Flux-density spectral analysis for several pulsars and two newly-identified gigahertz-peaked spectra

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ABSTRACT

In this paper we present results from flux density measurements for 21 pulsars over a wide frequency range, using the Giant Metrewave Radio Telescope (GMRT) and the Effelsberg telescope. Our sample was a set of mostly newly discovered pulsars from the selection of candidates for gigahertz-peaked spectra (GPS) pulsars. Using the results of our observations along with previously published data, we identify two new GPS pulsars. One of them, PSR J1740+1000, with dispersion measure of 24 pc cm$^{-3}$, is the first GPS pulsar with such a low DM value. We also selected several strong candidates for objects with high frequency turnover in their spectra which require further investigation. We also revisit our source selection criteria for future searches for GPS pulsars.

Key words: pulsars: general - pulsars: individual: J1740+1000, J1852–0635

1 INTRODUCTION

Of the about 2000 known pulsars, only around 400 have measured flux density spectra. For most of these cases, the flux density spectra can be described using a power-law of the form

$$S(\nu) = d \cdot \nu^\xi,$$

where $\nu$ denotes observing frequency, with negative spectral index $\xi$ of about −1.8; or by a combination of two power laws

$$S(\nu) = \begin{cases} \nu^\xi_1 : & \nu \leq \nu_0 \\ \nu^\xi_2 : & \nu > \nu_0 \end{cases}$$

with spectral indices $\xi_1$ and $\xi_2$ with average values of −0.9 and −2.2 respectively, with a break frequency $\nu_0$, which is typically around 1.5 GHz (Maron et al. 2000). The population of pulsars with such break in the spectra is about 10% of the sample analysed by Maron et al. (2000), and it is usually assumed that both $\xi_1$ and $\xi_2$ are negative with $\xi_2$ being steeper than $\xi_1$. For pulsars which can be observed at low frequencies (i.e. about 100–600 MHz), a low frequency turnover is observed in the spectra (Siebel 1978, Lorimer et al. 1995). In some cases, positive spectral indices have also been observed between 400 MHz and 1600 MHz (Lorimer et al. 1995).

Kijak et al. (2007) showed the first direct evidence of a high frequency turnover in radio pulsar spectra using multi-frequency flux measurements for candidates chosen from the objects which showed a decrease of flux density at frequencies below 1 GHz. The frequency at which such a spectrum shows the maximum flux is called the peak frequency $\nu_p$. Later, Kijak et al. (2011b) presented a new class of objects, called gigahertz-peaked spectra (GPS) pulsars. These sources exhibit a turnover in their spectra at high frequencies with $\nu_p$ about 1 GHz or above. To analyse the shapes of gigahertz-peaked spectra we use a function

$$S(\nu) = 10^{\alpha x^2 + b x + c}, \quad x \equiv \log_{10} \nu,$$

previously proposed for similar studies of pulsar spectra with turnover at low frequencies (Kuzmin & Losovsky 2001).

GPS pulsars have been demonstrated to be relatively young objects, and have a high dispersion measures ($DM > 150$ pc cm$^{-3}$) (Kijak et al. 2011b). They usually adjoin interesting and often dense objects in their vicinity, e.g. HII regions, compact Pulsar Wind Nebulae (PWNe). In addition, it seems that they are coincident with known but sometimes unidentified X-ray sources from 3rd EGRET Catalogue or HESS observations. This in turn suggests that the high frequency turnover owes to the environmental conditions around neutron stars and/or the physical properties of the interstellar medium. Though GPS pulsars represent the smallest group of radio pulsar spectra types today, Bates et al. (2013) estimate that the number of such sources may be as much as 10% of the whole pulsar population. It is obvious that without a more extensive sample of these sources, it is not possible to constrain reliably any statistics of their properties.

