Polarimetric profiles of 27 millisecond pulsars

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ABSTRACT
We present high time resolution polarimetric profiles of 27 predominantly southern hemisphere millisecond pulsars, 15 of which have no previously published polarimetry. These observations were made with a new 128-MHz baseband recorder at the Parkes Observatory. There has been some suggestion that millisecond pulsar profiles can undergo radical changes in both pulse shape and polarimetry, mainly due to discrepancies between the Bonn and Jodrell Bank polarimetric studies. If millisecond pulsars are intrinsically unstable, this has ramifications for precision timing and the millisecond pulsar emission mechanism. However, we find ourselves in good agreement with the Jodrell Bank data, and, in most cases, very poor agreement with the Bonn results. The presented polarimetric observations do display some phenomena common to those displayed by normal pulsars, including orthogonal mode transitions in position angle and associated sense changes of circular polarization. The behaviour of the position angle presented by these pulsars is, with some significant exceptions, a shallow or flat sweep across the pulse. This behaviour lends support to theories that suggest millisecond pulsar emission regions are wider, at least in terms of pulse longitude, than those of the normal pulsars. The broad millisecond pulsars J2124−3358 and J2145−0750 display position-angle behaviour that departs significantly from that expected if the magnetic field of these pulsars has a simple dipolar structure.

Key words: polarization – pulsars: general.

1 INTRODUCTION
The polarimetry of pulsars, as displayed by their mean pulse profiles, has provided a great deal of insight into the structure and geometry of the magnetic field in these objects. The prime tool for this analysis has been the application of the ‘rotating vector model’ (RVM) (Radhakrishnan & Cooke 1969) to the position angle of the linear polarization as a function of pulse phase. The underlying assumption is that there is a direct relationship between the orientation of the magnetic field lines and the position angle of the polarized radio emission. The characteristic S-shape of the position-angle dependence can be fitted with a trigonometric function that is parametrized by the impact parameter of the magnetic field with the line of sight and the magnetic inclination axis. This model can then be used to constrain the orientation of the magnetic field with respect to the rotation axis. The S-shape behaviour of the position angle is common in pulsars and analysis of the shape of the mean profiles, the number of components, their polarimetry, and the phase dependence of position angle has allowed authors to characterize a number of these ‘normal pulsars’ (Backer 1973; Rankin 1983; Lyne & Manchester 1988). The RVM has also been used as a constraint when investigating models of the underlying emission process (see Manchester 1995, for a review).

Millisecond pulsars (MSPs) represent a markedly different population to that of normal pulsars with periods near one second. Their spin periods are typically two to three orders of magnitude shorter and their inferred magnetic fields are three to four orders of magnitude smaller. Initial studies of a limited number of MSPs indicated that the millisecond pulsar population had polarimetric behaviour in common with that of the normal pulsars. Orthogonal mode transitions in position angle, sense changes in circular polarization, and in some cases consistent RVM fits to position angle have been observed (Thorsett & Stinebring 1990; Arzoumanian et al. 1996); in other cases the polarimetry has been inconsistent with a dipolar field model (Navarro et al. 1997). Since improvements in instrumentation have permitted the high time resolution required for MSP observations, polarimetric studies of a large number of predominantly northern hemisphere MSPs have been published (Sallmen 1998; Xilouris et al. 1998; Stairs, Thorsett & Camilo 1999). MSP polarimetry is now not easily reconciled with the models that have been so successful in characterizing the normal pulsar population. The main departure from normal pulsar behaviour is in the observed position angle. The characteristic steep S-shape is generally absent.

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the predominant behaviour being flat or very shallow position-angle sweeps. Furthermore, a number of MSPs display very complicated multicomponent position-angle swings that are not consistent with a simple dipolar field.

This paper represents the first polarimetry from 15 southern hemisphere MSPs, predominantly from the Parkes 70-cm and the Swinburne intermediate-latitude surveys. Polarimetry for a number of pulsars already in the literature is also presented in order both to confirm the validity of our polarimetric calibration and to provide an independent data set for comparison with the published work. We find ourselves in marked disagreement with some of the observations presented by Xilouris et al. (1998); however, our data are consistent with those published by other authors.

