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ARECIBO PULSAR SURVEY USING ALFA. II. THE YOUNG, HIGHLY RELATIVISTIC BINARY PULSAR J1906+0746

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ABSTRACT

We report the discovery of PSR J1906+0746, a young 144 ms pulsar in a highly relativistic 3.98 hr orbit with an eccentricity of 0.085 and expected gravitational wave coalescence time of ∼300 Myr. The new pulsar was found during precursor survey observations with the Arecibo 1.4 GHz feed array system and retrospectively detected in the Parkes Multibeam plane pulsar survey data. From radio follow-up observations with Arecibo, Jodrell Bank, Green Bank, and Parkes, we have measured the spin-down and binary parameters of the pulsar and its basic spectral and polarization properties. We also present evidence for pulse profile evolution, which is likely due to geodetic precession, a relativistic effect caused by the misalignment of the pulsar spin and total angular momentum vectors. Our measurements show that PSR J1906+0746 is a young object with a characteristic age of 112 kyr. From the measured rate of orbital periastron advance ($7\fdg57 \pm 0\fdg03$ yr^{-1}), we infer a total system mass of $2.61 \pm 0.02\ M_{\odot}$. While these parameters suggest that the PSR J1906+0746 binary system might be a younger version of the double pulsar system, intensive searches for radio pulses from the companion have so far been unsuccessful. It is therefore not known whether the companion is another neutron star or a massive white dwarf. Regardless of the nature of the companion, a simple calculation suggests that the Galactic birthrate of binaries similar to PSR J1906+0746 is ∼60 Myr^{-1}. This implies that PSR J1906+0746 will make a significant contribution to the computed cosmic inspiral rate of compact binary systems.

Subject headings: pulsars: general — pulsars: individual (PSR J1906+0746)

1. INTRODUCTION

Binary radio pulsars in compact short-period orbits around other neutron stars or white dwarfs are valuable to study for a variety of reasons. The ability to monitor precisely the pulsars as clocks in such systems allows exquisite tests of Einstein's theory of general relativity to be performed (e.g., Taylor & Weisberg 1989; Lyne et al. 2004). In addition, studies of the variations in pulse profile morphology and polarimetry provide probes of relativistic spin-orbit coupling in several systems (for a review, see Stairs 2003). As the rare end points of binary star evolution, relativistic binaries offer unique insights and powerful constraints on our physical understanding of the formation properties of compact objects (e.g., the natal kicks imparted to the neutron star; Lai et al. 2001; Willems et al. 2004). Since many of these binaries will coalesce due to gravitational wave emission well within a Hubble time, their merger rate (Phinney 1991; Burgay et al. 2003; Kim et al. 2003, 2004) is of great interest to the gravitational wave detector community as potential sources for current interferometers such as LIGO (Laser Interferometer Gravitational Wave Observatory; Abramovici et al. 1992).

Following the discovery of the original binary pulsar B1913+16 (Hulse & Taylor 1975), observational progress in finding further relativistic binaries was hampered by a lack of detector sensitivity and computational resources required to detect their strongly time-varying signals (Johnston & Kulkarni 1991). In recent years, as both of these obstacles are gradually being overcome, the sample of relativistic binaries with orbital periods

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less than a day has grown and now numbers eight (Manchester et al. 2005). Here we report the discovery of the latest addition to this growing population, PSR J1906+0746, found in the preliminary stages of a large-scale search for pulsars we are carrying out using the 305 m Arecibo Telescope (Cordes et al. 2006, hereafter Paper I). This new binary system promises to have a significant impact on all of the science areas mentioned above. In § 2 we detail the discovery and follow-up observations carried out so far. We then discuss the implications of these results on the nature of the companion (§ 3.1) and merger rate of compact binary systems (§ 3.2), and present evidence for pulse profile evolution (§ 3.3). In § 4 we summarize the main conclusions and look ahead to future work.