The evolution of the spectrum of PSR B1259−63 with orbital phase can be treated as a key factor to define physical mechanisms...
Table 1. The weighted means of all flux density measurements and their uncertainties for our sample of 21 pulsars are presented. Results from observations conducted in 2010 using the GMRT in phased array mode at 610 MHz are marked as $S_{610}$, those using the Effelsberg telescope in 2012 at three frequencies 2.6 GHz, 4.85 GHz and 8.35 GHz are denoted by $S_{2600}$, $S_{4850}$ and $S_{8350}$, respectively. The total number of observations at each frequency are given in parentheses; "<" denotes an upper limit. Flux density measurements from observations in 2008 are given in the footnote. Data collected in 2008 and 2010 were partially published (see Kijak et al. 2011c). Where possible, the value of $\xi$, the power index fitted to the spectra (using our data in combination with previously published data for individual pulsars), along with the reduced $\chi^2$, is given in the last two columns. There are no errors in the fits for $\xi$ for degenerate cases where the number of data points equals the number of parameters.

| Pulsar | Period (s) | DM (pc cm$^{-2}$) | Age (kyr) | $S_{610}$ (mJy) | $S_{2600}$ (mJy) | $S_{4850}$ (mJy) | $S_{8350}$ (mJy) | $\xi$ | $\chi^2$ |
|--------|------------|------------------|-----------|-----------------|-----------------|-----------------|-----------------|------|--------|
| J1305−3950 | 0.319 | 207 | 83.4 | 1.2±0.1(3) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1723−3659 | 0.203 | 254 | 401 | 2.9±0.2(2) | 1.2 | 1.2 | 1.2 | 1.2 |
| J1739−3023 | 0.114 | 170 | 159 | 2.7±0.2(2) | 1.2 | 1.2 | 1.2 | 1.2 |
| J1740+1000 | 0.154 | 24 | 114 | 2.0±0.7(2) | 1.2 | 1.2 | 1.2 | 1.2 |
| J1744−3130 | 1.07 | 193 | 796 | 1.7±0.3(2) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1751−3323 | 0.548 | 297 | 984 | 1.7±0.3(2) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1755−2521 | 1.18 | 252 | 207 | <1.0(2) | 0.3 | 0.3 | 0.3 | 0.3 |
| B1811+40 (J1813+4013) | 0.931 | 42 | 5790 | 0.185±0.036(1) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1812−2102 | 1.22 | 547 | 811 | <2.7(2) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1834−0731 | 0.513 | 295 | 140 | <1.6(3) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1835−1020 | 0.302 | 114 | 810 | 3.6±1.0(3) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1841−0345 | 0.204 | 194 | 355 | 3.5±2.0(2) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1842−0905 | 0.345 | 343 | 520 | 2.2±3.0(2) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1852−0635 | 0.524 | 171 | 567 | 7.0±0.7(3) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1857+0143 | 0.140 | 249 | 71 | <1.0(1) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1901+0510 | 0.615 | 429 | 313 | 3.4±1.5(2) | 0.3 | 0.3 | 0.3 | 0.3 |
| B1903+07 (J1905+0709) | 0.648 | 245 | 2080 | 0.59±0.12(2) | 0.3 | 0.3 | 0.3 | 0.3 |
| B1904+06 (J1906+0641) | 0.267 | 473 | 1980 | 1.23±0.042(1) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1905+0616 | 0.99 | 256 | 116 | 2.4±0.5(1) | 0.3 | 0.3 | 0.3 | 0.3 |
| J1910+0728 | 0.325 | 284 | 621 | 2.4±0.5(2) | 0.3 | 0.3 | 0.3 | 0.3 |
| B1916+14 (J1918+1444) | 1.18 | 27 | 88.1 | 2.13±0.019(1) | 0.3 | 0.3 | 0.3 | 0.3 |

Notes:
- $S_{1710}=9.0±0.5 (2) $, $S_{1710}=2.1±0.6 (1) $, $S_{1710}=0.4±0.1 (2) $.
able in the ATNF catalogue. The observations were conducted in the phased array mode of the GMRT (Gupta 2000), with the available 16 MHz bandwidth divided into 256 channels, and using a sampling rate of 0.512 ms. The typical integration time was about 30 min (for more details see Kijak et al. 2011b).

