Population synthesis of radio and gamma-ray millisecond pulsars from the Galactic disk

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Assumptions 1 - Spatial

- Pulsars from the Galactic disk - not in globular clusters
- Spatial distribution - Paczynski (1990)

$$n(r) \propto r \exp(-r / R_{\exp}), \text{ with } R_{\exp} = 4.5 \text{ kpc}$$

$$n(z) \propto \exp(-z / Z_{\exp}), \text{ with } Z_{\exp} = 0.20 \text{ kpc}$$

0.075 kpc for normal pulsars

- Supernova kick velocity - Maxwellian with σ = 70 km/s - Hobbs et al. (2005)

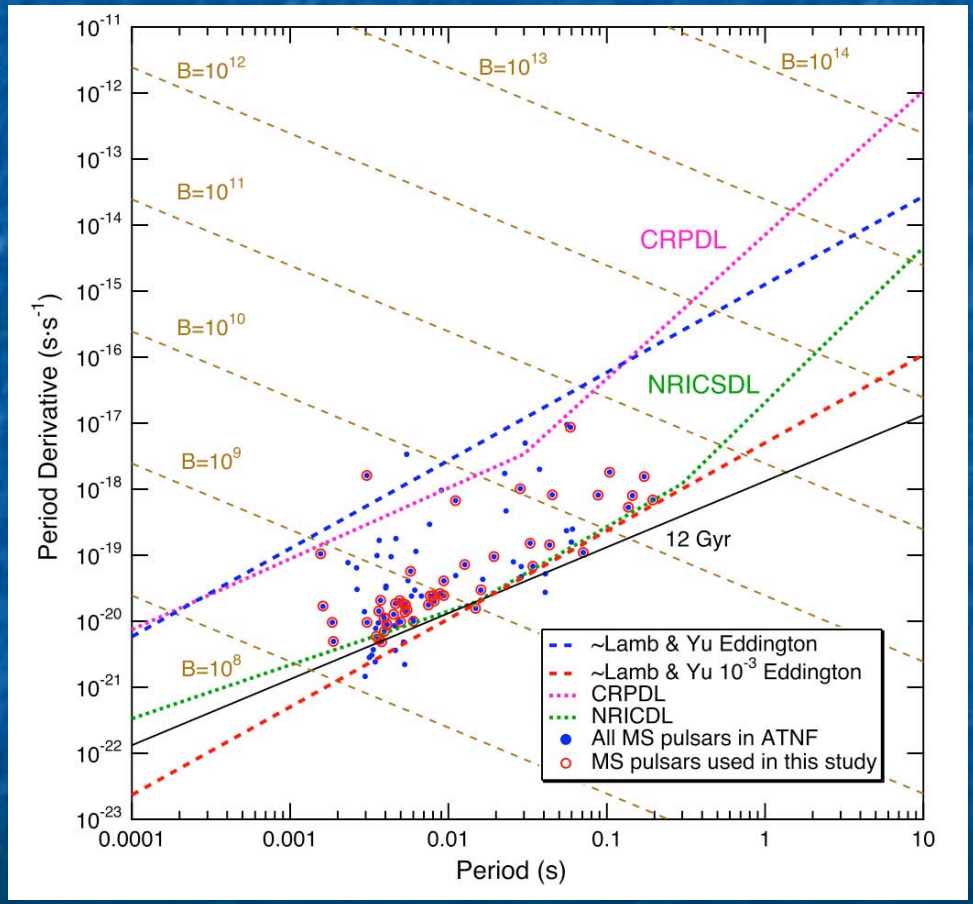
265 km/s for normal pulsars

- Uniform birth rate back to 12 Gyr
- Evolution in Galactic potential - Dehnen & Binney (1998)
- Present equilibrium spatial distribution - scale height 480 pc
  Similar to the scale height (exponential) of 510 pc - Cordes & Chernoff (1997) and to LMXBs of 410 pc - Grimm et al. (2002)
- All neutron stars remain bound to the Galaxy

