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# On the structure of pulsar magnetospheres

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The angles $\beta$ between rotation and magnetic axes in the radio pulsar magnetospheres can be calculated with several methods. In this paper we present the results of calculations for three samples of radio pulsars at 10, 20 and 30 cm wavelength obtained with two methods using statistical relationships. Some effects which can give errors in the values of $\beta$ are discussed. There are no correlations between values of $\beta$ and pulsar ages.

**Key words:** pulsars: individual: magnetosphere; plasma; instabilities

## INTRODUCTION

One of the most important parameters determining the geometry of the pulsar magnetosphere and its place in the physical processes that should be considered is the angle $\beta$ between the rotation axis and the magnetic moment vector $\mu$. This parameter allows to understand specificity of pulsar radiation, and the distribution of angles for objects of different ages gives the possibility to draw conclusions about the ways of their evolution. Discovering the sources with small values of the angle $\beta$ and with the values of about 90° makes it possible to predict the presence of their interpulse radiation. The calculation of the angles at different levels in the magnetosphere by observations at different frequencies can be used to check the assumption about the dipole magnetic field. It is also possible to estimate the distribution of appropriate levels of the generation of radiation from these data, to undertake mapping of these levels. The analysis of the results on angles $\beta$ in pulsars is one way of choosing an adequate model for these objects and the mechanism of their radiation.

## THE METHOD OF CALCULATIONS

The standard model of a pulsar magnetosphere was used for the calculations. Using profiles and polarization data for radio pulsars at waves with $\lambda = 10$ cm, 20 cm and near 30 cm we calculated the values of angles $\beta$ between rotation and magnetic axes. The detailed description of these methods is given in [1]. The analysis of the pulsar magnetospheres structure was based on the estimations of the angles $\beta$ for the samples of radio pulsars with known pulse profiles and monotonous behaviour of the position angle from [3] and [4]. For the analysis by the first method 80 objects from [3], 283 pulsars at 20 cm and 132 ones at 10 cm from [4] were selected. We have used 34 objects from [3], 40 pulsars at 20 cm and 31 ones at 10 cm from [4] for the analysis with the second method. Since the dependence of the position angle on the longitude was measured not for all pulsars and the measurements were made only within the main pulse the number of pulsars for calculating the angle $\beta$ with the second method was much smaller.

We denoted:

- sample 1 – the pulsars [4], whose parameters were measured at 10 cm;
- sample 2 – the pulsars [4], whose parameters were measured at 20 cm;
- sample 3 – the pulsars from [3], whose parameters were measured at the wavelength near 30 cm.

If the line of sight passes through the centre of the emission cone we can calculate values of $\beta_1$. The equations of the lower boundaries on the empirical relationship $W_{10}$(P) for the pulsar samples 1, 2 and 3 are:

$$\log W_{10} = (0.51 \pm 0.05) + (-0.25 \pm 0.09) \log P, \quad (1)$$
$$\log W_{10} = (0.50 \pm 0.03) + (-0.24 \pm 0.05) \log P, \quad (2)$$
$$\log W_{10} = (0.76 \pm 0.03) + (-0.27 \pm 0.08) \log P, \quad (3)$$

correspondingly.

The angles for most of the pulsars lie within the interval from 10° to 40° with the average value

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$< \beta_1 >= 18^\circ$ for the sample 1, $< \beta_1 >= 14^\circ$ for the sample 2, and $< \beta_1 >= 27^\circ$ for the sample 3.

We have obtained the values of $\beta_2$ with the second method. In this case we can define the dependence $W_{10}$(P) by a straight line inscribed into our data. The straight lines obtained with the least squares method for the samples 1, 2 and 3 are:

$$\log W_{10} = (1.12 \pm 0.05) + (-0.25 \pm 0.09) \log P, \quad (4)$$

$$\log W_{10} = (1.22 \pm 0.03) + (-0.24 \pm 0.05) \log P, \quad (5)$$

$$\log W_{10} = (1.16 \pm 0.03) + (-0.27 \pm 0.08) \log P, \quad (6)$$

correspondingly.

Observational data show that for the majority of pulsars the position angle behaviour is measured within the main pulse on a small part of longitude $\Phi$. Therefore it can be used for computing the maximum derivative of the position angle on longitude.

