What is special about HBRPs - High Magnetic Field Radio Pulsars

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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). Traditional pulsar emission theories postulate that radio emission is suppressed above this critical field. Although HBRPs and magnetars (AXPs) have similar spin parameters, their emission properties are different. It has been suggested that pulsar-like objects could evolve from normal radio pulsars to magnetars. Some authors have argued that the initial neutron star spin periods depend critically on their magnetic fields, in particular, there is a tendency for high-field systems to be born as slow rotators. This idea suggests a connection between radio pulsars and magnetars. The aim of this project is to understand emission properties of HBRPs. We hope to provide solid constraints on HBRPs radio emission characteristics by comparing HBRPs properties with the properties of normal pulsar population using radio multi-frequency and high time resolution data.

Main project goals

To obtain good understanding of the physics of the pulsar magnetosphere, we need information on: time-averaged polarization profiles (tell us about the structure of the magnetic field, the properties of the magnetosphere and the geometry of the star) & single pulse profiles (give us information on the instantaneous plasma conditions and radiation mechanism). To understand emission constraints from the HBRPs we have 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 polarization profiles, spectral indices values and single pulse profiles. We have undertaken this project in the aims of: 1) to investigate if HBRPs form transition objects between the normal pulsar population and magnetars or if they form a separate pulsar population & 2) to understand recent results from our paper [4]: a) why HBRPs contribute half to the total pulsar birthrate (even though they contribute to only few per cent of the total pulsar population), b) why up to 40 % of all pulsars are born with periods in the range 100–500 ms (which is in contradiction to the usual view where all pulsars are born as fast rotators). Here we present first results on the multifrequency polarimetry for the most interesting pulsars from our samples.

PSR J1718-3718

$P = 3.378\,\mathrm{s}$ $\dot{P}_{-15} = 1598$
$l = 350°$ $b = 0.22°$
$DM = 373\,\mathrm{pc\,cm^{-3}}$ $S_{1400} = 0.18\,\mathrm{mJy}$
$\tau_c = 33.5\,\mathrm{kyr}$ $B_{surf} = 7.44 \times 10^{13}\,\mathrm{G}$
$\dot{E} = 1600 \times 10^{30}\,\mathrm{ergs\,s^{-1}}$

