

Rotation measure variations for millisecond pulsars

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Introduction

Pulsars are rapidly rotating highly magnetized neutron stars. It has been observed that radio emission from pulsars is highly polarized. The polarization properties of a pulsar are very important for understanding various observed pulsar phenomena. Polarization observations tell us a lot of information, not only about the emission process itself, but also about the interstellar medium.

The observed radiation from pulsars is affected by propagation effects along the path between the pulsar and the observatory. One of the various propagation effects is Faraday rotation, that is, the rotation of the plane of linear polarization caused by the different phase velocities of the two hands of circular polarization in a magnetized plasma. Pulsar radiation typically has strong linear polarization making it relatively easy to observe Faraday rotation for these sources. Faraday rotation is described by the rotation measure (RM), defined by $\psi = \text{RM} \cdot \lambda^2$, where ψ is the linear polarization position angle (PA) and $\lambda = c/\nu$ is the radio wavelength corresponding to radio frequency ν . The rotation measure is approximated by $\text{RM} = 0.810 \int_0^D n_e \mathbf{B} \cdot d\mathbf{l}$, where n_e is the interstellar electron density in units of cm^{-3} , $\mathbf{B}$ is the vector magnetic field in microgauss, $d\mathbf{l}$ is an elemental vector along the line-of-sight toward us (positive RMs correspond to fields directed towards us) in parsecs and RM is in units of rad m^{-2} .

Long-term changes in pulsar PAs possibly result from changes in the polarization of the emitted radiation or from changes in the RM along the path. Intrinsic PA changes could result from precession of the pulsar spin axis or changes in the magnetic configuration of the star. RM changes can occur as the path to the pulsar traverses different regions of the interstellar medium (ISM) or in the Earth's ionosphere due to the diurnal and other changes in the ionospheric total electron content.

Observations and Results

The PPTA observations were made at intervals of 2–3 weeks using the Parkes 64-m radio telescope with the centre beam of the 20 cm Multibeam receiver. The Multibeam receiver has a bandwidth of about 300 MHz centered at about 1.4 GHz. The basic parameters for the 20 PPTA MSPs with RM values derived from PDFB2 observations are listed in Table 1.

All data were recorded using the PSRFITS data format with 1-minute sub-integrations. A short 2-minute observation of the pulsed calibration signal was made before each pulsar observation. Flux density scales were established using observations of Hydra A which was assumed to have a flux density of 43.1 Jy at 1400 MHz and a spectral index of -0.91 . All observations were processed using the PSRCHIVE software. Strong narrow-band radio frequency interference (RFI) was identified by searching for spectral channels that were significantly above the local mean; such channels were excised from the data. Similarly, broad-band impulsive RFI was identified on zero-DM summed time-domain data and excised. The variations in instrumental gain and phase across the band and the effects of cross-coupling in the feed were removed using the calibration observations.

To measure the long-term changes in mean PA, we took the weighted average of the differences between the PAs across an individual observation profile and the PAs across the grand-average profile. This gives a relative PA shift for that observation and its estimated uncertainty. This is then repeated for all observations of a given pulsar to give the PA variations across the data span.

Figures 1 shows that there is little if any significant long-term variation in the corrected PAs. This implies that the mean PA of the emitted pulses and hence the orientation of the spin and magnetic axes of the pulsar have varied by 1° over the nearly 5-year data span. This is not surprising since six of the 20 pulsars are isolated and none of the 14 binary pulsars is in a close orbit where geodetic precession might be expected. In addition, most of the binary companions are evidently of relatively low mass (0.5 M). Because of the great age of these MSPs, any free precession resulting from interactions or deformations in the spin-up phase would be likely to have dissipated by now.

Figure 2 shows the IRI-corrected PAs for two PPTA pulsars. The straight line on each plot results from a weighted least-squares fit of a straight line to the data. To reduce the short-term scatter, weighted averages of the corrected PAs over 100-day blocks are shown in the middle panel, again with the fitted straight line. If we assume that there has been no variation in the intrinsic PA over this interval, we can convert the observed PA variations to equivalent RM variations as shown in the lower panel.