Assumptions II

- Initial B field has a power law distribution with $n(B) \sim B^{-1.5}$ with $B_{min} = 2 \times 10^8$ G
- Po_{min} = 1.3 ms Chakrabarty (2005)
- Birth line is dithered between 1 and 10^{-3} times the Eddington critical accretion ~ Lamb & Yu (2005)
- Most LMXBs accrete at rates lower than the Eddington limit
- Curvature radiation and nonresonant inverse Compton pair death lines - Harding, Muslimov & Zhang (2002)

DETECTED RADIO PULSARS IN ATNF CATALOGUE



ATNF pulsar catalogue 1.27 - http://www.atnf.csiro.au/research/pulsar/psrcat/
Manchester, R. N., Hobbs, G. B., Teoh, A. & Hobbs, M., AJ, 129, 1993-2006 (2005)

Common Radio Model

- For both MSPs and normal radio pulsars
- Luminosity model - $L = 2.2 \times 10^{10} P^{-0.95} \dot{P}^{0.38} \ \mathrm{mJy \cdot kpc^2 \cdot MHz}$ Arzoumanian, Chernoff, and Cordes (2002) (*ACC*)
- Gaussian core beam - *ACC*
- Gaussian cone with emission heights from Kijak and Gil (1998 & 2003)
- Here short period pulsars are more cone dominated than *ACC* model (Gonthier et al. 2007 - astro-ph/0611236 & 0702097) - support from Crawford et al. (2001 & 2003) & Johnston & Weisberg (2006)

Radio Surveys and Detections

- 10 radio surveys detecting a total of 50 MSPs
- Detections and non-detections well reproduced

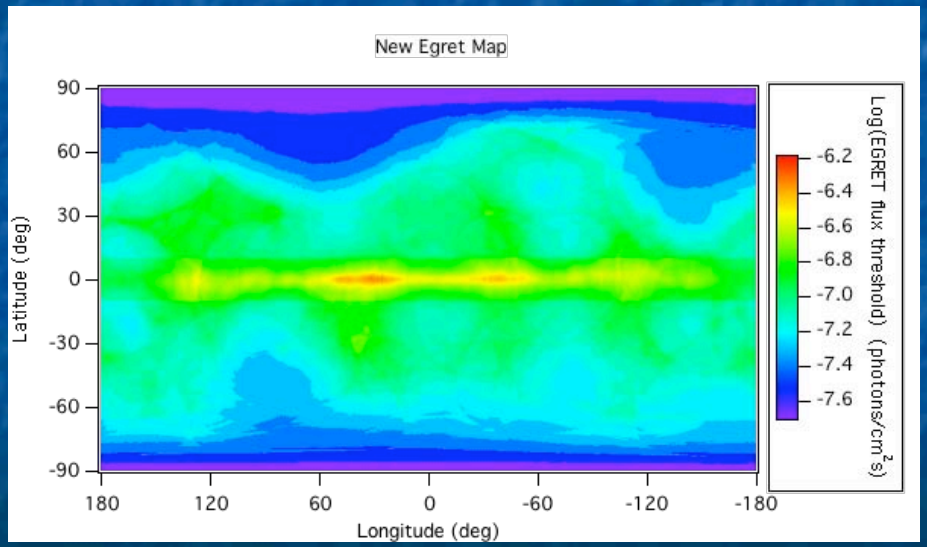
Survey	Det. - Sim.
Arecibo 3	4 - 6
Arecibo 2	2 - 0
Green Bank 3	0 - 2
Green Bank 2	1 - 0
Molongo 2	0 - 0
Parkes 2	18 - 15
Parkes 1	0 - 0
Jodrell Bank 2	0 - 0
Parkes Multibeam	22 - 21
Swinburne IL	12 - 9