2 OBSERVATIONS

The observations were carried out over approximately 200 d from late 2002 to 2003 July using the Parkes 64-m radio telescope. The observing system used was the Second Caltech–Parkes–Swinburne recorder (CPSR2), a baseband recorder that performs 2-bit sampling on four 64-MHz bands. The baseband data is processed in real time by an associated cluster of 30 dual-processor 2.2-GHz Pentium 4 computers. The data reduction consists of the formation of a 128-channel coherent baseband record. The Multibeam receiver is equipped with a noise diode that is used to inject a polarized reference signal into the feed horn. Separate observations of this reference signal are commonly used to determine the linear polarization. Separate observations of this reference signal are commonly used to determine the linear polarization.

Table 1. Flux density and polarimetric measurements for the majority of the pulsars presented. The tabulated flux values are suffering from a selection effect, discussed in Section 2.2, which overestimates the intrinsic mean flux. Spin and astrometric parameters for J1933–6210 and J2010–1323 are, as yet, not completely determined.

<table>
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<tr>
<th>Pulsar</th>
<th>$P$ (ms)</th>
<th>$P_{\text{f}}$ (10$^{-20}$)</th>
<th>$B_{\text{surf}}$ ($10^{3}$ G)</th>
<th>Ensemble average flux (mJy)</th>
<th>Published flux at 1400 MHz (mJy)</th>
<th>$(L/I)^{a}$ (per cent)</th>
<th>$(V/I)^{b}$ (per cent)</th>
<th>Total integration time (s)</th>
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</table>
| J2145–0750 | 16.05    | 2.99                       | 6.26                          | 9.4                        | 7.0$^{b}$,6.5$^{b}$           | 16                     | 5                      | 3597                     

Notes: $^{a}$Fractional polarization is presented as the average fractional polarization across the on-pulse region; this can produce anomalous results for narrow pulse profiles with low signal-to-noise ratio, especially in case $^{c}$. Uncertainties in the polarization are discussed in the text. MP refers to the main pulse region and IP to the interpulse region, defined by whichever profile component is strongest at this frequency. $^{b}$Flux calibrated using calibration observation separated from pulsar position. References: (1) Foster, Fairhead & Backer (1991), (2) Fomalont et al. (1992), (3) Camilo (1995), (4) Toscano et al. (1998), (5) Stairs et al. (1999), (6) Manchester et al. (2001).
the complex gains of the two polarizations. Implicit in this calibration scheme are the assumptions that the reference signal is 100 per cent linearly polarized, that it uniformly illuminates both receptors, and that the feed is ideal; that is, composed of two orthogonally polarized receptors. However, it has been shown that the receptors of the Multibeam receiver have ellipticities of approximately 5.7°, and that the reference signal consists of ∼3 per cent circular and ∼90 per cent linear polarization with a position-angle offset of ∼1.5° (van Straten 2004). The receptor ellipticities primarily act to rotate the observed polarization vector about the U-axis by ∼0.2 radians, an effect that remains untreated in the oversimplified calibration method in common use.

In order to calibrate the data presented in this paper, we employ the method developed by van Straten (2004) to determine both the full polarimetric response of the receiver as well as the Stokes parameters of the reference signal at a given epoch. Time variation of the complex gains of the two polarizations is estimated using measurements of the reference signal made near the epoch of the pulsar observation. If the Jones matrix, \( J_0 \), describes the instrumental response at the reference epoch, then

\[
J = G \, B_\beta(\beta) \, R_\phi(\phi) \, J_0
\]

(1)

represents the instrumental response at the epoch of interest. Here, \( G \) arises from the change in absolute gain, \( B_\beta(\beta) \) is the Lorentz boost transformation resulting from the change in differential gain, and \( R_\phi(\phi) \) is the rotation due to the change in differential phase. The coherency matrix of the reference signal observed at the epoch of interest is equal to

\[
\rho'_c = J \rho_c J^\dagger,
\]

(2)

where \( \rho_c \) represents the coherency matrix of the input reference signal determined at the reference epoch. Given \( \rho'_c, J_0 \) and \( \rho_c \), equation (2) is solved for \( G, \beta \) and \( \phi \).

