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Long-Term Behaviour of the Scintillation Velocity of PSR J1141−6545

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Abstract. We have obtained measurements of the scintillation parameters of the relativistic binary PSR J1141−6545 over a period of two years. The long-term aims of this experiment are: a measurement of the advance of periastron, a detection of the motion of the Earth, and an estimation of the binary orientation in the plane of the sky. We present data from several epochs throughout this two-year period and conclude that either intrinsic variations in the scintillation parameters as a function of orbital phase, or a systematic bias in the experimental method are responsible for any detected variations in the scintillation parameters. The level of this experimental error is comparable to the expected signature of the Earth's motion. The fitted velocities are consistent, in that they all present a velocity perpendicular to the orbital plane greatly in excess of that within the orbital plane. The locus of all the epochs presented here give an absolute perpendicular velocity of $131 \pm 14\,\mathrm{km\,s^{-1}}$ and an absolute parallel velocity of $7 \pm 10\,\mathrm{km\,s^{-1}}$.

1. Introduction

The observed deep scintillation of the radio wavelength emission from pulsars is considered to be the result of diffraction of the incident wavefront around small scale irregularities in the interstellar medium (ISM) (Ricket 1969). The timescale and de-correlation bandwidth of the scintillation is highly dependent upon a number of factors: the distance to the source; the relative velocities of the source, observer and scattering material; and the structure and distribution of the ISM (Cordes & Rickett 1998). If any of the aforementioned factors are time variable then the measured scintillation timescale will also vary in time. The binary pulsars present an interesting opportunity, in that their orbital velocity can be predicted from their binary parameters. This orbital velocity manifests as a changing projected transverse velocity, which should be reflected in the measured scintillation parameters. The obtained scintillation velocity, as a function of orbital phase, can be used to constrain the system inclination and argument of periastron, as well as the system runaway velocity. This experiment has been successfully conducted for only a small number of pulsars (Lyne & Smith 1982; Ord, Bailes, & van Straten 2002). In principle the motion of the Earth should also impart its signature upon the scintillation velocity. The magnitude of this effect is much smaller than the successfully detected pulsar velocity variations. Nevertheless, calculations of runaway velocity at different epochs should show a variation as a result of the motion of the Earth. We have conducted this experiment and have not detected any such variation. We therefore assert that the systematic error in this analysis is at least of order the projected Earth velocity in the direction of the binary. This error may be a result of insufficient resolution in scintillation timescale, or unmodeled variations in the scintillation timescale and bandwidth as a function of orbital phase.

2. Observations

PSR J1141−6545 was observed throughout 2002 and 2003 with the Parkes 64-m telescope for over ten hours per session, with one session per observing term, resulting in multiple epochs spread throughout the day-of-year. The 512×0.5 MHz filterbank centred at 1374 MHz was used with the centre element of the Parkes multi-beam receiver (Staveley-Smith et al. 1996) until its removal in late 2003. In each filterbank channel, the power in both linear polarisations was detected and summed before 1-bit sampling the total intensity every 250 μs.

The experimental method is discussed in more detail in Ord, Bailes & van Straten (2002). In short, average pulse profiles spanning 29 seconds of integration time were formed from each 500-kHz channel of the filterbank. A dynamic spectrum was then formed, presenting the flux of the pulsar as a function of both time and frequency. An autocorrelation analysis was performed upon this dynamic spectrum to obtain measures of the scintillation timescale and bandwidth as a function of orbital true anomaly. A projected transverse velocity was derived for the pulsar using the measured scintillation parameters. Finally a model of the pulsar orbital velocity, with parameters including binary inclination and runaway velocity, was constructed and applied to the derived scintillation velocity. A chi-squared minimisation analysis produced the preferred values of the fitted parameters.

3. Analysis

The data presented in Figure 1 show considerable variations between the 6 epochs presented. The scatter in the fitted runaway velocities is presented in Figure 2, There is no consistent annual variation in the measured velocities consistent with the motion of the Earth. This null result can be attributed to a number of contributing factors. The scatter appears to be a function of orbital phase, in that, some orbital phases display more scatter than others. It should be noted that the phase of least scatter in scintillation velocity is that corresponding to the longest scintillation timescale. As the autocorrelation method is applied to the dynamic spectrum using a fixed box size, chosen so as to not average over too large a fraction of the orbital period, the calculated scintillation timescales at this orbital phase may well be biased toward lower values. A contribution may also be due to a different line of sight through the ISM to the pulsar as a function of orbital phase. Which would produce systematic departures from the model. This is difficult to account for as the experimental method assumes that all contributions to the scintillation velocity, other than those resultant from binary motion, are stable throughout the orbit. The scin-

