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THE MODE-SWITCHING PHENOMENON IN PULSARS

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ABSTRACT

We report on a multifrequency, full polarization analysis of the two classical mode-switching pulsars PSR 0329+54 and PSR 1237+25 and compare properties of all known mode-switchers.

Simultaneous observations of PSR 0329+54 at 1.4 and 9.0 GHz show that the switch between modes is broad-band as it occurs simultaneously at both frequencies. During a switch, components in the profile alter their longitudinal positions so that the total pulse width is reduced. The spectra measured at the peak of different pulse components have only slightly different spectral indices in the normal mode. The pulse component spectra steepen or flatten when the pulsar switches to the abnormal mode, so that abnormal pulse profile shapes tend to be more frequency dependent than normal ones. All polarization properties, i.e. linear and circular polarization percentage and the polarization position angle sweep, are affected by a mode change; furthermore, the periodic intensity fluctuation from pulse to pulse, also known as the drifting subpulse phenomenon, changes its behavior dramatically from one mode to the other.

We interpret the mode-switching phenomenon as a change in the inhomogeneous chemical composition and/or structure of the pulsar surface followed by an alteration of the electrostatic conditions in the polar cap region above the surface, which leads to a different distribution of the particles in the magnetosphere. In the abnormal mode, the average plasma flow rate is apparently reduced so that radio emission is observed from lower levels in the magnetosphere. A high plasma flow rate, on the other hand, may be associated with nulls leading to overheating or changes in the composition of the pulsar surface.

Subject headings: pulsars — stars: pulsation

I. INTRODUCTION

While consecutive single pulses are very often strongly modulated in their intensity, a pulsar's average profile is in general time stable within the limits which are given by the signal to noise ratio and the number of pulses involved in the averaging process (Helfand, Manchester, and Taylor 1975). The profile is a characteristic feature of each individual pulsar and is generally considered to be determined by the geometry of the emission zone where it intersects with the line of sight.

Soon after the discovery of pulsars, however, two cases were found which showed a striking deviation from the usual behavior. PSR 1237+25 (Backer 1970) and PSR 0329+54 (Lyne 1971; Wielebinski *et al.* 1972; Hesse 1973) change their average profile sporadically by an amount much greater than is expected from the statistical variations. The pulse profile assumes an "abnormal shape" for some 10 to some 10,000 pulsar periods and then switches back to the "normal mode." Like the normal shape the abnormal shape is also stationary; however, more than one abnormal mode exists in the case of PSR 0329+54 (Hesse 1973). Recently four new mode-switchers were found: PSR 0355+54 (Morris *et al.* 1980), PSR 1822−09 (Morris, Graham, and Bartel 1981), PSR 1926+18 (Ferguson *et al.* 1981) and PSR 2319+60 (Wright and Fowler 1981*a*). Furthermore Wright and Fowler (1981*b*) have demonstrated that PSR 0031−07 also shows mode changes associated with the well known series of A, B, and C drift bands, so that the total number of known mode-switching pulsars is currently seven. A statistical analysis by Helfand, Manchester, and Taylor (1975) revealed the possible existence of two more mode-switchers, PSR 1133+16 and PSR 2045−16, although their behavior is not as clear as in the case of the above mentioned seven pulsars.

Not just the average pulse profile is affected during a mode switch, but also the single pulse behavior. The periodic subpulse fluctuation in PSR 1237+25 (Taylor, Manchester, and Huguenin 1975), PSR 1822−09 (Fowler, Wright, and Morris 1981) and PSR 2319+60 (Wright and Fowler 1981*a*), which is also termed "subpulse drifting," changes abruptly when a mode switch

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TABLE 1

ANTENNA AND RECEIVER CHARACTERISTICS

Antenna	Observing Frequency (GHz)	Conversion Factor (KJy^{-1})	System Temperature (K)	Recorded Polarization
Effelsberg				
(100 m) ...	0.83	1.4	500	Linear
	1.4	1.4	80	Circular
	1.7	1.4	70	4 Stokes parameters
	2.7	1.4	100	4 Stokes parameters
	5.0	1.3	70	Linear
	9.0	1.2	90	4 Stokes parameters
Stockert				
(25 m)	1.4	0.09	70	Circular
Arecibo				
(305 m) ...	0.43	14	140	4 Stokes parameters

occurs. We shall show that PSR 0329+54 behaves similarly, indicating that the drifting and mode-switching phenomena are also closely related in this pulsar.

Despite the fact that the mode-switching phenomenon has such an important effect on pulse emission, no elaborated theory as yet exists as to how to interpret it. The purpose of this paper is to present new results on the classical mode-switching pulsars PSR 0329+54 and PSR 1237+25 and to compare common properties of all mode-switchers so that a possible interpretation of the phenomenon can be investigated.

II. OBSERVATIONS

The observations were made with the 100 m telescope[5] in Effelsberg and the 25 m Stockert telescope[5,6] near Bad Münstereifel, West Germany, in the years between 1975 and 1979, and with the 305 m Arecibo telescope[7] in 1972 and 1977. Part of the observations were performed simultaneously with the 100 m and 25 m telescopes. The technical properties of the antennas and the receivers are summarized in Table 1.

After detection the signal was sampled, typically at intervals of 3×10^{-4} periods, but always at intervals comparable to or larger than the interstellar dispersion–sweep-time of the signal across the filter bandwidth. Average profiles were obtained by summing the single pulses synchronously with the pulsar period either off-line or, as in case of the 25 m observations, on-line. The data from the telescopes were written on magnetic tape for further processing.

[5]Operated by the Max-Planck-Institut für Radioastronomie, Bonn.

[6]Currently operated by the Astronomische Institut der Universität Bonn.

[7]Arecibo Observatory is operated by Cornell University under contract from the National Science Foundation.

III. RESULTS

The results we obtained are divided into five subsections. First we describe the long-term behavior of the switching phenomenon and demonstrate that the mode change occurs simultaneously over a broad frequency range. In the third subsection we compare average profiles in both modes at different frequencies and derive the dynamics of the spectral changes of profile components during the switching period. Polarization properties for both modes are presented in the next subsection. Finally, it will be shown how drastically the mode switch affects the organized behavior in single pulses.

a) Time Dependence

The long-term behavior (~ 2.3 d) of the pulse profile of PSR 0329+54 is shown in Figure 1 as a time series of intensity ratios, taken at 1.4 GHz with the 25 m telescope. We find that for $\sim 15\%$ of the time the pulsar is in its abnormal mode. Its duration can be as long as several hours or as short as several periods. The time for the switching process itself can be for PSR 0329+54 and PSR 1237+25 at least as short as the pulsar period, which is consistent with the behavior of PSR 1237+25 and PSR 1822−09 (Fowler *et al.*; Morris *et al.*).

b) Synchronous Mode Switching at Different Frequencies

Simultaneous dual-frequency observations of PSR 0329+54 were made with the 100 m and 25 m telescopes at 1.4 and 9.0 GHz. Figure 2 shows peak intensity ratios of different components as well as separations over a time period of ~ 90 minutes at both frequencies.

