# Polarization characteristics of radiopulsars


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## Abstract

It is widely known that the most important observational characteristics that depend strongly on pulsar inclination angle α is its mean profile and the plot of the position angle of linear polarization. They provide the most basic ideas about the geometric properties of the directivity pattern. But they appear to be non-reliable to determine the inclination angle. In Beskin & Philippov (2012) the method was proposed taking into account the circular polarization as well. This method is based on Kravtsov-Orlov equations, that allows to determine the plots of Stokes parameters in the neutron star magnetosphere along the ray trajectory, depending on local plasma parameters and magnetic field structure. Observations together with numerical simulation of the ray propagation in the magnetosphere allows us to determine the unknown parameters more accurately. Using this method, we firstly studied the influence of strong toroidal magnetic field (Philippov, Tchekhovskoy & Li 2014) on polarization characteristics of the radiation. Comparing the numerical results with observations of the position angle data spreading, we conclude that the radiation is being generated in a wide shell of tenth of star radii, depending on the frequency.


## Hollow Cone model

There are two modes in pulsar magnetosphere that determine the directivity pattern and the mean profiles of radiopulsars (see Figure 1). These modes are indistinguishable from the point of view of the mean profile.

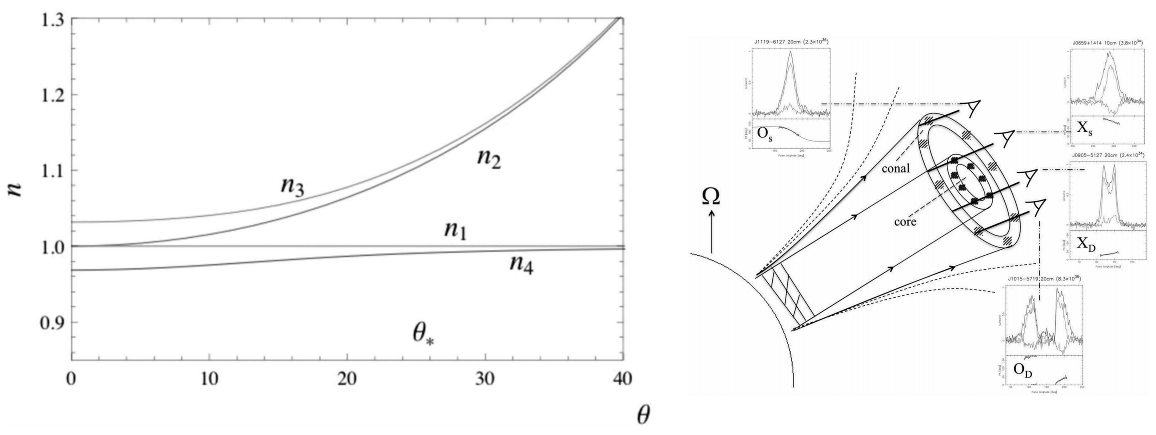


**Figure 1:** The refraction coefficients for plasma modes ($n_1$ - X-mode, $n_4$ - O-mode), and the schematic illustration of directivity pattern in hollow cone model.

As it is well known, the main assumptions of the Hollow Cone model are:

- the radiation is being generated deep near the surface, where the magnetic field is close to dipole;
- the emission propagates along a straight line;
- no cyclotron absorption;
- the polarization is formed at the point of emission (no limiting polarization), which gives us the so-called RVM curve for a position angle (Radhakrishnan & Cocke 1969)

However, accurate observations of p.a. and circular polarization showed, that this model is not working for most of pulsars, as anomalous p.a. plot shifts and other phenomena were being obtained.

## More accurate approach

The working method to combine all these effects and provide a numerical approach was given in [1]. Effects taken into account:

- the refraction of O-mode;
- the non-dipole magnetic field with a "split-monopole" solution for pulsar wind;
- the cyclotron absorption;
- limiting polarization effect, that describes the fixation of the radiation polarization characteristics at the point where it escapes into the region of rarefied plasma.

