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On the Solar Cycle Dependence of Dm-type III Burst Polarization Characteristics

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Polarization characteristics of more than 2000 type III bursts observed at 23.5 and 29.5 MHz during the period 1961–1971 have been analysed statistically. According to this material the cyclic variations of the degree of type III burst polarization p and of the ratio of linear and circular polarization p_l/p_c, if really existing, appear not properly to be in phase with the eleven-year solar cycle which, in principle, can be explained by suitably assumed coronal and magnetic field variations above active regions.
There are indicated cyclic variations of the centre-limb variation of the degree of type III burst polarization p which must be confirmed by further measurements. The remarkable maxima of p at about 30–40° heliographic longitude originally detected by Fomichev and Chertok for the declining phase of cycle No. 19 now appear reversed during the ascending phase of cycle No. 20. Such variation is theoretically expected from variations of the content of first and second harmonic type III burst emission as well as by variations of the critical levels of the electromagnetic wave modes in the solar corona.

Polarisationsmessungen von mehr als 2000 Typ III-Bursts auf den Frequenzen 23.5 und 29.5 MHz der Jahre 1961–1971 wurden statistisch untersucht. Nach dem vorliegenden Material erscheinen Zyklus-Variationen des Polarisationsgrades p und des Verhältnisses von linearer zu zirkularer Polarisation p_l/p_c – falls reell vorhanden – nicht in Phase mit dem 11jährigen Sonnenfleckenzyklus, was prinzipiell durch koronale Magnetfeldvariationen über aktiven Regionen erklärt werden könnte.
Es sind weiterhin Zyklus-Variationen der Mitte-Rand-Variation des Polarisationsgrades p der Typ III-Bursts angedeutet, die einer genaueren Bestätigung durch längere Meßreihen bedürfen. Die ursprünglich von Fomichev und Chertok in der abklingenden Phase des vorigen Sonnenfleckenzyklus festgestellten Maxima von p bei ca. 30–40° heliographischer Länge erscheinen in der ansteigenden Phase des gegenwärtigen Fleckenzyklus umgekehrt. Derartige Variationen ließen sich theoretisch sowohl durch Variationen des Verhältnisses der Emission von erster zu zweiter Harmonischen als auch durch Variationen der Höhe der kritischen Niveaus der Korona für die elektromagnetischen Wellenmoden durch Dichtevariationen erklären.

1. Introduction

Concerning the investigation of parameters connected with phenomena of solar activity the question of possible dependences on the phase of the solar cycle is of special interest. The present paper deals with a consideration of polarization characteristics of decametre type III bursts from this point of view. Results on this topic were hitherto missing in the literature.

The study is based on polarization measurements at 23.5 and 29.5 MHz obtained at the Heinrich-Hertz-Institute (HHI) during the period 1961–1971 (the data are published by Daene et al., 1965 and 1970 [6], [7]). The period under consideration covers four characteristic phases

- the declining phase of cycle no. 19 (1961–1963),
- the solar minimum and ascending part of cycle no. 20 (1964–1966),
- the maximum phase of cycle no. 20 (1967–1968),
- the declining phase of cycle no. 20 (1969–1971).

The analysis comprises the total degree of polarization

$$p = (p_l^2 + p_c^2)^{1/2}$$

as well as the degrees of linear and circular polarization, p_l and p_c, separately. The equipments were described by Daene and Voigt [6]. A brief summary of the most important instrumental parameters is contained in Tab. 1.

Table 1. Characteristics of HHI decam polarization observations

Observing frequency [MHz]	Receiver bandwidth [kHz]	Observed Stokes parameter	Start of daily observations flux	polarization
23.5	1.5	4	June 1957	June 1961
29.5	8	4	May 1960	March 1965

2. Long-term variation of the degree of polarization of type III bursts

Fig. 1 shows the variation of yearly mean values of the degree of polarization p of type III bursts at 23.5 MHz for the period 1961—1971 based on a total of more than 2000 major type III bursts and groups. For the years 1964—1965 only one mean value has been derived because of the small number of bursts during the solar minimum (26 and 55 bursts, respectively). For comparison yearly means of the Zürich definitive sunspot numbers are shown in Fig. 1. It is interesting to note that the average degree of type III burst polarization does not decrease with decreasing solar activity according to these measurements. However, the maximum value of 31 per cent is not reached during the solar minimum but during the phase of increase of activity of the new solar cycle (1966). During the following solar maximum (1967—1968) again the degree of type III burst polarization decreases up to about 20 per cent. After this period another increase of p can be stated.

