Population synthesis of radio and gamma-ray normal, isolated pulsars using Markov Chain Monte Carlo

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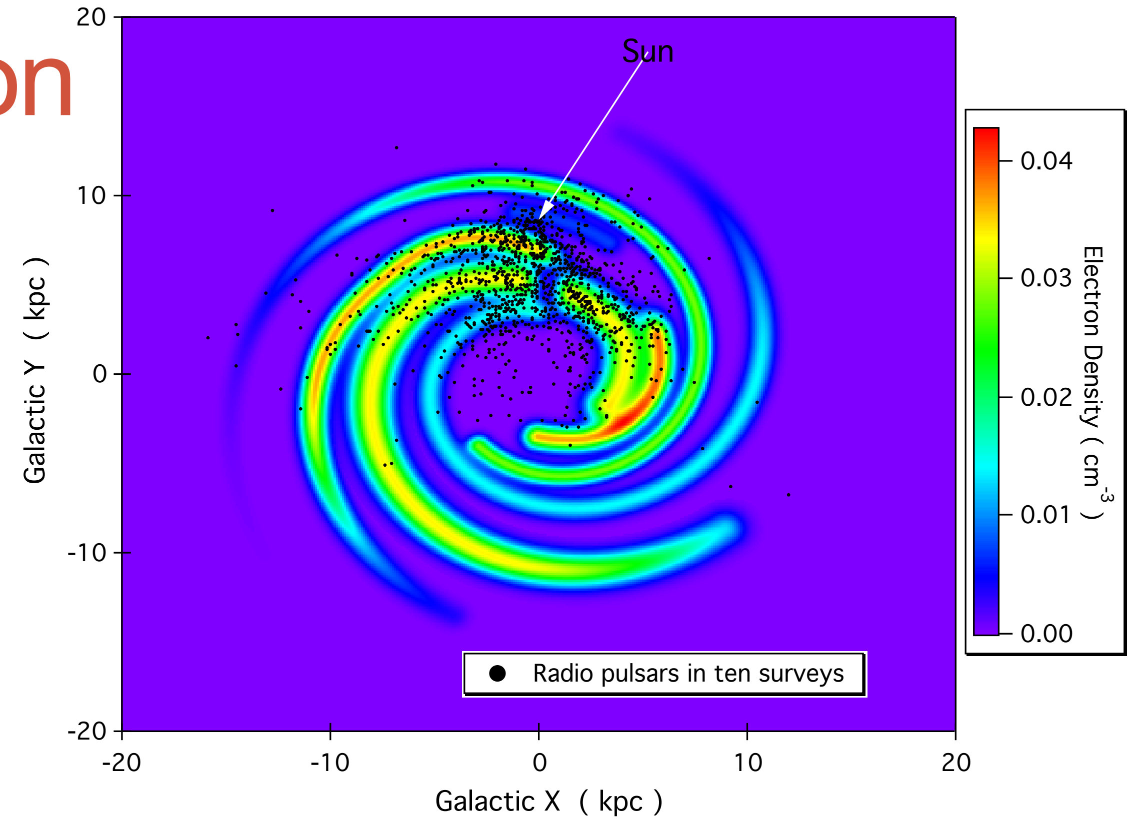
Birth and evolution

- Neutron stars are seeded in the spiral arms using the electron density model NE2001 - Cordes & Lazio (2003)



Supernova kick velocity distribution – Faucher-Giguère Kaspi (2006) – double sided exponential distribution of components

Trajectories are evolved in the Galactic potential – Paczyński (1990)

Birth magnetic field and period distributions

- For B_o – Log normal distribution
- For P_o - Gaussian distribution – need to explore other distributions
- Four free parameters to define the means and widths

Spindown

- Tchekhovskoy, Spitkovsky & Li (2013)

$$L = \left(1 + 1.2\sin^2\chi\right)L_o$$

Case 1 - Inclination angle alignment model – Weltevrede & Johnston (2008)

$$\sin^2\chi = \sin^2\chi_o e^{-t/\tau_\chi} \qquad \tau_\chi \sim 70\,\mathrm{Myr}$$

Case 2 - Magnetic field decay model – Colpi, Geppert & Page (2000)

