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Observations of millisecond pulsars at 8.35 GHz

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Abstract. New pulsar observations at 8.35 GHz with the newly built highly sensitive receiver of the Effelsberg 100-m Radio Telescope are reported. They resulted in the first detection of 3 millisecond pulsars J1713+0747, B1855+09 and J2145-0750 at this high frequency. The measured flux densities indicate that the spectrum of all three pulsars follows a single power law. PSR B1855+09 shows a significant increase of the Interpulse-to-Mainpulse amplitude ratio at high frequencies.

Key words. pulsars: general – millisecond pulsars: individual: J1022+1001, J1713+0747, B1855+09, J2145-0750

1. Introduction

Since the discovery of the first millisecond pulsar (MSP) B1937+21 at 81 MHz by Backer et al. (1982), MSPs have been observed and studied at a variety of frequencies up to 1.4 GHz. Currently only about 10% of known MSPs have been detected at 5 GHz (Kijak et al. 1997; Kramer et al. 1999), similarly to normal pulsars with about 170 detections (Maron et al. 2000). It seems that a small number of detected pulsars at high frequencies is caused generally by their steep spectrum. The only detection of the millisecond pulsar at 8.5 GHz was claimed by Thorsett (1991) for PSR B1937+21 in his PhD thesis but it has never been published. One can still see around 5% of normal pulsars at this high frequency. Previously it was commonly believed that the flux spectra of MSPs were steeper than those of normal pulsars. The distribution of spectral indices of MSPs is, in fact, not significantly different, with an average index of $\sim\!-1.8$ (Kramer et al. 1999; Toscano et al. 1998) as compared to normal pulsars, which show the same average spectral indices (Maron et al. 2000). Therefore, one comes to the conclusion that there exists no real difference in the spectral index between MSP and normal pulsars. In general, the emission properties of millisecond pulsars are similar to those of normal pulsars. However, the results presented by Kramer et al. (1999) suggest that most spectra for MSPs can be represented by a simple power law and show no clear indications of steepening at a few GHz (commonly referred to the high frequency break) which is seen in about 10% of normal pulsars detected at high frequencies (Maron et al. 2000). There are a few more differences like MSPs having additional profile components and a very weak frequency evolution of the pulse width (Kramer 2002), which is usually attributed to compact emission regions (Kijak & Gil 1998, 2003). In this letter we report new observations of millisecond pulsars with a highly sensitive 8.35 GHz receiver in order to address the above mentioned issues. Section 2 describes the observations and obtained results and their implications. Finally, we discuss our results in Sect. 3.

2. Observations and results

The observations have been made with the new 8.35 GHz secondary focus receiver with cooled HEMT amplifiers and a cooled polarization transducer. It is a single horn system with two opposite circularly polarized feed inputs to two cooled receiver channels which by default are further fed to a broadband polarimeter with a fixed bandwidth of 1.1 GHz. The wide bandwidths are essential to obtaininig good signal to noise ratio. However, wide bandwidths result in higher dispersive smearing for MSPs. In this case we need to use a narrow band. For example, using the new 8.35 GHz receiver with the 200 MHz bandwidth enabled us to reduce dispersion smearing from maximum 65 bins (at 1.1 GHz bandwidth) down to 12 bins ($\sim$4.1°) in the pulse window of 1024 bins for J1713+0747. The system temperature at zenith is $\sim$25 K. To measure flux density we carried out regular calibration measurements using an injected signal of a noise diode which was compared to the flux density of known continuum calibrators (Peng et al. 2000). We carried out our observations on 9 and 28 September 2002 and 17 January 2003. Detections of the MSPs were made on 9 September 2002[1].

As already mentioned, only the MSP B1937+21 had been detected at 8.5 GHz before our observations. However, with our hardware setup it was not possible to confirm that

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[1] Based on observations with the 100-m telescope of the MPIfR (Max-Planck-Institut für Radioastronomie) in Effelsberg.