Comparisons with measurements of a smaller number of type III bursts at 25.3 MHz during the years 1966—1968 reported by Chin et al. [4] do not show a good accordance to the observations presented here. Unfortunately also the period of observation at 29.5 MHz is too short for drawing reliable conclusions on cyclic variations at this frequency (Fig. 1). Taking into account that some details of the variations of p at 29.5 MHz, so far as observed, appear somewhat different from those at 23.5 MHz, the question of existence and character of cyclic variations of the degree of Dm-type III burst polarization, in spite of the relatively low standard deviations, seems not yet clearly solved experimentally.

Now we consider theoretically some possible influences of variations of physical parameters determined by solar activity on type III burst polarization data. At first we state that regarding the relation to different photospheric properties (e.g. area of the largest spot, magnetic spot type) apparently no essential changes during the solar cycle have been found (cf. Fig. 2). Therefore it may be concluded that cyclic dependencies of p, if they exist, must be the consequence of variations of solar parameters in greater than photospheric heights, e.g. the corona. As the essential factor potentially influencing the type III burst polarization the electron density must be considered.

It is well known that the electron density in the equatorial plane during the solar maximum is 2—4 times larger than during the minimum (Newkirk [20]). Similar variations are present for the polar regions and the whole solar sphere, and in particular above active regions. Such density variations are expressed also by several radio phenomena, e.g. variations of the starting frequencies of type III bursts, some variations of relations to noise storms (Korolev [15]), a variation of the basic component of solar radio emission (Krüger and Olmr [17]), and other phenomena.

Correspondingly, one can try to explain cyclic dependencies of the polarization characteristics of type III bursts by density variations: In the declining phase of solar activity a decrease of the electron density can be assumed and consequently deeper emission levels of the type III bursts at a fixed frequency are to be expected. Assuming greater magnetic fields in these levels and a positive relationship between H and p, an increase of p would be observed (cf. Chertok et al. [3]). In this way it could be quite possible, that for bursts originating in weak active regions ($S \leqq 200 \cdot 10^{-6} F_{\odot}$) the maximum value of p is exactly reached during the minimum period of solar activity (cf. Fig. 2). Larger active regions ($S > 200 \cdot 10^{-6} F_{\odot}$) practically do not occur during the minimum period but in the rising phase of the solar cycle. In this latter period the electron density must be assumed to be still sufficiently low in order to obtain higher degrees of polarization (Fig. 1).

For demonstration some estimations should be made: Assuming a distribution of the magnetic field in type III burst originating regions as $H \approx (\varrho - 1)^{-m}$ where $m \sim 1 \cdots 1.2$ (cf. Fomichev et al. [14]; Krüger et al. [16]) (ϱ = heliocentric distance), and in the solar maximum $\varrho_{\max} \approx 2.2$ for 23.5 MHz,

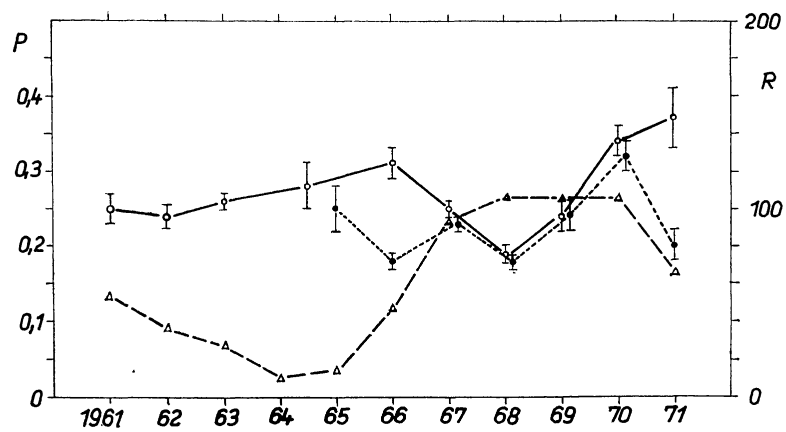

Fig. 1. Yearly means of type III burst polarization (○ 23.5 MHz, ● 29.5 MHz) and of Zürich sunspot numbers (△).

