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Pulsar observations at 150 MHz with Mauritius Radio Telescope – Preliminary results

N. H. Issur

University of Mauritius, Reduit, Mauritius
Raman Research Institute, Banaglore 560 080, India

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Abstract. The Mauritius Radio Telescope (MRT) has been used to observe some Southern Hemisphere pulsars at 151.6 MHz. A tracking system allowing observation of a source for 8 x sec (δ) minutes of time and a Fast Data Acquisition System were added to MRT in July 1996, for this purpose. With this new system, it is now possible to observe pulsars with an average flux density of about 100 mJy (with a signal-to-noise ratio of ≈ 25).

In this paper we describe the observations made with the new set-up and report our preliminary results on 3 pulsars, including the bright millisecond pulsar J0437-4715.

Key words : pulsars – millisecond pulsar

1. Introduction

Observational data obtained over a wide range of frequencies have been extremely useful to understand the behaviour of pulsars. While the first pulsar discovery was made with a telescope operating at a low frequency (81.6 MHz), most systematic pulsar surveys and studies have been made with telescopes operating at around 400 MHz or 1400 MHz. Southern pulsars, in particular, have not been well studied at longer wavelengths, an exception being the studies made by Alurkar et al. (1986) and Slee et al. (1986) at 80 and 160 MHz with the Culgoora circular array, which unfortunately is no longer operational.

We have initiated pulsar observations with the Mauritius Radio Telescope (MRT) to extend such studies of Southern pulsars at its observing frequency, with the aim of making a comparative study with results obtained at other frequencies about pulse shapes, flux densities, variability, scattering and if possible microstructure.

2. Observations

The Mauritius Radio Telescope (Golap et al. 1995) is a T-shaped array of helices, operating at 151.6 MHz. For the pulsar observations we have carried out, only the EW array is used. The new setup for pulsar observations, which became operational in July 1996 (Fig.1), includes a tracking system and a Fast Data Acquisition System (FDAS). A Pulsar Processor (PP) (McConnell et al. 1996) was also temporarily available. Accurate time is obtained from a Global Positioning System linked to the observatory clock.

The design of the tracking system for MRT is adopted from that used by Deshpande et al. (1989) for the Gauribidanur radio telescope. The two-degree tracking is achieved here by phasing the EW array within the primary beam of an EW group which has a Half-Power Beam-Width (HPBW) of $2^\circ \times 60^\circ$ with a maximum at a declination $\delta = -40.5^\circ$. The pointing accuracy is within the 90% gain points of the combined EW beam which has a HPBW of about $4'$ in the EW direction. In the FDAS used at MRT (Deshpande et al. 1997) signal voltages, covering a total prediction bandwidth of 1 MHz, are sampled at Nyquist rate, with 2-bit 4-level quantization. The data is recorded on the hard-disk of a 486 PC.

The sensitivity $S_{av,\,min}$ for plusar signals (i.e. the minimum detectable average flux density), corresponding to optimum smoothing (i.e. of the order of the observed pulse width W) and folding the data obtained in a time τ over the pulse period P, is given by (Vivekanand et al. 1982) :

$$S_{av,\,min} = \frac{\beta\,(2k\,T_{sys}/A_e)}{\sqrt{\Delta f_T \tau}} \times \sqrt{W/(P-W)} \qquad (1)$$

where β is a factor that takes into account the desired signal-to-noise ratio (S/N) and various processing losses, k is the Boltzmann constant, T_{sys} is the system temperature, A_e is the effective collecting area and Δf_T is the total bandwidth used. For the EW array $A_e \approx 4096\ \mathrm{m}^2$ (at $\delta = -40.5^\circ$) and if we considered a pulsar with a 5% observed duty cycle, then with $\tau = 8$ *mins*, $T_{sys} = 600$ K and $\beta = 25$, $S_{av,\,min}$ turns out to be ≈ 100 mJy. This corresponds to average flux density of about 25 mJy at 400 MHz, assuming a spectral index of -1.5.

About fifty pulsars were selected for the observation based on the above criteria. Observations were carried out from July to December 1996, mainly during week-ends when the interference level was low. Sources were tracked between the Half-Power points of an EW group beam, i.e for $8 \times \sec(\delta)$ minutes of time. Observations were recorded on both the FDAS and the PP, which proved useful as we could get an immediate idea of the data quality from the PP online display.