TABLE 1

Observed and Derived Parameters of PSR J1906+0746

Parameter	Value
Right ascension	19 06 48.673(6)
Declination	07 46 28.6(3)
Spin period, P (ms)	144.071929982(3)
Spin-period derivative, $\dot{P}$	$2.0280(2) \times 10^{-14}$
Epoch (MJD)	53590
Orbital period, P_b (days)	0.165993045(8)
Projected semimajor axis, x (lt s)	1.420198(2)
Orbital eccentricity, e	0.085303(2)
Epoch of periastron, T_0 (MJD)	53553.9126685(6)
Longitude of periastron, ω (deg)	61.053(1)
Periastron advance rate, $\dot{\omega}$ (deg yr^{-1})	7.57(3)
Dispersion measure, DM (cm^{-3} pc)	217.780(2)
Rotation measure, RM (rad m^{-2})	+150(10)
Flux density at 0.4 GHz, $S_{0.4}$ (mJy)	0.9(2)
Flux density at 0.8 GHz, $S_{0.8}$ (mJy)	0.72(15)
Flux density at 1.4 GHz, $S_{1.4}$ (mJy)	0.55(15)
Flux density at 3.2 GHz, $S_{3.2}$ (mJy)	0.12(3)
Flux density at 6.0 GHz, $S_{6.0}$ (mJy)	0.030(7)
Main pulse widths at 50% and 10% (ms)	0.6 and 1.7
Characteristic age, $\tau_c = P/2\dot{P}$ (kyr)	112
Magnetic field, $B = 3.2 \times 10^{19} (P\dot{P})^{1/2}$ (gauss)	1.7×10^{12}
Spin-down power, $\dot{E} = 3.95 \times 10^{46} \dot{P}/P^3$ (ergs s^{-1})	2.7×10^{35}
Inferred distance, d (kpc)	$\sim$5.4
Spectral index, α	$-1.3(2)$
Radio luminosity at 1.4 GHz, $S_{1.4}d^2$ (mJy kpc^2)	$\sim$16
Mass function, $f(m_p, m_c) = 4\pi^2 x^3/(T_\odot P_b^2)$ $(M_\odot)$	0.1116222(6)
Total system mass, $M = m_p + m_c$, $(M_\odot)$	2.61(2)
Gravitational wave coalescence time, τ_g (Myr)	$\sim$300

Notes.—Figures in parentheses are 1 σ uncertainties in the least significant digit(s) and the constant $T_\odot \equiv GM_\odot/c^3 \simeq 4.92\,5\ \mu$s. Definitions for B, τ_c and $\dot{E}$ are from Lorimer & Kramer (2005). The distance estimate uses the pulsar position, DM and the Cordes & Lazio (2002) Galactic electron density model. Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

2. DISCOVERY AND FOLLOW-UP OBSERVATIONS

PSR J1906+0746 was discovered in precursor observations with the Arecibo *L*-band Feed Array[22] (ALFA) system described in Paper I. In brief, ALFA collects radio signals from the Gregorian focus at Arecibo using seven cooled receivers that cover different parts of the sky in the 1.2–1.5 GHz band. Pulsar survey observations with the ALFA system (P-ALFA) were carried out in a precursor phase between 2004 August and 2004 October and covered a total of 15.8 deg^2 in the inner Galaxy ($40^\circ \leq l \leq 75^\circ$, $|b| \leq 1^\circ$) with 135 s pointings and 14.8 deg^2 in the anticenter region ($170^\circ \leq l \leq 212^\circ$, $|b| \leq 1^\circ$) with 67 s pointings. The incoming signals were amplified, filtered, and down-converted before being sampled by four Wideband Arecibo Pulsar Processors (WAPPs; Dowd et al. 2000). In the configuration used for this survey, the WAPPs provided a spectral resolution of 390.625 kHz for both polarizations over a 100 MHz band centered at 1.42 GHz. The polarization pairs were summed and written to disk every 64 μs. Initial data reduction was carried out at reduced spectral frequency and time resolution, as described in Paper I. PSR J1906+0746, was discovered with a signal-to-noise ratio S/N $\sim$ 11 in data taken on 2004 September 27. The pulsar was $2\overset{'}{.}5$ (1.47 beam radii) from the center of the beam (see Paper I), where the antenna gain is $\sim$5 times smaller than at its center.

With Galactic coordinates $l = 41\overset{\circ}{.}6$ and $b = 0\overset{\circ}{.}1$, PSR J1906+0746 lies in the region of sky covered by the Parkes Multibeam Pulsar Survey (PMPS; e.g., Manchester et al. 2001). Examination of the search output of the 35 minute PMPS observation of this position taken on 1998 August 3 showed a 144 ms periodicity with S/N $\sim$ 7. Although this was below the nominal S/N threshold of 8–9 of the PMPS, the data were also processed using techniques designed to retain sensitivity to binary pulsars. Using the "stack-and-slide" algorithm (Brady & Creighton 2000) implemented in the PMPS (Faulkner et al. 2004), PSR J1906+0746 appears with S/N $\sim$ 25. The pulsar was $3\overset{'}{.}8$ (only 0.5 beam radii) from the center of the beam. However, due to significant amounts of radio-frequency interference close to 144 ms, PSR J1906+0746 was not selected as a candidate in the PMPS.

