A Hare-brained Scheme to Explain the Intensity Variations in J0737−3039B

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Abstract. The recently discovered double pulsar system PSR J0737−3039 will provide fascinating insights into pulsar emission physics. One extraordinary phenomenon involves the orbital phase dependent intensity variations of the slow pulsar PSR J0737−3039B. These variations can be described using a simple geometric model based on a standard pulsar emission geometry together with the assumption that the intensity of PSR J0737−3039B increases substantially when it is illuminated by the emission beam from PSR J0737−3039A. In the context of this model, the observed properties of this system can constrain the spin axis and emission geometry of the millisecond pulsar PSR J0737−3039A. This model also predicts the future evolution of both the pulse profile of PSR J0737−3039A and the orbital light curve of PSR J0737−3039B thus enabling it to be tested by observations over the next few years.

1. Introduction

Recently, one of the "Holy Grails" of pulsar astronomy — a double-pulsar binary — was discovered by Burgay et al. (2003) and Lyne et al. (2004). The system, which contains the 22.7-ms pulsar PSR J0737−3039A and the 2.77-s pulsar PSR J0737−3039B (hereafter 'A' and 'B'), is eccentric ($e \sim 0.088$), extremely compact (orbital period, $P_{orb} \sim 2.45\,\mathrm{h}$), highly inclined ($i \approx 88.5°$), and strongly relativistic. The compactness and high inclination cause the emission from each pulsar to pass very near the other star — and therefore through the companion star's magnetosphere — while en route to our telescopes. Such a system will provide an unprecedented look into the physics of pulsar magnetospheres and provide important clues to the mystery of pulsar radio emission (see the papers in this volume by Burgay, Manchester, Kramer, Ransom, Arons and others).

Lyne et al. have reported that the pulsed flux density of each pulsar varies as a function of orbital phase. For 'A', there is a $\sim 30\,\mathrm{s}$ eclipse of the pulsed emission when 'B' passes directly in front of the pulsar (i.e. at conjunction) (Kaspi et al. 2004). 'B' experiences drastic but systematic flux variations each orbit including two "bursts" of $\sim 10\,\mathrm{min}$ duration where the pulsed flux density is large enough to easily allow the detection of individual pulses.

This work summarizes the model described by Jenet & Ransom 2004 which explains the intensity variations of 'B' and makes predictions for the future evolution of both the pulse profile of 'A' and the intensity variations of 'B'. The model makes the assumption that 'B' is bright whenever the emission beam from 'A' is illuminating it. Thus the observed pulse profile of 'A' and the flux variations in 'B' are intimately related to each other. Using this model, the spin axis and emission geometry of 'A' are constrained. The main strength of this geometric model is that it has predictive power. Since the spin axis of 'A' will precess about the orbital angular momentum vector (due to geodetic precession) at a rate of $4.8°$ per year, this model predicts that both the pulse profile of 'A' and the orbital locations where 'B' appears bright will change in a systematic way.

2.   The Model

The Jenet & Ransom model is based on two assumptions. First, the emission geometry of 'A' is described by the hollow cone model of Lyne & Manchester (1988). The hollow cone model consists of a circular emission region centered on the magnetic axis (See Figure 1). As the star rotates, the emission ring moves in and out of the observers line-of-sight, causing a sharp double peaked profile much like the one observed from 'A'. The second assumption is that the intensity of the 'B' pulsar increases whenever it is illuminated by the emission beam from 'A'. With these two assumptions, the locations and durations of the bright peaks in the pulse profile of the 'A' pulsar together with the high intensity orbital locations of 'B' can be determined given a knowledge of the orbital geometry, spin axis of 'A' and its emission geometry. Conversely, given a pulse profile of 'A' and a light curve of 'B' as a function of orbital longitude, one can constrain the spin axis and emission geometry of 'A'. More details of this model including the five constraint equations and the technique used for solving them are given in Jenet & Ransom 2004.

3.   The Results

The five angles which specify the orientation and emission geometry of the 'A' pulsar (See Fig. 1) can be determined using the Jenet & Ransom model. Uncertainties in the existing data allow for two possible solutions. The results are presented in Table 1. Note that the values in the table assume that the inclination angle, i, is $88.5°$. Current timing and scintillation data (Lyne et al. 2004, Ransom et al. 2004) are unable to distinguish between i and $180° - i$. Hence, for the case when the inclination angle is $91.5°$, λ goes to $180° - \lambda$ and all other parameters remain unchanged.

