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Probing nulling in millisecond pulsars

Kaustubh Rajwade[1*†], Yashwant Gupta[1], Ujjwal Kumar[1] and
Mihir Arjunwadkar[2]
[1]*National Centre for Radio Astrophysics, Ganeshkhind, Pune, India*
[2]*Centre for Modeling and Simulation, University of Pune, Ganeshkhind, Pune, India*

Abstract. Though the phenomenon of pulse nulling has been well studied for several bright 'normal' period pulsars, nulling studies for Millisecond Pulsars (MSPs) have not been done extensively as they require high sensitivity and high time and frequency resolutions. Such studies can be useful to probe the relevance of pulse nulling in the regime of lower magnetic fields and faster spin rates that apply for MSPs. We present new results from nulling studies of a set of 5 MSPs using the Giant Metrewave Radio Telescope (GMRT). We show that the MSP PSR J0437-4715 does not null for a duration longer than shown in earlier results. For the other weaker MSPs, we employ a novel technique to obtain robust estimates of null fraction. Our results tend toward the conclusion that the MSPs studied so far do not exhibit nulling.

Keywords : Neutron stars – Milli-second Pulsars – Nulling

1. Introduction

Since it was first reported (Backer 1970), the phenomenon of pulse nulling has been studied in great detail and over 100 pulsars are now known to show this property. However, there is a lot of variation in its nature, from one pulsar to another. The degree of pulse nulling or the Null Fraction (NF), which is a measure of the fraction of time for which a pulsar nulls, varies signficantly between pulsars, ranging from 0.1 % for pulsars like PSR B1917+00 (Rankin 1986) to more than 60% for pulsars like PSR J1752-2359 (Wang et al. 2007). Also, there is a large range in the typical

Currently at Department of Physics and Astronomy, West Virginia University, Morgantown, WV 26505, USA
†email: `kmrajwade@mix.wvu.edu`

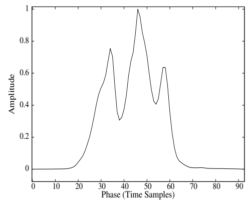
durations for which a pulsar nulls : from pulsars such as PSR B0826-34 (e.g Durdin et al. 1979; Gupta et al. 2004) and PSR B1931+24 (Kramer et al. 2006) which have a null fraction of more than 80% and have null durations of hours to days, to pulsars like PSR B0818-13 (Janssen et al. 2004) and PSR B0809+74 (Lyne and Ashworth. 1983) which null for 1 or 2 pulse periods and show a small null fraction (1.42%).

Milli-Second Pulsars (MSPs) are a sub-category of radio pulsars with lower magnetic fields (10^8-10^{10} Gauss) and smaller spin periods (less than $\sim$ 30 milli-seconds). Till now, very few single pulse studies have been reported for this relatively fainter category of pulsars; e.g. Vivekanand et al. (1998) have given a brief account of the nulling properties of PSR J0437-4715. Now, with significant improvements in telescope instrumentation and sensitivities and refined analysis techniques, it is much easier to study MSPs for nulling and other single pulse phenomena. Here we present observations, analysis and preliminary results from a sensitive study of pulse nulling for 5 milli-second pulsars, carried out using the GMRT at 325 MHz.

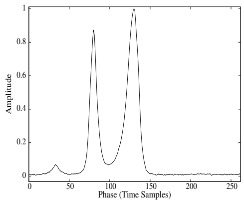
2. Observations and data analysis

The data for this study were obtained from the GMRT, as a by-product of a larger experiment designed to study the fine variations in dispersion measure (DM) over long durations (months to years), of a sample of 11 MSPs. At each epoch, all MSPs were observed simultaneously at 325 and 610 MHz using the total intensity output from the dual frequency phased array mode of the GMRT. To start with, the S/Ns were estimated for average profiles (obtained by incoherent dedispersion of the recorded time series data with the nominal pulsar DM, followed by folding at the topocentric period, using the commonly available package $PRESTO$) for all pulsars in the data set. These were then converted to effective single pulse S/N values by $S/N_{single} = \frac{S/N_{avg}}{\sqrt{N}}$ where N is the total number of pulses in the observation at a given epoch for that pulsar. Based on these, the brightest epochs for the brightest pulsars, where the S/N_{single} reached values close to 1 or higher, were selected for further scrutiny. In total, five MSPs were selected namely, PSR J0437-4715, PSR J2145-0750, PSR J1022+1001, PSR J0621+1002 and PSR J1730-2304 (Fig. 1).