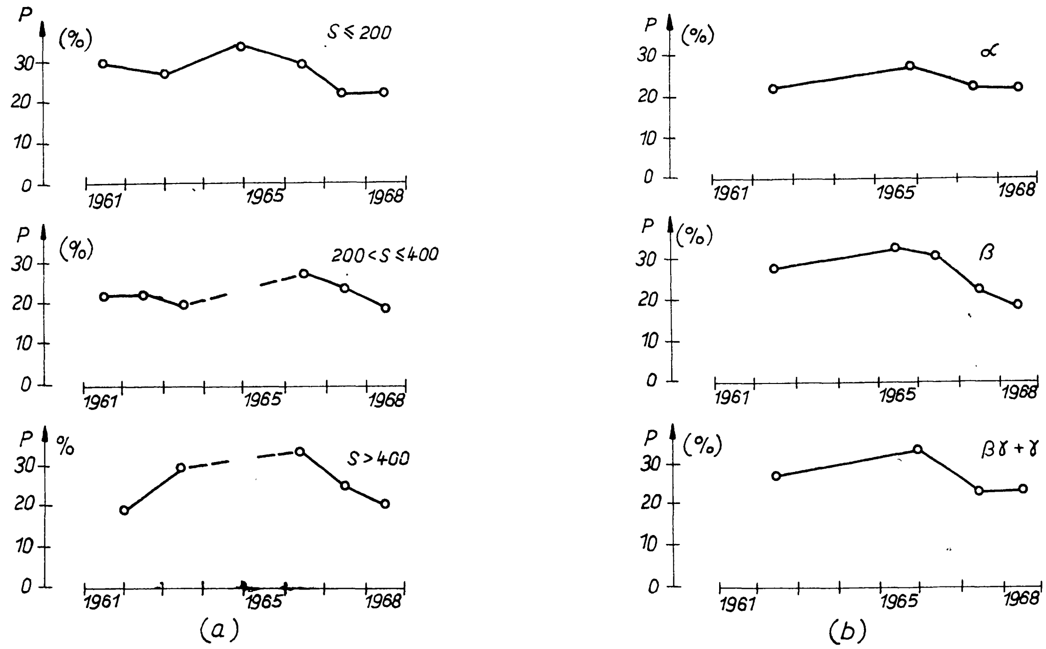

Fig. 2. Solar cycle dependency of p (23.5 MHz) for active regions corresponding to different S-values (a) and different magnetic classes (b).

and $p \sim H$, the observed variations of p with a factor 1.5 would demand, that the minimum emission height of 23-MHz type III bursts would be $\varrho_{\min} \approx 1.3$. Let us assume further that the height distribution of the electron density is $N = k \cdot 10^{4.32/\varrho}$, corresponding to the model of NEWKIRK [19], and the variation of N during the solar cycle consists only in a variation of the coefficient k, then for the above stated height variation of the type III burst emitting levels at the considered frequency of 23.5 MHz there follows a variation of $k_{\max}/k_{\min} \approx 3$.

3. Variations of the ratio of linear and circular polarization

The relatively large content of linear polarization is a characteristic property of type III radio bursts. This property includes the principal possibility of the Faraday effect. In order to check its influence on the measurements in Fig. 3 there are plotted all 23.5 MHz type III bursts of the period 1961–1968 in a p–r diagram (r = axial ratio of the polarization ellipse) according to AKABANE and COHEN [1]. From Fig. 3 it can be assumed that the effect of the Faraday rotation on the axial ratio

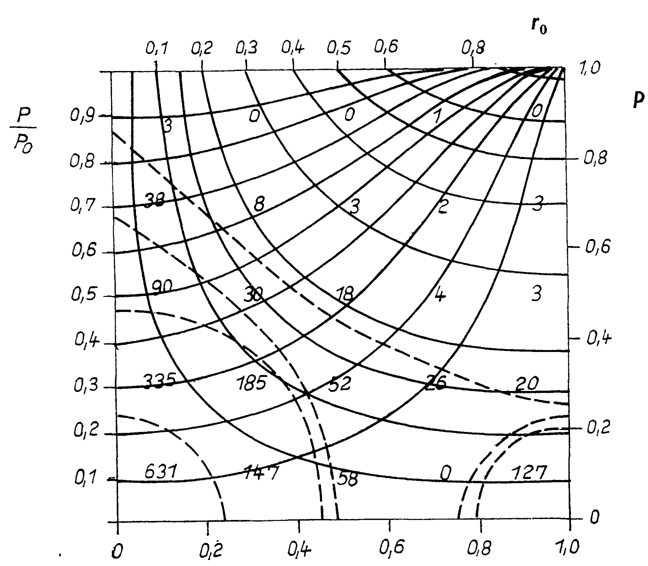

Fig. 3. p over r for 1787 type III bursts at 23.5 MHz during the years 1961–68. Dotted lines indicate the burst frequency. Solid lines denote Faraday depolarization curves according to AKABANE and COHEN (1961).

