POLARIZATION AND THE AGE OF PULSARS

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ABSTRACT. Using polarimetric radio profiles of 84 pulsars at a wavelength of 6 cm, we present a correlation between the polarization and characteristic age of pulsars. Considering the large error connected with the value of the characteristic age, we speculate about the possibility of identifying young pulsars through their polarimetric properties. Using this method we have identified more than 20 possibly young pulsars including some with a relatively high characteristic age. Of these objects, seven have already been proposed to be associated with supernova remnants. For the remaining pulsars we find a number of candidates for associated faint SNRs and present one of them. This shows that this method can be used as an additional independent indicator for the youthfulness of pulsars.

1. The Pulsar Age Problem

Although it is commonly believed that pulsars are born in the supernova explosions of massive stars, only about 2% of the presently observed population are considered to be associated with supernova remnants (hereafter SNRs). The standard explanation for this apparently low fraction of objects is a combination of the radio lifetimes of pulsars (\(\sim 10^7\) yr) compared to SNRs (\(\sim 10^5\) yr), the beaming fraction of radio pulsars and the fraction of all supernova that produce a neutron star. In order to decide whether an association is real or coincidental, a number of questions need to be considered (see e.g. Kaspi 1996). These include positional coincidence, agreement of the distances and ages of both the pulsar and the SNR and, if measured, the velocity vector of the pulsar should be consistent with its position offset from the center of the SNR. Agreement in age is of great importance, since the age of the pulsar should not much exceed \(10^5\) years.

The age of a pulsar can in principle be determined from its spin parameters. Given an initial spin period \(P_i\) and a magnetic field \(B\), the pulsar loses rotational energy, mainly through magnetic dipole radiation, but also through electromagnetic radiation and particle losses. The spin period \(P\) therefore increases with time. As the temporal derivative of the period \(\dot{P}\) can be measured with a high accuracy, the age of the pulsar can be determined if assumptions are made for \(P_i\) and the braking behavior (e.g. Manchester & Taylor 1977). The equation of motion is described by the differential equation

\[
\dot{\Omega} = -K\Omega^n,
\]

(1)

where \(\Omega = 2\pi/P\) and \(K\) is a constant. The braking index \(n\) depends on the specific
Fig. 1. Polarization profiles of four different pulsars. The enveloping solid line is the total power, the dark and the light shaded areas correspond to the linear and circular polarized power respectively. Basically all polarization states can be found. Examples are given for fully-, partly-, semi- and unpolarized profiles.

slow-down model. Integrating this equation yields an expression for the age:

\[ T = \frac{1}{n-1} \frac{P}{\dot{P}} \left[ 1 - \left( \frac{P_i}{P} \right)^{n-1} \right]. \quad (2) \]

It is a standard practice to define the "characteristic age" \( \tau \), where \( P_i \) is assumed to be 0 (corresponding to \( P_i \ll P \)) and \( n = 3 \) (corresponding to the braking torque through pure dipole radiation)

\[ \tau = \frac{P}{2\dot{P}}. \quad (3) \]

In principle, \( n \) can be calculated through measurement of \( \dot{P} \). In practice this is difficult due to the presence of timing noise and glitch activity for young pulsars. Nevertheless \( \dot{P} \) has been determined for four pulsars so far and varies between \( n=1.4 \) for the Vela pulsar and 2.8 for PSR B1509-58 (Manchester et al. 1985, Lyne et al. 1988, Manchester & Peterson 1989, Lyne et al. 1996). As can be seen in Eq. (2) this span already implies an uncertainty of a factor of about 4.5 for \( T \). All values are smaller than \( n = 3 \) which leads to a systematic underestimation by the characteristic age. This underestimation is important for long-period pulsars with \( P \gg P_i \).

Estimates for \( P_i \) on the other hand are mainly based on theoretical models. An exception is the Crab pulsar where the age is precisely known through Chinese records. The corresponding supernova explosion occurred in 1054 A.D.. Using Eq. (2), the initial period of this pulsar can therefore be calculated as \( P_i = 19.3 \text{ms} \). In the literature, estimates for the initial period of pulsars are found between virtually zero and about \( P_i = 500 \text{ms} \) (e.g. Lyne et al. 1985, Narayan & Ostriker 1990 and Lorimer et al. 1993). Therefore for short period pulsars, \( P_i \) could well be of the order of the present period. Therefore the characteristic age could easily overestimate the real age of these pulsars by more than an order of magnitude (Kaspi et al. 1997).
2. Relation to Pulsar Polarization

The examples of pulsar polarimetry in Fig. 1 show that basically all states of polarization can be found. One question is, if the degree of polarization (hereafter $\Pi$), which is defined as the polarized fraction of the total intensity, depends on any pulsar parameter at all. Although it was known that young pulsars often have highly polarized profiles (e.g. Manchester 1996), no significant correlations could be found so far. As demonstrated by von Hoensbroech et al. (1998a) this is mainly due to the fact that earlier investigations had been made at “classical” pulsar frequencies between 400 MHz and 1400 MHz. At frequencies higher than a few GHz clear correlations become obvious between $\Pi$ and the loss of rotational energy $\dot{E}$, respectively the surface accelerating potential.

At 4.9 GHz, for instance, pulsars with a high $\dot{E}$ clearly have a higher $\Pi$ than pulsars with a low $\dot{E}$ (for a possible physical explanation see von Hoensbroech et al. 1998b). As $\dot{E}$ decreases with the characteristic age, $\Pi$ also decreases (see Fig. 2). The potentially large error of the characteristic age induces a strong scatter in the horizontal direction of Fig. 2, making the correlation less significant than it is with $\dot{E}$. But one clear conclusion can be drawn from this plot: Young pulsars are higher polarized than old ones at 4.9 GHz.
GHz. Using this fact, we use the polarization of the 4.9 GHz radio profiles to identify sources with a relatively high characteristic age, which are possibly younger than they seem.