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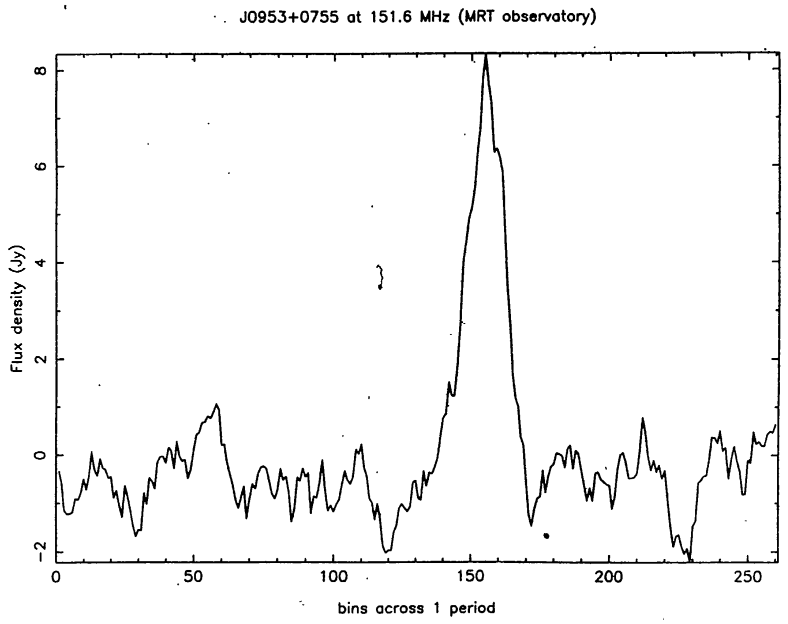


Fig. 3

Figure 3. This pulse profile of J0953+0755 in a bright phase is obtained from 8 minutes of incoherently dedispersed FDAS data using 64 frequency channels. The profile shown on 260 bins is smoothed by a 10-bin window and has a S/N of about 20. The flux-density scale may have large error as our helix beam is poorly known at this declination. The raw data had a lot of interference and we have tried to remove these as far as possible here.

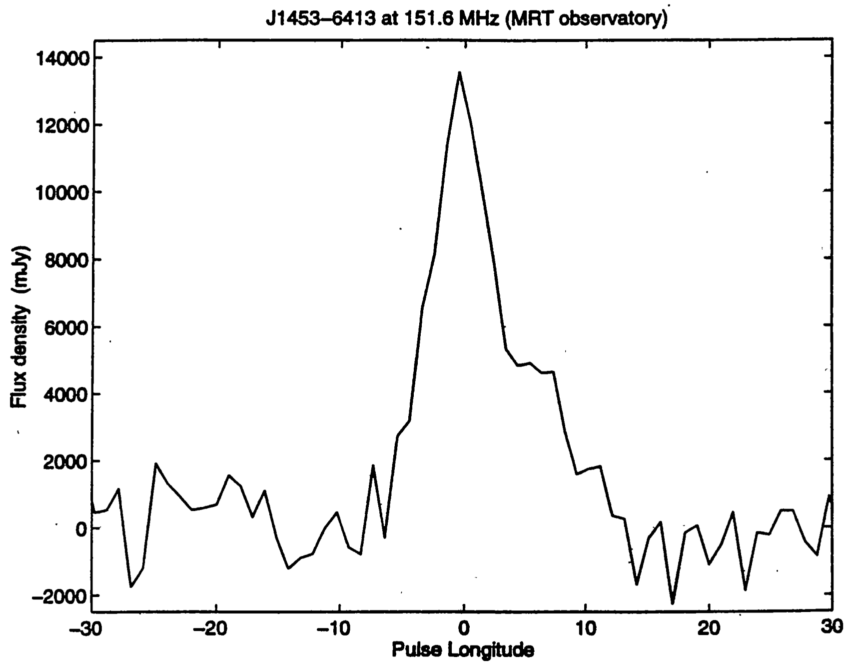


Figure 4. A typical pulse profile of J1453-6413 from 8 minutes of FDAS data after incoherent dedispersion over 256 frequency channels (512 is actually the optimum number for the DM of this pulsar) is shown. The profile was produced with 369 bins across the pulsar period without any further smoothing.

it difficult otherwise at frequencies below about 200 MHz). It has been observed over a wide range of frequencies ranging from 2360 MHz to a frequency as low as 76 MHz (McConnell et al. 1996) and has been found to have interesting properties regarding its pulse shape and microstructure (Ables et al. 1997).