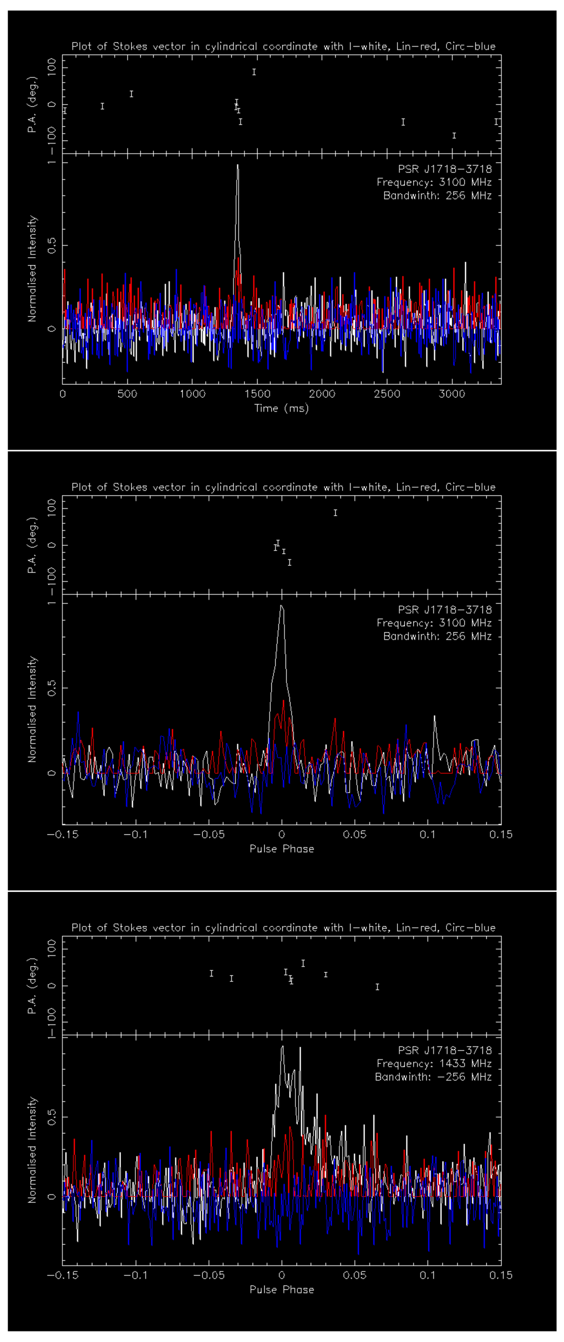

Figure 1: *Polarization profiles for PSR J1718-3718 at 3100 and 1433 MHz, showing total intensity as a white line, with linear intensity as red, and circular intensity as blue lines. The upper panels show the position angle of the linear polarization.*

PSR J1734-3333

$P = 1.169\,\mathrm{s}$ $\dot{P}_{-15} = 2279$
$l = 354.82°$ $b = -0.43°$
$DM = 578\,\mathrm{pc\,cm^{-3}}$ $S_{1400} = 0.5\,\mathrm{mJy}$
$\tau_c = 8.13\,\mathrm{kyr}$ $B_{surf} = 5.22 \times 10^{13}\,\mathrm{G}$
$\dot{E} = 56000 \times 10^{30}\,\mathrm{ergs\,s^{-1}}$

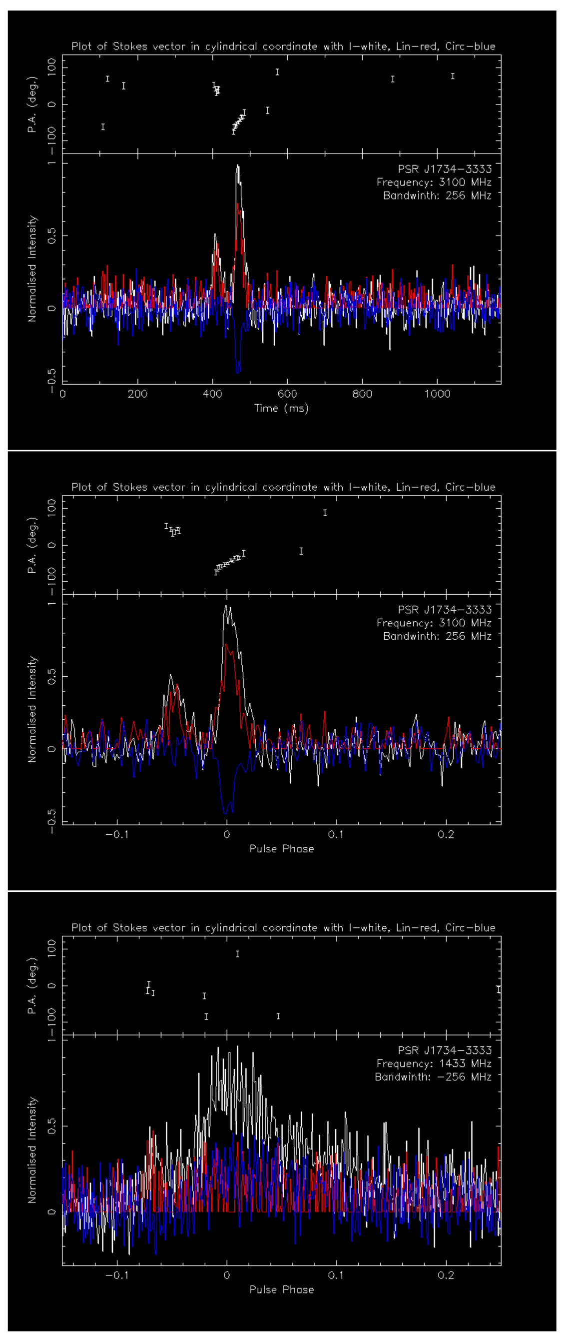

Figure 2: *Polarization profiles for PSR J1734-3333 at 3100 and 1433 MHz, showing total intensity as a white line, with linear intensity as red, and circular intensity as blue lines. The upper panels show the position angle of the linear polarization.*