The switch to the abnormal mode sets in at about $t = 5$ minutes and ends ~ 65 minutes later. The measurements show very convincingly that the phenomenon occurs at both frequencies simultaneously, at least within

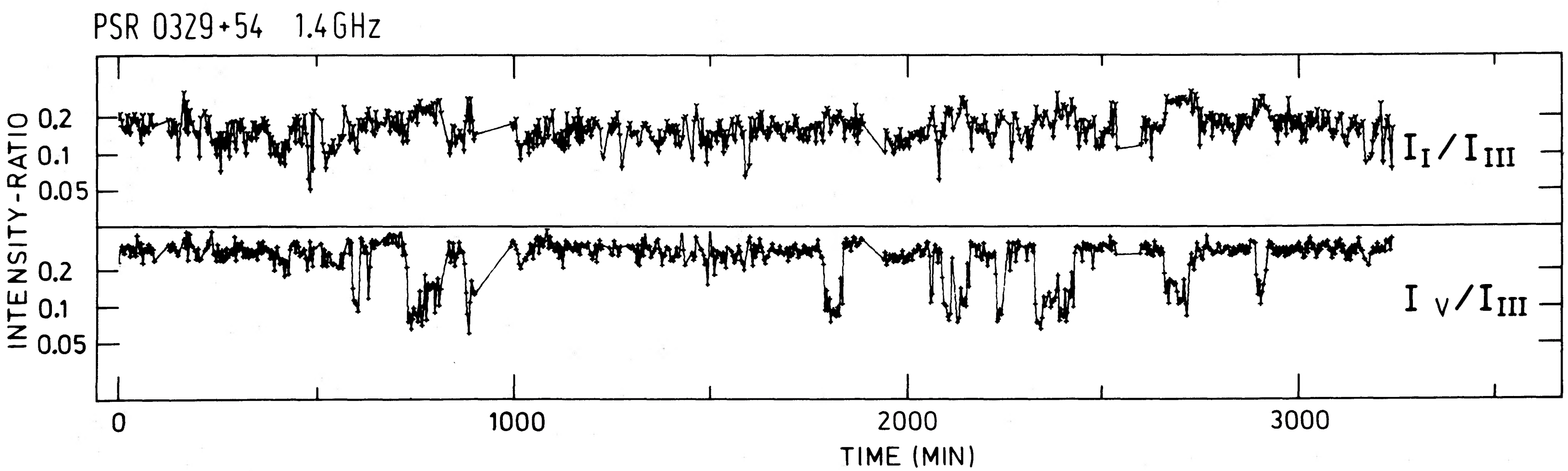

FIG. 1.—Time sequence of peak intensity ratios of components in the PSR 0329+54 profiles, each averaged over 330 adjacent pulse periods. See the top of Fig. 4 for component assignments.

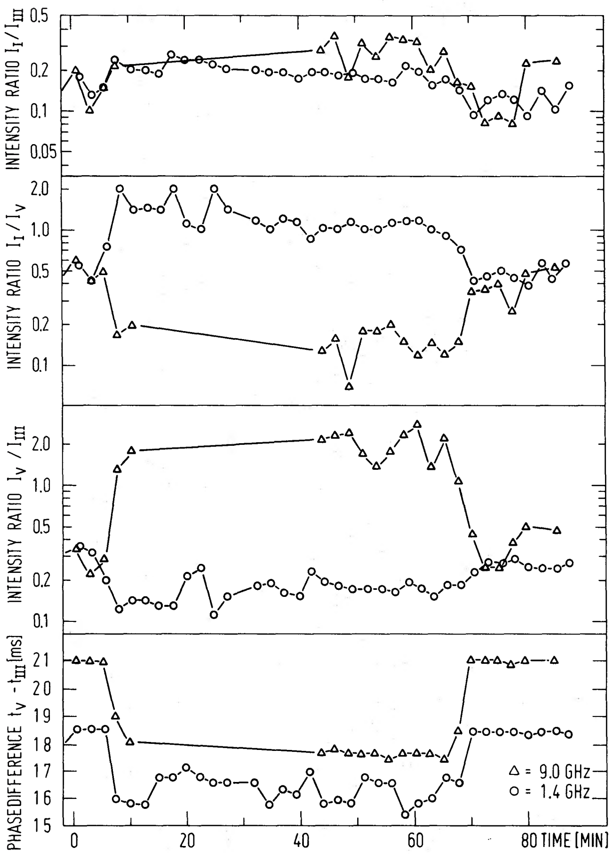

FIG. 2.—Intensity ratios for various components of PSR 0329+54 at 1.4 and 9.0 GHz simultaneously, and the separation between the peaks of components V and III as a function of time. The integration time is 200 pulse periods. The majority of the time is spent in the abnormal mode.

the 200 periods of our averaging time interval, and hence proves itself to be broad-band.

c) *Frequency Dependence of the Average Pulse Profiles*

Figures 3 and 4 show average profiles of PSR 0329+54 and PSR 1237+25 in the normal and abnormal modes over a broad frequency range. Both pulsars have in common that the abnormal mode profiles change with frequency much more substantially than their normal mode profiles. Some of their components in the abnormal mode are slightly shifted relative to their longitudinal positions in the normal mode. For PSR 1237+25 at 1.7 GHz and 2.7 GHz, this shift is just enough that the merged leading components can no longer be resolved; thus, the pulsar appears to exhibit a two-component rather than a five- or even six-component profile in the abnormal mode.

In accordance with Hesse's (1973) result at 2.7 GHz, we find for PSR 0329+54 at least three different abnormal modes at 1.4 GHz, denoted as A, B, and C. Such a variety of abnormal modes was not found at other frequencies, within an observation time on the order of 5000–10,000 periods.

