LONG-TERM VARIATIONS OF THE STRUCTURE OF CLOSED MAGNETIC CONFIGURATIONS ABOVE GREAT SUNSPOT GROUPS

A. Böhme
Zentralinstitut für Astrophysik der AdW der DDR
Observatorium fur solare Radioastronomie, 1501 Tremsdorf, DDR

ABSTRACT. An analysis of long-term behaviour of noise storm continua at different observing frequencies leads to the conclusion that the radiation signatures of sunspot groups with fixed parameters at photospheric level (total area, Brunnertype) depends on both the hemisphere and the phase of the solar cycle indicating a systematic variation of the structure of closed magnetic configurations above these sunspot groups with time.

ДЛИННОВРЕМЕННЫЕ ВАРИАЦИИ СТРУКТУРЫ ЗАМКНУТЫХ МАГНИТНЫХ КОНФИГУРАЦИЙ НАД БОЛЬШИМИ ГРУППАМИ СОЛНЕЧНЫХ ПЯТЕН: Анализ длинновременного поведения континуума **шумовых бурь** при разных частотах ведет к заключению, что излучаемость групп солнечных пятен с заданными параметрами фотосферы зависит от гемисферы и от фазы солнечного цикла. Оказывается, что вариящии структуры замкнутых магнитных конфигураций над этими группами пятен систематически зависят от времени.

DLHODOBÉ VARIÁCIE SLUČKOVÝCH ŠTRUKTÚR MAGNETICKÝCH KONFIGURÁCIÍ NAD VEĽKÝMI SKUPINAMI SLNEČNÝCH ŠKVŔN: Z analýzy dlhodobej hodnoty kontinua šumových búrok, pozorovaného na rôznych frekvenciách plynie záver, že pre určité konštantné parametre skupín slnečných škvŕn (celková plocha a zurišský typ) merané žiarenie závisí na fáze slnečného cykla a na príslušnej pologuli Slnka. Tieto merania sú interpretované tak, že vznikajú systematické časové variácie v slučkových štruktúrach magnetických konfigurácií nad skupinami slnečných škvŕn.

1. Contrary to the great number of publications dealing with data from rather restricted observing periods long-term behaviour of noise storms was the subject of merely two papers till now leading to quite peculiar results in

both cases. The probability of sunspot groups with fixed value of total area to emit a noise storm was pointed out by Korolev (1973) to very systematically with the phase of the solar cycle. ŠUK (1979) studied the frequency of occurrence of noise storms during cycle No. 20 and found out a second activity maximum not before 1974 at least for a few of the subtypes defined by Tlamicha et al. (1964). In either case, however, noise storm activity was characterized by noise storm occurrence in general without discrimination between some classes of observable parameters being typical for noise storm importance.

2. Investigations of long-term behaviour of noise storms may contribute to a better understanding of physical processes involved in the generation of both type I bursts and noise storm continuum. Moreover, noise storm continua rather than type I bursts can be used to study the topology of closed magnetic configurations above great sunspot groups and the distribution of plasma parameters within these configurations. Therefore, a systematic dependence of radiation signatures of sunspot groups with fixed parameters at photospheric level on the phase of the solar cycle can be regarded as a hint that the structure of closed magnetic configurations above these sunspot groups systematically variees with time. To clarify whether or not there are really changes of radiation signatures we tried at first to define an index suitable to point out general trends of long-term behaviour of noise storm continua during a solar cycle. Starting from these results we studied whether long-term behaviour is mainly determined by the occurrence of great sunspot groups and their parameters at photospheric level or whether systematic changes of their radiation signatures must be taken into consideration.

3. The number of hours per unit time interval with a noise storm continuum and their distribution according to hourly mean of flux density including data obtained in a broad range of observing frequencies can be assumed to be a suitable index to outline long-term behaviour of noise storm continua in a quantitatively exact manner being the starting point for the more retailed investigations mentioned above. With regard to the length of unit time intervals two contradictory aspects have to be taken into account. Rather short time intervals are needed especially for comparisons with other phenomena of solar activity. On the other hand, however, time intervals must be long enough to yield a data set sufficient to confirm the statistical significance of long--term effects.