Geodetic precession will cause ϕ to increase at a rate of $4.8°$ per year. Hence the pulse profile of 'A' and the bright orbital regions of 'B' will change in a predictable way. See Figure 2 and Jenet & Ransom 2004 for the details of these predictions.
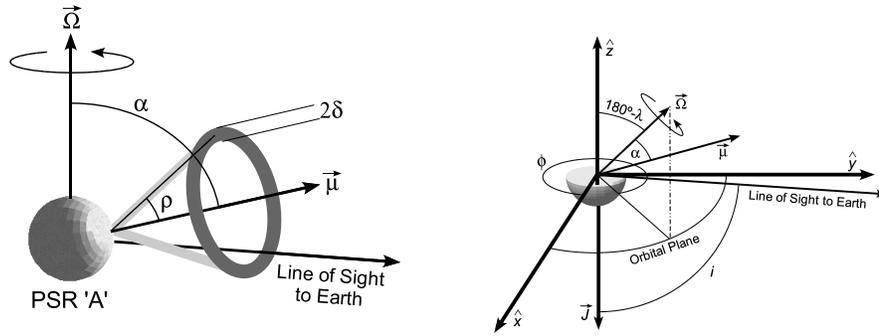
Figure 1. The emission geometry and orientation of PSR J0737−3039A. The orientation of the spin axis is $\vec{\Omega}$, which is separated from the orbital angular momentum, $\vec{J}$, by the angle λ, and the magnetic dipole axis, $\vec{\mu}$, by the angle α. The cone of emission has an opening half-angle of ρ and a thickness 2δ. The projection of $\vec{\Omega}$ onto the orbital plane defines the angle ϕ. The line-of-sight of the observer is inclined by the inclination angle i from $\vec{J}$ in the $\hat{y}$-$\hat{z}$ plane. The direction $\hat{x}$ is that of the line-of-nodes in the plane of the sky.
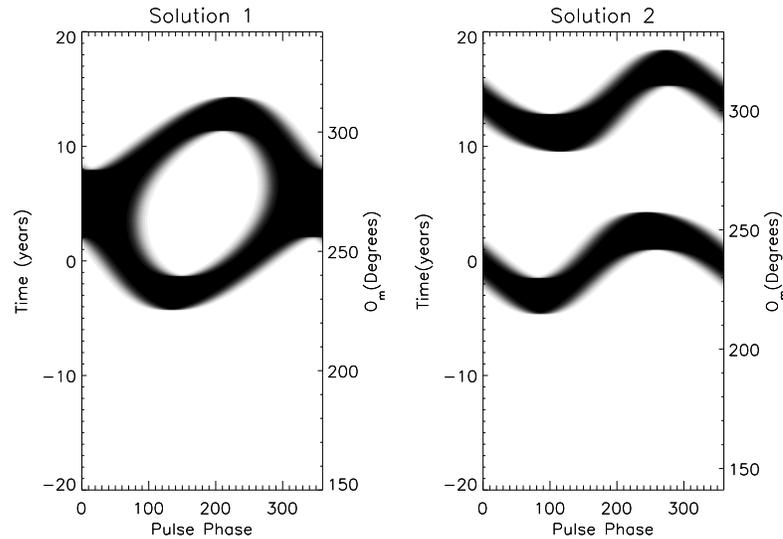
Figure 2. Predicted radio pulse profile evolution for PSR J0737−3039A given the two model solutions shown in Table 1. In both cases we predict that the separation of the two pulse components will increase by tens of degrees per year for the next several years and that the pulsar will disappear from view in ∼14 yrs for solution 1 or (briefly) in 4-5 yrs for solution 2. Both solutions can also explain why PSR J0737−3039 was not detected in the Parkes 70 cm survey, since the pulsar only became visible 4-5 yrs ago.

Parameter	Solution 1	Solution 2
λ	$167° \pm 10°$	$90° \pm 10°$
ϕ	$246° \pm 5°$	$239° \pm 2°$
α	$1.6° \pm 1.3°$	$14° \pm 2°$
ρ	$78° \pm 8°$	$42° \pm 4°$
2δ	$1.9° \pm 1.4°$	$15° \pm 2°$

Table 1.   This table gives the five angles determined by the Jenet & Ransom model. Both possible solutions are given, although solution 1 is preferred since it matches the polarization measurements of Demorest et al. (2004) and corresponds to a much more likely evolutionary scenario as determined by Willems, Kalogera, & Henninger (2004).

References

Burgay, M., et al. 2004, Nature, 426, 521

Jenet, F. A. & Ransom, S. M. 2004, Nature, 428, 919

Kaspi, V. M., Ransom, S. M., Backer, D. C., Ramachandran, R., Demorast, P., & Arons, J. 2004, ApJ, 613, L137

Lyne, A. G., et al. 2004, Science, 303, 1153

Lyne, A. G., & Manchester, R. N. 1988, MNRAS, 234, 477

Ransom, S. M., et al. 2004, ApJ, 609, L71

Willems, B., Kalogera, V., & Henninger, M., 2004, ApJ, 616, 414