue of Greenwich Observations.

Column 3 - the number of the spot in the Recurrent Catalogue of Greenwich Observations; the number in parentheses is the ordinal number of the return of the spot relative to the date of its origin.

Column 4 - the date of the spot's CMP in the given rotation.

Columns 5 and 6 - the heliographic longitude and latitude of the spot.

Columns 7 and 8 - the average corrected sunspot areas. $\bar{U}$ stands for the average corrected area of the sunspot umbra calculated from the daily values observed throughout the rotation (the number of days of observation is given in Column 9). $\bar{W}$ was calculated in the same way as $\bar{U}$ but stands for the average corrected area of the whole spot (umbra plus penumbra) in the given rotation. The areas are expressed in millionths of the area of the visible solar hemisphere (MSH).

Column 9 - the length of the actual observation of the spot in the given rotation expressed in days.

Columns 10 and 11 - average daily rate of decrease of the area of the umbra, $d\bar{U}/dt$, and of the whole spot, $d\bar{W}/dt$, expressed in MSH per day. These values express linear decrease of the areas.

Column 12 - the magnetic polarity of the long-lived sunspot expressed relative to the sign of the large-scale field in its neighbourhood. For example, the designation N/N - S is given for spot no 20 in Tab. 1, which means that the sunspot of positive polarity N was located in a locality with the same magnetic polarity N of the large-scale field, on whose background there was a field with the opposite S polarity.

Column 13 - the relative daily rate of decrease of the area of the spot umbra referred to the initial value of the umbra's area U_o ($d\bar{U}/dt/U_o$). The value in this column expresses the part of the umbra, relative to the initial value U_o, which decays per day.

Column 14 - the letter N indicates very conspicuous sunspots with "naked" characteristics.

The regularities of the decrease of average areas of umbras $\bar{U}$ and of whole sunspots $\bar{W}$, related to the long-lived "naked" spots, are illustrated in Figs 1 - 3.

Let us give a more detailed account of the way the average rate of daily decrease of the sunspot area is calculated. The average area of the umbra of the "naked" spots $\bar{U}$ (Tab. 1, Column 7) was calculated as the average of the daily corrected umbra areas (the number of days of observation is given in Tab. 1, Column 9), published in the Photoheliographic Results of the Royal Greenwich Observatory. The rate of decrease of the umbra area of a particular sunspot per day (the quantity $d\bar{U}/dt$ is given in Tab. 1, Column 10) is also an average value which was calculated as follows: The difference of the average areas of a particular umbra, $\bar{U}_2 - \bar{U}_1$, in two consecutive rotations (Tab. 1, Column 7) was divided by the number of days of one synodic rotation (27 days). By the initial average area U_o of a sunspot umbra we understand the average area of the umbra of "naked" spot in the first rotation considered.

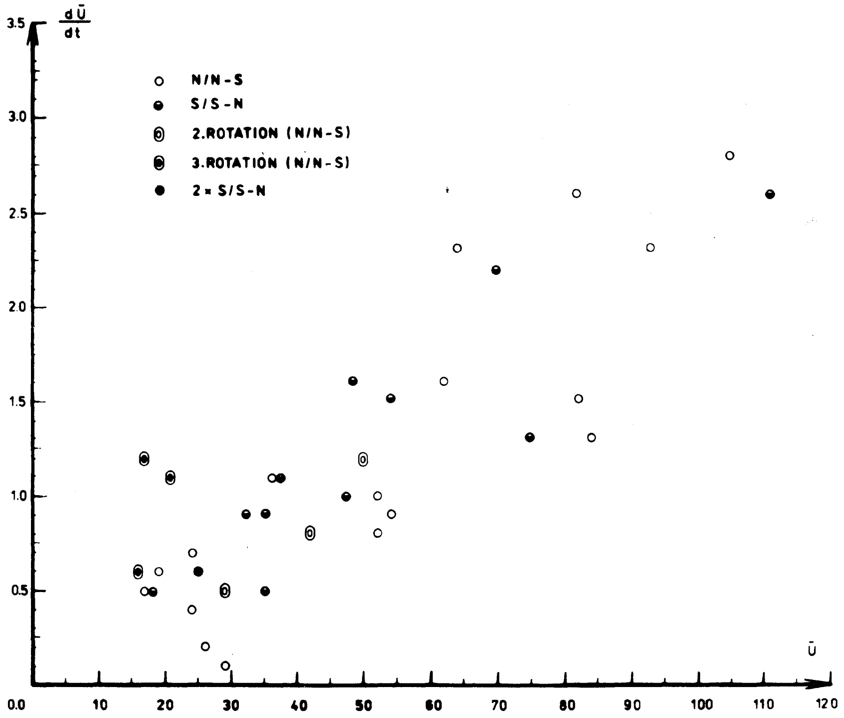

Fig. 1: The linear dependence of the daily areal decrease of umbras of long-lived "naked" spots on the initial average value of the sunspot umbra area $\bar{U}$, expressed by the relation $d\bar{U}/dt = 0.03\,\bar{U} - 0.25$.

The linear dependence of the decrease of the areas of umbras of long-lived "naked" spots on the their average initial umbral area $\bar{U}$ is shown in Fig. 1. The decrease of the umbra area as a function of $\bar{U}$, for the 30 "naked" spots being investigated can be expressed by the relation

$$d\bar{U}/dt = 0.03\,\bar{U} - 0.25 \qquad (1)$$

The mean daily rate of decrease $d\bar{W}/dt$ of the area of whole "naked" spots (umbra + penumbra) was calculated in a similar manner. The appropriate dependence on their average initial area of the whole spots $\bar{W}$ is shown in Fig. 2 and is expressed by the relation

$$d\bar{W}/dt = 0.03\,\bar{W} - 2.20 \qquad (2)$$

These linear dependences of the decrease of the areas of the umbras and whole "naked" spots on the initial value of the mean areas $\bar{U}$ and $\bar{W}$ contradicts the generally accepted idea that smaller spots disappear faster than larger.

