Binary Radio Pulsars
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Binary Pulsar Discoveries in the Parkes Multibeam Survey

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Abstract. The Parkes Multibeam survey has been very successful and has discovered about half of the known pulsars. Of these several are binary and millisecond pulsars. In this paper I discuss the procedures that are used for detecting binary pulsars and the current selection effects which arise because of limited data processing. While these selection effects are significant, many interesting binary systems have nevertheless been discovered and I describe some of these. Finally, I offer some indications as to how such searches are likely to proceed in the future.

1. Introduction

The Parkes Multibeam survey is the result of an international collaboration which has been in progress for the past 6 years. This paper is written on behalf of the whole collaboration, comprising the authors of the four papers listed below. The survey employs 13 simultaneous beams on the 64-m Parkes telescope at 1374 MHz. Each of the two polarisations on each beam has 288 MHz of band width and each position on the sky was observed for 35 min. These properties result in a unique sensitivity, up by a factor of about 7 on previous surveys. The main survey covered an area between longitudes 260° through the galactic centre to 50° and for latitudes less than 5°. Once a pulsar is discovered an intensive set of timing observations are made using either the Parkes telescope, the 76-m telescope at Jodrell Bank or the 1000-ft antenna at Arecibo. At present, all the data for the survey have been taken and the survey has roughly doubled the number of known pulsars during the past 5 years having discovered a total of 739 new pulsars (Manchester et al. 2001; Morris et al. 2002; Kramer et al. 2003; Hobbs et al. 2004).

2. Binary Pulsar Search Algorithms

Several search algorithms have been employed in the quest for new pulsars in the data. The primary search is a regular fast Fourier transform-based search which involves an 8-Mpt analysis on the time-series data for each trial value of DM from each beam. This is followed by a conventional incoherent addition of rotational frequency harmonics, providing a search in pulse width. This provides a very high sensitivity to pulsars which have a constant period. However, for pulsars which are in binary systems and whose frequency changes during the

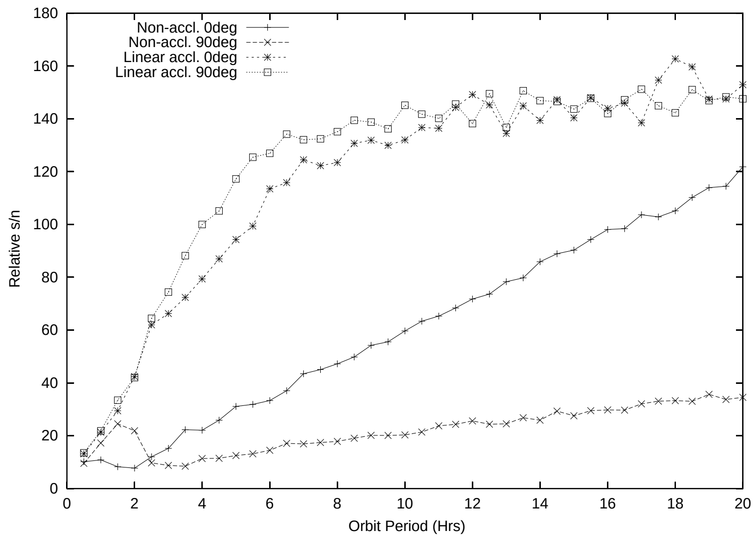

Figure 1. The sensitivity of the single-FFT and the segmented searches as a function of orbital period, for two different orbital phases (see text).

observation due to their binary motion, the limiting acceleration above which the sensitivity to pulsars is reduced significantly is given by $a_{\rm lim} = c/(\nu {\rm T}^2) \sim 100/\nu$ m/s^2, where ν (Hz) is the frequency of the highest strong harmonic of the pulsar rotational frequency and T (s) is the length of the FFT. This compares with the typical acceleration experienced by a pulsar in a double-neutron-star (DNS) system of $a_{\rm DNS} \sim 700/P_{\rm b}^{4/3}$ m/s^2, for an orbital period $P_{\rm b}$ (hr). Thus the sensitivity is significantly reduced for DNSs with $P_{\rm b} \leq 4\,\nu^{3/4}$ (hr).

Because this clearly places a severe restriction on the systems which can be discovered, we also employed an algorithm which provided much improved sensitivity to accelerated pulsars. We call this a segmented linear acceleration search (Faulkner et al. 2004a). It consists of splitting the time series into 16 segments of 0.5 Mpt data sets on each of which an FFT is performed. An incoherent addition of the 16 spectra is then conducted with the spectra being stretched linearly by appropriate amounts for a number of trial values of (constant) assumed acceleration. Conventional incoherent addition of rotational frequency harmonics is then also carried out for the search in pulse width.

In such analyses the limiting acceleration is given by $a_{\rm lim} = c/(\nu {\rm T}^2) \sim 30,000/\nu$ m/s^2. Comparing this with the typical $a_{\rm DNS}$ given above indicates that the sensitivity is significantly reduced for DNSs with $P_{\rm b} \leq 0.07\nu^{3/4}$, much improved over the single-FFT search.

The third search is the side-band search due to Ransom (2000) which consists of taking FFTs of the spectrum. This has good sensitivity to pulsar orbital periods of less than about 0.5 hr.