4. Solar activity remained at a comparatively low level during whole the cycle No. 20. Therefore, it was possible to identify sunspot groups emitting a noise storm continuum and the related values of flux density at the different observing frequencies with a high degree of accuracy. Basing on single frequency records at 287, 234, 113, 64 and 40 MHz long-term behaviour was studied at first using half-years as basic time intervals. The results obtained suggest to subdivide cycle No. 20 into 5 characteristic time intervals during which noise storm continua exhibited a rather homogeneous behaviour in different respect and which provide data sets sufficient for statistical significance tests. The general conclusions drawn from a detailed analysis of cycle No. 20 have been supported by a preliminary evaluation of the data obtained

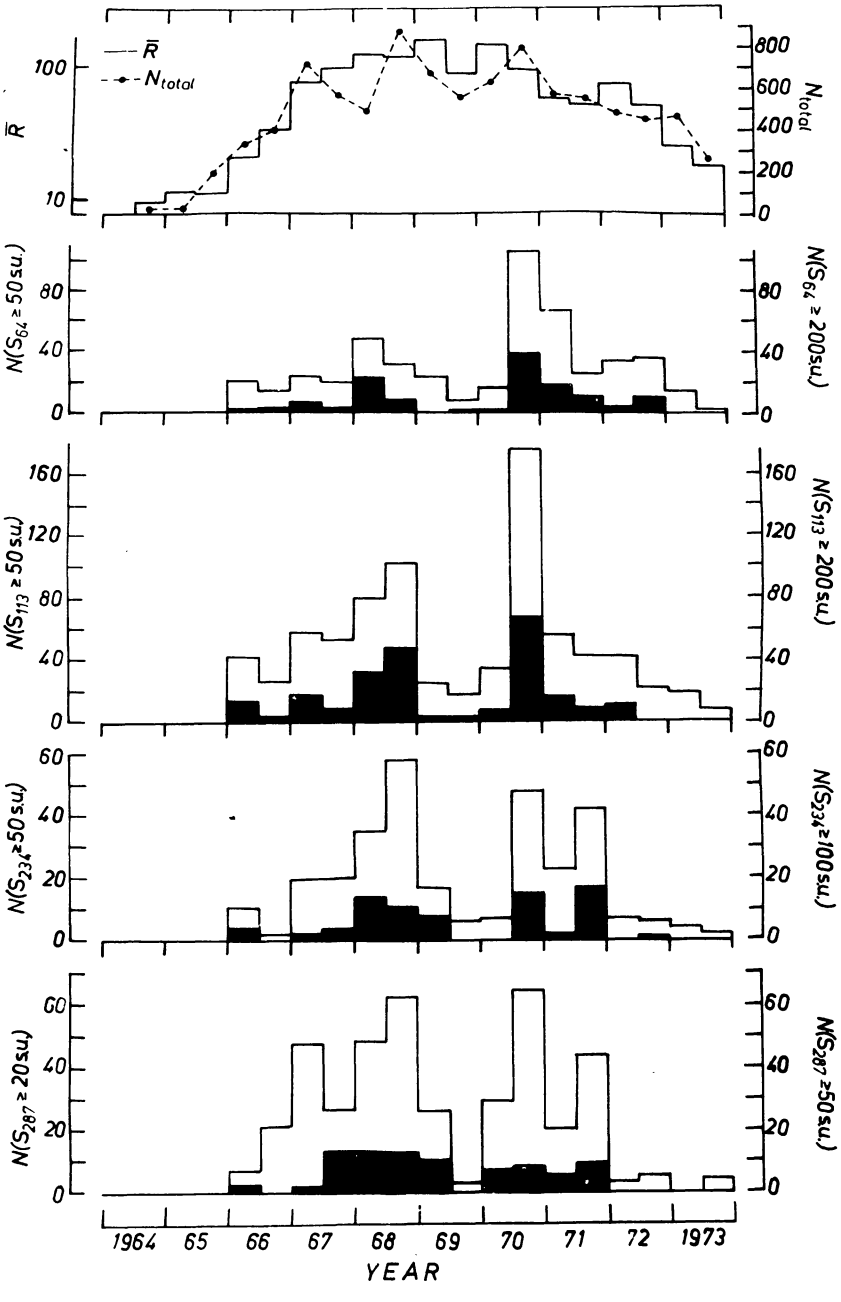

Fig. 1: Half-yearly mean $\bar{R}$ of sunspot relative number, total number N_{total} of hours per half-year with a noise storm continuum and half-yearly number of hours during which a high value of the hourly mean S_v of flux density could be stated at the observing frequencies 287, 234, 113 or 64 MHz, respectively, as a function of the phase of cycle No. 20.

