Part 4
Radio Properties

Section A
Pulse Structure

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Wide Beams from Young Pulsars (or One Pole for All)

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Abstract. Polarization observations show the existence of a well-defined group of young pulsars with highly linearly polarized mean pulse profiles. Many of these pulsars have interpulses. I suggest that both the main pulse and the interpulse in these pulsars are part of a very wide conal beam emitted along field lines emanating from a single magnetic pole. Such wide beams may be responsible for all interpulse emission.

1. Introduction

From the early days of pulsar astronomy, mean pulse polarization observations have played an important role in furthering our understanding of the pulse emission mechanism. For example, the rapid swing of position angle across the Vela pulsar mean profile led to the magnetic-pole model (Radhakrishnan & Cooke 1969). Pulsars with interpulses are generally interpreted as having emission from both magnetic poles, but Manchester & Lyne (1977) suggested that, in some cases, wide profiles could emanate from one pole. Analysis of large data sets (e.g. Rankin 1983, Lyne & Manchester 1988) has supported the magnetic pole model and shown that the central or 'core' emission has somewhat different properties to the outer or 'cone' emission. In this paper, I follow up on the ideas of Manchester and Lyne (1977) and identify a group of highly polarized and young pulsars as having very wide beams emitted from field lines related to a single magnetic pole. This idea is generalized to suggest that all main pulse – interpulse emission emanates from field lines associated with one pole.

2. Wide Beams and Interpulses

Most pulsars have a significant degree of linear polarization, typically 10 – 30%. However, in some pulsars, the mean pulse profile, or one component of it, is essentially completely linearly polarized. Examples are the Crab pulsar precursor component (Manchester 1971), the Vela pulsar (Krishnamohan & Downs 1983), PSR B0740−28 (Lyne & Manchester 1988), PSR B1356−60 and PSR B1737−30 (Wu et al. 1993). All of these are young pulsars with ages less than or about 10^5 years. To my knowledge, such highly polarized components are found *only* in relatively short-period pulsars with strong magnetic fields, that is, in young pulsars. Many of these pulsars have interpulses.

Another good example is PSR B1259−63, the only pulsar known to orbit a Be star (Johnston et al. 1992). This pulsar has a pulse period of 47.7 ms, a

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characteristic age of 3×10^5 yr and a strong interpulse. Both the main pulse and the interpulse are essentially 100% linearly polarized. On the basis of fits of the rotating vector model to the observed position angles and the shape of the mean pulse profile, particularly at high radio frequencies, Manchester & Johnston (1995) have argued that both components are emitted from a single group of polar field lines. The observed pulse width is then about 270° (Figure 1) and the angular half-width of the emission cone is about 76°.

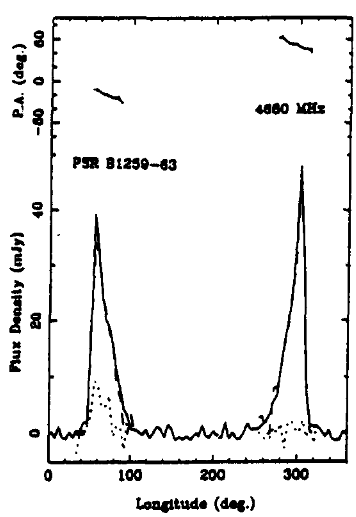

Figure 1. Mean pulse profile and polarization parameters for PSR B1259−63 at 4680 MHz. Linearly polarized intensity is indicated by the dashed lines and circularly polarized intensity by the dotted lines. (After Manchester & Johnston 1995)

I suggest that *all* such highly polarized components are part of wide beams and that, where there are interpulses in these pulsars, they are also part of the same beam. Pulsars such as the Vela pulsar and PSR B0740−28, where there is no observable (radio) interpulse, have a mean profile with a steep leading edge and a more gradual trailing edge, often with an indication of several pulse components. These are therefore interpreted as the *leading* edge of the wide beam.

