Pulsars : Problems & Progress
ASP Conference Series, Vol. 105, 1996
S. Johnston, M. A. Walker and M. Bailes, eds.

Further Observations of the Planets Pulsar

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Abstract. Recent results of timing observations of the planets pulsar, PSR B1257+12, are discussed. The current timing model includes significant contributions from the second and the third-order period derivatives. If these contributions are related to dynamical effects induced by a fourth distant planet, it would be a Saturn-mass object in a ~170 year orbit around the pulsar.

1. Introduction

The three planets around a 6.2-ms pulsar, PSR B1257+12, (Wolszczan & Frail 1992 ; Wolszczan 1994) remain the only known system of terrestrial mass bodies orbiting a star other than the Sun. The recent spectacular detections of giant planets around solar-type stars (Mayor & Queloz 1995; Marcy & Butler 1996) provide further evidence that extrasolar planetary systems exist in a variety of forms that would be difficult to anticipate on the basis of our present knowledge of the Solar system alone.

An extraordinary precision of the pulsar timing makes it a particularly suitable method in the studies of planetary perturbations (Wolszczan 1994) and in the searches for terrestrial-mass or even asteroid-mass planets outside the Solar system (Cordes 1993; Wolszczan 1996). Since the optical methods of planetary detection are currently not capable of such precision (e.g. Walker *et al.* 1995; Marcy & Butler 1996), the investigations of pulsar planets will remain a unique source of information on low-mass planets and on planetary dynamics in the foreseeable future.

In this paper, we summarize the most recent results of the continuing timing observations of PSR B1257+12, including a brief discussion of the emerging possibility of a fourth, more massive planet in the PSR B1257+12 system.

2. Observations and Timing Analysis

Timing observations of PSR B1257+12 with the 305-m Arecibo radiotelescope and the Princeton Mark-3 pulsar backend at 430 MHz and 1400 MHz are described in detail in Wolszczan (1994) and references therein. Since June 1994, the pulsar has been also observed with the Penn State Pulsar Machine (PSPM). The PSPM is a 2×128× 60 kHz channel pulsar receiver capable of a 4-bit sampling of the pulsar signal synchronously with the Doppler-tracked pulsar period at a maximum rate of 100 kHz. Compared to the Arecibo 2 ×32×250 kHz filterbank

https://doi.org/10.1017/S0252921100041105 Published online by Cambridge University Press

used by the Mark–3 system, the PSPM has a four times better frequency resolution which significantly improves a precision of the millisecond pulsar timing at low frequencies. In the case of PSR B1257+12, the improvement is expected to be at least a factor of two.

Since early 1994, activities related to the Gregorian upgrade of the Arecibo telescope have restricted its pointing capability. Observations at 1400 MHz have not been made since January 1994, followed by a suspension of the 430 MHz measurements about ten months later. Since April 1994, timing observations of the planets pulsar have been made with the 100–m radiotelescope of the Max–Planck–Institut für Radioastronomie (MPIfR) in Bonn, Germany, using the dual circular polarization 1.4/1.6 GHz receiving system and a $4 \times 60 \times 0.666$ MHz filterbank equipped with a hardware dedisperser (Kramer *et al.* , these proceedings).

The pulse time–of–arrival (TOA) measurements and analysis were carried out in a standard manner (Wolszczan 1994). In fitting a timing model to the 1400 MHz data, a constant offset between the Arecibo and Bonn TOA measurements was removed. The TOAs were corrected for a substantial dispersion measure variation which has occured over the 4 1/2 year observing period. A model including astrometric, dispersion, and spin parameters of the pulsar, as well as the dynamical parameters of its planetary system was least–squares fitted to the observed topocentric TOAs using a modified version of the timing analysis package TEMPO (Taylor & Weisberg 1989; Wolszczan 1994). The 430 MHz and 1400 MHz residuals from the best–fit timing model for PSR B1257+12 based on the Arecibo and Bonn data are shown in Fig. 1 along with the dispersion measure variations.

