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Letter to the Editor

Observations of millisecond pulsars at 4.85 GHz

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Abstract. Recent observations at high radio frequencies using the Effelsberg 100-m Radio Telescope of the Max-Planck-Institut für Radioastronomie have resulted in the detection of four millisecond pulsars at 4.85 GHz ; PSRs J1022+1001, J1713+0747, B1855+09 and J2145−0750. The typical flux density for these millisecond pulsars is around 1 mJy. Pulse shapes and flux densities of observed millisecond pulsars are presented.

Key words: Pulsars: general – millisecond pulsars: individual: J1022+1001, J1713+0747, B1855+09, J2145-0750 – Radiation mechanisms: miscellaneous

1. Introduction

The first millisecond pulsar was discovered following the search for radio sources with very steep spectra by Backer et al. (1982) at 1.4 GHz. Since then, millisecond pulsars have been observed at a variety of frequencies, but there have been only two reports of high frequency millisecond pulsar studies (above 3 GHz) in the literature: those of PSR B1937+21 at 4.8 GHz (Ryba 1991) and for PSR J0437−4715 at 4.6 GHz (Manchester & Johnston 1995). The latter authors quote a flux density of 8.5 mJy at 4.6 GHz for PSR J0437−4715. The flux density, pulse widths and pulse shapes over a wide frequency range are very important for the study of radio pulsar emission properties, in particular for such interesting objects like millisecond pulsars. In this paper, we report the first detection of weak millisecond pulsars ($S \lesssim 1$ mJy) and present their pulse shapes at the wavelength of 6.1 cm (4.85 GHz). Observations leading to the detection of millisecond pulsars were part of a large survey of pulse shapes at 6.1 cm at the Effelsberg Radio Observatory (Kijak et al. in prep.).

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2. Observations and results

The observations were performed with a new sensitive HEMT system at 4.85 GHz recently installed at the 100-m radiotelescope. The system uses a 500 MHz bandwidth and has a noise temperature of $T_{\rm sys} \lesssim 30K$ for elevations above 20 degrees. We used either 4 channels of a 8 x 60 MHz filter banks (equipped with 2 MHz V/f converters) as a de-disperser for two circular polarizations or broad band signals (using 10 MHz V/f converter) with 500 MHz bandwidth or a narrow-band polarimeter (also with 10 MHz V/f converter) with a bandwidth of 80 MHz for full polarimetry observations. A detailed description of the observing system and the calibration procedure can be found in Seiradakis et al. (1995) and Kramer et al. (1996).

We obtained average pulse profiles with satisfactory signal-to-noise ratios (S/N $\gtrsim$ 10) for four millisecond pulsars after 30 minutes integration time. The flux density for the detected pulsars is around 1 mJy (see Table 1 for details). The pulse shapes for individual pulsars are presented in Fig. 1. Table 1 gives the number of pulses analysed, the pulse widths at a level of 50 and 10 per cent of the pulse peak, respectively, as well as the mean flux for detected pulsars, the expected value of flux density calculated where possible by extrapolating the lower frequency fluxes (taken from Taylor et al. 1995 and Kramer et al. in prep.) and the dispersion smearing across the bandwidth used. The errors in flux density and pulse widths were estimated by taking the calibration procedure, the signal-to-noise ratio, dispersion smearing and resolution of the profiles into account. The error of pulse width is indicated by the error box visible in the lower right hand corner of each figure (see Fig. 1).

PSR J1022+1001 has the narrowest profile in our sample (Fig. 1a) and resembles the profile at 1.7 GHz (Camilo et al.

Table 1. Parameters of the millisecond pulsars observed at 6.1 cm.

PSR	Number of pulses	Time [min]	W_{50} [deg]	W_{10} [deg]	$S_{\rm Mean}$ [mJy]	$S_{\rm Exp}$ [mJy]	$\sigma_{\rm DM}$ [deg]	Comments
J1022+1001	138472	37	8.4	27.0	0.39 ± 0.05	0.25	1.6	FB
J1713+0747	984600	65	17.2	82.6	0.80 ± 0.04	0.87	8.4	NB
B1855+09	710438	59	31.6	60.0	$1.12 \pm 0.09^{*}$	0.55	5.5	NB
B1855+09*	710438	59	14.0	70.0			5.5	NB
J2145−0750	204546	54	$12.0^{\dagger}$	96.0	0.44 ± 0.03	0.76	7.4	BB

$\star$ - interpulse
$*$ - flux density for both main pulse and interpulse
† - refering to the width of the strongest (i.e. leading) component
FB - filter bank, NB - narrow band, BB - broad band

in prep.). The mean flux density of this pulsar is 0.39 mJy. The dispersion smearing $\sigma_{\rm DM}$ for this pulsar was 1.6°.

