Population synthesis of radio pulsars in the Fermi era

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Abstract

We present results of our pulsar population synthesis of pulsars from the Galactic disk using our previously developed computer code. From our studies of observed radio pulsars that have clearly identifiable core and cone components, in which we fit the polarization sweep as well as the pulse profiles to constrain the viewing geometry, we develop a model describing the luminosity and ratio of radio core-to-cone peak fluxes. In this model, short period pulsars are more cone-dominated. We explore models of neutron star evolution with and without magnetic field decay, and with different initial period distributions. We present preliminary results including simulated population statistics that are compared with the observed radio pulsar population. The evolved neutron star populations resulting from the simulation can be used to model distributions of gamma-ray pulsars for comparison to Fermi results. See the poster P2-85 by Pierbattista, Grenier, Harding & Gonthier.

Magnetic field and period birth distributions – 2 Cases

•Case A – field decay – Following our previous studies (Gonthier et al. 2004), we assume the decay of the magnetic field with a decay constant of 2.8 Myr. While we do not advocate that this is a clear evidence for field decay, we find that this method allows one to incorporate an alternative to the standard vacuum, dipole spin-down, for example Contopoulos & Spitkovsky (2006).

•At Birth – two independent distributions

$$P(\log B_o) = \sum_{i=1}^{2} A_i e^{-(\log B_o - \log B_i)^2/\sigma_i^2}$$

i	A_i	$\log B_i$	σ_i
1	0.6	12.5	0.65
2	0.3	13.0	0.8

$$P(P_o) \propto e^{-(P_o - \hat{P}_o)^2/\sigma_{P_o}^2}$$

$$\hat{P}_o = 300 \text{ ms}$$

$$\sigma_{P_o} = 300 \text{ ms}$$

•Case B – No field decay – Due to the short field decay constant of 2.8 Myr, we develop a no field decay model exploring a radio luminosity law that is proportional to the square root of the spin-down power as suggested by Faucher-Giguère & Kaspi (2006). With our set of assumptions defining the radio beam geometry and luminosity, we are unable to reproduce the observed Pdot-P distribution. So in order to achieve reasonable agreement, we correlate the initial period distribution with the magnetic field, which remains constant with a single log-normal B distribution and a correlated Gaussian P_o distribution.

•At Birth – correlated initial period and magnetic field distributions

$$P(\log B, P_o) \propto \exp\left\{ -\left[\begin{array}{l} \left(\log B - \mu_{\log B}\right)^2/\sigma^2_{\log B} + \left(P_o - \mu_{P_o}\right)^2/\sigma^2_{P_o} \\ -2\rho_{B-P_0}\left(P_o - \mu_{P_o}\right)\left(P_o - \mu_{P_o}\right)/\left(\sigma_{\log B}\sigma_{P_o}\right) \end{array} \right] / 2 / \left(1 - \rho^2_{B-P_o}\right) \right\}$$