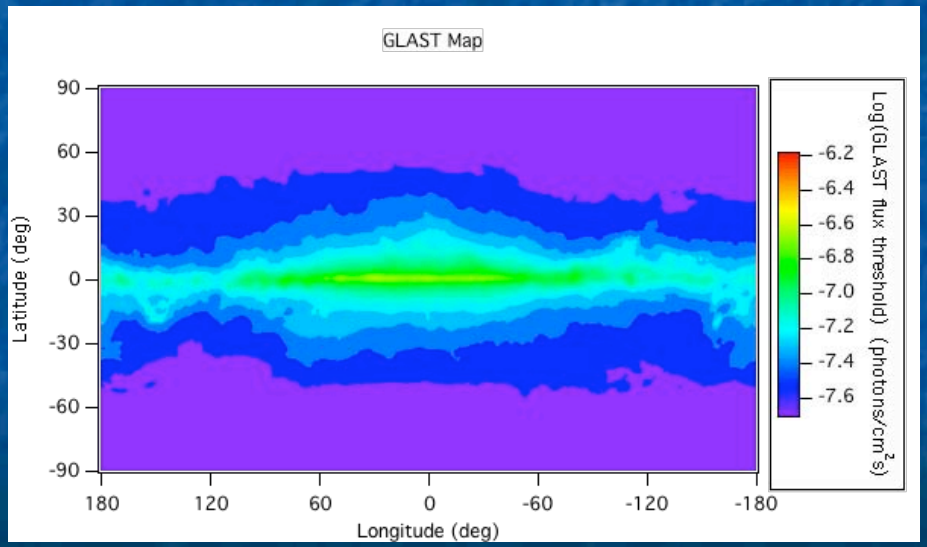
Gamma-ray Model

- Curvature radiation pair death line separates γ-ray emission models
- Most MSPs are below curvature radiation pair death line - below pair threshold - pair-starved polar cap (Harding, Usov & Muslimov 2005)
- Inverse Compton scattering - some pair cascades
- Unscreened electric field
- Self-limiting curvature radiation from all open field lines
- Since $E_\gamma > 100$ MeV - neglecting synchrotron emission
- Details in Alice Harding's talk