Comparison of the solutions of \( J_0 \) and \( \rho_c \) derived at different epochs indicates that, on time-scales of the order of a month, the ellipticities and relative orientations of the receptors vary by less than 1° and the polarization of the reference signal changes by less than 1 per cent. Therefore, although the formal error in each parameter is much smaller we conservatively assume that the accuracy of our receptor ellipticity and orientation estimates is of the order of one degree. Furthermore, by simulating the effects of incorrect calibration, we estimate that the relative distortion of total intensity is at most 2 per cent and the relative distortion of the linear and circular polarizations is less than 4 per cent. Table 1 presents average fractional linear, and average fractional absolute circular polarization measures for the observations. These values represent the fractional polarization averaged over the entire on-pulse region; as such, the peak polarization...
Polarimetric profiles of millisecond pulsars

Figure 2. As Fig. 1, for J1045 – 4509, J1455 – 3330, J1435 – 6100 and J1600 – 3053. The flux measure of J1435 – 6100 should not be considered precise (see text); it is therefore presented in relative flux units.

fractions are typically considerably higher that that presented in the table.

2.2 Flux calibration

The reference flux density of the noise diode was calibrated using observations of the radio galaxy, Hydra A. Unfortunately, calibration observations for individual pulsar detections were performed only if the observation was deemed to have a sufficient signal-to-noise ratio to warrant polarimetric calibration. As a result, the flux values presented in Table 1 are subject to a selection effect: only high signal-to-noise ratio observations were calibrated. The tabulated value is formed for an average of all the calibrated values for individual pulsars. A small number have no presented value as no flux-calibrated observation has yet been obtained for them.

3 MILLISECOND PULSAR POLARIMETRY

3.1 J0613 – 0200

Discovered in the Parkes 70-cm survey (Lorimer et al. 1995), PSR J0613 – 0200 is a 3.06-ms pulsar in a 1.2-d binary orbit with a companion of minimum mass 0.3 M⊙. As the relative strengths of the constituent components evolve considerably with frequency, it is possible to compare our result only with the 1410-MHz profile presented by Xilouris et al. (1998); we find ourselves in considerable disagreement. In Fig. 1, we show evidence of both linear and circular polarization in the two trailing components; the previously published profile shows no such polarization. We do, however, agree with Xilouris et al. (1998) in the form of the total intensity. As indicated by Stairs et al. (1999) there is very little evolution in total intensity between 410 and 789 MHz, but very rapid profile morphology evolution between these lower frequencies and the 1341-MHz profile presented here. The polarimetry at longer wavelength has been published by Stairs et al. (1999) and Sallmen (1998). At these lower frequencies the trailing component dominates and is more polarized than the presented 1341-MHz profile. The polarization position angle is not well defined.

3.2 J0711 – 6830

This is an isolated 5.49-ms pulsar discovered in the Parkes 70-cm survey (Bailes et al. 1997). We present, in Fig. 1, the first published polarimetry on this pulsar. There is emission evident throughout 75 per cent of the pulse period, but a large portion of this is at a low level. The majority of the pulsar flux is concentrated in two components that are both slightly polarized. The position-angle swing is flat.
across both components, with a possible orthogonal mode jump at the trailing edge of each component.

3.3 J1022+1001

This is a 16.5-ms binary pulsar with a 7.8-d orbital period. It was concurrently discovered at 370 and 430 MHz in both the Green Bank 140-ft telescope survey (Sayer, Nice & Taylor 1997) and the Princeton–Arecibo Declination-Strip survey (Camilo et al. 1996). There are a considerable number of polarimetric observations in the literature (Shrauner 1997; Sallmen 1998; Xilouris et al. 1998; Kramer et al. 1999; Stairs et al. 1999; Ramachandran & Kramer 2003). It should be noted that we are in complete agreement with previously published profiles except that presented by Xilouris et al. (1998). In this case we have agreement in terms of linear polarization and position-angle swing, but we show marked disagreement in the structure of circular polarization (see Fig. 1). The work presented here, together with that presented by other authors, indicates that the circular polarization profile presented by Xilouris et al. (1998) is incorrect. The presented profile appears to rest upon a plateau of low-level emission that is not evident in other published profiles. This plateau may be an artefact of the digitization process known as ‘scattered power’ (Jenet & Anderson 1998), which plagues observations of strong pulsars when limited precision is used during digitization.