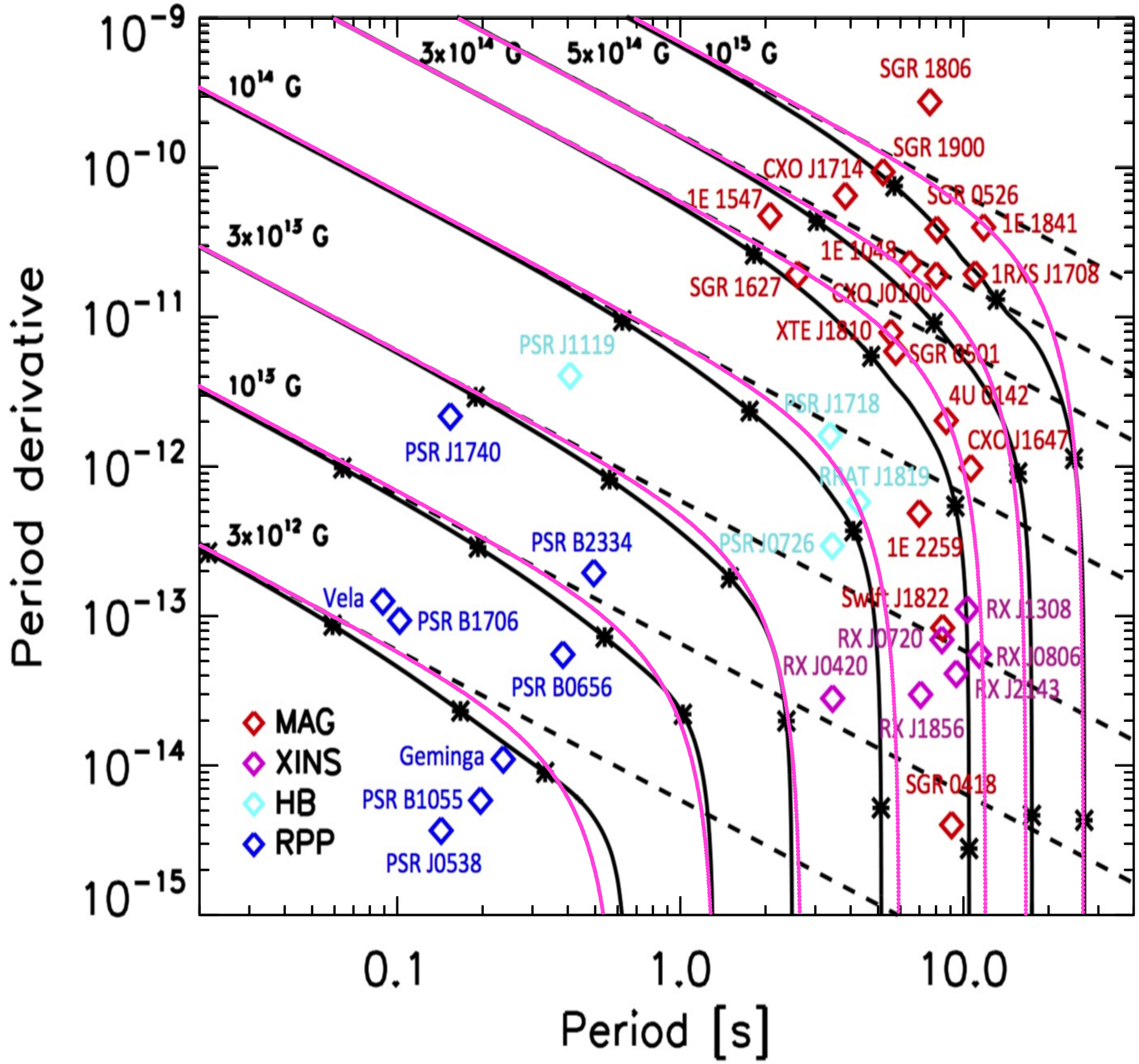
$$\frac{dB}{dt} = -aB^{1+\alpha}$$

Viganò et al. (2013) – Figure 10

$$a = 1\,\mathrm{Myr}^{-1}$$

$$\alpha = 0.7$$

$$\frac{dB}{dt} = -aB^{1+\alpha}$$



Radio beam geometry and emission

- Following Harding, Grenier & Gonthier (2007) and Pierbattista, Grenier, Harding & Gonthier (2012)
- Core and conal beams
  - Conal – altitude dependence following Kijak & Gil (2003)
  - In this study no special treatment for young pulsars, but we need to do something - ~ high altitude emission
  - Core-to-cone luminosity dependence – broken power law
- Radio luminosity – P and P_{dot} dependence as in previous studies

$$L_{\nu} = f\, P^{\alpha_R} \dot{P}^{\beta_R} \ \ \mathrm{mJy} \cdot \mathrm{kpc}^2 \cdot \mathrm{Mhz}$$

  - Exponents are free parameters

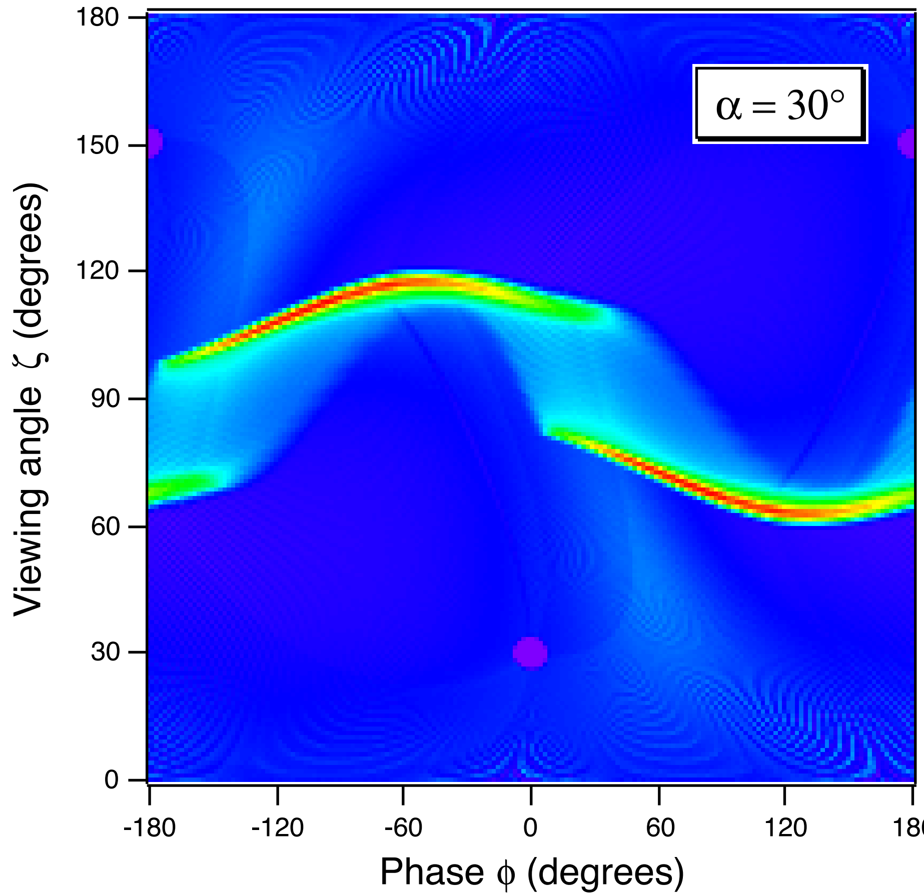
Gamma-ray beam geometry and emission

- Gamma-ray sky maps - Extended slot gap emission from Muslimov & Harding (2004)

- Gamma-ray luminosity similar to radio luminosity

$$L_\gamma = f\, P^{\alpha_\gamma}\, \dot{P}^{\beta_\gamma}\ \ \mathrm{mJy} \cdot \mathrm{kpc}^2 \cdot \mathrm{Mhz}$$

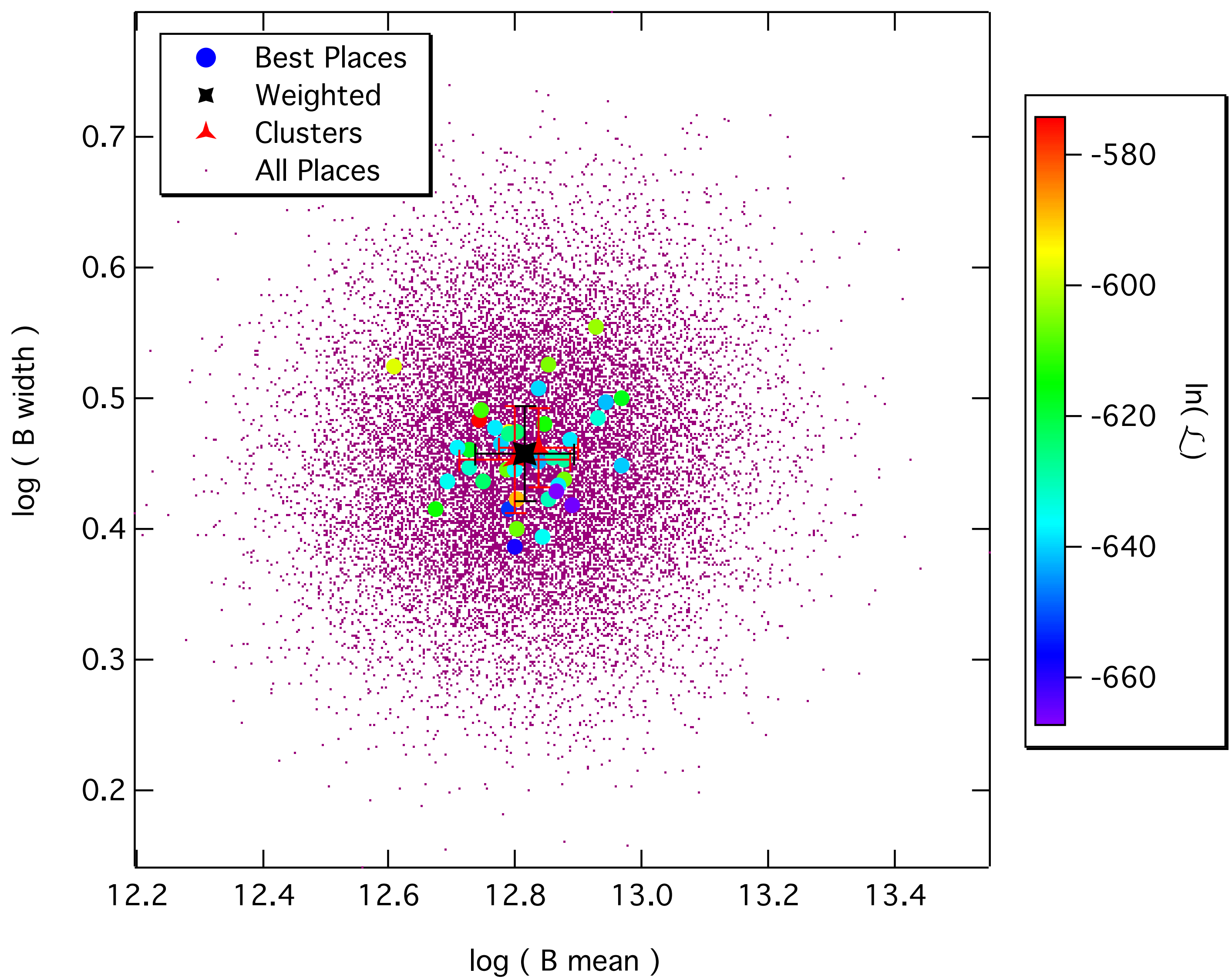
- Two more free parameters for a total of eight.