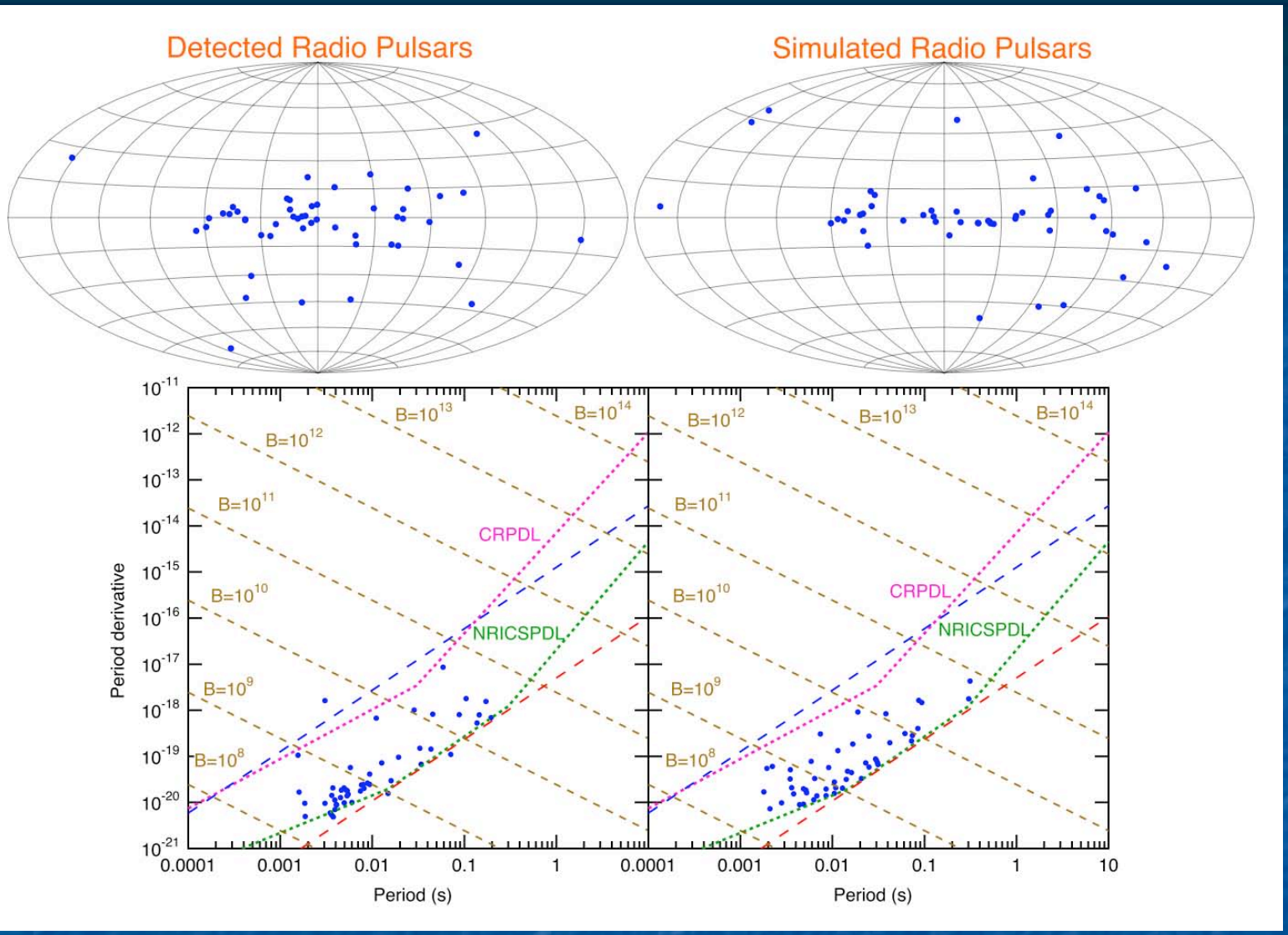
New Gamma-ray Thresholds

- EGRET threshold maps with dark clouds
- GLAST maps generated after DC2
- Also all-sky maps for AGILE - but not recently updated