Table 1

The rate of the daily areal decrease of long-lived "naked" sunspots

No	Gr No	Recur No	CMP	L	B	$\bar{U}$	$\bar{W}$	t	$d\bar{U}/dt$	$d\bar{W}/dt$	Mag F	$\frac{d\bar{U}/dt}{\bar{U}}$	R
01	22305	2076(2)	1970 03 04.8	159.0	+05.2	75	478	12	1.3	8.4	S/S-N	0.017	N
	22333	2076(3)	03 31.9	162.4	+04.2	39	249	13			S/S-N		
02	22377	2084(2)	1970 05 05.1	71.2	-21.1	24	163	13	0.4	2.8	N/N-S	0.016	N
	22416	2084(3)	06 01.8	64.1	-19.5	13	85	13			N/N-S		
03	22378	2081(2)	1970 05 05.9	60.1	-12.7	52	361	14	1.0	6.6	N/N-S	0.019	N
	22419	2081(3)	06 02.3	58.2	-12.9	26	183	13			N/N-S		
04	22460	2086(4)	1970 07 11.1	264.0	+16.7	32	210	14	0.9	6.6	S/S-N	0.028	
	22494	2086(5)	08 07.9	257.6	+16.8	07	30	10			S/S		
05	22511	2102(2)	1970 08 25.1	29.4	+04.9	18	111	13	0.5	3.4	S/S-N	0.027	N
	22546	2102(3)	09 21.3	29.6	+04.4	03	17	07			S/S-N		
06	22556	2108(1)	1970 09 29.4	282.6	-06.8	64	397	13	2.3	14.1	N/N-S	0.036	N
	22580	2108(2)	10 26.6	283.9	-06.4	03	15	08			N/N-S		
07	22669	2115(2)	1971 01 15.5	298.6	+19.5	24	141	13	0.7	4.1	N/N-S	0.029	N
	22700	2115(3)	02 11.9	297.5	+18.6	05	29	09			N/N-S		
08	22714	2124(1)	1971 02 24.8	127.4	-07.6	62	376	14	1.6	9.6	N/N-S	0.026	N
	22742	2124(2)	03 24.2	126.8	-08.6	19	114	13			N/N-S		
09	22720	2123(2)	1971 03 02.9	47.0	+24.9	25	159	12	0.6	3.8	S/S-N	0.024	N
	22746	2123(3)	03 30.8	38.7	+25.4	09	57	07			S/S		
10	22875	2137(2)	1971 08 20.1	317.2	+12.8	25	163	13	0.6	4.0	S/S-N	0.024	N
	22889	2137(3)	09 16.3	318.8	+12.4	10	55	11			S/S		
11	22915	2141(3)	1971 10 27.6	133.0	-05.4	54	301	13	0.9	4.4	N/N-S	0.016	N
	22935	2141(4)	11 23.9	133.3	-05.9	29	181	14	0.5	3.0	N/N-S	0.017	

Table 1 continued

11	22963	2141(5)	1971	12	21.2	134.2	-04.8	16	100	13	0.7	3.7	N/N-S	0.012	N
12	22931	2146(1)	1971	11	19.4	192.7	-13.3	82	507	13	2.6	16.5	N/N-S	0.031	N
	22959	2146(2)		12	17.1	188.2	-13.7	11	61	09			N/N-S		
13	23012	2149(2)	1972	02	14.7	124.1	+16.5	35	200	13	0.5	2.2	S/S-N	0.014	N
	23040	2149(3)		03	13.3	119.8	+16.7	23	142	13			S/S-N		
14	23046	2152(2)	1972	03	20.2	28.2	+08.1	35	224	13	0.9	5.6	S/S-N	0.025	
	23072	2152(3)		04	16.5	28.0	+07.7	12	72	13			S/S-N		
15	23078	2156(1)	1972	04	21.8	319.0	-10.0	48	328	14	1.6	11.3	S/S-N	0.033	
	23102	2156(2)		05	18.9	320.4	-09.1	04	27	08			S/S		
16	23117	2162(1)	1972	06	05.4	88.8	-14.7	52	358	13	0.8	6.2	N/N-S	0.015	N
	23136	2162(2)		07	02.8	85.9	-13.6	31	191	12			N/N-S		
17	23126	2160(2)	1972	06	16.7	298.4	-12.9	70	474	14	2.2	15.3	S/S-N	0.031	N
	23154	2160(3)		07	14.2	294.9	-11.8	10					S/S		
18	23130	2164(1)	1972	06	21.0	242.0	+08.3	37	244	13	1.1	7.6	S/S-N	0.029	N
	23157	2164(2)		07	18.2	244.5	+08.6	08	38	12			S/S-N		
19	23131	2165(1)	1972	06	21.5	235.7	-08.9	105	601	13	2.8	14.5	N/N-S	0.026	N
	23158	2165(2)		07	18.3	240.9	-10.0	30	209	13			N/N-S		
20	23196	2162(4)	1972	08	26.7	79.1	-14.2	26	188	13	0.2	2.2	N/N-S	0.007	N
	23224	2162(5)		09	23.0	79.7	-14.8	20	128	12			N/N-S		
21	23250	2174(1)	1972	10	22.0	56.8	-15.0	93	531	14	2.3	10.3	N/N-S	0.024	N
	23268	2174(2)		11	18.2	57.5	-13.4	32	254	13			N/N-S		
22	23486	2193(1)	1974	03	24.6	54.7	-08.8	19	130	13	0.6	4.2	N/N-S	0.031	N
	23495	2193(2)		04	20.8	56.8	-08.3	02	17	06			N/N-S		
23	23536	2197(1)	1974	07	14.5	15.4	-08.1	84	485	13	1.3	6.7	N/N-S	0.015	N
	23546	2197(2)		08	10.5	18.9	-08.7	50	303	13	1.2	6.5	N/N-S	0.025	
	23558	2197(3)		09	06.6	20.6	-07.4	17	127	17	1.2	6.6	N/N		