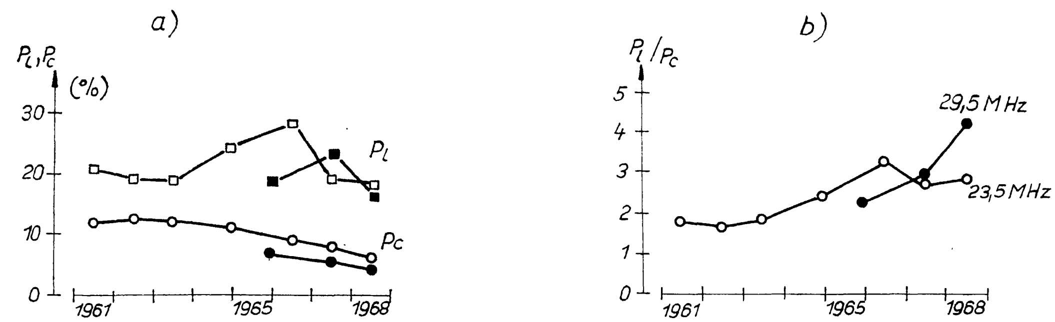

Fig. 4. Yearly means of p_e and p_c (a) and p_e/p_c (b) for type III bursts at 23.5 MHz (○, □) and 29.5 MHz (●, ■).

on the average should be less than about 40 per cent. Therefore the relative composition of p_c and p_l within this order of magnitude is not very strongly affected by the Faraday effect. Another source of error may be caused by instrumental polarization, however in comparison with records of other strongly (circularly) polarized burst types it is indicated that the observed high contribution of linear polarization has a real solar background.

Now Fig. 4 shows the variation of p_c and p_l at 23.5 and 29.5 MHz. It is to note that

- the variation of p_l determines the variation of p (cf. Fig. 1) at both frequencies,
- p_c varies only little with time (it cannot be decided here, to what extent a weak monotonic decrease of p_c is real or not),
- p_l is always greater than p_c, the ratio p_l/p_c varies similarly as p_l.

One possible interpretation could be the following: If predominantly one electromagnetic wave mode escapes from the source region, the action of the Faraday effect in fact should be very limited. An electromagnetic mode transformation would occur in QT-regions (Cohen [5]). According to Zheleznyakov and Zlotnik [23] the polarization ratio of the radiation leaving such a region is

$$\frac{p_l}{p_c} = 2\,e^{-\delta_0}\,\frac{\sqrt{1 - e^{-2\delta_0}}}{2\,e^{-2\delta_0} - 1}$$

where

$$\delta_0 = \left(\frac{\nu_t}{\nu}\right)^4 \ln 2$$

and

$$\nu_t = \left[2 \cdot 10^{17}\,\frac{N H^3}{d\theta/dz}\right]^{1/4}\ [\text{Hz}]\,.$$

Thus magnitude and orientation of p_c and p_l depend on ν and ν_t. With the exception of unpolarized or fully circularily polarized burst emission one gets from observations of the ratio p_l/p_c informations about the magnetic field H in the coupling region. For this purpose, analogously to the treatment of Fomichev and Chertok [11] curves of the parameter $(N H^3 \cdot |d\theta/dz|^{-1})$ over the resulting ratio p_l/p_c for the case $\nu_t < \nu$ for 23.5 and 29.5 MHz are shown in Fig. 5. From this, basing on the condition of

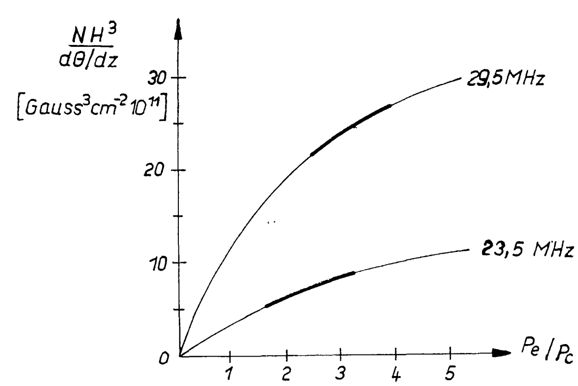

Fig. 5. Values of the parameter $NH^3\,|d\theta/dz|^{-1}$ over p_l/p_c for 23.5 and 29.5 MHz in the case $\nu_t < \nu$.

small Faraday effect $2\,\nu^{-1}\,\Delta\chi\,\Delta\nu < 1$ with $|\mathrm{d}\theta/\mathrm{d}z|^{-1} \sim 5 \cdot 10^{10}$ cm (cf. FOMICHEV and CHERTOK [11]) the following values of N and H in the transition region could be obtained:

for 23 5 MHz: $H \approx 3 \cdot 10^{-2}$ Gauss, $N \approx 4 \cdot 10^{5}\ \mathrm{cm}^{-3}$,
for 29.5 MHz: $H \approx 3.5 \cdot 10^{-2}$ Gauss, $N \approx 8 \cdot 10^{5}\ \mathrm{cm}^{-3}$.