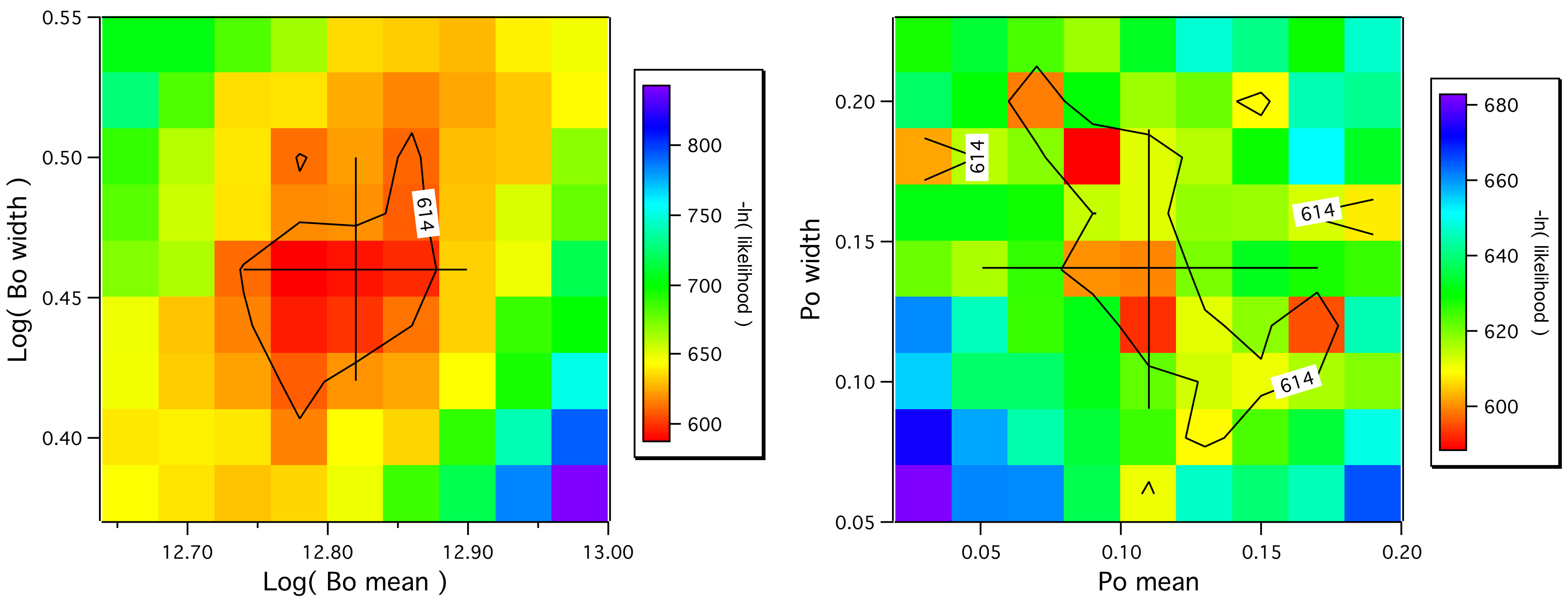
Markov Chain Monte Carlo

- 8 free parameters
- We compare 11 – 1 D histograms of P_{dot}, P, age, B, S_{1400} radio and gamma-ray pulsars as well as gamma-ray flux of Fermi pulsars.
- Each chain begins in a random place
- Large world - random uniform steps are performed if the ln likelihood increases, the small world is explored with normally distributed smaller steps
- Run for 500 simulations or 24 hours of CPU
- Weighted average and standard deviations are obtained from the final “best” place of each chain
- A K_{means} analysis is performed to examine the possibility of two clusters or regions of preference.

