Chin. J. Astron. Astrophys. Vol. 6 (2006), **Suppl. 2**, 126–128
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

A Propagation Model for Individual Pulse Polarization

S. A. Petrova ⋆

Institute of Radio Astronomy, 4, Chervonopraporna Str., Kharkov 61002, Ukraine

Abstract Polarization evolution of radio waves in the plasma of pulsar magnetosphere is considered. The polarization state of the natural waves linearly polarized in orthogonal directions is found to change considerably because of the wave mode coupling and the cyclotron aborption. It is shown that the original natural waves acquire elliptical polarization and become slightly non-orthogonal. A model of the individual pulse polarization is suggested based on an idea of fluctuations in the plasma flow. The implications of the individual pulse polarization data for diagnostics of pulsar plasma are outlined as well.

Key words: plasmas — polarization — pulsars: general — waves

1 INTRODUCTION

The magnetosphere of a pulsar contains an ultrarelativistic strongly magnetized electron-positron plasma, which streams along the open magnetic lines. The radio emission observed from pulsars is undoubtedly associated with the processes in the plasma flow. Whatever the emission mechanism, the resultant radiation should bear the properties of the ambient plasma.

The plasma of pulsar magnetosphere allows two non-damping natural waves, the ordinary and extraordinary ones, which are linearly polarized in orthogonal directions. The electric vector of the ordinary waves lies in the same plane as the wavevector and the ambient magnetic field, while the extraordinary ones are polarized perpendicularly to that plane. In general, the pulsar beam presents an incoherent mixture of the two polarization modes. The resultant position angle of linear polarization is certainly that of the dominant polarization mode.

This classical model of pulsar polarization has a certain observational support, but it appears too simplified, especially in application to the individual-pulse polarization. The observed polarization modes have elliptical polarizations and can be non-orthogonal. The pulse-to-pulse polarization fluctuations are caused not only by the fluctuations of the mode intensity ratio - the polarization characteristics of the modes vary as well, which can hardly be attributed to the variations of the ambient magnetic field. All of these peculiarities can be explained in terms of propagation effects in pulsar plasma.

2 POLARIZATION TRANSFER IN PULSAR MAGNETOSPHERE

2.1 Wave Mode Coupling

The main features of polarization evolution in the flow of pulsar plasma can be summarized as follows (see, e.g. Petrova 2006a and references therein). Deep inside the magnetosphere, the plasma number density is so large that the regime of geometrical optics holds: The natural waves propagate independently, with the electric vectors following the orientation of the ambient magnetic field. As the plasma number density decreases with distance from the neutron star, $N \propto r^{-3}$, the difference in the refractive indices of the modes decreases as well, $\Delta n \propto N$, and in the outer magnetosphere the scale length for beats between the modes, $L_{\rm b} \sim c\Delta n/\omega$, ultimately becomes comparable to the scale length for change in the plasma parameters, $L_{\rm p} \sim r$. Then the polarization planes have no time to follow the magnetic field direction and wave mode coupling starts. Each of the incident natural waves becomes a coherent mixture of the two natural waves peculiar to the ambient plasma. As a result, the waves acquire some circular polarization

⋆ E-mail: `petrova@ira.kharkov.ua`

and a shift in position angle of linear polarization, so that it no longer reflects the magnetic field geometry. Further on, as the plasma density decreases considerably, the waves decouple from the plasma and preserve their polarization state.

For fixed plasma parameters, both natural waves acquire the same shift in position angle and the same degree of circular polarization of opposite sense (Lyubarskii & Petrova 1999). So the outgoing radiation is a superposition of the elliptically polarized modes purely orthogonal at the Poincare sphere. This is in line with the commonly used empirical representation of pulsar polarization. However, a thorough analysis of observational data shows that the representation of purely orthogonal polarization modes is sometimes inapplicable - the modes can be markedly non-orthogonal.

2.2 Cyclotron Absorption

The non-orthogonality of polarization modes can be explained by the effect of cyclotron absorption. In the vicinity of the emission region, the magnetic field is so strong that in the rest frame of the scattering particles the radio frequency is much less than the electron gyrofrequency, $\omega' \ll \omega_H$. But as the magnetic field strength decreases rapidly with distance, $B \propto r^{-3}$, in the outer magnetosphere the radio waves meet the condition of cyclotron resonance, $\omega' = \omega_H$. Typically the resonance region lies beyond the region of mode coupling, but these regions can be quite close to each other, in which case the plasma number density appears large enough to provide further polarization evolution in the resonance region.

For the ordinary and extraordinary natural waves, the absorption coefficients are slightly different. The waves entering the resonance region present already a coherent mixture of the two natural waves. Since these constituents are absorbed not identically, the resultant polarization changes. For the two modes the ratio of the natural wave amplitudes is essentially distinct, so they suffer different polarization evolution and become non-orthogonal (Petrova 2006a).

3 STATISTICAL MODEL OF THE INDIVIDUAL PULSE POLARIZATION

In the framework of the propagation model of pulsar polarization, the fluctuations of the polarization characteristics of the modes are naturally attributed to the fluctuations in the plasma flow. The left plot of Figure 1 shows the numerically simulated distribution of the final position angles of the original ordinary and extraordinary waves given slight pulse-to-pulse fluctuations in the plasma parameters. In the right plot of Figure 1, we present the histogram of the position angles of the sum of the two modes with random intensity ratio. It is in qualitative agreement with the observed one (e.g. McKinnon 2003).