Table 1 continued

24	23553	2198(2)	1974	08 19.8	256.7	-14.4	36	214	14	1.1	6.9	N/N-S	0.030	N
	23566	2198(3)		09 16.2	254.2	-15.2	05	27	09			N/N		
25	23639	2207(1)	1975	06 30.5	62.9	+06.4	54	317	13	1.5	8.4	S/S-N	0.028	N
	23647	2207(2)		07 27.3	68.9	+07.5	13	90	13			S/S-N		
26	23639	2209(1)	1976	03 31.0	42.7	-07.8	111	703	14	2.6	15.6	S/S-N	0.023	N
	23697	2209(2)		04 27.4	41.3	-09.5	41	282	13			S/S-N		
27	23694	2208(2)	1976	04 14.7	208.0	+02.8	47	265	12	1.0	4.7	S/S-N	0.021	N
	23700	2208(3)		05 11.7	211.3	-00.1	20	139	13			S/S-N		
28	23713	2211(1)	1976	08 07.6	128.5	+15.9	82	547	13	1.5	11.6	N/N-S	0.018	N
	23718	2211(2)		09 03.9	128.3	+16.2	42	235	14	0.8	3.4	N/N-S	0.019	
	23724	2211(3)		10 01.1	129.1	+15.7	21	144	13	1.1	7.5	N/N-S	0.013	
29	23723	2212(1)	1976	10 01.1	128.8	-26.0	17	112	13	0.5	3.3	N/N-S	0.029	N
	23731	2212(2)		10 29.0	120.3	-27.8	03	22	07			N/N-S		
30	23732	2213(1)	1976	11 23.3	147.2	+11.0	29	211	13	0.1	2.4	N/N-S	0.003	N
	23736	2213(2)		12 20.5	148.3	+11.5	25	146	13			N/N-S		

Table 2

The rate of the daily areal decrease of type H sunspots

No	Gr No	CMP	L	B	U_o	W_o	t	Mag F	$d\bar{U}/dt$	$d\bar{W}/dt$	$\frac{d\bar{U}/dt}{U_o}$
01	22136	1969 10 10.3	276.3	-14.4	29	175	4	N/N-S	2.03	6.08	0.069
02	22437	1970 06 21.6	162.0	+19.5	20	137	6	S/S	1.19	6.54	0.074
03	22530	09 08.9	193.5	+10.2	20	129	4	S/S	1.83	7.68	0.091
04	22661	1971 01 03.4	97.9	+21.5	22	133	6	S/S-N	2.06	10.48	0.137
05	22721	03 03.8	34.9	+08.2	29	181	4	S/S-N	1.80	9.38	0.072

Table 2 continued

06	22730	1971	03	15.5	241.4	+18.8	21	112	4	S/S	1.05	5.79	0.065
07	22731		03	17.4	215.5	-04.7	26	182	6	N/N	3.22	22.93	0.201
08	22786		05	08.1	253.8	+11.0	24	172	3	S/S-N	2.03	18.77	0.088
09	22811		06	08.3	200.1	-05.9	27	162	4	N/N-S	1.45	8.47	0.066
10	22830		07	03.4	229.0	+16.5	23	138	6	S/S-N	2.03	10.14	0.101
11	22892		09	19.2	280.6	+04.6	27	167	3	S/S-N	2.94	14.70	0.127
12	22899		09	26.0	190.8	-14.2	34	197	3	N/N-S	6.34	29.25	0.352
13	22953		12	12.3	251.3	-02.9	28	93	4	N/N-S	4.67	3.50	0.245
14	22998	1972	01	30.3	325.3	+13.5	21	135	3	S/S-N	3.84	19.66	0.225
15	23039		03	11.3	145.0	-20.6	24	181	3	N/N-S	4.92	15.73	0.196
16	23084		04	26.8	252.7	+16.8	21	185	4	S/S-N	1.65	20.82	0.078
17	23166		07	27.5	119.2	+04.8	20	99	3	S/S	3.16	6.32	0.175
18	23199		08	30.0	36.6	-06.4	24	127	3	N/N-S	5.36	38.19	0.315
19	23377	1973	06	13.0	210.1	+15.6	24	188	5	S/S-N	3.10	29.47	0.172
20	23397		07	31.3	291.3	-04.9	31	136	4	N/N-S	2.08	7.96	0.090
21	23459	1974	01	14.5	245.9	-11.3	33	190	5	N/N-S	2.26	15.79	0.112
22	23471		02	14.0	203.8	-16.1	23	187	6	N/N	1.13	6.98	0.051
23	23503		05	05.2	225.3	-02.8	37	139	4	N/N-S	5.59	2.53	0.253
24	23540		07	20.5	296.5	-13.2	26	110	3	N/N-S	3.03	7.56	0.159
25	23556		08	25.3	182.8	+01.5	21	98	5	N/N-S	2.98	9.18	0.212
26	23602		12	23.7	35.4	+05.7	25	120	5	S/S-N	2.97	13.10	0.185
27	23634	1975	07	16.2	215.8	-10.3	14	106	4	N/N-S	2.12	13.43	0.163
28	23663		09	12.2	168.4	-08.5	19	121	3	N/N-S	2.93	12.23	0.195
29	23667		10	07.2	198.9	+32.8	20	127	3	N/N-S	3.94	9.84	0.218
30	23710	1976	06	27.5	312.3	-26.9	15	122	3	S/S-N	2.48	4.86	0.190