Normal and abnormal mode spectra for the peaks of different components are plotted in Figure 5. The abnormal mode spectra were derived from the intensity changes during several mode switches. They are based on the normal mode spectra of components I, III, and V which we assumed to be power laws with an index $\alpha = -2.3$ ($S = k\nu^{\alpha}$) (Sieber 1973). A distortion of the results due to interstellar scintillation can be excluded because first, scintillation becomes weaker towards higher frequencies; second, its ~ 2 MHz decorrelation bandwidth at 1.4 GHz is smaller than our observing bandwidth at that frequency; and third, the fading time, which is on the order of ~ 30 minutes at 1.4 GHz and correspondingly longer at higher frequencies, is much greater than the time interval over which we analyzed the intensity changes.

The dynamics of longitudinally resolved spectra during a mode switch may be described by the following scenario. In the normal mode, all three components have a power-law spectrum with approximately the same spectral index ($\alpha = -2.3$) from ~ 1 GHz to ~ 15 GHz. During a mode change, the spectral index splits up. The spectra of components I and III steepen to $\alpha = -2.8$ as intensities at the lower and higher frequencies increase and decrease respectively. The spectrum of component V, on the other hand, flattens to $\alpha = -1.4$, leaving the intensity unchanged at ~ 2.5 GHz.

Power laws fit the data reasonably well in the high frequency range from 1 to 15 GHz. However, as indicated by the 0.41 GHz profile, the power-law spectra cannot be extrapolated much further below 1 GHz, so that a break in the longitudinally resolved spectra of the abnormal mode is expected somewhere between 0.4 and 1.4 GHz, not far from the turnover point of the total pulse energy spectrum near 0.3 GHz (Sieber 1973). The 0.83 GHz profile was not used for the spectrum analysis because of the possibility that its mode belongs to a different class. Only between 1.4 and 9.0 GHz did the simultaneous observations clarify the relation between modes over that frequency range.

PSR 1237+25 also shows a steepening or flattening of its component spectra during a mode change, provided that the mode switch occurs simultaneously at widely separated frequencies as in the case of PSR 0329+54. The intensity ratios of components IV/I and II/I follow fairly well a power law from 0.3 to 1.7 GHz and from 0.3 to 0.6 GHz, respectively. The other components show a more complex behavior.

d) *Polarization Properties*

The polarization profiles of the two pulsars are presented in Figures 6 and 7. The normal mode of PSR

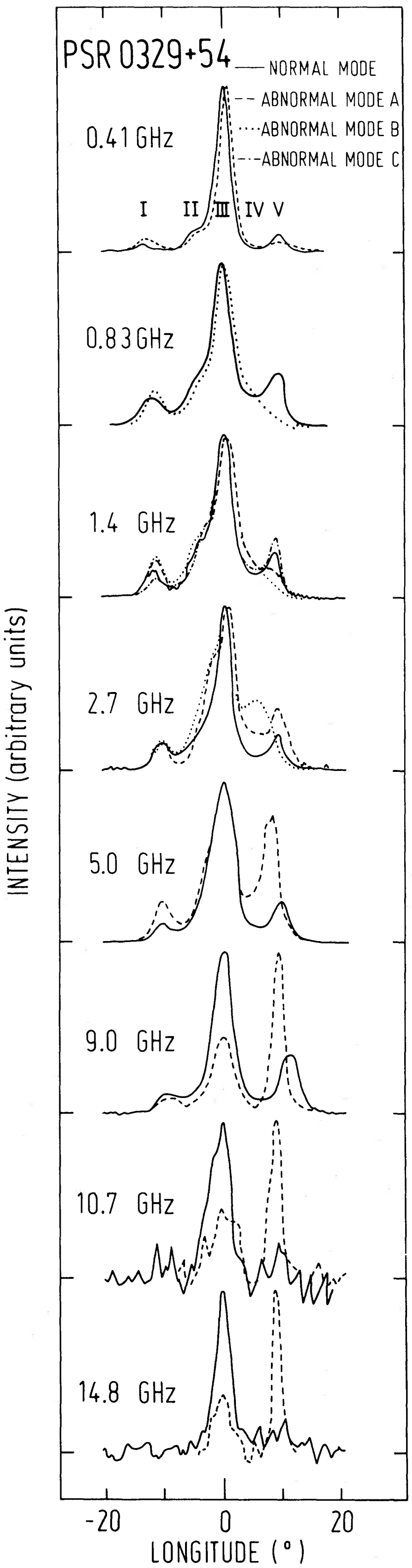

FIG. 3.—Pulse profiles of PSR 0329+54 in normal and abnormal modes, each averaged over more than 2000 pulse periods at each of eight different frequencies. Each profile is normalized to its peak value. Data at 0.41, 2.7, 10.7, and 14.8 GHz are taken from Lyne 1971, Hesse 1973, Wielebinski *et al.* 1972, and Bartel *et al.* 1978, respectively.