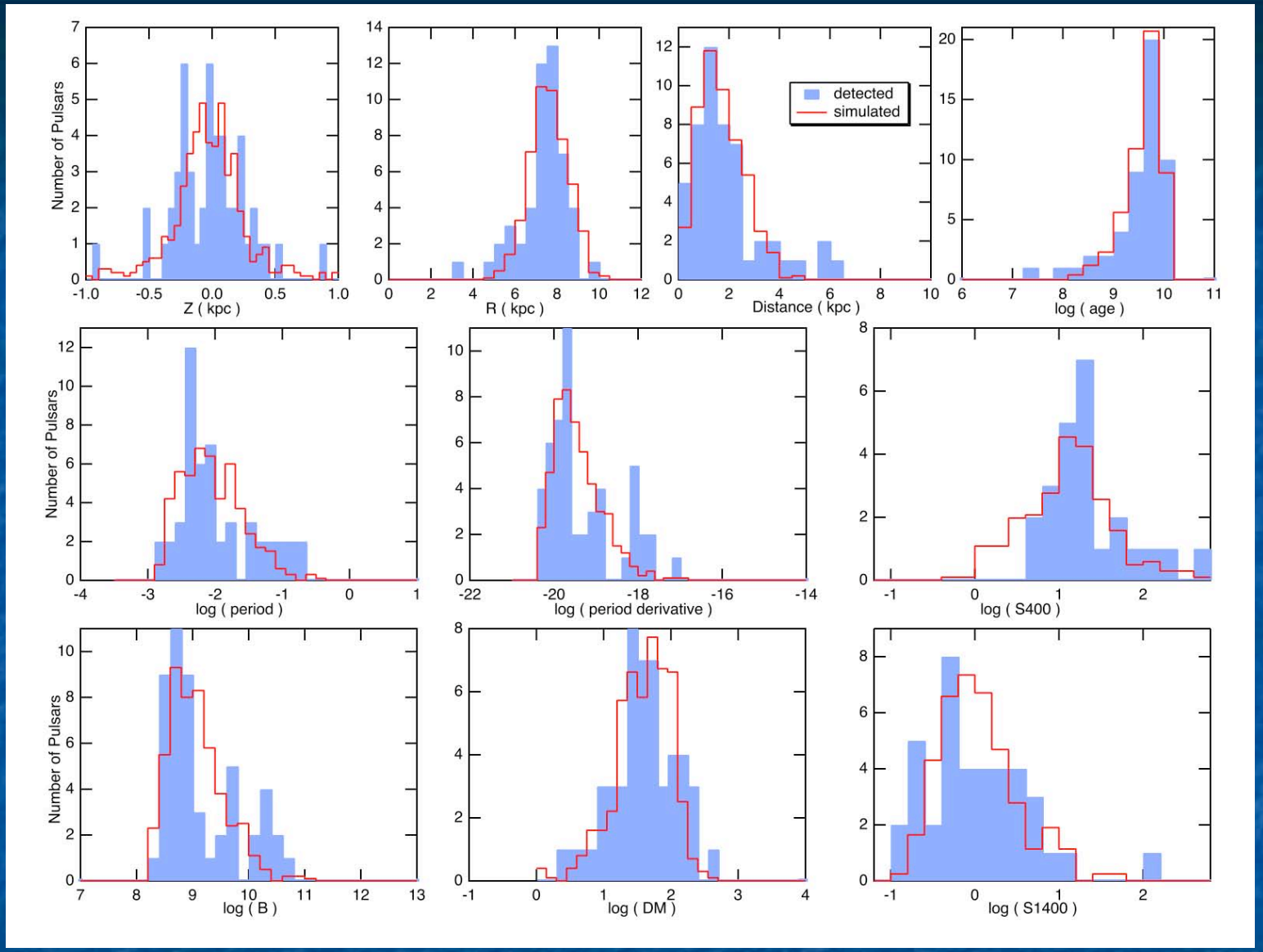




COURTESY OF ISABELLE GRENIER

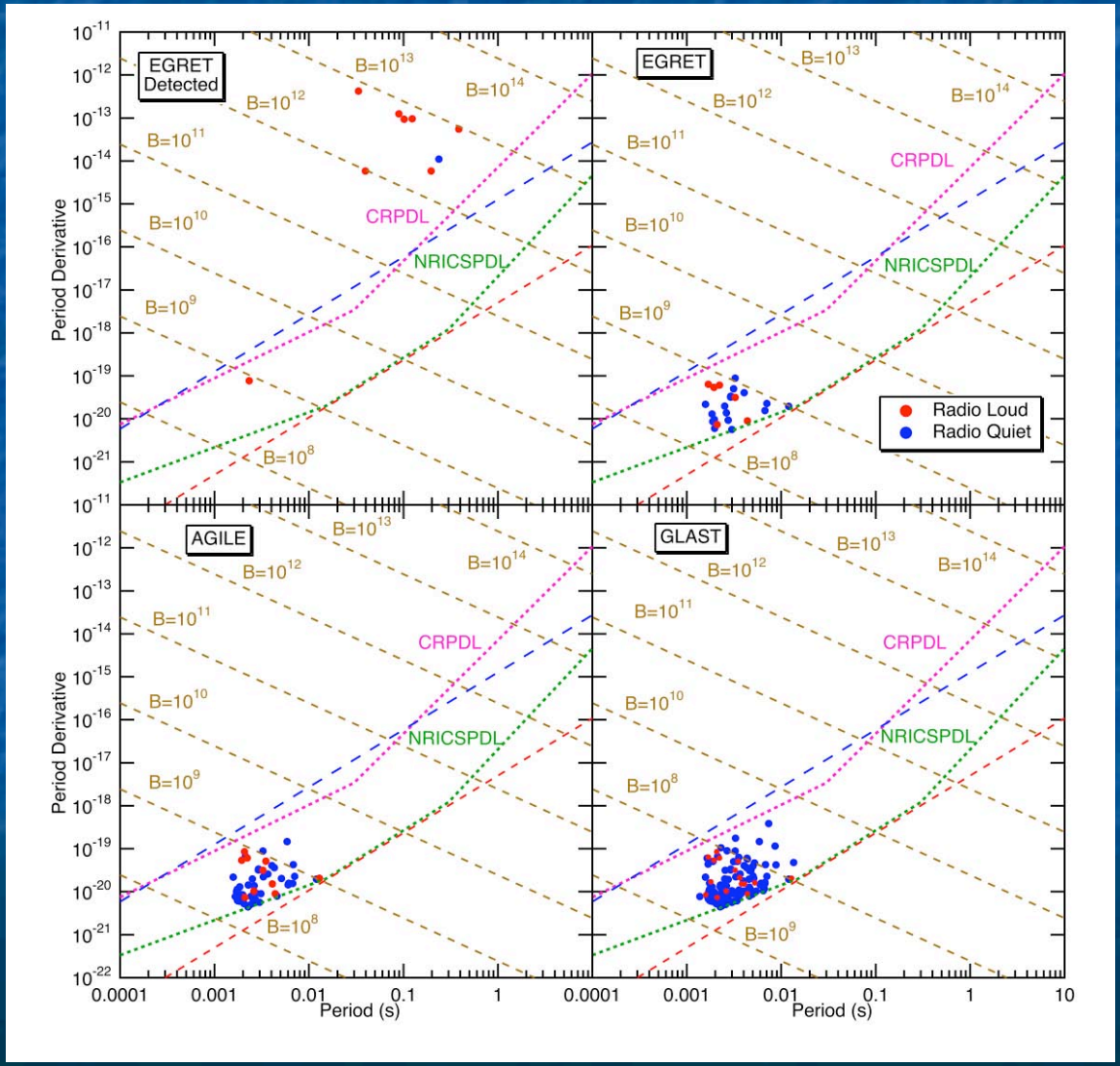


- Fairly good agreement with spatial distribution - more scatter than detected pulsars
- Clustering of detected pulsar around a period of 50 ms is not reproduced



- Histograms represent detected (shaded blue) and simulated (open red) radio millisecond pulsar characteristics
- Good overall agreement
- Some flexibility in luminosity model - a range in birth rate and gamma pulsars

