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Radio spectra of millisecond pulsars

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Abstract. Both the physics of the pulsar emission mechanism and free-free absorption in the intervening interstellar medium can be tested with the pulsar radio spectra. We have built on our previous work on describing LOFAR population of millisecond pulsars (MSPs; Kondratiev *et al.* 2016) and HBA census of slow pulsars (Bilous *et al.* 2016) and present the study of radio spectra of the MSPs with a special attention on the low-frequency turnover. Using LOFAR timing data allowed us to measure flux densities of many MSPs over time span of up to three years in the frequency range 110–188 MHz. This provided more reliable estimates of mean flux densities and spectra reducing the influence of refractive scintillation, ionosphere and other factors on a single flux measurement. Together with published data at other radio frequencies we constructed pulsars' spectra and fitted them with single or broken power-laws. We discuss the obtained spectra and their fits, paying special attention to the low-frequency turnover, and compare broadband radio spectra of MSPs to those of normal pulsars.

Keywords. pulsars: general, pulsars: individual (J0034−0534, J1640+2224, B1937+21, J2145−0750)

Pulsar radio spectra are crucial for testing radio emission theories and free-free absorption in the interstellar medium. Spectra of many pulsars start to flatten or turning over towards low frequencies, hence flux measurements < 200 MHz are very important. Recently we performed LOFAR censuses of both millisecond pulsars (MSPs; Kondratiev *et al.* 2016) and slow pulsars (Bilous *et al.* 2016), and measured flux densities in 110–188 MHz frequency range.

In this work we present MSP spectra for almost the same sample of MSPs with addition of a few more MSPs detected by LOFAR (current tally is 53 and 4 MSPs in HBA and LBA ranges, respectively). We used LOFAR timing data to expand our flux measurements of many MSPs over time span of up to three years (in total 1508 observations in HBA, and 18 in LBA). This provided us with more reliable estimates of mean flux densities and MSP spectra reducing the influence of refractive scintillation, ionosphere and other factors on a single flux measurement. Together with the published data at other radio frequencies we constructed MSP spectra and fitted them with the single or broken power-laws using the same approach as in Bilous *et al.* (2016). Few spectra presented here on Fig. 1 are preliminary and final results and conclusions will be presented in detail in the upcoming paper (Kondratiev *et al.*, in prep.).

Figure 1 shows spectra for four MSPs. Our LOFAR flux measurements for the PSR J1640+2224 hint at the possible turnover below 200 MHz. The recent work by Kuniyoshi *et al.* (2015) also predicts the turnover with the 97% probability. The MSP J2145−0750 has a clear turnover as was reported recently by a few authors as well. Contrary to Kuniyoshi *et al.* (2015) our fit does not show turnover for the PSR B1937+21 below 74 MHz as they claim. LOFAR flux measurements are largely underestimated due to the

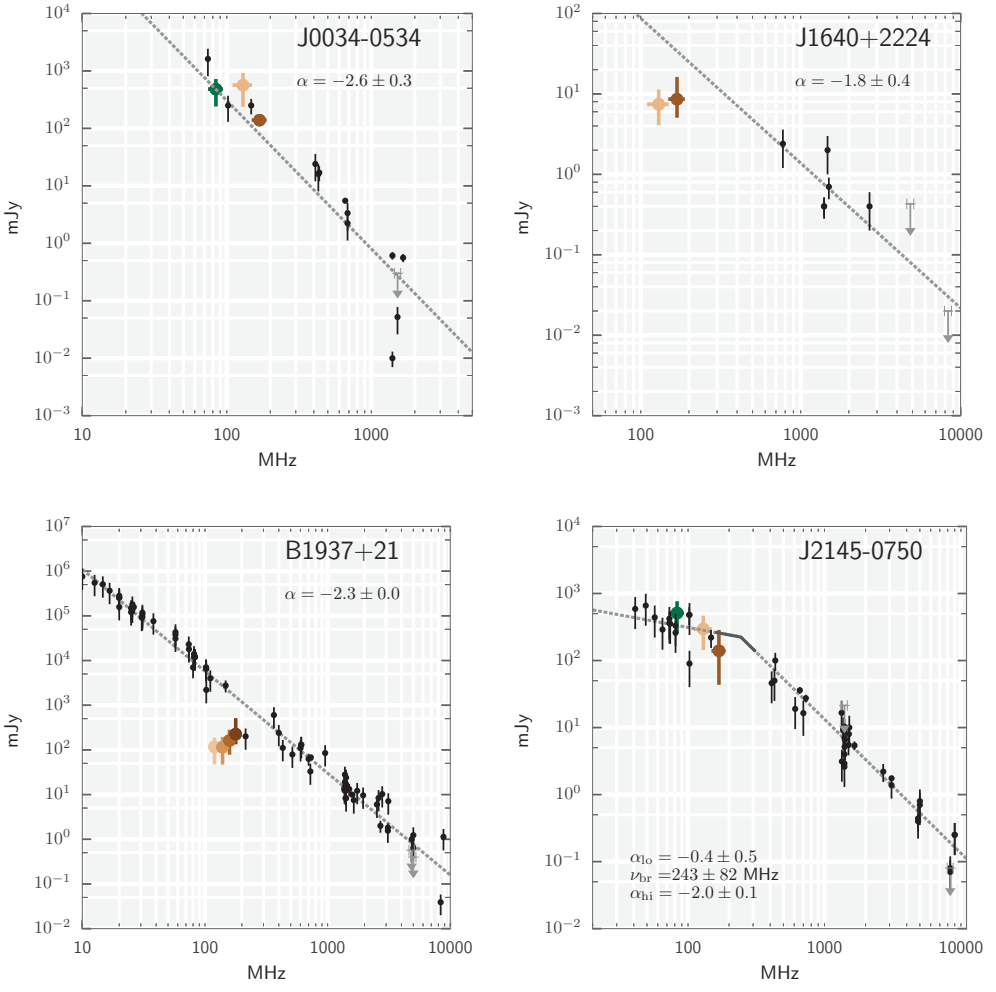

Figure 1. Examples of MSP spectra from the current work. LOFAR flux measurements are shown in shades of brown (HBA) or green (LBA), other literature values are shown in black. Fluxes are median values from all available observations (mostly timing), with uncertainties determined by the rms deviation from the median.

scattering, and a numerous flux measurements from interferometric observations down to 10 MHz do not show any sign of a turnover.

We do not see differences between the spectra of slow pulsars and MSPs both in spectral index distribution and the presence of the low-frequency turnover. In general, MSPs are weaker sources and much more affected by scattering at these low frequencies. Thus, flux density measurements from deep imaging observations are desirable. We also do not find any apparent relation between spectral break frequency and spin period (for both slow pulsars and MSPs) as some emission theories suggest.

References

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