Table 1

The number N' of hours with a noise storm continuum per characteristic time interval of cycle No. 20 and their estimated normed distribution p=N'(S_{287})/N' to the different values of S_{287} including confidence intervals p_1, p_2 calculated for an error probability of 5 %(S_{287}: hourly mean value of the flux density of a noise storm continuum at 287 MHz)

Time Interval	N'	S_{287} [s.u.]	$p \, {}^{p_1}_{p_2}$				
		0	1 - 4	5 - 9	10 - 20	21 - 50	>50
II64-II66	989	.243 0.270 .298	.458 0.489 .521	.137 0.159 .183	.032 0.055 .071	.017 0.025 .037	.001 0.002 .007
I67-II68	2674	.151 0.165 .179	.405 0.424 .443	.203 0.218 .234	.114 0.126 .139	.044 0.052 .061	.010 0.015 .020
I69- I70	1868	.196 0.214 .233	.535 0.558 .569	.140 0.155 .172	.036 0.044 .054	.014 0.020 .027	.006 0.009 .012
II70-II72	2869	.192 0.207 .222	.501 0.519 .538	.127 0.139 .152	.081 0.091 .102	.030 0.036 .043	.005 0.008 .010
I73- I76	2031	.159 0.175 .192	.629 0.650 .670	.117 0.131 .146	.028 0.035 .044	.005 0.008 .013	.00 0.000 .003

during cycle No. 21.

5. The analysis of cycle No. 20 suggests the following scenario:

a/ Figure 1 fives the half-yearly mean $\overline{R}$ of sunspot relative number, the total number N_{total} of hours per half-year with a noise storm continuum being mainly determined by the weak continua and the half-yearly number of hours with a strong (or even very strong) continuum at the different observing frequencies as a function of time. Whereas there is at least a rough agreement between the time dependence of $\overline{R}$ and N_{total} during cycle No. 20 strong continua significantly differ in the following respect:

- a clearly marked deficit of strong continua especially at 234 and 113 MHz can be pointed out not only for the secondary minimum of solar activity during second half-year of 1969, but for whole the time interval including both the first and second maximum of sunspot relative number, too;
- the occurence of strong continua during a solar cycle obviously depends on the observing frequency. Strong continua at low observing frequencies, especially at 64 MHz preferably appeared during a rather late phase of cycle No. 20. Whereas there was a sharp drop of strong continua at high observing frequencies, especially at 287 MHz after 1971 extremely strong continua at 40 MHz could frequently be observed still during 1972 and

Table 2

The numbers N' of hours with a noise storm continuum per characteristic time interval of cycle No.20 and their estimated normed distribution p=N'(S_{234})/N' to the different values of S_{234} including confidence intervals p_1, p_2 calcuted for an error probability of 5 % (S_{234}: hourly mean value of the flux density of a noise storm continuum at 234 MHz)

Time Interval	N'	S_{234} [s.u.]			p_1 p p_2			
		0	1 - 4	5 - 9	10 - 20	21 - 50	51 - 100	>100
II64-II66	989	.075 0.091 .111	.420 0.451 .482	.193 0.217 .244	.150 0.172 .197	.042 0.056 .071	.005 0.009 .017	.002 0.004 .012
I67-II68	2686	.072 0.082 .093	.340 0.357 .376	.227 0.242 .259	.149 0.162 .177	.100 0.112 .124	.027 0.034 .041	.008 0.011 .016
I69- I70	1868	.095 0.109 .124	.519 0.542 .564	.193 0.210 .229	.075 0.087 .100	.029 0.036 .045	.008 0.012 .018	.002 0.004 .008
II70-II72	2873	.098 0.109 .121	.433 0.451 .469	.177 0.191 .206	.115 0.127 .139	.068 0.078 .088	.026 0.032 .038	.009 0.012 .017
I73- I76	2029	.064 0.075 .087	.513 0.535 .556	.199 0.216 .235	.105 0.119 .134	.033 0.041 .050	.006 0.010 .012	.002 0.003 .007

later on, too. Quite similar tendencies can be stated also for cycle No. 21 (cf. Tab. 5, 6, 7);

- the variation of strong continua during cycle No. 20 suggests to subdivide this cycle into the 5 characteristic time intervals mentioned above: 1: July 1964 - Dec. 1966; 2: Jan. 1967 - Dec. 1968; 3: Jan. 1969 - June 1970; 4: July 1970 - Dec. 1972; 5: Jan. 1973 - June 1976.