3. Discussion

Timing parameters of PSR B1257+12 derived from the fit discussed above are not substantially different from the most recently published model (Wolszczan 1996). A three–planet model with perturbations between planets B and C and a significant second–order derivative of the pulsar spin period, $\ddot{P} = (4.8 \pm 0.2) \times 10^{-30}\ \mathrm{s}^{-1}$, predicts the observed TOAs with a $\sim$3 μs rms residual.

A non–zero $\ddot{P}$ for PSR B1257+12 is most naturally explained as a manifestation of the presence of a low–level timing noise in this pulsar. For the purpose of comparison of the timing behavior of PSR B1257+12 with that of other pulsars, we have used a 3–year section of our timing data to compute a "timing stability" parameter, Δt_8, as defined by Arzoumanian *et al.* (1994). For PSR B1257+12, $\Delta t_8 = -3.9$ which, when included in the $\dot{P}/\Delta t_8$ diagram of these authors, is not inconsistent with the hypothesis that the timing noise is a likely origin of the observed TOA variations. Further support for this conclusion is provided by the existing evidence for a microsecond–level timing noise in the millisecond pulsar, PSR B1937+21, (Kaspi, Taylor & Ryba 1994).

Another, perhaps more intriguing alternative is that the observed $\ddot{P}$ is due to a dynamical influence of a distant fourth planet in the pulsar system. For example, similar timing behavior of PSR B1620-24 in the globular cluster M4 has led Backer *et al.* (1993) and Thorsett *et al.* (1993) to postulate the presence of a third body in this binary system.

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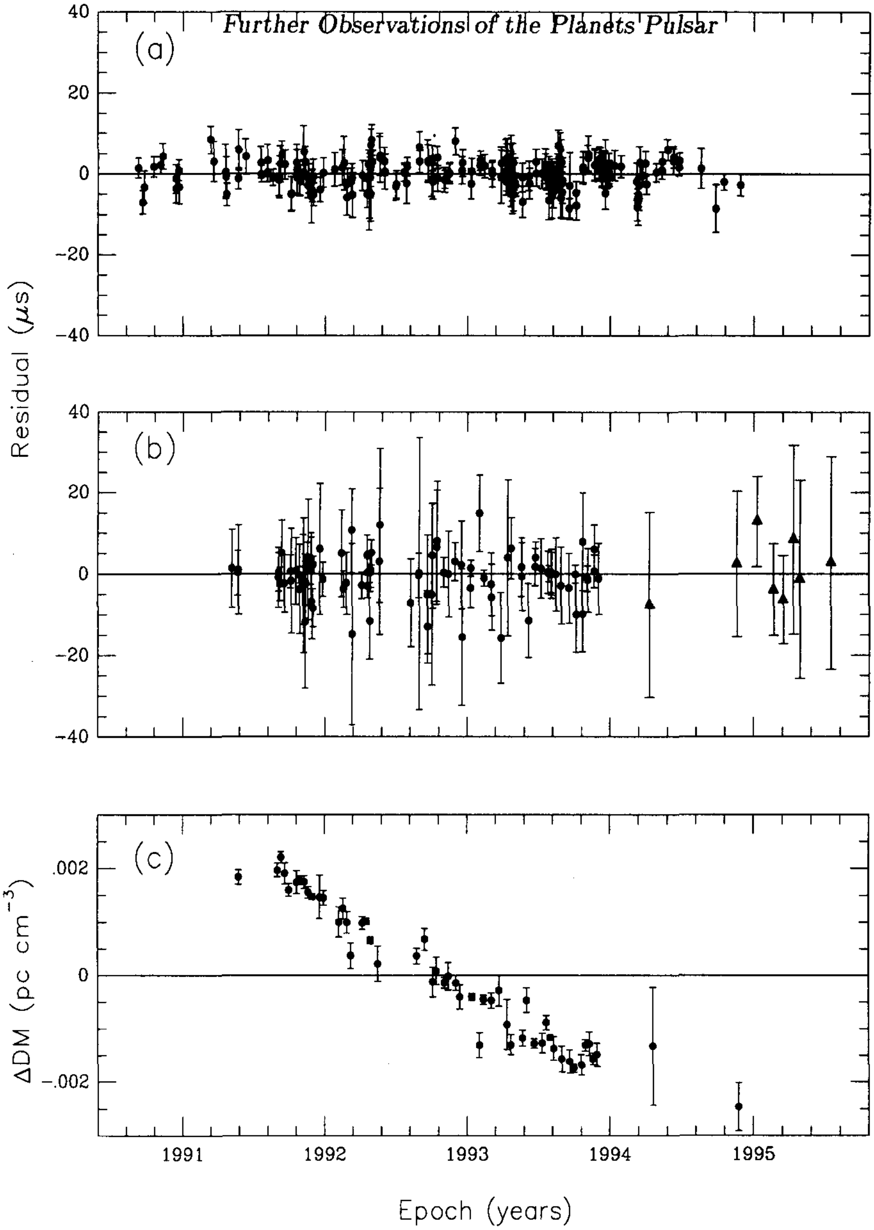