PSR	<i>P</i> (ms)	DM (cm^{-3} pc)	RM (rad m^{-2})	Data span (MJD)	Nr of Obs.
J0437–4715	5.757	2.64	−0.6	53703 – 55312	393
J0613–0200	3.062	38.78	9.7	53687 – 55407	125
J0711–6830	5.491	18.41	21.4	53660 – 55408	47
J1022+1001	16.453	10.25	−0.3	53727 – 55406	84
J1024–0719	5.162	6.49	−8.3	53688 – 55407	79
J1045–4509	7.474	58.17	92.3	53660 – 55408	110
J1600–3053	3.598	52.33	−15.8	53660 – 55406	103
J1603–7202	14.842	38.05	27.7	53703 – 55406	101
J1643–1224	4.622	62.41	−308.2	53724 – 55406	98
J1713+0747	4.570	15.99	9.3	53660 – 55406	112
J1730–2304	8.123	9.62	−7.2	53725 – 55387	70
J1732–5049	5.313	56.82	−6.7	53799 – 55117	22
J1744–1134	4.075	3.14	−1.6	53660 – 55406	107
J1824–2452	3.054	120.50	77.6	53688 – 55350	76
J1857+0943	5.362	13.30	18.2	53703 – 55406	62
J1909–3744	2.947	10.39	−6.5	53688 – 55406	174
J1939+2134	1.558	71.04	6.9	53816 – 55406	76
J2124–3358	4.931	4.60	−5.4	53660 – 55406	103
J2129–5721	3.726	31.85	23.5	53724 – 55389	62
J2145–0750	16.052	9.00	−1.3	53725 – 55389	67

Table 1 Parameters for the 20 PPTA pulsars

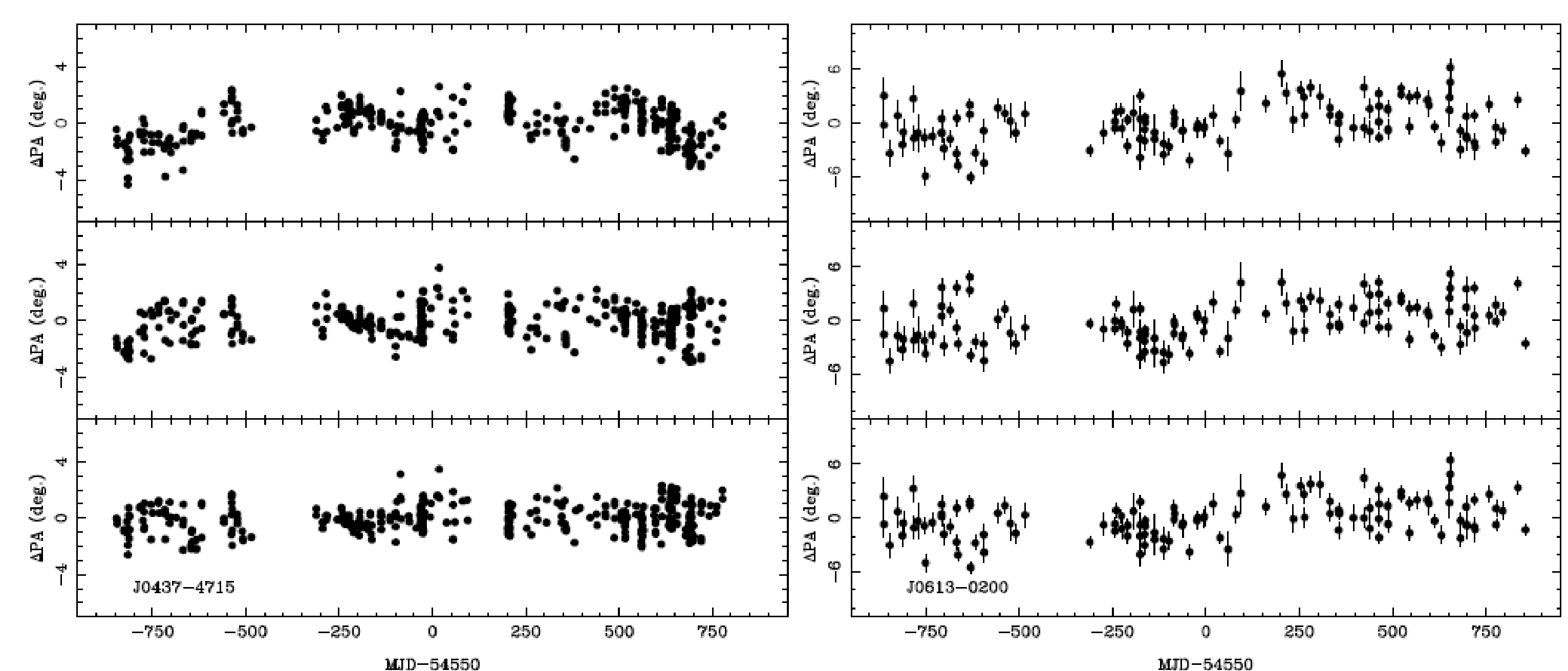


Figure 1: PA variations for two of the PPTA pulsars. In each sub-figure, the upper panel shows PA differences without ionospheric correction, the middle panel gives PA differences after ionospheric corrections using the Penticton program FARROT; the lower part shows differences after ionospheric corrections using the IRI ionospheric model