b/ A comparison between the normed estimated distributions N'(S_ν)/N' of hours with a noise storm continuum according to their hourly mean S_ν of flux density (N' = $\sum_{S_\nu}$ N'(S_ν): total number of hours with a noise storm continuum per characteristic time interval (cf. Bohme, 1986); ν: observing frequency) confirms the statistical significance of the above-mentioned tendencies (cf. Tab. 1, 2, 3, 4):

- the percentage of hours with a high value of S_{234}, S_{113} or S_{64}, respectively, was definitely lower during interval III than during the neighbouring intervals II and IV. At 287 MHz. however, the "gap" was partially masked by two different effects: The first one consists of the tendency of strong continua at 287 MHz to decrease more rapidly towards the end of the cycle than strong continua at the other observing frequencies. Ad-

Table 3

The number N' of hours with a noise storm continuum per characteristic time interval of cycle No. 20 and their estimater normed distribution $p = N'(S_{113})/N'$ to the different values of S_{113} including confidence intervals p_1, p_2 calculated for an error probability of 5 % (S_{113}: hourly mean value of the flux dencity of a noise storm continuum at 113 MHz)

Time Interval	N'	S_{113} [s.u.]		p_1 p p_2					
		0	1 - 4	5 - 9	10 - 20	21 - 50	51 - 100	101 - 500	>500
II64-II66	985	.433 0.464 .495	.166 0.189 .214	.090 0.108 .129	.080 0.097 .118	.065 0.080 .099	.019 0.027 .040	.024 0.035 .048	.000 0.000 .004
I67-II68	2691	.366 0.384 .402	.249 0.266 .282	.083 0.094 .105	.077 0.087 .099	.053 0.062 .071	.038 0.045 .054	.047 0.055 .065	.005 0.007 .011
I69 -I70	1863	.450 0.472 .495	.237 0.256 .276	.079 0.091 .105	.064 0.075 .083	.054 0.064 .076	.021 0.027 .036	.010 0.014 .020	.000 0.000 .002
II70-II72	2874	.463 0.481 .499	.204 0.219 .234	.066 0.075 .083	.057 0.066 .075	.035 0.041 .049	.044 0.052 .061	.047 0.054 .063	.008 0.011 .016
I73- I76	2011	.334 0.355 .376	.347 0.368 .389	.082 0.094 .108	.058 0.069 .081	.040 0.049 .059	.022 0.029 .037	.024 0.030 .039	.004 0.007 .012

Table 4

The number N' of hours with a noise storm continuum per characteristic time interval of cycle No. 20 and their estimated normed distribution $p=N'(S_{64})/N'$ to the different values of S_{64} including confidence intervals p_1, p_2 calculated for an error probability of 5 % (S_{64}: hourly mean value of the flux density of a noise storm continuum at 64 MHz)

Time Interval	N'	S_{64} [s.u.]		p_1 p p_2				
		0	1 - 9	10 - 19	20 - 50	51 - 100	101 - 500	> 500
II64-II66	988	.712 0.740 .767	.139 0.161 .185	.023 0.032 .045	.030 0.040 .055	.012 0.019 .030	.003 0.007 .015	.000 0.000 .004
I67-II68	2682	.660 0.677 .695	.139 0.152 .166	.059 0.068 .078	.058 0.067 .077	.008 0.011 .016	.015 0.019 .025	.003 0.004 .008
I69- I70	1858	.836 0.852 .868	.030 0.038 .048	.041 0.050 .060	.037 0.046 .056	.006 0.010 .015	.001 0.003 .007	.000 0.002 .005
II70-II72	2861	.775 0.789 .804	.014 0.019 .024	.044 0.051 .059	.056 0.064 .074	.028 0.034 .041	.032 0.038 .046	.002 0.004 .007
I73-II73	709	.899 0.921 .939	.007 0.013 .024	.017 0.027 .041	.012 0.020 .036	.010 0.017 .029	.001 0.003 .010	.000 0.000 .005

ditionally we find hints that the effectivity of the process which led to the deficit of strong continua during interval III increased with decreasing observing frequency at least in the frequency range $\geqslant$ 113 MHz (cf. Böhme, 1986);