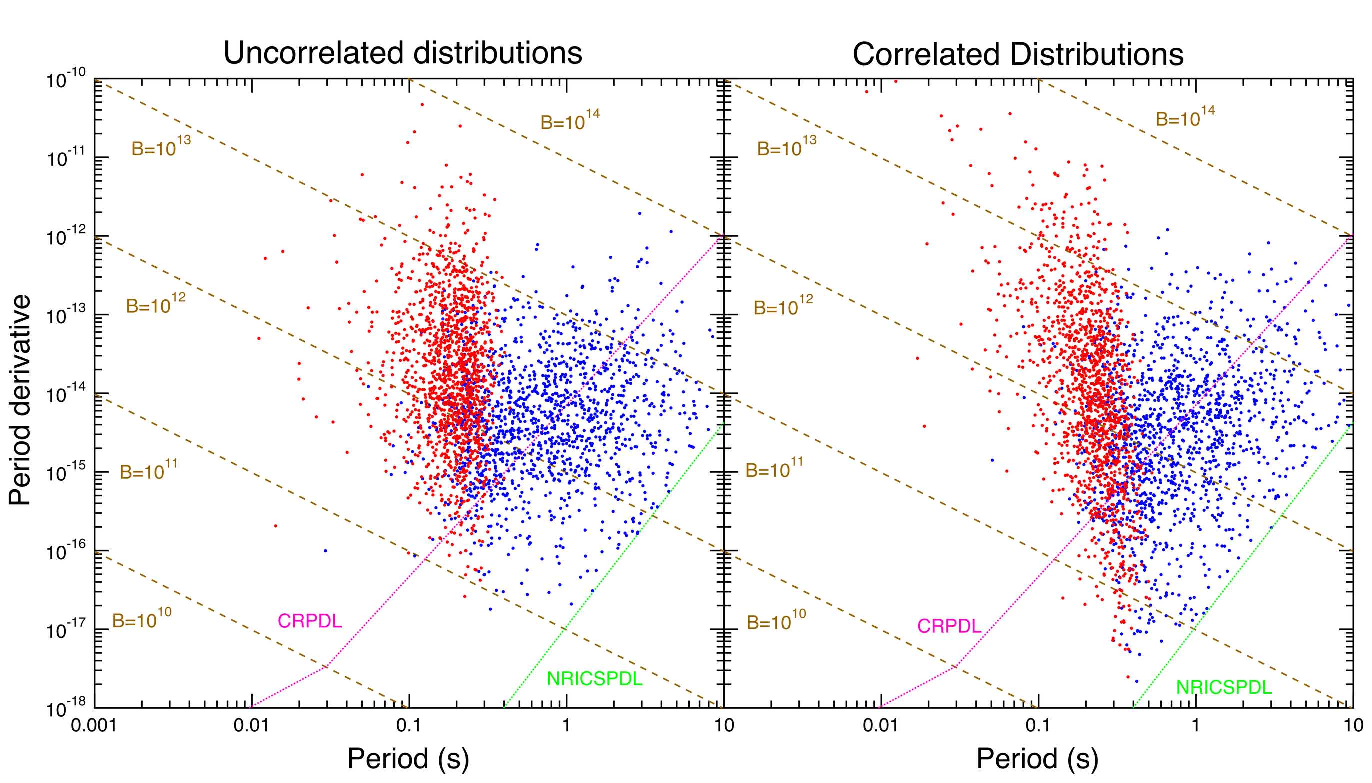
$$\mu_{\log B} = 12.9$$

$$\sigma_{\log B} = 0.7$$

$$\mu_{P_o} = 200 \text{ ms}$$

$$\sigma_{P_o} = 100 \text{ ms}$$

$$\rho_{B-P_0} = -0.6$$



– Figure 1 –

Pdot-P distribution of pulsars at birth (red) and at present (blue) illustrating the effect of correlating the magnetic field with the initial period using the same distributions in both cases. On the left the magnetic field distribution is the above distribution without the cross term while on the right they are correlated with the above coefficient of -0.6.

Radio Surveys

This population statistics study includes the characteristics of ten radio surveys including six with an observing frequency near 400 MHz - Arecibo 2 & 3, Greenbank 2 & 3, Molongo 2 and Parkes 2 surveys and four with an observing frequency near 1400 MHz - Parkes 1, Jodrell Bank 2, Parkes Multibeam and Swinburne Intermediate Latitude surveys. Our comparison group of pulsars are those detected by this group of surveys from which we derive pulsar statistics to compare to our simulation that includes the sensitivities of these radio surveys.

Radio luminosity

We use a luminosity model similar to the one used by Arzoumanian, Chernoff & Cordes (2002) (ACC) with the form given by

$$L_{\text{radio}} = \frac{66250}{R_f} P^{\alpha} \dot{P}_{15}^{\beta} \text{ mJy} \cdot \text{kpc}^2 \cdot \text{MHz}$$

We adjust the reduction factor R_f, and the exponents of the period α and period derivative β to achieve reasonable agreement among the properties of detected pulsars and those simulated as well as a neutron star birth rate similar to 2.1 neutron stars per century (Tammann, Löffler, & Schröder 1994). Our two cases discussed above required a set of different coefficients shown in the table below.

	R_f	α	β
Case A	1.7	-1.0	0.35
Case B	2.0	-1.5	0.5

Following the suggestion by Faucher-Giguère & Kaspi (2006), we constrain the radio luminosity of the no-field decay case B to be proportional to the square root of the spin-down power to explore if the need for field decay stems from our choice of the P and Pdot dependence of the radio luminosity. Despite choosing this dependence (Case B), we find that to avoid field decay we need to correlate the magnetic field to the initial period, which has a similar effect.