3.4 J1024–0719

This is an isolated 5.16-ms pulsar discovered in the Parkes 70-cm survey (Bailes et al. 1997). A polarimetric profile is presented in Xilouris et al. (1998), with which we are in general agreement (see Fig. 1). The third pulse component shows slightly more linear polarization in the previously published profile, but we agree with the form of the linear polarization and the flat position-angle swing.

3.5 J1045–4509

This is a 7.47-ms binary pulsar with an orbital period of about 4.1 d. It was also discovered in the Parkes 70-cm survey (Bailes et al. 1994). Both linear and circular polarization are present across nearly all the emission; the position-angle swing is complicated, but in general terms flat (see Fig. 2).

3.6 J1435–6100

Discovered in the Parkes Multibeam Survey (Camilo et al. 2001), J1435–6100 is a 9.3-ms pulsar in a 1.35-d orbit about a massive white-dwarf companion. The pulsar does not appear to display much polarization (see Fig. 2). This observation was calibrated using noise diode observations not coincident with the pulsar observation, therefore an accurate flux determination has not been possible. It is
possible that the apparent lack of polarized flux could be due to a lack of time resolution in the presented profile; only an observation of considerably higher signal-to-noise ratio would confirm this.

3.7 J1455−3330
PSR J1455−3330 is another pulsar discovered in the Parkes southern sky survey at 70 cm (Lorimer et al. 1995). It is a 7.9-ms pulsar in a 76-d binary orbit about a low-mass companion. There is no evident polarized flux from this pulsar (see Fig. 2).

3.8 J1600−3053
This is a 3.6-ms binary pulsar, in a 14.3-d orbit, recently discovered in the high-latitude pulsar survey conducted at Parkes observatory (Jacoby et al., in preparation). As shown in Fig. 2, the position-angle swing across the pulsar is essentially flat with two apparent orthogonal mode jumps. Both are associated with a null in the linear polarization and the trailing jump is also associated with a clear sense change in the circular polarization. These properties are reminiscent of the orthogonal mode jumps observed in unrecycled pulsars.

3.9 J1603−7202
PSR J1603−7202 is a 14.8-ms binary pulsar in a 6.3-d binary orbit, discovered in the Parkes 70-cm survey (Lorimer et al. 1996).

3.10 J1629−6902
This is an isolated 6.00-ms pulsar discovered in the Swinburne mid-latitude pulsar survey (Edwards et al. 2001). As shown in Fig. 3, the majority of the emission is only weakly polarized with a flat position angle. The central portion of the main peak is, however, considerably polarized, also with a flat position-angle swing. The two flat position-angle swings are separated in phase by a region of unpolarized emission and are separated in position angle by 90°. This is indicative of the position angle being flat across the entire pulse with an orthogonal mode jump between the two components.

3.11 J1643−1224
This 4.6-ms pulsar is in a long, 147-d, binary orbit. Polarimetric profiles of this pulsar have been published at 610 MHz by Stairs...
Figure 5. As Fig. 1, for J1824 − 2452, J1857 + 0943, J1909 − 3744 and J1911 − 1114.

et al. (1999) and 1410 MHz by Xilouris et al. (1998). We show a lesser degree of polarization than the 610-MHz observation (see Fig. 3), which is consistent with the trend, displayed by normal pulsars, of decreasing polarized flux at higher frequencies. Though consistent with the published 1410-MHz profile we include position-angle measurements closer to the leading edge of the emission than the plots presented by Xilouris et al. (1998).

3.12 J1713+0747
This is a 4.57-ms pulsar in a 67.8-d orbital period which exhibits bright scintillation maxima. The observations presented, in Fig. 3, are consistent with those of Sallmen (1998) and Stairs et al. (1999). Although we measure a small amount of circular polarization and Sallmen (1998) do not, this could be due to imperfect calibration in our data set, cf. Section 2.1. We are in marked disagreement with the position-angle swing presented in Xilouris et al. (1998), but the form of the linear and circular polarizations agree within experimental uncertainties.