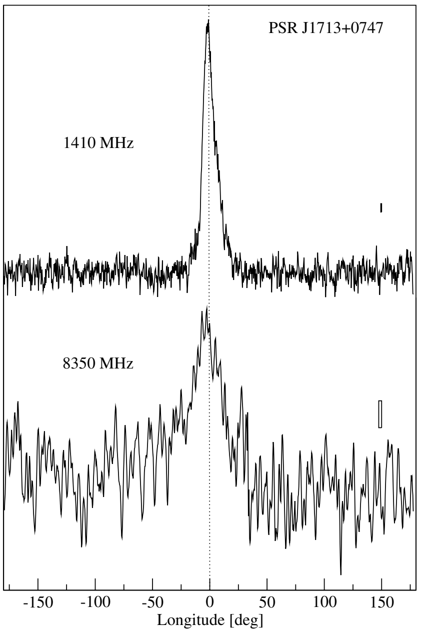

Fig. 1. The integrated profile of the PSR J1713+0747 at 8.35 GHz along with the profile at 1.41 GHz. The profiles have been aligned by timing model. Intensity of the profiles is shown in arbitrary units.

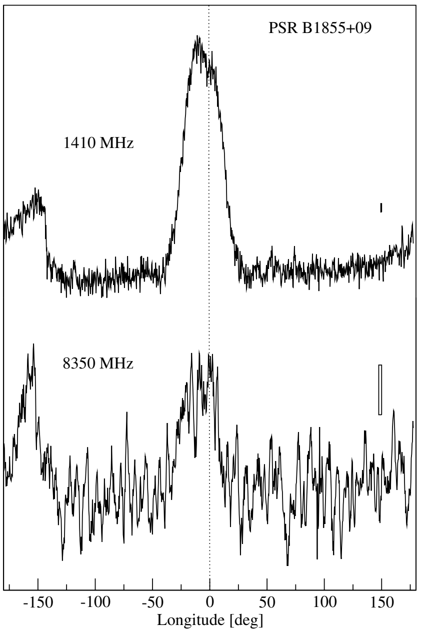

Fig. 2. The integrated profile of the PSR B1855+09 at 8.35 GHz along with the profile at 1.41 GHz. The profiles have been aligned by timing model. Intensity of the profiles is shown in arbitrary units.

detection due to dispersion measure smearing. Assuming that MSPs and normal pulsars have similar emission characteristics the reason for so few detections might be entirely technical. Observations with this new sensitive receiver resulted in the first detection of the 3 MSPs (out of 4) at 8.35 GHz made by Effelsberg Radiotelescope. All detections were made during one session in September 2002. We obtained pulsar profiles and calculated flux densities. For the cases where no detection was obtained we calculated upper limits for flux densities from the formula: $S < W_{50}/360° \cdot 5 \cdot \mathrm{rms}$ (Sieber & Wielebinski 1987), where pulse widths W_{50} were taken from 5 GHz profiles (Kijak et al. 1997) and rms was calculated from the observed noise signal of the binned pulse profile. We did not detect the PSR J1022+1001 and calculated the upper limit for flux density which is 0.05 mJy while our minimal detected flux density is 0.07 mJy. The details of observations are listed in Table 1.

The integrated profiles for the PSRs J1713+0747, B1855+09 and J2145-0750 are presented in Figs. 1–3 respectively. All 8.35 GHz integrated profiles were aligned by timing model with profiles at 1.4 GHz obtained during timing session on 22 September 2002 and then smoothed using a running mean method. Errors of resolution and rms are marked by error boxes (see Figs. 1–3).

