CHAPTER TWO

Pulsars: Their Scattering and Intrinsic Properties

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THE PARKES MULTIBEAM PULSAR SURVEY AND INTERSTELLAR SCATTERING

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Abstract. The Parkes multibeam pulsar survey is a major survey for pulsars lying within a 10°-wide strip along the southern Galactic plane, using the multibeam receiver on the Parkes 64-m radiotelescope. It is an international collaboration between groups at Jodrell Bank Observatory, Massachusetts Institute of Technology, Bologna Astronomical Observatory and the ATNF. The survey commenced in 1997 August, and has so far succeeded in finding more than 550 previously unknown pulsars. Many of these are distant, with some beyond the centre of the Galaxy according to current models of the interstellar electron density distribution. Interstellar scattering affects the pulse profile of many of the more distant pulsars even at 1374 MHz, the centre frequency of the survey. Preliminary results from the survey are presented.

Keywords: pulsars, interstellar medium

1. Introduction

Pulsars are remarkable objects. They are extraordinary laboratories for studies in high-energy astrophysics, they are among the most precise time keepers known, and they are almost ideal probes of the interstellar medium. For this meeting we will concentrate on the third area, using pulsars to probe the interstellar medium.

The observed emission from pulsars is pulsed and so group propagation delays can be measured. In particular, the frequency dependence of group delay, or dispersion, is determined by the line-of-sight integral of the interstellar free-electron density, commonly expressed as a dispersion measure (DM) in units of cm^{-3} pc. Given a model for this density, such as that by Taylor and Cordes (1993), distances to pulsars can be estimated from the DM. Conversely, if distances can be estimated independently, we get information about the electron density distribution.

Most pulsars have significant linear polarisation and some are essentially completely linearly polarised. This makes it relatively easy to measure Faraday rotation in the interstellar medium, which is proportional to the line-of-sight integral of $n_e B_l$, commonly known as the rotation measure (RM), where n_e is the electron density and B_l is the line-of-sight component of the interstellar magnetic field. Pulsars are unique in that as well as knowing the RM, we have the DM along the same path, enabling a direct measure of the mean line-of-sight component of the interstellar magnetic field, weighted by the local electron density. Such observa-

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tions can be used to study the structure of the Galactic magnetic field (e.g., Han *et al.*, 1999).

Finally, pulsars are essentially point radio sources, and so are ideal probes of the electron density fluctuations which result in interstellar scattering and hence scintillation. At radio frequencies less than or about 1 GHz, scattering is strong for most pulsars and both diffractive and refractive scintillation can be observed. For more distant pulsars, the extra path resulting from the scattering causes significant and easily measurable broadening of the pulse profile, usually in the form of an exponential tail on the pulse. For a scattering screen having a Kolmogorov spectrum of density fluctuations, the timescale for this broadening is proportional to $DM^{2.2}\nu^{-4.4}$ (Rickett, 1977).

Having stated all these good things about pulsars, it is only fair to acknowledge their one main disadvantage: in general, they are rather weak radio sources, with typical mean flux densities of a few mJy at frequencies around 1 GHz. Also, they have rather steep radio spectra, with a typical spectral index of about −1.5, and so are difficult or impossible to observe at high radio frequencies.

To make full use of pulsars as probes of the interstellar medium, you need a reasonable sample of pulsars spread widely across the Galaxy. Most known pulsars lie within a few kpc of the Sun, with only a few at distances comparable to that of the Galactic Centre. The Parkes multibeam survey is much more sensitive than previous surveys of its type, and so is finding many distant pulsars.

2. The Parkes Multiteam Pulsar Survey

The Parkes multiteam pulsar survey is a survey of the Galactic plane between longitudes of 260° and 50° and latitudes of ±5° using the Parkes 64-m radio telescope and the multiteam receiver (Lyne *et al.*, 2000). The multibeam receiver has 13 beams, each with two polarisations, and is centred at 1374 MHz. The 288-MHz bandwidth for each polarisation is split into 96 3-MHz channels to allow dispersion removal, detected, summed in polarisation pairs, high-pass filtered, one-bit digitised and recorded on magnetic tape. Data are sampled at 250 ps intervals and the observation time per pointing is 35 min. This gives a sensitivity for long-period pulsars off the Galactic plane of approximately 0.15 mJy, nearly seven times better than the previous best surveys of this type (Johnston *et al.*, 1992; Clifton *et al.*, 1992).