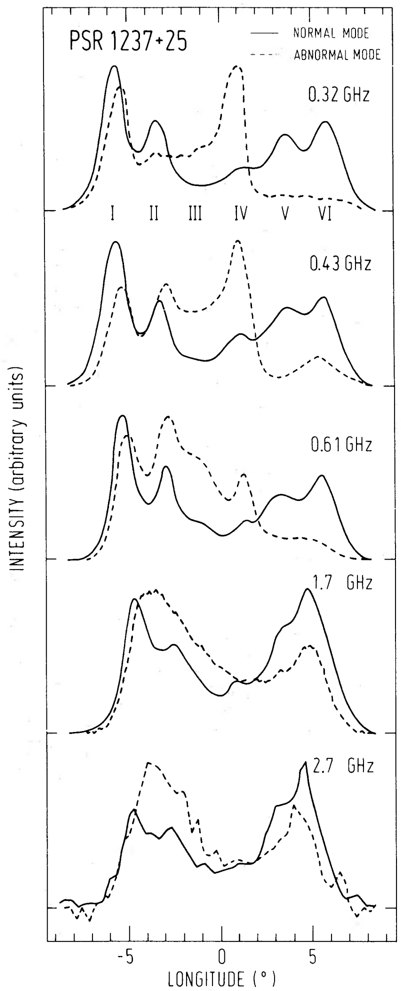

FIG. 4

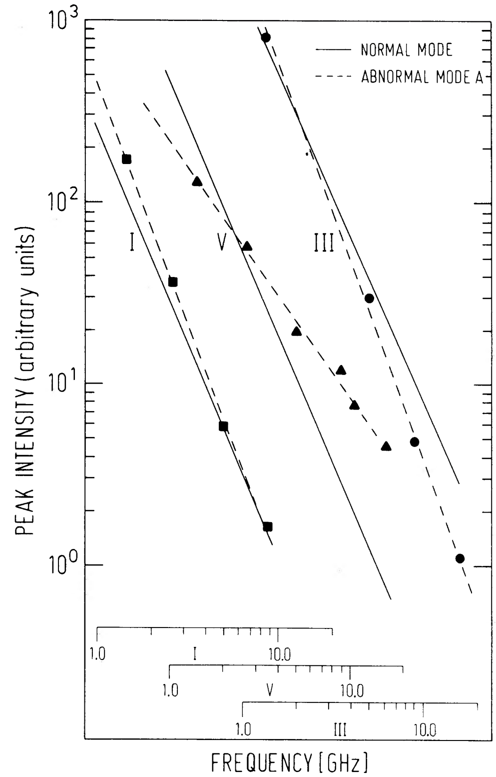

FIG. 5

FIG. 4.—Pulse profiles of PSR 1237+25 at five different frequencies. Profiles in the normal mode are averaged over ~ 1000, and in the abnormal mode, over ~ 100 pulse periods. Data at 0.32 and 0.61 GHz are taken from Backer 1971. The longitudinal phase relationship between the normal and the abnormal mode profiles at these two frequencies is unknown to us and was chosen to be approximately the same as at the other frequencies. Each profile is again normalized to its peak value.

FIG. 5.—Spectra measured at the peaks of the dominant components of PSR 0329+54 in the normal and abnormal modes

0329+54 at 1.7 GHz is characterized by a complex linear polarization profile and circular polarization that reaches -25%. The position angle does not sweep smoothly over the longitude range but is interrupted by three 90° transitions at the relative longitudes $-4°$, $+2°$, and $+11°$, most clearly demonstrated in the histograms of single pulse position angle sweeps in Figure 6.

The intensity profile of PSR 0329+54 changes only marginally during a mode change at 1.7 GHz, and similarly the polarization properties are also nearly constant. A slight shift of the main component in the abnormal mode is seen in the linear and circular polarization as well as in the position angle plots. The most obvious effect is the shift of one of the 90° transitions towards the profile center (from longitude $+11°$ [normal mode] to $+7°$ [abnormal mode]) which consequently leads also to a shift of the local minimum in the average linear polarization curve.

The polarization properties of PSR 1237+25 are presented for two frequencies in Figure 7. The intensity, linear polarization, and position angle profiles are similar for the normal mode over the frequency range of 0.43 to 1.7 GHz. The circular polarization, however, is clearly frequency dependent. For most of the leading half of the pulse, the sense of the circular polarization at 1.7 GHz is the opposite of that observed at 0.43 GHz. It

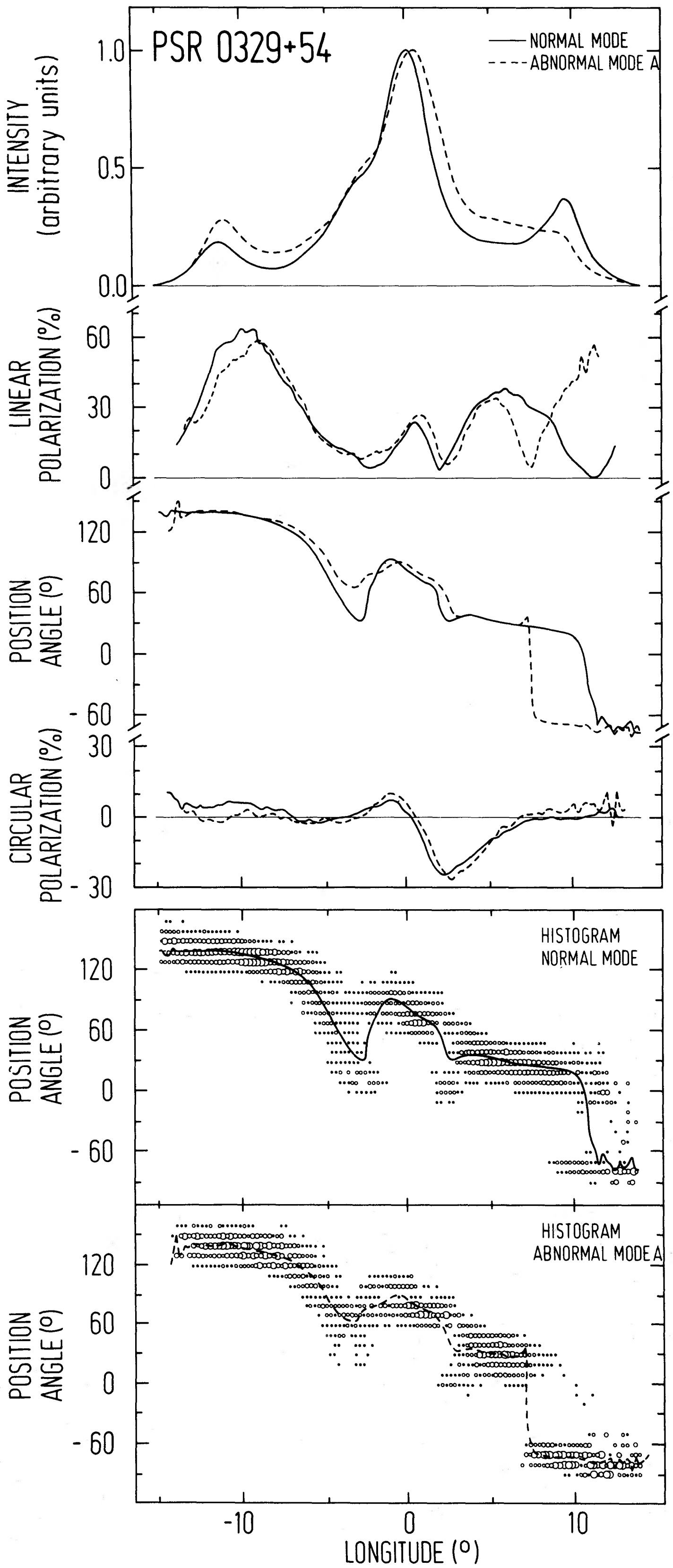

FIG. 6.—Polarization properties of PSR 0329+54 at 1.7 GHz in the normal mode and the abnormal mode A averaged over ~1000 and ~500 periods, respectively. Their peak intensities are normalized to unity. The time resolution is 300 μs and the signal-to-noise ratio for the peak of the profile is ~300, so that rms errors over most of the longitude range are negligible. The bottom diagrams display the relative frequency of occurrence of polarization position angles as a function of the longitude of single pulses. The size of the circles is proportional to the frequency of occurrence.

