Population Synthesis of Radio and Gamma-ray Pulsars in the Fermi Era

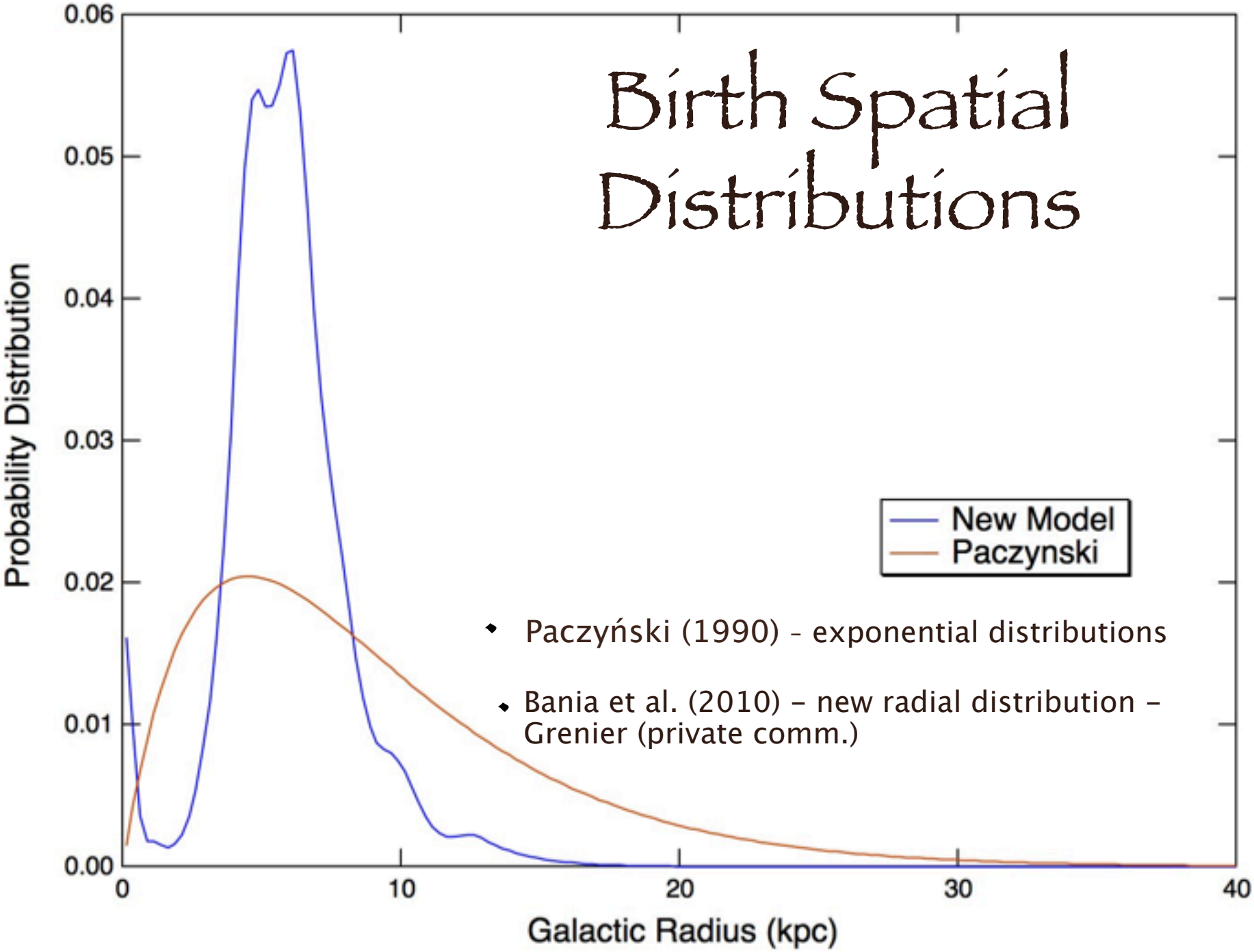
Peter L. Gonthier & Caleb Billman
Hope College, Holland, Michigan USA,
Victoria E. Merten, Washington & Jefferson College,
Washington, Pennsylvania USA
&
Alice K. Harding
NASA Goddard Space Flight Center
Greenbelt, Maryland USA

Topics

- Population statistics study of millisecond (MSPs) and normal, isolated (NPs) pulsars using both radio and Fermi observations

- Steps
  - Birth and evolution
  - Spin down
  - Emission
  - Detection

Birth Spatial Distributions

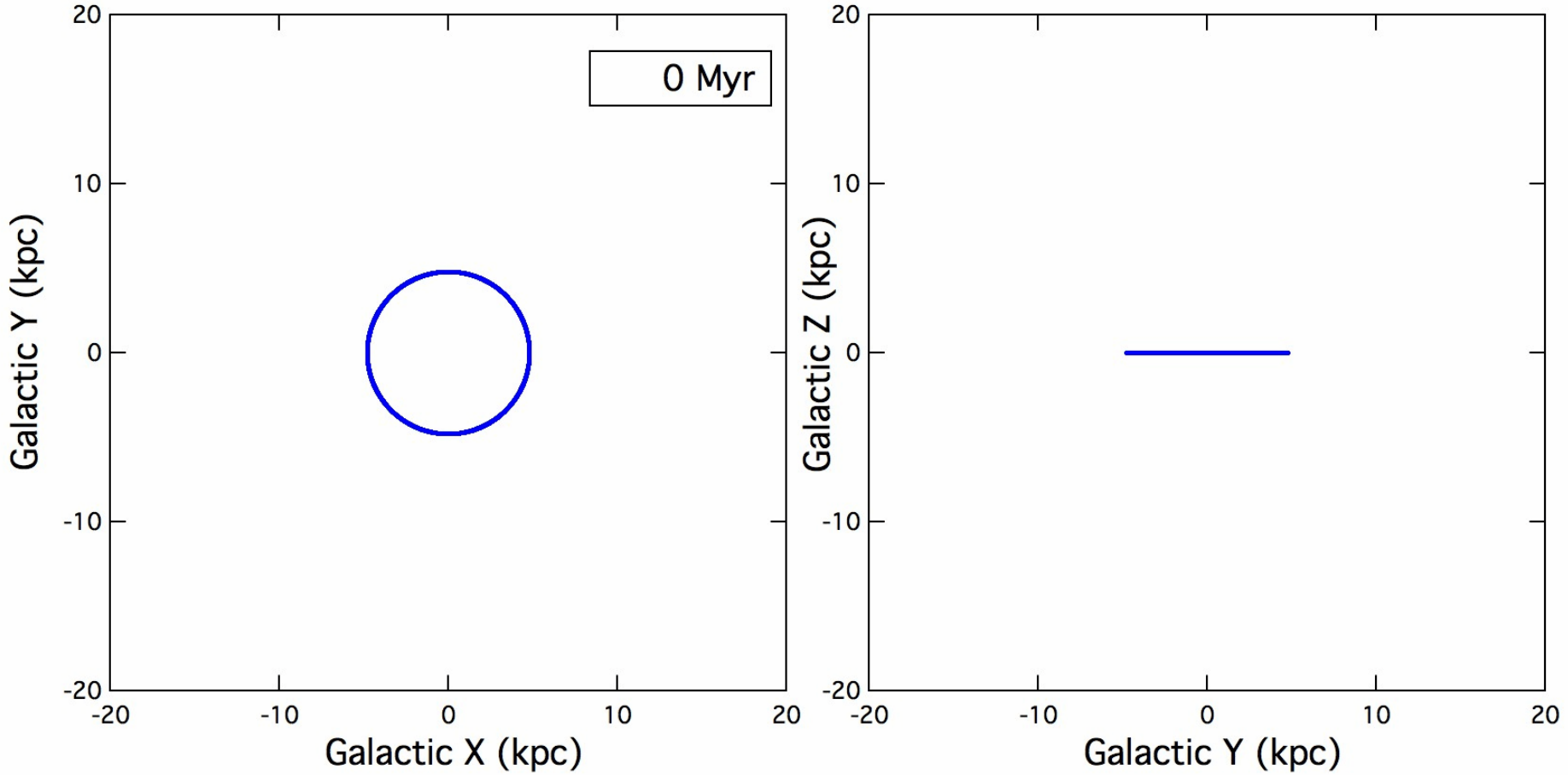


- Paczyński (1990) – exponential distributions
- Bania et al. (2010) – new radial distribution – Grenier (private comm.)

Supernova Kick

Hobbs et al. 2005 for both NPs and MSPs

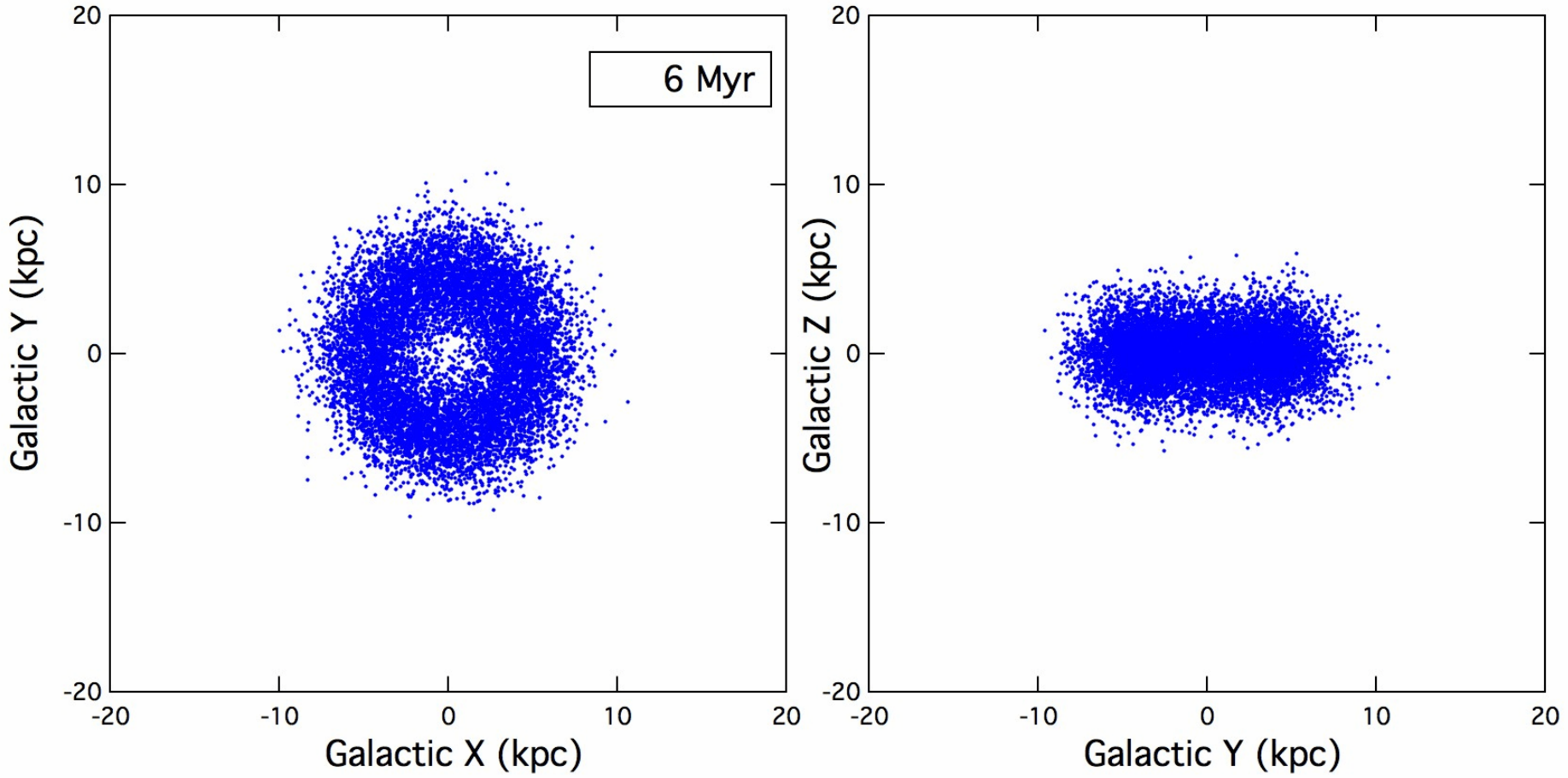
Galactic potential - Paczyński (1990)