## Enhancements

This work is the third in line of two already published papers studying the characteristics of pulsars based on polarisation data, with the first one [1] giving primary theoretical basis, and the second one analysing the statistics (in preparation).

In this work the improvements to the method were made to allow us to broaden the possibilities of the program and do numerical calculations for the most interesting cases.

- For inclination angle about 90° the effect of asymmetrical plasma density must be taken into account instead the one used in [1]. This effect is taken empirically as an exponential suppression along a line, where $\rho_{GJ} = 0$ (see Figure 2).
- The possibility to put any magnetic field was also added to the method, as it was interesting to study the case of the strong toroidal field (see Figure 3).

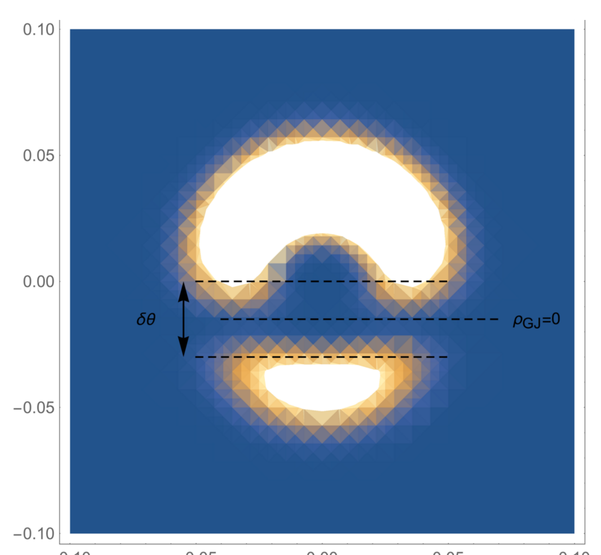


**Figure 2:** The asymmetrical profile density.

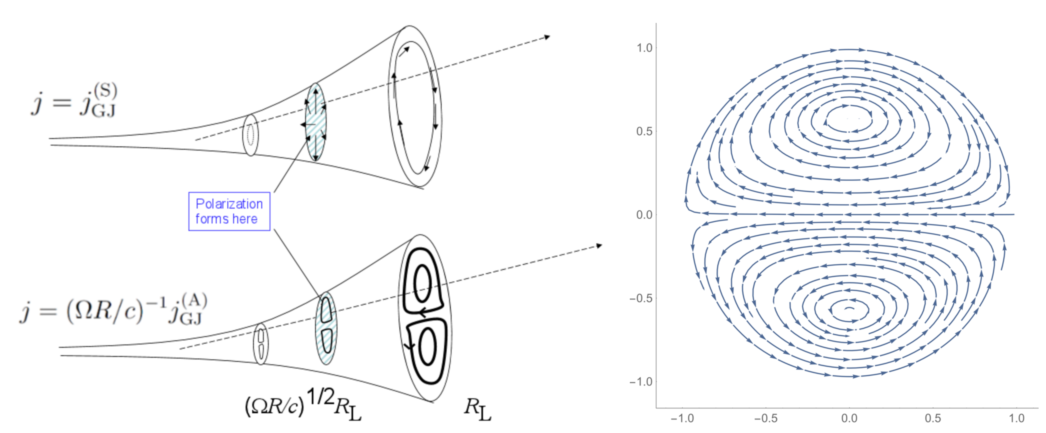


**Figure 3:** The large toroidal field structure, because of anomalous asymmetric current.

## Results

The difference of our p.a. curve from the standard RVM curve is as strong as the density of secondary plasma. Thus in the regions, where the plasma density is suppressed (central region of the hollow cone) our curve will tend to be close to the RVM, resulting the hump in the center (see Fig. 4). This phenomena can as well be observed in two-peaked profiles near the central region (see [2]), however, due to suppression of radiation in that region, it is hard to detect the p.a. value there.

