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Coherent origin of peculiar polarization in radio pulsars

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Abstract. The observed polarization of radio pulsars involves several peculiar effects, such as comparable amount of orthogonal polarization modes (OPMs) which often bear the same handedness of circular polarisation V. In the average profiles of B1913+16 and B1933+16, orthogonal jumps of polarization angle (PA) are observed to occur at the maximum V, instead of $V = 0$. High levels of V are also observed in core components (eg. in B1237+25), where they are accompanied by strong distortions of PA from the rotating vector model. In weakly polarized emission, PA jumps by 45° are observed in B1919+21 and B0823+26. It is shown that all these peculiarities can be interpreted in a model which assumes coherent addition of waves in natural propagation modes.

Keywords. pulsars: general, radiation mechanisms: nonthermal

1. The nature of orthogonal polarization modes

The model assumes that pulsars emit a linearly polarized signal $\vec{E}$ that enters some intervening birefringent region, characterised by the polarization basis $(\vec{x}_1, \vec{x}_2)$ (Fig. 1a). The basis is misaligned with $\vec{E}$ by the incident angle $\psi_{\rm in}$. The incident signal is split into two natural mode waves $\vec{E}_1$ (dotted) and $\vec{E}_2$ (solid) that are orthogonally polarized with respect to each other. While propagating through the region, the waves acquire a relative phase lag $\Delta\phi$ (Fig. 1a). After leaving the region, the waves combine, i.e. are added coherently. Thus, the model is empirical and similar to the Faraday rotation effect.

The two main parameters, $\psi_{\rm in}$ and $\Delta\phi$, are drawn from statistical distributions $N_{\psi,{\rm in}}$ and $N_{\Delta\phi}$, supposedly produced by the stochastic nature of the emission and propagation processes. The distributions represent the spread of values as recorded in single pulse observations at a fixed pulse longitude. As described in Dyks (2017, hereafter D17), the peak of $N_{\psi,{\rm in}}$ is determined by the relative orientation of the magnetic field in the emission and intervening regions. The peak position and width of $N_{\Delta\phi}$ are treated as free parameters. In general, arbitrary pairs of $\psi_{\rm in}$ and $\Delta\phi$ produce elliptically polarized radiation, with the ellipse major axis, hence the PA, at any orientation with respect to the main polarisation directions $\vec{x}_1$ and $\vec{x}_2$. However, when the lag distribution $N_{\Delta\phi}$ encompasses the value of $\Delta\phi = \pi/2$, the situation is different. As shown in Fig. 1, for $\Delta\phi = \pi/2$, only the ellipses parallel to either $\vec{x}_1$ or $\vec{x}_2$ are produced, regardless of the $\psi_{\rm in}$ value. Note that in Fig. 1 the same phase lag of $\pi/2$ is applied to two different incident angles: $\psi_{\rm in} = 65°$ (Fig. 1a) and 25° (1b). In this way two observed orthogonal modes are produced, as represented by the ellipses $\rm M_1$ and $\rm M_2$. Importantly, these observed modes should be discerned from the natural orthogonal propagation modes that are presented by the waves $\rm m_1$ and $\rm m_2$. The coherently produced orthogonal modes ($\rm M_1$ and $\rm M_2$) are elliptical, and can easily have the same handedness of V, which is the case for the values of $\psi_{\rm in}$ used in Fig. 1.

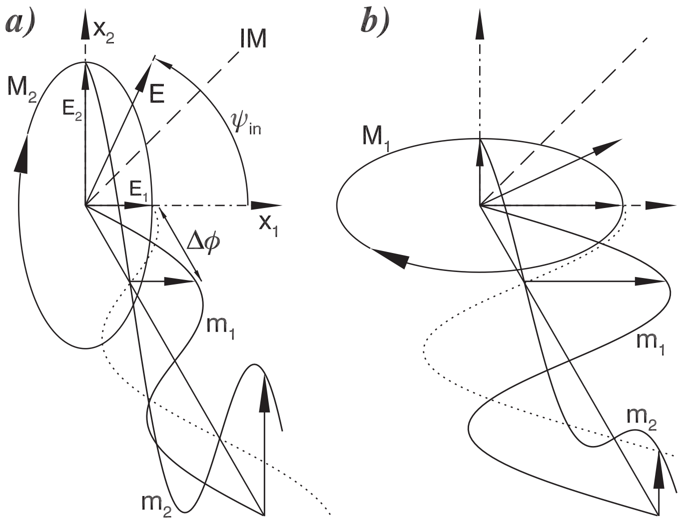

Figure 1. The origin of observed orthogonal polarization modes, represented by the ellipses M_1 and M_2, as a coherent sum of the phase lagged natural mode waves m_1 and m_2. Note the same handedness of both modes.

For phase lags in the vicinity of $\pi/2$, the orientation of the modal ellipses is always close to $\vec{x}_1$ or $\vec{x}_2$, so the corresponding (modal) PAs vastly outnumber other PA values (see Fig. 4 in D17). Here 'other values' means PAs for $\Delta\phi \neq \pi/2$ and arbitrary $\psi_{\rm in}$ that correspond to ellipses misaligned with respect to $\vec{x}_1$ or $\vec{x}_2$. These nonmodal PA values contribute to wide PA distributions that accompany the narrow modal PA peaks (in a PA distribution observed at a given pulse longitude).

In the course of pulsar rotation, $\psi_{\rm in}$ is changing with the pulse longitude. When $\vec{E}$ coincides with the dashed intermode separatrix (i.e. $\psi_{\rm in} = 45°$), the orthogonal mode jump at maximum V occurs. The maximum degree of circular polarisation that is observed at the PA jump, depends on the peak position and width of $N_{\Delta\phi}$. The step-wise PA curve of B1913+16 (Weisberg & Taylor 2002), with the OPM transitions at peaks of V, can be interpreted in this way (cf. figs 1 and 7 in D17). The application of the model to the loop-shaped core PA distortions (Mitra *et al.* 2016), and to the 45° PA jump, is also described in D17.

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