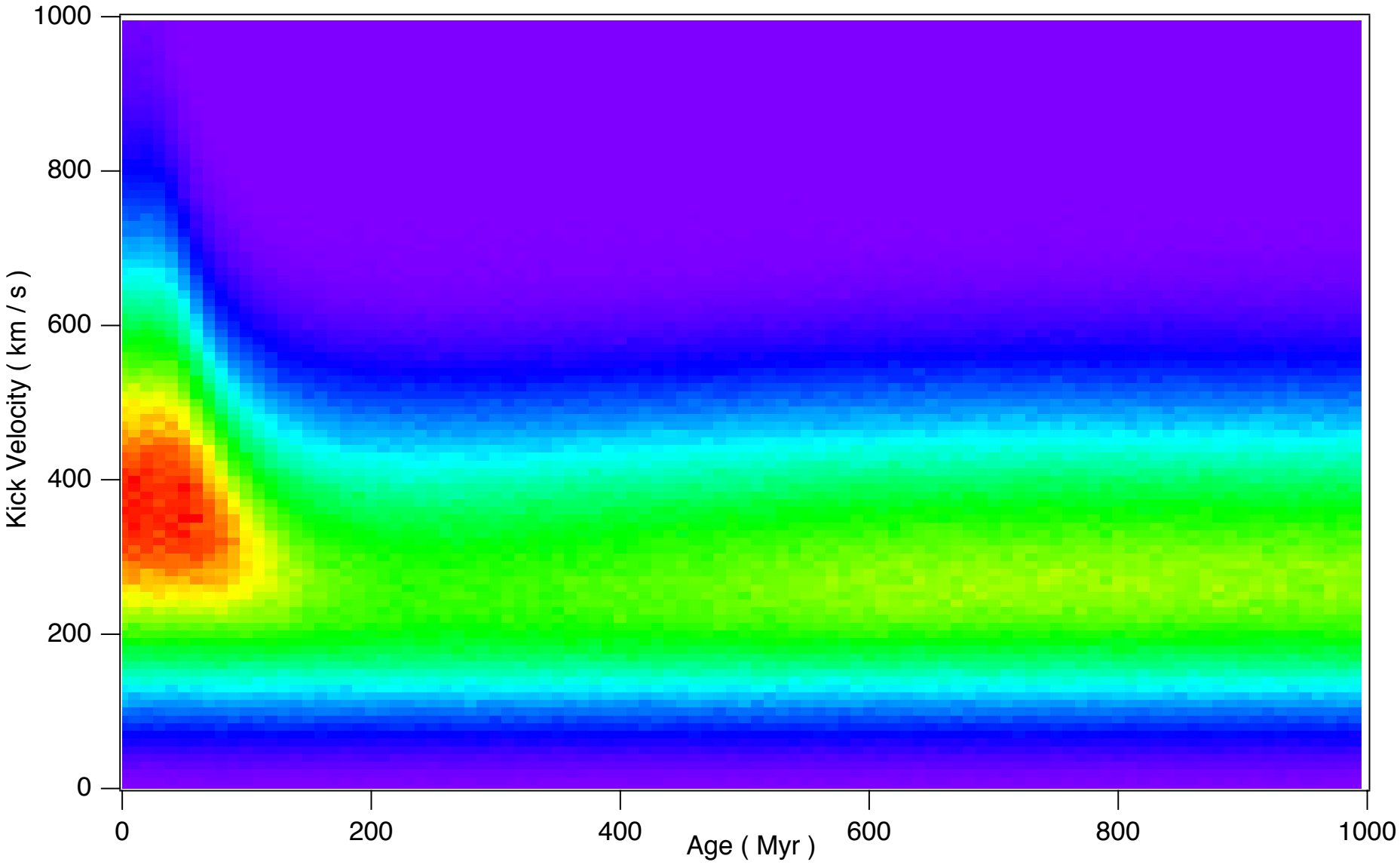
Supernova Kick

Hobbs et al. 2005 for both NPs and MSPs

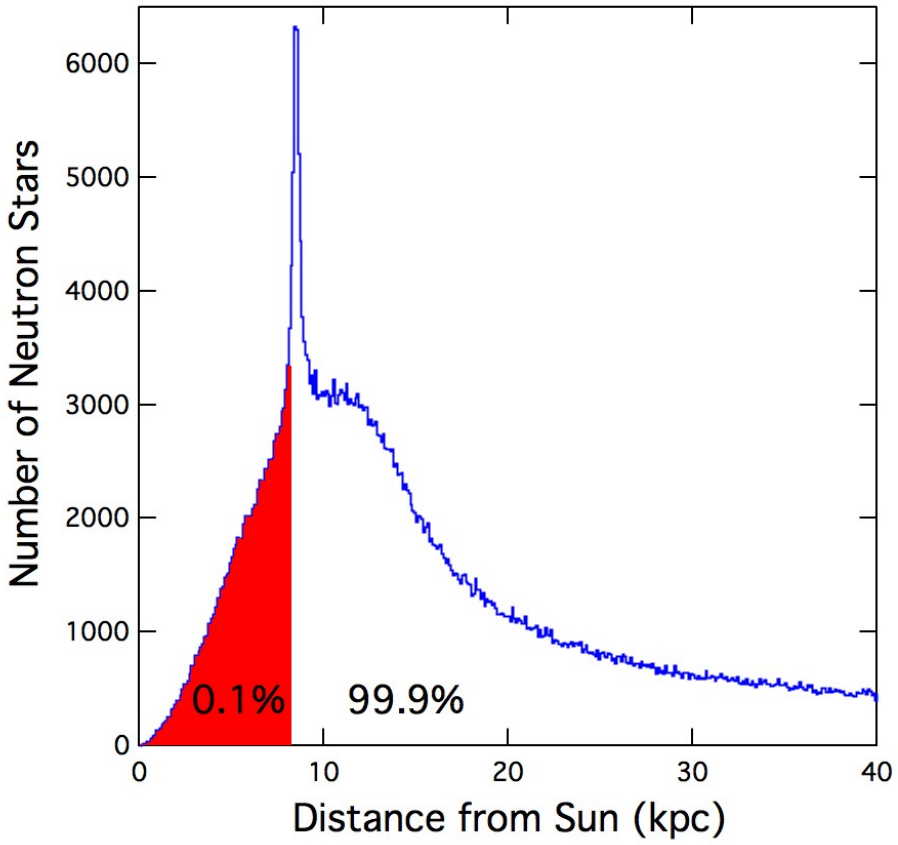
Galactic potential - Paczyński (1990)

