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Single Pulse Polarimetric Study of Partial Cones in Pulsars

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ABSTRACT
'Partial cones' are classified as pulsars where the steepest gradient (SG) of the polarization-position angle (PPA) traverse lies towards one edge of the total intensity pulse profile. In this paper we present single pulse polarimetric observations of seven pulsars classified as having partial cone profiles observed with the Gaint Meterwave Radio Telescope (GMRT) at 325 MHz and the Arecibo Observatory (AO) at 327 and 1420 MHz. Three pulsars, B0355+54, PSR B1745–12 and B0919+06, show sudden flarings where the weaker part of the pulse profile becomes brighter. These flarings persists for a few pulses and occur for some 1% of the time. We see evidence for drifting in PSR B0740–28 and PSR B1910+20 at the edges of their profiles, signifying that the emission is likely to be centered around the magnetic axis. For all the pulsars the SG point of the PPA is inferred to be towards the trailing edge of the profile. We conclude that the emission properties of these partial cone pulsars are consistent with the relativistic beaming model of Blaskiewicz *et al* (1991) where, due to aberration and retardation effects, the SG point of the PPA traverse lags the profile center.

Key words: miscellaneous – methods: MHD — plasmas — data analysis – pulsars: general, individual (B0355+54, B0540+23, B0740–28, B0919+06, B1556–44, B1745–12, B1910+20) — radiation mechanism: nonthermal — polarization.

I. INTRODUCTION

The pulsar emission beam is thought to have a circular shape with a central core emission region surrounded by nested conal emission (Backer 1976; Rankin 1983a,b; Mitra & Deshpande 1999). The emission is highly linearly polarized with the degree of polarization being as high as 70% to 80%. For a large number of pulsars the polarization position angle (PPA) across the pulse profile is seen to execute a smooth 'S-shaped' curve, which according to the rotating-vector model (RVM) proposed by Radhakrishnan *et al* (1969) and Komesaroff (1970) is considered as evidence for emission arising from the pulsar polar cap centered around the magnetic dipole. The flat portion of the 'S-shaped' curve is usually associated with the conal emission, while the core emission is seen in the region around the inflexion or the steepest gradient (SG) point (which according to RVM is interpreted as the plane containing the magnetic dipole axis). An improved RVM model was put forward by Blaskiewicz, Cordes & Wasserman (1991, hereafter BCW) where the authors investigated the relativistic effects of aberration and retardation (hereafter A/R) on pulsar emission properties. For emission arising from a finite height r_{em} from the center of the rotating neutron star with period P, they found the expression for the PPA ψ as a function of pulse longitude φ as,

$$\psi = \psi_\circ + \tan^{-1}\left(\frac{\sin\alpha\sin(\varphi-\varphi_\circ) - K\sin\xi}{\sin\xi\cos\alpha + \sin\alpha\cos\xi\cos(\varphi-\varphi_\circ)}\right) \quad (1)$$

where $K{=}6\pi(r_{em}/cP)$.

Here $\psi_\circ$ and $\varphi_\circ$ are arbitrary position angle and longitude phase offsets. The angle $\xi = \alpha+\beta$, where α is the angle between the rotation and magnetic axis, β is the angle between the rotation axis and the observers line-of-sight and c is the velocity of light. Note that eq. (1) reduces to the RVM for r_{em} tending to zero. Fitting the RVM (or BCW model) to the PPA traverse is extensively used to find the geometrical angles α and β for pulsars. Several merits and demerits for such fitting procedure can be found in Narayan & Vivekanand (1982), von Hoensbroech & Xilouris (1997) and Everett & Weisberg (2001).

The BCW model predicts that for radio emission arising from a constant finite height, the overall PPA traverse will lag the total intensity profile. To the first order, particularly for slow moving pulsars, this shift is a simple translation of the PPA traverse towards the trailing parts of the profile, and hence one could still model the PPA with the RVM. A consequence of this effect is that the SG point of the PPA

Table 1. Parameters for partial cone pulsars observed with the GMRT and AO.

PSR Bname	**PSR** Jname	**No Pulses (Obs, Freq.)**	**Period(s)** (s)	**log10(B$_{surf}$)** Gauss	**T$_{\rm age}$** kyr
B0355+54	J0358+5413	13112 (GMRT, 325 MHz)	0.156382	11.92	562
B0540+23	J0543+2329	2440 (AO, 327 MHz)	0.245974	12.29	251
B0740–28	J0742–2822	3629 (GMRT, 325 MHz)	0.166762	12.23	158
B0919+06	J0922+0638	1000 (AO, 1425 MHz)	0.430619	12.39	501
B1556–44	J1559–4438	3618 (GMRT, 325 MHz)	0.257056	11.71	3981
B1745–12	J1748–1300	2726 (GMRT, 325 MHz)	0.394133	11.85	5128
B1910+20	J0543+2329	2440 (AO, 1425 MHz)	2.2329	12.68	3467

traverse lags the center of the total intensity profile by an amount $\Delta\varphi = 4\pi(r_{em}/cP)$, a fact which has been observerd in several pulsars (see for *e.g.*, BCW; von Hoensbroech & Xiouris 1997; Mitra & Li 2004) and has been used to estimate the radio emission heights in pulsars. Note that if r_{em} is varying across the pulse profile, then the PPA traverse will shift by different amounts, causing distortions in the PPA swing (see Mitra & Seiradakis 2003).