The high degree of acceleration detected in the PMPS observation immediately implied that PSR J1906+0746 is a short-period binary system. To establish the orbital parameters, follow-up observations were initiated in 2005 May using the 76 m Lovell Telescope at Jodrell Bank. The data acquisition system used for these 1396 MHz observations was identical to that described by Hobbs et al. (2004). A preliminary orbital ephemeris was obtained from period determinations in 5 minute integrations over an initial 9 hr observation. The ephemeris was then refined in a timing analysis using the TEMPO software package,[23] where pulse times of arrival (TOAs) were fitted to a model including spin parameters, orbital elements, and pulsar position. The resulting ephemeris, based on 1640 TOAs spanning 158 days, is given in Table 1. As a check on the solution, the pulsar position was independently derived from a grid of Arecibo observations at 3 GHz. The position thus measured has an uncertainty of 9$''$ and is $6\overset{''}{.}7$ away from the timing position.

Although all data used for the timing solution were collected in the 1–2 and 3–4 GHz bands with Arecibo, we have also been able to detect PSR J1906+0746 at 430 MHz and 6 GHz with Arecibo and at 820 MHz with the Green Bank Telescope (GBT). The Arecibo data were collected using the WAPPs with 25 MHz bandwidth at 430 and 400 MHz at the higher frequencies. The GBT data at 820 MHz were obtained using the Berkeley-Caltech Pulsar Machine (Backer et al. 1997) in the 48 MHz bandwidth mode described by Camilo et al. (2002). With the exception of 430 MHz, the integrated pulse profiles (Fig. 1) show that the emission is characterized by a narrow main pulse and significant interpulse feature. The exponential tails present at 430 MHz are most likely due to interstellar scattering. Flux density estimates based on the off-pulse noise and the radiometer equation (e.g., Lorimer & Kramer 2005) at each of these frequencies are listed

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[22] See http://alfa.naic.edu.

[23] See http://pulsar.princeton.edu/tempo.