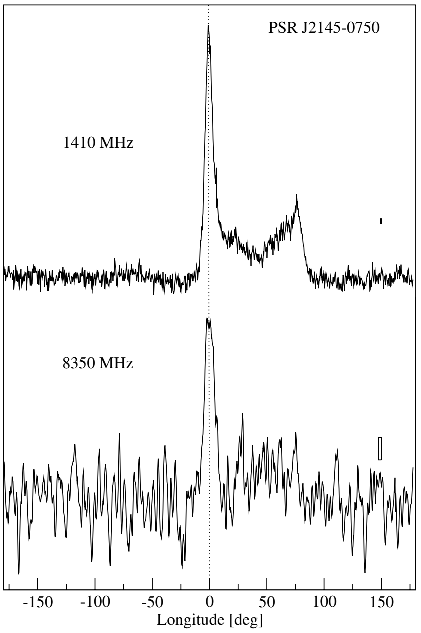

Fig. 3. The integrated profile of the PSR J2145-0750 at 8.35 GHz along with the profile at 1.41 GHz. The profiles have been aligned by timing model. Intensity of the profiles is shown in arbitrary units.

3. Discussion and summary

It is interesting that all detections were made at one of the three epochs, but we suppose a small-number statistics can be invoked to explain it. However, an estimate of the decorrelation bandwidth for diffractive scintillation made from known value at lower frequency 1.4 GHz (Ryba 1991) for PSR B1855+09 yields a few GHz at 8.35 GHz. Moreover, estimates based on Cordes & Lazio (2002) NE2001 model at 8.35 GHz yield 225 GHz, 86 GHz, 88 GHz and 665 GHz for J1022+1001, J1713+0747, B1855+09 and J2145-0750 respectively. This can be a reason why only some observations resulted in detections with our 200 MHz bandwidth. We combined our flux measurements at 8.35 GHz with data from lower frequencies (Kuzmin & Losovsky 2001; Kramer et al. 1999) to analyse spectra for the 3 detected pulsars (Fig. 4). We carried out a fitting procedure described in Maron et al. (2000) in order to obtain spectral indices for two power law parts of the spectrum and

Table 1. List of millisecond pulsars observed at 8.35 GHz. Number of pulses, period, mean flux density $S_{\rm mean}$, dispersion measure smearing $\sigma_{\rm DM}$ and pulse width at 50% of maximum intensity W_{50} are listed.

PSR	Number of pulses	Period [ms]	$S_{\rm mean}$ [mJy]	$\sigma_{\rm DM}$ [deg]	W_{50} [deg]
J1022+1001	653 187	16.45	<0.05	0.6	
J1713+0747	1 151 982	4.57	0.11	4.1	23
	2 346 630		<0.17		
B1855+09	1 910 351	5.36	0.1	2.5	33 (MP) 15 (IP)
	1 418 079		<0.28		
	1 997 058		<0.22		
J2145-0750	333 438	16.05	0.07	0.6	9
	671 546		<0.08		

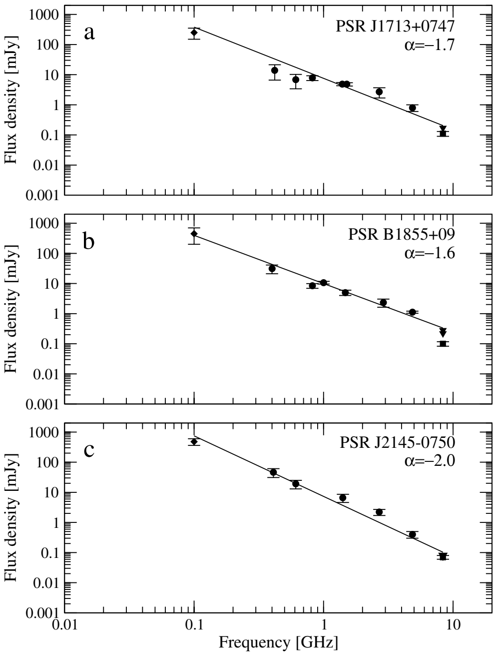

Fig. 4. Spectra of 3 millisecond pulsars together with a single power law fits and spectral indices. Diamonds denote 100 MHz data taken from Kuzmin and Losovsky (2001), circles denote data from 300 MHz to 4.85 GHz taken from Kramer et al. (1999) and references therein. Squares denote our 8.35 GHz observations and triangles show flux density upper limits calculated from our observations at 8.35 GHz.