For the Effelsberg observing project we selected pulsars based on our GMRT observations, along with data from the ATNF catalogue and Maron et al. (2000). Objects which appeared to have a flat spectrum or a positive spectral index below a frequency of 1 GHz were selected. To ascertain the full shape of the spectrum it was necessary to measure the flux densities at frequencies above 2 GHz. For these observations, we used the secondary focus receivers (with cooled HEMT amplifiers) with bandwidth of 100 MHz at 2.6 GHz, 500 MHz at 4.85 GHz and 1100 MHz at 8.35 GHz. These receivers provided circularly polarised LHC and RHC signals, digitized and independently sampled with 1024 bins per period, and synchronously folded using the topocentric pulsar rotational period (Jessner 1996). The typical integration time was around 20-25 min. The observations were intensity calibrated by the use of a noise diode and known continuum radio sources (NGC 7027, 3C 286, 3C 345).

Table 1 combines the weighted means of all flux density measurements and their uncertainties for our sample of 21 pulsars, acquired at different frequencies with the GMRT and the Effelsberg observing projects. Most sources in our sample have high DMs and hence the flux density variations caused by interstellar scintillations should be minimal. Nevertheless, observations at each frequency (with a few exceptions) were conducted at 2-3 different epochs to give us reliable estimates of the average flux and its uncertainties, which are used to construct the spectra for these pulsars, in combination with flux density data available from literature. In Tab. 1 we also present other basic parameters of these pulsars, such as age, dispersion measure and period.

1 http://www.atnf.csiro.au/research/pulsar/
high frequency observations using Effelsberg telescope due to an erroneous ephemeris. New measurements marked as open circles are presented in Fig. 1 along with previous results. One can note that the flux density at 1170 MHz, derived from a previous observing project (see Kijak et al. 2011b), appears to be substantially smaller than values obtained at neighbouring frequencies – this is possibly due to interstellar scintillations. Regardless of the reason causing the decrease of flux density at frequencies – this is possibly due to interstellar scintillations. Moreover, it is a relatively young object with high DM, as is typical of most of the GPS pulsars. To our knowledge there are no radio or high-frequency observations that would prove that this object has any kind of a peculiar environment, however one cannot rule out that possibility.

In Fig. 2 we present the spectrum of PSR J1852+0635. It seems to be obvious that we are dealing with a GPS-type spectrum. However, the object is a potential candidate for a pulsar with spectra described using the model presented in Löhmer et al. (2008). Thus, we attempted to fit three different functions that had been proposed in the literature, where

\[ S(\nu) = \frac{S_0}{1 + (2\pi\nu\tau)^2} \]  

and

\[ S(\nu) = S_0 \left( 1 + (2\pi\nu\tau)^2 \right)^{n-1} \cdot e^{-\nu_i/(\pi\nu\tau)} \]  

from Löhmer et al. (2008) are based on a nano-shot emission model. We also considered the empirical function presented in Eq. (3). Parameters were

- \( S_0 = 8.7 \pm 0.4 \) Jy, \( \tau = 0.03 \pm 0.003 \) ns, \( \chi^2 = 7.9 \) for the function presented in Eq. (4).
- \( S_0 = 404 \pm 13 \) Jy, \( \tau = 0.038 \pm 0.005 \) ns, \( \chi^2 = 15.4 \) for the function presented in Eq. (5).
- \( a = -0.99 \pm 0.28, b = 0.30 \pm 0.26, c = 0.92 \pm 0.01, \chi^2 = 10.8 \) for the function presented in Eq. (5).

For (4) we used a simplex fit procedure and a Levenberg-Marquardt method was found advantageous for (3) and (5).

The simple function presented in Eq. (4) provided the best fit with a nano-shot timescale of about 30 ps which is only 10% of what was found for typical pulsars by Löhmer et al. (2008). Alternatives (3) and (5) gave slightly worse agreements with the data, but generally speaking one finds that these three functions match the data quite well within the measured frequency interval. Only at frequencies above 20 GHz may one expect to be able to differentiate between them, with (4) and (5) being steeper than (3). All fits predict an average flux density of about 0.5 - 0.8 mJy.