The average pulse profile of PSR J1713+0747 is shown in Fig. 1b. It is complex, exhibiting four or more components. The measured flux density is 0.8 mJy and $\sigma_{\rm DM} = 8.4°$. We can see an evolution of the outer components at this frequency compared to 1.4 GHz (see Xilouris & Kramer 1996).

PSR B1855+09 has a very strong interpulse. Its amplitude is as large as 0.72 of the main peak intensity. The pulse shape was smeared during the observation by $\sigma_{\rm DM} = 5.5°$. Its morphological features are clearly visible (Fig. 1c).

PSR J2145-0750, which is presented in Fig. 1d, has a wide profile of about 100°. The pulse profile has a complex structure and is dominated by its leading component. The separation between the leading and trailing component is about 75°. The trailing component is weaker at this frequency as opposed to the situation at 1.4 GHz.

The 5 millisecond pulsars listed in Table 2 were observed but not detected. We calculated upper limits for the flux density by assuming pulse widths as observed at 1.4 GHz (see Kramer et al. in prep.) and a signal-to-noise ratio of five. As before, the expected flux densities were obtained by extrapolating data at lower frequencies.

Table 2. Upper limits $S_{\rm max}$ and expected values $S_{\rm Exp}$ for flux densities of millisecond pulsars which were not detected at 6.1 cm

PSR	Number of pulses	Time [min]	$S_{\rm max}$ [mJy]	$S_{\rm Exp}$ [mJy]
J1012+5307	679245	58	< 0.86	0.27
B1620−26	54005	10	< 0.32	0.16
J1640+2224	412500	21	< 0.43	
B1937+21	1425000	35	< 0.57	1.1
J2317+1439	514286	26	< 0.78	

3. Discussion

Observations of millisecond pulsars at high frequencies might be relevant in revealing the nature of pulsar emission which still remains uncertain (see Kramer 1995 and references therein). In this paper, we present a first sample of pulse shapes of millisecond pulsars at a high frequency (4.85 GHz).

We detected four millisecond pulsars from nine which we have observed. The average flux density for detected pulsars is about 0.7 mJy while the estimated upper limit for non-detected objects gives an average value of less than 0.5 mJy. Foster et al. (1991) obtained spectral indices for four millisecond pulsars in the frequency range between 425 MHz and 3 GHz. At 3 GHz their average flux density is about 1 mJy. Our measurements appear to be consistent with extrapolations based on the spectra taken from lower frequencies. PSR B1855+09 has a larger value of flux density than expected — a result of the stronger interpulse at this frequency compared to lower frequencies. In another case, PSR B1937+21 was not detected in spite of the fact that the expected flux density is larger by almost a factor of 2 than our upper limit (see Table 2). This is most likely due to the attenuation of the signal by dispersion smearing.

Thorsett and Stinebring (1990) found no evidence to suggest that the polarization properties of millisecond pulsars differ from those of long period objects. Xilouris et al. (1996) showed that the average profile for normal pulsars is progressively depolarized at high frequencies. Our data for B1855+09 and J2145-0750, show no polarized emission, corroborating these findings, suggesting that millisecond pulsars have a similar evolution but the depolarization takes place at a much lower frequency. Only PSR J1713+0747 remains very weakly polarized at 4.85 GHz, i.e. the degrees of linear and circular polarization are both about 5%.