These combinations of parameters are expected to exist in heights of about $2-2.5\ R_\odot$ above central parts of active regions or correspondingly at deeper levels above outer parts of active regions. Hence cyclic variations, especially of the electron density, could principally cause cyclic variations of the observed polarization ratio. But it must be mentioned that up to now it is not clear, whether the rays of type III bursts on their way to the observer are passing QT-regions ore not.

4. Cyclic variations of the centre-limb variation of the degree of type III burst polarization

A longitudinal dependence of the degree p of type III burst polarization was first stated by FOMICHEV and CHERTOK [10]. Other authors basing on smaller statistical materials did not find any centre-limb variations of p (ENOME [8]; CHIN et al. [4]). However, CHIN et al. stated a longitudinal dependence of the mean axial ratio of the type III burst polarization at 25.3 MHz which, considering the average relation between r and p (cf. Fig. 3), should indicate also a longitudinal dependence (inverse to r) of p. In the following it will be demonstrated, that the observed longitudinal distribution of the type III burst polarization is not constant with time but possibly exhibits cyclic variations.

4.1 Theoretical considerations

If we infer that the polarization of type III bursts at the basic (plasma) frequency is determined by the relation between the height difference Δh_θ of the cutoff levels of the ordinary and extraordinary electromagnetic wave modes and the radial extension of the source, the part of the radiation emitted in direction to the observer between these levels changes with heliographic longitude θ, and hence changes of the observed degree of polarization should result.

With increasing angular distance of the source from the central meridian the critical levels of the ordinary and extraordinary wave modes rise above the levels $X = 1$ and $X = 1 - Y$ and their distance Δh_θ decreases (Fig. 6a). Extraordinary radio waves originating in deeper parts of the source region cannot leave the sun because of the effect of refraction. The form of the resulting distribution of $\Delta h_\theta/h_\theta$ depends on those of h_θ and Δh_θ. A possible example is shown in Fig. 6b which demonstrates an essential influence of the refraction effect. For other model cases with smaller influence of the refraction weaker θ-dependencies would result.

It should be noted, that the effect of the difference between the optical depths of the ordinary and extraordinary waves on the basic frequency of Dm-type III bursts is negligible which is due to the small electron-ion collision frequency in this region. For the same reason the polarization of the second harmonic of Dm-type III bursts, which is due to the difference of absorption of the ordinary and extraordinary wave modes propagating towards the sun and then being reflected in direction to the earth, is practically zero (cf. FOMICHEV and CHERTOK [14]). Calculations show that even for relatively high magnetic fields the degree of polarization at 20—30 MHz does not exceed 10 per cent. Therefore the characteristics of both harmonics must be taken for a consideration of longitudinal dependencies of type III bursts.

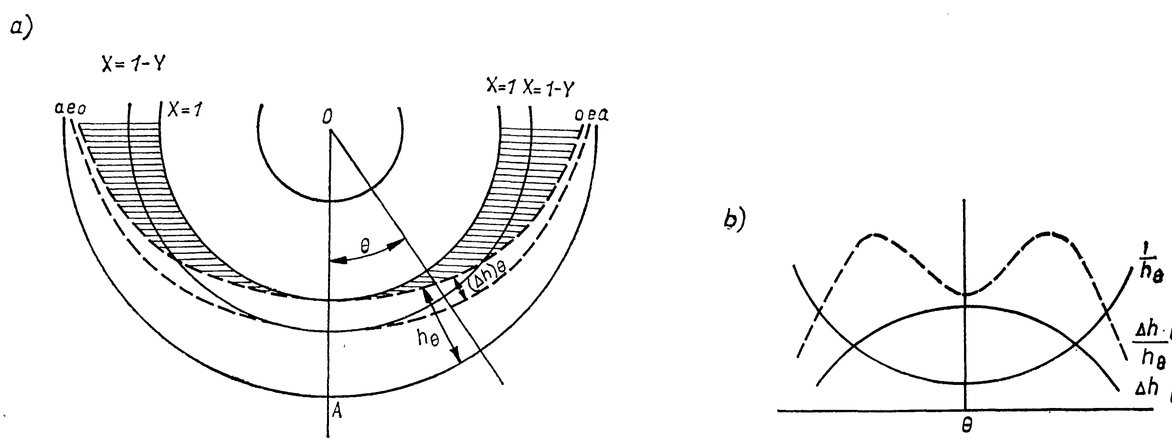

Fig. 6a. Critical levels of electromagnetic e- and o-modes in dependence of heliographic longitude θ.
Fig. 6b. Qualitative θ-dependency of the distance Δh_θ between the ordinary and extraordinary wave mode levels, the source height h_θ and the ratio $\Delta h_\theta/h_\theta$.