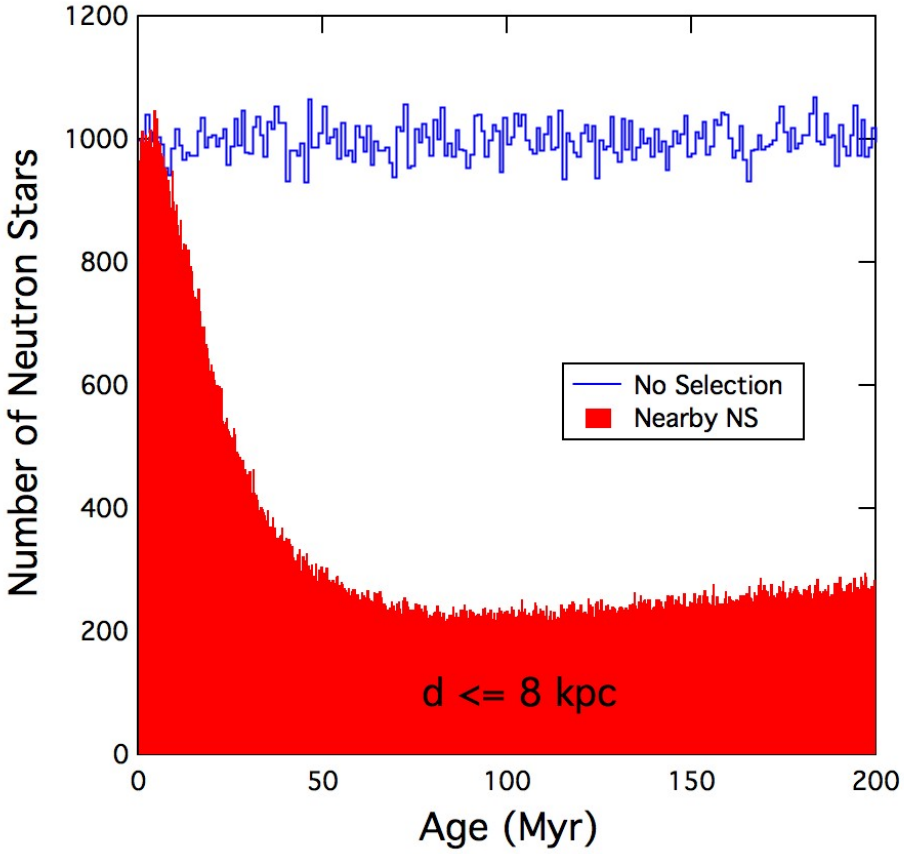


Kick Velocity vs. Age

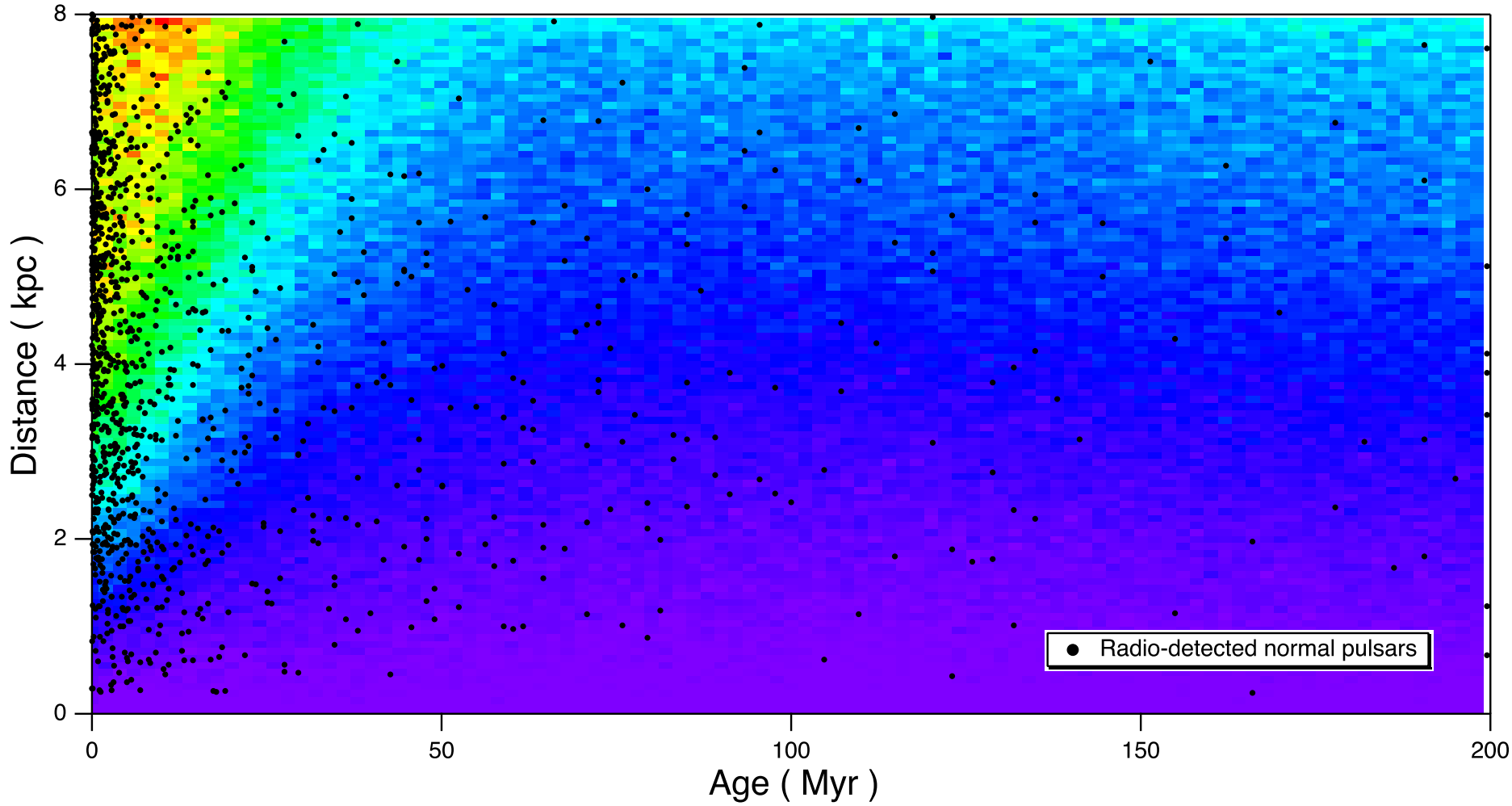


Distance Selection

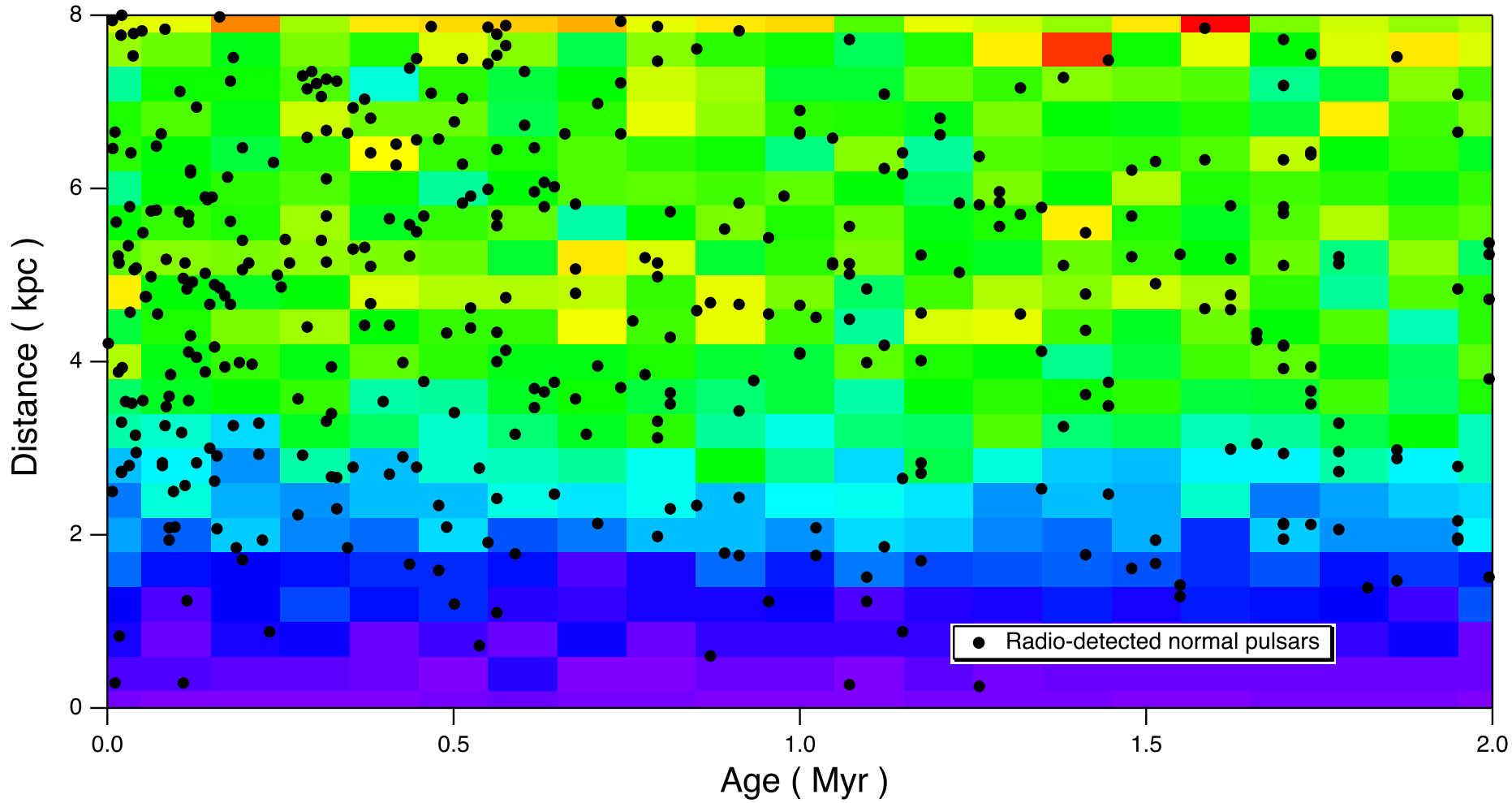




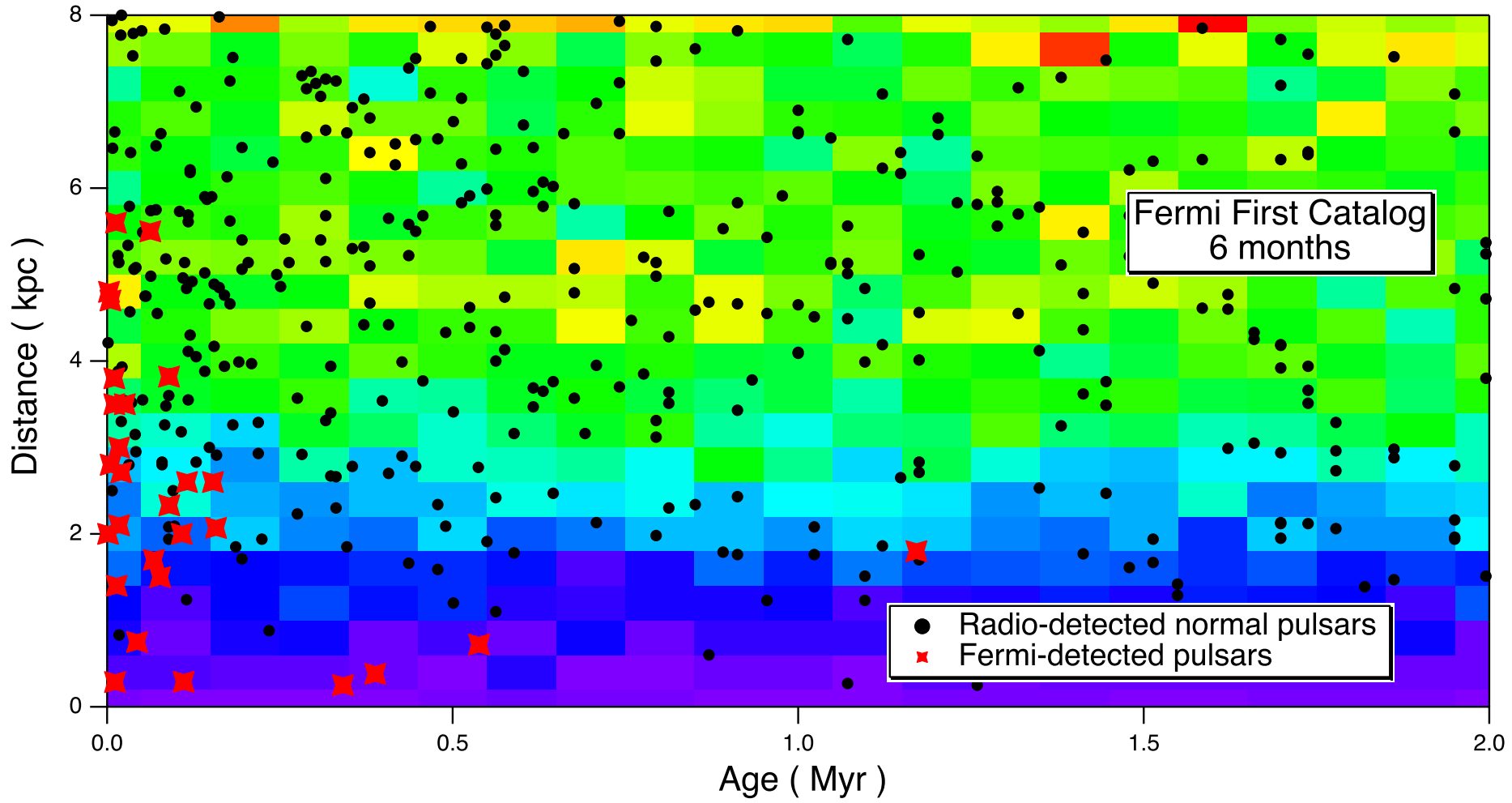
Present-day Distribution



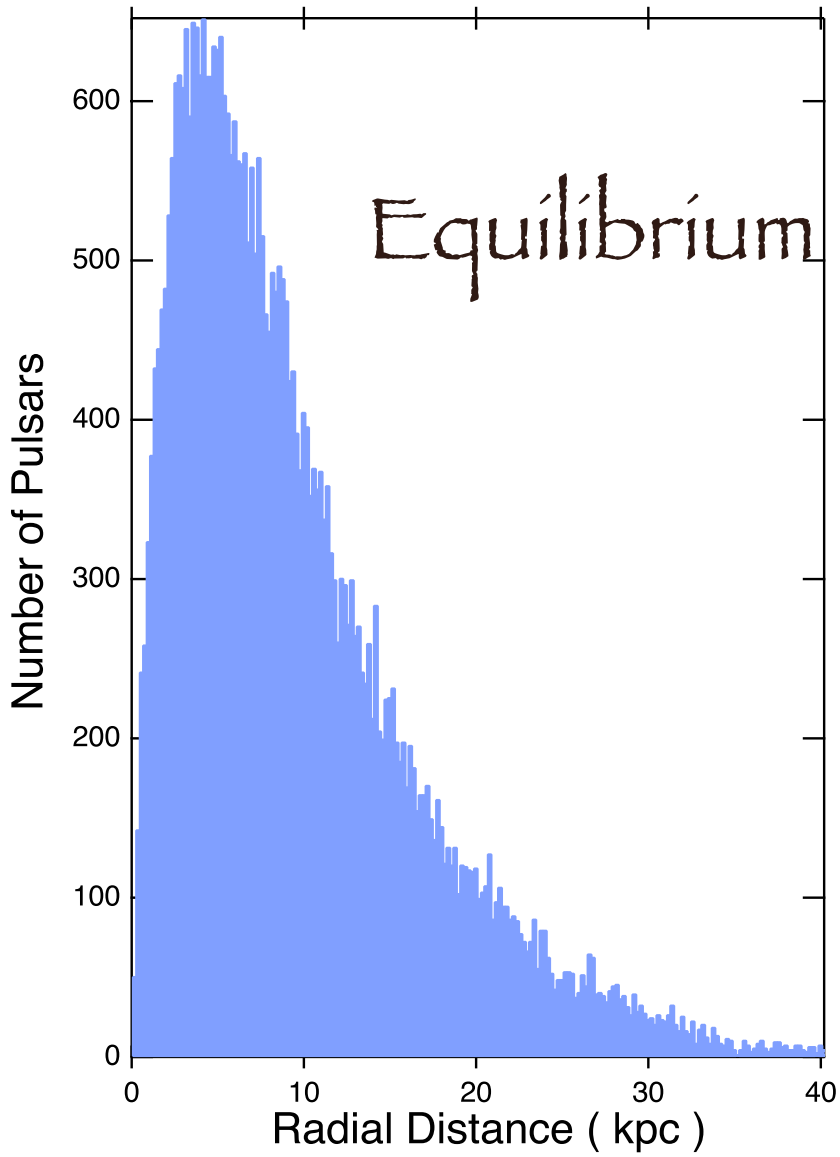