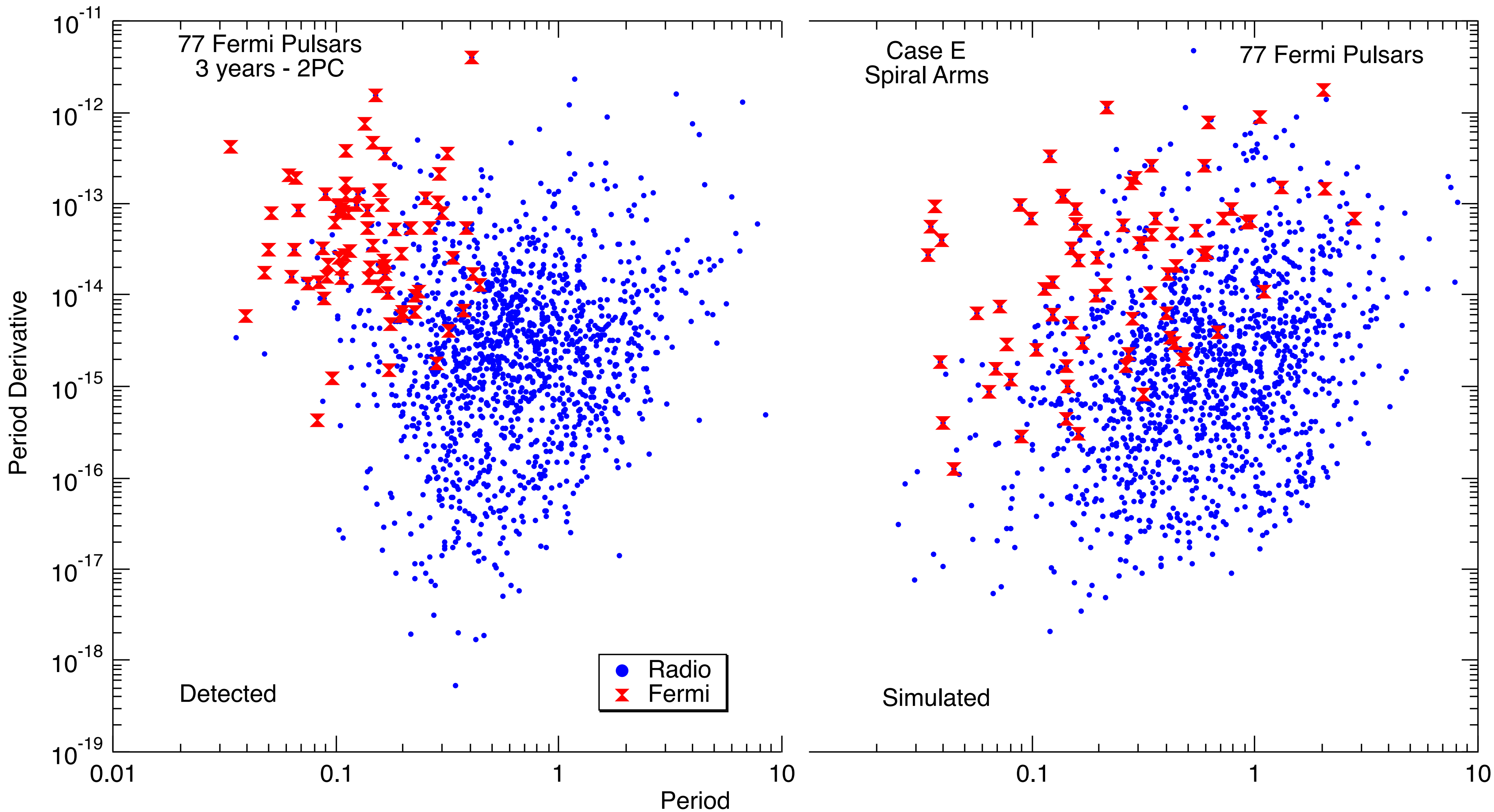
Example of case 2 – B field decay



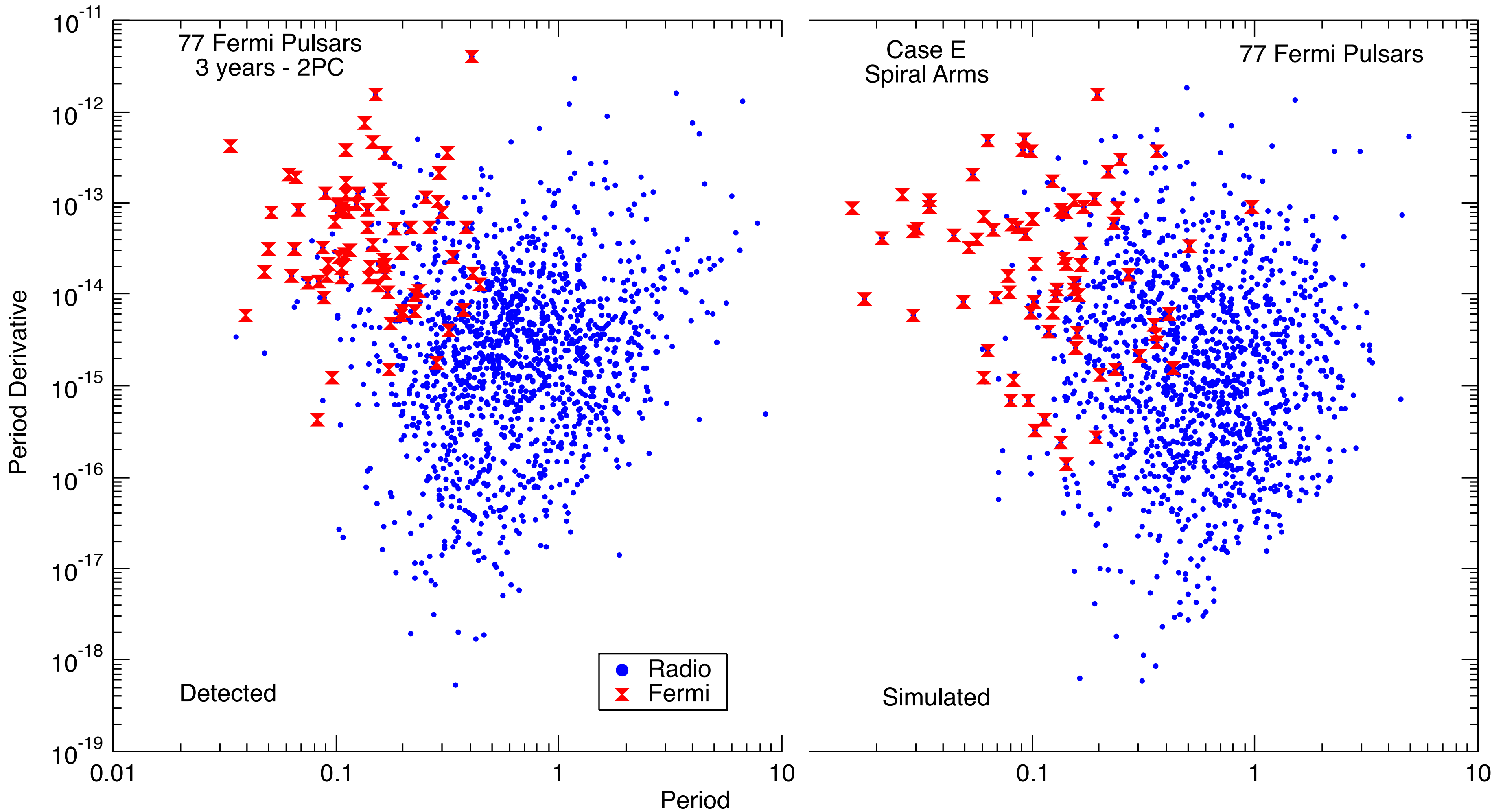
4 dimensional grid search



Case 1 – inclination angle alignment model



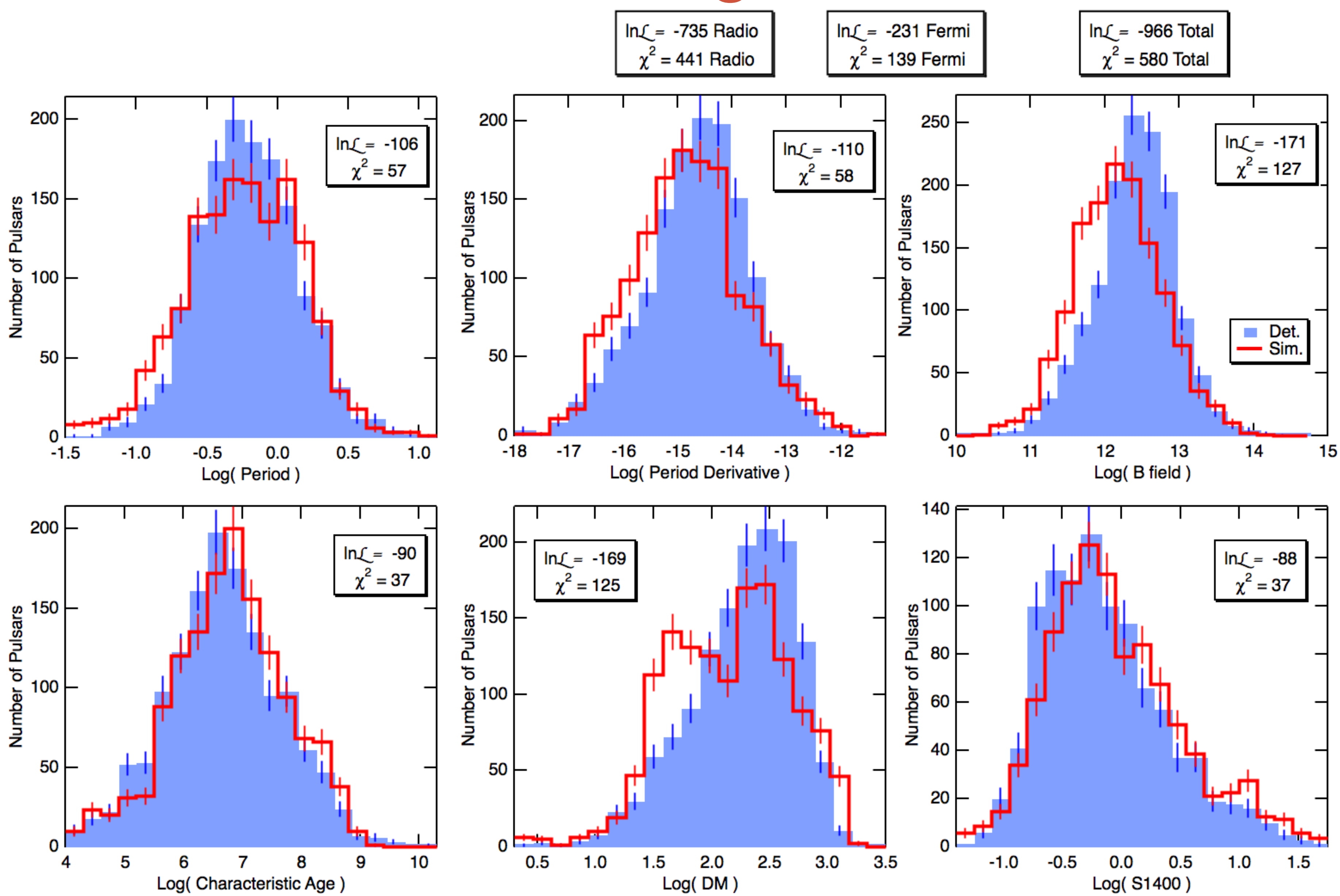
Case 2 – B field decay model



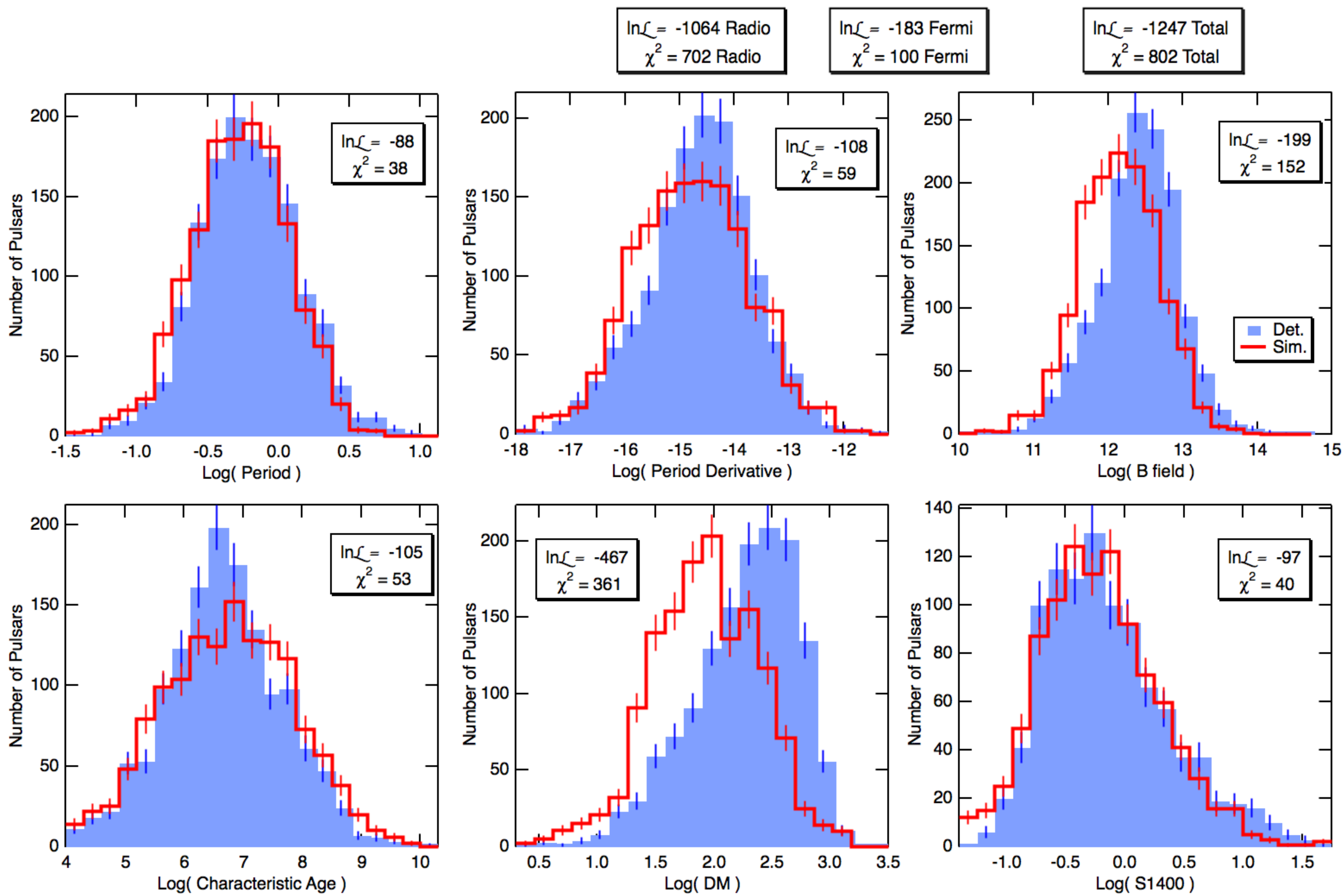
Conclusions

- Magnetic field decay seems to produce better agreement between the two models.
- However, the agreement is not entirely satisfactory as the Fermi high-spindown pulsars are not quite in the correct place in the P_{dot} – P diagram
- We need to compare 2D P_{dot} – P distributions.
- We need to examine the issue of convergence in the MCMC simulations
- We need to establish the confidence regions in the parameter space.
- More effort is on the way

