Wide profile drifting pulsars: an elegant way to probe pulsar magnetospheres

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Abstract. We present the results from a study of wide profile pulsars using high sensitivity multifrequency observations with the GMRT. Since the line of sight samples a large region of the polar cap in case of the wide profile pulsars, presence of simultaneous multiple drift regions is quite probable (as seen in PSR B0826–34 and PSR B0818–41). We solve the aliasing problem of PSR B0818–41 using the observed phase relationship of the drift regions, and determine its pattern rotation period \(P_4\) to be \(\sim 10\) s, which makes it the fastest known carousel. We find that, for all the pulsars showing drifting in multiple rings of emission, the drift pattern from the rings are phase locked. This can constraint the theoretical models of pulsar emission as it favors a pan magnetospheric radiation mechanism.

1. Introduction

Most pulsars have a narrow duty cycle of emission (5-10 % of pulsar period). This is generally consistent with the expectations of the angular width of the polar cap, given typical viewing geometries. However, there are a small but significant number of pulsars with unusually wide profiles, for which the emission is seen over a wide range of longitudes (\(\geq 90\) degrees). This is expected from pulsars which are highly aligned, i.e. the magnetic dipole axis is almost parallel to the spin axis, and emission is seen from one magnetic pole of the pulsar. In such a case, the line of sight (LOS) is very close to both the rotation and the magnetic axes, and consequently, we sample a large region of the polar cap. This has the exciting potential for a detailed study of the distribution and behavior of emission regions located in annular rings around the magnetic axis. The study of pulsars showing systematic subpulse drift patterns provides important clues for understanding the unsolved problems of pulsar emission mechanism. Constraints from such observations can have far reaching implications for the theoretical models, as exemplified by some recent results (e.g. Deshpande & Rankin (1999) and Gupta et al. (2004)). In this context, wide profile drifting pulsars can provide extra insights because of the presence of multiple drift bands. In this work, we have mainly concentrated on studies of two such pulsars, PSR B0818–41 and PSR B0826–34.

B0818–41 is a relatively less studied wide profile pulsar with emission occurring for more than 180 deg of pulse longitude. It has a period of 0.545 s and is relatively old, with a characteristic age of \(4.57 \times 10^8\) years. The inferred dipolar magnetic field of this pulsar is \(1.03 \times 10^{11}\) G, which is a typical value for
slow pulsars. From a study of its average polarization behaviour at 660 and 1440 MHz, Qiao et al. (1995) predict that the pulsar must have a small inclination angle between the magnetic and rotation axes.

PSR B0826−34 is a pulsar with one of the widest known profiles. Earlier studies of this pulsar (Durdin et al. (1979), Biggs et al. (1985), Gupta et al. (2004)) have revealed some unique properties: strong evolution of the average profile with frequency, apparent nulling for 70% of time, and a remarkable subpulse drift property – multiple curved drift bands with frequent changes and sign reversals of drift rate.

2. Observations and preliminary analysis

The GMRT is a aperture synthesis telescope consisting of 30 antennas, each of 45 m diameter, spread over a region of 25 km diameter. The GMRT can also be used in the tied array mode by adding the signals from the individual dishes, either coherently or incoherently (Gupta et al 2000). We performed polarimetric observations of PSR B0818−41 and PSR B0826−34 at multiple frequency bands (157, 244, 325, 610 and 1060 MHz), at different epochs, using the phased array mode of the GMRT. Some of the observations were simultaneous at 303 and 610 MHz, and were carried out using the “band masking” technique, details of which are described in Bhattacharyya et al. (2008). Data were recorded at a sampling rate of 0.512 ms. During the off-line analysis the raw data were further integrated to achieve the final resolution of 2.048 ms.

Average pulse profiles at different observing frequencies were obtained by dedispersion with a DM of 113.4 pc/cm³ for PSR B0818−41, and 52.2 pc/cm³ for PSR B0826−34. The main source of corruption of the data was found to be power line interference (50 Hz and its harmonics). The dedispersed data were put through a filtering routine which detected most (but probably not all) of the power line interferences and replaced them by appropriate random noise. The dedispersed, interference free data stretch were then synchronously folded with the topocentric pulsar period. Single pulse data streams were also generated from the dedispersed data, for both total intensity and full Stokes parameters.

3. Results

PSR B0818−41: We confirm the remarkable subpulse drift pattern for this pulsar, first reported by us in Bhattacharyya et al. (2007). At 325 MHz, we can clearly see simultaneous occurrence of three drift regions with two different drift rates (Fig 1a): an inner region with steeper apparent drift rate, flanked on each side by a region of slower apparent drift rate. Similar subpulse drifting is observed in both the inner and outer regions at 610 MHz, though the drift bands are weaker (Fig 1b). The closely spaced drift bands always maintain a constant phase relationship: the subpulse emission from the inner drift region is in phase with that from the outer drift region on the right hand side, and at the same time the emission in the inner drift region is out of phase with the outer drift region situated on the left hand side.