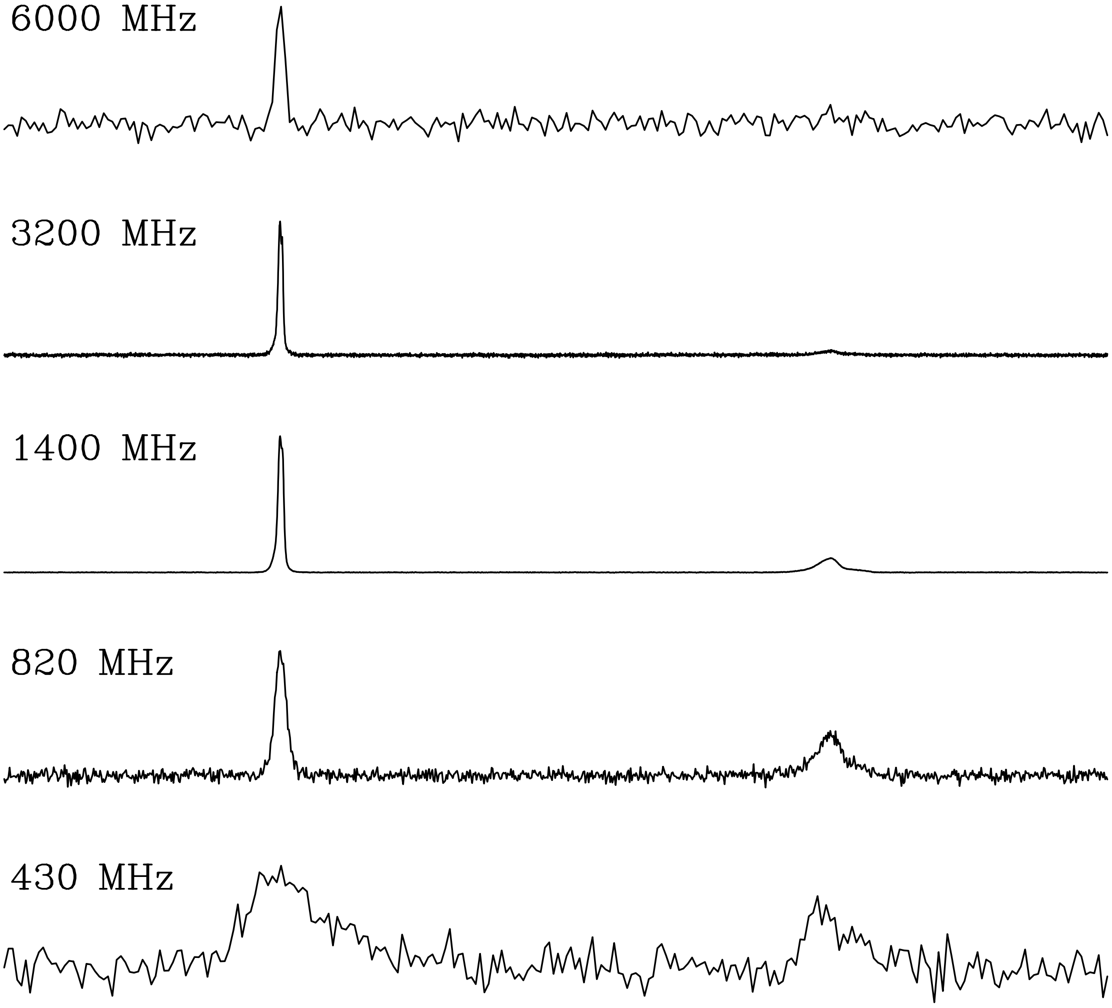

FIG. 1.—Multifrequency pulse profiles for PSR J1906+0746 obtained from observations at Arecibo (430, 1400, 3200, and 6000 MHz) and Green Bank (820 MHz). Each profile shows 360° of rotational and is freely available online as part of the European Pulse Network database (http://www.jb.man.ac.uk/~pulsar/Resources/epn).

in Table 1. Also listed is the spectral index, α, obtained from a fit to $S_\nu \propto \nu^\alpha$, where S_ν is the flux density at an observing frequency ν.

To measure the polarization properties of PSR J1906+0746, a 2.5 hr Parkes observation at 1.4 GHz using a wideband correlator was carried out on 2005 May 25, which provided all four Stokes parameters across a 256 MHz band. Both the main pulse and interpulse have high linear polarization (about 65% and 50%, respectively) with position angle swings of about 30° across both pulses, increasing for the main pulse and decreasing for the interpulse. The observed frequency dependence of position angle across the band implies a rotation measure (RM) of 150 ± 10 rad m^{-2}, consistent in sign with the Faraday rotation seen toward most other pulsars and extragalactic sources along nearby sight lines (Clegg et al. 1992).

3. DISCUSSION

3.1. *Nature of the Companion*

From the orbital parameters of PSR J1906+0746, we infer a Keplerian mass function $f(m_p, m_c) = (m_c \sin i)^3/(m_p + m_c)^2 = 0.11\ M_\odot$. Here m_p is the pulsar mass, m_c is the companion mass and i is the angle between the orbital plane and the plane of the sky. Our measurement of the orbital periastron advance $\dot{\omega} = 7\overset{\circ}{.}57 \pm 0\overset{\circ}{.}03$ yr^{-1}, is, after the double pulsar system Burgay et al. (2003), the second largest observed so far. Interpreting this large value within the framework of general relativity implies that the total system mass $M = m_p + m_c = 2.61 \pm 0.02\ M_\odot$. Using this, and the constraints from the mass function, we infer the limits $m_c > 0.9\ M_\odot$ and $m_p < 1.7\ M_\odot$. Measured masses of the neutron stars in double neutron star binary systems range from $1.25\ M_\odot$ (PSR J0737−3039B; Lyne et al. 2004) to $1.44\ M_\odot$ (PSR B1913+16; Weisberg & Taylor 2003), it is likely that the mass of PSR J1906+0746 is within these limits. If so, then $1.17\ M_\odot < m_c < 1.36\ M_\odot$ and $42° < i < 51°$, respectively. These inclinations place the size of any Shapiro delay well below the current level of timing precision.

Although it is possible, in principle, to account for the observed $\dot{\omega}$ by classical effects (e.g., by a tidally induced quadrupole moment from a main-sequence star companion; Smarr & Blandford 1976), as discussed by Kaspi et al. (2000), these are unlikely for this particular orbital configuration. The simplest interpretation is the relativistic case, and the above mass constraints suggest that the companion to PSR J1906+0746 is either a massive white dwarf or another neutron star. For the case of a white dwarf companion, the implication (Dewey & Cordes 1987; Portegies Zwart & Yungelson 1999; Tauris & Sennels 2000) would be that PSR J1906+0746 formed from a binary system of near unity mass ratio in which both stars were below the critical core-collapse supernova mass limit $M_{\rm crit} \sim 8\ M_\odot$.

