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Arecibo Observations of Parkes Multibeam Pulsars

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Abstract. The on-going Parkes multibeam survey has been astoundingly successful (Manchester *et al.* 2001), and its discovery of over 600 pulsars has opened up new avenues for probing the Galaxy's electron content and magnetic field. Here we report on recent observations made with the Arecibo 305-m telescope, where 80 distant, high dispersion measure pulsars (of which 35 are from the multibeam survey) were studied at multiple frequency bands in the range 0.4–2.4 GHz, in order to determine their scattering properties, rotation measures and spectral indices. The results will be used to meet a variety of science goals; viz., creating an improved model of the electron density, mapping out the Galactic magnetic field, and modeling the pulsar population.

Key words. Pulsars—interstellar matter—scattering—polarization.

1. Introduction

Pulsars make excellent probes of the interstellar medium, and measurements of their dispersion measures (DMs) and scattering properties help us to infer the interstellar electron density (n_e) and its distribution in the Galaxy. Although the best present model of n_e in the Galaxy (Taylor & Cordes 1993) has proven useful for many applications, it is poorly constrained towards the inner Galaxy. The most newly discovered pulsars from the Parkes multibeam survey (Manchester *et al.* 2001) have high DMs, with a median DM of 400 pc cm^{-3}, making them excellent probes of the electron content in and around inner parts of the Galaxy. The scattering properties of such distant pulsars are best studied via their pulse-broadening times (the lengthening of the pulse profile due to scattering of rays between the pulsar and the Earth). This requires data from a high frequency to obtain the intrinsic, un-broadened profile and a low frequency to measure the broadened profile.

As is well known, most pulsars are polarized, and the observed angle of polarization at some wavelength, λ, is rotated from its intrinsic angle by an amount $\Delta\psi = RM\ \lambda^2$, where the rotation measure (RM) is the integral of $n_e B$ along the line of sight (where B is the magnetic field). By measuring the polarization position angle of a pulsar at several frequencies, we can determine the RM and therefore the average magnetic field, weighted by electron density.

Observations show magnetic field lines in spiral galaxies tend to follow the spiral arms, with fields arranged either in clockwise and counterclockwise directions within an overall spiral pattern ("bisymmetric spiral structure") or with fields arranged in a more uniform direction ("axisymmetric spiral structure") (e.g., Wielebinski & Krause 1993). The origin and evolution of field patterns remain controversial (Zweibel & Heiles 1997). Further, observations suggest that the local magnetic field in our Galaxy is largely in the azimuthal direction, but its inclination differs from that expected for a bisymmetric spiral structure (e.g., Han *et al.* 1999). Clearly, a further study of the shape of the Galactic field is required.

The Parkes survey was conducted at a substantially higher frequency (1.4 GHz) than those commonly used in most earlier pulsar surveys. The newly discovered pulsars pose a challenge for models of the pulsar content in the Galaxy. An intriguing question is to what extent are they a new population, whose discovery was missed by earlier surveys due to their low luminosities at low frequencies and/or heavy scattering? The spectral behaviour, together with the scattering properties, will enable us to address this question, and will also help optimize the future directions of pulsar searches.

2. Observations and results

We have undertaken a study of the multibeam pulsars visible from Arecibo, along with previously known pulsars in the same region of the sky, in order to meet the above science goals. In the first phase (May–July 2001), observations were made of 35 pulsars from the multibeam survey for which sufficiently accurate positions were available (Manchester *et al.* 2001), and 45 previously known ones (Taylor *et al.* 1995) at 0.4, 1.2, 1.5 and 2.4 GHz. Observations at frequencies above 1 GHz were made with the new pulsar backend, the Wideband Arecibo Pulsar Processor (WAPP), whereby all four stokes parameters are measured. Data at 0.4 GHz were recorded with the Penn State Pulsar Machine (PSPM). Observations are made over bandwidths of 100 MHz at 1.2 and 1.5 GHz, 50 MHz at 2.4 GHz and 10 MHz at 0.4 GHz, with integration times of 300 to 600 seconds. The data products are made available in the following formats:

(1) total intensity profiles at all four frequency bands (Fig. 1), and
(2) polarization data (i.e., the stokes I, L, V profiles and position angle vs pulse phase) at 1.2 and 1.5 GHz (Fig. 2).

Detailed analysis and interpretation are underway. Follow-ups of the current study will involve the use of the GBT (Green Bank Telescope) and the GMRT (Giant Metre-wave Radio Telescope), as well as the Parkes 64-m telescope, for the study of the objects south of the equator.