If r_{em} does not vary significantly with pulsar period, then for faster pulsars, the PA traverse would shift significantly such that the steeper parts of the swing will be located more towards the extreme trailing parts of the profile. In fact, in a recent average-polarization study of young pulsars (with characteristic age below 75 kyr) by Johnston & Weisberg (2006, hereafter JW06) with periods around 100 ms, the PPA swing is seen to be flat across most of the leading portion of these pulse profiles and gradually steepen towards their trailing edges. JW06 consider two possible explanations for this effect: (a) that in these pulsars only the leading half of the polar cap is active, or (b) the lagging SG points are due to the A/R effects—and they favour the latter explanation. There exists another class of pulsars with mean periods of around 300 ms called 'partial cones' where only half of the 'S-shaped' curve is seen (Lyne & Manchester 1988, LM88 hereafter). In partial cones, just like in young pulsars, the PPA traverses are flat and the steepening of the PPA is observed mostly on the trailing edges of the profiles (but also in a few cases in the leading part). LM88 considered only explanation (a) of JW06 as a possible resolution for these 'partial cones'.

Identification of 'partial cones' requires unambiguous determination of the SG point of the PPA swing with respect to the total intensity profile. It is often difficult to discern the character of the PPA traverse using only average-profile polarimetry, as did LM88 and JW06. This is often difficult due to the presence of the "orthogonal" polarization modes (hereafter OPMs), which indeed are not always orthogonal (*e.g.*. Ramachandran *et al* 2004). Departures from modal orthogonality tend to produce complex average PPA behaviours, because their relative power often varies strongly with pulse longitude, and these can in turn lead to serious misinterpretations of a pulsar's PPA traverse. Hence, polarimetry of individual pulses is necessary to distinguish the OPMs and correctly assess the geometrical bases of the PPA swings (*e.g.*, Gil & Lyne 1994).

Furthermore, we note that no such single-pulse-based investigation of the properties of 'partial cones' has yet been carried out. Our purpose in this paper, then, is to delineate the emission properties of several pulsars that were identified by LM88 as having 'partial cones' profiles, and we combine observations from both the Giant Meterwave Radio Telescope (GMRT) and the Arecibo Observatory (AO) in order to do so. In §II. we describe the observations and the analysis procedure, §III. presents the results for the individual objects, and §IV. summerizes the various results.

II. OBSERVATIONS AND DATA ANALYSIS

The GMRT observations presented in this paper are a part of a proposed program for studying single pulse polarimetric properties of pulsars using the Giant Meterwave Radio Telescope (GMRT) at 325 MHz. The GMRT (Swarup *et al* 1991) is an array of 30 antennas with altitude-azimuth mounts, each of 45-m in diameter, spread out over a 25-km region located 80 km north of Pune, India. It is primarily an aperture-synthesis interferometer but can also be used in a phased array configuration. The GMRT operates at multiple frequencies (150, 235 , 325, 610 and 1000 - 1450 MHz) and has a maximum bandwidth of 32 MHz, split into upper and lower sidebands of 16-MHz each. At 325 MHz, which is the frequency of interest here, the feeds are linearly polarized and converted to circular via a hybrid. Our observations were carried out on 14 February 2006 using the phased-array mode of the GMRT (Sirothia 2000; Gupta *et al* 2000) in which the voltage signal of the upper 16-MHz sideband from each antenna is first added coherently and subsequently fed to the pulsar receiver. The pulsar backends compute the auto- and cross-polarized power between the two circularly polarized signals, and the data is finally recorded with a sampling time of 0.512 msec. A suitable calibration procedure as described in Mitra *et al* (2005) was applied to the observations to recover the calibrated Stokes parameters I, Q, U and V. The AO observations were carried out at both 327 MHz and within the 21-cm band in a manner very like that reported in Rankin *et al* (2006).

The calibrated Stokes parameters were used to compute the total linear polarization $L = \sqrt{U^2 + Q^2}$ and the PPA $\psi = 0.5\tan^{-1}(U/Q)$ of the several pulse sequences (hereafter PSs). Table gives the various parameters for seven partial cone pulsars as identified by LM88. In §III., for several cases we have fitted the RVM to the PPA traverse using the Everett & Weisberg (2001) convention.