It should be noted that the propagation origin of pulsar polarization implies a certain correlation between the ellipticity and position angle of the polarization modes: both these quantities are determined by

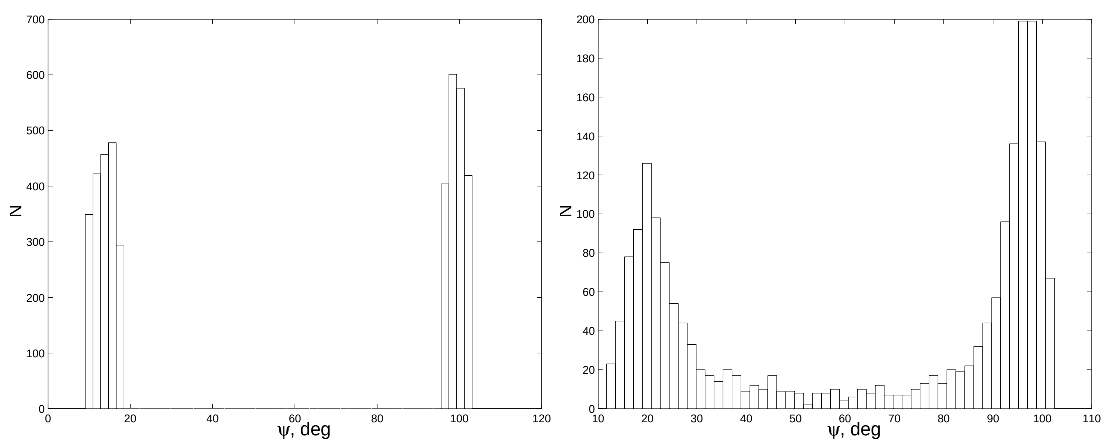

Fig. 1 Numerically simulated histograms of the final position angles given slight variations in the plasma parameters. Left: Position angles of the original ordinary and extraordinary modes. Right: Position angles of the sum of the two modes with random intensities.

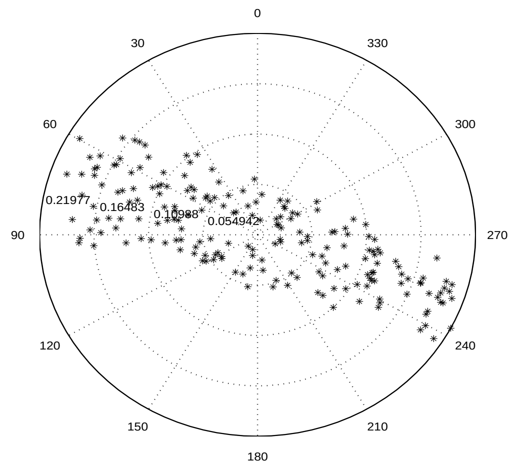

Fig. 2 Polarization orientations of the sum of slightly non-orthogonal modes given pulse-to-pulse fluctuations in the plasma parameters. The points are plotted in the Lambert's azimuthal equal area projection interrupted at the equator. Only the northern hemisphere is shown, where the ordinary wave dominates in intensity.

the instantaneous state of the ambient plasma. Figure 2 shows the two-dimensional scatter plot of the position angle and ellipticity in the Lambert's azimuthal equal area projection. One can see that the points prefer certain azimuths, just as is found in certain observations (Edwards 2004), though the overall scatter is markedly less. Thus, the expected correlation has a certain observational support, at least on a qualitative level. This is a strong argument in favour of the propagation model of pulsar polarization.

4 DISCUSSION AND CONCLUSIONS

The propagation model of pulsar polarization implies a unique possibility of diagnostics of pulsar plasma based on the polarization data. A simplified technique of the plasma density diagnostics and the preliminary results concerning the plasma density profiles can be found in Petrova (2003). A more general approach is developed in Petrova (2006a, b).

Note that the energetics of pulsar radio emission is much less than the total energetics of pulsar magnetosphere. Therefore it has long been thought that the radio emission can tell almost nothing about the global electrodynamics of pulsar magnetosphere. The suggested propagation model of pulsar polarization gives an opportunity to obtain the characteristics of the plasma flow, test the modern theories of pair creation cascade, find out the distribution of currents in the open field line tube, etc. A detailed description of pulsar plasma and comparison of the plasma fluctuations with the fluctuations in pulse intensities may also be useful for constraining the properties of the radio emission mechanism. Thus, further theoretical and observational studies of the individual pulse polarization in the light of propagation effects seem very promising.

Acknowledgements I am grateful to the Organizing Committee for the financial support which has made possible my participation in the Symposium. The work is in part supported by INTAS Grant No. 03-5727.

References

Edwards R., 2004, A&A, 426, 677
Lyubarskii Y. E., Petrova S. A., 1999, Ap&SS, 262, 379
McKinnon M. M., 2003, ApJ, 590, 1026
Petrova S. A., 2003, A&A, 408, 1057
Petrova S. A., 2006a, MNRAS, 366, 1539
Petrova S. A., 2006b, MNRAS, 368, 1764