In off-line processing, the data are dedispersed at many trial DMs and, for each DM, Fourier transformed to search for periodic and dispersed signals. Suspects are confirmed (or not) by reobservation with the centre beam of the multibeam receiver. Following confirmation, a 12–18 month program of timing observations is commenced, using either the centre beam of the multibeam receiver or a similar 1.4 GHz system on the Lovell telescope at Jodrell Bank Observatory.

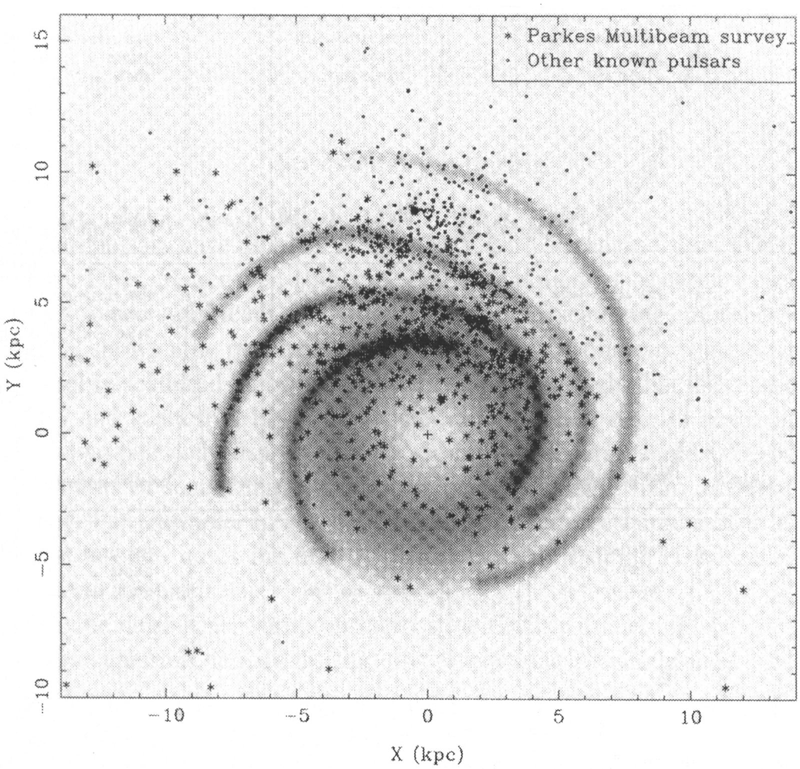

Figure 1. Distribution of all known pulsars (excepting those in globular clusters and the Magellanic Clouds) projected on to the Galactic plane. Pulsars discovered in the multibeam survey are marked with an asterisk, others by a point. The grey-scale represents the Taylor and Cordes (1993) Galactic electron density model, which was used with the DMs to compute the distances.

The survey commenced in August 1997 and is now about 70% complete. More than 550 previously unknown pulsars have been found so far, a large increment on the 700 or so known in the Galactic disk before the survey began. Many of these pulsars are young, and three of them have surface dipole magnetic fields (computed from the spin-down rate) stronger than any other known radio pulsars (Camilo *et al.*, 2000). For comparison, the median age and median distance of the previously known disk pulsars are respectively 8.3 Myr and 3.6 kpc, whereas the corresponding numbers for multibeam pulsars are 1.8 Myr and 7.1 kpc respectively.

Eight of the new discoveries are members of binary systems. One, PSR J1811-1736, is in an 18-day, highly eccentric orbit, and is almost certainly a double-neutron-star system (Lyne *et al.*, 2000). Another, PSR J1141-6545, is also in an eccentric orbit, but with an orbital period of only 5 h (Kaspi *et al.*, 2000). The pulsar has a period of 394 ms and is relatively young, with a characteristic age of 1.4×10^6 yr. Measurement of the relativistic precession of periastron gives a total mass for the system of 2.3 solar masses. This and the young age for the pulsar suggest