Following a phase in which the accretion of matter from the evolved and more massive primary star onto the initially less massive secondary pushed its mass above $M_{\rm crit}$, the secondary underwent a supernova explosion to form the currently observable pulsar. Two probable endpoints of this scenario are the binary pulsars B2303+46 (van Kerkwijk & Kulkarni 1999) and J1141−6545 (Kaspi et al. 2000).

The alternative case of a neutron star companion is particularly attractive following the recent discovery of the double pulsar system J0737−3039 (Burgay et al. 2003; Lyne et al. 2004). Given the small inferred characteristic age and large magnetic field of PSR J1906+0746, it could be the young second-born neutron star. In this case, as for PSR J0737−3039A in the double pulsar system, we would expect the companion to be a longer lived recycled pulsar, spun up to a period of a few tens of ms during an earlier phase of accretion.

To help establish the nature of the companion to PSR J1906+0746, we have carried out a search for radio pulsations in all data collected so far. Following Champion et al. (2004), we have removed the deleterious effects of the orbital motion on these observations by transforming the time series (dedispersed to the DM given in Table 1) to the rest frame of the companion. To account for the unknown orbital inclination, and hence mass ratio, of PSR J1906+0746 this process was carried out for 110 different assumed companion masses uniformly sampled in the range $0.9 < m_c < 2.0\ M_\odot$. The corrected time series were then searched for periodic signals by the same Fourier transform analysis used in the original survey. No convincing pulsar candidates were seen down to S/N limits of 6. The most sensitive observation we have made so far is a 2.2 hr Arecibo observation using four WAPPs to span a 400 MHz band centered at 1.4 GHz. Assuming a period of 15 ms and a 10% duty cycle for the putative pulsar, we estimate a limiting flux density of 5 μJy. At the nominal distance of 5.4 kpc, the corresponding 1.4 GHz luminosity limit is 0.1 mJy kpc^2; only 0.5% of all currently known pulsars (Manchester et al. 2005) have a luminosity below this value. In parallel to these deep periodicity searches, we have also carried out a search for single pulses in the dedispersed time series. No significant events were found down to flux density limits of 130 mJy at 1.4 GHz.

These deep searches suggest that the companion to PSR J1906+0746 is either (1) a white dwarf, (2) a faint radio pulsar with a luminosity below 0.1 mJy kpc^2, or (3) a pulsar whose radio beam does not intersect our line of sight. Option 1 will be hard to test conclusively. A 100 kyr white dwarf at a distance of 5.5 kpc will be of 24th magnitude. However, given the time necessary for the mass transfer phase in the aforementioned evolutionary scenario, a more probable age for the white dwarf might be ~1 Myr. For this larger age, the expected visual magnitude is 29. Even with the very best optical observations it may therefore not be possible to rule out this hypothesis. Given the sensitivity reached by our deep Arecibo observations, option 2 is unlikely to be testable in the near future. However, due to the high expected geodetic precession rate (see below) it remains a possibility that the radio beam of the putative companion pulsar will precess into our line of sight in the future. A further probe of the nature of the companion would be orbital-phase dependent variations in the pulse profile of PSR J1906+0746. This effect is now well established in the double pulsar binary system as the relativistic wind from PSR J0737−3039A impinges on the magnetosphere of its less energetic companion J0737−3039B (Lyne et al. 2004). While the larger orbital separation and higher rate of spin-down in PSR J1906+0746 will make any effect far less for PSR J1906+0746, it may be detectable in the future. There are no significant pulse profile variations with orbital phase in our current data.

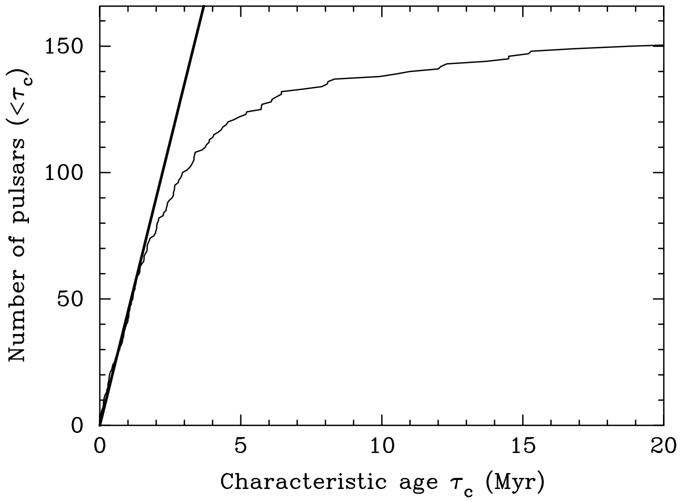

FIG. 2.—Cumulative distribution of characteristic ages for pulsars detected in the PMPS with similar surface magnetic fields to PSR J1906+0746. The heavy solid line shows the expected trend corresponding to a birthrate of potentially observable objects of 45 Myr^{-1} (see text).

