What is special about High Magnetic Field Radio Pulsars?  
– First results from the multifrequency polarimetry

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Abstract. The Parkes Multibeam Survey led to the identification of a number of long-period radio pulsars with magnetic field well above the ‘quantum critical field’ of \( \sim 4.4 \times 10^{13} \) G (HBRPs). The HBRPs have similar spin parameters to magnetars, but their emission properties are different, and contradict those theories that predict that radio emission should be suppressed above this critical field. Our observations support the suggestion that initial neutron star spin periods depend on their magnetic fields; in particular, there is a tendency for high-field systems to be born as slow rotators. The aim of this project is to understand the emission properties of HBRPs, using multiple radio frequencies and high time resolution data. One specific objective is to identify HBRPs radio emission characteristics that are different from those of normal pulsars.

1. Introduction

To obtain a good understanding of the physics of the pulsar magnetosphere, we need information on time-averaged polarisation profiles, which tell us about the structure of the magnetic field, the properties of the magnetosphere and the geometry of the star, and on single pulse profiles, which give us information on the instantaneous plasma conditions and radiation mechanism. To understand emission constraints from the HBRPs, we observed 34 long-period pulsars (17 HBRPs and 17 low-magnetic-field pulsars) at three different frequencies (in the range 700 - 3100 MHz) in order to achieve valuable multifrequency polarisation profiles, spectral indices values and single pulse profiles. Table 1 summarises observational characteristics for both modes of observations (multifrequency polarisation and single pulse, respectively) of the technical details for two receivers and different configurations used during our observations. The first and second rows in the table list central frequencies and backend instrumentation used; the next row lists the observational resolution, which is given by the number of bins in the profile; the observational bandwidths and used receivers are listed in the fourth and the fifth rows.

Our aims in this project are: 1) to investigate if HBRPs form transition objects between the normal pulsar population and magnetars or if they form a separate pulsar population, and 2) to understand recent results from our paper Vranešević et al. (2004): a) why HBRPs contribute half to the total pulsar birthrate (even though they contribute to only few per cent of the total pulsar population), and b) why up to 40 \% of all pulsars are born with periods in the range 100–500 ms (which is contrary to the usual view that all pulsars are born as fast rotators). Here we present first results on the multifrequency polarimetry for the most interesting pulsars from our samples.

2. The first results

For the purpose of the Bad Honnef Meeting we present the first results for five pulsars: four HBRPs (PSR J1718-3718, PSR J1734-3333, PSR J1814-1744, & PSR J1847-0130) plus a representative of our low-magnetic field pulsar sample, PSR J2144-3933. In Table 2, pulsar parameters are listed: pulsar spin characteristics, their Galactic positions, dispersion measures, widths of pulse at 50\% of peak, mean flux densities at 1400 MHz, pulsar distances, spin down ages, surface magnetic flux densities and spin down energy loss rates. The detection of these pulsars was challenging because: a) detection of long-period pulsars using conventional search techniques is hard due to red noise in the Fourier transform of time series seriously reducing the sensitivity; b) all our pulsars are very faint, near the detection limit of the instrument; and c) for the generally accepted spectral index of -1.8 we would need hundreds of hours of observations to achieve a significant signal to noise at 3100 MHz.

The fact that we detected HBRPs at 3100 MHz suggests that they must have relatively flat radio spectra. Data at 700 MHz are still being analysed.

Profiles at 1433 MHz for pulsars PSR J1718-3718 and PSR J1734-3333 show significant broadening of an intrin-
Table 1. Technical details for both modes of observations (multifrequency polarisation and single pulse). We used two receivers at Parkes radio telescope: MULTI – centre beam at the 13-multi-beam receiver and 1050CM – 10 cm and 50 cm bands at 10/50cm receiver, with different backend configurations: CPSR2 – Caltech-Parkes-Swinburne baseband Recorder II; PDFB1 – Prototype Pulsar Digital Filter Bank, WBCORR – Wideband Correlator, FB – Filterbank.

| Center Frequency [MHz] | 685 | 1369 | 1433 | 3100 | 1374 |
|------------------------|-----|------|------|------|------|
| Instrument name:       | CPSR2 | PDFB1 | WBCORR | PDFB1 | FB   |
| Nr of bins in profile  | 1024 | 512  | 2048 | 512  | 256  |
| Bandwidth [MHz]        | 64  | -256 | -256 | 256  | -288 |
| Receiver name          | 1050CM | MULTI | MULTI | 1050CM | MULTI |

A sically sharp pulse (compare middle and bottom panels of Figure 1), which is due to ray scattering by irregularities in the ISM (characteristic of distant, high DM pulsars). The other two HBRPs shown here, PSR J1814-1744 and PSR J1847-0130, are also very distant with high DMs (Table 2), but do not show significant scattering. This is consistent with greater scattering along lines of sight that pass nearer to the Galactic centre. For most pulsars the fractional linear polarisation decreases with increasing frequency. However, the HBRPs shown here (except J1814-1744, which has no detectable polarisation, see Figure 2a) have higher linear polarisation at 3100 MHz than at lower frequencies. All these HBRPs are young pulsars with pulse profiles which consist of one or two prominent components with higher linear polarisation at higher frequency, which is consistent with the recent results by Johnston & Weisberg (2006).