Preliminary results from our on-going analysis are briefly described below:

Pulse-broadening times: The observed pulse profile can be modeled as an intrinsic pulse shape convolved with a pulse-broadening function (i.e., the impulse response function characterizing the scatter broadening). Estimates (or upper limits) of pulse-broadening time (τ_p) have been obtained for about 40 objects, which marks as a substantial improvement upon the data available (for 170 of the $\sim$1500 pulsars known) for modeling the Galaxy's electron content. For several objects, measurements of τ_p have been made at 2 to 3 frequencies, and in some cases, there is also clear evidence

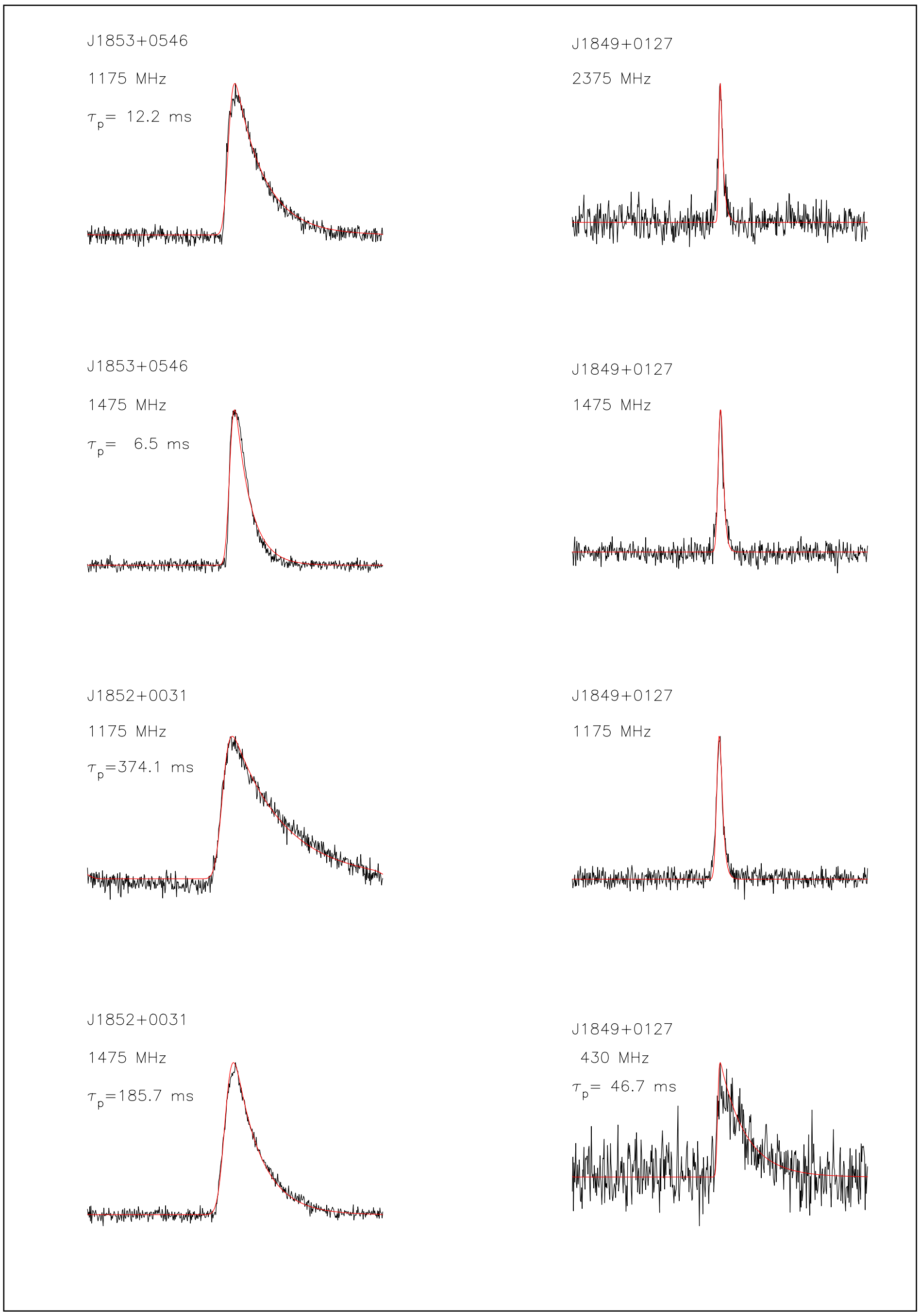

Figure 1. Examples of multi-frequency pulsar data. Scatter-broadened profiles are shown for a multibeam pulsar (J1853 + 0546) and a cataloged pulsar (J1852 + 0031) at two different frequencies (left panel). Profiles of another multibeam pulsar (J1849 + 0127) are shown at four frequencies (right panel); scattering is clearly visible at the lowest frequency, 430 MHz.