A new technique is introduced by us for resolving aliasing, utilising the constant offset (∼ 9P₁) that is seen between the peak emission from the leading and
trailing outer regions (Bhattacharyya et al. 2008b). The basic idea here is that combination of the angular separation between the sparks in the outer ring, the time of traverse of the LOS from the leading to the trailing outer component, and the drift rate of the sparks in the outer ring should all be matched so as to produce that this offset. From the results of our analysis, we find that the unaliased drift is too slow to allow this to happen. We propose that the drift rate is most likely first order aliased, and the corresponding pattern rotation period, $P_4$, is 10 s. This implies that PSR B0818–41 has the fastest known carousel.

**PSR B0826–34:** At any given time, the simultaneous multiple subpulses present in the main pulse window follow the same drift rate and sign, at both the frequencies (Figs 2a & 2b). The pulse regions showing different drift rates of opposite signs are always connected by a region showing smooth transition of drift rate. The gray scale plot of the single pulses from the higher sensitivity single frequency observations at 610 and 1060 MHz show coherent drifting in the main pulse (MP) and inter pulse (IP) regions, with approximately 6 drift bands in the MP and 4 drift bands in the IP, as seen in Figs 2a & 2b (see also Bhattacharyya et al. 2008a). The drifts in MP and IP regions are always locked in phase.

4. Interpretations

**PSR B0818–41:** The unique drift pattern of this pulsar can be naturally explained as being created by the intersection of our LOS with two conal rings on the polar cap of a fairly aligned rotator. Based on the frequency evolution of the average profile, observed PA swing and results from subpulse drifting,
we converged on two possible choices of emission geometry: **G-1** \((\alpha = 11 \text{ deg} \text{ and } \beta = -5.4 \text{ deg})\) and **G-2** \((\alpha = 175.4 \text{ deg} \text{ and } \beta = -6.9 \text{ deg})\). Whereas the features of the observed drift pattern are better reproduced by simulations of the radiation pattern using **G-1**, the geometry **G-2** appears to produce a better fit to the position angle swing of the linear polarisation.

Though the regular drift patterns observed in Fig. 1 are quite common for this pulsar, we sometimes observe changes of the drift rates, which are almost always associated with the occurrence of nulls. However, the phase locked relation is maintained across the regions of irregular drifting or nulling. This phase locked relation implies a common electrodynamic control between the rings.

**PSR B0826−34**: The radiation pattern is interpreted to be created by the intersection of our LOS with two conal rings on the polar cap of a fairly aligned rotator (Gupta et al. (2004), Esamdin et al. (2005), Bhattacharyya et al. 2008a). The observed wide pulse profile and its remarkable evolution with frequency can be explained by the intersection of the LOS with two concentric rings of emission. At lower frequencies (e.g. 157 or 325 MHz), the LOS mostly sees the inner ring and that gives rise to the MP emission. The LOS is sufficiently further than the outer ring of emission at these frequencies and almost no inter pulse emission is observed. As the frequency increases (e.g. 610 or 1060 MHz), one starts seeing emission coming from the second outer ring as well. As a consequence, the IP emission becomes dominant with increasing frequency.

For PSR B0826−34 we observe frequent nulling and changes of drift rates which are simultaneous for both the inner and outer rings. Esamdin et al. (2005) applied the method of phase tracking to the single pulse data and detected in total 13 drift bands in the pulse window. Phase locked relation between the inner and outer rings is evident from their results (Fig. 6 of Esamdin et al. (2005)). In addition, we observe significant correlation between total energy of the main pulse and the inter pulse. With increasing pulse lag this correlation follows similar trend as the auto correlation of total energy of the main pulse or the inter pulse. This indicate that the conditions of the magnetosphere are similar for inner and outer rings of emission (Bhattacharyya et al. 2008b).

5. Conclusions

We have investigated multiple drift regions in the pulsars B0818−41 and B0826−34 and found that the emission from inner and outer rings are locked in phase. Such a phase locked relation between the inner and outer rings could well be a common property for all wide profile pulsars, and maybe for all pulsars in general. The phase locked relation implies that inner and outer rings drift with the same angular rate, the emissions from the two rings are not independent, and conditions responsible for drifting are similar in both rings. This puts constrains on the theoretical models, favoring a pan magnetospheric radiation mechanism.

Hence our main conclusions are:

- Wide profile pulsars provide extra insights into pulsar emission processes;
• PSR B0818−41 and PSR B0826−34 are wide profile drifting pulsars with simultaneous multiple drift regions;

• Aliasing can be resolved using the phase relationship between leading and trailing outer regions; for PSR B0818−41 it indicates P4 10s, making it the fastest known carousel;

• Phase locked drift between inner and outer rings implies a common electrodynamic control over the entire polar cap.

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