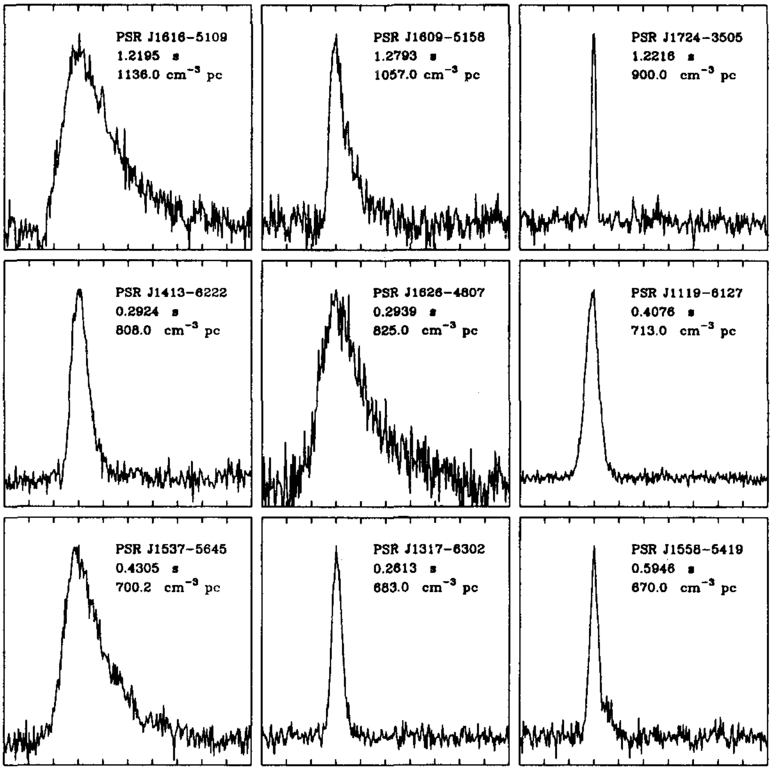

Figure 2. Mean pulse profiles at 1374 MHz for nine pulsars discovered in the Parkes multibeam pulsar survey. The whole pulse period is plotted for each pulsar. These pulsars all have relatively high dispersion measures (DMs) and are plotted in order of decreasing DM. The pulsar name, pulse period and DM are given for each profile.

that system has an unusual evolutionary history and consists of a neutron star and a heavy white dwarf, with the neutron star being the second-born compact star. Another system, PSR J1740-3052, has a very heavy companion, with a minimum mass of 11 solar masses (Stairs *et al.*, 2000). The companion has been identified as a K supergiant star, making this system one of only three with a massive non-degenerate companion.

Figure 1 shows the position of all known Galactic disk pulsars projected on to the Galactic plane. Distances were calculated using the pulsar DMs with the Taylor and Cordes (1993) Galactic electron density model, shown as a grey-scale in the Figure. On average, the multibeam pulsars are much more distant than previously known pulsars. Based on this electron density model, many lie beyond the Galactic Centre. However, the model is very uncertain in this region; the multibeam pulsars give us the opportunity to improve the model. There also appears to be a concentration of pulsars along the spiral arms. However, this may be simply a consequence

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of the increased model electron density in the arms. Further work is required to clarify this.

3. Interstellar Scattering

The multiteam pulsars have relatively large DMs, with a median value of 360 cm^{-3} pc; a few have DMs greater than 1000 cm^{-3} pc. At frequenties of about 1 GHz, one would expect to ree significant amounts of interstellar scattering, and indeed one does. Figure 2 shows nine pulsars with DMs in excess of 650 cm^{-3} pc. Several of these have highly scattered pulse profiles. It is notable, though, that the relationship between DM and scattering time-constant is nota uniform one. In particular, the figure shows two pairs of pulsars with very similar pulse periods and DMs but very different amounts of scattering. These differences must arise from different paths in the Galaxy. For example, in some cases the path may be tangential to a spiral arm, whereas in other cases the high DM may arise in a single HII region which happens to be in the path.

There may be large-scale variations across the Galaxy in the relative strength or spectrum of the electron density fluctuations responsible for scattering.

4. Conclusions

The Parkes multibeam survey is by far the most successful pulsar survey ever undertaken. It is finding a large sample of pulsars, most of which are young and distant. Many of these pulsars show significant amounts of interstellar scattering and resultant broadening of the pulse profile, even at the relatively high radio frequency of this survey. There is, however, no simple relationship between DM and pulse broadening. This sample will provide an excellent basis for investigations of interstellar phenomena, which should lead to significant advances in our understanding of the Galactic electron density distribution, the structure of the Galactic magnetic field and the distribution of pulsars in the Galaxy.

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