PSR J1814-1744

$P = 3.976\,\mathrm{s}$ $\dot{P}_{-15} = 743$
$l = 13.02°$ $b = -0.21°$
$DM = 792\,\mathrm{pc\,cm^{-3}}$ $S_{1400} = 0.7\,\mathrm{mJy}$
$\tau_c = 84.8\,\mathrm{kyr}$ $B_{surf} = 5.50 \times 10^{13}\,\mathrm{G}$
$\dot{E} = 470 \times 10^{30}\,\mathrm{ergs\,s^{-1}}$

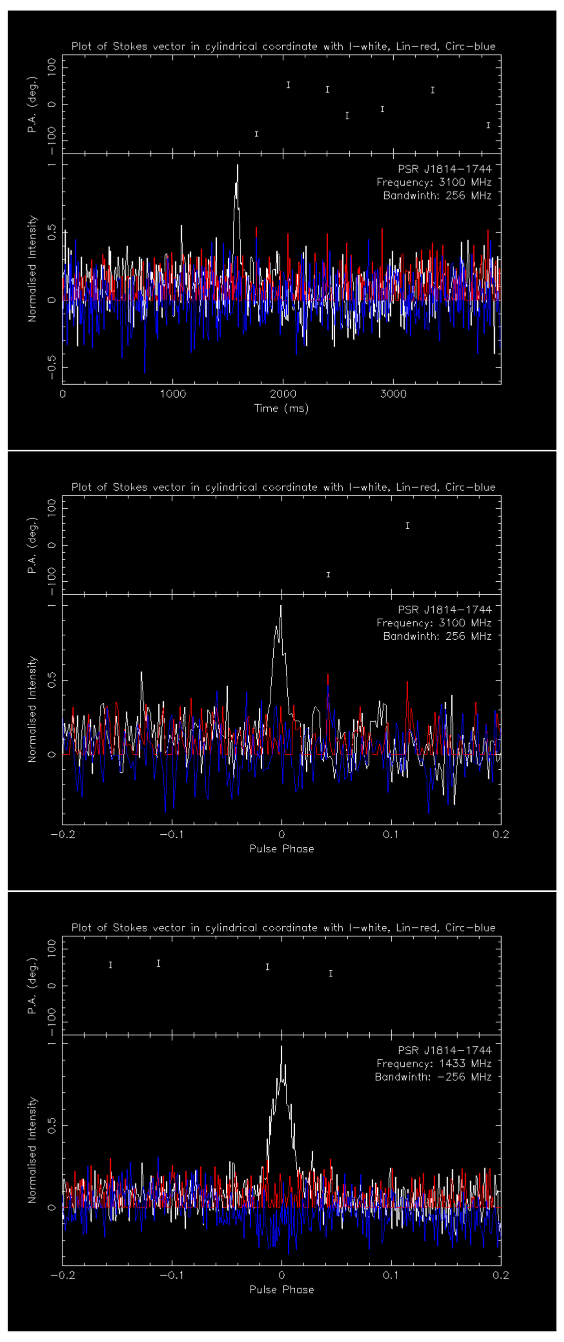

Figure 3: *Polarization profiles for PSR J1814-4444 at 3100 and 1433 MHz, showing total intensity as a white line, with linear intensity as red, and circular intensity as blue lines. The upper panels show the position angle of the linear polarization.*

PSR J1847-0130

$P = 6.707\,\mathrm{s}$ $\dot{P}_{-15} = 1275$
$l = 31.15°$ $b = 0.17°$
$DM = 667\,\mathrm{pc\,cm^{-3}}$ $S_{1400} = 0.33\,\mathrm{mJy}$
$\tau_c = 83.3\,\mathrm{kyr}$ $B_{surf} = 9.36 \times 10^{13}\,\mathrm{G}$
$\dot{E} = 170 \times 10^{30}\,\mathrm{ergs\,s^{-1}}$