3.2. *System Age and Implications for the Compact-Binary Merger Rate*

PSR J1906+0746 has the smallest characteristic age ($\tau_c =$ 112 kyr) of any binary pulsar currently known. It is also worth noting that, as seen for other young pulsars (e.g., von Hoensbroech et al. 1998), a significant amount of polarization is observed. As supernova remnant associations are known for isolated pulsars with similar spin characteristics as PSR J1906+0746 (e.g., PSR B0656+14; Thorsett et al. 2003), we have searched the available literature for signs of diffuse radio emission. No candidates are present in the most recent compilation of supernova remnants (Green 2004). Similarly, no extended radio emission is present at or near the pulsar position in a 332 MHz VLA observation of this region (Kaplan et al. 2002). The corresponding 1 σ surface brightness upper limit of $\sim 6\times10^{-22}$ W m^{-2} Hz^{-1} sr^{-1}, which is fainter than almost all known supernova remnants (Green 2004).

Regardless of the exact nature of the companion to PSR J1906+0746, the small τ_c for this pulsar is unusual when placed in context of the radio lifetimes of 10–100 Myr estimated for normal pulsars (see, e.g., Lyne et al. 1985; Bhattacharya et al. 1992). Unless τ_c is a significant underestimate of the true age of this pulsar, the implication is that we have found a pulsar which is only 0.1%–1% through its active radio lifetime. Since this is highly unlikely to occur by chance, the youth of PSR J1906+0746 suggests a potentially significant birthrate for this new class of objects.

A simple estimate of the birthrate can be made by considering the cumulative distribution of characteristic ages. Figure 2 shows this distribution for a subsample of 150 pulsars detected in the PMPS that have inferred magnetic field strengths within 1 dB of PSR J1906+0746 [i.e., $|\log(B) - \log(B_{1906})| < 0.1$]. This sample shows a linear trend at small ages with a slope of 45 Myr^{-1}. The relative dearth of pulsars with larger ages reflects the difficulty of detecting them (e.g., due to luminosity decay, period-dependent beaming effects, or motion away from the Galactic disk). Nevertheless, the slope of the trend does provide a good estimate of the formation rate of normal pulsars detectable