- comparing intervals II and IV the percentage of hours with a high value of S_{287} ($S_{287} >$ 20s.u.) is significantly lower for interval IV rather than interval II. This result is at least partially due to the lack of strong continua at 287 MHz in 1972. In contrast to 287 MHz the fraction of hours with a high value of S_{64} was definitely enhanced during interval IV;
- the above-mentioned surplus of hours with $S_{287} >$ 20s.u. during interval II can be shown to be caused in the first place by the noise storm centres at the southern hemisphere though solar activity was less strongly developed at the southern rather than at the northern hemisphere during interval II.

c/ The long-term behaviour especially of strong noise storm continua can mainly be interpreted by a systematic change of radiation signatures of the sunspot groups with the phase of cycle No. 20:

- the flux density of a noise storm continuum increases on the average with

Table 5

Half-yearly mean, maximum und minimum of sunspot relative number ($\bar{R}$, R_{max}, R_{min}), number of sunspot groups G per half-year and the half-yearly number of hours $N(S_{234})$ with a noise storm continuum of mean flux density S_{234} during cycle No. 21

half-year	$\bar{R}$	R_{max}	R_{min}	G	S_{234} [s.u.] 5 9	10 19	20 29	30 49	50 69	70 99	100 199	$\geq$ 200	$\sum N(\ )$ $S_{234} \geq 5$	$\sum N(\ )$ $S_{234} \geq 30$	$\sum N(\ )$ $S_{234} \geq 50$
I 77	20	74	0	65	33	26							59		
II 77	35	75	0	104	50	53	5	3	1				112	4	
I 78	83	158	8	180	140	105	31	38	28	11	1		354	78	40
II 78	102	177	13	242	210	111	30	22	2	13	11	1	400	49	27
I 79	138	226	61	310	165	73	50	25	8	6	9		336	48	23
II 79	$\boxed{173}$	302	84	322	206	89	23	18	7	1			344	26	8
I 80	157	256	36	$\boxed{326}$	168	102	62	67	30	24	17	17	487	155	88
II 80	152	260	53	308	241	100	36	21	10	1	8	6	423	46	25
I 81	128	214	44	286	178	148	44	24	17	7	1	2	421	51	27
II 81	$\boxed{153}$	263	57	$\boxed{321}$	197	126	66	55	23	12	1		480	91	36
I 82	124	258	32	220	278	151	72	78	32	17	15	16	659	158	80
II 82	109	272	19	220	244	152	71	52	24	10	4	1	558	91	39
I 83	79	146	10	176	165	86	41	38	17	3	1		351	59	21

Remark 1: The full lines encircle the ranges of S_{234} with $N(S_{234}) > 10$, the dashed lines those with $N(S_{234}) > 100$;

Remark 2: No radio data were available between November 1-16, 1979

Table 6

Half-yearly mean, maximum und minimum of sunspot relative number ($\bar{R}$, R_{max}, R_{min}), number of sunspot groups G per half-year and the half-yearly number of hours $N(S_{113})$ with a noise storm continuum of mean flux density S_{113} during cycle No. 21

half-year	$\bar{R}$	R_{max}	R_{min}	G	S_{113} [s.u.] 10 19	20 29	30 49	50 69	70 99	100 199	200 499	500 999	≥1000	$\sum_{S_{113}\geq 10} N(\ )$	$\sum_{S_{113}\geq 50} N(\ )$	$\sum_{S_{113}\geq 100} N(\ )$
I 77	20	74	0	65												
II 77	35	75	0	104	22	12	16	3	1					54	4	
I 78	83	158	8	180	60	30	19	18	24	29	12			192	83	41
II 78	102	177	13	242	43	43	33	21	15	3	1	1		160	41	5
I 79	138	226	61	310	55	33	17	21	20	4			2	152	45	6
II 79	$\boxed{173}$	302	84	322	49	18	16	13	4	4	4			108	25	8
I 80	157	256	36	$\boxed{326}$	76	44	39	23	28	15	23	8		256	97	46
II 80	152	260	53	308	76	31	8	10	6	3	12	7		153	38	22
I 81	128	214	44	286	95	25	18	14	14	12	4	1	1	184	46	18
II 81	$\boxed{153}$	263	57	$\boxed{321}$	67	50	55	17	38	18	11	2		258	86	31
I 82	124	258	32	220	87	50	24	16	30	22	12	4		245	84	38
II 82	109	272	19	220	80	49	53	23	18	32	33	2		280	108	67

Remark 1: The full lines encircle the ranges of S_{113} with $N(S_{113}) > 10$, the dashed lines those with $N(S_{113}) > 50$;

Remark 2: The observed flux densities wave not corrected for the contribution of the quiet sun (2-3 s.u.)