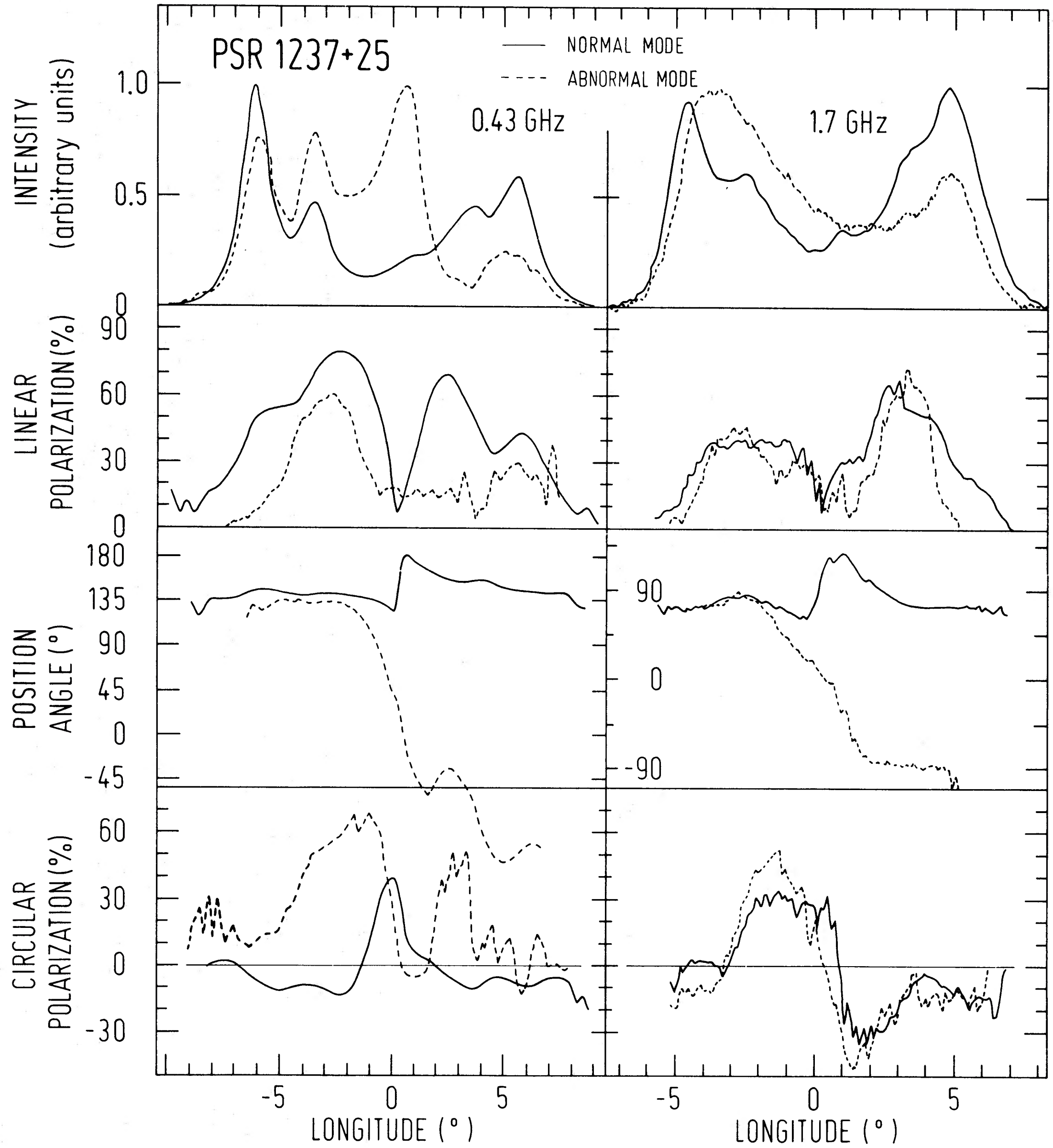

FIG. 7.—Polarization properties of PSR 1237+25 at 0.43 and 1.7 GHz in the normal and abnormal mode averaged over 1600 and 74 periods at 0.43 GHz and 512 and 256 periods at 1.7 GHz, respectively. Peak intensities are normalized to unity. The time resolution is in both cases 500 μs.

peaks at 0.43 GHz at about the middle of the pulse profile, exactly at the longitude where linear polarization drops to nearly zero and the position angle makes a rapid sweep while being nearly constant outside the center.

During the abnormal mode of PSR 1237+25, all polarization properties are strongly frequency dependent. A 90° polarization position angle transition probably occurs around longitude ~3.5° at 0.43 GHz. It does not occur at 1.7 GHz. Circular polarization reaches 65% at 0.43 GHz, the highest percentage ever observed in pulsars.

Comparing polarization properties in both modes at each particular frequency, Figure 7 shows that the average abnormal mode profile is at both frequencies narrower than the normal one. At 1.7 GHz the polarization properties are in general only moderately affected by a mode switch, except for the position angle sweep. At 0.4 GHz, however, the changes of all polarization properties are much more pronounced.