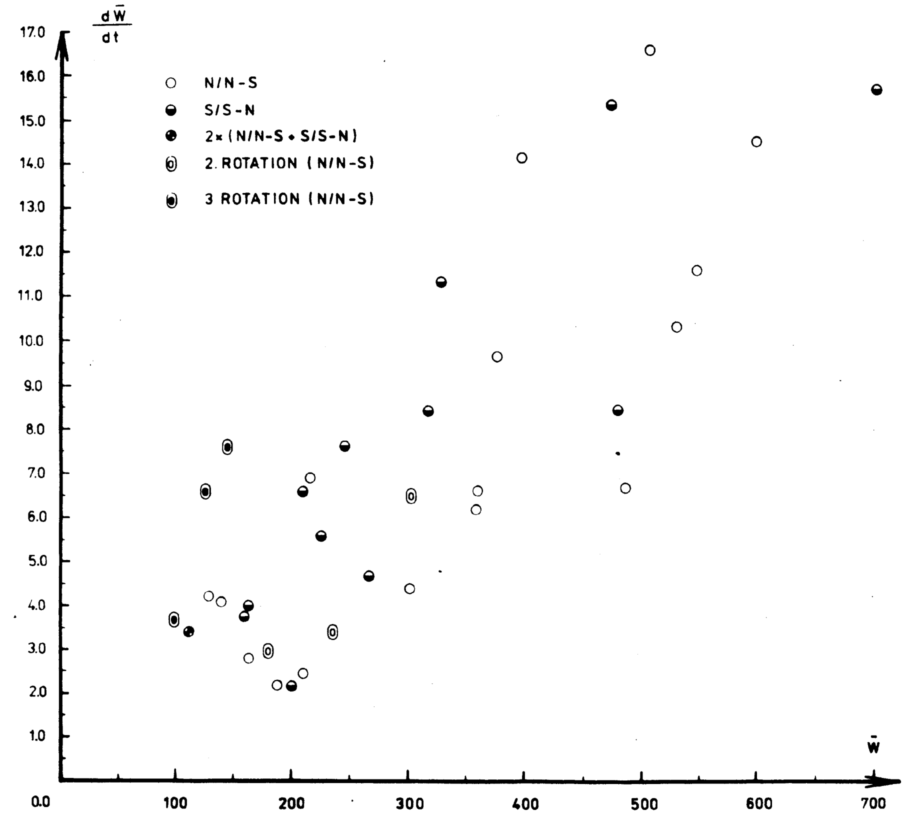

Fig. 2: The linear dependence of the daily decrease $d\bar{W}/dt$ of the whole "naked" sunspot area on the average area $\bar{W}$, expressed by the relation $d\bar{W}/dt = 0.03\ \bar{W} - 2.20$.

This problem could be treated independently on the basis of the average lifetimes of spots with particular areas. The analysis of the sample of 30 "naked" spots being studied can also be used to determine what percentage of the spot area will decay per unit time (one day) in the case of small and large "naked" sunspots. This quantity, the relative daily rate of decrease of the umbra area, expressed in fractions of the area of the initial value $\bar{U}$ (the first rotation average area value) is given in Tab. 1, Column 13, and is depicted as function $\bar{U}$ in Fig. 3.

The analysis showed that the relative daily rates of decay of the "naked" spots does not depend significantly on the initial size of the spots. On the average, 0.022 of the initial umbra area $\bar{U}$ decays per day. As shown in Fig. 3, the scatter of the relative daily decay rate of spots about the ave-