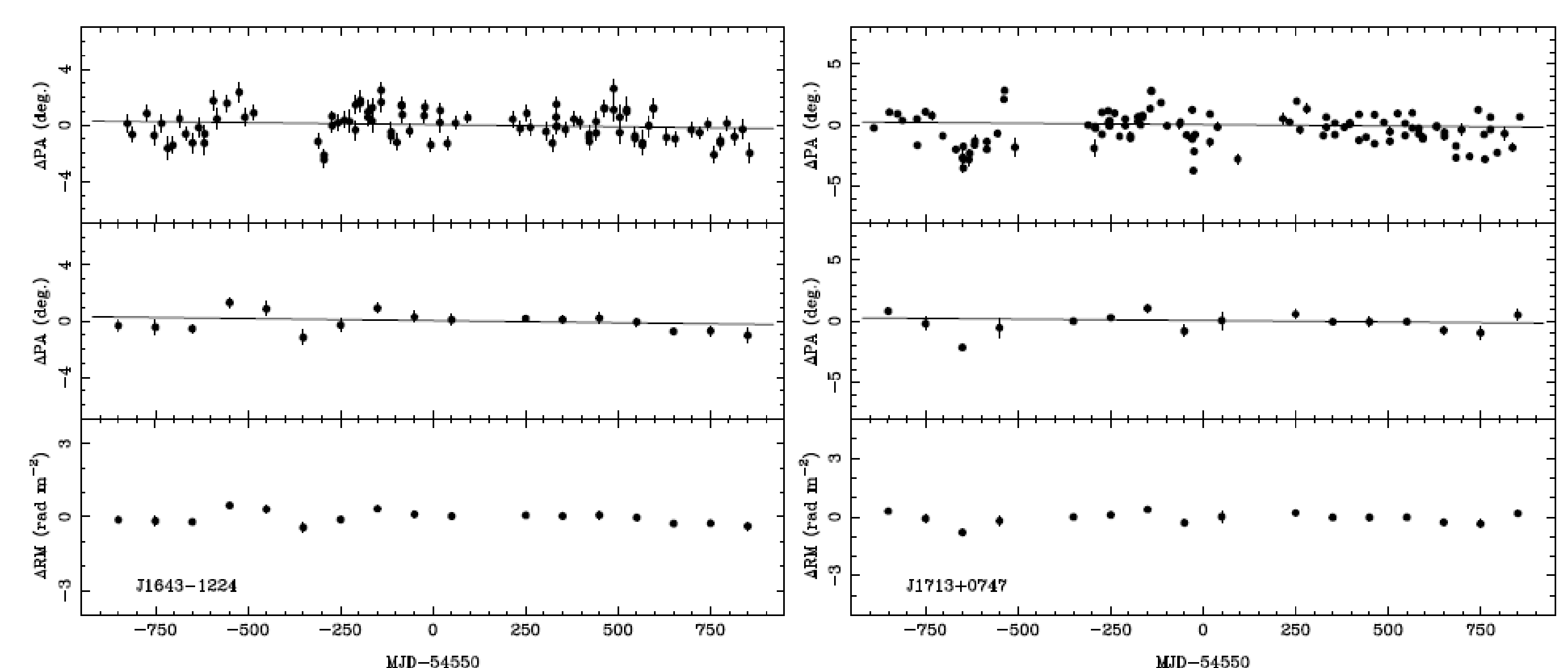


Figure 2: PA variations for two of the PPTA pulsars. The upper panel of each sub-figure has the IRI-corrected PA variations showing the fitted linear trend. The middle panel shows the same data averaged over 100-day blocks with the fitted line as in the upper panel. The lower panel shows the smoothed variations converted to RM changes.

Conclusions

We have analyzed the time variations of mean absolute pulse position angle over 4.8 years. The largest systematic effect found was that due to variations in the Earth's ionosphere. Little or no significant long-term variation in interstellar RM was found with limits typically about $0.1 \text{ rad m}^{-2} \text{ yr}^{-1}$ in absolute value. In a few cases, apparently significant RM variations over timescales of a few 100 days or more were seen. These are unlikely to be due to localized magnetized regions crossing the line of sight since the implied magnetic fields are too high. Most probably they are statistical fluctuations due to random spatial and temporal variations in the interstellar electron density and magnetic field along the line of sight.

The details of this work can be found in Yan et al. 2011, *Ap&SS*, 335, 485.