Figure 1. Residuals from the best-fit timing model for PSR B1257+12. *(a)* The Arecibo measurements at 430 MHz, *(b)* the 1400 MHz measurements at Arecibo *(circles)* and Bonn *(triangles)*, and *(c)* the dispersion measure variations around the best-fit value of 10.186 pc cm^{-3}.

https://doi.org/10.1017/S0252921100041105 Published online by Cambridge University Press

As discussed by Rasio (1994), in the case of circular, coplanar, edge-on orbits, one can establish analytical relationships between the spin frequency derivatives and orbital elements of an outer planet. Moreover, if the mass of such planet is small enough and the frequency derivatives up to the third-order one are measurable, it is possible to calculate the outer planet orbit in a straightforward manner (Rasio 1994, Eqs. [8–10]). For PSR B1257+12, numerical values of the spin frequency and its first three derivatives are: $f = 160.8$ Hz, $\dot{f} = 8.6 \times 10^{-16}$, $\ddot{f} = (-1.25 \pm 0.05) \times 10^{-25}$, and $\dddot{f} = (1.1 \pm 0.3) \times 10^{-33}$, respectively. At a relevant level of accuracy for this calculation, the errors in f and $\dot{f}$ are entirely negligible. Also, $\dot{f}$ has been corrected for kinematic effects (Camilo, Thorsett & Kulkarni 1994).

Assuming the pulsar mass of 1.35 $M_\odot$, these values of spin parameters give a planet in a ~170 year orbit, with the orbital radius of ~35 A.U. and the planetary mass of ~95 $M_\oplus$, which would be a Saturn-mass object at a Pluto-like distance from the pulsar. Of course, this result critically depends on the assumption that $\dot{f}$ is dominated by orbital dynamics and on the currently very uncertain value of $\dddot{f}$. Further timing observations of PSR B1257+12 will allow to constrain it more meaningfully.

Acknowledgments. I thank Dr. F. Rasio for discussions. This research was supported by the NASA grant NAGW-3405 and the NSF grant AST 93-17757.

References

Arzoumanian, Z., Nice, D. J., Taylor, J. H. & Thorsett, S. E. 1994 ApJ, 422, 671

Backer, D. C., Foster, R. S. & Sallmen, S. 1993, Nature, 365, 817

Cordes, J. M. 1993, in *Planets around Pulsars*, ed. J. A. Phillips, S. E. Thorsett, S. R. Kulkarni, ASP Conf. Ser., 36, 43

Camilo, F., Thorsett, S. E. & Kulkarni, S. R. 1994, ApJ, 421, L15

Kaspi, V. M., Taylor, J. H. & Ryba, M. 1994, ApJ, 428, 713

Marcy, G. W. & Butler, R. P. 1996, ApJ, in press

Mayor, M. & Queloz, D. 1995, Nature, 378, 355

Rasio, F. A. 1994, ApJ, 427, L107

Taylor, J. H. & Weisberg, J. M. 1989, ApJ, 345, 434

Thorsett, S. E., Arzoumanian, A. & Taylor, J. H. 1993, ApJ, 412, L33

Walker, G. A. H., *et al.* 1995, Icarus, 116, 359

Wolszczan, A. & Frail, D. A. 1992, Nature, 355, 145

Wolszczan, A. 1994, Science, 264, 538

Wolszczan, A. 1996, in *Compact Stars in Binaries*, IAU Symp. 165, ed. J. van Paradijs *et al.* , p. 187