- γ-ray luminosity increases with decreasing period
- Distribution depends strongly on index of power law describing initial magnetic field



Normalization of Simulation

- Normalization of radio luminosity - birthrate of 2.1 normal neutron stars per century using Parkes MB survey only

- 20% variation in radio luminosity - Predicts a MSP birth rate of

$4\text{-}5 \times 10^{-4}$ per century

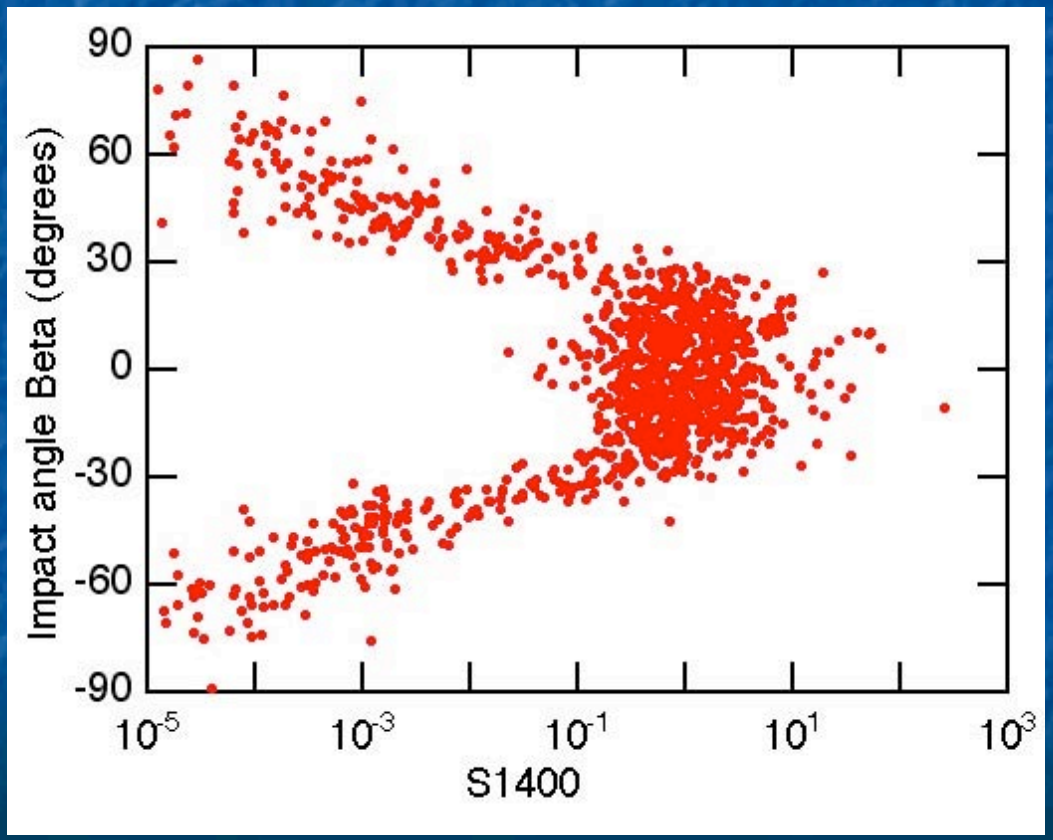
- 2.9×10^{-4} Lorimer (2005)
- 6.5×10^{-4} Kiel & Hurley (2006)

