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Pulsar Radio Spectra - High Frequency Turnover

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Abstract We present the first direct evidence for turnover in pulsar radio spectra at high frequencies. New data for some pulsars, taken with the GMRT, show the *maximum flux* in the spectrum to be $\sim$ 1 GHz. We also find some evidence that this *peak frequency* of turnover in pulsar spectra appears to depend on dispersion measure and pulsar age.

Key words: pulsars: general — pulsars: radio spectra — pulsars: individual: B1054−62, B1740−31, B1822−14, B1823−13

1 INTRODUCTION

A typical pulsar spectrum is steep compared to spectra of other non-thermal radio objects and can be described by a simple power law in the observed radio frequency range, with a mean spectral index -1.8 (Maron et al. 2000). Whereas several pulsars have a straight spectrum down to the lowest observable frequencies, some pulsars show a low-frequency turnover in the spectrum (Malofeev et al. 1994). The frequency at which such a spectrum shows the *maximum flux* is called the *peak frequency*, and it occurs in the range $\sim$ 100 to 400 MHz for most pulsars with turnover spectra. It is still an open question whether the cause of the turnover is some kind of absorption in the magnetosphere, efficiency loss of the emission mechanism or an interstellar effect (Sieber 1973).

In a recent paper (Kijak & Maron 2004), the authors analysed the collected pulsar spectra and presented several pulsars as candidates for a high frequency (at $\sim$ 1 GHz) turnover in spectrum (see Fig. 1 for an example). In this paper, we present recent observations of some of these candidates using the GMRT and report confirmation of a new aspect of pulsar radio spectra – a *maximum flux* or turnover at a frequency above 1 GHz.

2 OBSERVATIONS AND RESULTS

The observations were made at several epochs between November 2004 and February 2005, using the GMRT at one of the following three frequencies at each epoch: 325 MHz, 610 MHz or 1060 MHz, with a 16 MHz bandwidth. We used the phased array mode with 0.512 ms sampling and 256 spectral channels across the band (Gupta et al. 2000). We observed a total of 11 pulsars in total intensity mode at several different epochs (see Table 1 for details). Some pulsars were not observed at the lower frequencies due to scatter broadening being comparable or larger than the pulse period. To estimate the mean flux density ($S_\nu = E/P$) of the pulsars, we carried out regular calibration measurements of known continuum sources (e.g. 1311−22, 1822−096, 2350+646 and 3C48) from which an appropriate calibration scale for the pulsar data was established.

We obtained good quality pulse profiles for most of the observed pulsars. Some of these are presented in Figures 2, 4, 6 and 8 (in combination with some data taken from Gould & Lyne 1998). Pulse broadening at the low frequencies is visible in three pulsars presented here (Figs. 2, 4 and 6). The calculated average flux densities are given in Table 1. Using these in combination with data from literature, we have constructed spectra for these pulsars and find three pulsars with clear indication of a turnover at frequency

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Table 1 Observed pulsars at the GMRT. PSRs with high-frequency turnover are marked in bold. The total number of epochs of flux measurements at each frequency are given in prentheses.

PSR	$\nu_{\rm obs}$ (MHz)	$t_{\rm av}^{\rm obs}$ (min)	$\langle S_{\rm mean}\rangle$ (mJy)	PSR	$\nu_{\rm obs}$ (MHz)	$t_{\rm av}^{\rm obs}$ (min)	$\langle S_{\rm mean}\rangle$ (mJy)
B1557−50	325	16	128±38 (1)	**B1823−13**	1060	23	3.6±0.8 (4)
DM=261	610	9	65.7±13 (3)	DM=231			
	1060	5	24.6±1.4 (3)	B1830−08	610	12	18.5±3.2 (2)
B1641−45	610	10	630±53 (3)	DM=411			
DM=480	1060	4	323±52 (2)	B1838−04	610	10	12.7±0.5 (2)
B1740−31	325	25	7.6±0.6 (2)	DM=324	1060	3	2.7±0.8 (1)
DM=192	610	10	10.2±3.5 (2)	B2303+46	325	21	5.3±0.6 (2)
	1060	12	3.0±0.3 (4)	DM=62	610	18	2.8±1.3 (2)
B1815−14	610	13	$>$ 3.9 (2)		1060	16	1.2±0.4 (2)
DM=625	1060	15	8.6±0.2 (2)	B2319+60	325	15	84.2±2.5 (2)
B1820−14	1060	13	1.2±0.1 (2)	DM=95	610	5	39±12 (1)
DM=648					1060	11	23.9±0.3 (2)
B1822−14	610	18	1.6±0.3 (2)				
DM=354	1060	20	2.4±0.5 (4)				