### 3.2 Candidates for GPS pulsars

Fig. 3 presents the spectra of PSRs J1705−3950, J1812−2102 and J1834−0731, which can be considered good GPS candidates. New measurements points (open circles) along with the data from the ATNF catalogue (black dots) show negative spectral index at frequency ranges above 1 GHz for these objects.

PSR J1705−3950, while having flux measurements at only two frequencies, seems to be a strong GPS candidate since it clearly shows a moderately high positive spectral index at frequencies close to 1 GHz. The spectra of PSRs J1755−3251 and J1857+0134 (not presented in Fig. 3) are similar to the spectrum of PSR J1705−3950, although in those cases we have only one flux measurement and one upper limit (see Table 1). Nevertheless, these two objects can be also considered good GPS candidates that deserve further investigation.

In the cases of PSRs J1812−2102 and J1834−0731, from a consideration the level of the upper limit at 610 MHz and flux density measurements at higher frequencies (see Fig. 3), it appears that at frequencies below 1 GHz their spectra may be flat or even exhibit a positive spectral index. Moreover, both objects are relatively young, and have high DMs which makes them similar to other GPS

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**Figure 3.** The radio spectra of PSRs J1705−3950, J1812−2102 and PSR J1834−0731. Open symbols denote our observations conducted in 2010 (610 MHz) and 2012 (2.6 GHz and 4.85 GHz), whereas black dots denote data from the ATNF catalogue. Triangles are upper limits. The straight lines represent our fits to the data using power-law function (upper limits were excluded from the fitting procedure).
In this section we present the spectra of pulsars chosen from the remaining 16 objects in our sample. For those with four and more observing points there is a strong suggestion that their spectra do not show any signs of the GPS. As for the spectra of the remaining objects it was impossible to properly classify them due to the deficiencies of the flux measurements.

The spectra for 7 of these remaining 16 pulsars from Table 1 are presented in Fig. 4 and Fig. 5. For these objects we are probably dealing with a single power-law spectrum (the fits are presented along with data points). However, spectra of PSRs B1811+40 and B1904+06 presented in Fig. 5 are potential candidates for broken spectra type with break frequencies 700 MHz and 2.3 GHz, respectively.

The data for PSR B1916+14, as in the case of PSR J1852–0635, was matched to the three different functions, and we obtained reasonable fits with the following parameters:

- \( S_0 = 1.9 \pm 0.27 \text{ Jy}, \tau = 0.1 \pm 0.03 \text{ ns}, \chi^2 = 11.9 \) for function presented in Eq. (3).
- \( S_0 = 202 \pm 303 \text{ Jy}, \tau = 0.074 \pm 0.02 \text{ ns}, \chi^2 = 13.5 \) for function presented in Eq. (5).
- \( a = -1 \pm 0.3, b = -0.64 \pm 0.08, c = 0.13 \pm 0.022, \chi^2 = 10.7 \) for function presented in Eq. (5).

Again, the fits only begin to diverge significantly above 20 GHz, but here average fluxes of the order of \( \mu \text{Jy} \) are to be expected, which will require a larger and more sensitive instrument that the currently available 100-metre class of radio telescopes.

In Table 1 we also include power-law spectral indices fitted for another 7 objects with spectra containing flux measurements at only two frequencies (PSRs J1723–3659, J1739–3023, J1744–3130, J1751–3323, J1835–1020, J1842–0905 and J1901+0510). For obvious reasons we did not conduct any fitting procedure for pulsars with flux density measured at only 1 frequency.

One has to remember that almost all the above pulsars (with the only exceptions being PSRs B1811+40 and B1916+14) are objects with relatively high DMs. Therefore, using the standard pulsar flux measurement methods for these objects can cause erroneous results, especially when the observations are conducted at low observing frequencies where the pulsars are significantly affected by scattering. This typically happens when the scattering tail is long enough to be a significant fraction of the pulsar period. In such cases one may overestimate the off-pulse level, which in turn would lead to an underestimate of the pulsar flux density.

