Peculiar nulling in PSR J1738 2330

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Abstract. Several pulsars show sudden cessation of pulsed emission, which is known as nulling. The number of known nulling pulsars has not been significantly enhanced in the last decade, although the pulsar population has more than doubled following the Parkes multi-beam pulsar survey. A systematic follow-up study of the new pulsars, discovered in this survey, is being carried out by us at 325-MHz with GMRT. The peculiar nulling behaviour of PSR J1738 2330, observed as a part of this 325-MHz GMRT survey, is reported in this paper. The pulsar appears to show a periodic null-burst cycle with an upper limit to nulling fraction, of about 90 percent. The pulsed flux density declines by a factor 94 during the nulling pulses in this pulsar.

1. Introduction

In some pulsars, the pulsed radio emission often abruptly stops for several periods. This phenomenon, called \"pulse nulling\", was discovered by Backer in 1970 (Backer 1970). The fraction of pulsars with no detectable emission is known as the nulling fraction (NF) and is a measure of degree of nulling in a pulsar. Several attempts have been made to correlate pulsar NF with various pulsar parameters, but till date no strong correlation exists. Rickett (1976) concluded that NF in general increases with pulsar period, but pulsars close to the \"death line\" in P - B diagram are more likely to null. No such correlation between NF and age was reported in a given morphological class, when pulsars were grouped in different classes based on average profile morphology, implying stars that null more belong to prolate classes, which are systematically older (Rankin 1986). A detailed study on 72 nulling pulsars suggested a correlation between NF and pulsar period (Biggs 1992). In recent past, more sensitive studies of nulling to estimate pulsar NFs more accurately have been carried out on a larger sample of pulsars (Vivekanand 1995; Wang et al. 2007) with this motivation. As the pulsar population has more than doubled after the recent Parkes multi-beam pulsar survey (Manchester et al. 2001), a 325-MHz survey of probable nulling pulsars, discovered in the Parkes multi-beam pulsar survey, with Giant Metrewave Radio Telescope (GMRT; Swarup et al. 1991) is being carried out by us to estimate their NFs. This paper presents the results on the peculiar nulling behaviour of PSR J1738 2330 observed in our survey.

The GMRT observations are described in Section 2 along with the analysis procedure used. In Section 3, our results are presented and these are discussed in Section 4.
Figure 1. ON-pulse and OFF-pulse energy distributions are shown in the left panel for PSR B0809+74 and in the right panel for PSR B1112+50.

2. GMRT Observations

For the initial phase of this survey, probable nulling pulsars were selected from those discovered in the Parkes multi-beam pulsar survey. A few well known nulling pulsars, such as PSR B0809+74 and PSR B1112+50, were also included as control pulsars. Observations of 20 sources, for about 2 hours each, were carried out with GMRT in a phased array mode at 325 MHz with 16 MHz of bandwidth. The two hands of circularly polarized voltages from 15 GMRT antennas including the compact central square and 3 arm antennas were added after compensating for phase delays forming a coherent sum. The sum of detected polarized powers was then recorded on a hard disk with a sampling time of 1 ms with 256 spectral channels across the band. The minimum detectable flux with a signal-to-noise ratio (SNR) of 6 was estimated to be around 7.4 mJy. So, these observations are more sensitive to single pulses compared to some of the previous observations (Wang et al. 2007).

The data for each pulsar were de-dispersed using programs in a publicly available package SIGPROC (http://sigproc.sourceforge.net). The resultant time series was folded every period to 128 phase bins across the pulse period. A baseline, estimated using bins 25 to 120 away from the pulse, was subtracted from the data for each period. Then, two sequences were formed by averaging the energies in bins 13 to 17 (ON-pulse energy) and bins 42 to 46 (OFF-pulse energy). The two sequences were then normalized by the mean pulse energy. The energy in the scaled sequences were also binned to 100 bins to form the ON-pulse and OFF-pulse energy distributions. An excess at zero energy in the ON-pulse energy distribution indicates the fraction of nulled pulses or NF of the pulsar. This can be estimated by removing a scaled version of OFF-pulse energy distribution at zero energy from the ON-pulse distribution. The procedure is
Figure 2. The top plot shows the modulation of pulsar energy for successive 16 period subintegrations as a contour plot for bins 1 to 42 of the data dedispersed to 128 bins across the period. Bursts near subintegrations 15, 38, 70, 75, 105, 118, 145, 178 and 210 are seen in the bins corresponding to the pulse window in the average profile, shown in the lower plot, interspersed with nulls.

similar to that used for detecting pulse nulling in single pulse sequences (See Ricketings 1976; Vivekanand 1995).

