

# Tracking dispersion measure variations of timing array pulsars with the GMRT

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**Abstract.** We present the results from nearly three years of monitoring of the variations in dispersion measure (DM) along the line-of-sight to 11 millisecond pulsars using the Giant Metrewave Radio Telescope (GMRT). These results demonstrate accuracies of single epoch DM estimates of the order of  $5 \times 10^{-4} \text{ cm}^{-3} \text{ pc}$ . A preliminary comparison with the Parkes Pulsar Timing Array (PPTA) data shows that the measured DM fluctuations are comparable. We show effects of DM variations due to the solar wind and solar corona and compare with the existing models.

**Keywords.** (stars:) pulsars: general, ISM: general, Sun: corona

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## 1. Introduction

Dispersion measure quantifies the integrated dispersive effect of the plasma between the pulsar and the observing telescope, on the propagating broadband pulsar signal. In general, it varies with time due to reasons such as the transverse motion of pulsar sampling different lines of sight (LOS) through inhomogeneous and turbulent interstellar medium (ISM), solar wind and solar corona, plasma density changes in the binary orbit and drifting wisps of ionized gas in supernova shell. For Pulsar Timing Arrays (PTAs), which aim for a final accuracy of 100 ns or better at L band, DM variations as small as  $\sim 5 \times 10^{-5} \text{ cm}^{-3} \text{ pc}$  need to be corrected for. Meanwhile, the timing accuracies currently achieved for most of the PPTA pulsars are still of the order of a  $\mu\text{s}$  and above (Manchester 2011) and therefore DM corrections could improve these. As indicated from the observations by Backer *et al.* (1993), Hobbs *et al.* (2004), later from analytical derivation, for a turbulent ISM,  $|d(DM)/dt| \approx 0.0002 \sqrt{DM} \text{ cm}^{-3} \text{ pc yr}^{-1}$ , which implies significant change over a period of a few days to a week for a typical DM of a few tens of  $\text{cm}^{-3} \text{ pc}$ . The GMRT, using its low frequency capability, can provide more accurate DM measurements by taking advantage of the inverse-square law dependency of the delay on the observing frequency, as has been demonstrated by Ahuja *et al.* (2005), who had achieved an accuracy of up to  $5 \times 10^{-3} \text{ cm}^{-3} \text{ pc}$  for long period pulsars.

## 2. Observations and analysis

A program was initiated at the GMRT, in Nov 2009, to carry out roughly bi-weekly simultaneous dual-frequency observations at 325 and 610 MHz for 11 millisecond pulsars (MSPs), primarily to track the DM variations accurately and study their effects on

**Table 1.** Summary of the DM measurements for nine of the MSPs. The catalogue period is in ms,  $DM_{cat}$  and  $\langle DM \rangle$  are in  $\text{cm}^{-3} \text{pc}$ .  $rms_{DM}$  and  $\langle error \rangle$  are in  $10^{-4} \text{cm}^{-3} \text{pc}$ . The last four columns give the mean of DM, rms of DM, the mean absolute error of DM over all the epochs and the equivalent TOA error at L band (corresponding to the rms) in  $\mu\text{s}$ .

PSR	$P_{cat}$	$DM_{cat}$	$\langle DM \rangle$	$rms_{DM}$	$\langle error \rangle$	$\Delta TOA_l$
J2145-0750	16.0524	8.9977	9.0066	3.10	0.90	0.65
J1744-1134	4.07454	3.1390	3.1396	2.30	1.07	0.53
J1730-2304	8.12279	9.6170	9.6275	5.00	1.13	1.06
J1713+0747	4.57013	15.993	15.993	5.20	1.17	1.09
J1909-3744	2.94710	10.393	10.394	2.60	1.30	0.55
J1643-1224	4.62164	62.412	62.424	14.0	1.57	3.00
J0437-4715	5.75745	2.6447	2.6490	4.28	—	0.90
J1022+1001	16.4529	10.252	10.239	5.70	2.10	1.20
J0613-0200	3.06184	38.779	38.795	5.00	2.50	1.05