III. RESULTS

PSR B0355+54: Although the pulse profile at various fre-

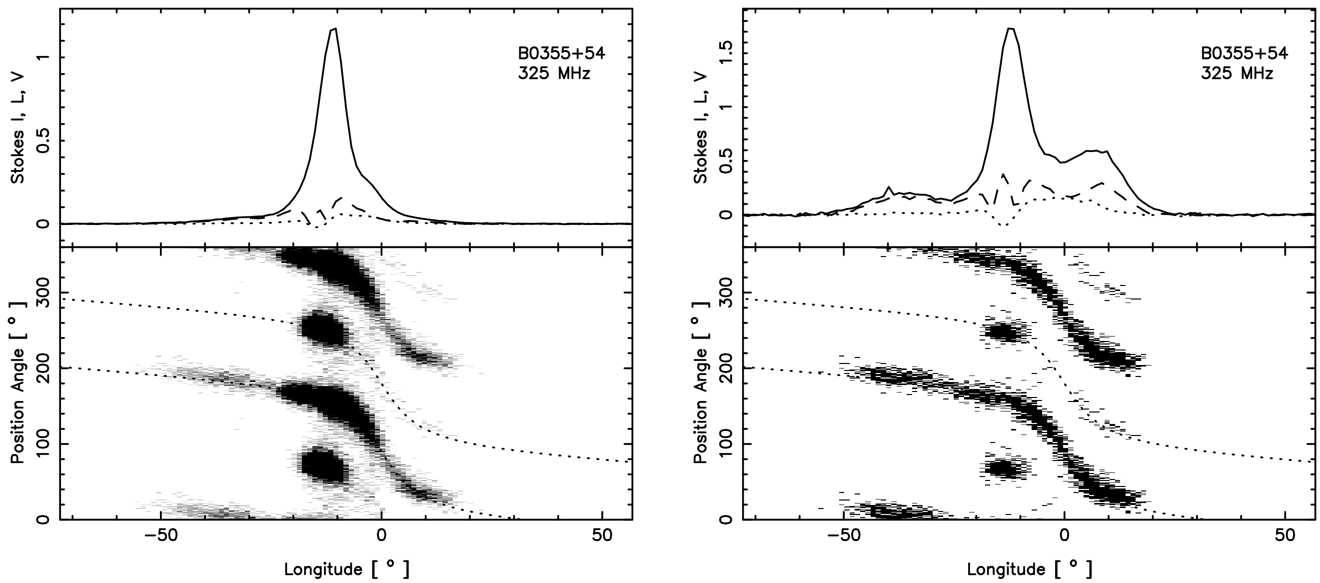

Figure 2. PPA histograms for PSR B0355+54: all single pulses (left) and the 'flared' intervals (right). The dashed line is an RVM fit to the PPA traverse and the longitude origin correpond to the SG point of the PPA swing. The top panels show the average Stokes I, L and V. See text for further details.

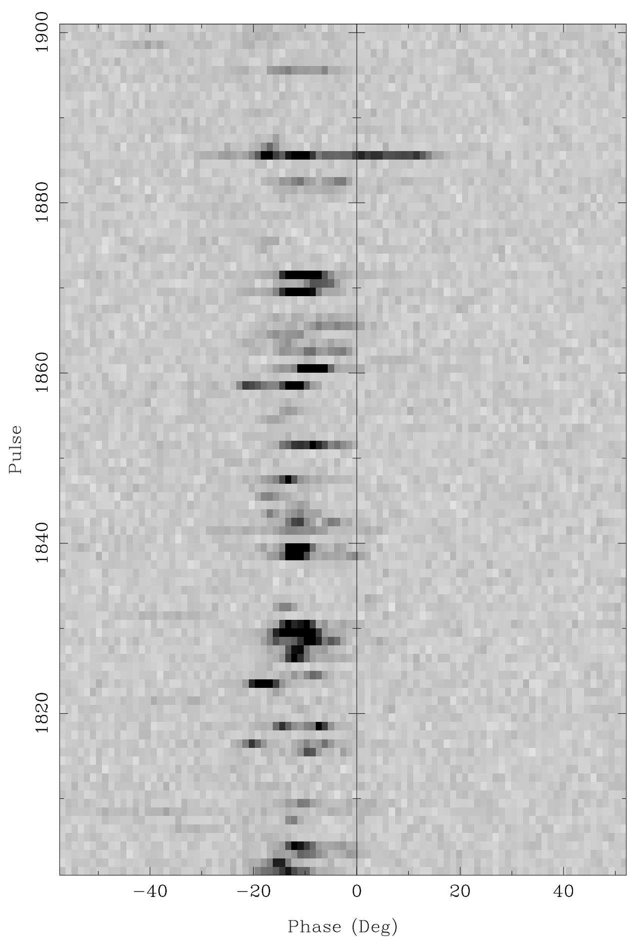

Figure 1. A 100-pulse sequence (1800–1900) of PSR B0355+54. The longitude origin corresponds to the SG point of the PPA swing. Notice the sudden flaring that occurs at pulse 1887.

quencies (*e.g.*, LM88; Gould & Lyne 1998 (hereafter GL98); Xilouris *et al* 1998) clearly show three components, the pulsar is classified as a core single by Rankin (1993) due to the domination of its bright central component over the weak conal outriders at metre wavelengths. The central component's steep spectrum (see LM88; Morris *et al* 1980) and underlying antisymmetric circular polarization argue strongly that it is core-like. By contrast, LM88 identify this pulsar as having a 'partial cone' profile with the SG point of PPA traverse lying towards the trailing edge of its profile.

Figure 1 displays a typical 100-pulse sequence from the GMRT observations at 325 MHz. Here the pulsar shows significant dynamicity in its pulse-to-pulse fluctuation properties: the core component is seen to vary dramatically, often going through core nulls, the conal components also show significant intensity variations, and overall the pulsar nulls some 30% of the time. Remarkably, there are occassional pulses which exhibit sudden flaring on the edges of the profile noticed (*e.g.*, pulse no 1887 in Fig. 1). These flarings last only for a single pulse, and the pulsar's emission then reverts back to its usual character. Changes in the average pulse shape of PSR B0355+54 were noticed earlier by Morris *et al* (1980) at 11 cm, where average profiles over short intervals were seen to slowly change from one profile mode to the other over some 1000 pulses. We see no such a mode change, however, in our observations.

The pulses exhibiting the sudden flarings can readily be segregated and used to form a partial profile of the pulsar in this unusual mode. Practically, we defined small windows at the profile edges and took at our criterion that the power within one or the other exceeded 3 times the off-pulse rms noise level. The flaring was then found to occur only 1.6% of the total time. Flaring at the leading and the trailing edge was generally uncorrelated, and we did not find any periodicity in the flaring events. Figure 2 gives the total and partial profiles, and there appear to be no differences in the