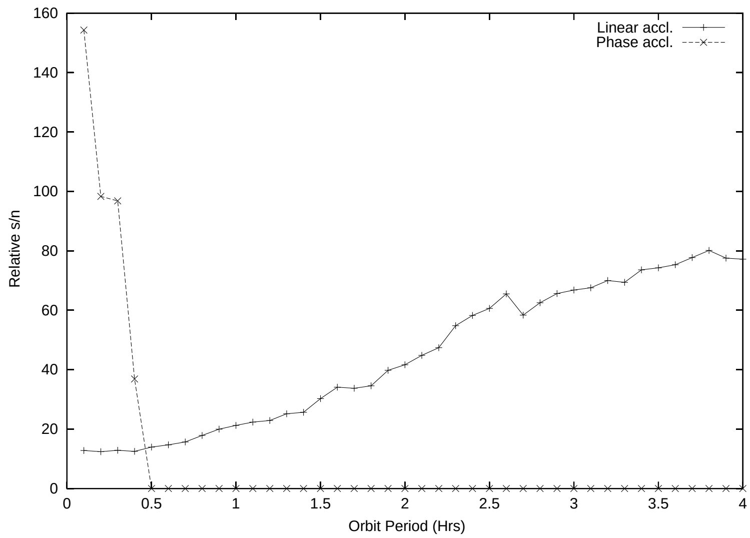

Figure 2. The sensitivity of the segmented and sideband searches (see text for details).

We now consider the sensitivity of these processes to a typical pulsar which has a rotational period of 10 ms, a 5% duty cycle and a signal-to-noise ratio of about 200 in the regular FFT analysis if the pulsar were solitary and not accelerated in a binary system. Figure 1 shows the signal-to-noise ratio which would be obtained if the pulsar were in a DNS system in a circular orbit with various orbital periods. Clearly, regular FFT analysis has a sensitivity which is reduced by a factor of several even for orbital periods as large as 20 hr. It is clear from this figure that the segmented search has a much better sensitivity down to orbital periods of 4 to 5 hr, below which the sensitivity drops off rapidly. Figure 2 shows a blow-up of the short-period portion of the diagram showing the high sensitivity of the side-band search for periods of less than about 0.3 hr but, for periods between this and about 3 hr, the sensitivity of the survey is presently very poor.

In spite of the limitations of these processes, 29 binary pulsars were detected in the survey, of which 19 were new pulsars and 10 previously known. One previously known binary pulsar in the area covered by the survey was not detected, but this was a weak one in a globular cluster. Figure 5 shows these detections and the diagonal line delineates the region of the diagram where the sensitivity is much reduced to a DNS with a 10% duty cycle.

3. The Discoveries

A number of interesting pulsars are amongst the discoveries. PSR J1141−6545 is a 394-ms pulsar in a 2.4-hr eccentric orbit (Kaspi et al. 2000). The rate of advance of periastron of this system has been measured to be 5.3° per year, indicating a total system mass of $2.3\,M_\odot$. This suggests that the companion is either a very light neutron star or more likely a white dwarf star. PSR J1743−3924 is a 172-ms pulsar again in a 2.4-hr orbit but this time very circular. The mass function suggests that the companion is a very low-mass dwarf star with mass $\gtrsim 0.1\,M_\odot$. At the other extreme of orbital period is PSR J1752−2855, which is a 3.9-ms pulsar in a 110-day circular orbit. The mass function suggests that the companion star has a mass of $\gtrsim 0.2\,M_\odot$.

Two pulsars have been discovered in orbit with massive companions in highly eccentric orbits. The first of these is PSR J1740−3052, which has a rotational period of 570 ms, and an orbital period of 230 days (Stairs et al. 2001). The orbit has an eccentricity of 0.6 and the companion must have a mass in excess of $11\,M_\odot$. Optical searches for the companion star have so far proved inconclusive and it remains a possibility that it is a black hole. The second pulsar in this class is PSR J1638−4715, which was first detected in August 1998 but was then not seen until the end of 2002 in spite of many observations. The pulsar has a rotational period of 764 ms and is in an orbit having an eccentricity of about 0.9 with a period of around 5 yr. The companion mass must be greater than about $4.5\,M_\odot$. and it seems that the absence of detections after the initial discovery was due to a large amount of multi-path scattering or absorption of the radiation from the pulsar by material associated with the companion star while the pulsar was close to periastron. This pulsar clearly has close similarities to PSR B1259−63, which is in a 3.4-yr orbit with a $10\,M_\odot$ Be star (Johnston et al. 1992, and in this volume).

Two DNS systems have been discovered. The first was PSR J1811−1736, which is a 104 ms pulsar in a 19-day highly eccentric orbit (Lyne et al. 2000). The periastron advance has been measured to be 0.0093(4) degrees per year indicating a total mass of 2.7(2) $M_\odot$ so that the companion star is probably also a neutron star. The second pulsar, PSR J1756−2251, was discovered recently, has a rotational period of 28.5 ms, and is in a mildly eccentric 7.7-hr binary orbit (Faulkner et al. 2004b). The measured periastron advance of 2.60(1) degrees per year indicates a total mass of 2.60(2) $M_\odot$. Again this almost certainly has another neutron star companion.

4. Concluding Remarks

In principle, it should be possible to achieve the same sensitivity as solitary pulsars for binary pulsars over all orbital parameter space. However orbital-period/pulse-period selection effects are currently determined by the available processing resources. New processing beyond that described in this paper is under way for more extreme systems and further processing will proceed as computer resources become available. However, it is clear that, with much smaller observation time on each point in the sky, ALFA will require much less search effort in acceleration space and have relatively smaller loss of sensitivity for extreme binary systems.

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