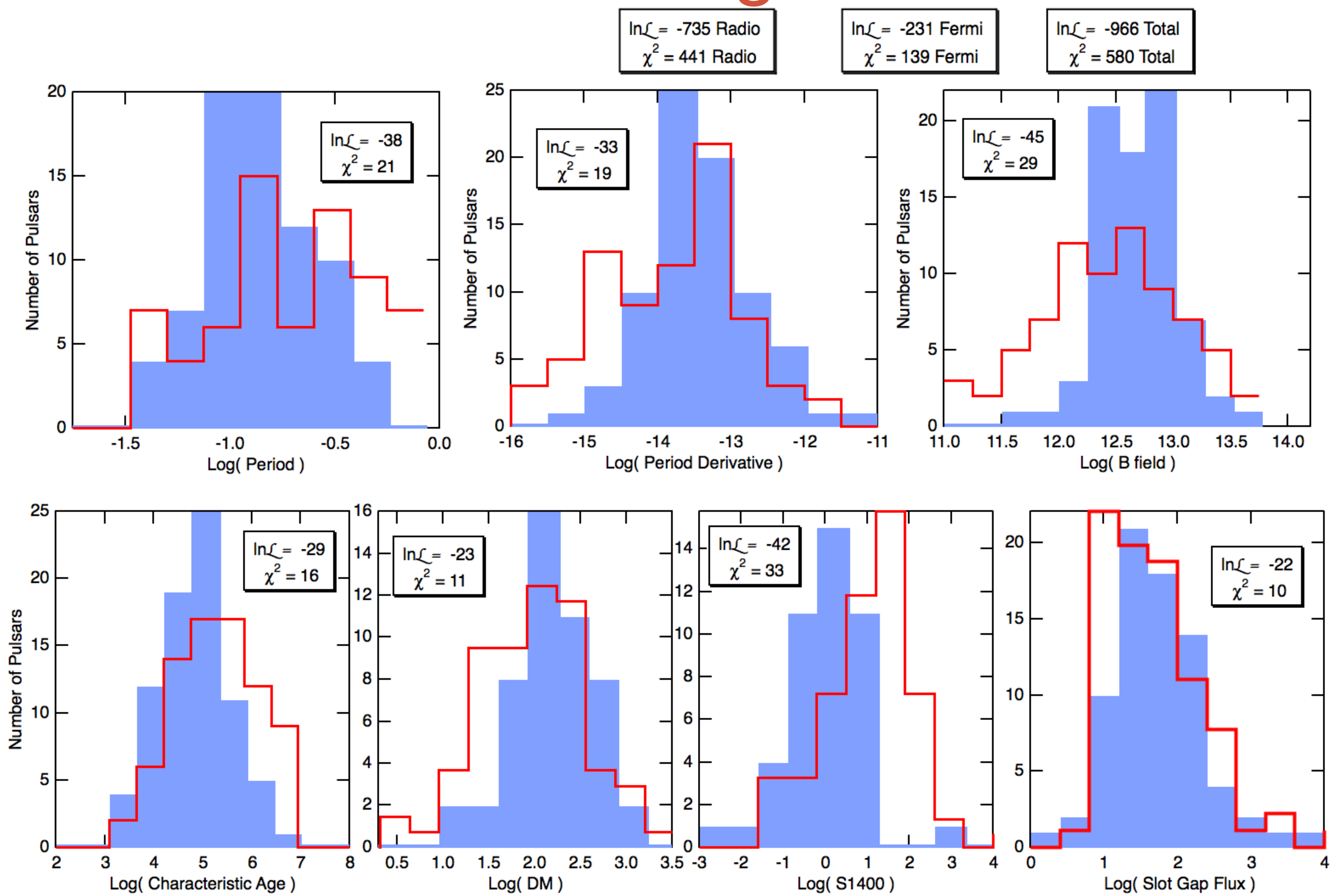
Case 1 – radio histograms



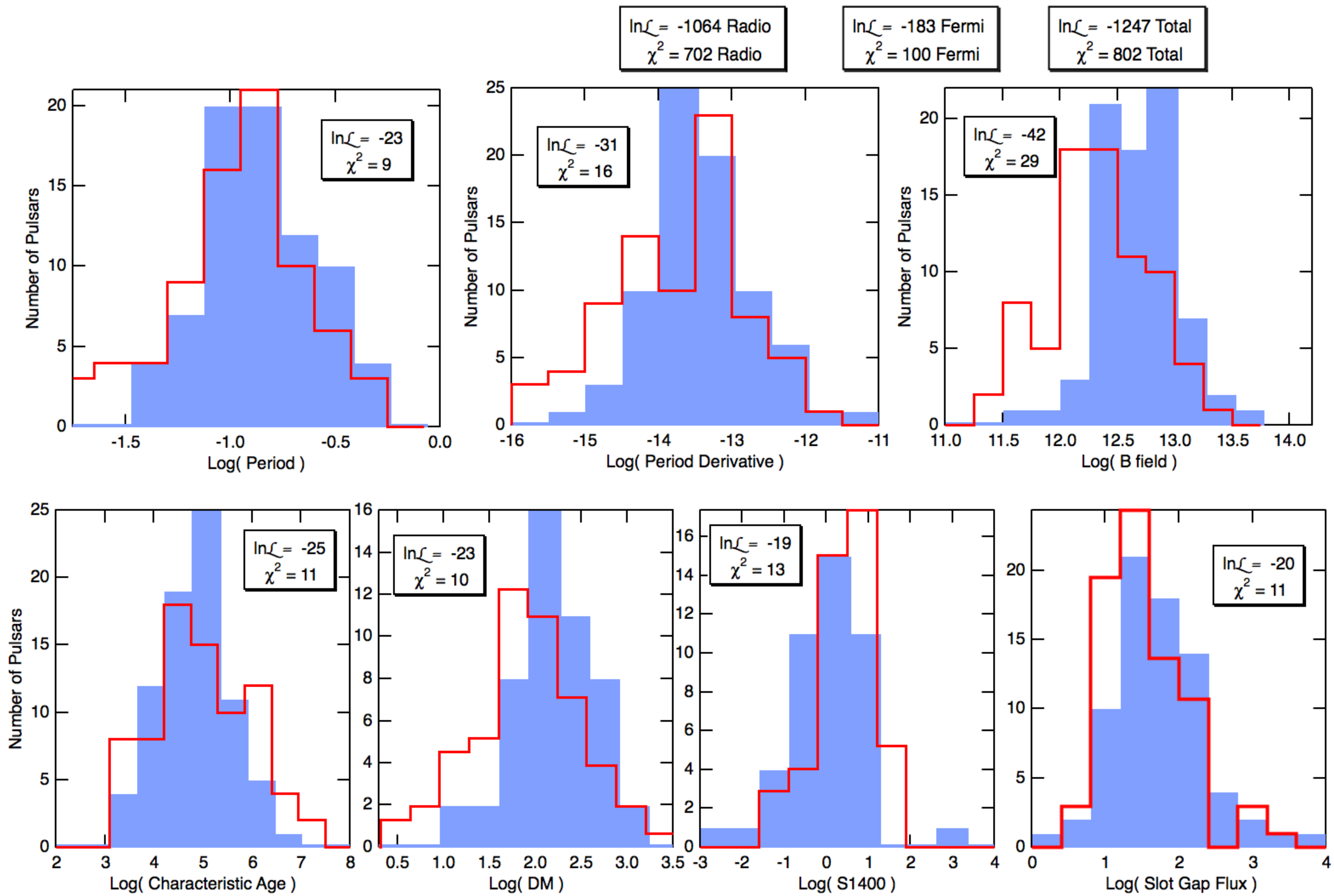
Case 2 – radio histograms



Case 1 – Fermi histograms

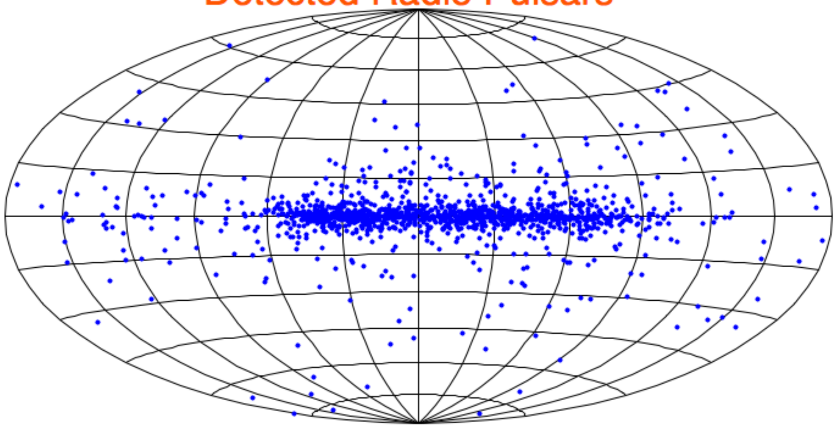