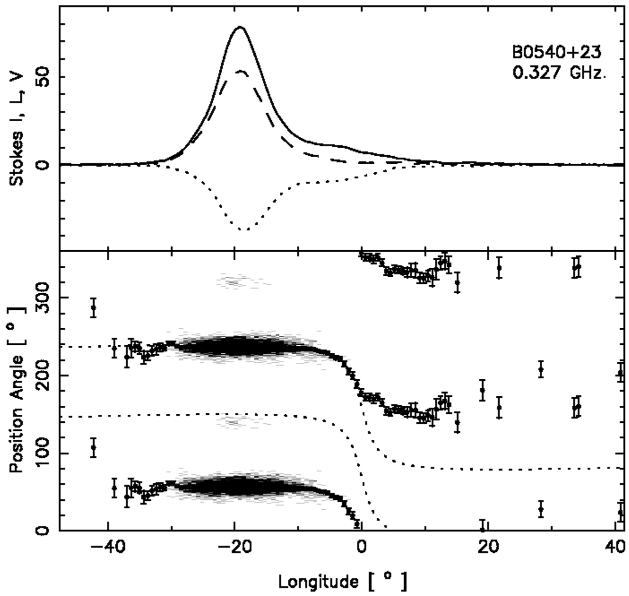

Figure 3. The the bottom panel of the left plot is a histogram of PPA for all the single pulses of PSR B0540+23. The dashed line is a RVM fit to the PPA traverse, and the longitude origin correponds to the SG point of the PPA swing. The top panel shows the average Stokes I, L and V.

polarization properties of the flared versus the normal pulse emission.

Given that these flared pulses exhibit a fuller profile, we have a fortunate opportunity to further explore the emission geometry for the pulsar. The left-hand panel of Fig. 2 shows the PPA histogram of the total pulse sequence, where the PA tracks of both OPMs are visible. To fit the RVM to the displaced PA track, we use a two-way mode separation technique (*e.g.*, Gil *et al* 1992) to separate the two OPM tracks. The RVM fitting was carried out using the more extended primary polarization mode (hereafter PPM) track, which yielded the basic emission geometry, α = 50.4°±5° and β= -4.8°±1°, consistent with the previous findings of LM88 and Rankin (1993). The SG point of the PPA track is obtained with an accuracy of ±0.5° and corresponds to the longitude origin in Fig. 2.

In our view, the morphology of the flared-pulse profile is consistent with the core-cone model for pulsar emission, which prompted us to investigate this issue in further detail. To do this, we first fitted a set of five Gaussian functions to the flared pulse profile and found that they adequately represent the profile as a central core and two nested conal emission components. As noted earlier, there is strong evidence that the central component is in fact a core-emission feature, and its peak leads the SG point of the PPA traverse by 10.5°. Further the midway point between the peaks of the outer components leads the SG point by some 13.5°, and hence the core peak lagsthe midway point by about 3°. The overall geometrical evidence here can be understood by invoking the effects of A/R (BCW). If we assume that the flared pulse profile illuminates the full polar cap, then the BCW model gives an emission height for the outer cone of about 450 km. Furthermore, based on the longitude displacement of the core with respect to SG point, the core emission height is found to be about 300 km. These height estimates of a few hundred kms are quite reasonable when compared to the radio-emission heights estimated in pulsars.

PSR B0540+23 is identified as a 'partial cone' by LM88, and its SG point falls on the trailing edge of its profile. The multifrequency average polarimetry GL98 shows a flattish PPA traverse sloping gently downward towards the trailing part of the profile. However the SG point is not obvious in these observations.

A PPA histogram computed from the AO 2440-length pulse sequence (hereafter PS) at our disposal is shown in Figure 3. The PPA is largely flat under most of the leading part of the profile (with weak evidence of OPM activity) and then droops down towards the faint trailing edge of the profile. This character of the PPA traverse essentially confirms LM88's identification of this pulsar as having a 'partial cone' profile. We did not find evidence of flared emission in either the leading or trailing parts of the profile—nor did we evidence of drifting. We have tried to fit the RVM to the pulsar's PPA traverse; however no adequate fit could be obtained for its full extent. The flat PPA towards under the leading part of the profile indicates that the pulsar has a outer (equatorward) line of sight; however, we found no combination of α and β that could fit the PA traverse under the trailing part of its profile. The dotted line shown in Fig. 3 is for $\alpha = 117°$ and $\beta = -1.7°$, and it is merely a guess for the PA traverse. I t is possible that significant OPM emission is present in the trailing part of the profile, causing the averge PPA to deviate from the RVM, although the lack of strong linear depolarization tends to argue against such a presence. This effect cannot easily be verified given the low single pulse S/N in the trailing parts of the profile. The SG point, however, lies towards the trailing edge of the profile as expected for for the A/R effect.

PSR B0740–28 This bright southern pulsar is yet another example of the 'partial cones' identified by LM88. Average-profile studies show significant pulse shape evolution (*e.g.*, GL98) for this pulsar, and it is known to have as many as seven components at 1.4 GHz (Kramer 1994).

Figure 4 displays the average Stokes profile and the grey-scale PA histogram of the PS observed with the GMRT. Performing a similar analysis as in B0355+54, we failed to find any evidence for flared pulses in the profile edges.These high S/N observations, however, do define the PA traverse over a much wider longitude range, than previously. While the average PA under the main pulse is consistent with earlier published polarimetry, the extensions of the PPA towards the trailing and the leading edges of the profile shows significant distortions. No meaningful RVM fit to the average PA traverse was possible. The single-pulse PA histogram extends over a smaller longitude range since the individual pulses are weak at the profile edges. Using both the average and single-pulse PPA traverses, we have estimated the SG point by using a differencing scheme and find that they agree with each other and correspond to the longitude origin in Fig. 4.