The procedure was first applied to data on two well known nulling pulsars, PSR B0809+74 and PSR B1112+50. The ON-pulse and OFF-pulse energy distributions for PSR B0809+74 are shown in the left panel of Figure 1. This prominently nulling pulsar has a clear bimodal ON-pulse energy distribution, with two peaks - one around the mean pulse energy and the other around zero pulse energy. The zero energy excess represents the nulled pulses and their ratio to total number of pulses gives an estimate of its NF. This was found to be 1 percent, consistent with previous studies (Lyne & Ashworth 1983). In contrast, PSR B1112+50 is known to exhibit a large number of nulled pulses and this is evident from its ON-pulse and OFF-pulse energy distributions shown in the right panel of Figure 1. These distributions provide an estimate for this pulsar's NF to be 61 percent, comparable to previously known results (Ricketings 1976).

3. Nulling in PSR J1738 2330

PSR J1738 2330 was discovered in the Parkes multi-beam pulsar survey (Manchester et al. 2001; Lorimer et al. 2006). It has a period of about 1.9 s and a moderate DM (99.3 cm$^{-3}$ pc). It was observed on November 22, 2008 for about two hours with GMRT. The dedispersed data were folded every 16 periods to 128 bins and these are shown in Figure 1 along with its average profile. The pulsar seems to have periodic bursts, with an average duration of about 50 peri-
odds, interspersed with nulls of about 510 periods. Work is currently in progress to check this periodic behaviour using Fourier analysis. Recently, evidence for such periodic nulling has been reported in PSR B1133+16 (Herndal & Rankin 2007) and PSR J1752+2359 (Lewandowski et al. 2004). If the periodic feature is confirmed, PSR J1738 2330 joins this class of pulsars.

It is also evident from Figure 3 that the pulsar has a high NF. The null periods were visually identified from Figure 2. Averaged profile of nulled pulses and burst pulses (i.e., periods with detectable emission in the pulse window), culled from this single pulse analysis, were formed and are shown in Figure 3. It is clear from the average profile of all nulled pulses that there is no detectable weak emission during the pulse window. The average $\nu$ density in the pulsed emission during burst pulses is 94 times higher than that during nulled pulses, similar to results on other pulsars where this has been studied (Lyne & Ashworth 1983; Vivekanand & Joshi 1997).

The ON-pulse and OFF-pulse energy distributions for this pulsar were obtained in a manner similar to PSR B0809+74 and B1112+50 and these are shown in Figure 3. These distributions are similar to PSR B1112+50, confirming a high NF for this pulsar. Our preliminary estimate for the upper limit to NF from this analysis is about 90 percent.

4. Discussions and future work

PSR J1738 2330 seems to show a periodic null-burst cycle. An upper limit to its NF of about 90 percent was obtained for the first time. The pulsed $\nu$ density declines by a factor of 94 during the nulled pulses in this pulsar.

Nulling is a poorly understood phenomenon. It could be due to a cessation of pair production in the polar gap (Ruderman & Sutherland 1975). In this framework, nulling behaviour of PSR J1738 2330 suggests a periodic instability.
in the pair cascade in the polar gap. Another interesting possibility has been recently suggested by Her ndal & Rankin (2007), where a periodicity in nulling could be caused by a partially ignited sub-beam carousel. If this is indeed the case, a large number of sub-beams are not ignited in any carousel model proposed for this pulsar. Alternatively, the nulled pulses could be caused due to refraction effects or precession of the star. However, multi-frequency observations and polarization study of this pulsar is required to test these models and such studies are planned in future with GMRT.

Acknowledgments. The Giant Meterwave Radio Telescope is a part of project by National Center for Radio Astrophysics which is funded by Tata Institute of Fundamental Research and Department of Atomic Energy.

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