Case 2 – Fermi histograms

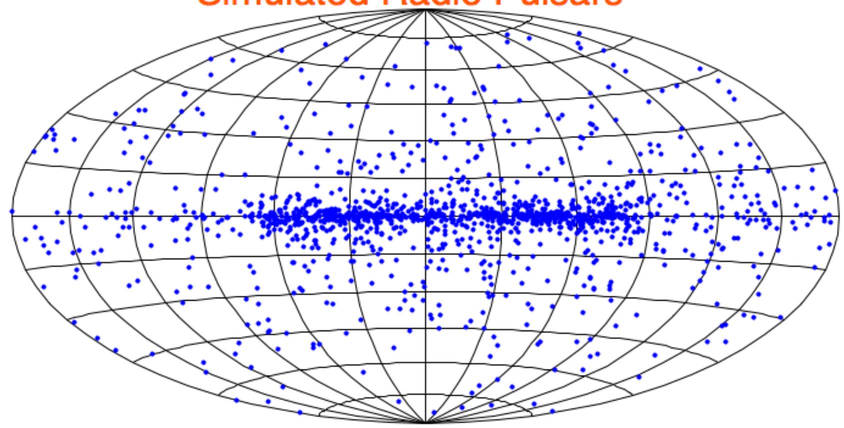


Case 1 – Aitoff plots

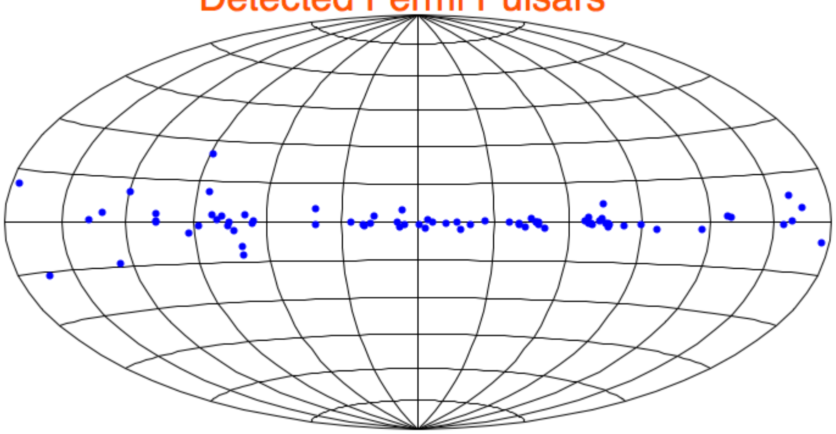
Detected Radio Pulsars



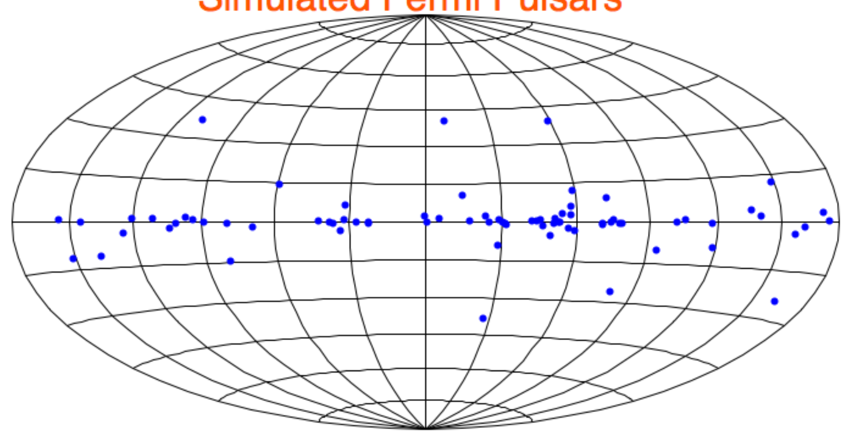
Simulated Radio Pulsars



