DISCOVERY OF PLANETS AROUND A MILLISECOND PULSAR; A. Wolszczan, NAIC/Arecibo Observatory

A recent survey of the sky at high galactic latitudes with the 305-m Arecibo telescope has revealed two new millisecond radio pulsars: PSR1257+12 and PSR1534+12. The characteristics of this survey and a description of the relativistic binary pulsar PSR1534+12 are given in (1). Here, we concentrate on the 6.2-ms pulsar PSR1257+12 and discuss a recently established evidence for a reflex motion of this object due to the presence of two or more orbiting planet-sized bodies (2).

Systematic measurements of the times of arrival (TOA) of pulses from PSR1257+12 have been made at Arecibo since July 1990. A timing model including the pulsar's rotational parameters (period, $P$ and its derivative, $\dot{P}$) and the fixed celestial coordinates as measured with the Very Large Array (VLA) (2), when fitted to the data, has resulted in large post-fit residuals shown in Fig.1a. These residuals measure deviations of the arrival times predicted by the model from the actual TOAs and clearly indicate a quasi-periodic “wandering” of TOAs with an amplitude of $\pm 3$ ms, which is comparable to the pulsar period. A timing “noise” of this magnitude is entirely uncommon in very old, millisecond pulsars, which are known to be extraordinarily stable rotators (3). Similarly, the observed residuals are very difficult to explain in terms of other phenomena such as a free precession of the neutron star (4) and interstellar or circum-pulsar propagation effects (5). Careful tests have eliminated instrumental problems as a possible source of the measured timing residuals. Consequently, the most plausible remaining possibility is that the observed residuals are caused by a reflex motion of the pulsar in response to the presence of orbiting planet-like objects.

The hypothesis that PSR1257+12 possesses a planetary system has been tested by constructing a timing model including multiple, noninteracting Keplerian orbits and fitting it to the data along with the standard pulsar parameters. The residuals obtained after fitting single circular orbits with periods of 98.2 days and 66.6 days are shown in Figures 1b,c, respectively. Clearly, the quasi-periodic fluctuations of pulse arrival times of Fig.1a can be accounted for by an orbital motion of two low-mass bodies around the pulsar. This is further confirmed by the result of a fit of two orbits to the timing data (Fig.1d). The residuals shown in Fig.1d are almost entirely random and their rms variation is only $\sim 18\mu$s. Assuming a standard pulsar mass of 1.4 $M_\odot$, setting orbital inclinations to 90$^\circ$ and using the best fit parameters of the model, one obtains lower limits to the planetary masses, 3.4 $M_\oplus$ and 2.8 $M_\oplus$, and the corresponding distances from PSR1257+12, 0.36 AU and 0.47 AU. The model fit also requires small but significant eccentricities ($\sim 0.02$) of both orbits.

Figure 1. Post-fit residuals of pulse arrival times from PSR1257+12 for different timing models discussed in the text.

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The observed period variations are compared to the two–planet model prediction in Fig. 2. The maximum period change, ±15 ps, corresponds to a projected velocity and amplitude of the pulsar’s reflex motion of ±0.7 m/s and ±900 km, respectively. Clearly, much smaller period variations would still be resolved — a sensitivity which significantly exceeds present capabilities of the optical single-line spectroscopy. A possibility that there is a third planet in the 1257+12 system, with Earth-like mass and orbital parameters, is indicated by a significant discrepancy between timing and VLA–derived positions of the pulsar (2).

![Figure 2. A comparison of period variations of PSR 1257+12 (filled circles) with a two–planet model prediction (solid line).](image)

A surprising detection of the first planetary system outside our own, existing around an old (∼10⁹ yr) neutron star that has most likely undergone a spin–up episode in a binary system (6), may be easier to explain than a recently reported evidence for a single planet–sized object around a young pulsar PSR 1829-10 (7). In principle, the 1257+12 planets could have condensed out of the material ablated by the pulsar from its evaporating stellar companion (5). The detections of planetary companions to neutron stars and a very high accuracy of the pulse timing suggest that, in the years to come, this technique will play a major role in the process of identification and investigations of the extra–solar planetary systems.

REFERENCES