The derivative sign can not be determined from the observations in the main pulse only and we must solve the problem for $C > 0$ and $C < 0$. For pulsars under consideration, the computed values of $\beta_2$ were systematically higher than the values of $\beta_1$. This is clearly seen in calculations with $C < 0$. Mean values of $\beta_2$ are:

$< \beta_2 >= 33.9^\circ$ for the sample 1, $< \beta_2 >= 33.9^\circ$ for the sample 2, and $< \beta_2 >= 36.4^\circ$ for the sample 3 if $C > 0$;

$< \beta_2 >= 52.1^\circ$ for the sample 1, $< \beta_2 >= 54.1^\circ$ for the sample 2, and $< \beta_2 >= 49.1^\circ$ for the sample 3 if $C < 0$.

The angles at different wavelengths for both signs of the maximum derivatives of the position angle of polarization are almost equal (within errors). The comparison of the calculated angles $\beta_1$ and $\beta_2$ shows that for most pulsars $\beta_2 > \beta_1$. It should be expected, since taking into account the passage of the line of sight not through the centre of the radiation cone should lead to overestimates of the angle $\beta$.

## RESULTS AND CONCLUSIONS

Comparison of the derived mean $\beta_2$ values with the results at wavelengths longer than 30 cm [1] indicates a surprising agreement: $\beta_2 = 36.4^\circ$ for $C > 0$ and $\beta_2 = 49.1^\circ$ for $C < 0$. Since these values were obtained for the completely different pulsar samples, we conclude that, on average, the inclination of the magnetic dipole to the rotational axis is approximately in the middle of the interval from 0° and 90° for all pulsars. The mean value of this angle over all $\beta_2$ values is 43.5°.

The pulsars with $\beta \leq 10^\circ$ belong to the class of objects with possible interpulses and significant interpulse emission. They are PSR B1641-45, 1642-03 and 1944+17. The pulsars with $\beta > 80^\circ$ may belong to orthogonal rotators with the possible interpulses at a distance of 180° from the main pulse. The candidate in such objects is PSR B2321-61.

The difference obtained in the calculations of the $W(P)$ from the usually accepted in the polar cap model ($P^{-0.5}$) may be due to two reasons. The first one relates to the possible influence of the multipole components of magnetic field in the deep layers of the magnetosphere. A deviation from the dipole is assumed in many pulsar models, including the paper of the Ruderman and Sutherland [2], to ensure an abundant production of the secondary electron-positron plasma. However, calculations showed that the role of the quadrupole component of the magnetic field is unessential. The width of the radiation cone for the quadrupole field would be considerably less than in the case of the dipole structure and the dependence on the rotation period would have been stronger. The second reason is connected with the growth of plasma instabilities in the pulsars magnetospheres. The main instability is the two-stream one, which leads to a marked increase in the amplitude of Langmuir waves. At a distance of about 10 radii from the star the wave amplitude will increase by about two orders of magnitude. In these areas the radio emission at high frequencies is generated. The lowest frequencies (around 100 MHz) are generated at very large distances from the neutron star surface. Therefore, it is thought that at these levels the width of the cone is determined completely by the dipole dependence and a slope of 0.5, which corresponds to the universal proportionality, is obtained.

In the calculations, it suffices to use the catalogue value of the pulse width $W_{10}$ since the effects of observed pulse broadening due to the transition to full width $W_0$ and restrictions associated with the emission of radiation along a tangent to the field line, compensate each other approximately.