PSR J2144-3933 which is part of our low-magnetic-field sample, shows curious features, see Figure 3: a) polarisation intensities at low frequencies are stronger compared with published data (Manchester et al. 1998), b) there is a significant increase in circular polarisation going towards higher frequencies, and c) depolarization of linear component at 3100 MHz (which may be due to reduction of profile resolution). All of these are going to be explored in more detail.

3. Discussion

Using the birthrate code from Vranesevic et al. (2004) and accurately accounting for all known selection effects and using the beaming fraction given by Tauris & Manchester (1998), we calculated that 187±103 long-period radio pulsars with magnetic field above the quantum critical field are active in the Galaxy and that one such pulsar is born each 500 years.

It is puzzling that this calculated number of HBRPs in the Galaxy is comparable with the predicted number of neutron stars at the supersonic propeller stage, according to the results presented by Beskin at the meeting. In their analysis of statistical distribution of extinct radio pulsars (Beskin & Eliseeva 2005a) and neutron stars at the supersonic propeller stage (Beskin & Eliseeva 2005b), they include evolution of the...
axial inclination and use two models for the particle acceleration region: hindered particle escape from the stellar surface (Ruderman & Sutherland 1975), and free particle escape (Arons 1979). They found that transition of a radio pulsar to the propeller stage can occur at the short periods $P \sim 5 - 10$ s and the number of those extinct radio pulsars (with spin parameters similar to HBRPs) is much larger than when using standard model (in which no evolution of inclination angle of magnetic axis to the spin has been accounted for).

Another interesting result regarding the influence of inclination angle $\alpha$ is on the stability of dipolar magnetostatic equilibrium in newly born neutron stars, presented at the meeting by Geppert & Rheinhardt. They assumed that newly born NSs with highly magnetized progenitors and proto-NS phase surface magnetic fields of $\gtrsim 10^{15}$ G (gained by flux conservation) that also have sufficiently fast rotation (initial period of $P \lesssim 6$ ms) and $\alpha \lesssim 45^\circ$ retain their magnetic fields and appear, after a rapid spin down, as magnetars. Others (with $P \gtrsim 6$ ms and $\alpha \gtrsim 45^\circ$) lose almost all of their initial magnetic energy by transferring it into magnetic and kinetic energy of relatively small-scale fields and continue their life as radio pulsars with a dipolar surface field of $10^{12-13}$G (for more details see Geppert & Rheinhardt 2006). The implication for HBRPs, as a young highly magnetised objects, is that they should have $\alpha < 45^\circ$. This is the case for one of the well known HBRPs, the 1610-year-old pulsar PSR J1119-6127, $\alpha = 19^\circ$ (Geppert & Rheinhardt 2006). Gonzalez, at this meeting, presented recent results on X-ray detection from this high-B radio pulsar and from a few other HBRPs, with the main highlights being their unusual thermal emission, which they explained in terms of anisotropic high temperature distribution and a small emitting area.

The detection of magnetospheric radio emission from a magnetar has just been announced by Camilo et al. (2006). The data show highly linearly polarized, bright radio pulsations from XTE J1810-197, which is a transient AXP. The fact that this source had very faint X-ray properties in its quiescent phase, similar to soft X-ray detection of PSR J1718-3718, suggests that XTE J1810-197 could have generated familiar radio pulsar emission before the outburst observed in early 2003. This makes a plausible direct link between radio pulsars and magnetars.

4. Summary

The idea that HBRPs were born as a slow rotators is in agreement with Ferrario & Wickramasinghe (2006), who argued that initial neutron star spin periods depend critically on their magnetic fields. There is a tendency for high-field systems to be born as slow rotators. Recent results by Vink & Kuiper (2006) show no evidence for magnetars being formed from millisecond proto-NSs. It is possible that magnetars have stellar progenitors with high magnetic field cores, which is the fossil-field hypothesis of Ferrario & Wickramasinghe (2006). It remains unclear whether HBRPs evolve into magnetars or whether HBRPs and magnetars form distinct populations from birth.

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Fig. 2. Multifrequency polarisation profiles for pulsars: a) PSR J1814-1744 and b) PSR J1847-0130. The top panels show integrated pulse profiles plotted for a whole pulsar period versus flux at 3100 MHz. The middle and bottom panels plot zoom in pulsar profiles at 3100 MHz & 1433 MHz for a) and 1375 MHz for b). All panels show total intensity as a solid line, with linear intensity as dashed, and circular intensity as dotted lines. The upper frames for all panels show the position angle of the linear polarisation.

Fig. 3. Multifrequency polarisation profiles for pulsar PSR J2144-3933, showing total intensity as a solid line, with linear intensity as dashed, and circular intensity as dotted lines; the upper frames for all panels show the position angle of the linear polarisation. The panel a) shows integrated pulse profiles plotted for a whole pulsar period versus flux at 1433 MHz. Panels b), c), and d) plot zoom in pulsar profiles at 3100, 1433 and 1369 MHz, respectively.

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