Present-day Distribution

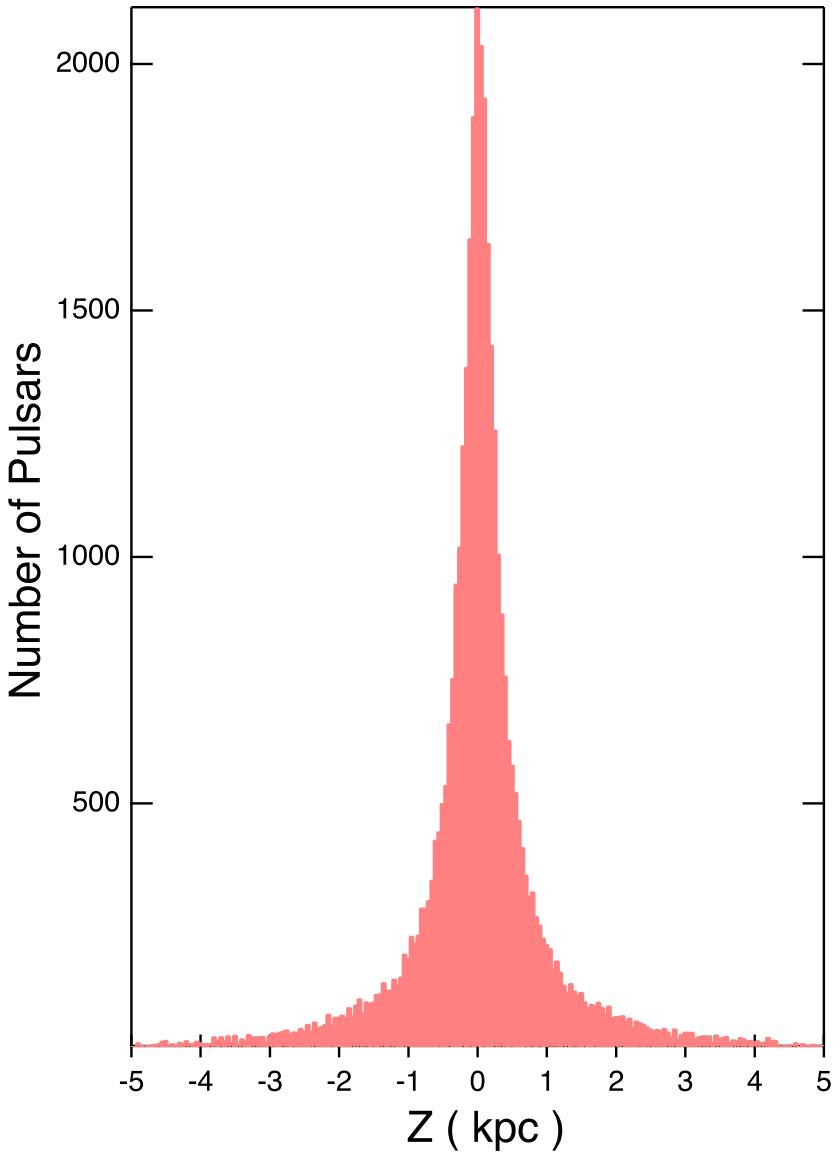


Present-day Distribution



Present-day MSPs





Spin-down - NPs

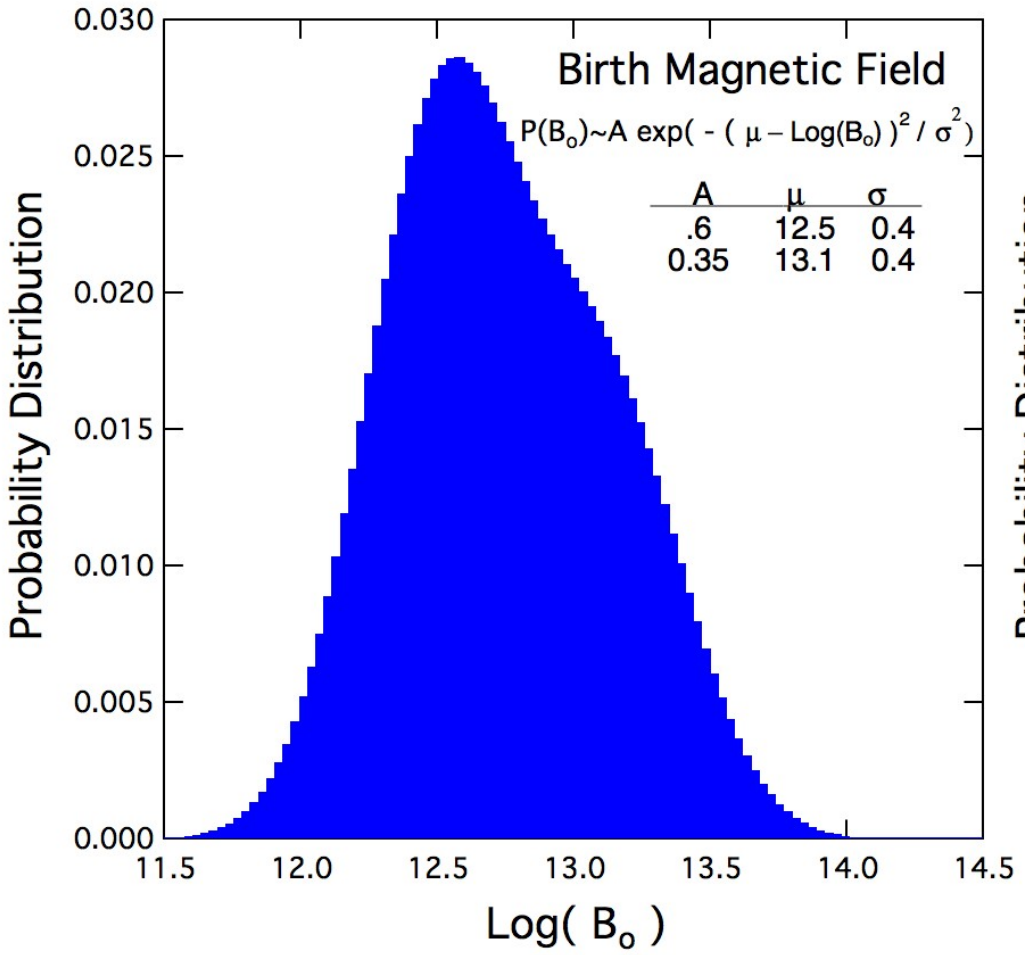
- Gonthier et al. 2002
- Gonthier et al. 2004 – full beam geometry
- Faucher-Guigere & Kaspi 2006