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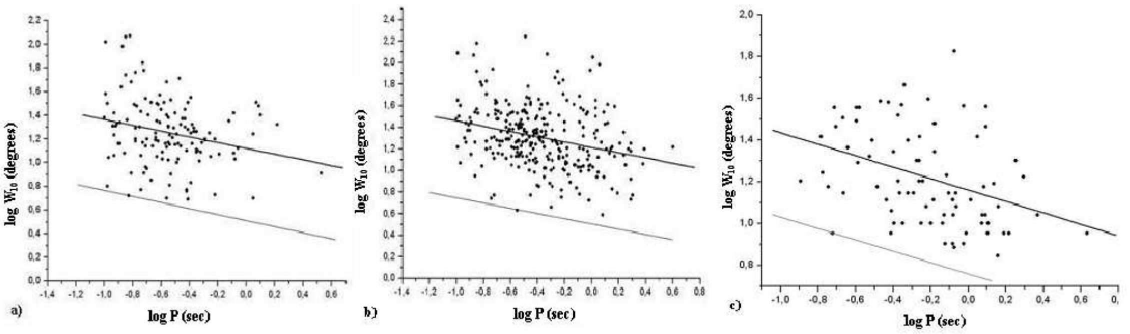
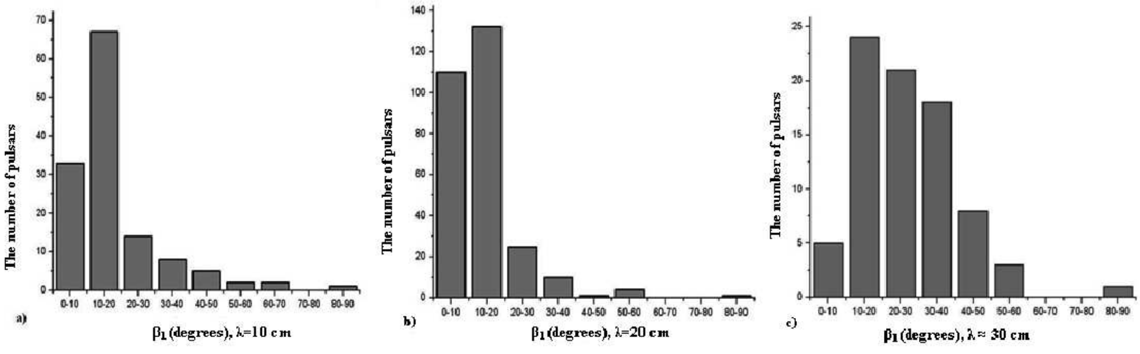


Fig. 1: The dependence of the observed width $W_{10}$ on the pulsar period P. a) Sample 1, b) Sample 2, c) Sample 3



$<\beta_1> = 18°$ $<\beta_1> = 14°$ $<\beta_1>=27°$

Fig. 2: The histogram of the pulsar number on the value of $\beta_1$.

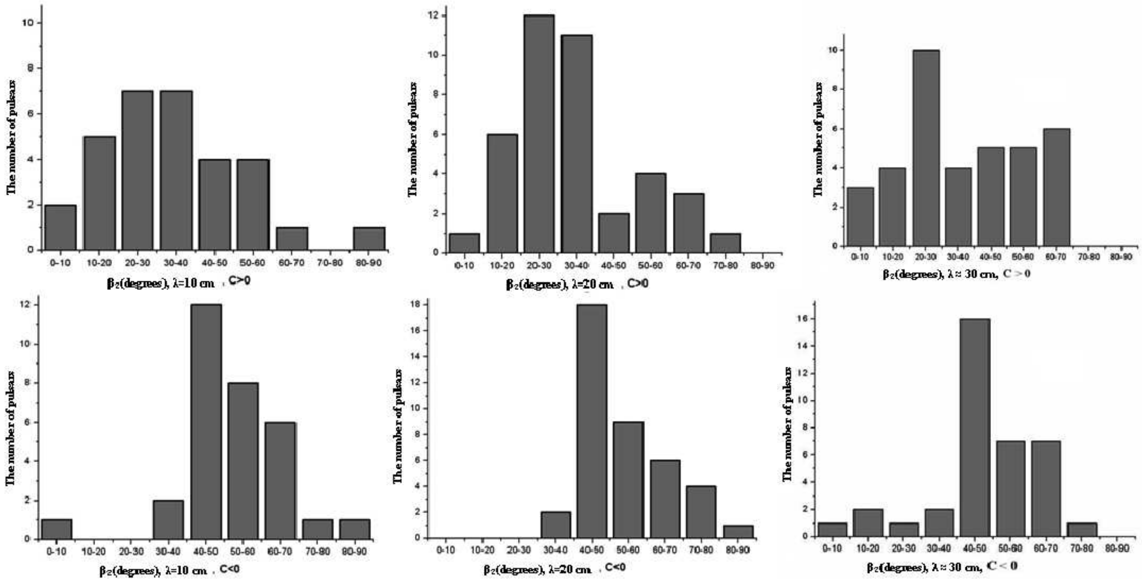


Fig. 3: The histogram of the pulsar number on the value of $\beta_2$.