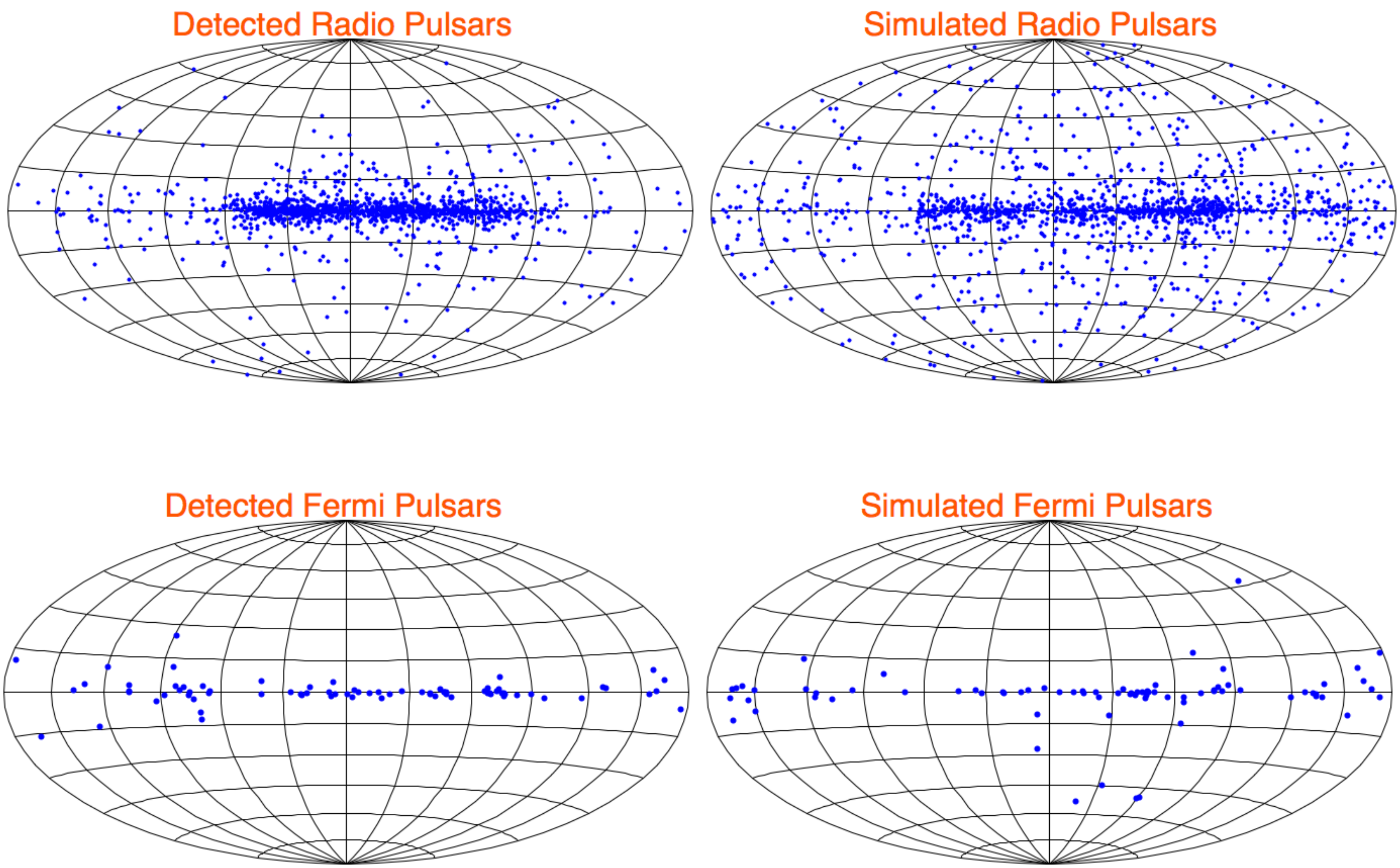
Detected Fermi Pulsars



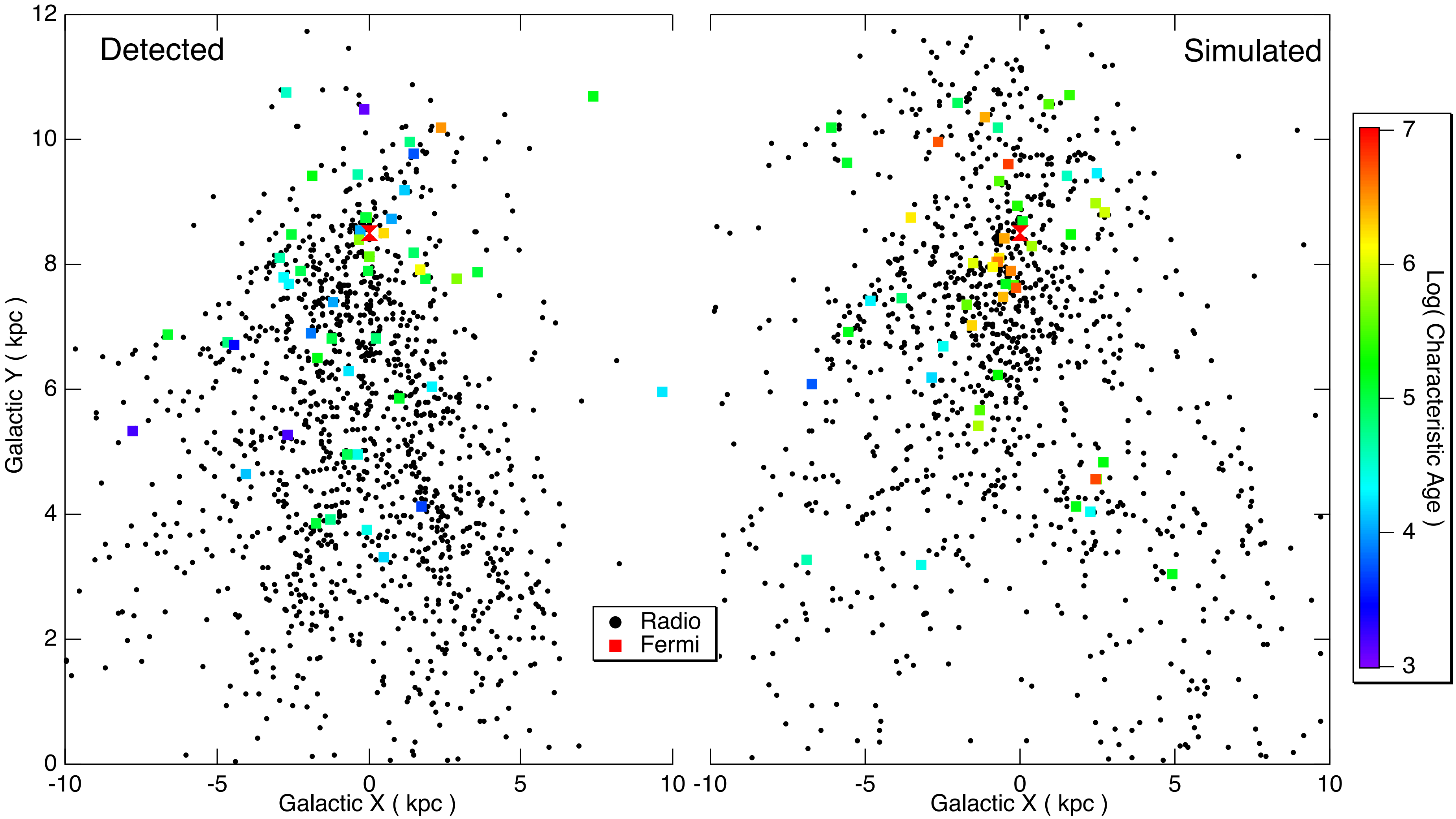
Simulated Fermi Pulsars



Case 2 – Aitoff plots



Case 1 – xy Galactic plane



Case 2 – xy Galactic plane