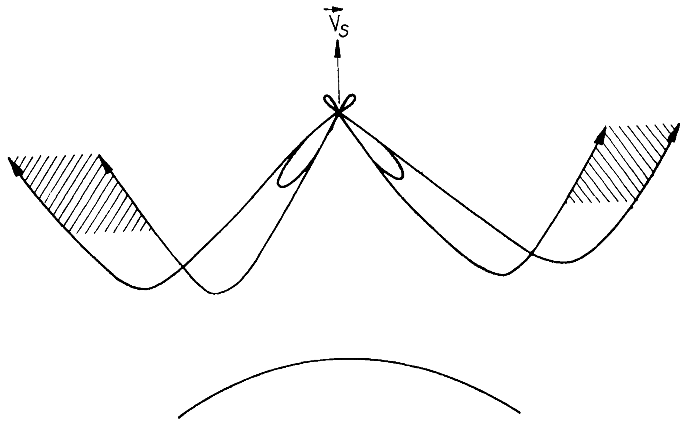

Fig. 7. Directivity of the second harmonics of type III bursts (cf. ZHELEZNYAKOV and ZAITSEV [22].)

Observations of WILD et al. [21] indicated a relative increase of type III harmonic emissions with increasing central meridian distance, i.e. the radiation of the first harmonic is visible on the whole solar disk while the emission of the second harmonic is observable only at favourable central meridian distances.

Such longitudinal selective effects occur also by the action of the combination scattering process of the generation of the second harmonic. At $2\,\omega_p$ the directivity diagram has two wings towards the sun symmetrically to the exciter speed direction (Fig. 7, cf. ZHELEZNYAKOV and ZAITSEV [22]). Thus the radiation escapes from the sun at angles different from the direction (e.g. assumed radial) of the exciting agent of the type III bursts (FOMICHEV and CHERTOK [13]).

Consequently, at larger heliographic longitudes the degree of type III burst polarization can decrease because of the weak polarization of the second harmonic. In this way the degree of type III burst polarization and its longitudinal variation is determined by several effects which are related to the first as well as to the second harmonic.

4.2 Observational results

The present investigation is based on such type III bursts which were associated with flares of known heliographic position or cases assumed to belong to certain active regions on days, when only one active region was present on the visible hemisphere of the sun. Corresponding to these data the mean values of p of type III bursts in 20-degree intervals of related photospheric longitudes have been derived and plotted in Fig. 8—11. From these plots the following tendencies are to be stated:

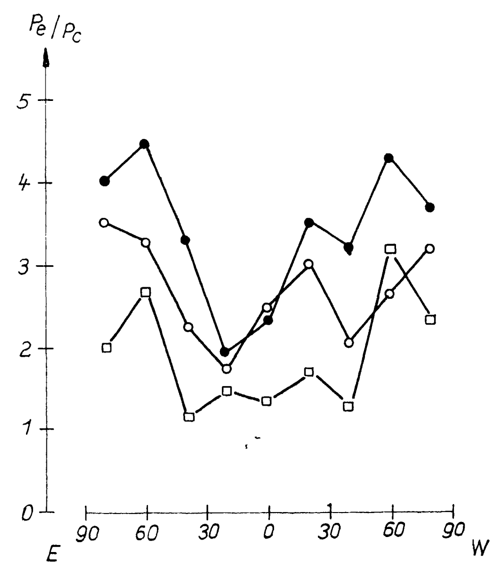

Fig. 8. Distribution of the ratio p_l/p_c over heliographic longitudes (□ — 1961…63, 23.5 MHz, ○ — 1964…68, 23.5 MHz, ● — 1965…68, 29.5 MHz).

