Radio Polarization and Geometry of PSR J1119–6127

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Abstract

Using 1400-MHz archival data from the Parkes radio telescope, we present radio polarization characteristics for PSR J1119–6127, a very young pulsar notable for its large magnetic field. We discuss the polarization features of PSR J1119–6127 and consider the pulsar in the context of a recent theoretical model of pulsar spin-down; this spin-down model can in principle be tested with polarization and timing data from this pulsar. Constraints on the pulsar's emission geometry obtained from a rotating vector model fitted to the available position angle data are not suffcient to test the spin-down model, but additional data may allow a significant test in the future.

Introduction

Pulsar polarimetry is one of the keys to understanding the process and geometry of radio emission from pulsars. In the rotating-vector (RV) model of polarization (Radhakrishnan & Cooke 1969), the polarization of radio emission is linked to the emission geometry so that as the pulsar rotates, the axis of linear polarization is aligned with the projected direction on the sky of the pulsar's magnetic dipole axis. The pulsar's emission geometry itself may be described by two angles, each measured from the pulsar's angular momentum vector: the magnetic inclination angle α is the angle between the spin axis and the magnetic dipole axis, and the angle β measures the minimum separation between the magnetic dipole axis and an observer's line of sight (Everett & Weisberg 2001). Given this geometric description, the RV model defines the linear polarization position angle (PA) ψ as a function of pulse phase ϕ according to:

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

where $\zeta = \alpha + \beta$. With sufficient coverage over pulse phase, a fit for RV model parameters ψ_0, ϕ_0, α, and β may be performed. Since ϕ_0 is the phase corresponding to the center of the magnetic pole, the fit determines the geometry not only of the pulsar itself, but of the pulsar's regions of radio emission, which can lie at various positions relative to the pulsar's magnetic axis. Emission at the magnetic axis is not always present, and emission may not be symmetrical about the axis, in some cases giving rise to one or more pulses that lead or trail the beam center (Lyne & Manchester 1988).

PSR J1119–6127

- Discovered August 1997 in the Parkes Multibeam Pulsar Survey
- Inferred surface magnetic field is very large: 4.1×10^{13} G
- One of the youngest known pulsars: $\tau = 1.7 \pm 0.1$ kyr

Right Ascension, α (J2000)	11 19 14.30 ± 2
Declination, δ (J2000)	–61 27 49.5 ± 2
Galactic Longitude, *l*	292.15°
Galactic Latitude, *b*	–0.54°
Period, *P*	408 ms
Spin-down Luminosity, *Edot*	2.3×10^{36} erg s^{-1}
Braking Index, *n*	2.91 ± 0.05
Dispersion Measure, DM	707 ± 2 pc cm^{-3}

(Camilo et al. 2000)

Observations and Results

- Observations taken 16 January and 18 January 1999 with the Parkes radio telescope; total integration time 48 min.
- Center frequency 1366 MHz; bandwidth 128 MHz.
- Position angle was corrected for Faraday rotation.

(See Crawford et al. 2001b; Manchester et al. 1998 for details.)

Summary of Results:

Rotation Measure, RM	+823 ± 6 rad m^{-2}
Mean LOS magnetic field	+1.43 ± 1 μG[1]
Fractional on-pulse linear polarization, <*L*>/*S*	74%
Fractional on-pulse circular polarization, <*V*>/*S*	–8%[2]
Fractional absolute on-pulse circular polarization, <|*V*|>/*S*	10%
Mean flux density at 1366 MHz, *S*	1.0 mJy
Polarization error (2σ)	3%

[1]Positive values correspond to magnetic field lines toward the observer.
[2]Positive values correspond to left circular polarization

Features of the Polarization Profile

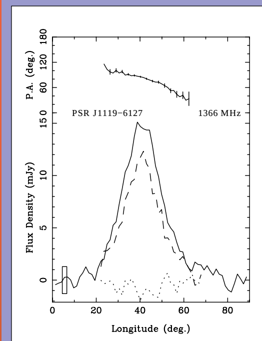

Figure 1. Polarization profile for PSR J1119–6127 at a center frequency of 1366 MHz. In the lower part of the plot, the solid line indicates total intensity. The dashed and dotted lines indicate the linearly and circularly polarized intensity, respectively. Positive values of circular polarization correspond to left-circular polarization. The height of the box in the lower left-hand corner is twice the baseline scatter. The upper part of the plot shows the PA plotted as a function of pulse phase on the same axis. The pulsar is highly linearly polarized, consistent with trends noticed for young energetic pulsars.