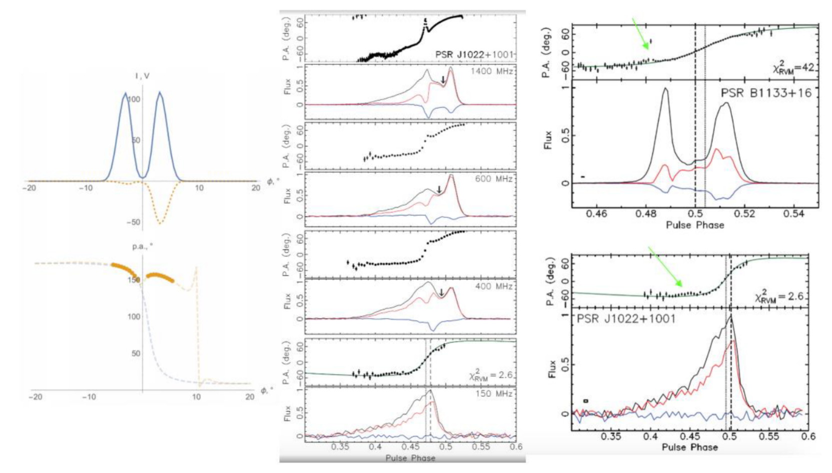

**Figure 4:** Central hump due to plasma density suppression in simulations (left) and in the observations (right).

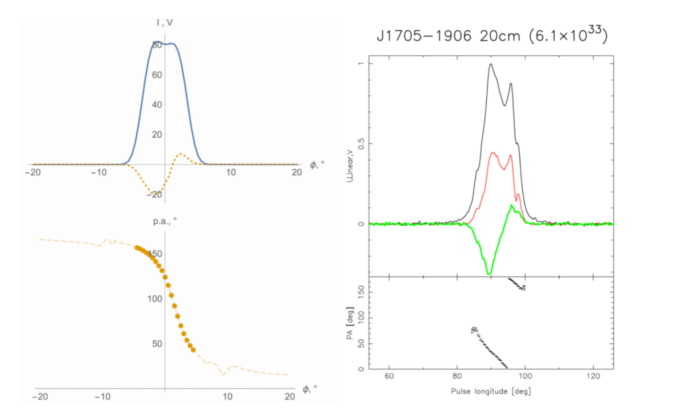


**Figure 5:** V sign transition due to large toroidal magnetic field ~ 60° in simulations (left) and in observations (right).

When turning on the large toroidal field from [3], the plots change drastically, as it can be seen from Figure 5. This particularly can explain the transition of the sign of circular polarization in some pulsars (see [2]).

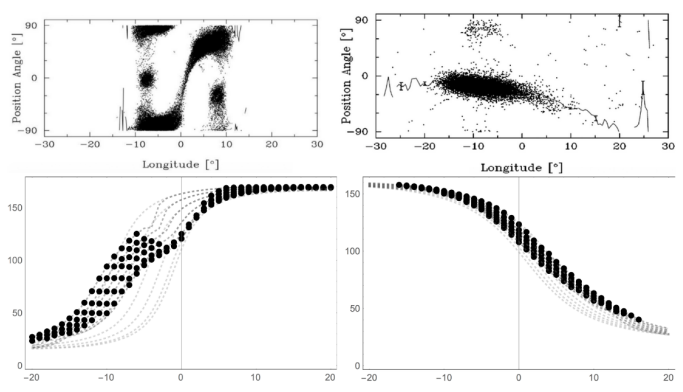

**Figure 6:** The comparison of P.A. curve width with the observational data for two cases of pulsars.

Some pulsars' p.a. data is widely spread with a characteristic width of about ~30° at 1.43 GHz and ~20° at 400 MHz, depending on whether the pulsar has a single-peaked or a double-peaked profile. This fact was not considered in numerical simulations before. We show, that this spread can be explained by the generation of radiation in a wide shell above the star surface. On Figure 6 we show the p.a. spreads for two cases. The simulation data involves radiation, coming from heights above the surface from 10 to 60 in star radii.

For a single-peaked pulsar we consider the simulation on two frequencies 1.5 GHz and 0.4 GHz, considering the radiation from a wide shell. Comparing with the observations (data from [4]) we conclude, that the 1.5 GHz radiation is generated in the narrower shell (~20R), than for the 0.4 GHz (~60R) (see Fig. 7 and Fig. 8).