Radio Beam Geometry

CORE BEAM:

The core beam is assumed to be a Gaussian centered along the magnetic axis with a characteristic width, ρ_{core} (ACC):

$$\rho_{\text{core}} = 1^{\circ}.5 P^{-1/2}$$

CONE BEAM:

The conal beam following the work of Kijak & Gil (1998; 2003) is also described with a Gaussian with a characteristic width

$$\rho_{\text{cone}} = 1^{\circ}.24 r_{KG}^{1/2} P^{-1/2},$$

$$r_{KG} = 40 \nu_{\text{GHz}}^{-0.26} \dot{P}_{-15}^{0.07} P^{0.30}$$

where r_{KG} is the emission altitude in stellar radii. The characteristic width ρ_{cone} is the opening angle where the intensity of the profile is 0.1% of the peak intensity.

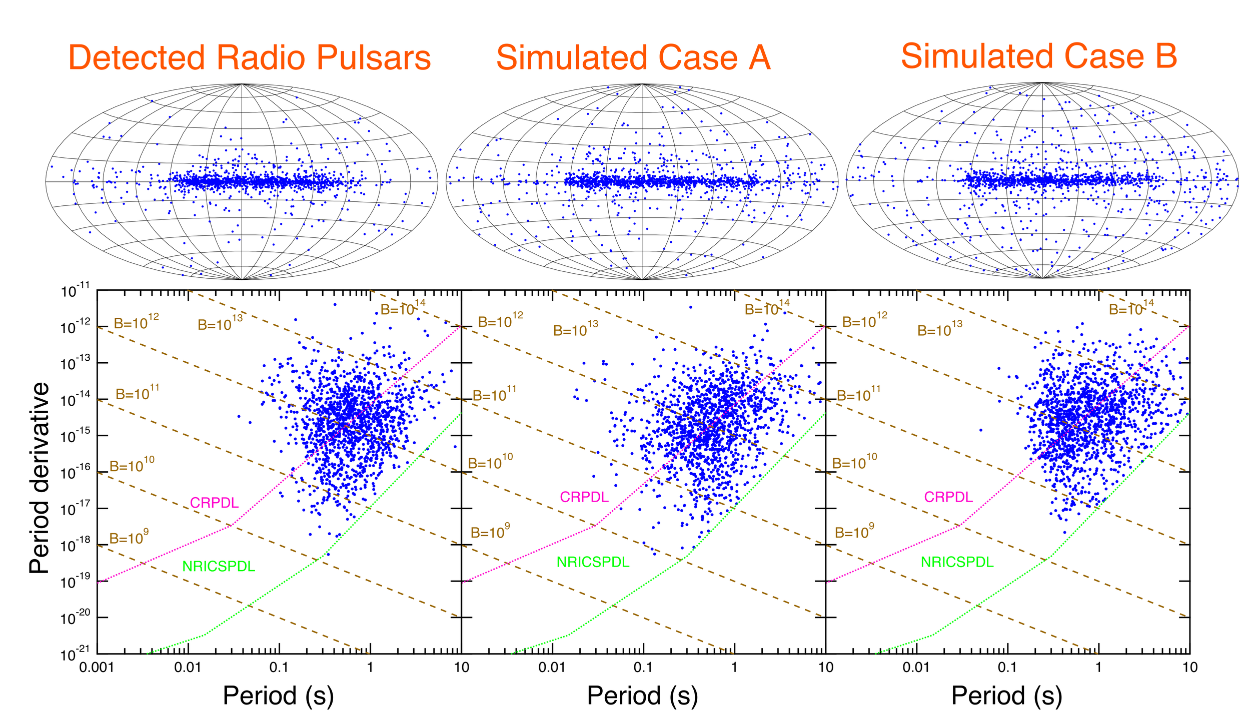
RATIO OF THE RADIO CORE-TO-CONE PEAK FLUXES:

Using this beam geometry and the Rotating Vector Model, we studied (Gonthier et al. 2006) about 20 pulsars with three peaks in their profiles and with polarization data in the EPN database primarily from the Gould & Lyne (1998). Using the above Kijak & Gil formulation for the cone beam from our fits of the profiles, we find a ratio of the core-to-cone peak fluxes to be

$$r_{\text{peak}} = \begin{cases} 25 P^{1.3} \nu^{-0.9}, & \text{for } P < 0.7\text{s} \\ 4 P^{-1.8} \nu^{-0.9}, & \text{for } P > 0.7\text{s} \end{cases}$$

where ν is the observing frequency in MHz. In this model, short period pulsars are much less core dominated and, in fact, when P < 0.05 s, the profile is cone dominated. Crawford et al. (2001 & 2003) studied a number of young pulsars, finding that the profiles have large linear polarization and little circular polarization, suggesting that the emission is cone dominated. More recently Johnston & Weisberg (2006) have a similar conclusion from polarization studies of 14 young pulsars.