3.13 J1730−2304
Sallmen (1998) and Xilouris et al. (1998) both present a 1410-MHz profile of this isolated 8.12-ms pulsar. As presented in Fig. 4, we find ourselves in good agreement with Sallmen (1998). However, we are in disagreement with the form of polarization presented by Xilouris et al. (1998), who present a profile with considerably more linear polarization. We do find a similar position-angle swing to that presented by Xilouris et al. (1998).

3.14 J1732−5049
This 5.3-ms pulsar is in a 5.26-d binary orbit around a high-mass companion. It was recently discovered in the Parkes mid-latitude pulsar survey (Edwards et al. 2001). The emission is slightly polarized across the majority of the profile; there is a flat position-angle swing, with a clear orthogonal jump (see Fig. 4).

3.15 J1744−1134
This nearby, isolated, 4.07-ms pulsar was discovered in the Parkes 70-cm survey (Bailes et al. 1997). Polarimetric profiles have been published by Stairs et al. (1999) at 610 MHz, and by Xilouris et al. (1998) at 1410 MHz. Stairs et al. (1999) present a completely polarized profile at 610 MHz and a flat position-angle swing. The profile presented here, taken at 1405 MHz, is also completely linearly polarized with a flat position-angle swing (Fig. 4). In contrast, Xilouris et al. (1998) present only a partially polarized profile, but with a consistent flat position-angle swing.
3.16 J1757−5322

This pulsar is often considered to be the twin of PSR J1732−5049, as it was discovered on the same day only ∼5° apart on the sky and exhibits a similar pulse morphology. It is an 8.87-ms pulsar, in orbit about a high-mass companion and discovered in the Parkes mid-latitude survey (Edwards et al. 2001). Although similar to the total intensity profile of its twin, this pulsar displays a higher degree of polarization. The position-angle swing has a shallow slope across the central component (Fig. 4).

3.17 J1824−2452

This isolated 3.05-ms pulsar was discovered in the globular cluster M28 (Lyne et al. 1987). The presented 1405-MHz profile is consistent with that presented by Sallmen (1998). It is interesting to compare these profiles with the 610-MHz profile presented by Stairs et al. (1999). Significant profile evolution occurs between the lower frequency and the presented profile, but the polarization fraction appears stable. The position angle is more clearly defined at the higher frequency and extends across a greater fraction of the emission (Fig. 5).

3.18 J1857+0943

This 5.36-ms pulsar in a 12.34-d orbital period binary has been studied at 1400 MHz by Segelstein (1986) and 1410 MHz by Xilouris et al. (1998). The results presented here (Fig. 5) are in agreement with those previously published. The position-angle swing across both components is quite complicated. Even the interpulse displays position-angle discontinuities indicative of orthogonal mode switching. Xilouris et al. (1998) present a profile of greater signal-to-noise ratio, and make the observation that the position-angle discontinuity is actually not quite orthogonal. We cannot confirm this, but can confirm that at the pulse phase coincident with the discontinuity, the linear polarization is non-zero, and there is no sense change in the circular polarization. This is inconsistent with an orthogonal mode.

3.19 J1909−3744

This 2.9-ms pulsar, with a 1.5-d orbital period, is showing a great deal of promise as a precision timing target (Jacoby et al. 2003). It was discovered as part of the Swinburne high-latitude pulsar survey (Jacoby et al., in preparation). The pulse profile is very narrow, extending over only 2 per cent of the pulse period. Both linear and circular polarization are of moderate degree, and concentrated in the centre of the emission (Fig. 5).

3.20 J1911−1114

J1911−1114 is a 3.6-ms pulsar in a 2.7-d binary orbit discovered in the Parkes 70-cm survey. The profile presented here (see Fig. 5) is of
limited signal-to-noise ratio, but an appreciable degree of polarization is evident in both the leading and trailing profile components. The leading component shows a flat position-angle swing, whereas there is evidence of very rapid position-angle variation across the remainder of the profile.