Even more interesting is the lrf spectral analysis for this pulsar which shows a sharp fluctuation feature at 0.612 rotation periods (hereafter P_1) on the extreme leading and trailing edges of the profile (see Fig. 4, right-hand plot). No such feature was identified in the recent fluctuation spectral study of Weltevrede *et al* (2006) at 21 cm. This clear

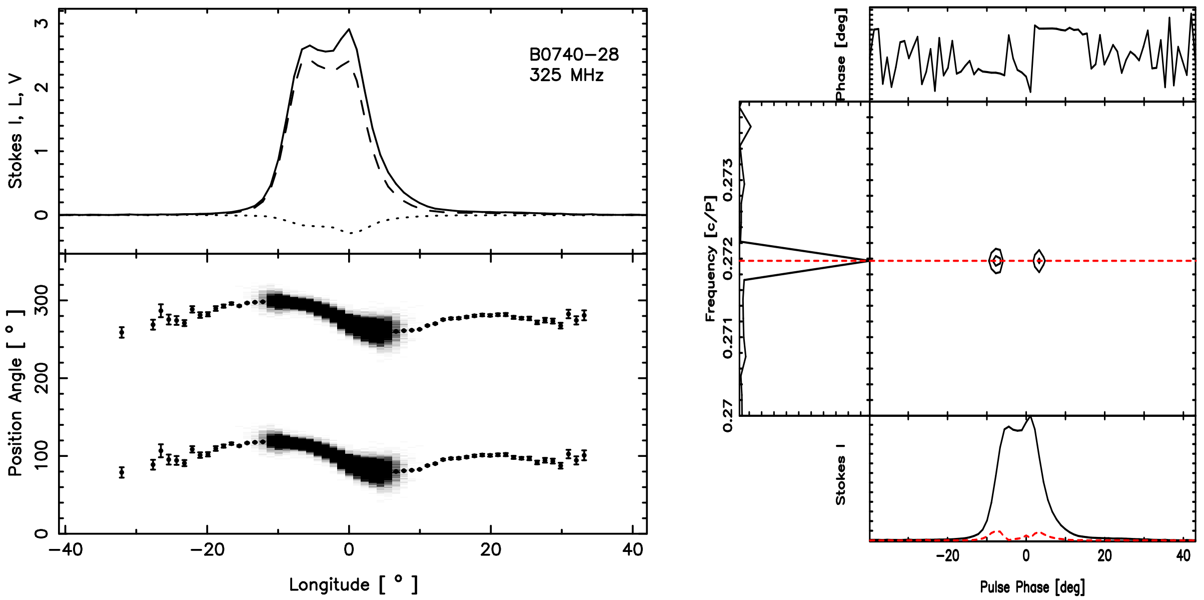

Figure 4. Left hand plot: PPA histogram of PSR B0740–28 (bottom panel) shown in grey scale. The overlayed black circles with error bars correspond to the average PPA. The plot has been repeated twice for clarity. The upper panel shows the average total intensity (Stokes I, solid line), linear (V, dashed) and the circular (Stokes V, dotted) polarization. **Right hand plot:** longitude-resolved fluctuation (hereafter lrf) spectra (central panel) in contours. The longitude-averaged fluctuation spectrum (left panel), phase (top panel), and the total and modulated power (bottom panel) are also shown.

evidence of subpulse modulation strongly suggests that the pulsar is illuminating the whole polar cap with a subbeam drift around the magnetic axis as has been observed in several other such pulsars.

B0919+06: LM88 classifies this pulsar as exhibiting 'partial cone' emission, with its SG point falling on the leading side of its profile. The star's average profile has a long weak leading extension as well as its bright trailing component, and this structure shows little variation over the broad band of available observations (*e.g.*, BCW & GL98). A recent PS polarimetric study (Rankin *et al* 2006) discovered that occasional events occur which shift the emission from the trailing into the usually very faint leading part of the profile. During such an episode the longitude region of bright single pulses literally appears to "walk" into the faint leading region over a few pulses, remain there for several tens of pulses, and then "walk" back to its usual position (see their figs. 1 and 3). The effect is similar to the 'flaring' events seen in PSR B0355+54 and discussed earlier. In both cases we note that the width of the flared region is similar to that of the average profile width.

The 327-MHz PS in fig. 3 of Rankin *et al* (2006) clearly shows that the PPAs exhibit strong OPM emission under the leading part of its profile. The average PPA thus shows a complicated behaviour which indeed probably led LM88 to conclude that the SG point fell within the leading portion of the profile. Here we have used the 1400-MHz PS in Rankin *et al* (2006) to fit the RVM to the PPA traverse. The PPAs at this frequency are mostly dominated by a single OPM. We have fitted the RVM to this mode which yields values for α and β of 174.6° and 0.4°, respectively, and which are 98% correlated. The fitted PA traverse is shown in Fig. 5, where the longitude origin is taken at the SG point—which

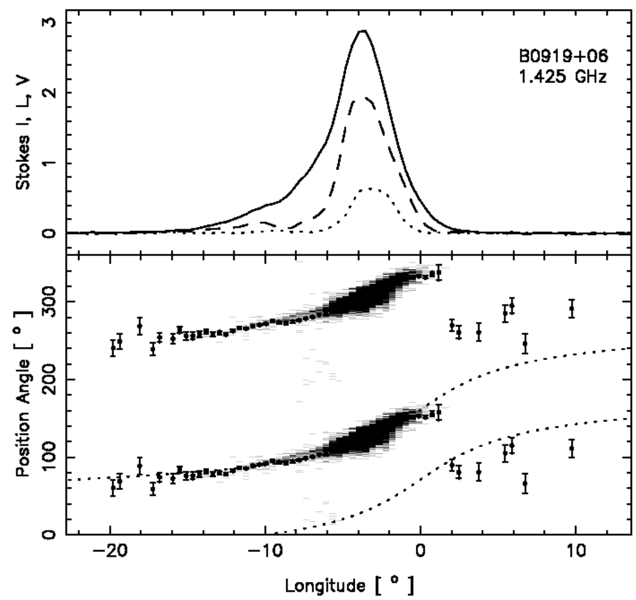

Figure 5. The the bottom panel of the left plot gives a PPA histogram for the single pulses of PSR B0919+06. The dashed line is an RVM fit to the PPA traverse and the longitude origin correponds to the SG point of the PPA swing. The top panel shows the average Stokes I, L and V.

falls on the extreme trailing edge of the profile. Clearly, this is consistent with the A/R effect as predicted by the BCW model. We have not found any evidence of drifting subpulses in this pulsar.

