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PSR J1906+0746: From relativistic spin-precession to beam modeling

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Abstract. Shortly after the discovery of PSR J1906+0746, some hints of profile variations were already interpreted as first signs of relativistic spin-precession occuring. Using observations from the Nançay, Arecibo and Green Bank Radio Observatories, we report here the measurement of pulse profile and polarimetric variations. Using the Rotating Vector Model, we show that PSR J1906+0746 is likely to be an orthogonal rotator ($\alpha \simeq 80°$). Fitting our polarimetric data to a precession model, we determined the geometry of the pulsar and found a wide misalignment angle ($\delta = 89^{+85}_{-44}$ deg, 95% C.L.), although the uncertainty is large. Assuming this geometry, we constructed the beam maps of both magnetic poles.

Keywords. pulsars: individual (J1906+0746)

1. Introduction

PSR J1906+0746 is a young pulsar in a 4-hr orbit around a massive companion (Lorimer *et al.* 2006). With a pulsar mass $M_p = 1.323 \pm 0.011\,\mathrm{M}_\odot$ and a companion mass $M_c = 1.290 \pm 0.011\,\mathrm{M}_\odot$ derived from timing measurement by Kasian (2012), one can estimate the relativistic spin-precession period to be 165 years assuming General Relativity.

Relativistic spin-precession in binary pulsars is a long-known effect that is due to spin-orbit coupling (Damour & Ruffini 1974; Barker & O'Connell 1975). The consequence of this precession is that our line of sight crosses different parts of the radio beam with time. Hence we can expect pulse shape and polarization variations.

The non-detection of the interpulse in archival data and an increase of the signal-to-noise ratio (SNR) for the main pulse between 1998 and 2005, suggested the first sign of change in the beam orientation with respect to our line of sight (Lorimer *et al.* 2006). Profile shape variations were also reported by Kasian (2008) when they presented their timing solution. More recently, they reported a preliminary beam map for the main pulse (Kasian 2012).

We present in these proceedings further observations that allow us to determine the geometry of the pulsar and produce improved maps of its radio beam.

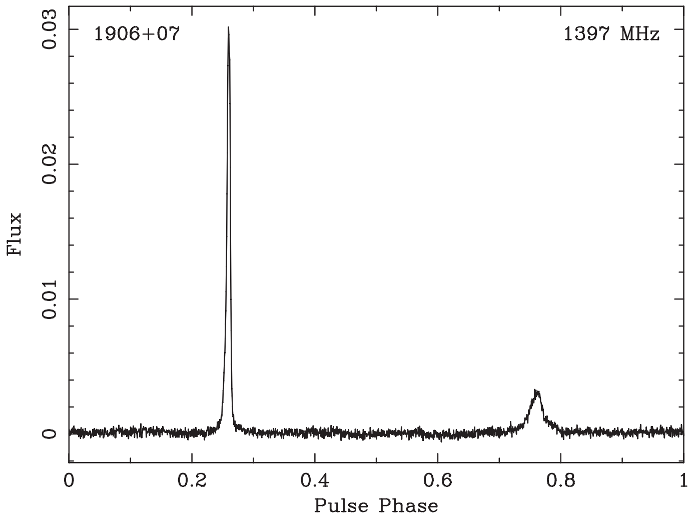

Figure 1. Mean pulse profile of PSR J1906+0746 as recorded in 2005 with the NRT.

2. Observations

This pulsar was observed from 2005 to 2009 with the BON backend at the Nançay Radio Telescope (hereafter NRT; Desvignes 2009) and the WAPPs, ASP and GASP backends at the Arecibo 305-m Observatory and the Green Bank Telescope respectively (for further details, see Kasian 2012). All these observations were done at L-Band. Only the NRT observations provide calibrated full Stokes profiles that were de-Faradayed with a Rotation Measure of 149 rad m^{-2} and hence were used for the polarimetric study. Given the low SNR of the NRT daily observations, the NRT profiles were integrated to form 13 profiles spanning 3 to 6 months to obtain reliable polarimetric fits.

3. Profiles and polarimetric changes

The mean pulse profile at the beginning of our dataset in 2005 consists of 2 sharp pulses separated by almost 180° (see Fig. 1). Over the 3 years course of the data span, we measured a change in the separation of the two pulses to be $2.1^\circ \pm 0.1^\circ$ yr^{-1}.

The flux density of both components was also estimated for each dataset using the radiometer equation, e.g. Lorimer & Kramer (2005). It decreased by a factor of $\sim$3 and $\sim$4.5 for the main pulse and the interpulse respectively.

Our polarization data first confirmed the high degree of linear polarization noticed in the discovery paper (Lorimer *et al.* 2006). However the circular polarization under the main pulse gradually vanished between our first and last epochs. According to the Rotating Vector Model (RVM) put forward by Radhakrishnan & Cooke (1969), the typical 'S' curve of the Polarization Position Angle (PPA) can be described in terms of the geometry of the pulsar:

$$\tan(\psi - \psi_0) = \frac{\sin\alpha \sin(\phi - \phi_0)}{\sin(\alpha + \beta)\cos\alpha - \cos(\alpha + \beta)\sin\alpha\cos(\phi - \phi_0)}, \tag{3.1}$$

where α is the angle between the rotation and magnetic axis and β denotes the impact parameter. Here ψ is the measured PPA at the longitude ϕ, ϕ_0 the longitude under the magnetic axis at the closest approach of the line of sight and ψ_0 the PPA at the longitude ϕ_0.