a quantitative measure of the goodness-of-fit. Comparison of the χ^2-statistics for both single and two power law cases was used to judge whether the break was significant. In all cases the probability that the two power law is a good fit is smaller than for the single power law. However, the measured flux density at 8.35 GHz for B1855+09 $S_{\rm mean} = 0.1 \pm 0.02$ mJy is smaller than expected from the single power law spectrum (see Fig. 4b) and indicates a possible break in spectrum at high frequency. Except for J0437−4715 no other MSPs show the high frequency break (>1 GHz) in their spectra (Kramer et al. 1999). However, one cannot exclude that spectra presented in Fig. 4 do show signs of steepening at high frequencies and further observations are needed to settle this point.

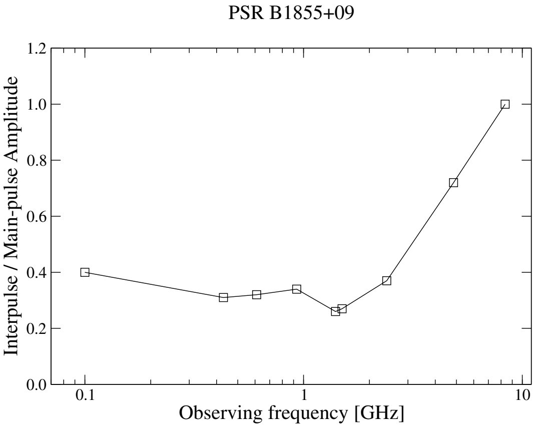

Fig. 5. Interpulse-to-Mainpulse amplitude ratios at different frequencies for B1855+09. Data at 104 MHz were taken from Kuzmin et al. (1990), data at 430 MHz, 1.4 GHz and 2.4 GHz from Thorsett & Stinebring (1990) and at 4.85 GHz from Kijak et al. (1997).

The most interesting case in our sample is PSR B1855+09 which shows an inter-pulse (IP) apart from the main-pulse (MP). For this pulsar we observed a very strong IP compared to observations at lower frequencies, with the amplitude ratio (IP/MP) close to unity at 8.35 GHz (Fig. 5). The significant increase of this ratio above 3 GHz is clearly seen. A similar tendency was observed in the millisecond pulsar J2322+2057 (Nice et al. 1993) and J1012+5307 (Kramer et al. 1999) and also in the normal pulsars B0826+34 (Biggs et al. 1985) and B1929+10 (Wielebinski et al. 1993).

Summing up, high sensitivity of the new 8.35 GHz receiver enabled clear detection of 3 MSPs at this high freqiuency. All three pulsars have single power law spectra. The spectral index in the wide frequency range including high frequency observations $\bar{\alpha} = -1.8$ for these MSPs (see also Kramer et al. 1998) is exactly the same as in normal pulsars (Maron et al. 2000). The measured flux density of PSR B1855+09 indicates the possibility of a high frequency break in the spectrum, just like in normal pulsars. However, the above mentioned spectral behaviour of B1855+09 should be confirmed by more observations and flux density measurements at 8.35 GHz. A possible switch between MP and IP may be observed for this pulsar at frequencies above 8.35 GHz. This may also be possible in PSR J1012+5307 (Kramer et al. 1999). This effect has already been observed for normal pulsar B0826-34 (Biggs et al. 1985; Esamdin et al. 2003).

Our high frequency observations confirm the finding of Kramer et al. (1998) and Kramer (2002) that millisecond pulsars have properties similar to normal pulsars except that their luminosity is some 10 times lower. Further observations are planned to increase the sample of detected millisecond pulsars.

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