PSR B1822−09 is another relatively young pulsar with an interpulse (Gil et al. 1994) and a highly linearly polarized 'precursor' component (Manchester et al. 1980) which leads the main pulse by about 15°. Following on the above ideas, I suggest that all pulse components from this pulsar are emitted from field lines associated with one polar cap, with the 'interpulse' being a cut through the trailing side of a very wide beam. This pulsar exhibits remarkable mode changes in which the precursor disappears and the interpulse appears (Gil et al. 1994), showing that there is a close connection between these two pulse components, a fact not easy to explain if they are emitted from opposite poles. Furthermore, a very similar phenomenon may have been observed in PSR B1259−63 (Johnston - this volume). There is a strong anti-correlation between the intensities of the two pulses with a timescale for variations of several minutes. If this can be shown to be a mode-changing phenomenon, it will add weight to the one-pole interpretation of PSR B1822−09.

PSR B0950+08 is another interesting case. It is a short-period pulsar, admittedly not very young ($\sim 2 \times 10^7$ yr), with a highly linearly polarized 'interpulse' (Lyne & Manchester 1988). This pulsar is usually interpreted as having the emission beam axis nearly aligned with the rotation axis (e.g. Narayan & Vivekanand 1983a; Gil 1983). However, this requires a rather *ad hoc* assignment of preferred field lines for the emission and/or highly non-circular beams. A much simpler interpretation of the observed emission from this pulsar is that both components are cuts through a single wide beam. The beam axis need not be close to the rotation axis, i.e. an aligned geometry is not required. This interpretation is supported by the observed interpulse – main pulse separation of about 150° and (except at low radio frequencies) the steep outer edges and saddle-like inner edges of the mean pulse profile.

Similar pulse profiles are observed for the high-energy emission from the Crab pulsar (Ulmer et al. 1994) and Vela pulsar (Kanbach et al. 1994), strongly suggesting that they are emitted from field lines associated with a single polar region. In both cases the highly polarized radio pulse component (precursor for the Crab pulsar) leads the first high-energy component by about 25° of phase (see e.g. Manchester & Taylor 1977). If, as suggested above, we interpret these radio components as the leading edge of a very wide conal beam, then the radio, optical, X-ray and γ-ray emission beams can all have the same symmetry axis.

Following Smith (1986) and Romani and Yadigaroglu (1995), I suggest that the high-energy pulses are emitted high in the pulsar magnetosphere where there is substantial distortion of the magnetic field lines due to retardation effects. However, in contrast to these and other authors, I suggest that, in these short-period pulsars, the radio pulse components are emitted in the same vicinity. An implication of this is that, in contrast to the conclusions of Radhakrishnan & Cooke (1969), the relatively rapid swing of position angle seen in (for example) the Vela radio pulse does *not* imply that the viewing angle is passing close to the symmetry axis of the beam. Romani & Yadigaroglu (1995) have shown that, for the high-energy pulses, rapid position-angle swings occur near the edges of wide conal beams emitted high in the pulsar magnetosphere. I suggest that the radio-frequency observations may be interpreted in a similar way.

Emission from a single wide cone greatly eases several problems with the two-pole interpretation of interpulses. For example, there is no problem in accounting for the sharp cusps in both optical pulses from the Crab pulsar - it is very improbable that we would see both if the main pulse and interpulse were separate beams with circular symmetry. Similarly, the slow position angle swings through relatively narrow pulses in pulsars such as PSR B0740−28, which led Narayan & Vivekanand (1983b) to postulate beams elongated in the meridional direction, are easily accounted for. The observed beam *is* elongated in that direction – it is one side of a very wide cone.

It is possible that all emission from 'interpulse' pulsars originates from field lines associated with a single magnetic pole, even in millisecond pulsars. Rotating vector fits which seem to imply emission from two poles do not necessarily have this implication. They merely imply that the polarization symmetry axis is the same (or nearly the same) for the two parts of the beam which may or may not come from the same location. The very wide profiles for pulsars such as PSR J0437−4715, where the emission covers more than 80% of the period but there is no sign of an interpulse (Johnston et al. 1993), also suggest a one-pole model with a very wide beam. If these ideas are correct, they imply that pulsars emit beamed radiation *only* from one pole.

3. Conclusions

I suggest that the highly linearly polarized pulse components emitted from young pulsars are part of a very wide conal beam. Often only the leading cut through this beam is detectable. A consequence of this is that high-energy pulsed emission has the same axis of symmetry as the radio emission. Furthermore, it is possible that all pulsed emission, including interpulse emission, originates from field lines associated with one pole. These ideas have wide-ranging implications for studies of pulse emission mechanisms, beam morphology, and the pulsar population and birthrate.

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