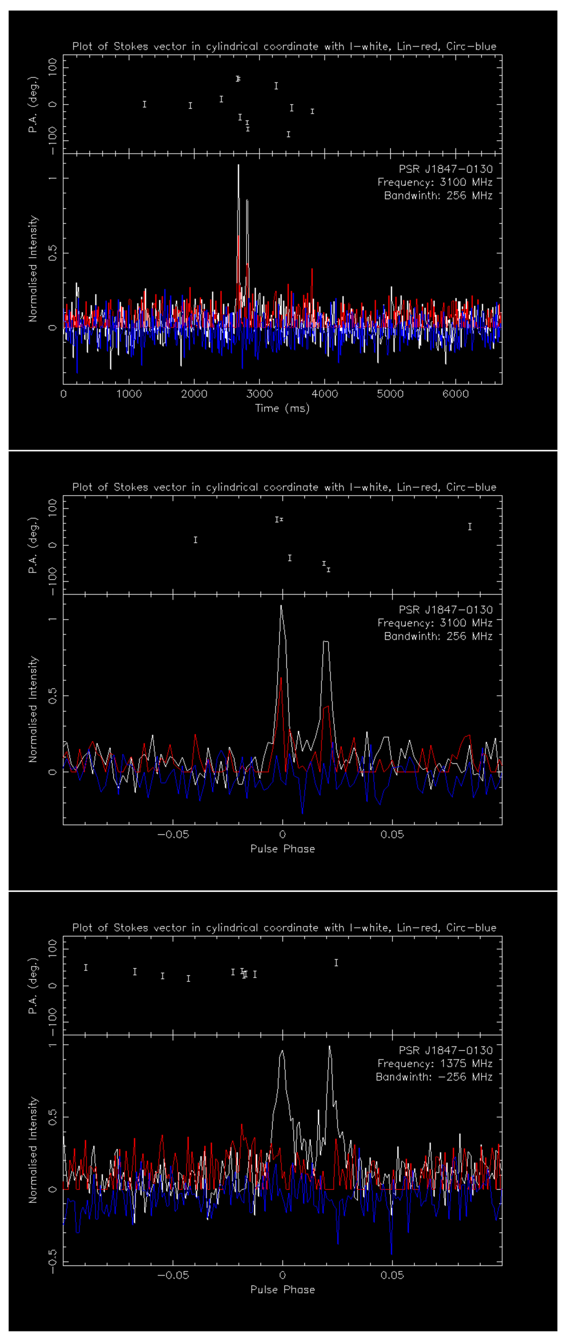

Figure 4: *Polarization profiles for PSR J1847-0130 at 3100 and 1375 MHz, showing total intensity as a white line, with linear intensity as red, and circular intensity as blue lines. The upper panels show the position angle of the linear polarization.*

PSR J2144-3933

$P = 8.510\,\mathrm{s}$ $\dot{P}_{-15} = 0.496$
$l = 2.79°$ $b = -49.47°$
$DM = 3.35\,\mathrm{pc\,cm^{-3}}$ $S_{1400} = 0.8\,\mathrm{mJy}$
$\tau_c = 272000\,\mathrm{kyr}$ $B_{surf} = 0.208 \times 10^{13}\,\mathrm{G}$
$\dot{E} = 0.032 \times 10^{30}\,\mathrm{ergs\,s^{-1}}$