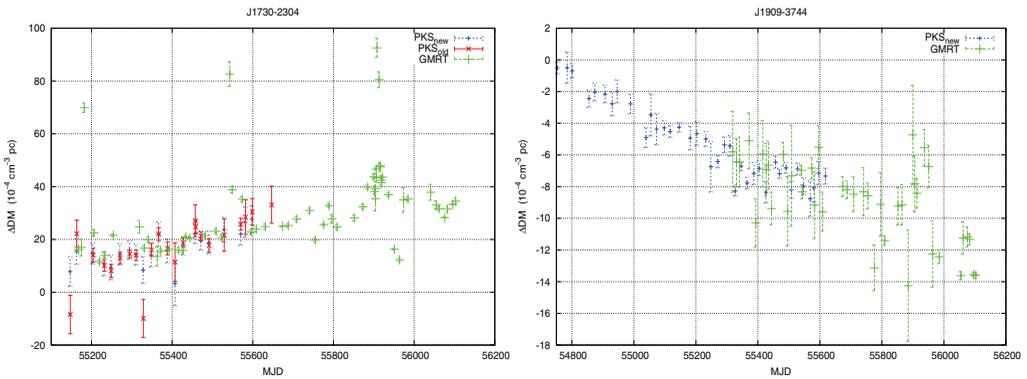
timing accuracy as well as for studying DM variations due to the solar corona and the solar wind. The observations used the GMRT software back-end (Roy *et al.* 2010) in the simultaneous dual-frequency phased array mode, giving total intensity time-series from 512 channels over 32 MHz of bandwidth at each frequency. In this mode the data streams from the two frequencies are locked to each other without any instrumental delay, allowing accurate DM estimates without requiring absolute timing measurements. The data were incoherently dedispersed and folded using a Doppler corrected period. The delay was computed using the peak of the cross-correlation between the profiles at the two frequencies. The DM was computed as  $DM = (\Delta t/K) \times 1/(\nu_1^{-2} - \nu_2^{-2}) \text{cm}^{-3} \text{pc}$ , where  $K$ , called dispersion constant, is equal to  $4.1488080 (\pm 30) \times 10^3 \text{MHz}^2 \text{cm}^3 \text{pc}^{-1} \text{s}$  and  $\Delta t$  is the total delay, as seen at the solar system barycenter, between the signals at the two frequencies  $\nu_1$  and  $\nu_2$ . Errors were estimated by propagating the off-pulse noise of the two profiles to estimate the rms error of the measured delay.

### 3. Results, conclusions & future goals

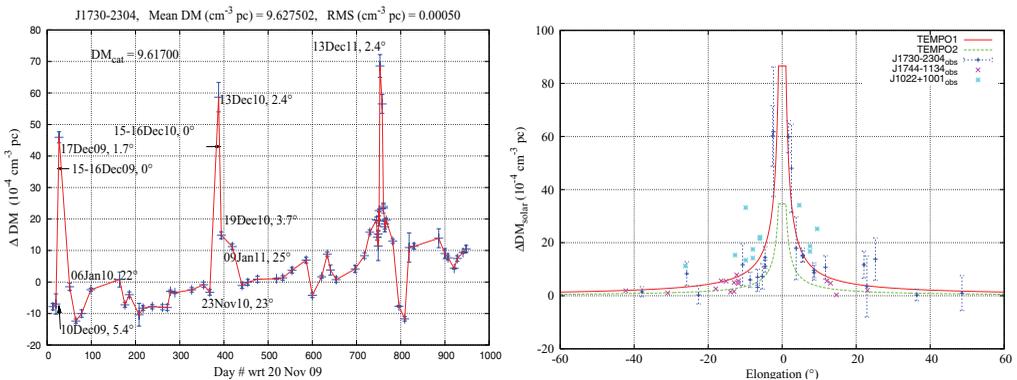
Significant DM variations are detected (Table 1) for all the pulsars, with accuracies of  $5 \times 10^{-4} \text{cm}^{-3} \text{pc}$  achieved for most of them. For most pulsars, the rms DM variation is comparable to that seen in the PPTA data and also to the reported value from You *et al.* (2007a). The DM variations seem to show significant correlation with the Parkes data for four MSPs (Figure 1).

The effects of solar corona are clearly detected in the case of low ecliptic latitude pulsars (Figure 2), even though many of our data points, up to  $25^\circ$  from the Sun, seem to disagree with the predictions based on the two-state solar wind model of You *et al.* (2007b), indicating possibilities for further refinements of the model including effects of special events like coronal mass ejections (CMEs).

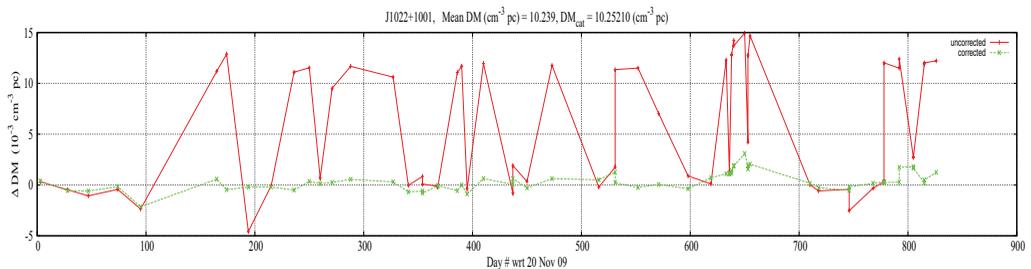
Two-state jumps in PSR J1022+1001's DM variation (Figure 3) are found to be due to small, but quite well defined profile shape changes, akin to the well known mode changing phenomenon seen in some pulsars. Further comparisons and studies (e.g. ISM structure function analysis) will be possible in future as our data extend to longer time spans.



**Figure 1.** Comparison of DM time-series from the GMRT and Parkes, for PSRs J1909-3744 & J1730-2304.



**Figure 2.** *Left:* DM variations for PSR J1730-2304, showing large increases around the times of closest approach to the Sun. *Right:* Consolidated DM variation as a function of elongation from the Sun from data for all pulsars and comparison with TEMPO1 (red) & TEMPO2 (green).



**Figure 3.** Two-state DM fluctuation for PSR J1022+1001.

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