Changes in Polarization Position Angle Across the Eclipse in the Double Pulsar System
R. Yuen1,2, R. N. Manchester1, M. Burgay3, F. Camilo4, M. Kramer5, D. B. Melrose6 and I. H. Stairs6

1 CSIRO Astronomy and Space Science, Australia Telescope National Facility, P.O. Box 78, Epping, NSW 1710, Australia
2 SIA, School of Physics, the University of Sydney, NSW 2006, Australia
3 INAF-Osservatorio Astronomico di Cagliari, Loc. Poggio dei Pini, Strada 54, I-09012 Cagliari, Italy
4 Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA
5 IFAC, Piazza Forlanini 34, 1-20133 Milano, Italy
6 Department of Physics and Astronomy, University of British Columbia, Vancouver, BC V6T 1Z1, Canada

Abstract
We investigate the changes in polarization position angle in radiation from pulsar A around the eclipse in the Double Pulsar system PSR J0737-3039A/B at the 20 cm and 50 cm wavelengths using the Parkes 64 m telescope. The changes are ~2° during and shortly after the eclipse at 20 cm but less significant at 50 cm. We show that the changes in position angle during the eclipse can be modeled by differential synchrotron absorption in the eclipse regions. Position angle changes after the eclipse are interpreted as Faraday rotation in the magnetotail of pulsar B. Impacted charge densities are consistent with the Goldreich-Julian density, suggesting that the particle energies in the magnetotail are mildly relativistic.

The Double Pulsar
Discovered by Burgay et al. (2003) and Lyne et al. (2004), the Double Pulsar system consists of two pulsars (pulsar A and pulsar B) both radiating at radio frequencies, and with the almost edge-on orbit, an eclipse is observable at orbital longitude of ~90° measured from the ascending node, when pulsar A moves behind pulsar B, and lasts for ~30 s.

Mechanisms to change P.A.
Eclipse region: synchrotron absorption
Relative to the magnetic field direction, the perpendicular electric vector component of radiation is more strongly synchrotron absorbed. The position angle of the transmitted radiation changes with increasing optical depth, τ = αL, with the position angle moving toward the angle of the projected magnetic field. Here L is the effective path length through the absorbing medium and α is the polarization-averaged synchrotron absorption coefficient for a relativistic thermal distribution of particles (Lyubikov and Thompson 2005). Denoting χ_L and χ_e to be the incident and emergent polarization angles relative to the projected magnetic field direction, the intensity perpendicular and parallel to the projected magnetic field are,

\[ I_p = \frac{I_0}{1 + \chi_L^2 + \chi_e^2 - 2\chi_L\chi_e \cos \chi_{eL}} \]

Assuming \( \chi_e = 45° \), and using our data, this gives an order of magnitude change in polarization or position angle, \( \Delta \chi_p = \chi_e - \chi_p \) of 10°. This is consistent with our measurements suggesting that differential synchrotron absorption in the closed field-line regions can plausibly account for the observed position angle changes during the eclipse.

Magnetotail: Faraday rotation
Decomposition of linearly polarized radiation into two circular modes that propagate at slightly different phase velocities results in Faraday rotation of the plane of the received linear polarization. The change in position angle, \( \Delta \chi_p \) is given by,

\[ \Delta \chi_p = \frac{\chi_e - \chi_p}{\chi_{eL}} \]

where \( n_e \), \( B \), and \( L \) are the electron density in \( \text{cm}^{-3} \), the average magnetic field in microgauss, and the pathlength in parsecs respectively, and \( \cos \chi_{eL} \) is the angle between the magnetic field and the ray path, \( RM \) is the rotation measure. Assuming magnetic field scales as \( r^2 \) up to \( L/2 \) in the magnetotail (\( L = 1.5 \times 10^{16} \) pc is the semi-major axis of pulsar B’s orbit), and with \( \Delta \chi_p \sim 5° \), gives \( n_e \sim 40 \, \text{cm}^{-3} \). This is comparable to the estimated corotation charge density (Goldreich and Julian 1969), \( n_e \sim 20 \, \text{cm}^{-3} \). This suggests that Faraday rotation may be responsible for the changes in position angle away from the eclipse region.


References

Differential absorption in eclipse regions
With our 18s averaging time covering approximately 6.5 revolutions of pulsar B, the direction of the differential synchrotron absorption relative to the incoming radiation will vary during B’s rotation and along the path through the magnetosphere. It will also change as the line of sight to A moves through B’s magnetosphere because of the orbital motion. The effect of synchrotron absorption can be approximated by averaging the magnetic field perpendicular to the rotation and magnetic axes to zero leaving a net magnetic field along B’s rotation axis.

Net field in B’s magnetotail
The large inclination angle in pulsar B results in an asymmetric field structure in the oppositely directed magnetic fields in the two lobes from the magnetotail as the pulsar rotates within the confining magnetosheath (Spitkovsky and Arons 2004). Together with the misalignment between the rotation axis and the orbital normal, a net magnetic field in the line of sight results.

Results
We consistently detected changes in position angle during and shortly after the eclipse at both wavelengths (Figure 1). During the eclipse, position angle at 20 cm first shows a decrease of ~6° ± 3° relative to the mean baseline level (horizontal line), then rises to its maximum value of ~3° ± 2° above the baseline at the end of the eclipse. It remains high for the following phase bin, then drops back to the baseline value. Corresponding changes in polarization angle at 50 cm were also detected, but the uncertainties are larger. Nevertheless, the position angle changes shortly after the eclipse is consistent with those at 20 cm. Partitioning the 20 cm files randomly into two subsets show consistent changes in position angle during the eclipse, i.e., a decrease during ingress followed by an increase during egress (Figure 2). Partitioning the dataset into either two, three or four subsets, either randomly or chronologically, produced similar results.

Figure 1: Changes in P.A. (upper two curves) and total intensity (lower two curves) at 50 cm and 20 cm around the eclipse.

Figure 2: Two partitions of 20 cm data files showing consistency in changes in P.A. around the eclipse.

Figure 3: Strong relativistic wind from pulsar A blows at pulsar B causing its magnetosphere to distort and the magnetospheric material to flow in the radial direction. Because of the magnetic field, there is a magnetotail that is curved behind pulsar B.

Data analysis
Data of interest were taken at 1369 MHz (20 cm) using the center beam of the Multibeam receiver, and at 730 MHz (50 cm) using the 10/50 cm dual-band receiver. All observations had a sub-integration time of 30s.

Presence of an eclipse in a data file is confirmed by checking the coverage of orbital phase of 90° using the PSRCHIVE software suite (Hotan et al. 2004).

To improve the signal-to-noise ratio, data were summed in each band and binning the results in orbital phase. The phase bins were ~0.7° or ~18 s in width.

Stokes parameters were summed across the main pulse and interpulse to form the average Stokes parameters for each orbital phase bin.

Figure 4: Two partitions of 20 cm data files showing consistency in changes in position angle away from the eclipse.

Figure 5: Changes in P.A. (upper two curves) and total intensity (lower two curves) at 50 cm and 20 cm around the eclipse.