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Timing the Relativistic Binary Pulsar PSR J1141−6545

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Abstract. New timing is presented for the binary pulsar PSR J1141−6545. This binary pulsar is unusual because, although the orbit is eccentric, the pulsar appears to have a white-dwarf companion. The dissymmetric nature of this system makes it of special relevance to relativists as only one of the components is strongly self-gravitating. Our observations show that the young pulsar's spin down behaviour is not well described by a period and period derivative, but rather exhibits significant "timing noise." Despite this limitation, the system's orbit appears to be decaying at the rate predicted by general relativity. The inclination angle of the orbit as derived from relativistic observables is consistent with that derived from scintillation parameters.

1. Introduction

PSR J1141-6545 was discovered as part of the prolific Parkes multibeam survey (Kaspi et al. 2000). It is a 395 ms pulsar in a 4.8-hour binary with an orbital eccentricity of 0.17. The minimum companion mass is $\sim 1\,M_\odot$ and the total system mass is $\sim 2.3\,M_\odot$. Ord, van Straten, & Bailes (2001a) used HI absorption measurements to demonstrate that the system was in a favourable location in the Galaxy for establishing the validity of general relativity. The pulsar's scintillation timescale has been demonstrated to be well correlated with orbital phase. Ord, Bailes, & van Straten (2001b) showed how this can be used to determine not only the runaway velocity of the system but also give the orbital angle of inclination, which they showed was near 76 degrees. Regular timing observations showed that the time dilation and gravitational redshift term was measureable, and that this combined with the advance of periastron predicted a rate of orbital decay consistent with observations at the four sigma level (Bailes et al. 2003). More recently, Ransom et al. (in this volume) demonstrated that the new double pulsar PSR J0737−3039 also has very suitable scintillation timescales and bandwidths for derivation of its runaway velocity and orbital inclination.

2. Timing Results

It is apparent from Figure 1 that PSR J1141−6545 is no longer well-described by a simple timing model with just one period derivative. This timing noise affects the fitted orbital period derivative depending upon how many higher order period derivatives are used to describe the spin-down. Pre-whitening the

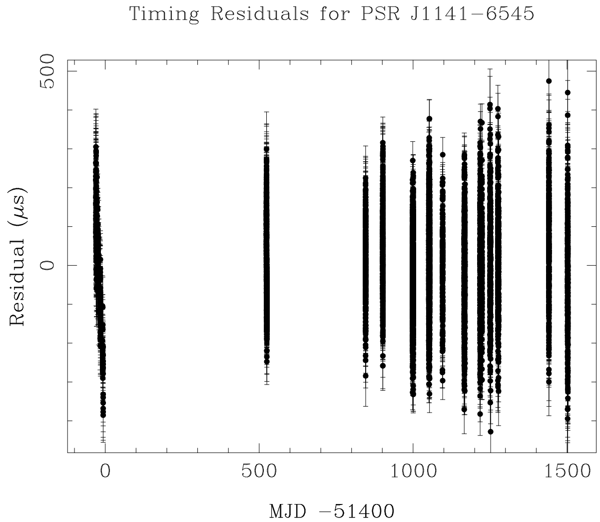

Figure 1. Timing residuals for PSR J1141−6545 after fitting for just a single period derivative. Residual slopes in the times of arrival are apparent in the first group of points. We associate these with timing noise, often present in young pulsars like PSR J1141−6545.

timing in this way is not ideal, and may ultimately limit the accuracy with which we can measure some of the relativistic parameters. Nevertheless, there is no reason to suspect that the underlying orbit is at all affected by the timing noise, and although we expect the parameters associated with Shapiro delay to be more difficult to measure as a result, long-term secular trends should still be possible to determine with the passage of time.

Slow pulsars require several thousand rotations for their profiles to become stable. In the case of PSR J1141−6545 this is longer than the signature of some of the timing parameters. The 4.8-hour orbit means that to be sensitive to effects such as Shapiro delay we would ideally like to get an arrival time every five minutes or so. In this time, PSR J1141−6545 only completes about 750 rotations. We have found that baseband observations of this pulsar in two contiguous bands only 64 MHz apart are strongly correlated. So the use of larger telescopes or more sensitive receivers will not necessarily aid in the improvement of its parameters which require the average profile to become stable before improvements in arrival time accuracy can be used to better constrain timing models.

As the dramatic discovery of the double pulsar has demonstrated, the Galaxy is no doubt populated by many relativistic systems with orbital periods less than a couple of hours. If we were ever fortunate enough to discover such a system, the entire orbit might only be of order $<$1000 pulse periods! Pulse stability would make measurement of Shapiro delay parameters very difficult.