3. Results

![PSR B1915+13](image)

Fig. 3. Faint shell structure around PSR B1915+13 at λ = 11 cm. 2° × 2°–map from Reich et al. (1990). Accessible through [http://www.mpifr-bonn.mpg.de/survey.htm](http://www.mpifr-bonn.mpg.de/survey.htm).

Among the 84 pulsars for which 4.9 GHz data were available (Komesaroff et al. 1974, von Hoensbroech & Xilouris 1997, von Hoensbroech et al. 1998a), 24 have a degree of polarization exceeding 30%. All pulsars and their parameters are listed in Tab. 1. For two pulsars we could not examine high resolution radio maps of their surroundings, another four lie in regions of strong Galactic background emission which makes it difficult to detect possible faint SNRs. Among the remaining 18 pulsars we find 7 known proposed associations with SNRs – corresponding to a fraction of \( \sim 40\% \) – and a couple of SNR-candidates. This is far above the fraction of pulsar-SNR associations in the whole pulsar sample which does not exceed \( \sim 2\% \).

Fig. 3 shows a faint shell structure which we found around PSR B1915+13 at a wavelength of \( \lambda = 11\text{-cm} \). The data were taken from the Effelsberg 11cm Galactic plane
### Tab. 1 - Highly polarized pulsars at 4.9 GHz

| Pulsar         | l/b [°] | P [ms] | \( \tau \) [log yr] | \( \Pi \) [%] | Remarks & Ref. |
|----------------|---------|--------|----------------------|--------------|----------------|
| B0136+57       | 129.2/−4.0 | 272    | 5.6                  | 57 ± 1       |                |
| B0144+59       | 130.1/−2.7 | 196    | 7.1                  | 47 ± 2       |                |
| B0355+54       | 148.2/0.8  | 156    | 5.8                  | 59 ± 1       |                |
| B0450+55       | 152.6/7.5  | 341    | 6.4                  | 46 ± 1       |                |
| J0538+2817     | 179.9/−1.7 | 143    | 5.8                  | 63 ± 2       | association [1]|
| B0540+23       | 184.4/−3.3 | 246    | 5.4                  | 33 ± 1       |                |
| B0559−05       | 212.2/−13.5| 396    | 6.7                  | 36 ± 6       | no map         |
| B0611+22       | 188.8/2.4  | 335    | 5.0                  | 42 ± 8       | association [2]|
| B0740−28       | 243.8/−2.4 | 167    | 5.2                  | 71 ± 1       | no map         |
| B0833−45       | 263.6/−2.8 | 89     | 4.1                  | 70 ± 5       | association [3]|
| B0919+06       | 225.4/36.4 | 431    | 5.7                  | 55 ± 1       |                |
| B1702−19       | 3.2/13.0   | 299    | 6.1                  | 38 ± 2       |                |
| B1737−30       | 358.3/0.2  | 607    | 4.3                  | 74 ± 5       | strong background|
| B1800−21       | 8.4/0.1    | 134    | 4.2                  | 85 ± 3       | association [4]|
| B1822−14       | 16.8/−1.0  | 279    | 5.4                  | 90 ± 6       | association [5]|
| B1822−09       | 21.4/1.3   | 769    | 5.4                  | 32 ± 1       | strong background|
| B1823−13       | 18.0/−0.7  | 102    | 4.3                  | 91 ± 4       | strong background|
| B1828−10       | 20.8/−0.5  | 405    | 5.0                  | 63 ± 3       | strong background|
| B1853+01       | 34.6/−0.5  | 267    | 4.3                  | 77 ± 11      | association [6]|
| B1913+10       | 44.7/−0.6  | 405    | 5.6                  | 54 ± 4       |                |
| B1915+13       | 48.3/0.6   | 195    | 5.6                  | 34 ± 1       | SNR candidate  |
| B1929+10       | 47.4/−3.9  | 227    | 6.5                  | 66 ± 1       | strong background|
| B2011+38       | 75.9/2.5   | 230    | 5.6                  | 58 ± 2       | association [7]|
| B2334+61       | 114.3/0.2  | 495    | 4.6                  | 57 ± 6       |                |

**TABLE I**

Highly polarized pulsars at 4.9 GHz. All data were taken with the Effelsberg 100m radio telescope except for B0833-45 (Komesaroff et al. 1974). Known associations with SNRs are marked. It is not ruled out that some of them are chance associations. References are: [1] Anderson et al. (1996), [2] Davies et al. (1972), [3] Large et al. (1968), Kassim & Weiler (1990), [5] Reich et al. (1986), [6] Wolszczan et al. (1991), [7] Kulkarni et al. (1993).

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survey (Reich et al. 1990). Large scale diffuse background emission has been subtracted appropriately. This pulsar has a spin period of \( P = 195 \) ms and a characteristic age of \( \tau = 4 \cdot 10^5 \) yrs. If this would be the pulsars true age an associated SNR should have vanished. The pulsar radiation is about 34% polarized at 4.9 GHz which could indicate a smaller true age. It is not yet clear if the shell structure around this pulsar is of non-thermal origin, but a verifying observation will be carried out soon.

The results show that the selection of highly polarized pulsars at about five GHz is a powerful method to identify possibly young pulsars. We stress that the method is totally independent of any other pulsar parameter and could be particularly useful to choose additional candidates for the search of associated faint SNRs.
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