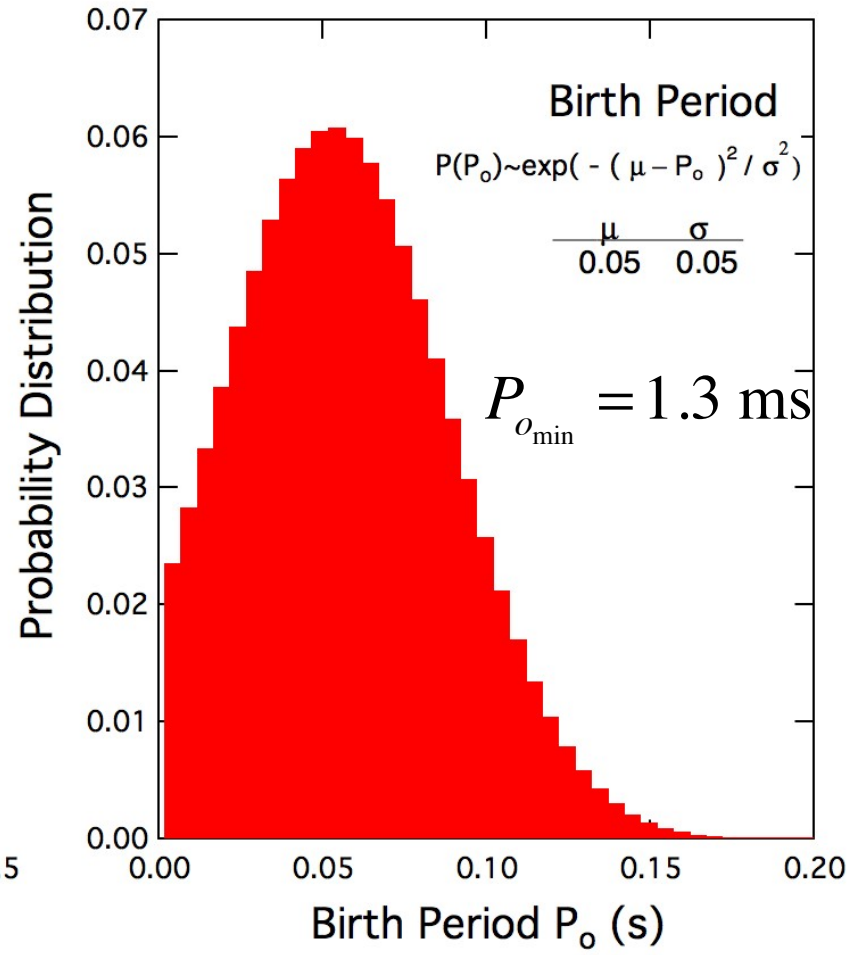
  Our field decay is due to our luminosity model

  But many different sets of assumptions.

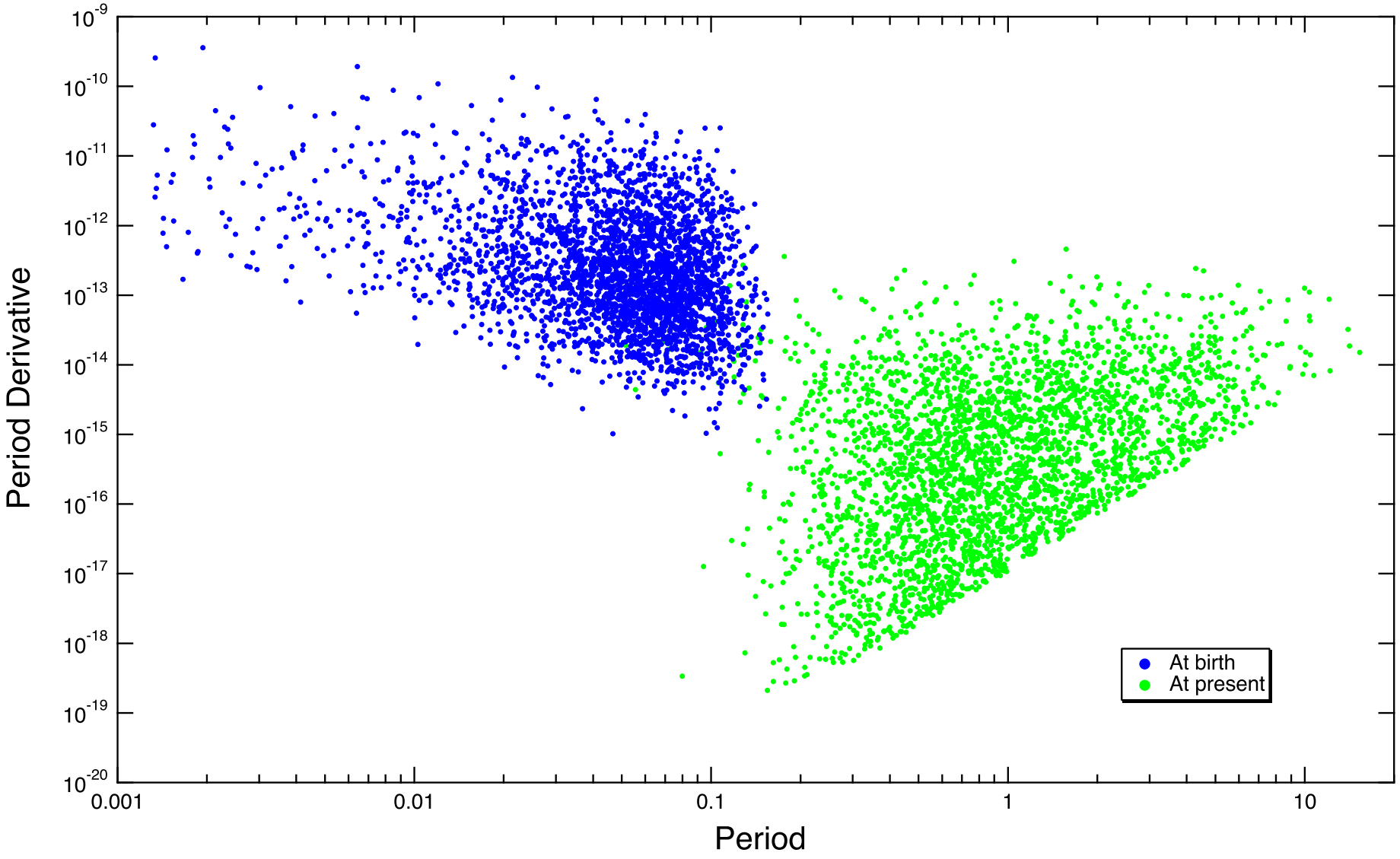
- Contopoulos & Spitkovsky (2006) – suggesting that magnetic field decay mimics some form of spin-down – Spitkovsky (2006)
- We assume - "Field decay" – spin-down $\tau \approx 2.8$ Myr