In Figure 2 we plot the reduced Chi squared as a function of angle of inclination after pre-whitening the residuals. It is clear that the inclination angle will never be strongly determined by this method, but it is pleasing to see that the incli-

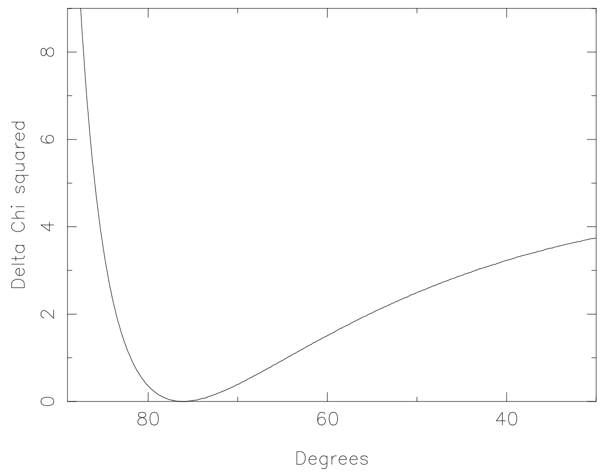

Figure 2. Reduced Chi squared for PSR J1141−6545 as a function of inclination angle. This plot was derived by using the mass function and the sum of the masses to determine the companion mass for a given inclination angle and computing the Chi squared by fitting for the remaining parameters. The result is consistent with the inclination angle derived from scintillation measurements.

nation so derived agrees with Ord, Bailes and van Straten's interpretation of its scintillation parameters. With instruments like the Square Kilometre array, it would be possible to identify binary pulsars purely from their scintillation properties, and maybe even measure the shape and period of their orbits!

In Figure 3 we plot the mass–mass diagram for this pulsar, and include the inclination angle limits derived from the scintillation parameters. The consistency with General Relativity is now very good, although the orbital period derivative limits are not that strict. Provided the timing noise limitations can be overcome, we would hope that by the end of the decade the limit on the orbital period derivative $\dot{P}_{\rm b}$ will be near 1% of its value.

3. Conclusions

PSR J1141-6545's youth means that new strategies are required to combat the deleterious effects of timing noise to reap its full potential for our testing of General Relativity. Within these limitations it currently appears to be internally consistent. The scintillation parameters have predicted an inclination angle for the binary which is perfectly consistent with that derived from the post-Keplerian parameters. Saturation coverage of the orbit a few times a year is probably a better strategy for observing this source than short observations more frequently as it minimises the effects of timing noise on the orbital parameters.

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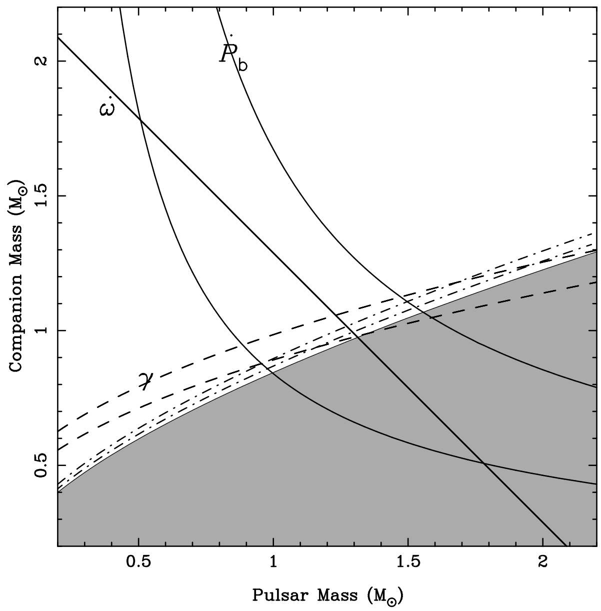

Figure 3. Mass–mass diagram for PSR J1141−6545 after fitting for both a period derivative and a period second derivative. Also shown (in dash-dotted) lines are the constraints from scintillation (see Ord, this proceedings). The post-Keplerian parameters agree beautifully with these limits.

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References

Bailes, M., Ord, S. M., Knight, H., & Hotan, A. W. 2003, ApJ, 595, L49

Kaspi, V. M., et al. 2000, ApJ, 543, 321

Ord, S. M., Bailes, M., & van Straten, W. 2002a, MNRAS, 337, 409

Ord, S. M., Bailes, M., & van Straten, W. 2002b, ApJ, 574, L75