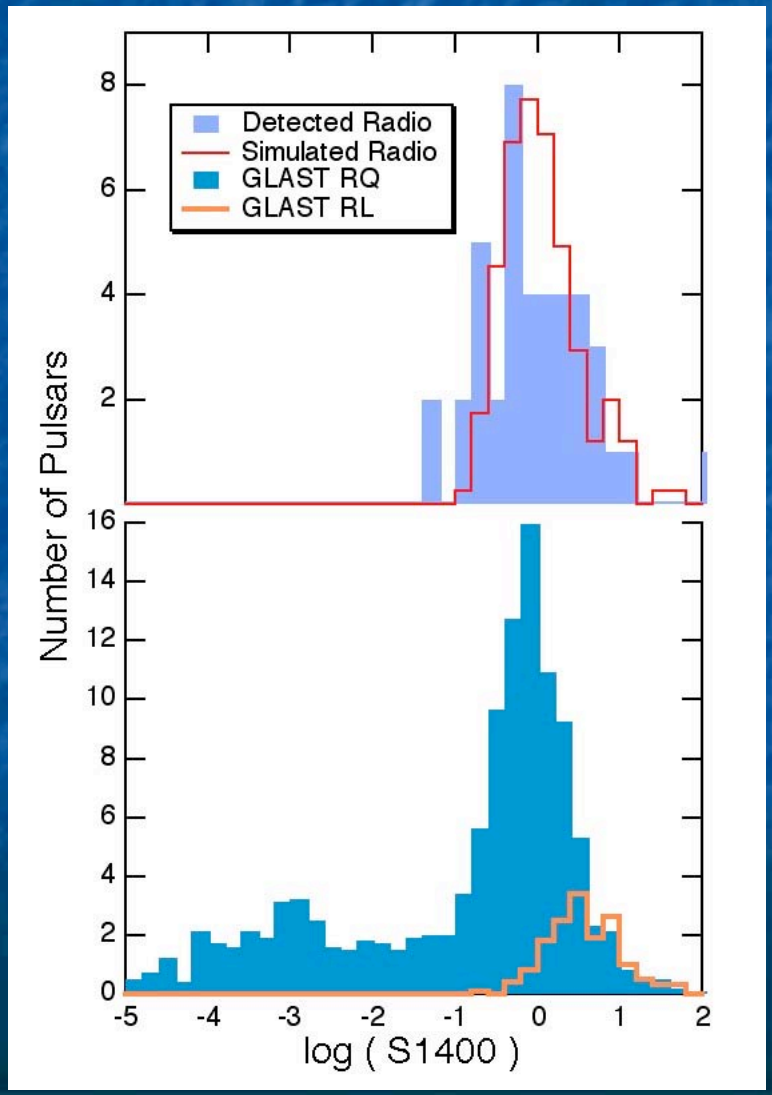
Summary Statistics

Instrument	Radio-loud γ-ray pulsars	Radio-quiet γ-ray pulsars
EGRET (DETECTED)	1	?
EGRET (SIMULATED)	6	15-19
AGILE(SIMULATED)	10	34-45
GLAST (SIMULATED)	16	99-131 (35)

But 70% of MSPs are in binaries

GLAST Radio-Quiet Pulsars





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