### 3.3 Other pulsars

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### 4 SUMMARY AND DISCUSSION

In this paper, we report two newly-identified GPS pulsars, PSR J1740+1000 and PSR J1852–0635. We also present the spectra for 17 other pulsars, 13 of which are constructed for the first time. Among these, three sources can be considered as good candidates for gigahertz-peaked spectra pulsars. Both the newly identified GPS pulsars are relatively young objects (115 kyr for PSR J1740+1000 and 567 kyr for PSR J1852–0635), which is a common characteristic for other known GPS pulsars. We have to note that PSR J1740+1000 is the first object exhibiting this phenomenon that has a low DM (24 pc cm$^{-3}$).

In case of PSR J1740+1000 we present the spectrum over a wide frequency range, which is an improvement with regard to the previously published one (Kijak et al. 2011b). The new spectrum

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**Figure 4.** The radio spectra of three pulsars: PSRs J1905+0616, J1910+0728 and B1916+14. Open circles denote our observations conducted in 2008 and 2010 (1070 MHz and 610 MHz, respectively), and 2012 (2.6 GHz and 4.85 GHz), whereas the black dots denote data from Maron et al. (2000). The straight lines represent our fits to the data using a power-law function (in the case of PSR B1916+14 the marginal data point was excluded from the fitting procedure). The resulting spectral indices are presented in Table 1.

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pulsars. However, it definitely requires further investigation to decide whether we are dealing with cases of turnover or broken type of spectra. The spectral indices fitted to high frequency flux values for these two pulsars (excluding data points that are upper limits) are presented in Table 1; the values of \(-2.0\) and \(-1.41\) seem to indicate regular steep spectra; however, it was shown by Kijak et al. (2011) that, in the high frequency range, most of the verified GPS pulsars behave like normal spectra pulsars.
still contains the flux measurement at 1170 MHz (see Fig. 1) which is unusually low compared to measurements at nearby frequencies, and we consider it to be unreliable and excluded it from the spectral fitting procedure. The reason for this may be interstellar scintillations (as suggested in the discovery paper, McLaughlin et al. 2000), and we plan to address this issue with future observations near the frequency of 1 GHz. For the other new GPS pulsar we only want to mention that the 1.4 GHz measurement (full circle in Fig. 2) is also slightly lower than the shape of the spectra (based on our data) would suggest. This measurement was obtained by Hobbs et al. (2004) and published in the Parkes discovery paper.

For the majority of the remaining pulsars we obtained spectral indices which range from +0.3 to −2.0. Six of these can be considered to indicate flat spectra ($\xi > -1.0$). From our sample, we have selected three good GPS candidates. One of these sources is PSR J1705−3950, with the spectral index $\xi = +0.3$ based on observations made at two frequencies only (see Fig. 3). Because of its low declination we were unable to obtain flux measurements at high frequencies using the Effelsberg radio telescope; such measurements would be possible only using Australian telescopes. The other two candidates, PSR J1812−2102 and J1834−0731, show typical spectra at high frequencies, but the flux density upper limits we obtained at 610 MHz suggest that the spectra deviate from a simple power-law which may be an indication of a possible GPS behaviour.

4.1 GPS pulsars

Summarizing, after the addition of the two new identifications presented here, we now have 11 GPS pulsars known. This number includes six objects presented in Kijak et al. (2011a), two radio magnetars (Kijak et al. 2013), and PSR J2007+2722 presented by Allen et al. (2013). This will definitely improve the statistics, which is important when trying to make reliable conclusions about general properties of this class of objects (both pulsars and radio magnetars). However, the still relatively small sample of GPS pulsars, and no direct correlation between spectra shapes and physical parameters (internal or external) that could affect the radiation properties implies a still somewhat limited understanding of the properties of these objects as a group. Thus, successful searches for more GPS pulsars and low frequency flux measurements in radio pulsars are very important.