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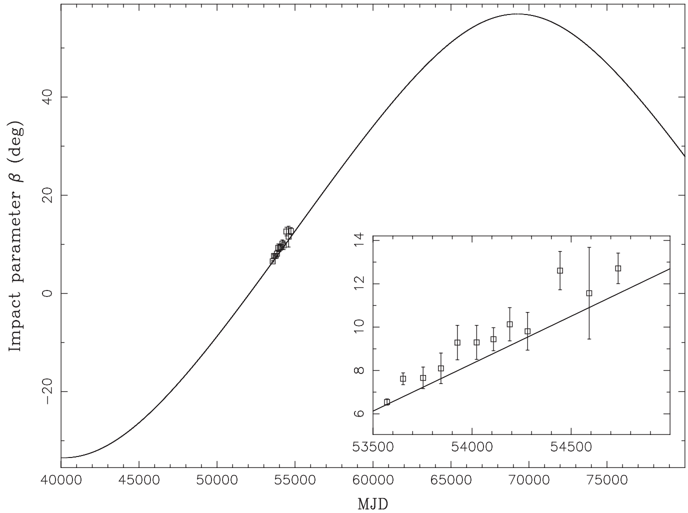

Figure 2. Impact parameter β as a function of MJD. The black boxes show the impact parameter as determined by the simple RVM fits. The black line represents the model from the best fit values given by Table 1. The inset shows a zoom over the data.

Fitting the RVM to each of our 13 polarimetric profiles, we measured α to be close to 80° for all epochs. A constant value of α is expected and this result strongly suggests an orthogonal rotator, with the two pulses representing the cone of emission of both magnetic poles. The RVM results also show a small increase of β with time (i.e. the slope of the PPA under the main pulse in decreasing with time), indicating that our line of sight is moving away from the magnetic poles. More importantly, a marginal decrease of ψ_0 is also detected.

In the next section, we used this change in ψ_0 to determine the geometry of the system and map the radio emission beams.

4. Modeling of relativistic spin precession

Kramer & Wex (2009) have shown that the absolute value of the PPA ψ_0 should change with time. Applying their global precession model and fitting for the magnetic inclination angle α, the misalignment angle δ, the reference precessional phase Φ^0_{SO} plus the 13 phase offsets give the results reported in Table 1.

The magnetic inclination angle is consistent with the value determined with the simple RVM fit. The large value of the misalignment angle explains our quick detection of the precession effects. Its large uncertainty can be justified by the fact that the impact parameter did not have a sign reversal as it happened for PSR J1141−6545 (Manchester *et al.* 2010).

With the geometry of the system derived, we can now produce a map of the emission beam. First, a set of gaussians is fitted to all profiles. The height of the gaussians are normalized using flux density measurements.

Table 1. Results of the global precession model at a 95% confidence level.

α	δ	Φ^0_{SO}	χ^2_{red}
81^{+1}_{-66}	89^{+85}_{-44}	83^{+117}_{-93}	2.22

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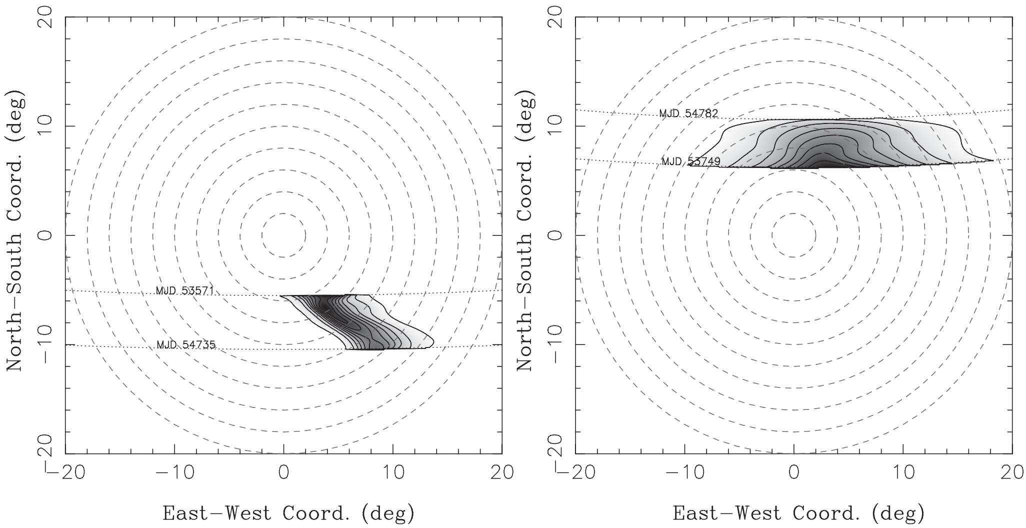

Figure 3. *Left panel:* Beam map of the main pulse. The gray contour plot shows an axial emission with a decrease in intensity as the line of sight moves away from the magnetic pole. *Right panel:* Beam map of the interpulse. In both plots, the black lines represent the increments of emission, in steps of 10%.

When producing the beam map for PSR J1141−6545, Manchester *et al.* (2010) aligned the pulse profiles using the edges. In this work, the profiles are aligned with respect to the magnetic poles based on the individual measurements of ϕ_0 given by the simple RVM fits, hence making no assumption on the beam shape. This alignment based on polarimetric results explains the offset in the main pulse longitude between this beam map and the one produced by Kasian (2012).

The results of the beam maps are shown Fig. 3. In the case of the main pulse, we see axial emission with the flux decreasing as the line of sight is moving away from the magnetic pole. For the interpulse, the emission is more extended.

The beam maps clearly show the change in the separation of the two components as the line of sight is moving away from the magnetic poles. These profile variations will undoubtedly have an impact on the timing study of this pulsar (van Leeuwen *et al.*, in prep.) beyond the usual timing noise in young pulsars (Lyne *et al.* 2010).

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