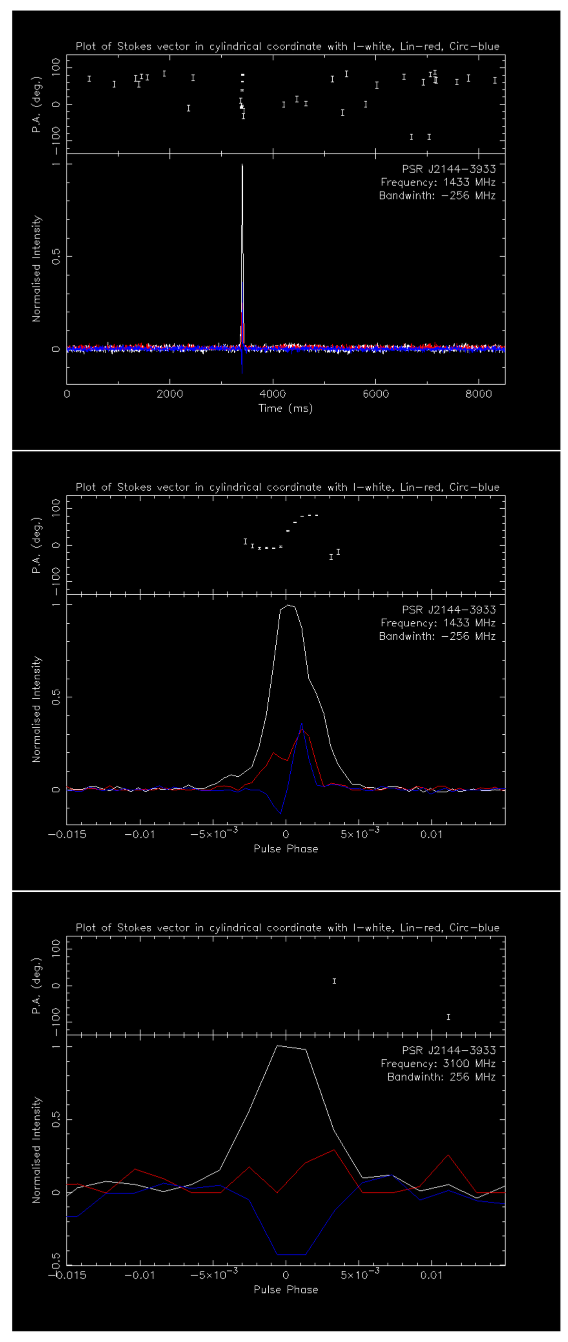

Figure 5: *Polarization profiles for PSR J2144-3933 at 1433 and 3100 MHz, showing total intensity as a white line, with linear intensity as red, and circular intensity as blue lines. The upper panels show the position angle of the linear polarization*

The first results

All pulsars that we've shown here are challenging for search as well for analysis: a) detection of long-period pulsars using conventional search techniques is a hard job, as red noise in FT of time series seriously reduces the sensitivity; b) all our pulsars are very faint, near the limit threshold of the instrument; c) for the generally accepted spectral index of -1.8 we would need hundreds of hours of observations to achieve only few S/N at 3100 MHz.

The fact that we detected HBRPs at 3100 MHz shows that they generally have flat radio spectra. Data at 700 MHz are not yet analyzed.

Profiles at 1433 MHz for the first two presented pulsars show significant broadening of an intrinsically sharp pulse which is due to ray scattering by irregularities in the ISM (characteristic of distant, high DM pulsars). The other two HBRPs are also very distant with high DMs, but do not show significant scattering. This show us that scattering is greater over lines of sight which are toward to the Galactic centre.

It has been shown that fractional linear polarization generally decreases with increasing frequency, but our results do not support this. The HBRPs shown here (except J1814-1744, which doesn't show any sign of polarization at any frequency) have higher linear polarisation at 3100 MHz compared to lower frequencies. All these HBRPs are young pulsars with pulse profiles which consist of one or two prominent components with high linearly polarized fraction at higher frequency, which is consistent with [2].

PSR J2144-3933 which is part of our low-magnetic-field sample, shows curious features: 1) polarization intensities at low frequencies are stronger compared with published data, 2) there is a significant increase in circular polarization going towards higher frequencies, & 3) depolarization of linear component at 3100 MHz (which may be due to reduction of profile resolution). All of these need to be explored in more detail.

Using birthrate code from [4] and accurately accounting for all known selection effects we have calculated that 187±103 long-period radio pulsars with magnetic field above the quantum critical field are active in Galaxy with one of this kind of pulsar born each 500 years in the galaxy.

Summary

The idea that HBRPs were born as a slow rotators is in agreement with [1], where they argued that initial neutron star spin periods may depend critically on their magnetic fields. There is a tendency for high-field systems to be born as slow rotators. Moreover, recent results by [3] do not find evidence that magnetars are formed from millisecond proto-NSs allowing for the possibility that magnetars descend from stellar progenitor with high magnetic field cores, which supports the fossil-field hypothesis [1]. It remains unclear if HBRPs evolve to become magnetars or if HBRPs and magnetars are separate populations, different from birth.

Acknowledgements

The ATNF Pulsar Catalogue has been used: *http://www.atnf.csiro.au/research/pulsar/psrcat/*, (Manchester, R. N., Hobbs, G. B., Teoh, A. & Hobbs, M., 2005, AJ, 129, 1993). All data were analyzed off-line using the *PSRCHIVE* software package (Hotan A. W., van Straten W., and Manchester, R. N., 2004, PASA, 21, 302): *http://www.atnf.csiro.au/research/pulsar/psrcat/*

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