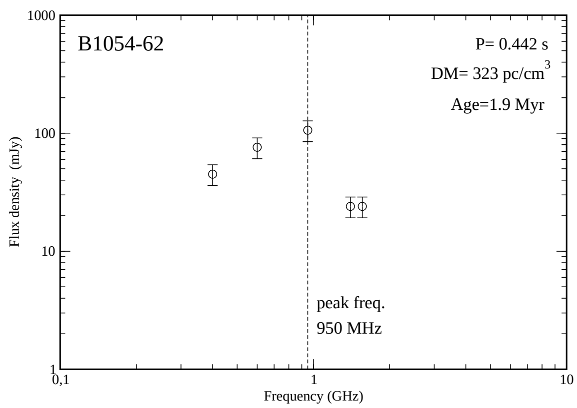

Fig. 1 Example of a spectrum with high frequency turnover (from KM04). Data were taken from C91, T93, vO97, K95 and W93 (see References).

above 600 MHz (Figs. 5, 7 and 9). We note that all the four pulsars – B1054−62, B1740−31, B1822−14 and B1823−13 – with turnover above 600 MHz presented in this paper have fairly high dispersion measure (DM) values, ranging from 192 to 354. However, it is interesting that not all pulsars with high DM values in our set show a high frequency turnover (Fig. 3 and Table 1).

3 DISCUSSION AND CONCLUSIONS

In their paper Kijak & Maron (2004) identified 19 pulsars as possible candidates for high frequency turnover spectra, based on the known flux estimates (see their figure 1 and table 1). However, a careful examination of the profiles of these candidate pulsars (using the European Pulsar Network Data Archive [1]) shows that scintillation pulse broadening at the lower frequencies is comparable to or larger than the period for some of them (e.g. B1820−11). This results in the flux values being underestimated at the lower frequencies, giving a false impression of a high frequency turnover. From the low frequency observations reported here, we can see that four more candidate pulsars (B1557−50, B1641−45, B1830−08 and B1838−04) turn out *not* to show a high frequency turnover. The three candidate pulsars that we have confirmed to have a high

[1] www.mpifr-bonn.mpg.de/div/pulsar/data/

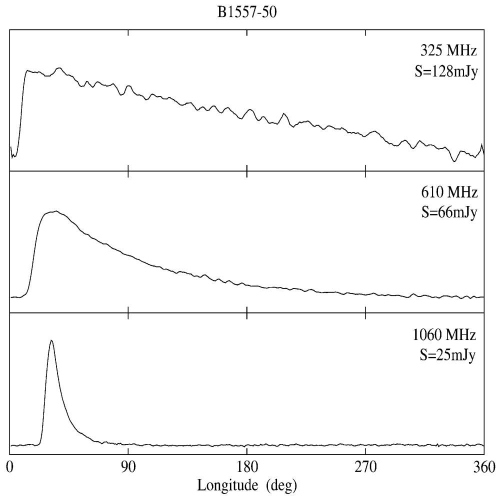

Fig. 2 Profiles for PSR B1557−50 with the GMRT.