We have monitored this pulsar quite regularly at MRT and found its flux to be highly variable. Since we could observe the source for only 8 to 12 minutes per day, this apparent 'daily' variation in intensity may well be due to variations over shorter time-scales that are attributable to diffractive scintillations with chance coincidences at the time of our observation.

One of our best detections of J0437-4715 is from the data collected on 27 July 96. We observe a very broad pulse profile with a width at outer half-power points of about 125^0 in longitude (fig.2). Three components are clearly seen along with a possible suggestion of a fourth component. The peak at zero longitude most probably corresponds to the highest one seen in the high frequency profiles, as deduced from examination of the 'aligned' 1520 MHz profile shown in Fig. 2. The high peak at longitude $\approx -60^o$ and the 'shoulder' at longitude $\approx 40^o$ in our 150 MHz profile are comparable in strength to the main peak. The corresponding components are relatively weak at higher frequencies compared to the main one, indicating steeper spectral indices for the outer components. This is contrary to the general trend for pulsars, but confirms what has been noted earlier for J0437-4715 by Johnston et al. (1993) and McConnell et al. (1996).

The average flux density we obtain on our 27 July 96 data is of the order of 620 mJy with a peak of more than 2 Jy, assuming an effective sky background temperature of about 220K. This is not incompatible with the 327 MHz values of Ables et al. (1997), where a typical value of 1 Jy is obtained for the peak flux density.

PSR J0953+0755 (P = 0.253s, DM = 2.97 *pc.cm*$^{-3}$)

We have detected this northern hemisphere pulsar even though in this direction our antenna gain is reduced to only about 9% of its peak gain. It was seen to be very bright for a few days in September 96 (Fig. 3) with the peak flux-density rising to about 8 Jy. The flux–density scale we use assumes an effective background temperature of 380 K and may be in large error as the helix beam is poorly known at this declination. The width of the pulse is large, consistent with the Pulsar Catalog values for other frequencies (Taylor et al. 1993). The interpulse, known to occur near 150^o of longitude with about 2% of the main pulse intensity, is expected to be too weak to be detected with the sensitivity of MRT in this direction.

We made several observations of this pulsar, but on most days it could not be detected even when observing conditions were good (incidentally, the brightening was observed when interference level was high). This suggests a variability by a factor of at least 20 in the flux density, either intrinsic or arising out of the scintillation effects. This pulsar has in fact been reported to show flux density variations up to 80 times its normal value (Deshpande et al. 1995).

3. Data analysis

We have used an incoherent dedispersion scheme to process our FDAS data. Successive stretches of data with 2N samples each are Fourier transformed to get the equivalent outputs of N frequency channels. After detection, these outputs are added together after suitable time-shifting to take into account delay due to dispersion as given by the equation below (Huguenin 1976) :

$$t_{delay}\ [secs] = 8.29 \times 10^3\ DM\ [pc.cm.^{-3}]\ (\Delta f/f_0^3) \qquad (2)$$

where the channel bandwidth Δf and centre frequency f_0 are in MHz.

The best time resolution is achieved when the dispersion-smearing inside each channel (equal to t_{delay}) becomes equal to 1/Δf (Deshpande et al. 1989). For convenience, N is chosen as a power of 2 nearest to the optimum one. For DM values ranging from the lowest one known (2.65 $pc.cm^{-3}$ for J0437-4715) to less than 400 $pc.cm^{-3}$, it is sufficient to have N between 64 and 1024 at our observing frequency.

In practice the processing involves several steps. The 2-bit 4-level samples are decoded to yield the corresponding voltages. These are Fourier analysed and spectrometer data with the chosen number of spectral channels are produced. Channels affected by interference are noted for rejection in the dedispersion. We also view the data as a time-sequence and note narrow spikes of emission in time for rejection. After dedispersion, the time-series has a sampling interval proportional to N ($64\mu secs$ for N = 64).This can be viewed for single pulses or resampled and folded over the apparent pulsar period to obtain an average pulsar profile, with a chosen number of bins across the period. Sub-folds can also be produced and used to check the data quality and to search for any drift in the pulse arrival.