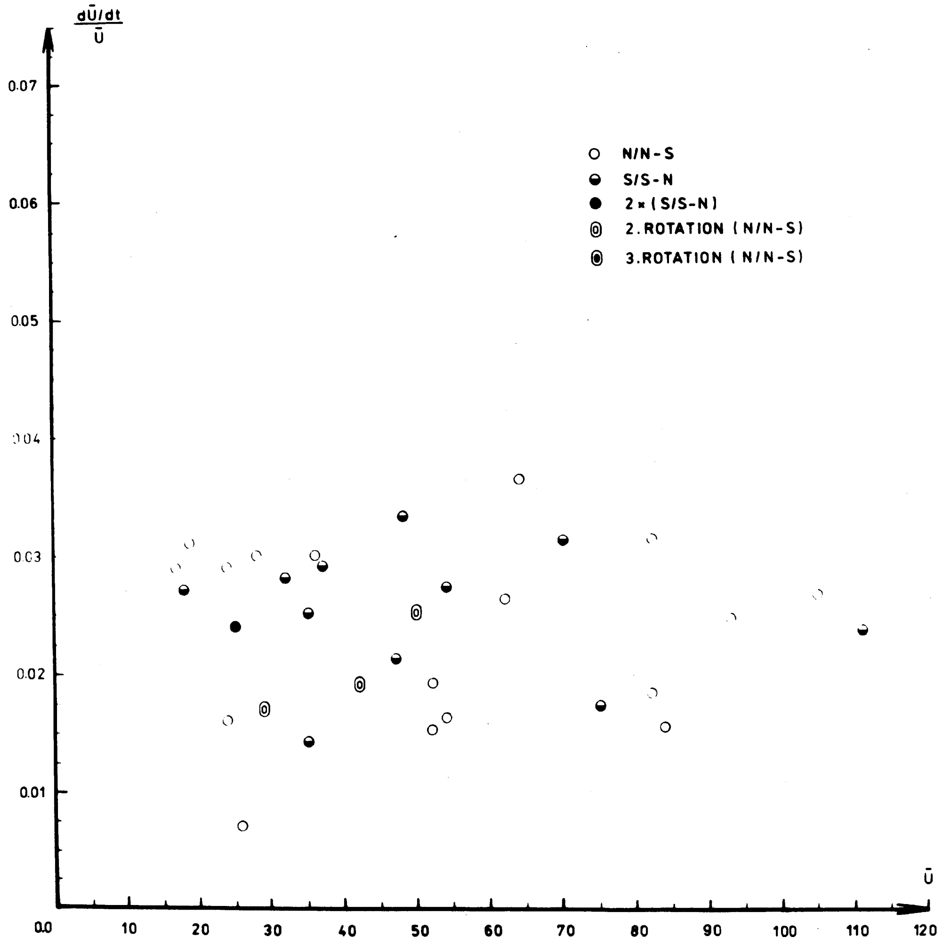

Fig. 3: Relative daily rate dŪ/dt of areal decrease of the umbra of "naked" spots expressed in fractions of the first rotation area value Ū. The area of "naked" spots decreases, on the average, by 0.22 Ū per day.

rage value of 0.022 is larger for small sunspots (0.01 - 0.03). For spots larger than 90 MSH it is about 0.02 Ū.

Type H spots

The basic data on the sample of 30 Zürich H-type sunspots are given in Tab. 2. Table 2 is arranged in a similar manner as Tab. 1 for the "naked" spots. Table 2 does not contain the numbering from the Recurrent Catalogue of Greenwich Observations, because the H-type spots were observed and treated for

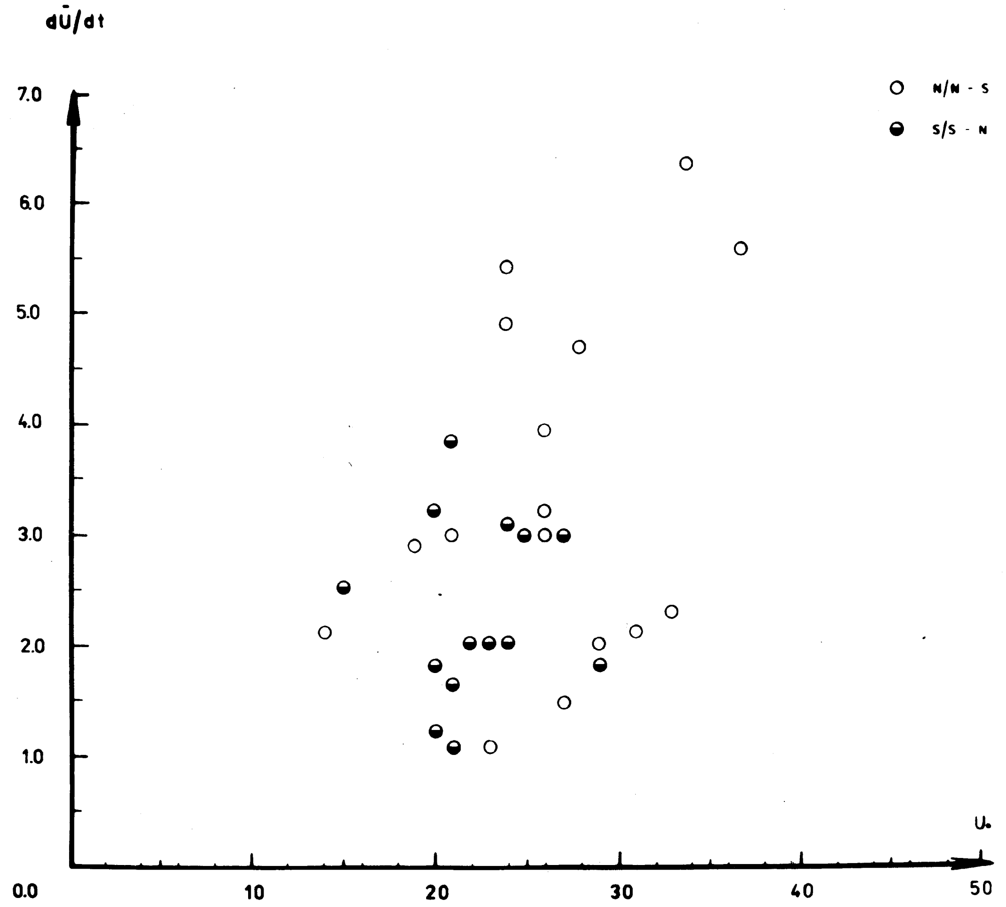

Fig. 4: Linear dependence of the daily decrease of the umbra area of Zürich H-type spots (Tab. 2) on the initial area value U_0, expressed by the relation $d\bar{U}/dt = 0.23\ U_0 - 2.80$.

one passage across the solar disk. The average rate of decrease of the umbra area of the H-type spots was, therefore, calculated in a different way than for the "naked" spots. The average daily value of the sunspot umbra $\bar{U}$ was calculated for the period in which the spot was located east of the CM and, similarly, the average daily value for the period when it was west of the CM. The data designated as t (Tab. 2, Column 8) represent the time interval between the mean values $\bar{U}_E$ and $\bar{U}_W$. In Tab. 2, Column 10, the quantity $d\bar{U}/dt = (\bar{U}_E - \bar{U}_W) / t$.