Table 7

Half-yearly mean, maximum und minimum of sunspot relative number ($\overline{R}$, R_{max}, R_{min}), number of sunspot groups G per half-year and the half-yearly number of hours $N(S_{64})$ with a noise storm continuum of mean flux density S_{64} during cycle No. 21

half-year	$\overline{R}$	R_{max}	R_{min}	G	S_{64} [s.u.]						$\sum N()$	$\sum N()$
					50 99	100 199	200 499	500 999	1000 1999	≥ 2000	$S_{64} \geq 50$	$S_{64} \geq 200$
I 77	20	74	0	65								
II 77	35	75	0	104	8						8	
I 78	83	158	8	180	15	3					18	
II 78	102	177	13	242								
I 79	138	226	61	310	6	3	1	1			11	2
II 79	$\boxed{173}$	302	84	322	2	3	3				8	3
I 80	157	256	36	$\boxed{326}$	12	14	23		1		50	24
II 80	152	260	53	308	1	7	9	6	6		29	21
I 81	128	214	44	286	20	9	8	4	2	1	44	15
II 81	$\boxed{153}$	263	57	$\boxed{321}$	31	9	50	6	8	4	108	68
I 82	124	258	32	220	4	3	11	4	5	1	28	21
II 82	109	272	19	220	9	11	6	5	4	4	39	19

Table 8

Total number of sunspot groups, number of great sunspot groups and the estimated normed distributions of the latter groups according to their maximum area A_{max} and the Brunnertyp BT_{max} characterizing their highest stage of development for different time intervals of cycle No. 20

			G'(A_{max})/G'(A_{max} 300)					G'(BT_{max})/G'(D-H)		
			A_{max}					BT_{max}		
Time Interval	G'	G'(A_{max} 300)	300 499	500 699	700 1000	1000	G'(D-H)	D	G,H	E,F
166-1168	1170	158	.48	.21	.18	.13	181	.55	.15	.30
169- 170	812	101	.46	.26	.15	.14	127	.48	.20	.32
1170-1172	1089	119	.48	.24	.13	.16	141	.45	.24	.31

G': total number of sunspot groups

G'(A_{max} 300): number of sunspot groups reaching an total area 300 $10^{-6} A_o$ at least on 2 consecutive days during their stay in the longitude range between 45°E and 45°W 1/

G'(A_{max})/G'(A_{max} 300): estimated normed distribution of the above-mentioned sunspot groups according to maximum total area A_{max}($10^{-6} A_o$) to which the sunspot groups came up their stay in the longitude range between 45°E and 45°W 2/

G'(D-H): Number of sunspot groups reaching Brunnertypes between D and H at least on 2 consecutive days during their stay in the longitude range between 45°E and 45°W 3/

G'(BT_{max})/G'(D-H): estimated normed distribution of the above-mentioned sunspot groups according to Brunnertyp BT_{max} characterizing their highest stage of development during their stay in the longitude range between 45°E and 45°W 2/

Remarks:

1/ Unipolar groups reaching areas 300 10^{-6} A_o were omitted from the compilation

2/ Sunspot groups were only classed with an interval of A_{max} or BT_{max} if they remained within this interval at last during 2 consecutive days