There are still many open questions as to whether millisecond pulsars possess a different emission region geometry and emission mechanism from that of normal pulsars. The concept of a radius-to-frequency mapping says that the radio emission at diffirent frequencies is emitted at diffirent altitudes above the polar cap. Several authors discussed the above concept and they

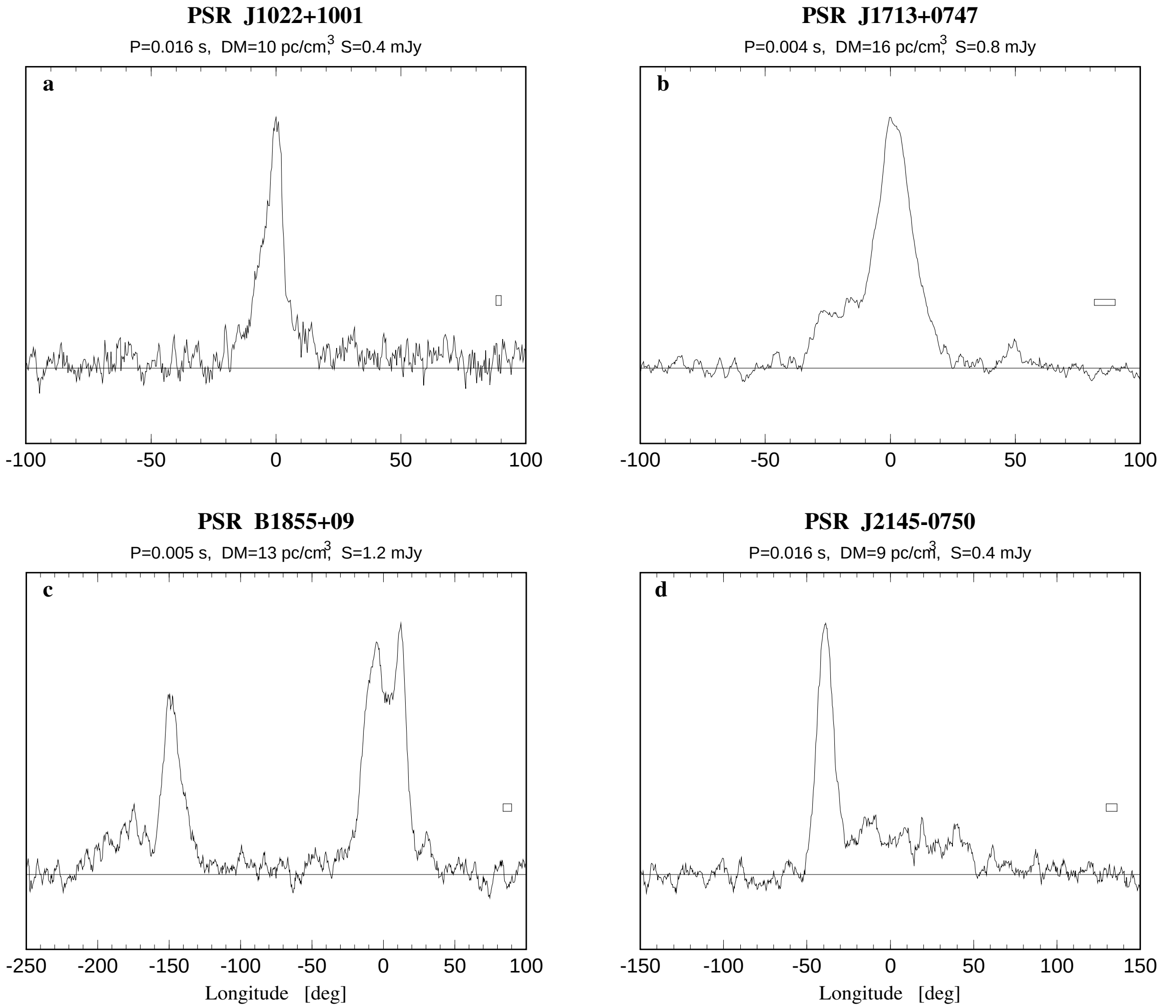

Fig. 1. Total intensity profiles observed at 4.85 GHz of a) PSR J1022+1001, b) J1713+0747, c) PSR B1855+09 and d) PSR J2145−0750.

argue that the emission region is very compact and located near the surface of the neutron star (Cordes 1978, Gil & Kijak 1993, Kramer et al. 1996, Xilouris et al. 1996 and references therein). The geometrical analysis indicates that for millisecond pulsars the radiation at this frequency is generated few stellar radii from the polar cap of the neutron star (Gil & Krawczyk 1996 and Kijak & Gil 1996). The above facts strongly support the claim that millisecond pulsars have the same mechanism of radio emission as the normal pulsars.