The analysis of the sample of 30 Zürich H-type spots indicates that the rate of decrease of the umbra area is a linear function of the initial umbra area U_0 (Fig. 4):

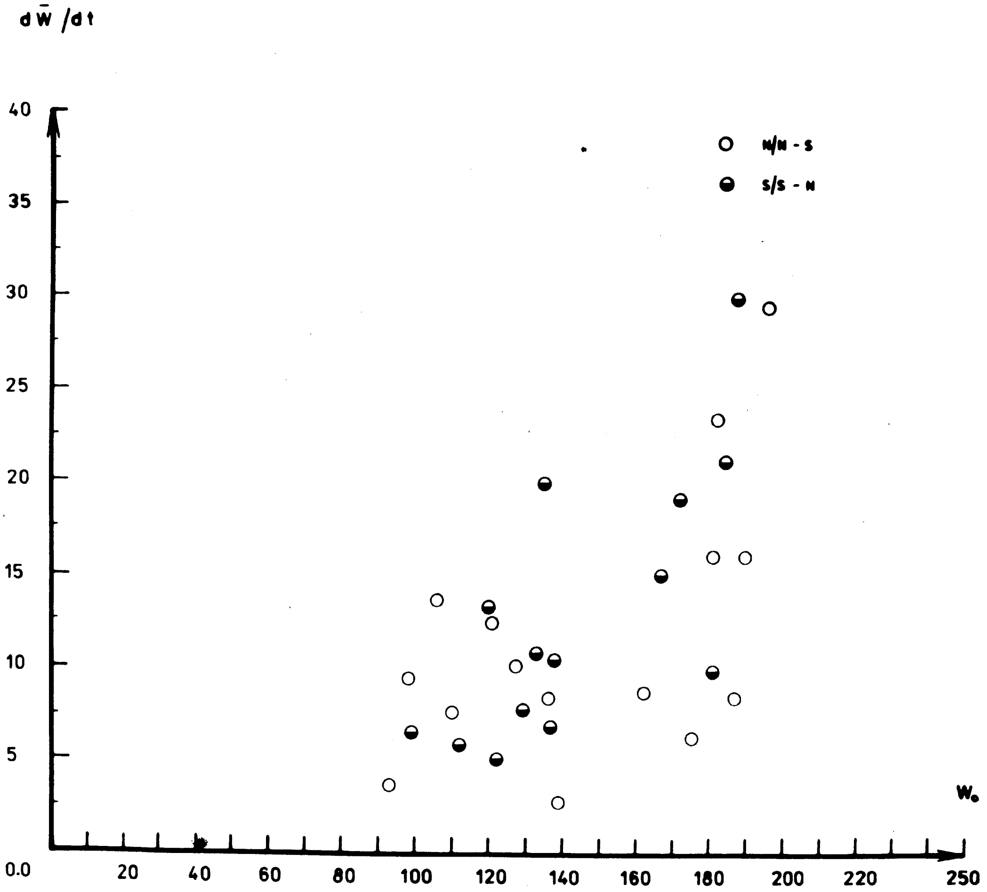

Fig. 5: Linear dependence of the daily decrease of the whole Zürich type-H spots areas on the initial value W_0, expressed by the relation $d\bar{W}/dt = 0.23\,W_0 - 20.60$.

$$d\bar{U}/dt = 0.23\,U_0 - 2.90 \qquad (3)$$

The daily average rate of decrease of the area of whole spots, $d\bar{W}/dt$, of the Zürich H-type spots is a linear function of the initial area W_0 and can be expressed by Eq. (4), illustrated in Fig. 5:

$$d\bar{W}/dt = 0.23\,W_0 - 20.60 \qquad (4)$$

Figure 6 shows the relative daily rate of decrease of the umbra areas of Zürich H-type spots. Assuming that $(d\bar{U}/dt)/\bar{U}$ remains constant with initial areal value U_0, the average relative daily rate of areal decrease is $0.17\,\bar{U}$, which is 7 times higher than for the "naked" spots. In general, the comparison

