PROCEEDINGS OF SCIENCE

# Searching for a pulsar–black hole binary

**Ralph Eatough***, **Michael Kramer, Andrew Lyne, Michael Keith**
*The University of Manchester, Jodrell Bank Observatory, Macclesfield, Cheshire, SK11 9DL, UK*
*E-mail:* ralph.eatough@pulsarastronomy.net

Double neutron star systems in which at least one of the stars is a radio pulsar currently provide the most precise tests of theories of gravity in the strong-field regime. Unfortunately pulsars such as these are selected against in most surveys because of Doppler smearing of their pulse frequency. Acceleration algorithms in both the time and frequency domain can be used to compensate for changing pulse frequency but are limited by computing resources. Here we present ongoing work using a coherent time domain acceleration search for re-processing the Parkes Multibeam Pulsar Survey. Our new search method is capable of detecting pulsars with orbital periods two to four times shorter than previous searches and with accelerations up to four times the most relativistic system currently known, the double pulsar J0737-3039. Finding more systems like the double pulsar and those with even more extreme parameters, such as pulsars orbiting black holes, will provide the most stringent tests of general relativity and alternative theories of gravity to date.

*From Planets to Dark Energy: the Modern Radio Universe*
*October 1-5 2007*
*The University of Manchester, UK*

*Speaker.

## 1. Relativistic binary pulsars

Double neutron star systems with at least one radio pulsar provide an ideal situation for testing theories of gravity: two point masses, one “atomic clock”, in a relativistic binary system. Einstein’s general theory of relativity predicts modifications to the standard Keplerian orbits in such systems, so called Post Keplerian (PK) parameters. Measurements of the PK parameters in the double pulsar system J0737-3039A/B agree with general relativity to 0.05% level, the most precise test in the strong field regime ever [1]. Stellar population studies suggest more extreme systems such as pulsars orbiting black holes exist. In these systems the PK parameters will be larger due to the higher orbital velocities and increased component masses. Pulsar–black hole systems may be archived in recent pulsar surveys but remain undetected because of the effects described in section 2.

## 2. The detection problem

Pulsars in binary systems show periodic changes in their pulse frequency due to the Doppler effect. Traditional Fourier based periodicity searches are not sensitive to varying frequency signals. Assuming a constant orbital acceleration, $a$ the changing pulse frequency is characterised by a quadratic drift in pulse phase in the time domain. The time series can be modified to remove the drift in the pulsar signal for any given acceleration, $a$. As depicted in Equations 2.1 to 2.4 in a blind search this must be done for many possible values of the orbital acceleration.

$$\tau_{\rm p}(t) = \tau_0(1+a_1 t/c) \Rightarrow \mathrm{FFT}(1) \tag{2.1}$$

$$\tau_{\rm p}(t) = \tau_0(1+a_2 t/c) \Rightarrow \mathrm{FFT}(2) \tag{2.2}$$

$$\tau_{\rm p}(t) = \tau_0(1+a_3 t/c) \Rightarrow \mathrm{FFT}(3) \tag{2.3}$$

$$\vdots$$

$$\tau_{\rm p}(t) = \tau_0(1+a_{\rm n} t/c) \Rightarrow \mathrm{FFT(n)} \tag{2.4}$$

For each acceleration trial, $a$ the time series data are transformed using the Doppler formula to give the time interval in the pulsar rest frame, $\tau_{\rm p}$ relative to the interval in the observed frame, $t$. The constant, $\tau_0$ is used for normalisation purposes [2]. A periodicity search is then performed on each of the corrected time series using the Fast Fourier Transform (FFT) algorithm [3]. An appropriate acceleration step size must be chosen such that the “acceleration space” is sufficiently sampled but the number of computations remains feasible.