Birth Field and Period

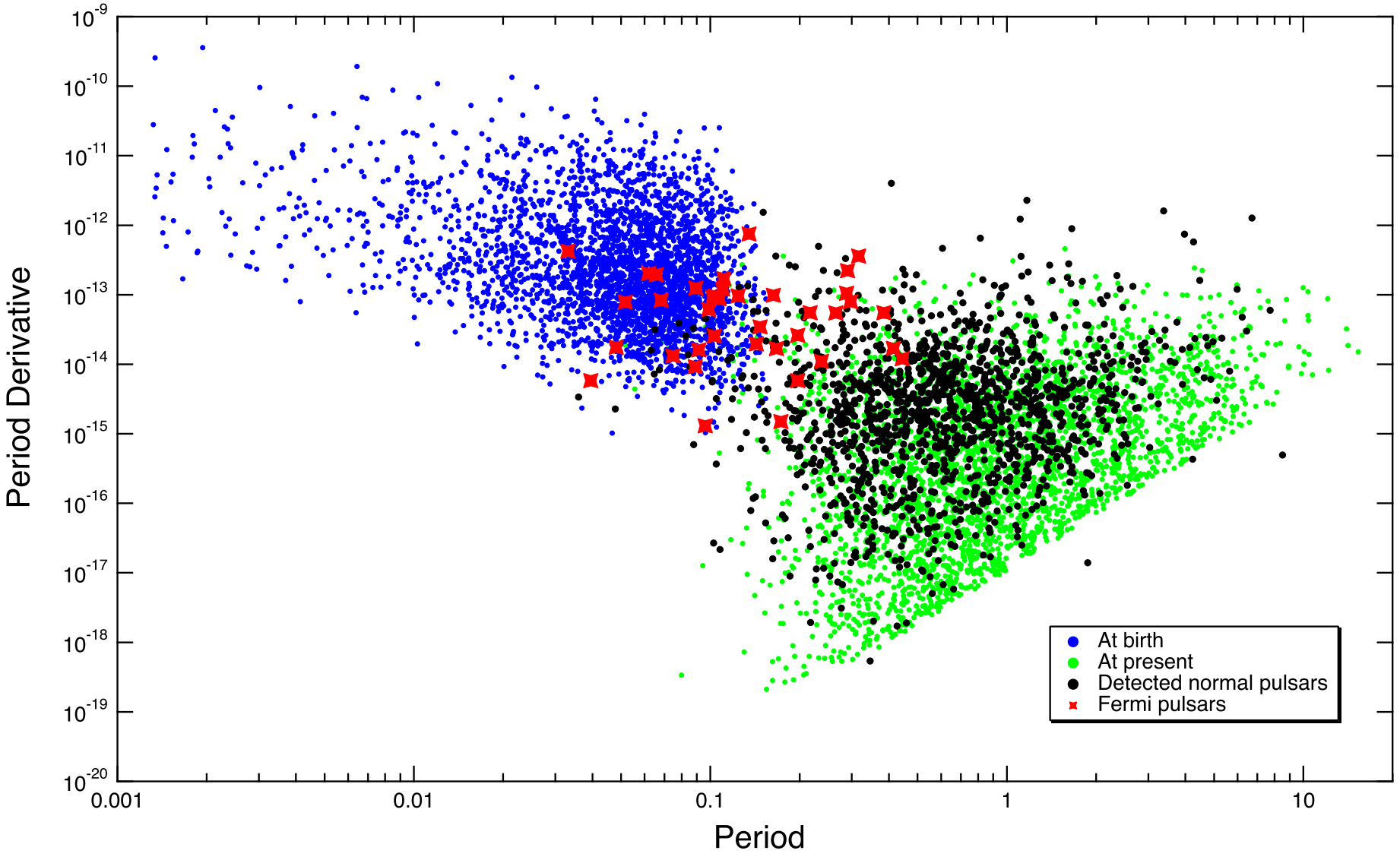




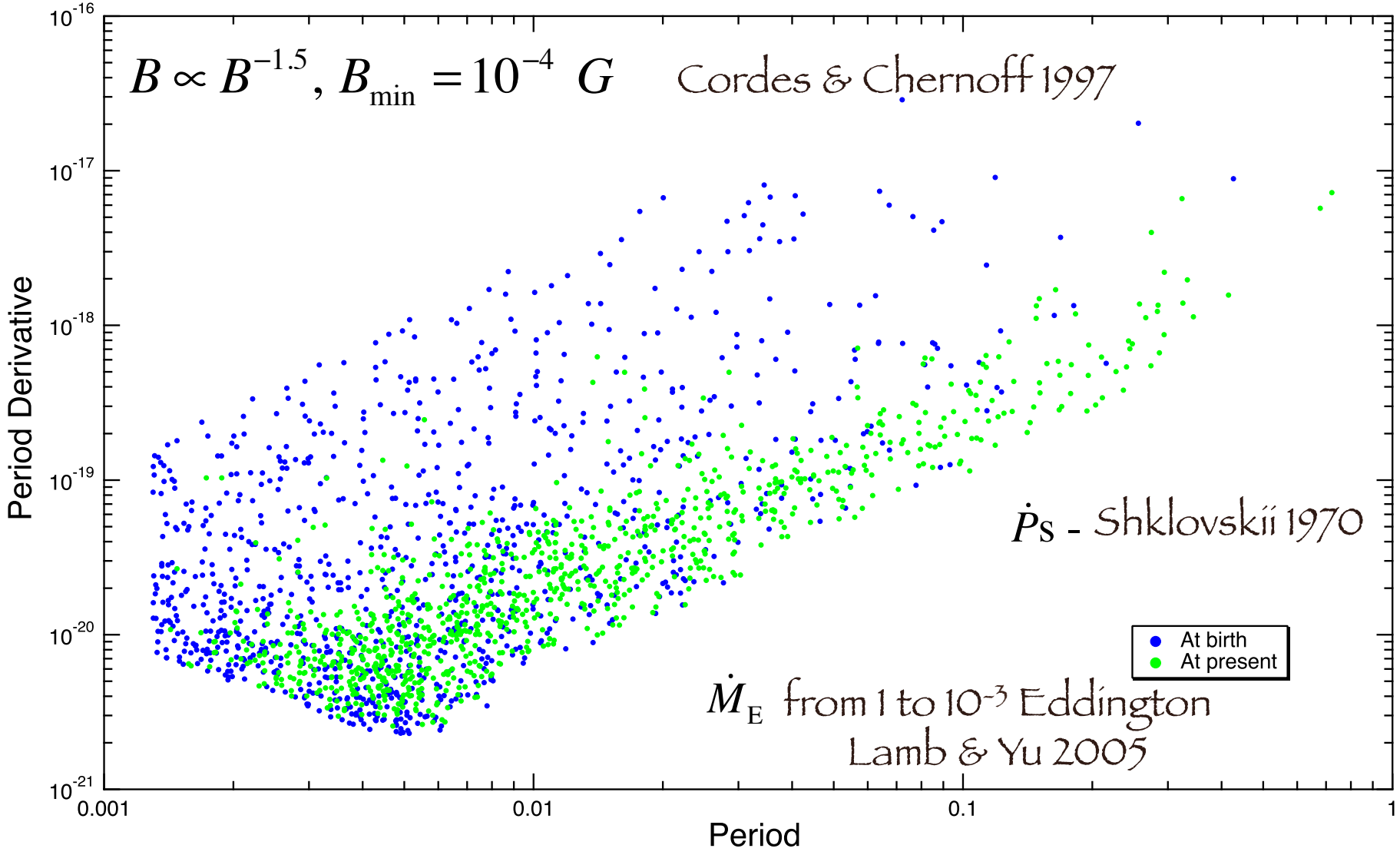
Birth to Present - NPs



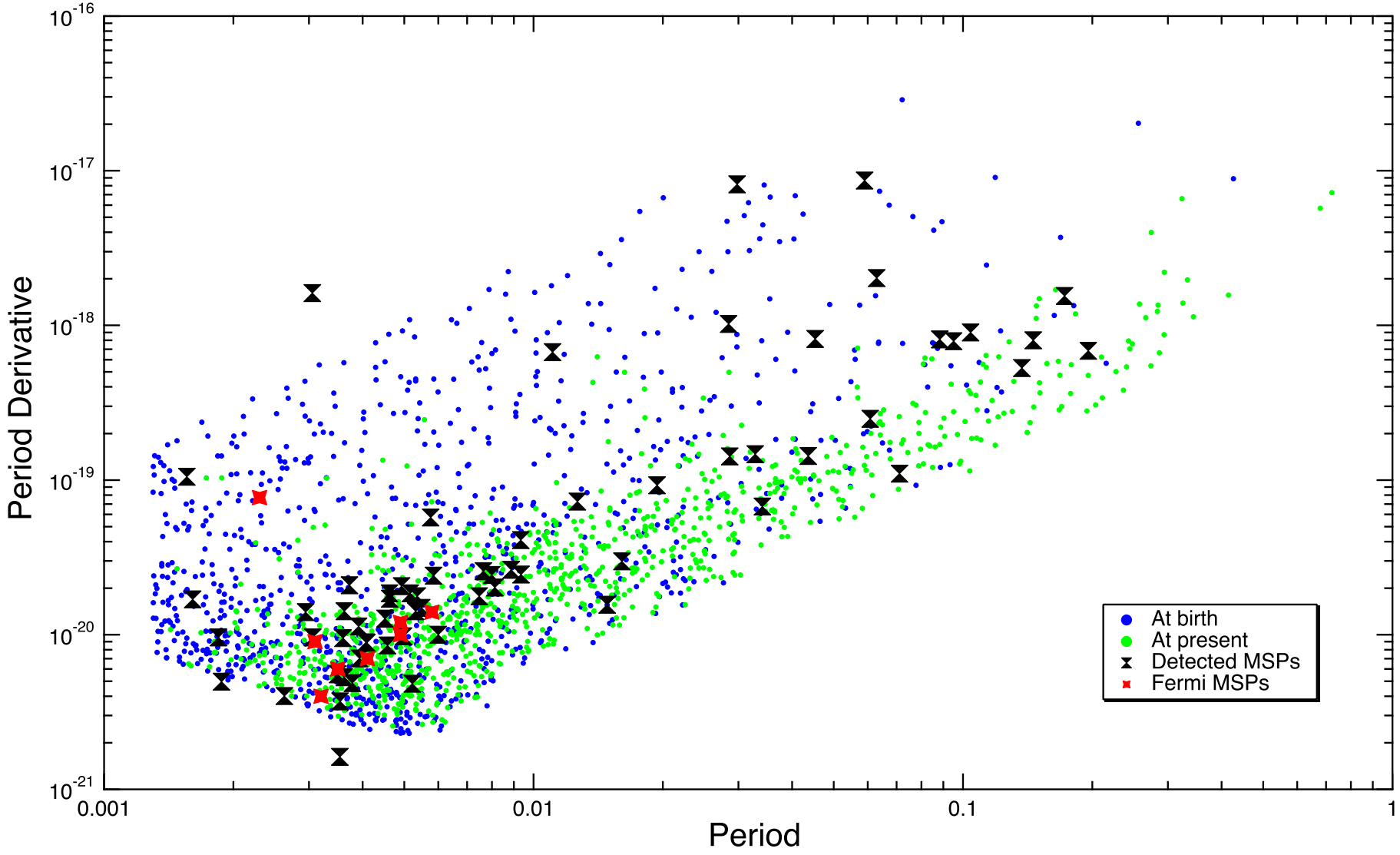
Birth to Present - NPs



Birth to Present - MSPs



Birth to Present - MSPs



Radio Emission

Story, Gonthier & Harding 2007
Harding, Grenier & Gonthier 2007

- Core and a cone beam – full beam geometry
  - Core – Gaussian – widths Arzoumanian, Chernoff & Cordes 2002 (ACC02)
  - Cone – hollow Gaussian – widths Kijak & Gil 1998 & 2003
- Luminosity – standard candle approach – P & Pdot power law as in ACC02
- Core/Cone Luminosity – broken power law in P & Pdot
- Energy spectra – power law with separate indices

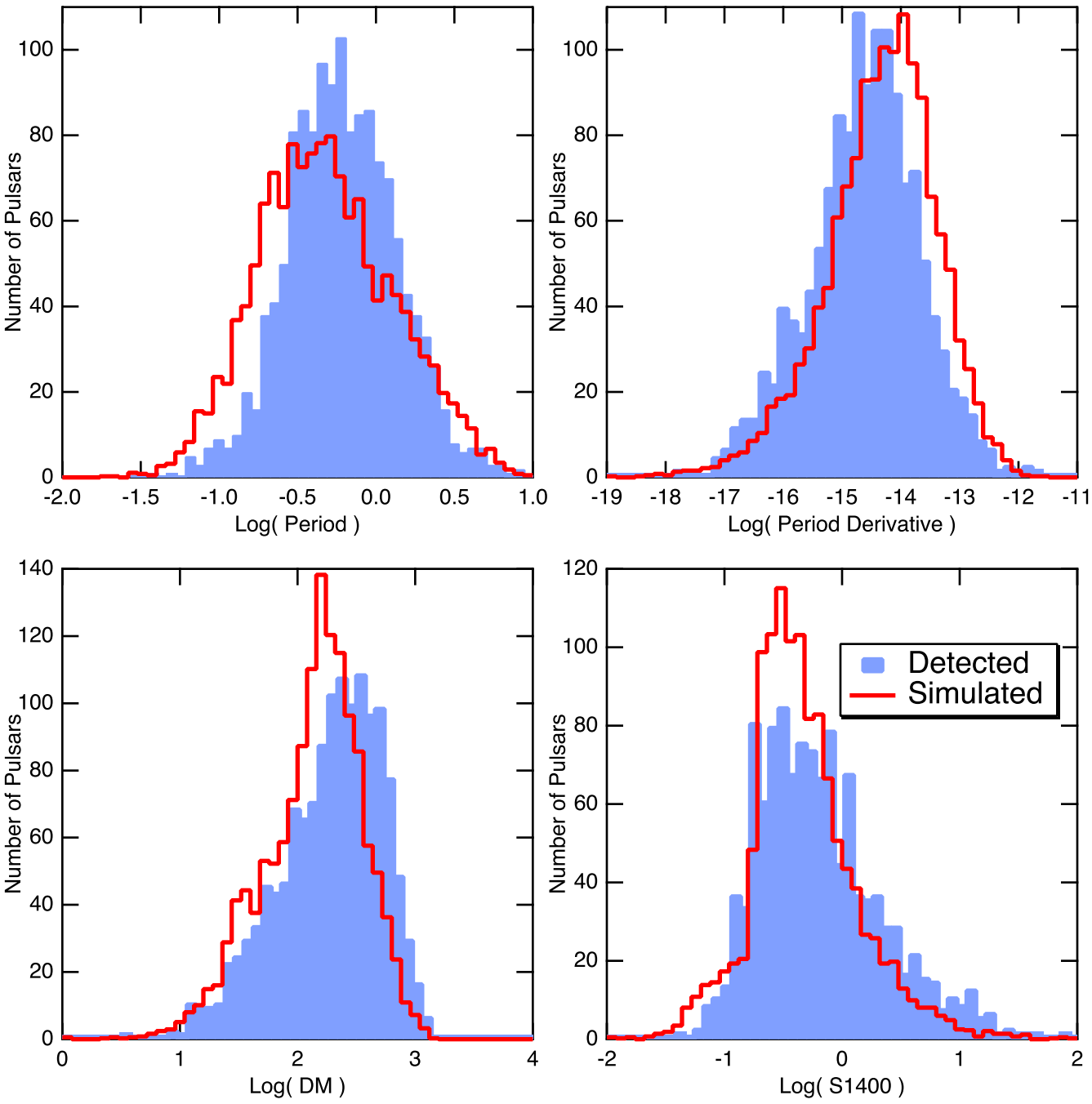
10 Radio Surveys

Name	Frequency (MHz)
Arecibo 3	430
Arecibo 2	430
Greenbank 3	390
Greenbank 2	390
Molongo 2	408
Parkes 2	436
Parkes 1	1520
Jodrell Bank	1400
Parkes MB	1374
Swinburne IL	1374