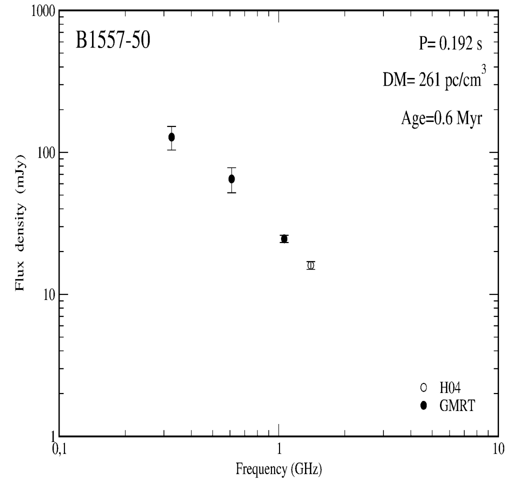

Fig. 3 The spectrum of PSR B1557−50.

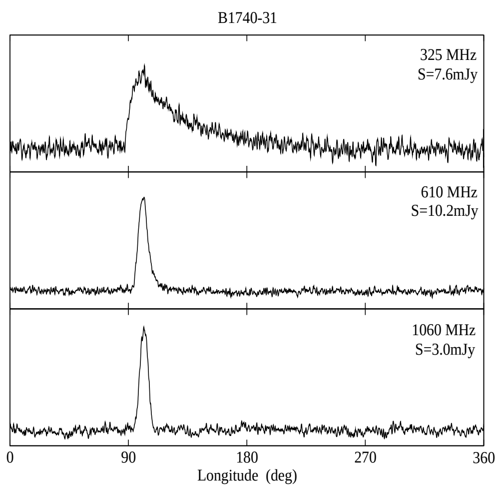

Fig. 4 Profiles for PSR B1740−31 with the GMRT.

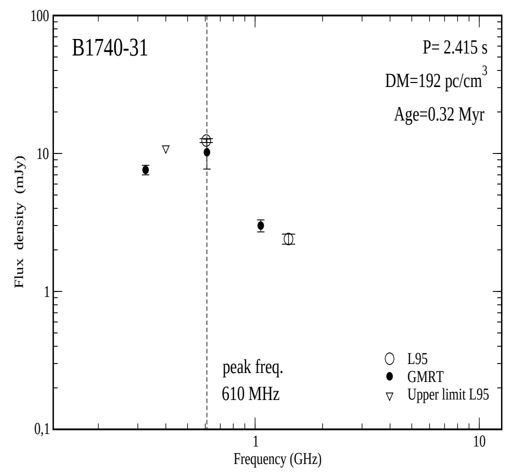

Fig. 5 The turnover spectrum of PSR B1740−31.

frequency turnover are B1740−31, B1822−14 and B1823−13. Of the remaining in the list of Kijak & Maron (2004), there are still a few that need low frequency observations to elucidate the true nature of their spectra (e.g. B1240−64, B1815−14, B1820−14, B1828−10, B1823−11 and B1834−04) – these are still good candidates for high frequency turnover but they were not included in the statistical analysis that followed.

To carry out a detailed analysis of turnover effects, we took the results for 41 pulsars with turnover spectra from the literature (Sieber 1973; Malofeev et al. 1994) and combined them with those from our study (B1054−62, B1740−31, B1822−14 and B1823−13). This set of 45 pulsars was analyzed to check for correlations between *peak frequency* ($\nu_{\rm peak}$) and other pulsar parameters. Figure 10 indicates that $\nu_{\rm peak}$ correlates with DM. We also find a fairly strong dependence of $\nu_{\rm peak}$ on pulsar age τ (Fig. 11). On the other hand, the correlation coefficient between $\nu_{\rm peak}$ and period P is relatively small ($r = 0.4$).