3/ Sunspot groups reaching Brunnertyps D 10 were omitted from the compilation

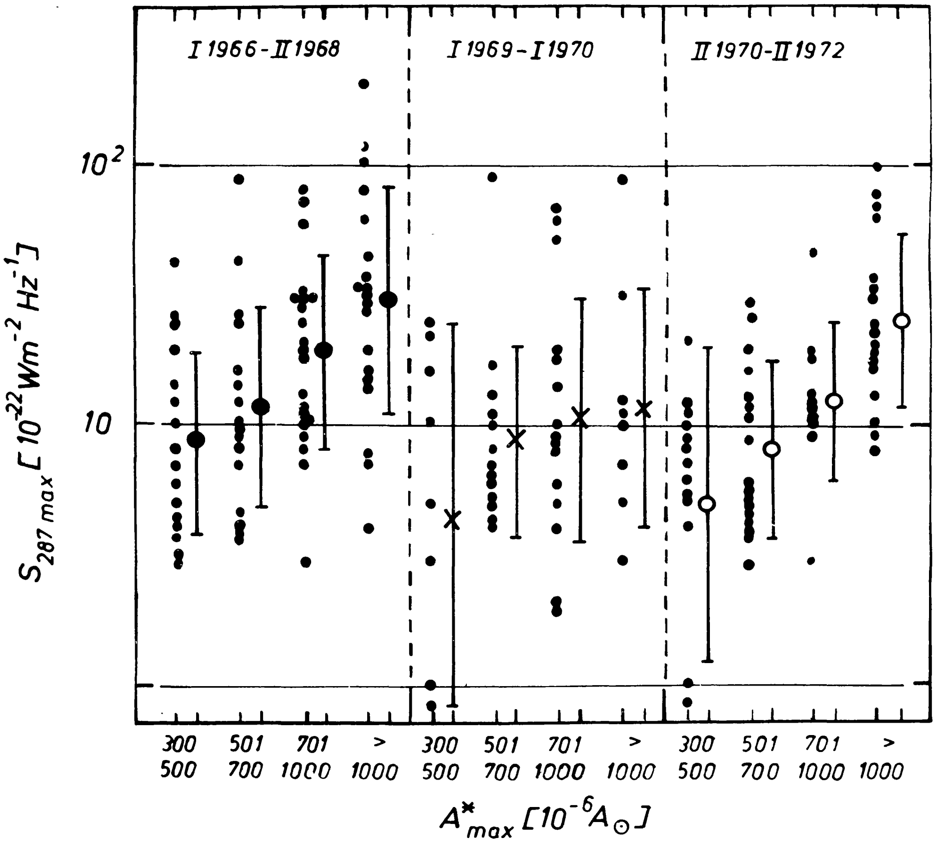

Fig. 2: Comparison between maximum hourly means $S_{287\ max}$ of flux density of 287 MHz reached by the different noise storm centres during time intervals Jan. 1966 - Dec. 1968, Jan. 1969 - June 1970, July 1970 - Dec. 1972 and the maximum areas A_{max} to which the related sunspot groups came up during the "visibility" of the noise storm centres.

increasing area of the related sunspot group, too. Comparing two time intervals a lower fraction of hours with high value of S has consequently to be expected for the interval which has the lower percentage of highly developed sunspot groups relative to the total number of sunspot groups being potentially able to emit a noise storm continuum. It can be shown, however, that the low percentage of strong continua stated for interval III cannot be explained in this manner. Table 8 gives the estimated normed distributions of great sunspot groups according to their maximum area A_{max} reached by the groups during their stay between 45°E and 45°W for time intervals II (including sunspot groups from 1966), III and IV, respectively. The distributions had been normed to the total number of sun-