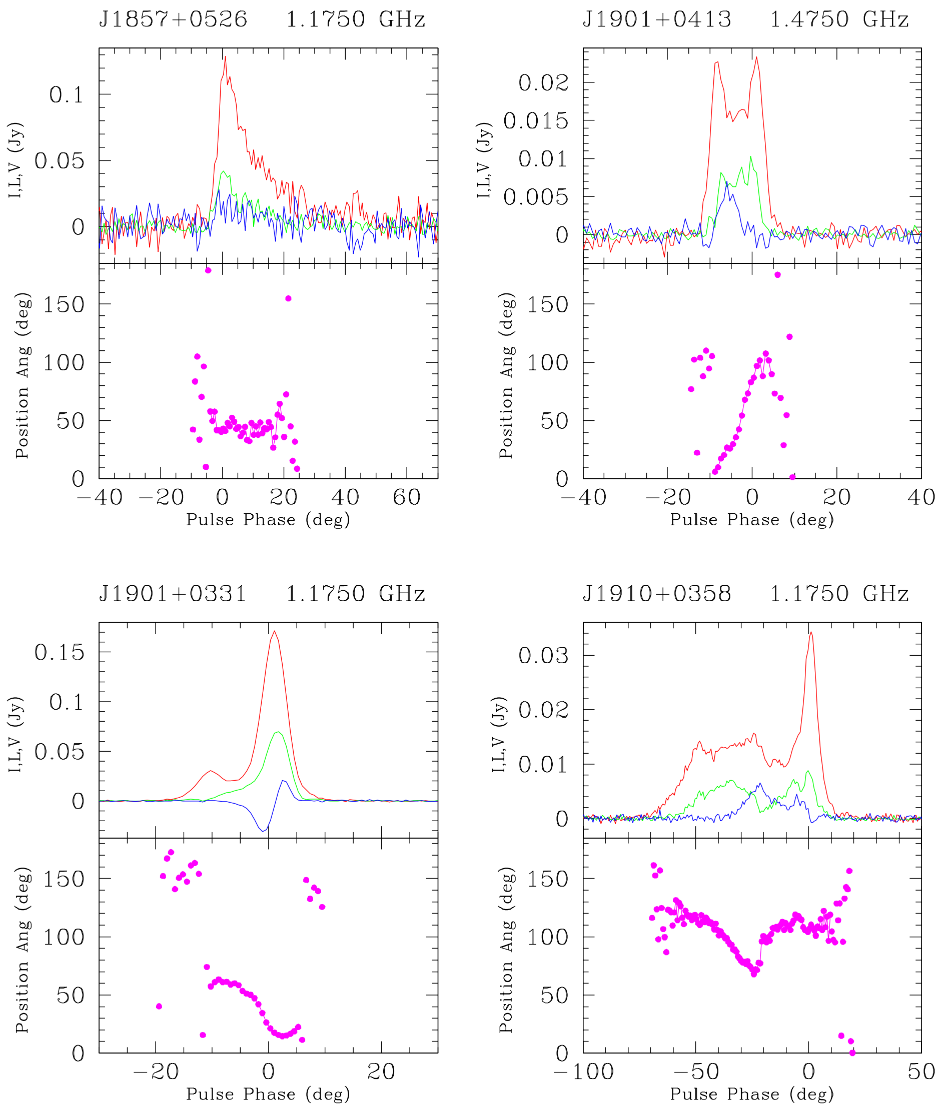

Figure 2. Polarization profiles for four distant pulsars observed with the WAPP: PSRs J1857 + 0526 and J1901 + 0413 are new discoveries from the multibeam survey. The upper panels show the total intensity, linearly polarized flux density and circular polarization, and the lower ones are the plots of position angle vs pulse phase within the on-pulse window.

that the scaling of τ_p with frequency is significantly weaker than that expected ($\sim \lambda^{4.4}$) from standard theories (Fig. 1). Such anomalous scattering has been predicted recently by Cordes & Lazio (2001).

Rotation measures: Although we derive full Stokes profiles from our data in multiple frequency bands, our current estimates of RM are obtained by measuring the rotation of position angle across the 100 MHz band near 1.2 GHz. This technique yields satisfactory results for data with sufficiently good signal-to-noise ratios. Our analysis so far has provided RMs for about 40% of the observed objects. The new estimates range from $\sim$100 to $\sim$1000 rad m^{-2}, and these measurements will significantly improve upon the data available for studying the structure of the Galactic magnetic field.

Spectral behaviour: The multi-frequency nature of our observations allow estimation of the spectral indices of these pulsars. Almost all multibeam objects have been detected at 2.4 GHz with signal-to-noise ratios quite comparable to those at 1.2 GHz, despite the fact that the observations were made with similar levels of sensitivity. This may indicate that the spectra of the new pulsars are somewhat flatter than those for the population known from earlier low-frequency searches.

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