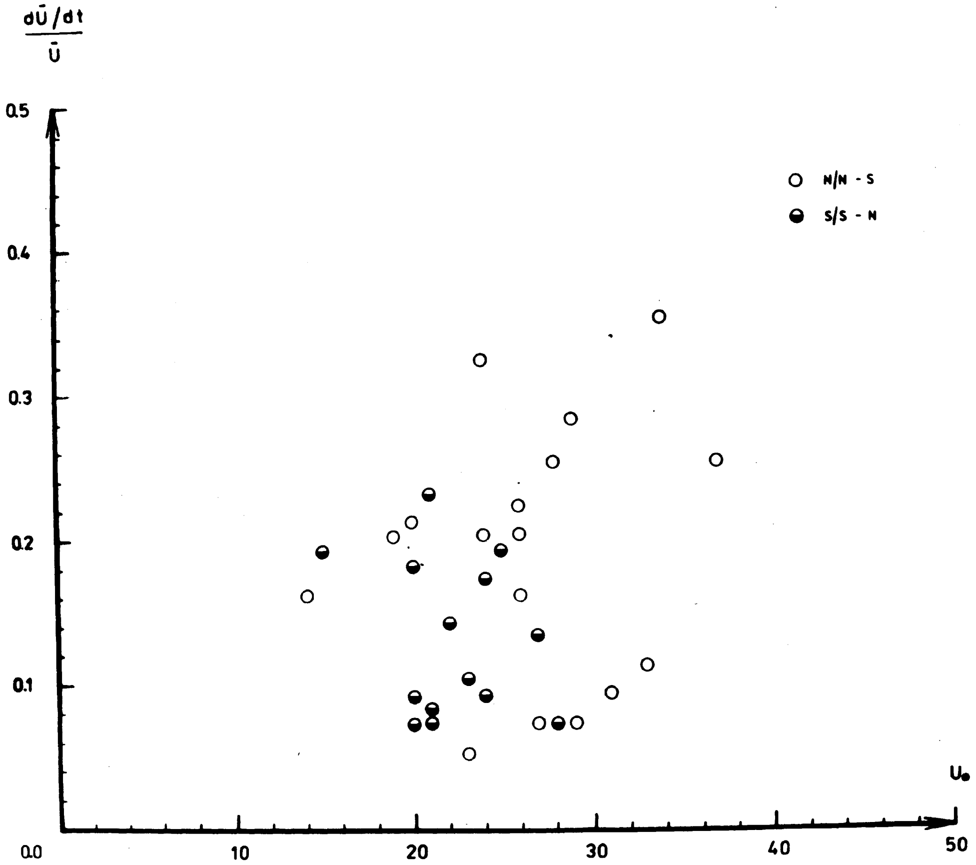

Fig. 6: The dependence of the relative (expressed in fraction average east $\bar{U}$) daily rate of areal decrease of the umbras of Zürich H-type spots, on the initial area value U_0. On the average, the umbra area of the Zürich H-type spots decreases by 0.17 $\bar{U}$ per day.

of all three calculated quantities, $d\bar{U}/dt$, $d\bar{W}/dt$ and the relative daily rates of areal decrease, for both samples of long-lived sunspots, clearly indicates that the area of the "naked" spots of the same size decreases 6 - 8 times slower than the area of the Zürich H-type sunspots. Figure 7 shows the difference the two long-lived spot groups as regards $dU/dt = f(\bar{U})$. The "naked" spots are represented by black dots, the H-type spots by white dots.

The "naked" spots, which are usually also of the Zürich H-type, differ from the sample of H-type spots only in that they do not display chromospheric brightening. The different final stages of the two analogous types of active regions indicate that the decay of the spot depends on the degree of its interaction with the ambient medium. It is as yet not clear the mechanism of

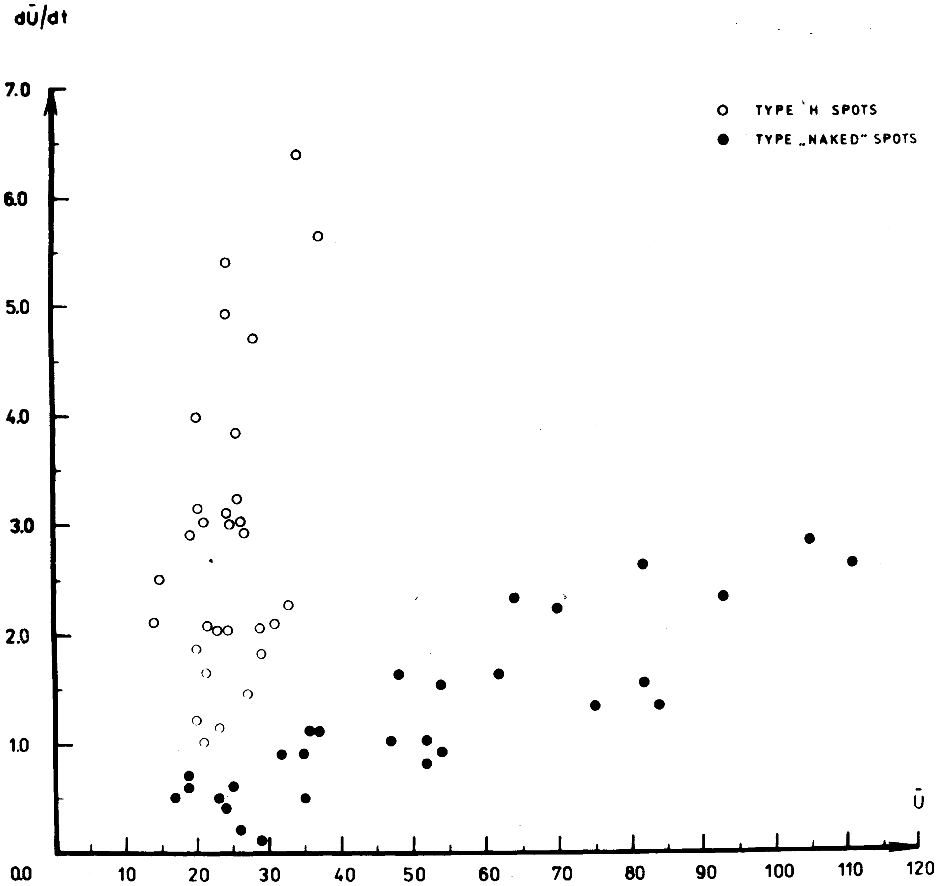

Fig. 7: The difference between the linear daily decrease of the umbra area of "naked" spots (black dots) and Zürich H-type spots (white dots), illustrated by the emirical fact that the decay of unipolar spots depends not only on $\bar{U}$, but also on the interaction type of spots.

the penetration of the spot into the activity of its neighbourhood (especially upwards into the chromosphere).It is probable that the spot itself, the manner in which the internal and external force are balanced within it, reflects the parameters of the ambient medium. If the second alternative applies, then also the usual quantities such as the lifetime of the spot, its rate of decay, possibly also its form and the compactness of its umbra are affected by the morphology and dynamics of the active region as a whole. The observed extensive interval (1.0 - 5.5) of the decay rate of H-type spots whose size $\bar{U}$ = 20 MSH, as shown in Fig. 7, would satisfy this interpretation well.

