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PULSARS AT PARKES

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ABSTRACT

Recent surveys at Parkes, in particular the 70 cm survey of the southern sky, have discovered many pulsars, including 17 millisecond pulsars in the Galactic disk. Timing and polarization observations of some of these pulsars are described. The only two pulsars known to be in orbit around massive non-degenerate stellar companions were also discovered at Parkes, and some recent observational results for these pulsars are also presented.

Key Words : Pulsars, Astrometry

I. INTRODUCTION

The Parkes 64 m radio telescope is well suited to pulsar observations: it is large in area, it can track for long periods, and it has sensitive receivers giving frequency diversity and polarization capability. These properties allow both sensitive searches and detailed follow-up observations to investigate the properties of the pulsars discovered. More than half of the known pulsars have been discovered in searches involving the Parkes telescope.

II. SEARCHES

About a year ago, we completed the Parkes Southern Survey, a complete survey of the southern sky for both millisecond and 'normal' pulsars. This survey was a collaboration between the Australia Telescope National Facility and the University of Manchester, Jodrell Bank, with contributions from several other groups (Manchester et al. 1996). The observing frequency was 436 MHz and filterbanks giving 256×0.125 MHz for each of the two polarizations were used to provide dispersion discrimination. A sampling interval of 0.3 ms was used and each of 45,000 points across the sky south of the celestial equator was observed for 2.5 min, giving a total data base of more than a terabyte. Work-station networks were used to process the data. Briefly, the analysis consisted of dedispersing the data for each of 600 trial dispersion measures (DMs), doing a 512K-point FFT, summing harmonics and searching for significant signals. Several hundred suspects from this analysis were reobserved at Parkes to determine the reality of the signal and, if confirmed, to determine the basic pulsar parameters.

The survey was very successful, discovering 102 pulsars of which 17 are millisecond pulsars (MSPs) in the Galactic disk, more than half the total number known. A total of 196 previously known pulsars were detected, only two of which are MSPs. A detailed description of the survey system and results from the first half of the survey are described in Manchester et al. (1996) and references therein. Results from the second half of the survey are given by Stappers et al. (1996), Bailes et al. (1996), Lorimer et al. (1996) and Lyne et al. (1996). Epecially significant were the discoveries of the nearest and brightest known millisecond pulsar, PSR J0437−4715, (Johnston et al. 1993) and an eclipsing binary pulsar with very short orbital period, PSR J2051−0827, (Stappers et al. 1996). Fig. 1 shows the Galactic distribution of the newly discovered pulsars. Implications for the Galactic population of pulsars are discussed by Bailes et al. (1996), Lorimer et al. (1996) and Lyne et al. (1996).

In another major collaboration with Jodrell Bank, we plan to use the 13-beam receiver being constructed for Parkes (Staveley-Smith et al. 1996) for a senstive survey along the southern Galactic plane. This receiver system will operate at frequencies about 1400 MHz and filterbanks for each of the 26 signals (two polarizations per receiver) will have 96 channels over a bandwidth of 288 MHz. We plan to observe for about 30 min per position, giving a sensitivity about four times better than that of the Johnston et al. (1992a) survey of the Galactic plane. With these parameters, we hope to detect about 450 pulsars of which about 300 will be new discoveries. This will substantially increase the population of known pulsars (currently about 700) and hopefully result in the discovery of some interesting and perhaps unique objects.

III. TIMING AND POLARIZATION

Surveys such as these provide the basis for a wide variety of follow-up studies with relevance to fields such as stellar and galactic evolution, high-energy astrophysics, interstellar medium studies, celestial mechanics and fundamental tests of gravitational theories. At Parkes, we especially concentrate on precision timing and polarization measurements which are relevant to all of these fields. Much of this work is in collaboration with the Caltech pulsar group led by S. R. Kulkarni and uses the Caltech correlator (Navarro 1994), now based at Parkes. This instrument has a maximum bandwidth of 128 MHz with 512 lags split between two or four polarizations and has a synchronous integrator which

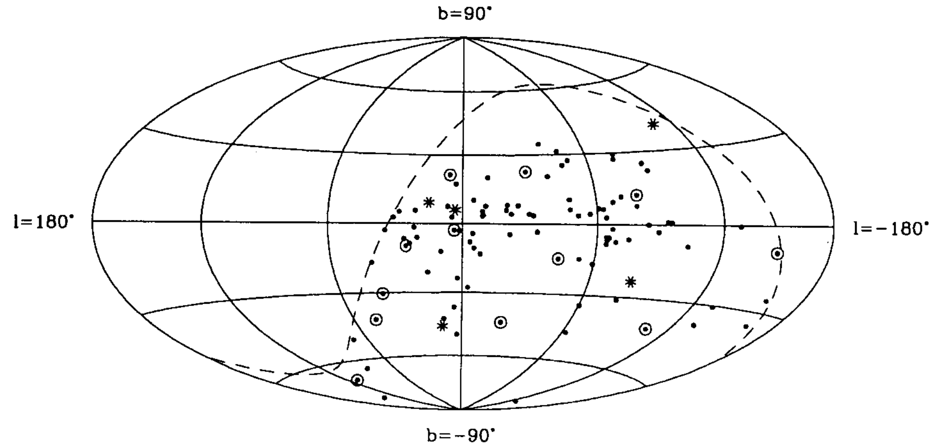

Fig. 1.— Distribution in Galactic coordinates of the 102 pulsars discovered in the Parkes southern survey. Of these, 17 are millisecond pulsars (MSPs) and, of the MSPs, 12 have a stellar binary companion. Single MSPs are marked with $*$ and binary MSPs with $\odot$.

provides 1024 points per period for pulsars with periods greater than about 2.5 ms.