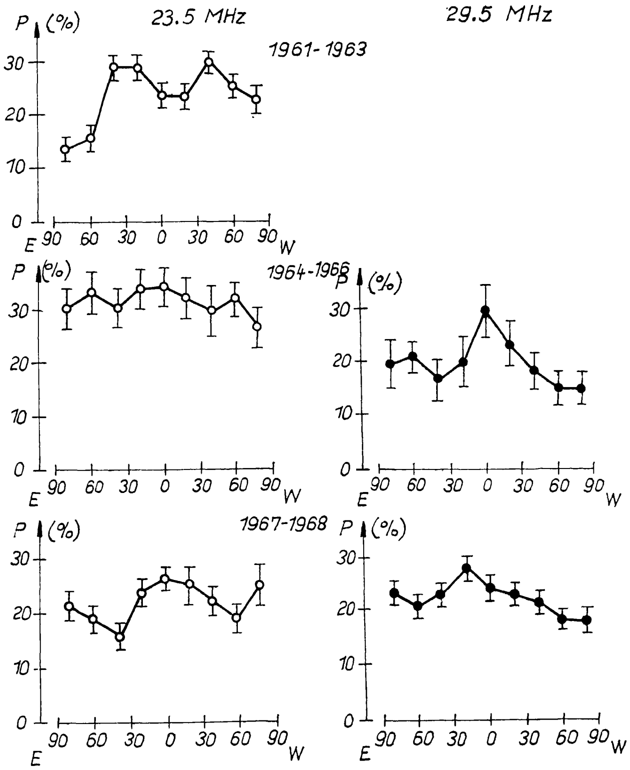

Fig. 9. θ-Dependency of p for different phases in the solar cycle.

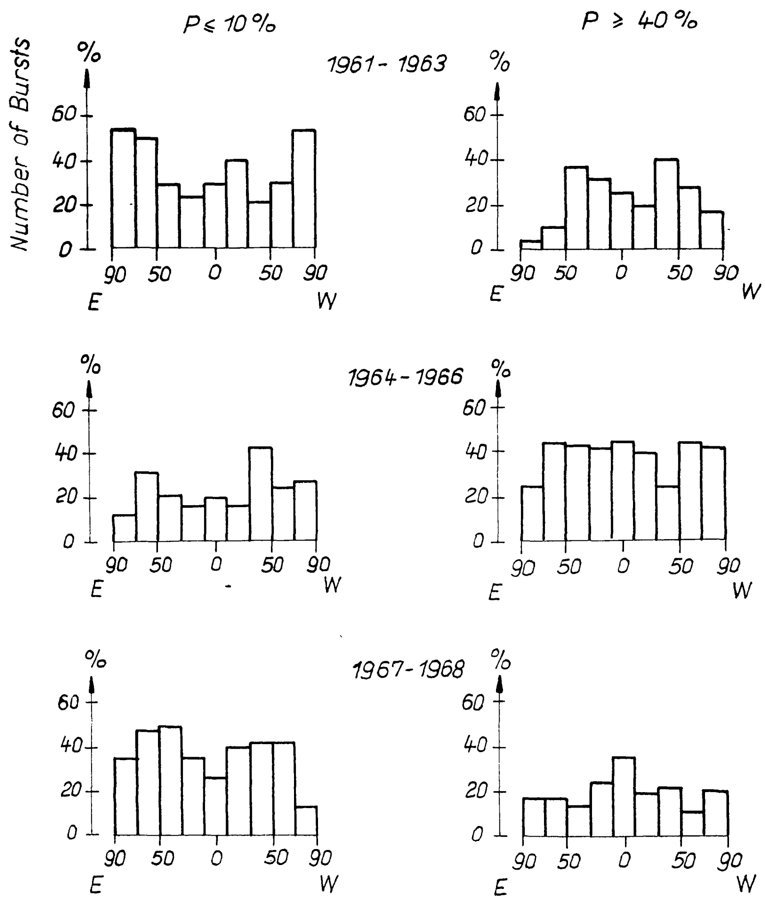

Fig. 10. Heliographic longitude distribution of type III bursts at 23.5 MHz of weak ($p \leqq 10\%$) and strong ($p \geqq 40\%$) polarization for different periods.