B1556–44 is a well studied southern pulsar. Its profile has a triple form at low frequencies with a broad central

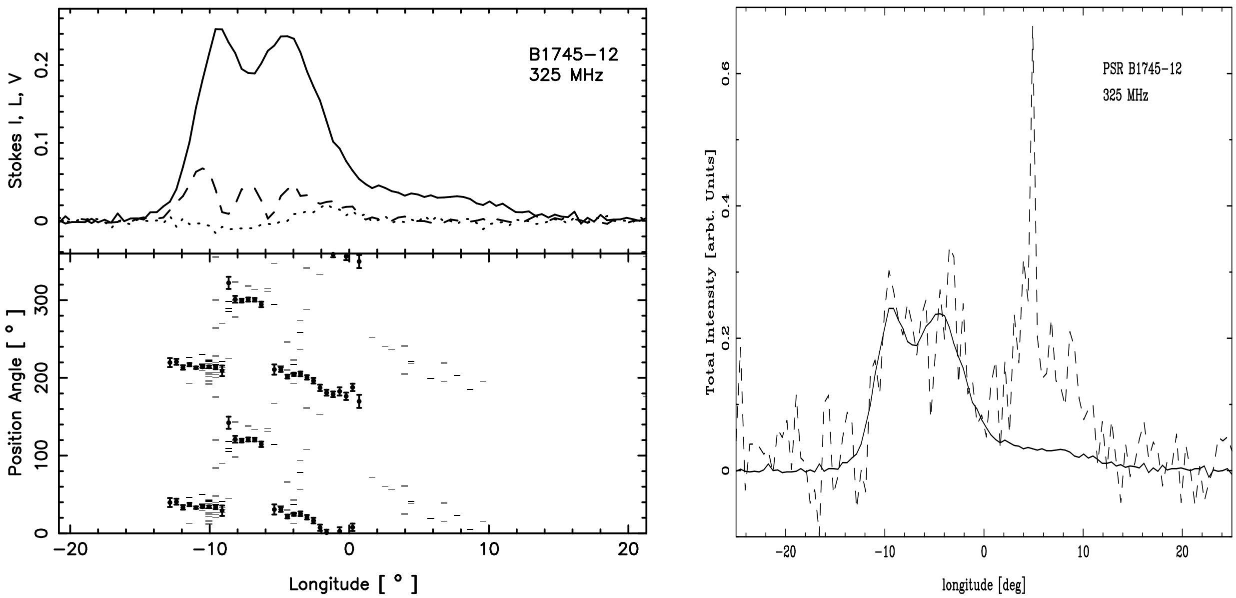

Figure 7. Left hand plot: PPA histogram for PSR B1745–12 as in Fig. 4 (left). **Right hand plot:** average total intensity profile (solid line) for the total PS of PSR B1745–12 and the partial-average profile (dashed line) of the 'flared' pulses. See text for details.

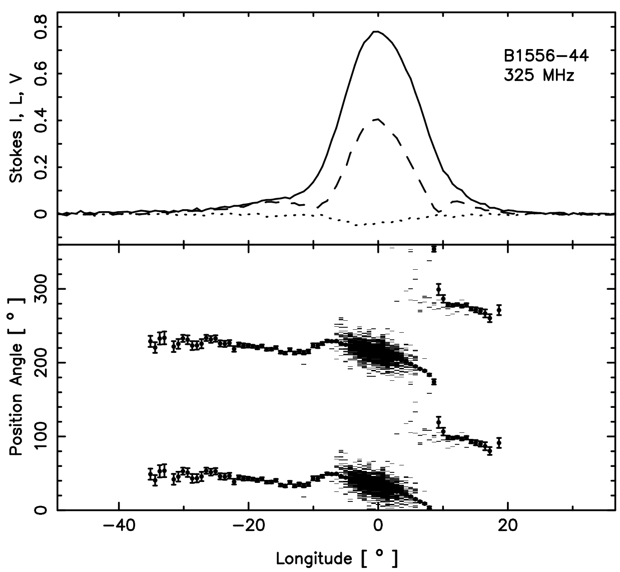

Figure 6. PPA histogram for PSR B1556–44 as in Fig. 4 (left).

component and weak conal outriders (*e.g.*, LM88; Manchester, Han & Qiao 1998, hereafter MNQ); but observations at higher frequencies show that this central component is comprised of two overlapping features. Other average polarimetric studies of this pulsar include McCulloch *et al* (1978, 631 MHz), Wu *et al* (1993; 1560 MHz), Manchester *et al* (1980; 1612 MHz), and van Ommen *et al* (1997; 800 and 950 MHz), and orthogonal PPA "jumps" associated with the conal components can be seen in several of these. LM88 identified the star's profile as showing 'partial cone' emission and argued that the SG point was located on the leading side of its profile.

Figure 6 shows a PPA histogram of B1556–44 computed from a GMRT PS at 325 MHz, where we can readily see that the PPA traverse is not easily interpreted according to the RVM. The PPA behaviour under the central and trailing components here is very similar to that at higher frequencies, but a prominent non-orthogonal "jump" (by about 50°) is seen on the trailing edge of the first component. We find no evidence for flared pulses in this pulsar.