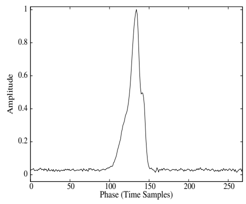
Thus we were able to confirm that the NF value for PSR J0437-4715 is zero, for a collection of a million pulses, which is significantly stronger than the earlier results (Vivekanand et al. 1998). For the other MSPs, the effectiveness of this technique depends strongly on the S/N of the data. As these were faint MSPs, lower S/N resulted in overlap of histograms (as seen in right panel of Fig. 2). In such cases, Ritching's method did not give useful results. To overcome this limitation, subsequent N pulses were added to make one single pulse to increase the S/N of the data such that the standard deviation (σ) of the new distributions reduced. For a certain value of N, the histograms became completely distinct. This method did not give the NF but did give us an upper bound on the timescales of nulling if the MSP were to null.



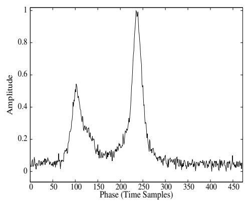
(a) PSR J0437-4715



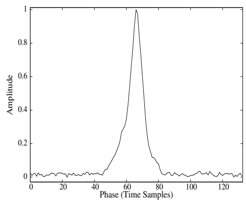
(b) PSR J2145-0750



(c) PSR J1022+1001



(d) PSR J0621+1002



(e) PSR J1730-2304

Figure 1: Average profiles of GMRT observations at 325MHz of the selected MSPs

As S/N was the main limitation in estimating the NF, we used a statistical approach (see Arjunwadkar et al., this volume) to obtain a value for the NF. The method consists of Expectation Maximisation (EM) algorithm to estimate the mixture parameters, a Bayesian Information Criterion (BIC) technique for finding the optimal number of gaussian components and a bootstrap method for obtaining confidence intervals. This technique proved to be a powerful tool to estimate null fractions of datasets with low S/N.

These pulsars were studied for their nulling properties. Firstly, a traditional Ritching's algorithm (Ritchings 1976) was used to infer the NF of these pulsars. Histograms of the ON and OFF pulse energies were made. For PSR J0437-4715, we got a complete separation of histograms (No ON bins within 3-σ of the OFF histogram) as illustrated in Fig.2.

3. Results and conclusions

We have carried out a study of nulling properties of a sample of MSPs. We confirmed that PSR J0437-4715 does not null by analyzing over a million pulses which is a much significant result compared to the previous one for this pulsar. For 4 other MSPs, due to S/N limitations, we were not able to obtain a value of the NF using traditional methods but were able to estimate an upper bound on the nulling timescales. These values range from a few hundred milli-seconds to a few seconds, which are much shorter compared to the shortest nulling timescales for normal pulsars. The gaussian mixture modelling technique (Arjunwadkar et al., this volume) helped us to get some estimates for the NF of our MSPs as shown in table 1. The number of pulses analyzed

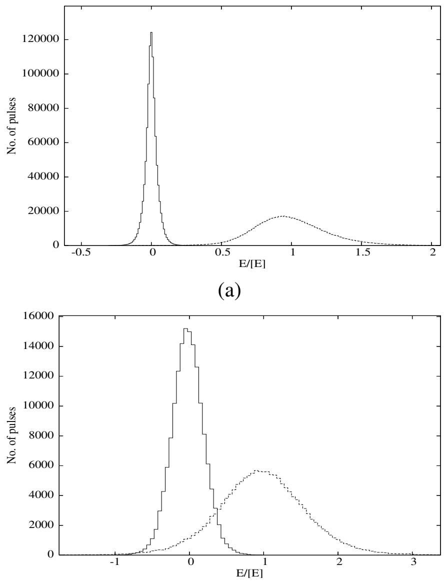


Figure 2: OFF pulse (solid) and ON pulse (dotted) energy histograms for a) PSR J0437-4715 and b) PSR J2145-0750

Table 1: Preliminary NF estimates (with confidence intervals).

J-name	Period (ms)	Epoch	No. of Pulses	Null Fraction (%)
PSR J0437-4715	5.75	All epochs combined	1000000	0.0 (Ritchings' method)
PSR J2145-0750	16.05	10 Jul 2011	50,000	0.02 (0.0,0.07)
		29 Jul 2011	50,000	0.03 (0.0,0.10)
		09 Jan 2011	10,000	0.0 (0.0, 0.30)
		21 Aug 2011	14,000	0.0 (0.0, 0.70)
PSR J1022+1001	16.45	11 Dec 2011	40,000	0.0 (0.0, 0.0)
		10 Dec 2010	70,000	6.4 (4.60, 8.30)
		14 Feb 2012	30,000	6.3 (3.30, 8.90)
		18 Dec 2011	12,000	7.9 (2.90, 12.60)
PSR J1730-2304	8.122	04 Feb 2012	1,40,000	4.8 (3.5, 6.3)
PSR J0621+1002	28	03 May 2010	40,000	In progress

is slightly lower than the value reported for each MSP as some pulses got rejected during outlier removal.

The values of the NF lie in the range of 0-10%. These are early results, and improvements of this new analysis technique that are being tried, are expected to yeild refined estimates. This seems to be an interesting result as it hints towards a possibility that MSPs do not show nulling.

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