In connection with the naked spots, let us remind one of the problems of sunspot physics. In particular, the decrease of temperature in the spot is related to the reduction in the convective energy transfer in the region of the sunspot. According to this concept, the accumulated energy is balanced by the radiation in the chromospher. As the definition of "naked" spots indicates, it is the radiation of flocculas in the neighbourhood of the "naked" spots which is unexpectedly lacking.

3. NORMED RATE OF SLOW, STEADY-STATE DECREASE OF THE AREAS OF "NAKED" SUNSPOTS

With regard to specifying the mechanism of the slow decay of magnetic fields of old unipolar sunspots, the question arises as to manner in which the size of the spot will affect the process involved. Does the decay rate of the sunspot depend on its area? If this is so, is the decay rate larger for the small spots, or on the contrary, for the large spots of the same type of interaction? In the preceding section, we found that the decay rate of unipolar sunspots depends on the interaction type of spot. In this section, we shall only speak of the "naked" spots. We ask whether the decrease in the area of a single spot with an umbra area of 100 MSH per day is equal to the sum of the daily areal decreasas of 10 combined spots, each of which has an umbra of 10 MSH. The overall sum, expressing the areal decrease of 5 spots, each of which has an area U equal to 20 MSH.

Let us norm $d\bar{U}/dt$ as a function of the initial average area $\bar{U}$, taken Eq. (1) for the decay of the chosen standard initial area $\bar{U}$ = 100 MSH. In this particular case, we have taken $\bar{U}$ = 100 MSH to be the standard value. The decrease of the whole area of the sunspot $d\bar{W}/dt$, is normed similarly by Eq. (2) with respect to the chosen standard value $\bar{W}$ = 600 MSH. The normed decay values of the "naked" spots are given in Tab. 3. They are marked SR (standard rate) and they are the sum of the particular numbers of smaller umbras (10, 20..) to be equal to chosen area value (100, 600).

The Zürich H-type spots could not be normed because our sample of these spots has a small interval of U_o and W_o values as can be seen from Tab. 2 and Figs. 4 and 5. The H-type spots are also characterized by a large scatter of $d\bar{U}/dt$- and $d\bar{W}/dt$- values about the average.

The normed decay values (SR) of the "naked" spots, given in Tab. 3, are evidence that large "naked" spots decay faster than small ones. The small spots, $\bar{U}$ = 10 -20 MSH and $\bar{W}$ = 100 - 200 MSH, have the most developed stability mechanism and their decay is 3 - 6 times slower than that of the larger spots. May be this result is only response to the selection of the very stable small "naked" spots, or to the uncorrectness of the Eqs. (1) and (2) for small "naked" spots.

4. CONCLUSIONS

The selection of the sample of the 30 "naked" spots from a more general

Table 3

The standard rates (SR) of the areal decrease of the various "naked" spots
The chosen $\bar{U}$ = 100 MSH , SR_{100} = 2.8 MSH per day, Eq. (1)

$\bar{U}$	10	20	30	40	50	60	70
SR Eq. (1)	0.5	1.7	2.1	2.4	2.5	2.6	2.7
SR - 2.8	-2.3	-1.1	-0.7	-0.4	-0.3	-0.2	-0.1
2.8/SR	5.6	1.6	1.3	1.2	1.1	1.1	1.0

The chosen $\bar{W}$ = 600 MSH, SR_{600} = 15.8 MSH per day

$\bar{W}$	100	200	300	400	500
SR Eq. (2)	4.8	10.5	13.0	14.4	15.4
SR - 15.8	-11.0	-5.3	-2.8	-1.4	-0.4
15.8/SR	3.3	1.5	1.2	1.1	1.0

group of Zürich H-type spots, observed in the years 1969 - 1976, required a more detailed analysis of the daily data on the H-alpha structure (SGD), magnetic fields (Mt. Wilson, Solnechnye dannye) and corrected sunspot areas (Greenwich observations).

The following conclusions can be drawn from the analysis of the area decay curves of the "naked" spots (listed in Tab. 1) and Zürich H-type spots (listed in Tab. 2):

1. The studied spots, regardless of whether they belong to the group of "naked" or Zürich H-type, are characterized by the sign of their magnetic induction agreeing with the polarity of the ambient magnetic field (the longitudinal B-component is involved). Not one case of different polarities was observed.

2. It was found that the linear dependence of the areal decrease of the umbra U and of the total spot area W on the initial values differs with the type of unipolar spots. The "naked" spots decay at a rate which is 6 - 8 times slower (Fig. 7) than the Zürich H-type spots.

3. Table 3 gives the values of the normed curves of areal decrease, $d\bar{U}/dt$ and $d\bar{W}/dt$, for the standard initial values $\bar{U}$ = 100 MSH and $\bar{W}$ = 600 MSH and the "naked" spots. The norming indicates that small "naked" spots ($\bar{U}$ = 10 MSH) decay 3 - 5 times slower than large spots ($\bar{U}$ larger than 50 MSH).

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