The first of the new GPS pulsars presented here, PSR J1740+1000, was discovered in an Arecibo survey (McLaughlin et al. 2000) and reported to have an unusually high positive spectral index of 0.9 (McLaughlin et al. 2002), which made it a good candidate object. The new observations indeed appear to be sufficient to identify the PSR J1740+1000 spectrum as a GPS-type. The object is very interesting from several points of view. XMM-Newton observations have revealed the existence of a PWN around the pulsar with a complex morphology (very extended pulsar tail, Kargaltsev et al. 2008). Later, Kargaltsev et al. (2012) reported absorption features in the X-ray spectrum of this ordinary rotation-powered radio pulsar and concluded that some of these features, thought to be unusual in neutron star spectra, are probably more common than earlier expected. The authors believe that their findings bridge the gap between the spectra of pulsars and other, more exotic neutron stars, i.e. “X-ray dim Isolated NSs” (XDINSs), Central Compact Objects (CCOs), and “Rotating Radio Transients” (RRATs). PSR J1740+1000 was also considered by Romani et al. (2011) as a candidate “sub-luminous” $\gamma$-ray pulsar. Additionally, PSR

![Figure 5. The radio spectra of four pulsars: PSRs B1811+40, J1841−0345, B1903+07 and B1904+06. Open circles denote our observations conducted in 2010 (610 MHz) and 2012 (2.6 GHz and 4.85 GHz), whereas the black dots denote previously published data. The straight lines represent our fits to the data using a power-law function. The resulting spectral indices are presented in Table 1.](image-url)
J1740+1000 reveals a new aspect of pulsars with gigahertz-peaked spectra: with a DM of 24 pc cm$^{-3}$ (which along this line of sight corresponds to a distance of 1.2 kpc Cordes & Lazio 2002), it is much closer to us than other objects of this kind.

Due to the high dispersion measures of the GPS pulsars that were presented by Kijak et al. 2011a and Kijak et al. 2011b, it has been suspected that high DM may have an important role to play in producing the GPS feature in radio pulsar spectra. However, with the recent GPS identifications reported here, it looks more likely that the effect may be related more to the environmental conditions in the close vicinity of these objects, rather than to the value of the DM. If that is the case, then the apparent observational trend for the GPS pulsars to prefer higher DM values may be a pure selection effect. As the GPS phenomenon is rather a rare occurrence it is obvious the chance for finding such objects increases with the size of the volume searched. This however does not exclude the possibility of finding such objects at relatively low distances.

The case of PSR B1259−63 shows that the GPS feature observed in the spectrum can be caused by the absorption effects in the near vicinity of the pulsar Kijak et al. 2011a, 2013. Our results for PSR J1740+1000 definitely support that idea, as it is another object with a peculiar environment, which makes it very similar to other GPS pulsars and magnetars.

An alternative mechanism, the flux dilution (which is caused by anomalous scattering) may also lead to a decrease of energy at lower frequencies, hence it may change the appearance of pulsar radio spectra (J. Cordes – private communication). However, this would be somewhat difficult to explain the case of PSR J1740+1000, which is a relatively nearby source and hence likely to be less affected by strong scattering effects.

5 CONCLUSIONS

In their recent statistical study Bates et al. 2013 concluded GPS sources may possibly constitute up to 10% of the whole pulsar population, which could add up to as many as 200 objects. We believe that the currently small size of the GPS pulsar sample does not come from the fact that they are a rare phenomenon, but rather from our limited knowledge of pulsar spectra in general, especially at frequencies below 1 GHz.

The GPS phenomena in radio magnetars along with the first low DM GPS pulsar reported here lead us to revisit our criteria of selecting candidate GPS sources. In the future searches, we would focus on sources with interesting (or extreme) environment rather than those with high DM. This would make the objects with PWN/SNRs found in high-energy observations excellent GPS pulsar candidates, and vice-versa, the sources with identified GPS would be good targets for high-energy observations.