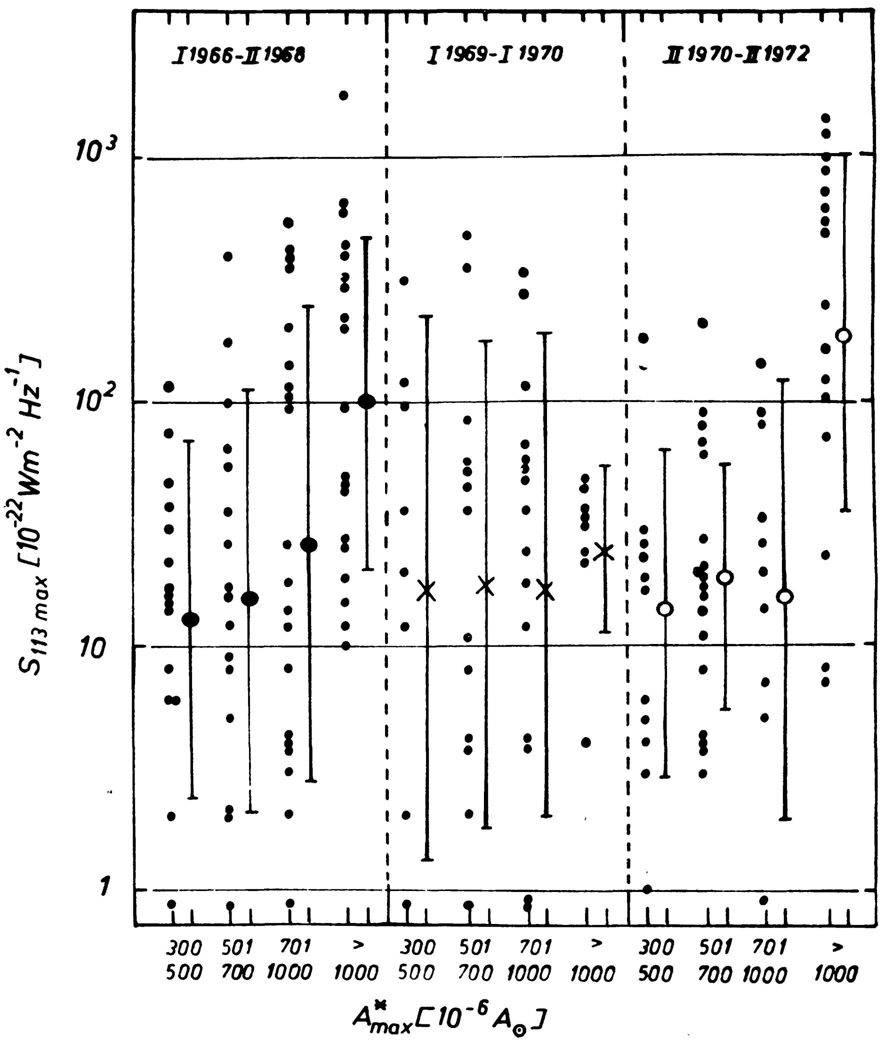

Fig. 3: Comparison between maximum hourly means $S_{113\ max}$ of flux density at 113 MHz reached by the different noise storm centres during time intervals Jan. 1966 - Dec. 1968, Jan. 1969 - June 1970, July 1970 - Dec. 1972 and the maximum areas A_{max} to which the related sunspot groups came up during the "visibility" of the noise storm centres.

spot groups per time interval reaching an maximum area $300.10^{-6}A_0$ because the continua treated in the present investigation were emitted by sunspot groups with an area $300.10^{-6}A_0$ with a few exceptions only. A similar distribution according to Brunnertype is given in Table 8, too. It clearly results from Table 8 that there is no difference between the normed estimated distributions calculated for the time intervals mentioned above. A reduced emissivity consequently has to be assumed for sunspot groups of interval III to explain its deficit of strong continua. This assumption can directly be verified, too. A comparison between the maximum values of S_{287} reached by the different noise storm centres and the maximum areas A_{max} to which the related sunspot groups came up during the "visibility" of the continua clearly suggests that the emissivity especially of very great sunspot groups (A_{max} $1000.10^{-6}A_o$) was definitely diminueshed during interval III as against both the other intervals (cf. Fig. 2). A similar result was obtained at 113 MHz, too (cf. Fig. 3). These findings agree quite well with the long-term behaviour pointed out by Korolev (1973). Future model calculations have to clarify whether or not this change of emissivity is connected with the general decrease of electron temperature in the corona during the midth of a solar cycle (Gnevyshev, 1977);

- comparing intervals II and IV the excess of hours with S_{287} 20s.u. stated for interval II is predominantly caused by the noise storm centres at the southern hemisphere. The areas of the noise storm emitting sunspot groups remained definitely lower at the southern rather than at the northern hemisphere during interval II. It can be shown, however, that sunspot groups observed at the southern hemisphere during interval II were able to emit continua being significantly stronger at 287 MHz than those coming from comparable sunspot groups at the northern hemisphere and than those coming from comparable sunspot groups during interval IV, too. These differences of radiation signatures can probably be interpreted by differences between the structure of the closed magnetic configurations developing above sunspot groups with fixed value of total area;
- comparing intervals II and IV the surplus of strong continua at low observing frequencies stated for interval IV cannot be explained by an excess of very great sunspot groups during this late phase of the cycle but by a change of radiation signatures, too. Sunspot groups of interval IV were able to emit continua being significantly stronger at 64 MHz than those coming from the comparable sunspot groups of interval II. This result suggests an increase of height extension of the closed magnetic configurations above sunspot groups with fixed value of total area with increasing phase of cycle No. 20 or at least between the time intervals II and IV.

Summarizing these results it can be expected that long-term behaviour of noise storm continua will be a valuable tool in future to study long-term variations of the structure of closed magnetic configurations above great sunspot groups.

REFERENCES

Böhme, A.: 1986, Dissertation B, AdW der DDR, Berlin

Gnevyshev, M.N.: 1977, Solar Phys. 51, 175

Korolov, O.S.: 1973, Astron. Ž. 50, 817

Šuk, J.: 1979, Bull. Astron. Inst. Czechosl. 30, 274

Tlamicha, A., Křivský, L., Olmr, J.: 1964, Bull. Astron. Inst. Czechosl. 15, 133