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Shape of pulsar beams revisited

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Abstract. Using a carefully selected subset of the recently published multifrequency polarimetric observations of 301 radio pulsars (Gould & Lyne 1997), we have attempted modeling the shape of pulsar beams. From the 6-frequency data selected on conal triple and multiple component profiles, we find that there are *three distinct cones* of emission and that the pulsar beam shape changes from circular (for an aligned rotator) to latitudinally compressed form (for an orthogonal rotator). We see no evidence in support of the evolution of the pulsar beam shape as a function of period, while as expected the overall size scales as $P^{-0.5}$, where P is the pulsar period.

1. Introduction

A knowledge about the shape of pulsar emission beams is an essential ingradient in understanding the pulsar emission mechanisms. Several attempts to model the pulsar beam have been made earlier. In their study, Narayan & Vivekanand (1983) concluded that the beam is elongated in the latitudinal direction. Lyne & Manchester (1988), on the other hand, argued that the beams are essentially circular. Biggs (1990) found, based on the geometry of the cone of open field-lines, that the beam shape is a function of the angle between the rotation and the magnetic axes.

In this paper, we re-examine this question within the basic framework advanced by Rankin (1993). We test for a signature of a possible confined 'conal-component' geometry by taking into account all the relevant geometrical and frequency dependent effects, and solve consistently for the parameters defining the shape of the pulsar beam. Recently published multifrequency (234 to 1642 MHz) polarization data (Gould & Lyne 1997) have made this investigation possible.

2. Data set and model for shape of pulsar beam

We use the data on 39 pulsars with only triple (T) and multiple (M) profiles (as classified by Rankin, 1983) where the angle (α) between the rotation axis and the magnetic axis has been estimated using 'core widths' (Rankin, 1990). We use the observed separation between the peaks of the outermost components as the apparent width (ϕ_{υ}) of the cone and the impact angles (β) as estimated by Rankin (1993) using polarization data and the Radhakrishnan & Cooke model (1969).

Note that the different frequency data on a given pulsar provide independent cuts (at different $\frac{\beta}{\rho}$) across the beam since the beam radius (ρ) evolves with frequency while β is constant for a given pulsar. We use this aspect which amounts to an increase in the number of independent constraints by a large factor. We would like to contrast this with an approach where the different frequency data for each pulsar is first used separately to model the frequency dependence of the observed widths and then to obtain the width at a chosen reference frequency for comparison with similar data on other pulsars. The latter approach fails to take into account the dependence of the widths on $\frac{\beta}{\rho}$, when the beam is non rectangular.

We assume that the pulsar emission beams are in general elliptical in shape. The observed component separations (ϕ_υ) should satisfy the following relation,

$$\frac{\sin^2(\phi_\upsilon/4)\sin(\alpha)\sin(\alpha+\beta)}{\sin^2(\rho_\upsilon/2)} + \frac{\sin^2(\beta/2)}{\sin^2(R\rho_\upsilon/2)} = 1 \qquad (1)$$

where ρ_υ and R are the longitudinal size and the axial ratio of the beam cone, respectively. We assume that R is a function of α, while ρ_υ depends on frequency υ and period P. The υ and P dependence of ρ_υ as suggested by Thorsett (1991) & Gil (1981) respectively are used together in a form, $\rho_\upsilon = \rho_o\,(1 + K\upsilon^{-\zeta})P^{-0.5}$, where ρ_o and K are constants and ζ is the index describing the evolution with frequency.

We model the dependence of R on α through a functional form similar to that used by Biggs (1990) as $R=R_o \times (1 - K_1 \times 10^{-4}\,\alpha - K_2 \times 10^{-5}\,\alpha^2)$, where R_o is the axial ratio at α=0 and K_1, K_2, are constants. While Biggs (1990) found R_o=1, K_1=3.3 & K_2=4.4, we treat these as free parameters in our model.

With the above model we seek the values of the free parameters that provide the most compact distribution of ρ_o. This distribution indicates that there are indeed three distinct cones of emission. Allowing this possibility we estimate that best-fit values for R, ζ, K, K_1 and K_2 and the ρ_o values corresponding to three cones, based on the data set consisting of α, β and ϕ_υ's. The best-fit descriptions of ρ_υ and R are then used to display the total set on a normalized scale as shown in Fig. 1. The three best fit cone rings are also indicated.

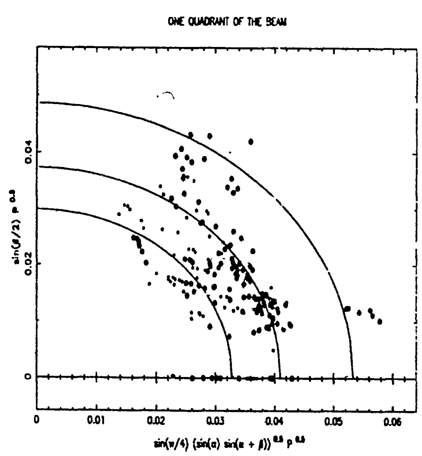

Figure 1. Distribution of the (x,y) locations of the conal components on a common scale. The three solid lines indicate the three emission cones in the quadrant shown.

3. Results and discussions

The minimum χ^2 corresponding to the model best-fit to the data is consistent with the uncertainties of α, β and ϕ_v. The frequency scaling law corresponding to the central cone is found to be, ρ_v= 4.79°(1+66 ν_{MHz}^{-1})$P^{-0.5}$. Thus, the beam size changes rapidly : higher in the lower frequency range, decreasing with increasing frequency with a limiting minimum value. The inner and outer cones have sizes 0.8 and 1.3 times that of the central cone. We also found that the data favours the $P^{-0.5}$ dependence and clearly reject the Lyne and Manchester (1988) suggestion for the $P^{-1/3}$ dependence based on the goodness of fit criteria.

We do find clear evidence for beam compression in the meridional direction at large α values, a trend similar to that suggested by Biggs (1990). However, we find the compression 10% higher (K_1=7.2, K_2=4.4), than that suggested by Biggs.

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