High linear polarization:

- Similar to linear polarization found in PSR J1513–5098 (B1509–58), which has comparable age, magnetic field, and rotational period (Crawford et al. 2001b).
- High linear polarization consistent with previously noticed trends for pulsars with high spin-down luminosity, small characteristic age (Crawford et al. 2001b; Gould & Lyne 1998).
- Confirmed by analysis of ATCA radio imaging data at 2496 MHz (see Crawford et al. 2001a), which gives fractional linear polarization of 68±8% (1σ).

PA Swing and RV Fit:

- The RV model fits the data well, with no complications. Best-fit RV model is shown in Figure 2.
- Sharp PA swing, corresponding to small β.
- Consistent with partial conal beam structure interpretation (Lyne & Manchester 1998).
- Constraints on model parameters α and β are shown in Figure 3.

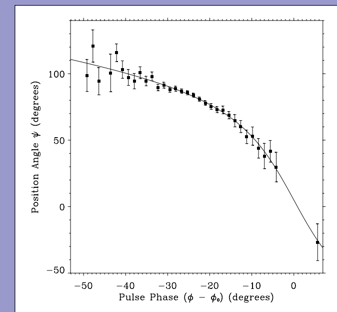

Figure 2. PA as a function of pulse phase for PSR J1119–6127, with the best-fit RV model overlaid. Selected points had uncertainty less than 15°. The pulse phase point $(\phi - \phi_0) = 0$ is the center of the best fit, corresponding to the magnetic pole sweeping past the line of sight. The peak of the profile, where the PA uncertainty is smallest, leads $(\phi - \phi_0) = 0$, suggesting that the emission is emanating from the leading edge of a conal beam.

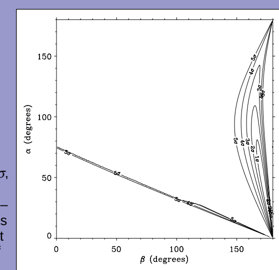

Figure 3. Confidence regions in α (magnetic inclination angle) and β (impact parameter) for the RV model best fit. Contours at 1σ, 2σ, 3σ, 4σ, and 5σ confidence levels are indicated. At the 3σ level, $-20° < \beta < 0°$ and $\alpha < 140°$. This constraint on α is not sufficient to test the spin down model of Melatos (1997).

Testing a Model of Pulsar Spin-Down

Model proposed by Melatos (1997):

- Treats the pulsar and its inner magnetosphere as a single perfectly conducting sphere rotating in a vacuum.
- Predicts first and second braking indices *n* and *m* given the pulsar's period, period derivative, and magnetic inclination angle α.
- No free parameters; highly falsifiable.
- So far applied with some success to the Crab pulsar, PSR B0540–69, and PSR J1513–5908.
- The clean polarization profile and measurable braking index of PSR J1119–6127 make it a candidate for testing the model.

Testing the Model Observationally:

- Despite the good fit of the RV model to the polarization data, α can only be constrained to $\alpha \leq 140°$ at the 3σ level (see Figure 3).
- The 3σ constraint on α is insufficient for a meaningful test of the model.

Prospects For a Future Test:

- ~12 hr of observation time with a similar system could produce a 3σ constraint on α that would permit a significant test.
- Improvements in the measurement of *n*, through better timing observations, could also contribute to such a test (see Figure 4).

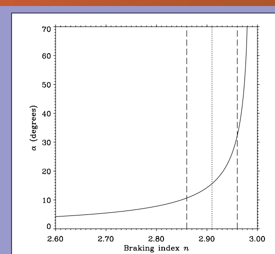

Figure 4. Plot of magnetic inclination angle α as a function of braking index *n* for PSR J1119–6127, as predicted by the model of Melatos (1997). The vertical lines correspond to the observed range of *n* = 2.91 ± 0.05 measured for PSR J1119–6127 (Camilo et al. 2000). This corresponds to $10° < \alpha < 32°$ in the model. The greater slope around *n* = 2.96 indicates that reducing the uncertainty in *n* would significantly reduce the range of α that could be in agreement with the model.

Conclusions

- The polarization profile of PSR J1119–6127 exhibits a high degree of linear polarization, consistent with trends for other young, energetic pulsars.
- Polarization data indicates that the pulse leads the symmetry axis, supporting interpretation of the pulse profile as a partial conal beam.
- PSR J1119–6127 is suitable to test the magnetosphere model of Melatos (1997); further data could make such a test possible.

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