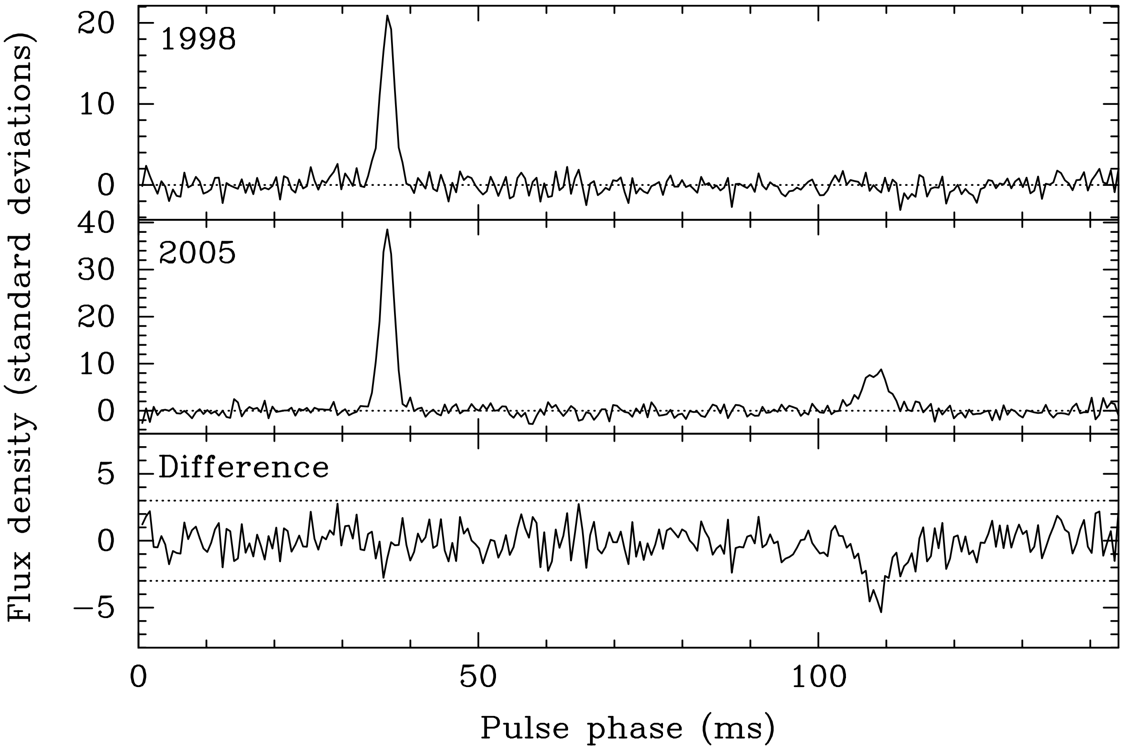

FIG. 3.—Integrated pulse profiles of PSR J1906+0746 showing 360° of rotational phase. The upper panel shows the detection at 1.374 GHz from the 35 minutes of PMPS data taken on 1998 August 3. The middle panel shows a 35 minute observation with the same observing system taken on 2005 September 4. The bottom panel shows the difference profile (i.e., 1998 minus 2005 data) after scaling both profiles to the area of the main pulse. The dashed horizontal lines show ±3 standard deviations computed from the off-pulse noise region. The limiting instrumental time resolution of both these profiles is 2.1 ms.

by the PMPS with similar magnetic fields to PSR J1906+0746. Since the PMPS has only detected one J1906+ 0746-like pulsar in this sample, the inferred birthrate of *similar pulsars potentially observable in the PMPS* is $45/150 = 0.3$ Myr^{-1}.

To scale this rate over the whole Galaxy, we used a Monte Carlo simulation to estimate the total Galactic volume probed by the PMPS for J1906+0746-like objects. The simulation seeded a model galaxy with pulsars following the distribution and luminosity functions derived by Lorimer (2004). We find that the PMPS should detect roughly one J1906+0746-like pulsar for every 40 in the Galaxy. With this scaling, we estimate the birthrate of PSR J1906+0746-like objects to be $\sim 60 \times (0.2/f)$ Myr^{-1}, where f is the unknown fraction of 4π sr covered by the radio beam. For a steady state population of compact binaries similar to PSR J1906+0746, we can reasonably assume that the merging rate is equal to the birthrate. Our first-order estimate therefore implies a merger rate of J1906+0746-like binaries similar to that derived recently by (Kalogera et al. 2004) for double neutron star binaries. Once the nature of the companion is established, the inclusion of PSR J1906+0746 in future population synthesis calculations will provide an important additional constraint on the merger rate of compact binaries (Kim et al. 2003, 2004).

The orbital eccentricity of 0.085 for PSR J1906+0746 is remarkably similar to that of PSR J0737−3039 (Burgay et al. 2003), but smaller than observed for other double neutron star systems. As proposed recently by Chaurasia & Bailes (2005), for PSR J0737−3039, this is likely a selection effect: systems with similar orbital periods but significantly higher eccentricities would coalesce on much shorter timescales than the likely age of PSR J0737−3039 ($\sim 10^8$ yr). As a result, more eccentric binaries are much less likely to be observed. For systems as young as PSR J1906+0746, where there has been less time for significant gravitational wave decay, systems with higher eccentricities could in principle be observed. Until further examples of young compact binary pulsars are discovered, it is difficult to conclude whether the low eccentricity is a necessary feature of these systems. If it is, we will have better constraints on the sequence of events that leads to the formation of pulsars, including supernova kicks (see, e.g., Dewi et al. 2005). If it is not, then there is the exciting possibility of finding other young pulsars in even more compact and eccentric orbits.

3.3. *Pulse Profile Evolution*

It is now established for pulsars observed in four other relativistic binaries (PSR B1913+16 [Weisberg et al. 1989; Kramer 1998; Weisberg & Taylor 2002], PSR B1534+12 [Stairs et al. 2004], PSR J1141−6545 [Hotan et al. 2005], and PSR J0737−3039B [Burgay et al. 2005]) that the mean pulse profile varies with time. With the possible exception of PSR J0737−3039B (Burgay et al. 2005), the simplest explanation for this effect is geodetic precession—a general relativistic effect in which the pulsar spin axis precesses about the total system angular momentum (Damour & Ruffini 1974). The profile variations occur as the precessing pulsar beam changes its orientation with respect to our line of sight. Given the highly relativistic nature of PSR J1906+0746, we also expect to observe this effect in this system. Using the above mass constraints and the standard geodetic precession formulae (Barker & O'Connell 1975), for PSR J1906+0746 we find that the expected precession rate is $2\overset{\circ}{.}2$ yr^{-1} for the double neutron star case, or $1\overset{\circ}{.}6$ yr^{-1} for the neutron star–white dwarf case. These correspond, respectively, to precession periods of 164 and 225 yr. The change in the angle between the line of sight and the spin axis is likely to be significantly smaller than the precession rates imply themselves (see, e.g., Hotan et al. 2005).