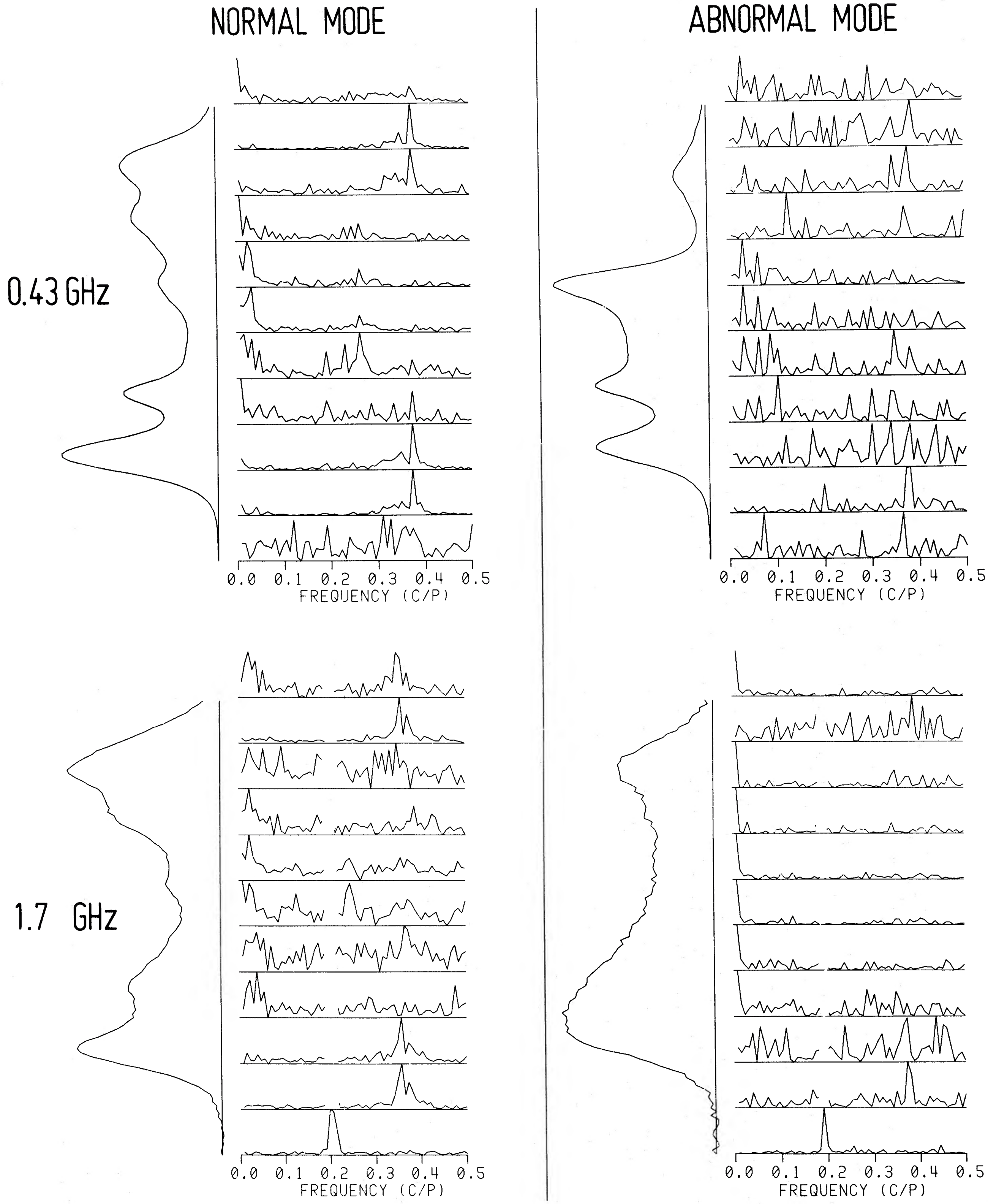

FIG. 8.—Pulse-to-pulse fluctuation spectra of PSR 1237+25 at 0.43 and 1.7 GHz for 128 periods in the normal and the abnormal mode. The spectra are longitudinally resolved so that each corresponds to that particular longitude range of the average pulse profile which is defined by the zero baseline of the spectrum and the zero baseline of the spectrum above it. The off-pulse reference spectrum is given at the bottom. At 1.7 GHz it shows a strong line at ~ 0.2 cycles per period which is due to the 50 Hz power supply frequency. Data had been disregarded around this frequency. For comparison reasons, the total pulse fluctuation spectrum is given at the top. All spectra are normalized to their peak deflection. Zero frequency components have been dropped.