### 3.21 J1933−6210

This 3.5-ms pulsar in a 12.8-d binary system displays an interesting polarimetric structure (see Fig. 6). The two main components display a small degree of both linear and circular polarization.

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**Figure 7.** As Fig. 1, for J2124−3358, J2129−5721 and J2145−0750.

**Figure 8.** RVM fits to the positional angle of linear polarization displayed by J1022+1001 (left) and J1824−2452 (right).
position angle is measurable over a large fraction of the emission. The position angle displays a shallow sweep across the regions of greatest polarization. The degree of polarization in the extremities of the profile is very low.

3.22 J1939+2134

The polarimetry of this 1.55-ms isolated pulsar, the first discovered (Backer et al. 1982), has been studied by a number of authors (Ashworth, Lyne & Smith 1983; Stinebring & Cordes 1983; Stinebring 1983; Stinebring et al. 1984; Thorsett & Stinebring 1990; Sallmen 1998; Stairs, Thorsett & Camilo 1999) with whom we are in agreement. The position-angle swings across both components are flat with an orthogonal mode jump in the position angle on the leading edge of the main pulse (see Fig. 6).

3.23 J2010−1323

This isolated 5.2-ms pulsar, discovered in a high-latitude pulsar survey (Jacoby et al., in preparation), displays very little polarization (Fig. 6).

3.24 J2051−0827

This eclipsing, binary millisecond pulsar was discovered in the Parkes 70-cm survey (Stappers et al. 1996). It has a 4.5-ms spin period and a 0.099-d orbital period. The polarimetry of this pulsar has been presented at 410 MHz and 610 MHz by Stairs et al. (1999) and at 1410 MHz by Xilouris et al. (1998). The polarimetry is consistent across this entire frequency range and we find ourselves in general agreement with the profile presented by Xilouris et al. (1998) (Fig. 6). The profile presented here displays a slightly lower degree of polarization, but the profiles are in agreement at the level of experimental uncertainty.

3.25 J2124−3358

This 4.9-ms isolated pulsar discovered in the Parkes 70-cm survey displays the most interesting position-angle evolution of all the pulsars presented in this paper (see Fig. 7). The pulsar has emission extending almost entirely throughout the pulse period, with a very complicated multicomponent profile. Every component displays some degree of polarization, but with varying degree. One component is almost entirely linearly polarized and displays a position-angle sweep of shallow, but stable slope. Although the emission is almost continuous across the pulsar period, the position-angle evolution is not smooth, and shows discontinuities and jumps throughout. The complex position-angle behaviour is reminiscent of that displayed by PSR J0437−4715 (Navarro et al. 1997) and the J2145−0750 profiles presented here and in Stairs et al. (1999).

3.26 J2129−5721

Discovered in the Parkes 70-cm survey, this is a 3.7-ms pulsar in a 6.6-d binary orbit about a companion with minimum mass of 0.14 $M_\odot$ (Lorimer et al. 1996). The polarimetric profile displays moderate circular and linear polarization, with a position-angle swing across the profile that, although generally flat, displays some structure (see Fig. 7).

3.27 J2145−0750

J2145−0750 is a 6.8-d binary pulsar with a spin period of approximately 16.05 ms. Stairs et al. (1999) have observed this pulsar at 410, 610 and 1414 MHz and present polarimetric behaviour in good agreement with that presented here (see Fig. 7). The pulsar is only weakly polarized, but the polarization angle is measurable across the entire profile. The position-angle evolution is complicated and displays regions of both flat and varying position angle, together with discontinuities and orthogonal transitions. As reported by Stairs et al. (1999) another polarimetric profile presented by Xilouris et al. (1998) shows markedly different behaviour. The profiles differ in both fraction and structure of polarization as well as position angle. Sallmen (1998) also report two different polarimetric profiles for this pulsar, one consistent with that reported by Xilouris et al. (1998) and one consistent with that presented here. Sallmen (1998) observe that this behaviour could be due to competition between non-orthogonal modes of emission. We have observed this pulsar on a number of occasions throughout the last 200 d and have not observed the pulsar to be in any other state than that presented here.