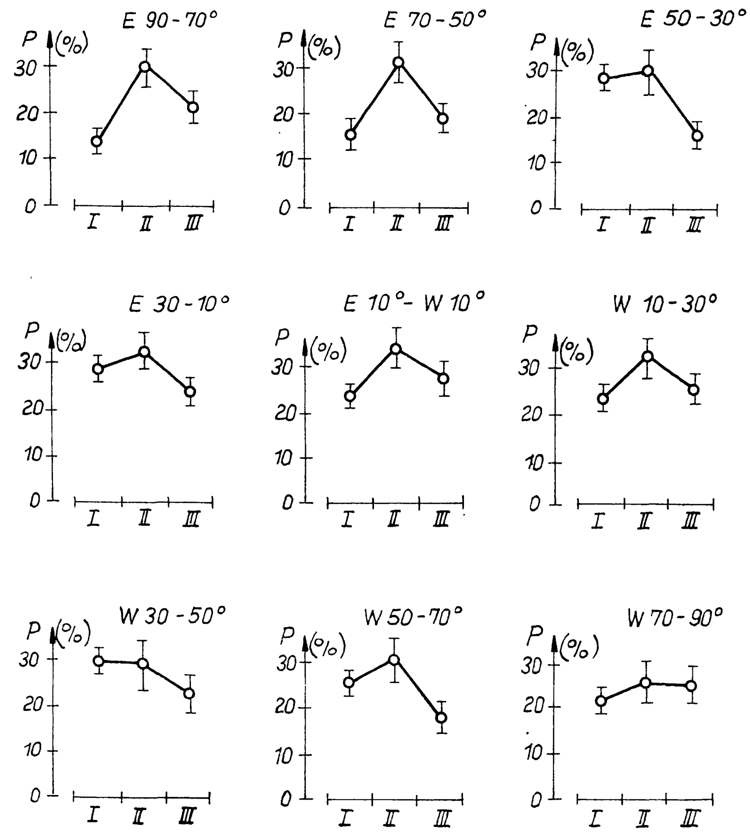

Fig. 11. Solar cycle variation of the degree of polarization at 23.5 MHz for different intervals of heliographic longitude. I — 1961…1963; II — 1964…1966; III — 1967…1968.

a) During the declining phase of the past solar cycle at 23.5 MHz two maxima of p near $\theta \sim 30-40°$ were indicated (cf. FOMICHEV and CHERTOK [11]). The number of weakly polarized bursts increased towards the solar limb.
b) With the begin of the new solar cycle this picture of θ-dependency changed rapidly. After a transition period the form of the longitudinal dependence of p was reversed during the solar maximum 1967—68. The maximum values of p were situated near the central meridian and at middle longitudes ($\theta \approx 30\cdots60°$) minima of p occurred. Fig. 11 shows, that the main effect was set up by the distribution of weak polarized bursts ($p \approx 10$ per cent).
c) The variation of the magnitude of p varies according to the already discussed general tendencies.
d) Though fairly in accordance, the above stated tendencies are better expressed at 23.5 than at 29.5 MHz.

5. Conclusions

The main extract of the present discussion of the polarization properties of Dm-type III bursts can be summarized as follows. Long-term variations of the degree of type III bursts polarization and its longitudinal dependency are indicated but an experimental verification by observations of other stations appears yet missing.

Theoretically the discussion on generation and variations of type III burst polarization characteristics must contain different considerations for the emissions at both, the first and second harmonic of the electron plasma frequency. Regarding the first harmonic it has been proposed that independently of its original state of polarization, under the action of an external magnetic field the escaping conditions are favourable only for the ordinary electromagnetic wave mode. Different ratios of N and H are generally capable to modify the escape conditions and herewith the polarization properties.

For an interpretation of the dependency of the degree of type III burst polarization on heliographic longitude the following possibilities have been taken into consideration:

a) a longitude dependency of the ratio $\Delta h_\theta / h_\theta$ between the difference of the critical levels of both electromagnetic wave modes and the source height of the type III burst emission (Fig. 6) and
b) the directional emission diagram of the second harmonic preferring emissions into angles corresponding to middle heliographic longitudes.

Hence cyclic variations of $p(\theta)$ indicate changes of the wave propagation conditions caused by density and magnetic field variations during the solar cycle and the shift of heliographic latitudes of the active regions in the period of the transition from one solar cycle to the other. The latter effect is expected, beyond others, leading to a shift of the longitude zone exhibiting the relatively weak polarized second harmonic emission towards the central meridian.

A possible effect of asymmetry of the dependency $p(\theta)$ could be connected with an asymmetrical structure of the active regions as well in longitudinal as in latitudinal direction.

It should be stressed out that due to the strong influence of refraction the character of the discussed polarization dependencies is expected to depend on the frequency so that the decameter and meter regions could exhibit different results.

In summary, the present work is in favour of an existence of cyclic variations of the polarization characteristics of solar type III bursts. There are possible explanations of these effects depending on variations of solar plasma parameters (electron density, magnetic fields, geometrical configuration). A more detailed study on this topic seems worthwhile if further observational evidence basing on reliable measurements of one or more solar cycles will be available.

Acknowledgements

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