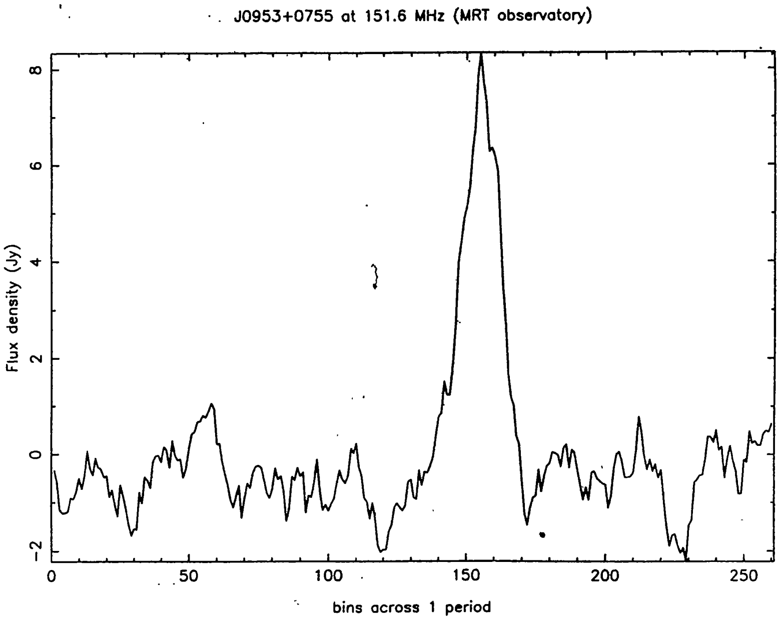
The flux density scale calibration is based on an estimate of the system temperature, which includes a contribution of 300 K from the receiver noise. The effective sky background temperature at 151.6 MHz is estimated by extrapolating the 408 MHz values of Haslam et al. (1982) using a special index of -2.5 and taking into account the response of our tracking beam towards the source of interest. The collecting area is assumed to be equal to its theoretical value and may be in error by about 20%.

4. Preliminary results

From the data processed so far, we have detected 9 pulsars. These have periods from the millisecond range to about 1 second and DM values up to 71 $pc.cm^{-3}$. We discuss here our results on three of these pulsars where we have good detections.

(PSR J0437-4715 (P=0.00575s, DM=2.65pc.cm^{-3}))

This millisecond pulsar was discovered in 1993 during a sensitive survey of the southern sky for millisecond pulsars (Johnston et al. 1993). It is in a 5.74-day circular orbit with a low-mass white dwarf companion (Bell et al. 1995) and is the closest and brightest millisecond pulsar which can be observed at low frequencies (dispersion smearing and scatter broadening makes



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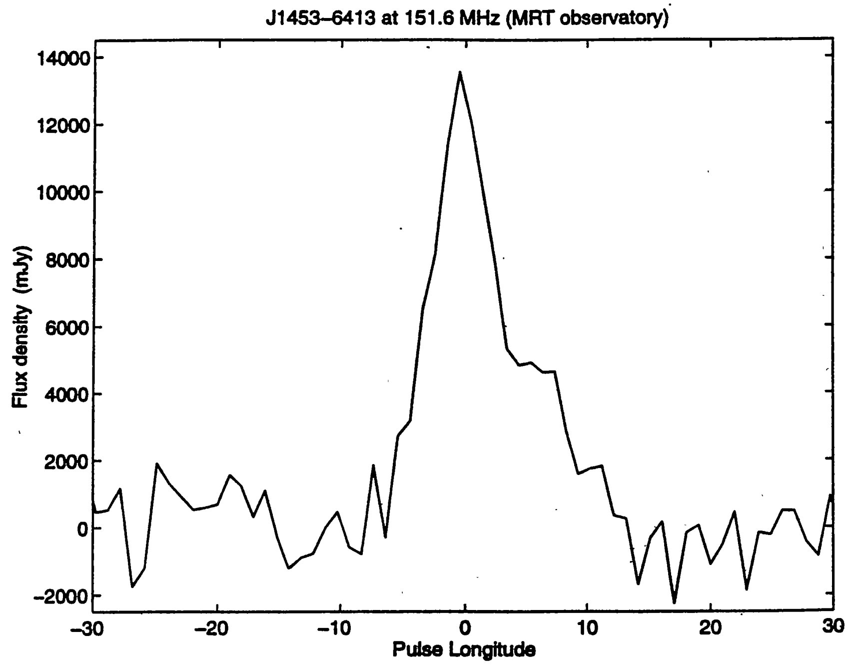

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