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A broad-band perspective on circular polarization in radio pulsar observations

Lucy S. Oswald[1,2]

[1]Department of Astrophysics, University of Oxford, Denys Wilkinson building, Keble road, Oxford OX1 3RH, UK

[2]Magdalen College, University of Oxford, Oxford OX1 4AU, UK
email: lucy.oswald@physics.ox.ac.uk

Abstract. We investigate the broad-band behaviour of circular polarization in radio pulsar profiles and show the relationship between polarization fraction and what proportion of that polarization is circular, both across frequency, and for a large number of pulsars viewed collectively. The behaviour observed may be explained by pulsar polarization originating from the partially-coherent combination of two linearly-polarized orthogonal modes with different flux spectral indices. (See also the poster in the "supplementary information".)

Keywords. pulsars: general, polarization

1. Introduction

The presence of circular polarization in pulsar observations is yet to be conclusively explained. Past work has shown, for example, a relationship between orthogonal polarization modes and circular polarization behaviour in single pulses (Karastergiou *et al.* 2003) and an explanation for departures from the rotating vector model as originating from coherent addition of orthogonal modes (Dyks 2017). We investigate the origins of pulsar radio polarization through studying the broad-band behaviour of circular polarization and how that evolves with frequency and across the pulsar population.

2. Method

We use data from the P574 project, which observes pulsars using the Parkes Ultra-Wideband Receiver (UWL), producing high quality polarized pulse profiles across the broad frequency range 700-4000 MHz, as described in Johnston *et al.* (2021) and Sobey *et al.* (2021). Auto- and cross- correlations of the signals from the two orthogonally polarized feeds of the UWL provide polarization measurements as Stokes parameters I, Q, U and V. Circular polarization is $V = 2E_xE_y \sin\phi$, where $E_{x,y}$ are the electric field amplitude components in an x-y basis and ϕ is the phase offset between them.

For this work we selected 81 bright pulsars, each unaffected by radio frequency interference and with peak signal-to-noise ratio $S/N > 10$. We split the frequency band into 8 channels and summed the Stokes parameters across the pulse profile to give a single value per channel ($I^* = \Sigma I$ etc.). Summing reduces complexity and increases signal-to-noise ratio, but loses information about variability across the pulse profile.

We define two parameters to investigate polarization behaviour. Polarization fraction is $P^*/I^* = \frac{\sqrt{{Q^*}^2+{U^*}^2+{V^*}^2}}{I^*}$. Circular contribution θ^* is defined as the polar angle on

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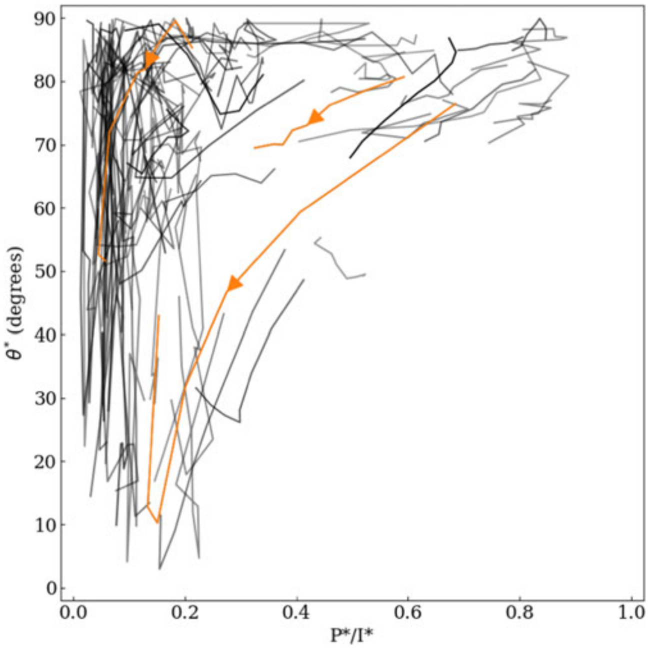

Figure 1. θ^* vs. P^*/I^* (both defined in the text) plotted across frequency as individual lines for each of 81 pulsars and shaded according to log-scaled signal-to-noise ratio of total intensity, to aid visual separability of different tracks. Three example tracks are picked out in orange, with arrows marking the direction of increasing frequency.

a Poincaré half-sphere, as $\theta^* = \arctan\left(\frac{\sqrt{Q^{*2}+U^{*2}}}{|V^*|}\right)$, such that fully linearly polarized radiation has $\theta^* = 90°$, and $\theta^* = 0°$ describes fully circularly polarized radiation.

3. Results

Each line in Figure 1 shows the variation of both θ^* and P^*/I^* for a single pulsar. Plotting them all together builds a statistical distribution of the polarization behaviour of the pulsar population. Highly polarized pulsars (large P^*/I^*) are predominantly linearly polarized (large θ^*), but less polarized pulsars can have any level of circular polarization. Although measurement accuracy is more difficult at lower polarization fractions, this behaviour is clear even if only considering pulsars with polarization fractions greater than 20%. Looking at the frequency-dependent tracks, there is a tendency to move from high-polarization, high-linear points to low-polarization, increased-circular, both when considering individual cases (see figure) and as a whole. The frequency-dependent effect is likely impacted by summing Stokes parameters across pulse phase, but consistent with the collective behaviour of the pulsar sample.

4. Conclusions

This behaviour, both collectively and across frequency per pulsar, can be explained if the observed polarization results from the partially coherent combination of two linearly-polarized orthogonal modes with different flux spectra. The same scenario may be relevant under more extreme conditions for magnetars, for example providing an explanation for the dramatic variations in the radio polarization of the magnetar XTE J1810–197 seen by Dai *et al.* (2019).

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