Low frequency flux density measurements, which are crucial in searching for new GPS pulsars, can be difficult (or sometimes impossible) to conduct in the traditional way due to some of the known effects of interstellar medium. Thus, we are able to determine pulsar flux densities using the standard on and off pulse energy estimates only when the scattering time is small enough. Many of the candidates for GPS pulsars have very high dispersion measures and at the lower frequencies they are not observable by means of regular pulsar observations, due to the extreme scattering which can smear their emission over the entire rotational period. This makes the observed radiation unpulsed (in extreme cases), or at least distorts the profile baseline to a degree that negates the standard means of making the flux density measurements. For these cases, the only way to determine the pulsar flux is using interferometric continuum imaging techniques (see for example Kouwenhoven et al. 2000). Thus, the interferometric imaging technique is important in these cases, providing an alternative for the typical pulsar observations and making possible verification of the gigahertz-peaked spectra, especially in the case of strong pulse scatter-broadening (Lewandowski et al. 2013).

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APPENDIX: PULSE PROFILES AND WIDTHS

In this appendix, we present pulse profiles for the observed pulsars collected during our observing projects and the width measurements of the profiles.

Figs. 6-9 show the pulse profiles, acquired with both the GMRT (at 610 MHz and 1170 MHz) and the Effelsberg telescope (at 2600 MHz, 4850 MHz and 8350 MHz). We used the profiles to calculate the flux densities presented in Tab. 1. The flux density values on the y-axes are expressed in arbitrary units.

The measurements of the pulse width are listed in Table 2.
Flux-density spectral analysis for several pulsars

Figure 7. Pulsar profiles—continued. Vertical axes present the flux density values in arbitrary units.

Figure 8. Pulsar profiles—continued. Vertical axes present the flux density values in arbitrary units.
Figure 9. Pulsar profiles - continued. Vertical axes present the flux density values in arbitrary units.

Table 2. Pulse widths for observed pulsars.

| Pulsar       | Frequency (MHz) | $W_{10}$ (deg) | $W_{50}$ (deg) |
|--------------|-----------------|----------------|----------------|
| J1705−3905   | 610             | 69.9           | 38.3           |
| J1723−3659   | 610             | 42.2           | 23.1           |
| J1739−3023   | 610             | 23.8           | 13.1           |
| J1740+1000   | 2600            | 37.3           | 20.4           |
|              | 4850            | 36.3           | 19.3           |
|              | 8350            | 33.1           | 19.0           |
| J1744−3130   | 610             | 17.5           | 9.58           |
| J1751−3323   | 610             | 30.8           | 16.9           |
| B1811+40     | 2600            | 16.9           | 8.88           |
| J1812−2102   | 2600            | 15.5           | 8.49           |
|              | 4850            | 13.1           | 7.16           |
| J1834−0731   | 2600            | 17.2           | 9.42           |
|              | 4850            | 16.6           | 9.08           |
| J1835−1020   | 610             | 15.5           | 8.52           |
| J1841−0345   | 610             | 39.3           | 21.5           |
|              | 4850            | 35.4           | 19.4           |
| J1842−0905   | 610             | 25.2           | 13.8           |
|              | 4850            | 35.4           | 19.4           |
| J1852−0635   | 610             | 93.3           | 25.7           |
|              | 1170            | 94.7           | 12.7           |
|              | 2600            | 70.4           | 37.4           |
|              | 4850            | 64.8           | 37.4           |
|              | 8350            | 59.6           | 11.5           |
| J1901+0510   | 610             | 111            | 61.0           |
| B1903+07     | 2600            | 37.4           | 20.5           |
| B1904+06     | 2600            | 49.4           | 27.1           |
| J1905+0616   | 2600            | 6.76           | 3.71           |
|              | 4850            | 6.77           | 3.72           |
| J1910+0728   | 610             | 46.1           | 25.3           |
|              | 2600            | 32.5           | 17.8           |
| B1916+14     | 2600            | 5.70           | 3.13           |