We have used this instrument to make timing measurents for all of the millisecond pulsars disovered in the Parkes southern survey. Especially interesting results have been obtained for PSR J0437−4715 (Sandhu et al. 1996). This pulsar has a pulse period of 5.75 ms and is in orbit around a white-dwarf companion with an orbital period of 5.74 d. Timing measurements from early 1994 to the present have been fitted by a model which includes proper motion, a secular change in the projected semi-major axis of the orbit, and annual parallax. Residuals from this fit have an rms amplitude of only 0.85 μs, showing that the intrinsic rotation period of the pulsar is very stable. The pulsar position is determined to a few tens of micro-arcsec, allowing a very precise determination of the pulsar proper motion, the value of which is about 140 mas yr^{-1}. This proper motion results in a change in the projected semi-major axis of the orbit, which has also been measured. Finally, the timing measurements give a value of about 6.5 mas for the parallax, implying a distance of about 160 pc, close to the DM-derived distance of 140 pc.

Polarization measurements show that PSR J0437−4715 has a very wide and complex pulse profile. As shown in Fig. 2 (cf. Navarro & Manchester 1996), the pulse profile has many components extending over about 80% of the pulse period and there are rapid and complex changes in polarization across the pulse. An orthogonal position-angle transition is seen near the peak of the main component and there is a rapid change in the sign of circular polarization at the same phase. Even after taking the orthogonal transition into account, the observed variations in position angle are very different from the standard rotating-vector pattern seen in most pulsars. This may indicate the presence of multi-pole magnetic-field components in the emission region.

IV. PSR B1259−63 AND PSR J0045−7319

PSRs B1259−63 and J0045−7319 are the only two known pulsars to orbit a massive non-degenerate star. PSR B1259−63 is in a highly eccentric orbit around a Be star, SS2883, with an orbital period of about 3.5 yr (Johnston et al. 1992b). Each periastron, the pulsar passes through the circumstellar disk of the Be star, resulting in dramatic changes to the DM, rotation measure and scattering properties of the pulsar. The most recent periastron occurred in 1994 January (Johnston et al. 1996). About 3 months before this, the radio pulse, which is normally close to 100% linearly polarized (Manchester & Johnston 1995), became completely unpolarized, probably because of differing Faraday rotation along different scattering paths. Similar depolarization occurred at higher frequencies as periastron was approached. A few weeks before periastron, the dispersion measure increased by several cm^{-3} pc and, after periastron, the rotation measure changed from its normal value of about +20 rad m^{-2} to negative values as large as −7000 rad m^{-2}. Modelling these changes shows that, at the periastron radius of the pulsar ($\sim 30R_*$), the electron density in the circumstellar disk is about 6×10^6 cm^{-3} and the magnetic flux density is about 25 mG. Further investigations of these phenomena are planned for the next periastron in 1997 May.

PSR J0045−7319 is the only known pulsar in the Small Magellanic Cloud. It is in a highly eccentric orbit around a B star, with an orbital period of about 51 d (Kaspi et al. 1994). Timing observations over the past four years have revealed small perturbations to the observed orbital parameters (Kaspi et al. 1996). The longitude of periastron is advancing at a rate of 0.0259 ± 0.0005 deg yr^{-1}. This value is about six times

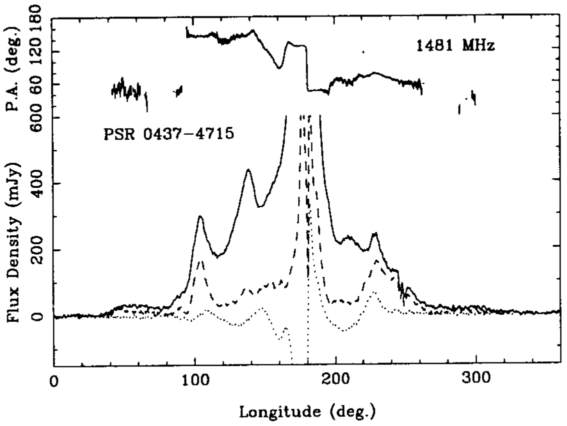

Fig. 2.— Polarization properties of PSR J0437−4715 at 1481 MHz. The full pulse period is shown. In the lower part, the pulse total intensity (Stokes I - full line), the linearly polarized intensity (dashed line) and the circularly polarized intensity (Stokes $V = I_L - I_R$) are shown, and the upper part gives the position angle of the linearly polarized part. Note that the lower plot is truncated at about 15% of the peak flux density.

larger than the periastron advance expected from general relativity and is attributed to the oblateness of the rapidly spinning B star. Precession of the orbital plane has also been detected, with an observed change of the orbital inclination of 30 ± 2 arcsec yr^{-1}. Detection of this effect shows that the spin axis of the B star is inclined to the orbit normal by between 25° and 41°. Precession of the spin axis about the system's total angular momentum results in a corresponding precession of the orbital plane – the first clear detection of classical spin-orbit coupling outside the Solar System. Since the orbit normal and the B-star spin axis were almost certainly aligned before the supernova explosion that created the neutron star, the present misalignment is good evidence that the neutron star received a kick as a reaction to an asymmetry in the supernova explosion. The observed high space velocities of pulsars probably result from such kicks.

V. CONCLUSIONS

The Parkes radio telescope is a superb instrument for pulsar observations. With its sensitive receivers, searches for pulsars have been very successful. Its frequency versatility and polarization capabilities make possible a wide range of pulsar investigations, leading to many interesting results.

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