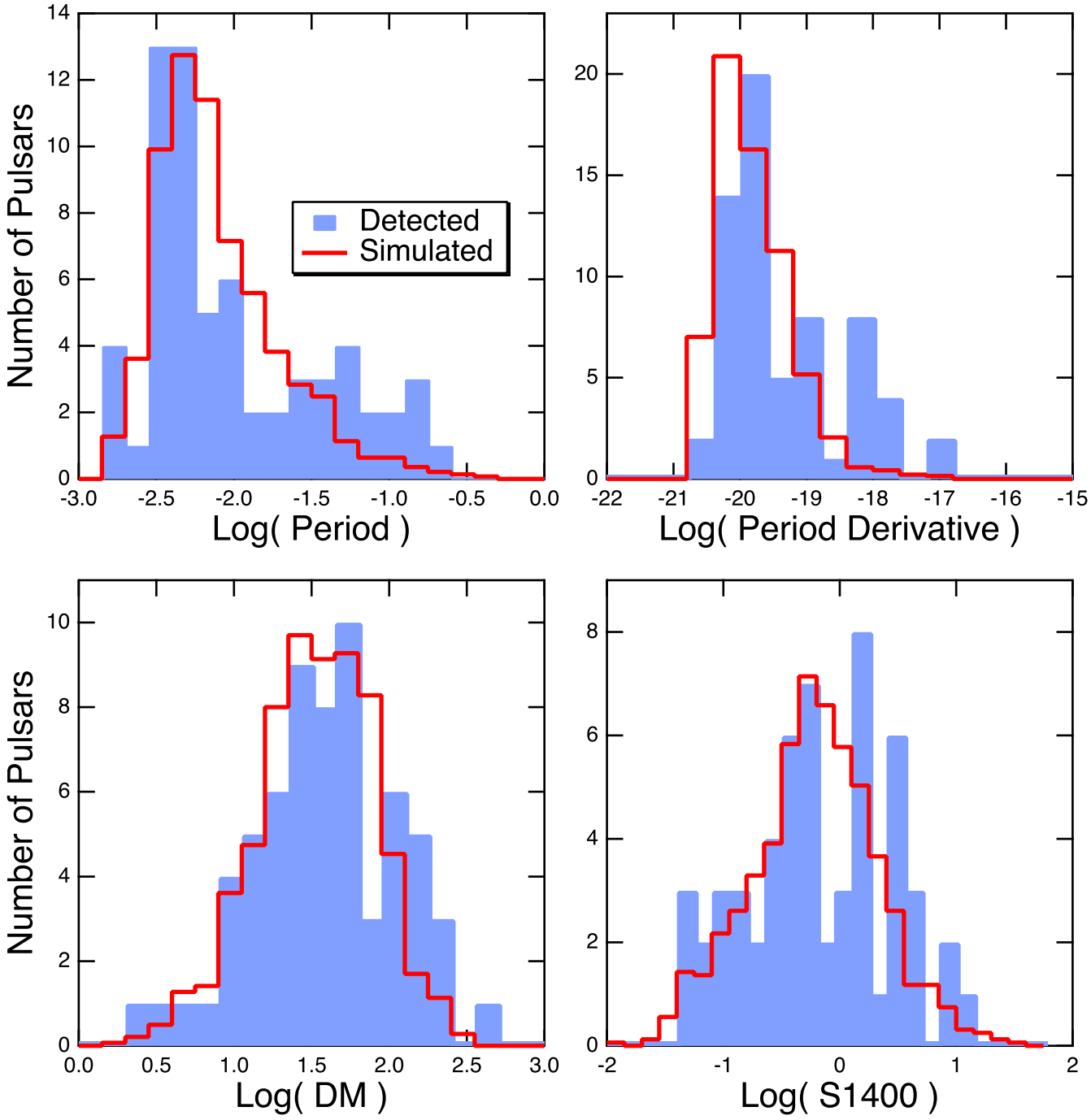
1420 Normal Pulsars
64 Millisecond Pulsars
no globular pulsars
no Pdot < 0

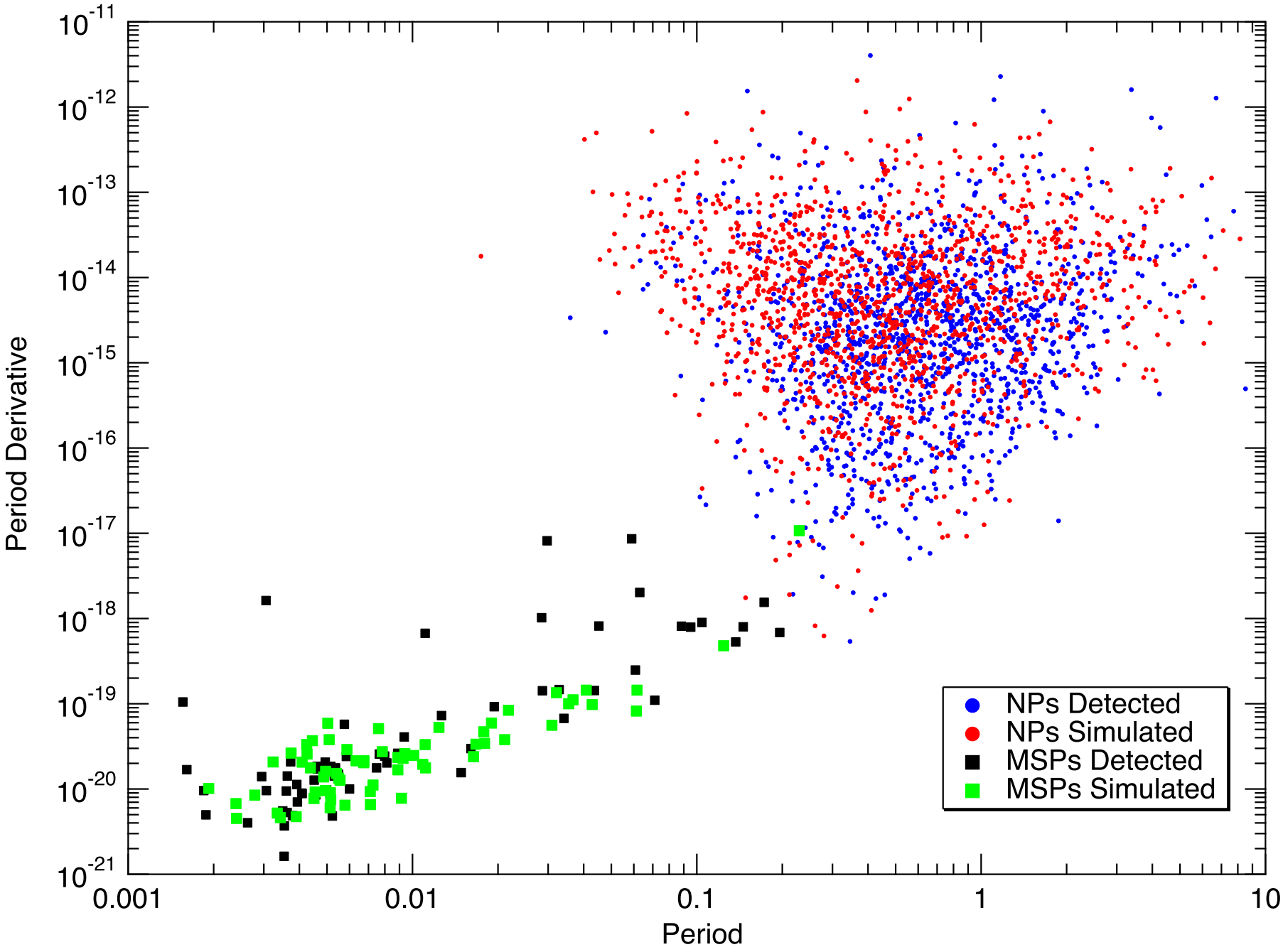
NPs birth rate
~ 2 NS/century
Tammann et al. 1994