## 3. Re-processing the Parkes Multibeam Pulsar Survey

We chose to search the largest and most successful pulsar survey, the Parkes Multibeam Pulsar Survey (PMPS) [4]. The PMPS covers the galactic plane in the regions $|b| < 5^\circ$ and $260^\circ < l < 50^\circ$, at a radio frequency of 1374 MHz. Approximately 35,000 independent observations were performed with the Parkes radio telescope to sample this region. Each observation can be processed separately on different CPU’s making the data reduction suitable to parallel computing.



PoS(MRU)092

The PMPS data have been re-processed twice forming the work of two PhD thesis [5][6]. However, previous processing runs did not have sensitivity to large orbital accelerations that might be present in systems such as pulsar–black hole binaries. The key features of this re-processing run are as follows:

- Sensitivity has been increased to a wider pulsar acceleration range up to $1000\mathrm{ms}^{-2}$ (c.f. J0737-3039A/B maximum acceleration of $\sim 250\mathrm{ms}^{-2}$). Pulsars with orbital periods of less than one hour can be detected.
- New terrestrial interference removal scheme, “zero dispersion measure filtering”.
- Advanced candidate scoring and selection tool, JReaper, designed by Mike Keith.
- New computing resources, DCORE 72 node Beowulf cluster at Jodrell Bank, and Manchester HEP group 2000 node supercomputer.

## 4. Early results

Re-processing was started in mid 2007. Tests on two known relativistic binary neutron star systems reveal a factor of two improvement in sensitivity from previous processing (figure 2). It is expected

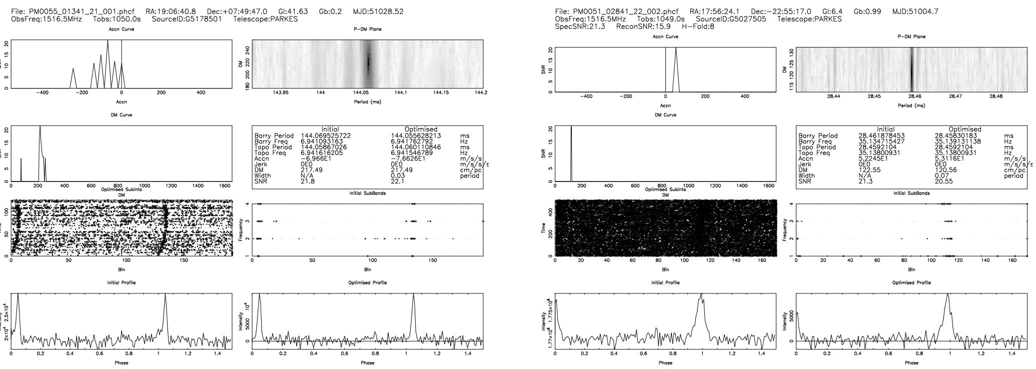

**Figure 1:** (*left*) PSR J1906+0746 re-detected with SNR 21.8 compared to previous detection with SNR 13.6. (*right*) double neutron star system PSR J1756-2251 re-detected with SNR of 21.3 compared to prior detection with SNR 10.6.

re-processing will produce $\sim 11$ million pulsar candidates presenting a significant data analysis task.

## References


[1] M. Kramer et al., *Tests of General Relativity from Timing the Double Pulsar*, *Science* **314** (2006) 97K.

[2] F. Camilo et al., *Observations of 20 Millisecond Pulsars in 47 Tucanae at 20cm*, *ApJ* **535** (2000) 975-990.

[3] M. Frigo, S. G. Johnson, *The Design and Implementation of FFTW3*, *Proceedings of the IEEE* **93** (2005) 216-231.

[4] R. N. Manchester et al., *The Parkes multi-beam pulsar survey - I. Observing and data analysis systems, discovery and timing of 100 pulsars*, *MNRAS* **328** (2001) 17M.

[5] G. Hobbs, *Searches and Timing of Radio Pulsars*, *PhD thesis* (2002).

[6] A. J. Faulkner, *A Search for Fast Binary Galactic Pulsars*, *PhD thesis*, (2004).