We find it difficult to understand how these non-RVM PPA effects are produced. The depolarization of the bright central component must surely be indicative of OPM mixing, but the PPM there shows no obvious RVM connection to the fully linearly polarized (and thus unimodal) leading and trailing components. Detection of the secondary polarization mode (hereafter SPM) might provide added insight, but the single pulses are not strong enough to distinguish the OPMs. As a consequence no reasonable RVM fit to the PPA traverse was possible, though Fig. 6 does suggest a steepening downward trend from the leading to the trailing edge of the profile. Surely we see no evidence that SG point falls prior to the bright component as was suggested by LM88. In fact, MHQ's 21-cm observation tends to indicate that the SG is closer to the peak of the central component. If we take this as true, then the SG point lags the profile centre rather than leading it—and is thus compatible with an A/R explanation.

B1745–12 has been observed at several frequencies (410, 610, 910, 1420, and 1642 MHz by GL98; and 1.1 GHz by Xilouris *et al* 1991) and can be viewed generally as having three profile components with a relatively strong leading component. It waclassified as a conal triple by Rankin (1993), whereas LM88 view it as a possible 'partial cone'.

The 325-MHz GMRT observation in Figure 7 clearly shows the three components, however the trailing feature is significantly weaker here. The S/N of individual pulses is small, but the average-polarization indicates that the PPA traverse is relatively flat under the bright leading compo-

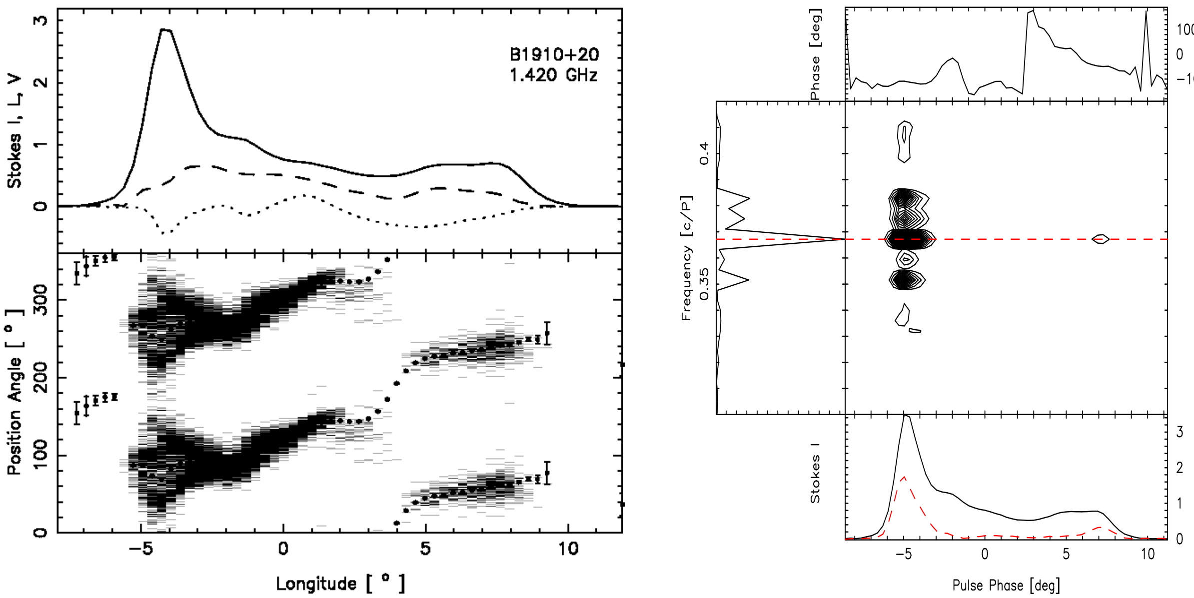

Figure 8. PPA histogram **Left hand plot** and lrf spectra **Right hand plot** for PSR B1910+20 as in the respective Fig. 4, left and right, respectively.

nents (with a prominent OPM "jump" between them) and steepens strongly towards the weaker trailing edge of the profile. We have fitted the OPM-corrected average PPA traverse to the RVM, and the SG point is taken as the longitude origin in Fig. 7. This SG point is poorly contrained owing to the depolarization at positive longitudes, although we can be certain that it cannot be earlier than indicated. For B1745–12, α and β were determined as 48° and –0.7°, respectively, though their high correlation (98%) does not constrain the geometry well.

The overall pulse shape and the location of the SG point is consistent with the description that the pulsar is a partial cone. The low level emission in the trailing part of the cone is seen to extend upto 14°—similar, that is, to the leading extent of the profile. A search for 'flares' on the profile edges showed that on 14 occasions events occurred on the trailing edge of the profile as seen in Fig. 7 (right). We found no evidence for drifting in the PSs.

B1910+20 The pulsar is classified as exhibiting a 'partial cone' by LM88 with the SG point falling in the trailing part of the profile. Average profiles at 610 and 1410 MHz (GL98) show that the pulsar's profile has a strong leading and weak trailing component. The PPAs exhibit a complex (and ostensibly non-RVM) traverse, and no simple conclusion regarding the SG point can be drawn from this published polarimetry.

The PPA histogram in Figure 8 (left plot) was computed from a strong 906-pulse, 1420-MHz AO PS. The PA distribution is usually complex and cannot be described by the smooth RVM model. This poses a fundamental difficulty in estimating the SG point in this pulsar. We have not found any evidence of 'flared' emission at the profile edges. Strong longitude-stationary subpulse modulation was first reported in the leading component (Weltevrede *et al* (2005, 2007), whereas our fluctuation spectral analysis (Fig. 8, right display), shows a 2.7 cycle/P_1 modulation feasure in both the trailing and leading components.