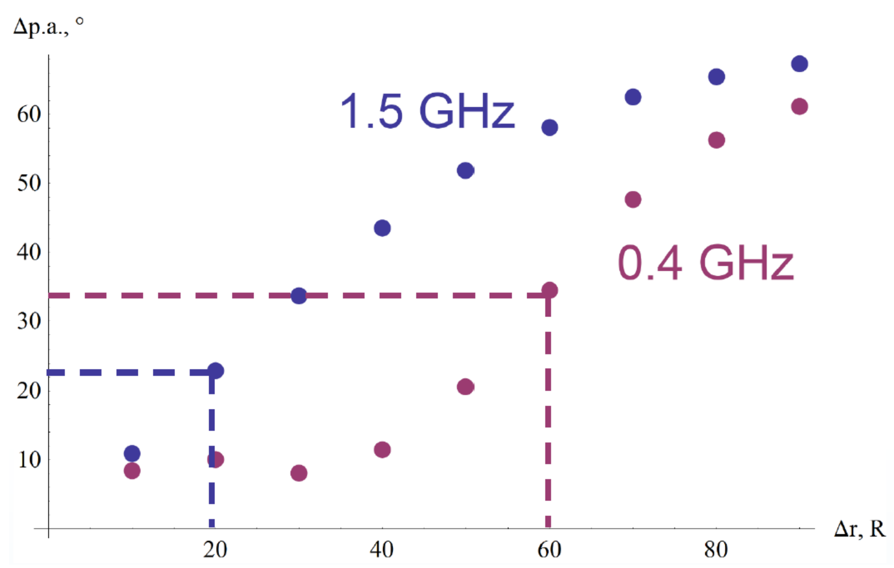


**Figure 7:** The dependence of the P.A. curve width and the width of radiation shell.

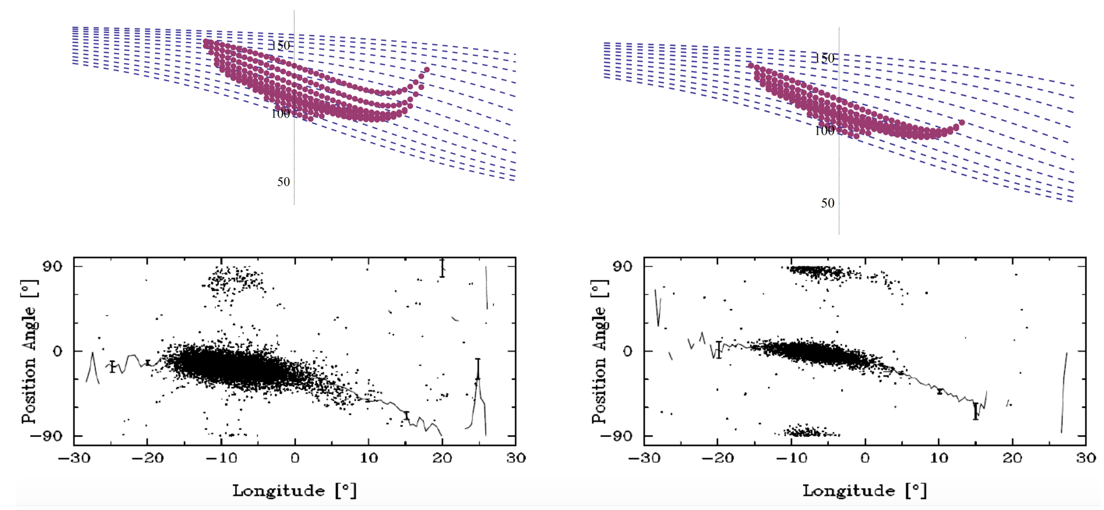


**Figure 8:** The comparison of simulation for 0.4 GHz (top-left) and 1.5 GHz (top-right) with the observation (bottom-left and bottom-right).


## References

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