Normal Pulsars



MSPs Pulsars

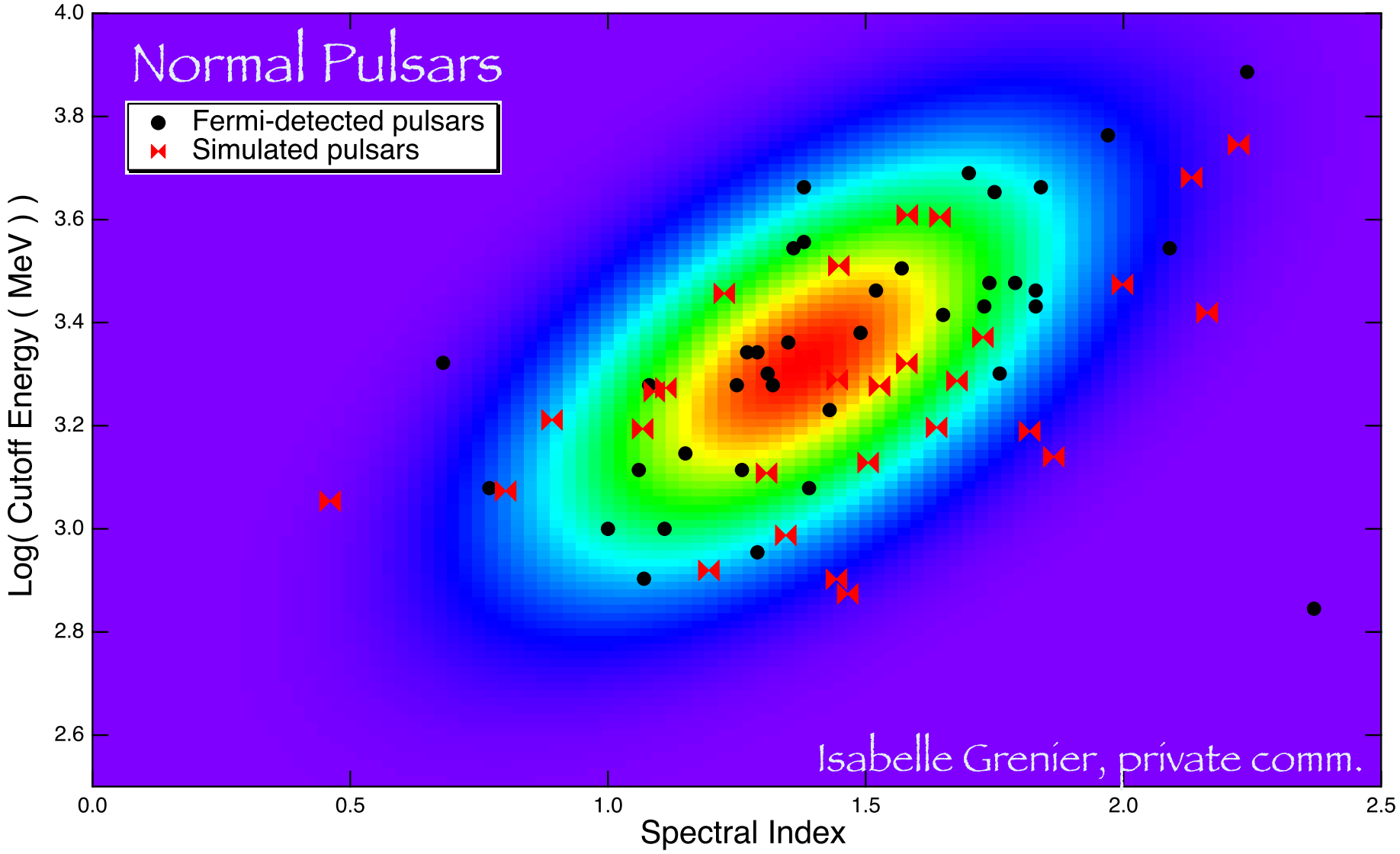


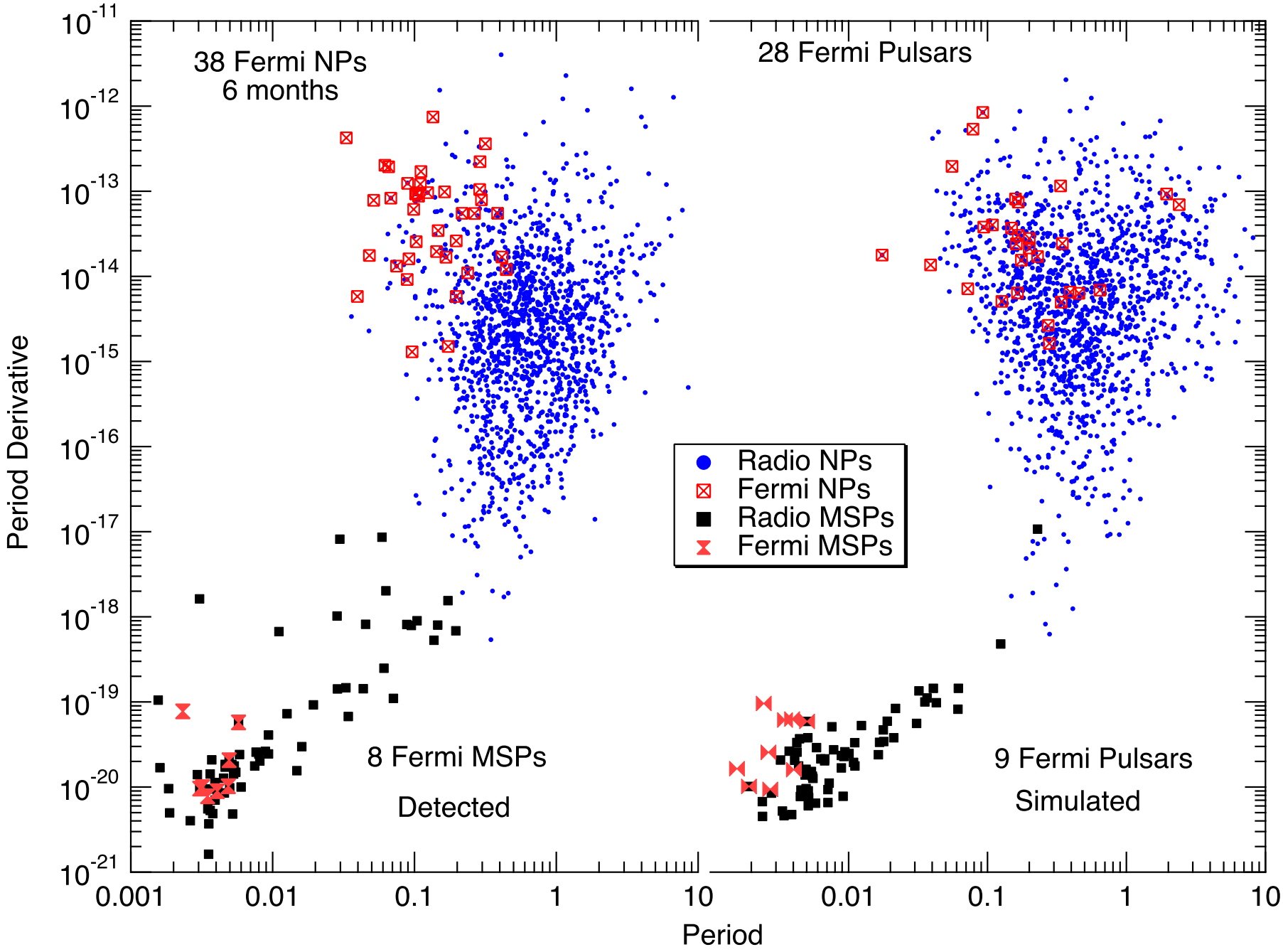

Period Derivative
Period
0.001
0.01
0.1
1
10
NPs Detected
NPs Simulated
MSPs Detected
MSPs Simulated

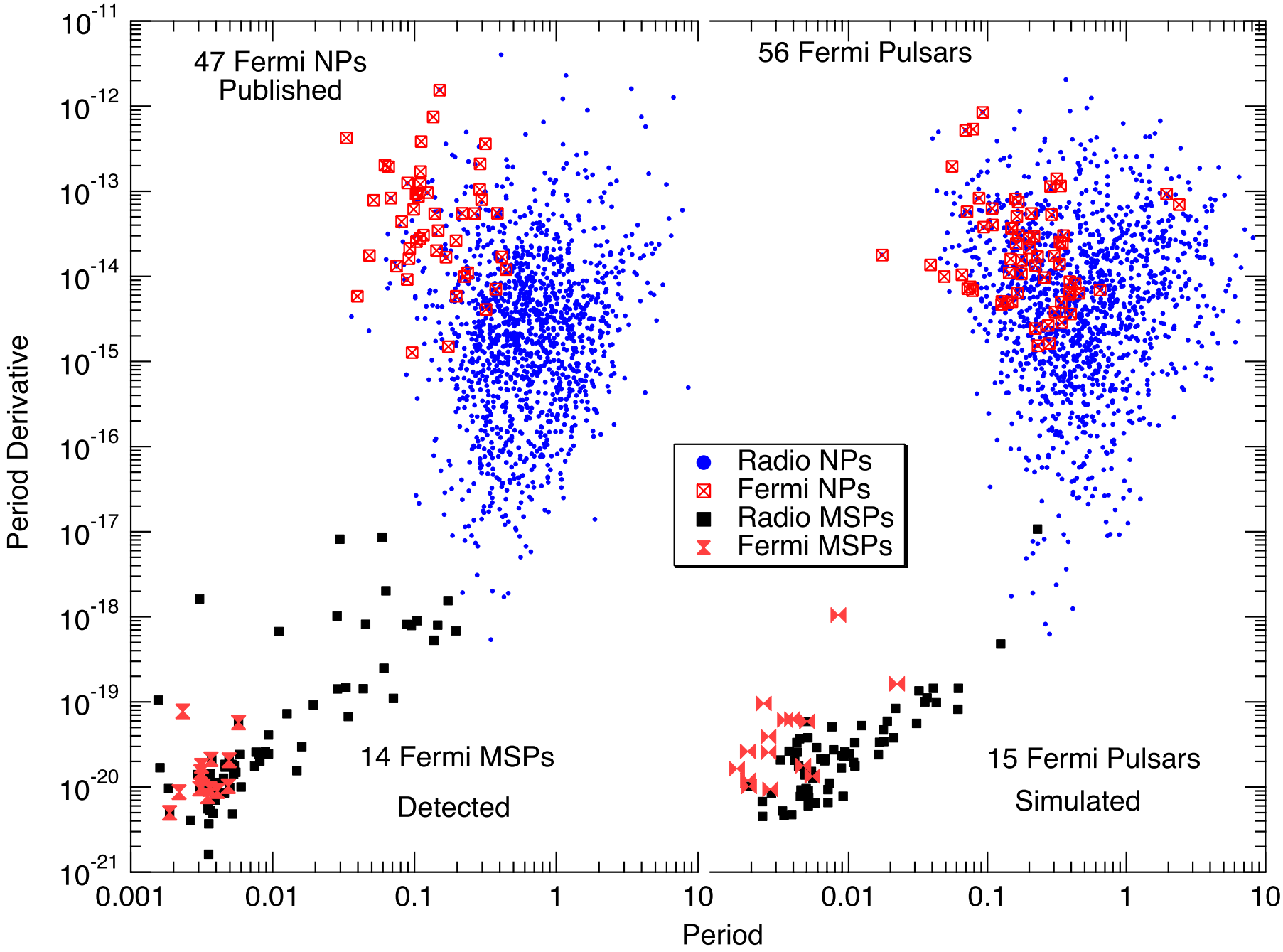
Gamma-Ray Emission

- Luminosity
  - Muslimov & Harding 2003
  - Muslimov & Harding 2004 – $E_{||}$ in extended Slot Gap
  - Pierbattista et al. in preparation
- Flux
  - Sky maps (Alice's talk) of the emission region – Harding, Grenier & Gonthier 2007
  - High altitude emission from the Crab – Harding et al. 2008
  - Venter, Harding & Guillemot 2009

Fermi - Spectral Features




38 Fermi NPs
6 months
28 Fermi Pulsars
Radio NPs
Fermi NPs
Radio MSPs
Fermi MSPs
8 Fermi MSPs
Detected
9 Fermi Pulsars
Simulated
Period Derivative
Period
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
10^-21
0.001
0.01
0.1
1
10
0.01
0.1
1
10


47 Fermi NPs
Published
56 Fermi Pulsars
Radio NPs
Fermi NPs
Radio MSPs
Fermi MSPs
14 Fermi MSPs
Detected
15 Fermi Pulsars
Simulated
Period Derivative
Period
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
10^-21
0.001
0.01
0.1
1
10
0.01
0.1
1
10

Summary – Fermi Pulsars

Time Frame	Det. Normal	Sim. Normal +/- 10%	Det. MSPs	Sim. MSPs. +/- 10%
6 months	38	28	8	9
1 year		38		11
Published ~ 2 years	47	56	14	15
3 years	~61*	67	~37*	18

* Alice Harding's earlier talk

Conclusions

- Numbers are reasonable, but do not tell the whole story. Issues with the simulation:
  - NPs – too many young short period and large Pdot radio pulsars and not enough high Edot young pulsars gamma-ray pulsars
  - MSPs – too many older radio MSPs, need younger ones and Fermi pulsars need lower Edots
- More studies are needed of correlations of radio and gamma-ray light curves further constrain viewing and beam geometry
  - Venter, Harding & Guillemot 2009
  - Pierbattista et al. in preparation – more radio time lag and gamma-peak separation
  - Johnson & Harding in preparation
- Better understanding is needed of pulsar spin-down with age