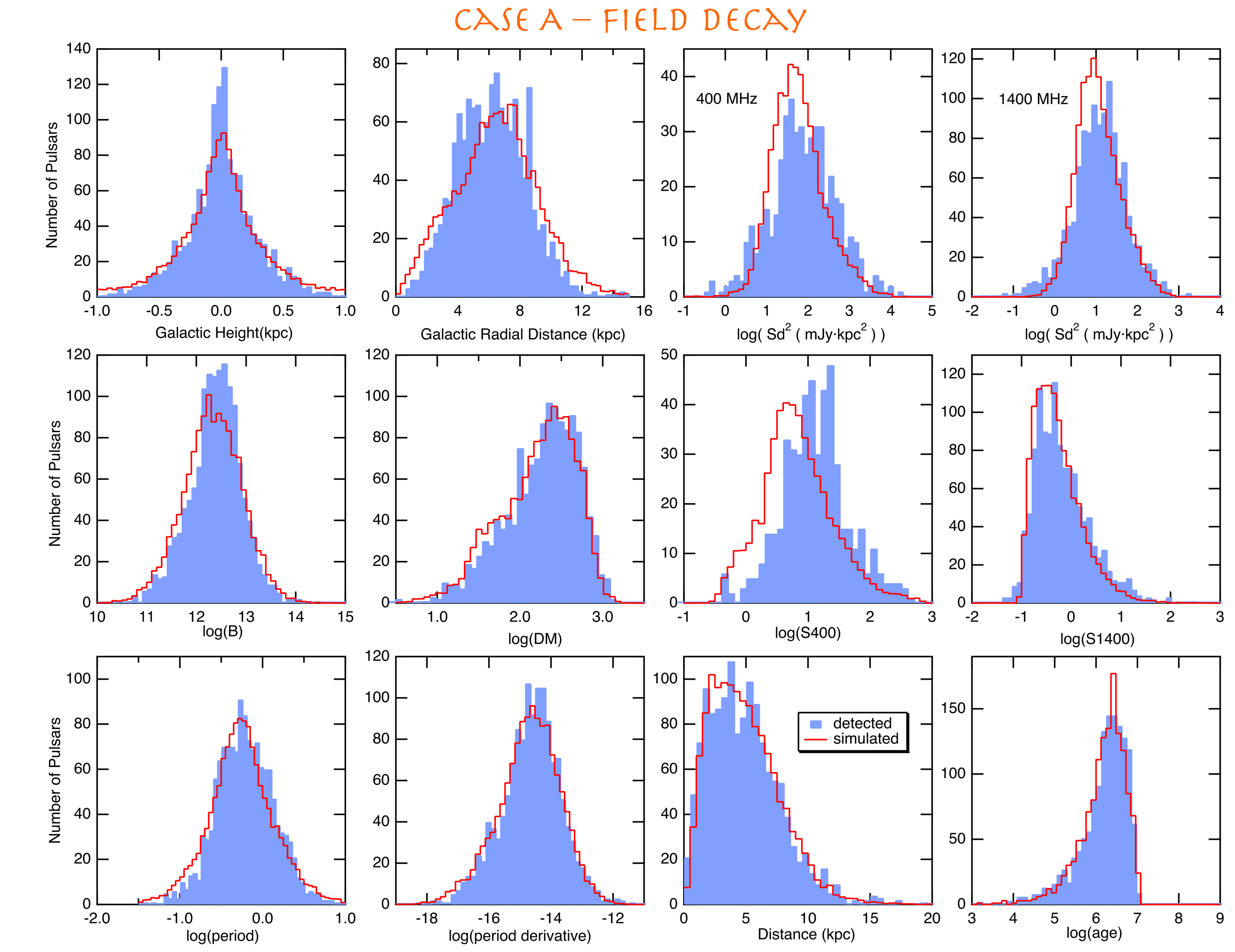
Aitoff Projections and Pdot – P Diagrams