In Figure 2 we present the profile development of PSR J1713+0747 between 1.4 GHz and 4.85 GHz. At low frequency this pulsar has very weak outer components, while at the high frequency all outer components are suprisingly brighter. We note that this phenomena is consistent with the conal structure of mean pulsar beams as seen in slow rotating pulsars like PSR B1642−03 (Seiradakis et al. 1995).

It is significant that a strong interpulse in PSR B1855+09 was observed. The ratio of interpulse to main-pulse intensity is $S_{IP}/S_{MP} \sim$ 0.72 at 4.85 GHz, as compared with $S_{IP}/S_{MP} \sim$ 0.37 at 2.4 GHz, $S_{IP}/S_{MP} \sim$ 0.26 at 1.41 GHz and $S_{IP}/S_{MP} \sim$ 0.31 at 0.43 GHz, respectively (Thorsett & Stinebring 1990). A similar increase of S_{IP}/S_{MP} at higher frequencies was observed already in millisecond pulsar J2322+2057 at 1.4 GHz by Nice et al. (1993) and in the "normal" pulsar B1929+10 at 33.9 GHz by Wielebinski et al. (1993). It has been suggested that the increase of the interpulse intensity seen in PSR B1929+10 at 33.9 GHz can be explained by a single-pole model with a double-conal beam (Wielebinski et al. 1993 and references therein).

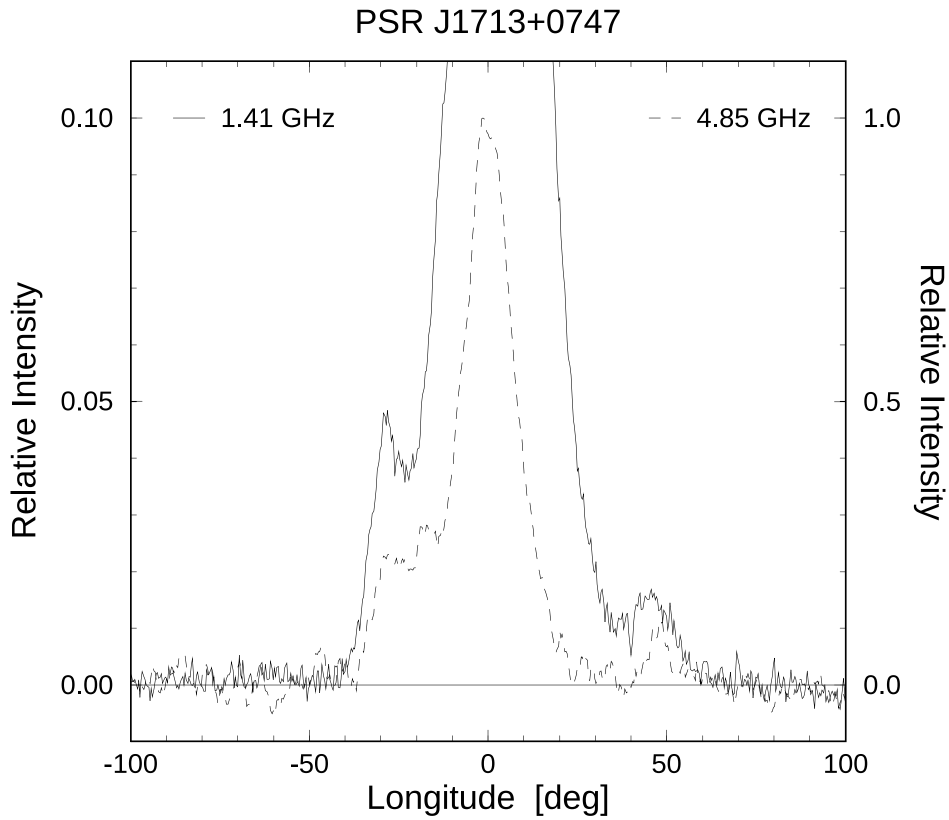

Fig. 2. Total intensity profiles of PSR J1713+0747 at 1.41 GHz and at 4.85 GHz. Intensity is in arbitrary units at each frequency. The profile at 1.41 GHz is presented with enlarged scale (left scale).

Additional observations of millisecond pulsars, including full polarimetry, are needed at several frequencies. The data presented here are just the start of future investigations of the fundamental emission chracteristics (i.e. flux density, profile frequency-development and polarization properties) and the mechanism of radio emission of neutron stars.

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