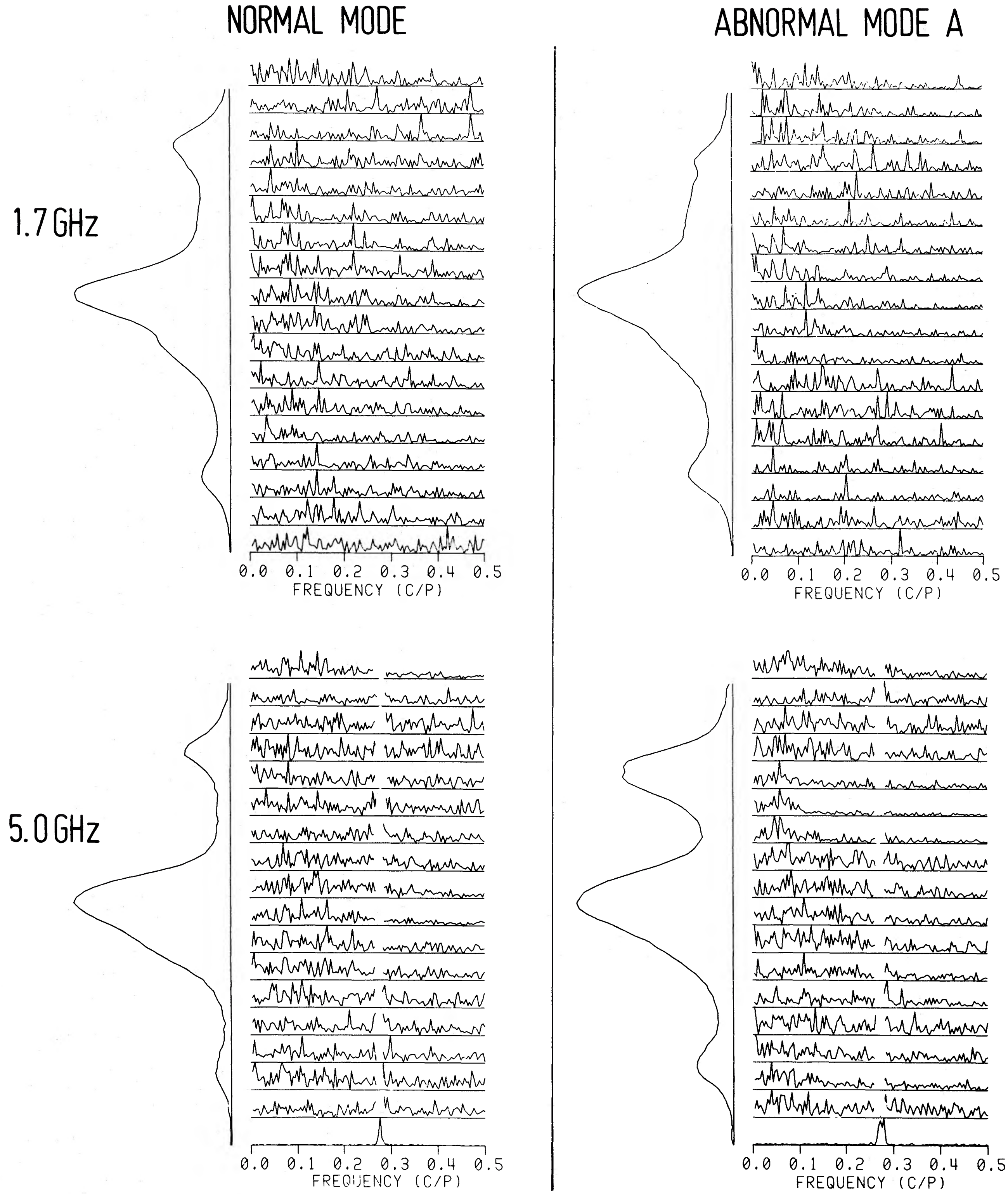

FIG. 9.—Pulse-to-pulse fluctuation spectra of PSR 0329+54 at 1.7 and 5.0 GHz for 256 periods in the normal mode and abnormal mode A. For further explanation, see Fig. 8.

e) *Fluctuation Properties*

One of the most intriguing phenomena observed in mode-switching pulsars is their single-pulse fluctuation behavior. As first recognized by Taylor *et al.*, PSR 1237+25 switches off its well known periodic fluctuation pattern in the wings of the profile (Backer 1973). Figures 8 and 9 show longitudinally resolved fluctuation spectra of PSR 1237+25 and PSR 0329+54 in the normal and abnormal mode at two frequencies. A periodic fluctuation of $P_3 \sim 0.37$ cycles per P_1 for PSR 1237+25, where P_1 is the basic pulsar period, is clearly visible in the leading and trailing part of the pulse window in the normal mode. This phenomenon is generally attributed to a slow drifting or, as Hankins and Wright (1980) suggested, to a spiraling of subpulses around the magnetic pole axis. When the pulsar switches to the abnormal mode, the periodic fluctuation almost completely ceases, leaving only a weak fluctuation line at the leading part of the profile. It regains its former properties as soon as the pulsar switches back. This phenomenon is observed for PSR 1237+25 at both frequencies. Note that in the abnormal mode the periodic fluctuations in the central parts of the pulse profile also disappear.

For PSR 0329+54 (Fig. 9), there is no prominent spectral line for the normal mode, but a red excess of the spectrum over the whole longitudinal range, and especially in the range of the main component at 5.0 GHz, is observed. In the abnormal mode the red excess is only marginally more pronounced at 1.7 GHz. At 5.0 GHz, however, a broad fluctuation spectral line at 0.06 cycles per P_1 at the longitude of the leading part of the fifth component is clearly visible. Hence PSR 0329+54 shares the common property of PSR 0031−07, PSR 1237+25, PSR 1822−09, and PSR 2319+60, namely markedly changing its single-pulse fluctuation behavior, at least at some frequencies, when changing from one mode to the other.

f) *Summary of the Observation Results*

The results on the mode-switching phenomenon in PSR 0329+54 and PSR 1237+25 can be summarized as follows:

1. The components of the average pulse profile change their relative intensity and alter their longitudinal position when a switch occurs.
2. The pulse to pulse fluctuation behavior is fundamentally different in both modes.
3. The polarization state is affected by a mode switch. The linear polarization position angle is affected most strongly.
4. The mode-switching phenomenon occurs simultaneously over a broad frequency range.
5. Abnormal mode pulse profiles are strikingly more frequency dependent than normal mode pulse profiles. The mode switch has the effect of changing the spectral index differently for different components in the pulse profile.
6. The mode switching time can be at least as short as the pulsar period P_1.

IV. DISCUSSION

The detailed investigation of the characteristics of PSR 0329+54 and PSR 1237+25 during mode switches has shown that, in general, the total intensity, polarization (linear, angle, and circular), and the drifting behavior of subpulses are affected by mode switches. All these effects can be found as well in the other known mode-switchers (see Table 2).

TABLE 2

SEVEN MODE-SWITCHING PULSARS WITH PROPERTIES WHICH ARE AFFECTED DURING A MODE SWITCH

Properties	PSR 0031−07	PSR 0329+54	PSR 0355+54	PSR 1237+25	PSR 1822−09	PSR 1926+18	PSR 2319+60
Intensity	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Linear Polarization	?	Yes	?	Yes	?	?	Yes
Circular Polarization	?	Yes	?	Yes	?	?	?
Polarization Position Angle	?	Yes	?	Yes	?	?	No
Longitudinal Position of components	Yes	Yes	?	Yes	Yes	Yes	Yes
Spectra of components	?	Yes	?	Yes	?	?	?
Fluctuation spectrum (Drifting)	Yes	Yes	?	Yes	Yes	?	Yes
Reference	1	2	3	2	4	5	6

NOTE.—Matrix elements indicate: "yes" switch occurs; "no" no switch has been observed; and "?" no information available.

REFERENCES: (1) Wright and Fowler 1981*b*. (2) This paper. (3) Morris *et al.* 1980. (4) Fowler *et al.* 1981. (5) Ferguson *et al.* 1981. (6) Wright and Fowler 1981*a*.

In the following we will first discuss the polarization behavior more thoroughly.

The histogram of polarization angles of PSR 0329+54 in the normal mode clearly demonstrates that the polarization angle (PA) sweeps smoothly over the longitude range if, similar to many other pulsars (Backer and Rankin 1980; Cordes, Rankin, and Backer 1980), allowance for 90° flips in angle is made.

This sweep is consistent with the single vector polarization model (Radhakrishnan and Cooke 1969; Komesaroff 1970) in which PA is given by

$$\tan(\mathrm{PA}) = \frac{\sin\chi \sin l}{\sin\phi \cos\chi - \cos\phi \sin\chi \cos l}, \qquad (1)$$

where l is the longitude in the pulse period, χ, the angle between the magnetic axis and the rotation axis, and ϕ, the angle between the line of sight and the rotation axis.

In case of PSR 1237+25, only the position angle sweep in the abnormal mode seems to be adequate for an interpretation in terms of the single vector model, whereas the position angle behavior in the normal mode is more complicated. An interesting feature is that the abnormal mode position angle sweep at 1.7 GHz departs from the "ideal case," given by equation (1), insofar as it is significantly faster on the trailing side of the pulse center than on the leading side. This phenomenon does not occur at 0.43 GHz.