IV. CONCLUSION

'Partial cones' were identified by LM88 as pulsars with profiles where the PPA steepens asymmetrically on either the leading or trailing edge of the profile, and this effect is apparently often emphasized by a highly asymmetric intensity distributionsuggesting that a part of the cone is missing. Two plausible ideas have been articulated to understand this observational circumstance:

- First, one might conclude that only a part of the polar cap is active. The argument here is that the SG point of an RVM PPA traverse corresponds to the "fiducial" plane containing both the rotation and magnetic axes, and hence were this point to fall asymmetrically toward one side of the profile, we may conclude that only a part of the polar cap is active (*e.g.*, LM88 and JW06); and
- second, we should expect that the SG point of the PPA traverse will be shifted later by A/R effects according to the BCW theory if the emission height is sufficiently large. Were this interpretation correct and appropriate, it not only explain the observed assymetry (see JW06) but provides a quantitative measure of the emission height.

Our polarimetric PS analyses in the foregoing section throw significant light on this dilemma of interpretation. Two of the pulsars, PSR B0355+54 and B1745–12, exhibit 'flared' pulses from the fainter parts of their emission cones. The 'flares' persist for only a single pulse and occur only some 1% of the time. The width of the 'flared' profile, however, does not exceed the aggregate profile width, or in other words, the 'flared' state represents a temporary brightening of fainter parts of the profile. The bright and faint parts of the profile, taken together, then seem to represent emission from all or most of the polar cap. Moreover, both PSR B0740–28 and B1910+20 show modulation signature under the leading and trailing parts of their profiles. If we attribute this to the standard $\mathbf{E}\times\mathbf{B}$ drift mechanism (Ruderman & Sutherland 1975), then this modulated emission should be centred about the magnetic axis. This again supports the conclusion that emission arises from the full polar cap.

The overall evidence tends to support the conclusion that partial cones are indeed *aberrated* cones. In a number of cases above, the SG point falls well after the profile centre even in cases when emission from most of the polar cap is apparently accounted for. The BCW model can naturally explain the PPA traverses that are displaced toward later longitude. Furthermore, for emission arising from finite height, BCW physically restricts the SG point to fall *only* on the trailing side of the profile. For all the four partial cones in our sample for which a full analysis was possible, we find that the SG point of the PPA traverse is located either centrally or within the trailing half of the profile with respect to the overall total intensity profile symmetry. In fact, there are 32 pulsars in LM88's 'partial cone' sample, and for 22 of these the SG point was found to fall within the trailing half of the profile. LM88 used average polarimetry to determine the SG point of the PPA traverse, which can often lead to incorrect interpretation due to the presence of the OPMs. For example PSR B1556–44 was identified by LM88 to have a leading SG point, whereas our analysis shows that this point falls on the trailing side. PSR B0919+06, which was also found to have a leading SG point in LM88, surely exhibits an almost textbook case of a trailing SG point on the basis of Rankin *et al* (2006) PS polarimetry (as well as that of BCW). Although further single pulse studies are needed to fully resolve the significance of the LM88 'partial cone' category, a strong tendency for the SG to fall with a trailing asymmetry appears to predominate.

Within the RVM model the SG is interpreted as the point lying in the meridional plane containing the rotation and magnetic dipole axes. However, in the BCW model, the SG in no longer the point that contains the magnetic axis. If the emission across the profile originates from a single emission height, then due to aberration the midway point of the total intensity profile precedes the meridoinal plane by an amount $\pi(r_{em}/cP)$, and the SG is delayed by $3\pi(r_{em}/cP)$ (BCW; Dyks, Rudak & Harding 2004; Gangadhara & Thomas 2006). In reality though, pulsar emission arises from different heights, with the conal emission probably arising higher than the central core emission. Consequently, the shifts in the profile center and the SG shift with respect to the the meridional plane will be $2\pi(r_{em}/cP)$ (see Dyks, Rudak & Harding 2004). Hence the longitude of the magnetic axis should lie midway between the centre of the total intensity profile and the SG point. Gangadhara & Thomas (2006) have successfully applied this model to the millisecond pulsar PSR J0437–4715. Similar effects seem to prevail in PSR B0355+54, where the central core component leads the SG point by $\sim 10.5^\circ$. If we regard the core as originating from a finite height within a bundle of field lines centred on the meridional plane, this plane would lead the SG point by about 7°. The PPA corresponding to the meridional plane would then be rotated with respect to the SG point PA by about 50° (see Fig. 2). Understanding the location of the SG point have further implications in studies where absolute fiducial PA orientation was determined by Johnston *et al* (2005) and Rankin (2007) to claim the alignment of supernova kicks with the pulsar rotation axis.

The BCW-model prediction that the SG point is shifted in a trailing/lagging sense appears to provide a natural explanation for the PPA symmetry-point offsets observed in most pulsars with 'partial cones' profiles. Note that the location of the SG point with respect to the total intensity profile depends on both the pulsar rotation period P and the radio emission height r_{em}. Were the emission height constant (independent of rotation rate), then the SG point would be displaced ever later in faster pulsars. On the other hand, if the emission across the polar cap arises from different heights, it is conceivable that different sections of the PA traverse will be displaced by different amounts, resulting in complicated non-RVM PA traverses (see *e.g.*, Mitra & Seiradakis 2003). Hence in general, one would expect slower pulsars to show more RVM-like PPA traverses with the SG point more centrally located, whereas the PPA traverses of faster pulsars should be even more delayed and possibly distorted. Clearly, the effect should be very pronounced in MSPs—and this is perhaps what is observed in the MPS population, where the faster the pulsar the more distorted and less RVM-like the PPA traverses (Stairs *et al* 1999; Xilouris *et al* 1998; Ord *et al* 2004). 'Partial cones', however, in the terms of LM88, are a class of pulsars whose typical median rotation period is about 300 ms; and for these we here propose that the SG points of their PPA traverses tend to fall within trailing areas of their profiles because of A/R effects. Further careful single pulse polarimetric studies are necessary to firmly establish this circumstance.

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