4 THE ROTATING VECTOR MODEL

The slow-pulsar population commonly display a distinct S-shaped position-angle swing across the integrated mean polarimetric profile. This S-shaped curve can be fitted by a trigonometric function, first presented by Radhakrishnan & Cooke (1969). In this formalism the orientation of the magnetic field with respect to both the line of sight to the pulsar, and its spin axis, can be constrained. The measured position angle, $\psi$, is presented as a function of the angle between the rotation and magnetic axes $\alpha$, the angle between the magnetic axis and the line of sight $\beta$ and pulse phase $\phi$:

$$\tan(\psi(\phi) - \psi_0) = \frac{\sin \alpha \sin(\phi - \phi_0)}{\cos \alpha \sin \beta - \sin \alpha \cos \beta \cos(\phi - \phi_0)},$$

where $\zeta = \alpha + \beta$ and is the angle between the spin axis and the line of sight, $\phi_0$ is the pulse phase of Steepest position-angle swing and $\psi_0$ is a constant position-angle offset. Although the RVM has proven extremely successful in characterizing the normal pulsar population, it has been less effective when applied to MSPs. In general the position-angle swing presented in these profiles is shallow, with no S-shaped curve. Under these circumstances the model does not provide a strong restriction on the magnetic field inclination, especially when the profile is narrow. The common orthogonal jumps also add further complications. This failure to follow the RVM description leads us to the conclusion, in common with other authors (Sallmen & Backer 1998; Stairs et al. 1999) that the MSP magnetospheres are, in general, more complex than those of the normal pulsar population.

4.1 J1022+1001

This pulsar is the exception to the general MSP population presented here, in that it does display an S-shaped swing in its position angle, albeit with a pronounced short-term deviation for a few degrees of pulse phase (see Fig. 8). The position-angle curve has been investigated by a number of authors and measurements of the magnetic field orientation angles have also been presented by Xilouris et al. (1998), Stairs et al. (1999) and Ramachandran & Kramer (2003). We find $\beta = 6.2 \pm 0.1$, which is slightly lower that that presented by the other authors, who find a result $\beta \sim 7^\circ$. The discrepancy could well be due to the marked departure from traditional S-shape behaviour at the leading edge of the position-angle swing.
4.2 J1824–2452

Backer & Sallmen (1997) and Stairs et al. (1999) present values of α and β for this pulsar measured at 820 MHz and 610 MHz, respectively. Backer & Sallmen (1997) estimate α = 50° and β = 40°. Stairs et al. (1999) present a consistent result of α = 40°±1.7°, β = 40°±10°. Our measurements, centred at 1373 MHz, provide a possible fit with α = 34°±4° and β = 84°±13° (see Fig. 8); although not consistent within the formal errors, this result is consistent within the systematic errors resultant from applying the RVM to poorly sampled spin-period coverage. This result indicates that the emission geometry is consistent across a considerable range of radio frequency.

5 CONCLUSIONS

The new MSP polarimetric profiles presented in this paper are consistent with the MSP profiles previously published in that; the position-angle swings are generally flat: a small number of pulsars have very complicated, non-dipolar-position-angle swings; and the MSPs display some features, such as circular polarization sense changes and orthogonal mode behaviour, that are common to normal pulsars. Within our own data set we find no evidence for any variability of MSP polarimetric profiles, as has been suggested by Stairs et al. (1999) to explain the disparity between the J2145–0750 profile and that presented by Xilouris et al. (1998). If variable polarimetric structure could be confirmed this would further challenge pulsar emission models, for if the polarimetry is indicative of magnetic field structure, then changing polarimetric profiles imply changing field structures. Such a field geometry change, with no associated effect on the total intensity profile, would be difficult to explain in terms of current emission models. In common with other authors (Stairs et al. 1999) we, in some cases, measure polarimetric profiles inconsistent with those presented by Xilouris et al. (1998), but are consistent with other authors. The simplest interpretation of this is that many of the measurements presented by Xilouris et al. (1998) are in error and that millisecond pulsar profiles are reasonably stable.

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