Turning now to the statistical analysis of turnover effects, we first note that the correlations with other parameters can be more firmly tested if the error bars on the low frequency flux estimates (see Fig. 10 for example) of the pulsars are reduced. The large error bars translate to large errors in the estimates of the

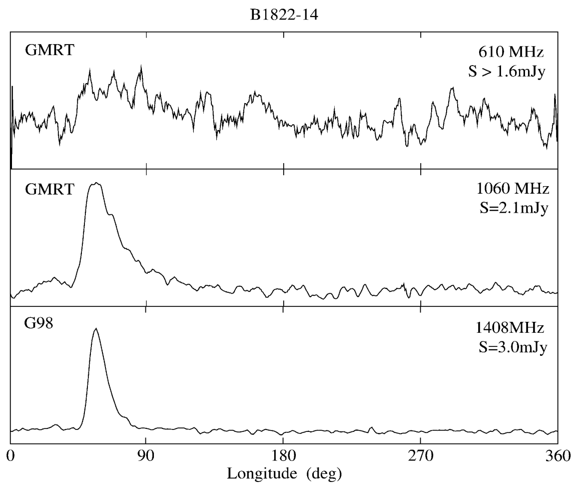

Fig. 6 Frequency evolution of profiles for PSR B1822−14.

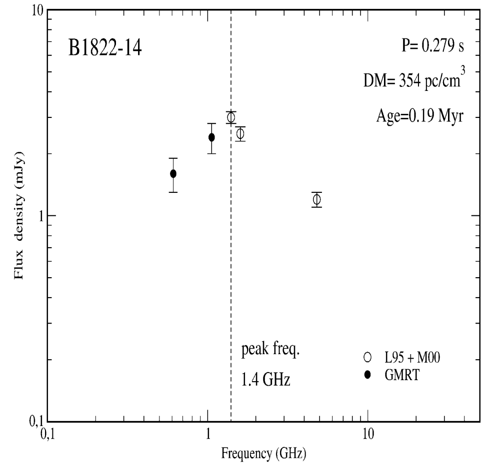

Fig. 7 The turnover spectrum of PSR B1822−14.

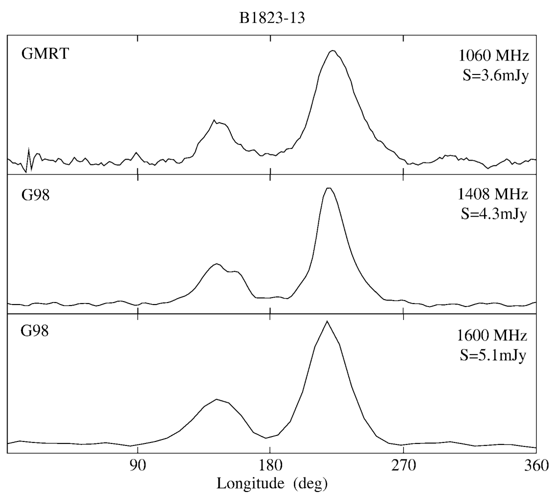

Fig. 8 Frequency evolution of profiles for PSR B1823−13.

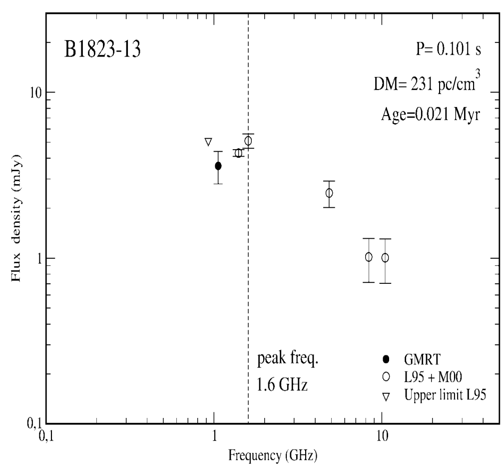

Fig. 9 The turnover spectrum of PSR B1823−13.

peak frequency in the spectrum, increasing the scatter in these correlation studies. Secondly, we note that it is possible that the tendency for higher turnover frequencies to occur for pulsars with higher DMs could be a selection effect. The difficulties in low frequency observations (due to excessive pulse broadening) of high DM pulsars with low frequency turnovers could account for their absence from the lower right hand portion of Figure 10. However, this would not explain why pulsars with low DMs do not show turnovers at around 1 GHz. Hence, we think that the result is genuine and not a selection effect.