– Figure 2 –

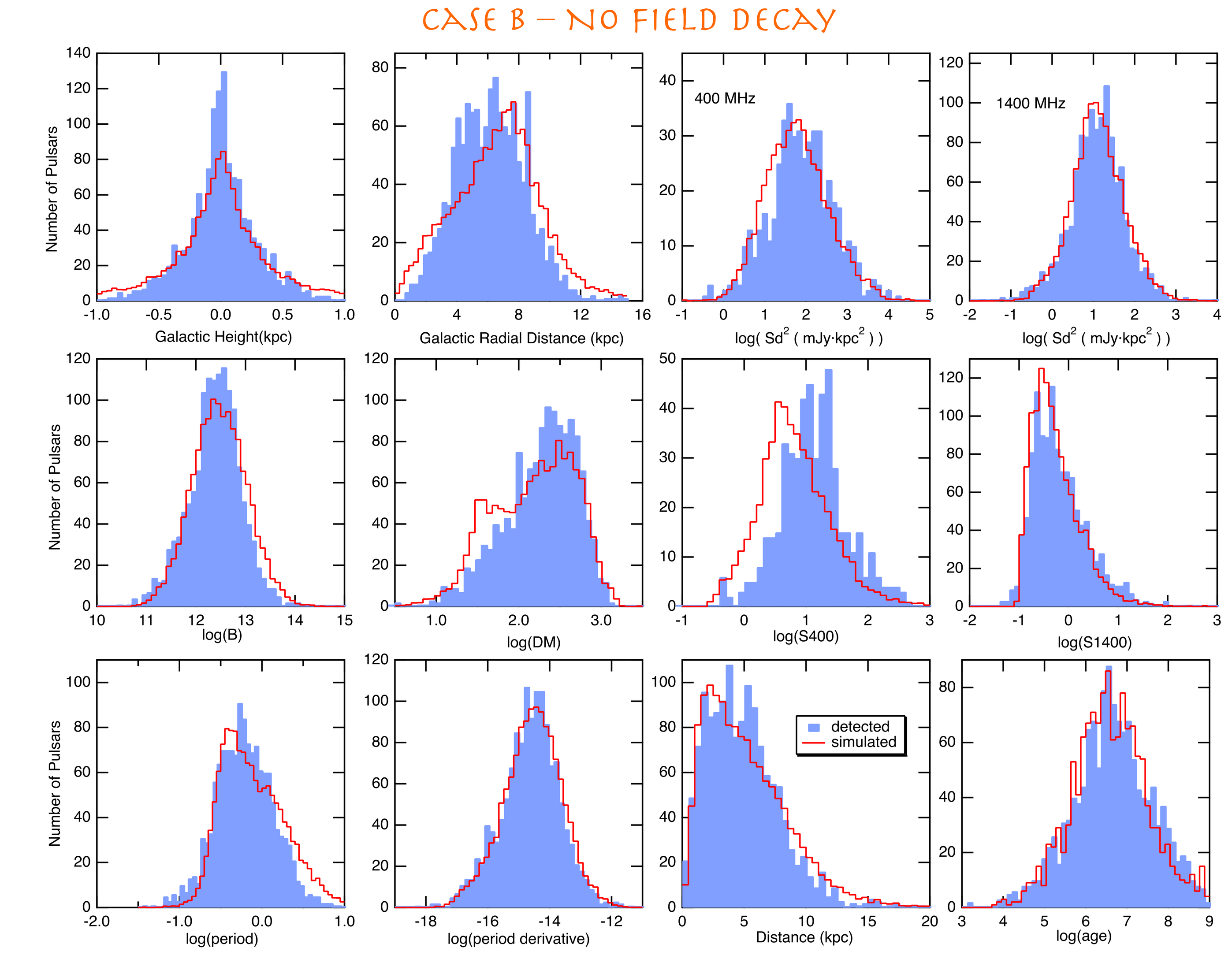
Pulsar Characteristics

CASE A – FIELD DECAY



– Figure 3 –

CASE B – NO FIELD DECAY



– Figure 4 –

Conclusions

- We find that we need a spin-down different than the standard vacuum dipole spin-down mimicked here by magnetic field decay or a correlation of the initial period with the magnetic field followed by dipole spin-down.
- Both very different cases explored here provide reasonable comparisons with characteristic of detected pulsars.
- The evolved population of neutron stars for both of these cases provide a population of gamma-ray pulsars that can be compared to Fermi detections. (See the poster See the poster P2-85 by Pierbattista, Grenier, Harding & Gonthier).

Acknowledgements

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