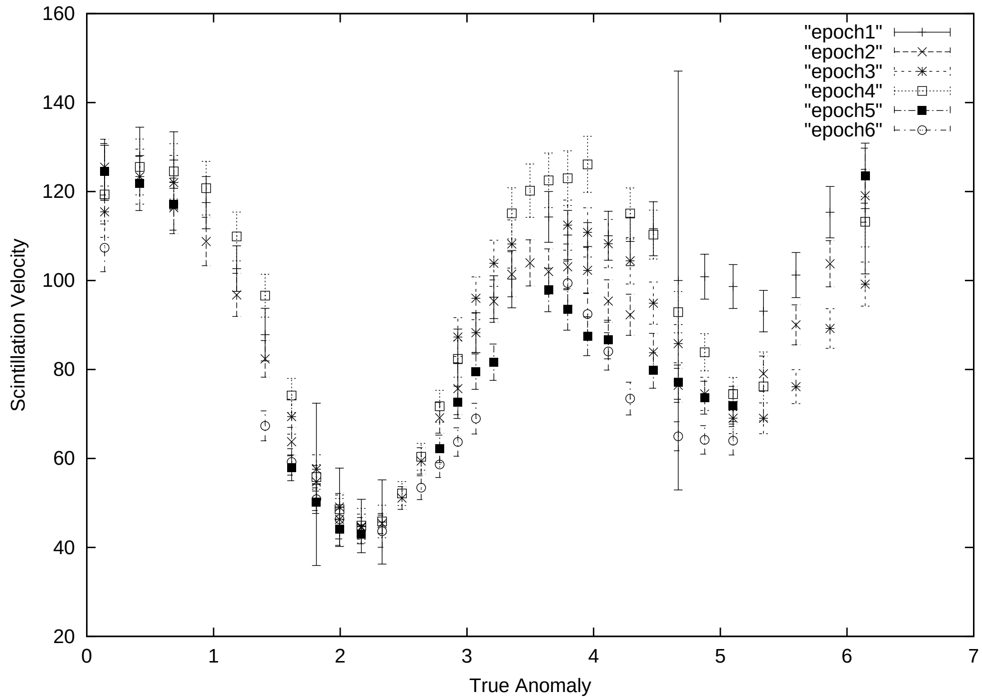

Figure 1. Multiple epochs of data plotted together. The scatter in the points is evident and contains contributions from both the motion of the Earth and systematic measurement bias.

tillation bandwidth is of comparable size to the channel width, therefore if small changes in the scintillation bandwidth are evident as a function of line of sight, these may not be reflected in the measured scintillation velocities.

The values obtained are generally consistent, in that measurements performed at multiple epochs do confirm that the velocity perpendicular to the line of nodes is significantly larger than that along the line of nodes. Although the quoted error is probably less than the true error due to the systematic effects discussed above.

The locus of the velocity fits gives a velocity perpendicular to the line of nodes of $131 \pm 14\,\mathrm{km\,s^{-1}}$ and $-7 \pm 10\,\mathrm{km\,s^{-1}}$ parallel to the line of nodes.

4. Solutions

The instrumental restrictions imposed by channel width outlined above can be lifted by the application of the baseband recorder CPSR2. The use of this instrument will allow arbitrarily narrow frequency channels, subject to restrictions imposed by the pulsar signal to noise ratio. The possibility of bias in the measurement of long scintillation timescales may well be countered by introducing a variable length autocorrelation window, but this may introduce more systematic effects than it removes. As our observations of this pulsar continue we will at-

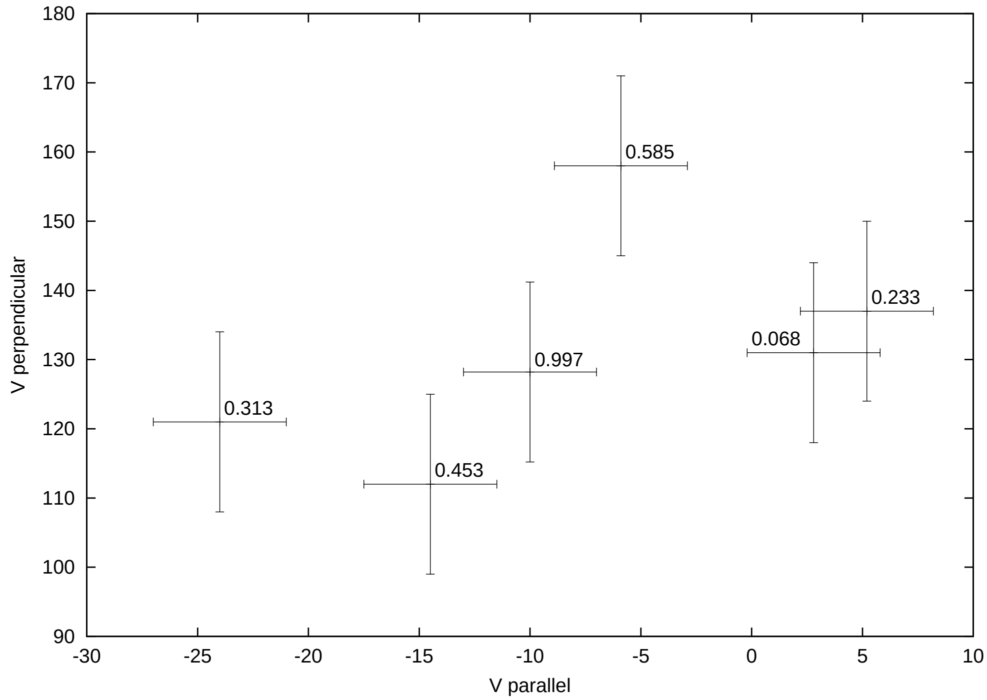

Figure 2. The best fit runaway velocities plotted with labels corresponding to a measure of the phase of the Earth in its orbit about the Sun. Clearly points at similar Earth orbital phases are markedly scattered, suggesting intrinsic systematic measurement error is greater than the variation induced by the motion of the Earth

tempt to fully quantify these systematic biases and develop methods to remove them from the experiment. This analysis is becoming more widely applicable as more pulsars display these effects, including the double pulsar binary (Ransom et al., in this volume). Our observing program is ongoing, and the archive data are being reprocessed with the aim of refining our methods to reduce the systematic effects present in these experiments

References

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