The relation with pulsar age (Fig. 11) is also interesting. Millisecond pulsars, which are very old objects, show no evidence for spectral turnover down to 100 MHz (Kuzmin & Losovsky 2001) and this result is consistent with our finding. On the other hand, no turn-over in the spectra of millisecond pulsars above 100 MHz and our results are in contradiction with a possible correlation between *peak frequency* and period, $\nu_{\rm peak} \propto P^{-0.36}$ (Malofeev 1996). We suggest that a period dependence of $\nu_{\rm peak}$ does not exist (see for example Figs. 5, 7 and 9).

Now, we turn to the question: what is the possible cause of spectral turnover in pulsars? In this context, it is interesting to note that two pulsars with *maximum flux* at high frequencies (B1054−62 and B1823−13)

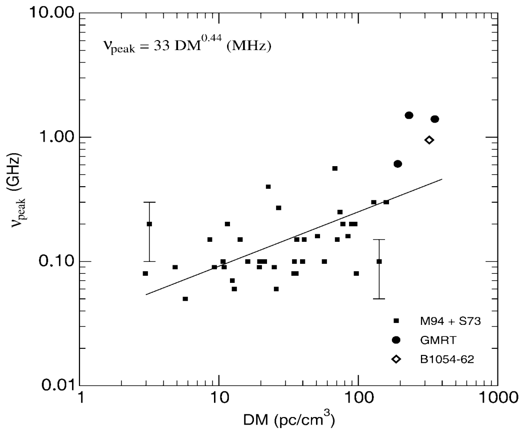

Fig. 10 Peak frequency versus DM. A formal fit gives $\nu_{\rm peak} = 33\,{\rm MHz} \times {\rm DM}^{0.44\pm0.08}$ with $r = 0.65$.

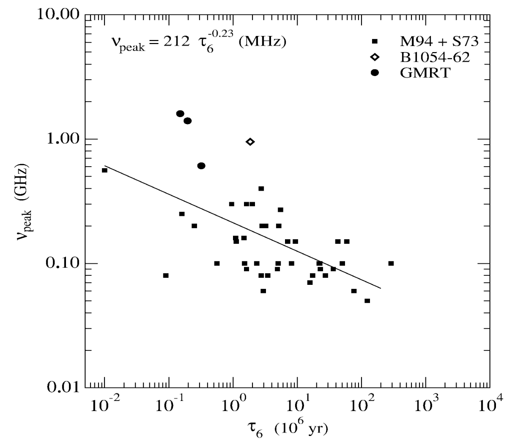

Fig. 11 Peak frequency versus age. A formal fit gives $\nu_{\rm peak} = 212\,{\rm MHz} \times \tau_6^{-0.23\pm0.05}$ with $r = 0.60$.

have been shown to have very interesting interstellar environments (Koribalski et al. 1995; Gaensler et al. 2003). This could suggest that the turnover phenomenon is associated with the enviromental conditions around the neutron stars, rather than related intrinsically to the radio emission mechanism.

Finally, we summarize our main conclusions: First, we find clear evidence for spectral turnover at $\sim$ 1 GHz for some pulsars. Second, we find some evidence that the *peak frequency* in pulsar spectra is correlated with DM and characteristic age of the pulsars – the *peak frequency* is higher for pulsars with larger DM and smaller age. Though it is still an open question about the cause of the turnover mechanism in pulsar radio spectra, we believe that our results shed new light on this effect and can help us to resolve this problem.

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