In the following we will discuss the results from three different points of view.

a) Magnetic Field Vector Change in the Pulsar Interior

If the magnetic field in the presumed interior of the pulsar undergoes slight changes in its direction and if these changes can be transferred fast enough through the pulsar surface, then the magnetic field can also change in that emission region of the pulsar where the magnetic field energy density is supposed to be larger than the local plasma energy density. A change in the magnetic field will most likely alter all electrostatic and electromagnetic properties of the whole magnetosphere so that an observer then "sees" the magnetic field lines and the emission cone at an angle which is dependent on which mode is active. If we assume that the magnetic field configuration determines the pulse polarization state, then a change in the position angle sweep and a change in the pulse profile together with a longitudinal shift of the components are plausible even from the pure geometrical arguments. However, it is not clear whether changes of the magnetic field can occur in the pulsar interior in less than a pulsar period. MHD motions may indeed occur, but they lead to an evolution of the magnetic field on the time scale of the pulsar lifetime not of its period as conjectured by Flowers and Ruderman (1977). Even if the magnetic field changes so fast in the pulsar interior, it appears to be quite unlikely that the change can be transferred on the same time scale to the outside world. The high conductivity of the metal-like surface material will shield the magnetosphere from the pulsar interior to a great extent (Ruderman 1981). Hence, such an interpretation of the mode-switching phenomenon seems unlikely on physical grounds.

b) Absorption in the Outer Magnetosphere

Blandford and Scharlemann (1976) suggested a model in which the observed features of pulsar radiation are due to the time and longitudinally varying absorption behavior in the outer magnetosphere. Recent evidence for the occurrence of absorption of pulsar radiation within the magnetosphere has been presented by Bartel *et al.* (1981) and Bartel (1981*a*, *b*).

If the mode-switching, phenomenon is interpreted in this way, then all changes in the Stokes parameters, the fluctuation behavior, and the spectra of components should be attributed to a change in the longitudinally dependent optical depth in the magnetosphere. Longitudinally dependent Faraday rotation should then be observable in the normal as well as in the abnormal mode. We indeed observed a frequency dependent polarization position angle sweep over the longitude range in the abnormal mode of PSR 1237+25. However, longitudinally dependent Faraday rotation should result in a larger deviation from the "ideal" position angle sweep at 0.43 GHz than at 1.7 GHz, which is not observed.

c) Change in the Excitation of Charged Particles

We believe that most of the observed features can be qualitatively understood in the general frame of the Ruderman and Sutherland model (1975), where a potential gap develops in the magnetic polar cap region that is discharged by pair production in areas which, due to an $\boldsymbol{E}\times\boldsymbol{B}$ force, precess slowly around the magnetic axis. These discharges or sparks eventually give rise to charged particles which move along the curved magnetic field lines and radiate at the local plasma frequency in the radio range.

The chemical composition and/or the structure of the pulsar surface may not be homogeneous (Jones 1978; Cheng and Ruderman 1980*b*) and could be subject to alterations between two or even more equilibria. That would change the electrostatic conditions in the sparking zone so that the locations at which discharges set in and the density of the electron-positron plasma that is created strongly depend on the mode of the pulsar. Consequently the drifting behavior of the sparking areas (Wolszczan 1980) and hence the pulse-to-pulse fluctuation as well as the spatial distribution of the outflowing charged particles may well change.

A different distribution of charged particles may be related to a different "coherence function" (Buschauer and Benford 1980) which determines whether the emission process is narrow- or broad-band and hence to which degree radiation at a certain frequency gets its contributions from different locations along the open magnetic field lines. Since the pulsar period P_1 does not change from mode to mode, the longitudinal shift and the reduction of the total pulse width in the abnormal mode suggest that the emission in the abnormal mode originates on the average from a lower level in the magnetosphere where the divergence of the quasi-dipolar magnetic field lines is less. Such a situation would naturally occur if the plasma flow rate and thus the plasma density at any given level had been reduced in the abnormal mode. The flattening and/or steepening of the pulse component power-law spectra may then be expected from a "coherence function" which varies in time and longitude of the pulse profile. Also, at this lower level, the influence of the higher order multipoles will be greater and may result in a detectable deviation of the dipolar polarization position angle sweep as is observed for PSR 1237+25. Other evidence for the existence of higher order multipoles is given by Wolszczan, Bartel, and Sieber (1980).

Transitions of 90° in the polarization position angle are interpreted by Cheng and Ruderman (1980*a*) in a model in which two orthogonal polarization modes compete, with the outcome depending on the local plasma density. During a mode switch, when the longitudinal distribution of charged particles is expected to change, a longitudinal shift of the 90° transition in the polarization position angle may well occur.

Thus, many of the mode changing phenomena may be explained if it is assumed that, due to some change in the sparking process, the mean rate of plasma generation is reduced during the abnormal mode.

If this result can be generalized to other mode-changing pulsars, then the observation of PSR 0031−07 (Wright and Fowler 1981*b*), which shows very regular behavior, indicates that the low plasma flow rate (narrow profile) is associated with slowly drifting sparks. Furthermore, the sequence of drift bands A, B, and C in PSR 0031−07, from slow to fast drifting subpulses (narrow to broad profile) followed by null pulses, is a sequence from low to high plasma flow rate. Exactly the same sequence is observed in the case of PSR 2319+60 (Wright and Fowler 1981*a*). This sequence of events suggests that pulse nulling may be, in contrast to mode-switching, a consequence of an episode of high plasma flow rate. Therefore, for example, the spark discharge may be extinguished by overheating of the stellar surface or by excessive bombardment leading to chemical or physical changes in the stellar surface (Vivekanand and Radhakrishnan 1980).

V. CONCLUSION

Theoretical arguments and observational evidence indicate that neither the pulsar interior nor the outer magnetosphere is likely to be the location where the mode-switching phenomenon originates. Instead, we suggest that the phenomenon is linked to the pulsar surface.

Inhomogenities in the chemical composition and/or the structure of the pulsar surface may give rise to two or more equilibria of the electrostatic conditions in the polar cap region. The density profile over the polar cap cross section of the outflowing plasma then depends strongly on the equilibrium present. The different polarization properties, subpulse organization, and intensity distribution of the pulses are then a manifestation of the different metastable plasma modes of the magnetosphere.

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