The PMPS detection of PSR J1906+0746 provides a 7 yr baseline to look for pulse-shape changes in this new system. Figure 3 shows a comparison between the integrated profiles at 1400 MHz from the 1998 PMPS detection and a recent Parkes observation at the same frequency using the same observing system. We have scaled each profile to the area of the main pulse and formed the "difference profile" by subtracting the 2005 profile from the 1998 one. In the absence of any profile evolution, the difference profile should be free from systematic trends and have a standard deviation consistent with the quadratic sum of the off-pulse noise present in the two input profiles. We observe a significant departure from random noise around the interpulse region, which is not detectable in the 1998 observation. It is also notable that the peak S/N (which we define as the peak of the main pulse divided by the off-pulse standard deviation) seen in 2005 is 80% larger than observed in 1998. Accounting for variations in telescope gain for the two observations, and the fact that the 1998 observation was offset from the nominal position by $3\overset{\prime}{.}8$, we expect a S/N increase of only 30%. As scintillation is not expected at this frequency for this DM, these observations suggest that the flux density of PSR J1906+0746 has increased since 1998. Further observations with better S/N, flux calibration and polarimetric capability are required to confirm and quantify these changes.

4. CONCLUSIONS AND FUTURE WORK

We have presented the discovery and initial follow-up observations of PSR J1906+0746, a young 144 ms pulsar in a highly relativistic 3.98 hr orbit about a $>0.9\ M_\odot$ companion. The new system emphasizes the relative immunity of surveys with short integration times to the smearing of pulsar signals caused by fast orbital motion. It also shows the value of storing archival search data for retrospective analysis. The orbital characteristics and total mass of the binary system, $2.61 \pm 0.02\ M_\odot$, inferred from the measured periastron advance $\dot{\omega} = 7\overset{\circ}{.}57 \pm 0\overset{\circ}{.}03\ \mathrm{yr}^{-1}$, suggest that the companion is either another neutron star or a massive white dwarf. In the former case, the 112 kyr characteristic age of PSR J1906+0746 would imply that its companion is a short-period recycled neutron star. However, despite intensive searches, we have been so far unable to detect radio pulsations from the companion. Optical searches for a white-dwarf companion could possibly clarify the situation. Regardless of the nature of the companion, the apparent youth of PSR J1906+0746 implies a birthrate of $\sim$60 Myr^{-1} for similar objects in the Galaxy. Note that this estimate assumes a beaming fraction for these objects of 20%.

Future radio timing and polarimetric observations of PSR J1906+0746 should allow the study of several relativistic effects. The very narrow pulse shape observed (Fig. 1) means that our current Arecibo TOAs have an uncertainty of $\sim$5 μs in a 5 minute integration. Simulations based on this level of precision show that we expect to measure the gravitational redshift and time dilation parameter, γ, within the coming year and, within a few years, measure the rate of orbital decay, $\dot{P}_b$. Such measurements would determine the orbital inclination and masses of the stars so that the system could possibly be used for further tests of general relativity. Assuming reasonable ranges for the pulsar mass, the orbital inclination angle is likely to be in the range $42^\circ < i < 51^\circ$. For this range of inclinations, a measurement of the Shapiro delay is less likely at the present level of precision. The distance to PSR J1906+0746 is currently estimated using the Cordes & Lazio (2002) electron density model. As for PSR B1913+16, kinematic contributions to $\dot{P}_b$, which depend on the assumed location in the Galaxy and hence the distance, are likely to be a limiting factor for high-precision tests of general relativity with this system. We are currently attempting to obtain independent distance constraints via the detection of neutral hydrogen absorption and emission.

Comparing pulse profiles taken in 1998 and 2005, we have found some evidence for long-term evolution of the pulse profile. Given that the expected geodetic precession period is only $\sim$200 yr, the observed variations could be the first manifestations of this effect. Future observations with high time resolution and polarimetric capabilities should provide more quantitative insights and may permit a mapping of the radio beam of PSR J1906+0746, as has been possible for PSR B1913+16 (Weisberg & Taylor 2002).

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